Making Conservation Tillage Conventional:

Building a Future on 25 Years of Research

Proceedings of the 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture.

Auburn, AL, USA 24-26 June 2002

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for Sustainable Agriculture, Auburn, AL, USA
24-26 June, 2002

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FOREWORD

Conservation tillage systems were a relatively new technology in 1978, when representatives from six states presented 10 papers at the *First Annual Southeastern No-Till Systems Conference* in Griffin, Georgia. Since then, hundreds of papers have been presented at the annual Conferences, which have rotated among 12 southeastern states. This year, about 80 papers will be presented from 16 states and six nations.

This year's theme, *Making Conservation Tillage Conventional: Building a Future on 25 Years of Research*, recognizes the quarter-century of work by farmers, USDA-ARS and university scientists, extension specialists, USDA-NRCS conservationists, and crop consultants to develop farming methods that promote farm productivity and conserve and improve the vital soil and water resources for future generations.

The editors of the 1978 Proceedings (J.T. Touchton and D.G. Cummins) listed seven of the most common questions that needed to be answered:

1) What is the impact of no-tillage farming on the environment?
2) What types of mulches should be used and what are their values?
3) Is soil compaction a problem in these systems?
4) Is in-row subsoiling beneficial?
5) Are insects more of a problem than in conventional-tillage?
6) What is the impact of continuous no-tillage on weed populations?
7) What are the best methods of weed control?

Over the past 25 years we have learned much about these topics, but- judging by the papers in these Proceedings, they still remain important subjects for research.

We thank the authors, participants, sponsors, and all of the people who have contributed to these 25 Conferences.

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ABOUT SERA-IEG-20

The Southern Conservation Tillage Conference for Sustainable Agriculture (SCTCSA) is the main activity of the Southern Extension and Research Activity - Information Exchange Group 20 (SERA-IEG-20). It is sponsored by the Southern Association of Agricultural Experiment Station Directors (SAAESD), and the Association of Southern Region Extension Directors (ASRED), as well as the Cooperative State Research, Education and Extension Service (CSREES), and the participating state universities and federal agencies.

The primary mission of the SCTCSA is to provide a medium for exchanging information about conservation tillage and related technology between and among researchers, extension personnel, NRCS personnel, crop consultants, agrochemical companies and farmers. The primary goal of most conservation tillage research is to develop improved technology to increase yields and/or profitability of agricultural crops and livestock while maintaining or improving the quality of soil and water resources available for agricultural, domestic and recreational uses. The overall objective of the SCTCSA is to expand the conservation tillage systems in the South for the purpose of controlling erosion and reducing environmental degradation.

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HISTORY AND FUTURE CHALLENGES AND OPPORTUNITIES IN CONSERVATION TILLAGE FOR A SUSTAINABLE AGRICULTURE: RESEARCH AND EXTENSION PERSPECTIVE

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INDIVIDUALS

Mistakes are always made when writing about history. Therefore, I apologize for mistakes that may be made in writing this paper. I am sure that important people, places and events will be overlooked. Much of this paper deals only with the factors that led to the beginning of these conservation tillage conferences, those who have participated, and research and extension efforts that we have reported in our proceedings. From this background and analysis we should be able to draw some conclusions and make predictions for our future.

In the 1960's the world experienced the "Green Revolution," a revolution that helped ward off starvation in many parts of the world. During the past 25 years the world has experienced another revolution called the "Conservation Tillage Revolution." Those of us involved with these conferences in the southern USA have played a major role in the advancement of this revolution. In the beginning we faced opposition at every turn including comments like: its trash farming, it takes more chemicals, you have to burn the crop residues because insects and diseases will eat up the crops, we need better and more workable equipment, all of our present crops are not bred for short season multiple cropping systems, it won't work on my farm, the fertilizer won't work on top of the ground, we can't control perennial grasses like Johnsongrass or bermudagrass, and the list of bone picking by the buzzardsgoes on and on. Of course questions are always good, but when the negative attitudes are coming from your own academic colleagues, who are ignorant on a subject, they can pose the biggest drag on the advancement of new and important technology. Although some of these questions still come up when conservation tillage is first introduced to new locations, it doesn't take long until successes cause these new people to begin repeating the same virtues of the practice as if they are the ones to make the initial discovery. I always tried to practice advice by Shirley Phillips, with whom I sought council in 1973. One week after I began work at the Georgia Experiment Station, Experiment, GA., he advised me, "If someone tells you 'it won't work' quickly remove yourself from that individual and move on to someone who has an open attitude. Don't waste your time with all the negative people you will face." I have repeated his comment hundreds of times over the past 29 years. A positive attitude is the key to providing solutions to the opportunities we face.

By the 1970s all of the southeastern states had some research history and experience with no-till crop management. Some states were also emphasizing multiple cropping systems research and the advantages for such farming practices in the Southeast. The coupling of no-till planting of the summer crop in succession systems resulted in more efficient use of land as well as savings in labor, equipment and fuel, and reduced soil erosion. These concepts were the results of research projects being carried out by university and USDA-ARS research personnel. For example, Dr. Lloyd R. Nelson wrote the first Hatch project in Georgia, dedicated solely to this subject and initiated some field research at Griffin, GA in 1972. The title of the project was "Minimum Tillage Multiple Cropping Systems for the Southeast." In the summer of 1973 Dr. Raymond N. Gallaher was hired at the Georgia Station at Griffin to take over this project. In the summer of 1975, Gallaher was Chairman of a program at the Georgia Experiment Station, Experiment, GA entitled "Feeds and Feeding Research Day." This was a one-day program that involved research scientists presenting research information in an extension format and included a display of posters and no-tillage equipment, oral presentations, and a field tour of no-till multiple cropping research at the Georgia Station. Those who participated and especially the administration and

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Table 1. Past conferences, chairmen, and citations of proceedings.

Year	Location	Program Chairman or Co-Chairmen	Proceedings
1978	Griffin, GA	J.T. Touchton Agronomy Department University of Georgia 1109 Experiment St. Griffin, GA 30223-1797	Touchton, J.T., and D.G. Cummins (eds.). 1978. Proc. First Annual Southeastern No-Till Systems Conference. Experiment Georgia 29 November 1978. Georgia Exp. Sta. Special Pub. No. 5 Univ. of Georgia, Agri. Exp. Stn., Experiment, GA.
1979	Lexington, KY	Shirley Phillips Agronomy Department University of Kentucky Lexington, KY. 40546	No Proceedings Published
1980	Gainesville, FL	R.N. Gallaher PO Box 110730 Agronomy Department University of Florida Gainesville, FL 32611	Gallaher, R.N. (ed.). 1980. Proc. 3rd Annual No-Tillage Systems Conference. Williston, Florida 19 June 1980. Inst. Food & Agri. Sci., Univ. of Florida, Gainesville, FL
1981	Raleigh, NC	A.D. Worshum, W.M. Lewis & G.C. Naderman Crop Science Department NC State Univ. Raleigh, NC 27650	Lewis, W.M. (ed.). 1981. No-Till Crop Production in North Carolina – Corn, Soybean, Sorghum, and Forages. North Carolina Agri. Extension Service AG-273, Raleigh, NC.
1982	Florence, SC	J.H. Palmer Agronomy Department Clemson University Clemson, SC 29634	Palmer, J.H., and E.C. Murdock (eds.). 1982. Proc. 5th Annual Southeastern No-Till Systems Conference. Florence, SC 15 July 1982. Agronomy and Soils Extension Series No. 4. Clemson Univ. Clemson, SC.
1983	Milan, TN	E.L. Ashburn & T. McCutchen Univ. of Tennessee West TN Agic. Exp. Stn. Jackson, TN	Jared, J., F. Tompkins, and R. Miles (eds.). 1983. Proc. 6th Annual Southeastern No-Till Systems Conference. Milan, TN 21 July 1983. Univ. of Tennessee Inst. of Agri., Knoxville, TN.
1984	Headland, AL	J.T. Touchton Agronomy Department Auburn University Auburn, AL 38301	Touchton, J.T., and R.E. Stevenson (eds.). 1984. Proc. 7th Annual Southeast No-Tillage Systems Conference. Headland, AL 10 July 1984. Alabama Agri. Exp. Stn., Auburn Univ., Auburn, AL.
1985	Griffin, GA	W.L. Hargrove Agronomy Department University of Georgia 1109 Experiment Station Griffin, GA 30223-1797	Hargrove, W.L., F.C. Boswell, and G.W. Langdale (eds.). 1985. Proc. 1985 Southern Region No-Till Conference. Griffin, GA. 16-17 July 1985. Georgia Agri. Exp. Sta., Univ. of Georgia, Athens, GA
1986	Lexington, KY	R.E. Phillips and K. L. Wells Agronomy Department Univ. of Kentucky Lexington, KY 40546	Phillips, R.E. (ed.). Proc. Southern Region No-Till Conference. Lexington, KY 18 June 1986. Kentucky Agri. Exp. Stn., Southern Region Series Bulletin 319. Univ. of Kentucky, Lexington, KY
1987	College Station, TX	T.J. Gerik and B.L. Harris Blackland Research Center Temple, TX 76501	Gerik, T.J., and B.L. Harris. (eds.). 1987. Proc. Southern Region No-Tillage Conference. College Station, TX 1-2 July 1987. Texas Agri. Exp Stn. MP-1634, Texas A & M Univ. System. College Station, TX
1988	Tupelo, MS	N.W. Buehring & J.E. Harrison Mississippi State Univ. NE Miss. Branch Stn. Verona, MS 38879	Hairston, J.E. (ed.). 1988. Proc. 1988 Southern Conservation Tillage Conference. Tupelo, MS 10-12 August 1988. Mississippi Agri. and Forestry Exp. Stn., Special Bulletin 88-1. Mississippi State Univ., Mississippi State, MS.

Table 1. continued

Year	Location	Program Chairman or Co-Chairmen	Proceedings
1989	Tallahassee, FL	D.L. Wright and I.D. Teare University of Florida N. Florida Res., & Educ. Ctr. Rt. 3 Box 4370 Quincy, FL 32351	Teare, I.D. (ed.). 1989. Proc. 1989 Southern Conservation Tillage Conference. Tallahassee, FL 12-13 July 1989. Inst. of Food and Agri. Sci. Special Bulletin 89-1. Univ. of Florida, Gainesville, FL.
1990	Raleigh, NC	M.G. Wagger NC State University Raleigh, NC 27650	Mueller, J.P., and M.G. Wagger (eds.). 1990. Proc. 1990 Southern Region Conservation Tillage Conference. Raleigh, NC 1990. NCSU Special Bulletin 90-1. North Carolina State Univ., Raleigh, NC.
1991	N. Little Rock, AR	S.L. Chapman & T.C. Keisling University of Arkansas Soil Testing & Res. Lab. P.O. Drawer 767 Marianna, AR 72360	Keisling, T.C. (ed.). 1991. Proc. 1991 Southern Conservation Tillage Conference. North Little Rock, AR 18-20 June 1991. Arkansas Agri. Exp. Sta. Special Report 148, Univ. of Arkansas, Fayetteville, AR
1992	Jackson, TN	J.F. Bradley & M.D. Mullen University of Tennessee P.O. Box 1071 Knoxville, TN 37901	Mullen, M.D., and B.N. Duck (eds.). 1992. Proc. 1992 Southern Conservation Tillage Conference. Jackson and Milan, TN 21-23 July 1992. Tennessee Agri. Exp. Sta. Special Publication 92-01. Univ. of Tennessee, Knoxville, TN.
1993	Monroe, LA	P.K. Bollich Louisiana State Univ. LA. Agric. Exp. Stn. P.O. Box 1429 Crowley, LA 70527-4129	Bollich, P.K. (ed.). 1993. Proc. 1993 Southern Conservation Tillage Conference for Sustainable Agriculture. Monroe, LA 15-17 June 1993. Louisiana Agri. Exp. Stn. Ms. No. 93-86-7122. Louisiana State Univ., Baton Rouge, LA.
1994	Columbia, SC	W.J. Busscher & P.J. Bauer USDA-ARS Coastal Plans Res. Ctr. Florence, SC 29501-1241	Bauer, P.J., and W.J. Busscher (eds.). 1994. Proc. 1994 Southern Conservation Tillage Conference for Sustainable Agriculture. Columbia, SC 7-9 June 1994. USDA-ARS Coastal Plains Soil, Water, and Plant Research, Florence, SC.
1995	Jackson, MS	N.W. Buehring & W.L. Kingery Mississippi State Univ. NE Miss. Branch Stn. Verona, MS 38879	Kingery, W.L., and N. Buehring (eds.). 1995. Proc. 1995 Southern Conservation Tillage Conference for Sustainable Agriculture. Jackson, MS 26-28 June 1995. Mississippi Agri. and Forestry Exp. Stn Special Bulletin 88-7., Mississippi State Univ., Mississippi State, MS
1996	Jackson, TN	P. Denton, J.H. Hodges, III, & D.Tyler Univ. of Tennessee Plant & Soil Sci. Dept. Knoxville, TN 37901	Denton, P., N. Eash, J. Hodges, III, and D. Tyler (eds.). 1996. Proc. 19th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Jackson and Milan, TN 23-25 July 1996. Univ. of Tennessee Agri. Exp. Stn. Special Public. 96-07. Univ. of Tennessee, Knoxville, TN.
1997	Gainesville, FL	R.N. Gallaher & D.L. Wright PO Box 110730 Agronomy Dept. Univ. of Florida Gainesville, FL 32611	Gallaher, R.N., and R. McSorley. 1997. Proc. 20th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Gainesville, FL 24-26 June 1997. IFAS Coop. Extn. Service, Special Series SS-AGR-60, Univ. of Florida, Gainesville, FL.
1998	North Little Rock, AR	S.L. Chapman & T.C. Keisling Univ. of Arkansas P.O. Box 391 Little Rock, AR 72203	Keisling, T.C. (ed.). 1998. Proc. 21st Annual Southern Conservation Tillage Conference for Sustainable Agriculture. North Little Rock, AR 15-17 July 1998. Arkansas Agri. Exp. Stn. Special Report 186, Univ. of Arkansas, Fayetteville, AR.

Table 1. continued

Year	Location	Program Chairman or Co-Chairmen	Proceedings
1999	Tifton, GA	J.E. Hook Univ. of Georgia-NESPAL Coastal Plain Exp. Sta. P.O. Box 748 Tifton, GA 31793-0748	Hook, J.E. (ed.). 1999. Proc. 22nd Annual Southern Conservation Tillage Conference for Sustainable Agriculture, Tifton, GA 6-8 July 1999. Georgia Agri. Exp. Sta. Special Pub. 95. Univ. of Georgia, Athens, GA.
2000	Monroe, LA	P.K. Bollich Rice Research Station, Louisiana Agric. Exp. Stn., LSU AgCenter, P.O. Box 1429, Crowley, LA 70527-1429	Bollich, P.K. (ed.). Proc. 23rd Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Monroe, LA 19-21 June 2000. Louisiana Agri. Exp. Sta., LSU Agri. Center Manuscript No 00-86-0205, Louisiana State Univ. Crowley, LA 70527-1429.
2001	Oklahoma City, OK	J.H. Stiegler Plant & Soil Sci. Dept. Oklahoma State Univ. Stillwater, OK 74078	Stiegler, J.H. 2001 (ed.). Proc. 24th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, Oklahoma City, OK 9-11 July. Oklahoma Agri. Exp. Sta. Misc. Pub. MP – 151. Oklahoma State Univ. Stillwater, OK.
2002	Auburn, AL	D.W. Reeves, R.L. Raper, and K. Iversen USDA-ARS-NSDL 411 S. Donahue Dr. Auburn, AL 36832	E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

related industry hailed this program a great success. Proceedings of the research day presentations were also published (Gallaher and Baird, eds. 1975). Gallaher's chapter in the proceedings was entitled "All Out Feed Production by Multiple Cropping" (Gallaher, 1975). Preliminary data on a large number of double and triple cropping systems using no-till planting of summer crops was presented from field studies in north, central, and south Georgia that illustrated the tremendous potential for no-till multiple cropping management for helping solve the feed grain deficit in Georgia. Gallaher remained at the Georgia Station for three years until the summer of 1976, at which time he was employed by the University of Florida to establish and coordinate a program similar to the one in Georgia. Dr. Joe Touchton, a recent graduate of the University of Illinois, was hired by the University of Georgia to replace Gallaher in the fall of 1976. Dr. Touchton's research project continued to emphasize no-till multiple cropping with significant emphasis being placed on soil fertility management. It is ironic that like Gallaher, Dr. Touchton remained with the University of Georgia for only three years because of an offer by Auburn University, who wanted someone to establish and coordinate a project on no-till multiple cropping for that state. Dr. Touchton's replacement at Georgia, Dr. W.L. Hargrove, was a graduate of Kentucky, had training in no-tillage and continued to emphasize no-till multiple cropping and soil properties. Dr. Hargrove also left the University of Georgia after a few years and moved into international agriculture. Dr. Terry Keisling was another research scientist employed by the University of Georgia in the early years of no-till multiple cropping emphasis. He moved to the University of Arkansas and has played an important role in the advancement of no-till multiple cropping in that state. Some other scientists involved with our early progress who were graduates from institutions with no-tillage histories include: Dr. David L. Wright, Professor at the University of Florida and graduate from VPI, Dr. Don Tyler, Professor at the University of Tennessee and graduate of the University of Kentucky, Dr. Paul Denton, Professor at the University of Tennessee and graduate of North Carolina State University, and Dr. Normie Buehring, Professor at Mississippi State University and graduate from Oklahoma State University. The author apologizes for leaving names of other important leaders out of the list. However, their names are documented in Table 1.

In addition to research and extension work by scientists in their respective states, most have been involved in international activities. We have been invited to all continents as consultants, participants in no-till and multiple cropping conferences and field days, as well as teachers of short and long courses to farmers, college students, and employees of industry and research and extension institutions. In addition to our travels to other countries, we have been host to visiting farmers and scientists from all over the world as well. Many of us collectively have also trained hundreds of graduate students, both from the USA and foreign countries, who have been and are actively involved with conservation tillage multiple cropping.

STRIP-TILL PLANTER INVENTION

One of the major hindrances to the progress of no-till in the coastal plains states was poor seed establishment and crop failures due in many cases to soil compaction. An expert on this subject was Dr. A.C. Trouse, Jr., USDA-ARS, located at the National Tillage Machinery Laboratory, Auburn, AL. Dr. Trouce interacted with the Harden's, a farm family from Banks, AL, during the early 1970s, the results of which was the invention of the no-till plus planter by Mr. J.C. Harden. Mr. Tony Rutz, Chevron Chemical Co., and Dr. R.N. Gallaher traveled to Banks, AL in 1975 to see the invention and discuss the possibility of its manufacture with the Hardens and with Brown Mfg. Co. In 1976 Dr. Trouce, Dr. Gallaher, the Harden's, and the Brown family were part of a news release program announcing this new invention and plans for its production. The national news release program was held in Troy, AL and was sponsored by Chevron Chemical Co. We stressed the potential of the new no-till plus planter for possible solutions to many of the no-till failures in the coastal plains states. Other farmers like Mr. Danny Stevens of Florida, and companies like Cole Mfg. and Kelly Mfg. soon came out with their versions of the no-till plus planters. These actions gave proof that the new invention was being implemented in no-till management. Names of this invention changed over time from "no-till plus," "no-till plus in-row subsoil, " "row-till," and today it is known as "strip-till." The earlier versions of strip-till planters did not include the subsoil or in-row subsoil unit on their planters, but at least one version used small tillers to till small strips of rows for planting into established sod crops. The invention of the strip-till planter by the Harden family has played a major role in the progress of no-till farming in the South and many other places in the world.

CONFERENCES

The above gives some background setting the stage for a mechanism to meet the need to share information on the progress of no-till and multiple cropping systems among interested parties in the southeastern states. The idea of establishing annual southeastern conferences was initiated from conversations with Mr. Tony Rutz, a former representative of Chevron Chemical Co., while returning from the above-mentioned trip to Troy, AL in 1976. Ideas we discussed included having a program similar to the research day held at Experiment, GA in 1975 that would be hosted by a single state, but involve interested parties on the program from each of the southeastern states. We received endorsement of the general idea from Mr. Shirley Phillips at Kentucky. We wanted to involve all interested parties on the program by having them give oral or poster presentations, trying to have successful no-till multiple cropping farmers on the program, gearing information exchange toward the extension of our work, and having a proceedings of presentations that would be published using English units. We felt that the proceedings would not only provide documentation of information for extension but also provide additional justification to administrators for approval of participants to travel and participate. There were, at that time, and are even more today, dozens of refereed scientific publication outlets for exchange of research among scientists, but the numbers of outlets directed to the public (farmers) were limited at the time and still are today. A comment by Touchton in the preface of the seventh Southeastern No-Tillage Systems Conference was one of the main bases for publication of the proceedings. Touchton wrote, "Generally, there is a 2- to 5-year delay in transmitting data from the researcher to the agricultural community. Since there is a critical need for the limited conservation tillage data that are available, the Southeastern No-Tillage Systems Conference was established to provide a rapid means for communication among researchers and the community. The proceedings associated with this conferences are one method being used to rapidly transmit research data" (Touchton, 1984 see citation in Table 1.).

By 1977, discussions with other no-tillage and multiple cropping systems leaders in the Southeast led to an agreement for each of the seven states to host the conferences on a rotating basis. Because Georgia had an already established history of no-till multiple cropping systems research, we decided to begin the conferences at Experiment, GA, and to rotate the remaining conferences north and south to give states like Florida, South Carolina, and Alabama more time to establish research and extension programs.

We agreed on a name for the conferences entitled "Southeastern No-Tillage Systems Conference." This name emphasized the Southeast as the area of the country on which the conference was focused, on planting directly into sods, cover crops or crop residues without plowing, on tillage and cropping systems-especially multiple cropping, and the word conference to imply information exchange. We were successful in completing the original plan for the seven original conferences (Table 1.).

Dr. Shirley Phillips had begun suggesting that the conferences include all of the southern states prior to the completion of the original plan. There was also an interest by the Southern Experiment Station and Cooperative Extension Directors to formalize the conferences into a working group

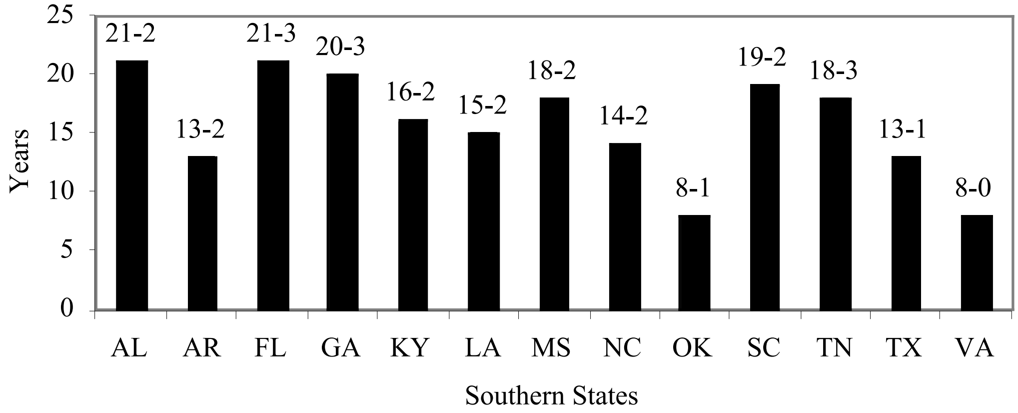

Fig. 1. Number of years each state participated in the 25 tillage conferences. The second number is the number of times a state has hosted this conference.

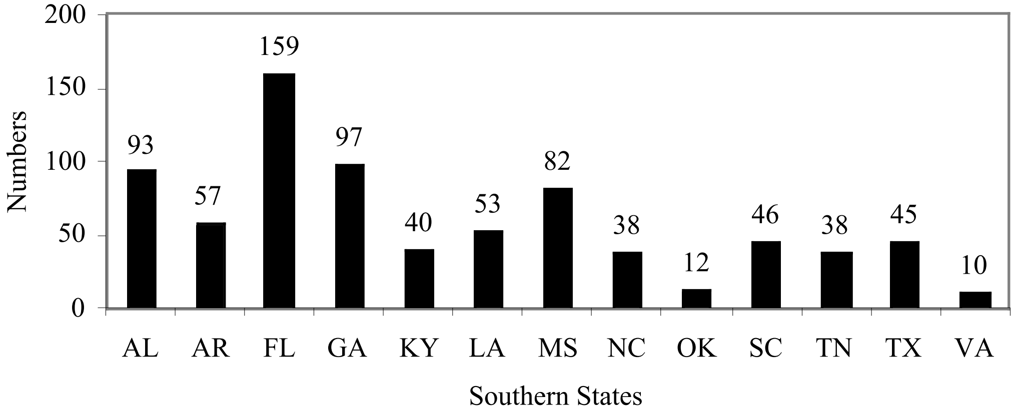

Fig. 2. Number of papers from each state in the 24 proceedings of the 25 tillage conferences

under their direction. With this in mind, Georgia again became the host of the eighth conference under the new name entitled "Southern Region No-Till Conferences" (Table 1). By 1988, participants were encouraging broader participation by changing the name of the conference to include the word "conservation tillage" instead of no-till or no-tillage. The apparent thought in this was that we would get greater participation by organizations who stressed conservation tillage since no-till/no-tillage, along with other types of minimum tillage were all parts of conservation tillage. Therefore in 1988, Mississippi State University was the first state to host the conference with the new name "Southern Conservation Tillage Conference" (Table 1). This name lasted until 1993 when the words "Sustainable Agriculture" were added to the title of the conferences. Therefore, Louisiana State University was the first state to host the conference with the new name "Southern Conservation Tillage Conference for Sustainable Agriculture" (Table 1). This latter name has lasted to the present time and appears to continue to be relevant to today's activities. This does not mean, however, that we have been exclusionary over the years because we have also had guest speakers from Washington, DC, several other states, and from abroad.

CONFERENCE PROCEEDINGS

All host states have published a proceedings of papers presented with the exception of the second conference in 1979 in Kentucky (Table 1.). States who have hosted the conferences three times include Florida, Georgia, and Tennessee. Most other states have hosted the conference twice except for Oklahoma and Texas who have been host one time and Virginia who never hosted a conference (Table 1).

Publications in the conference proceedings reveal numerous items regarding our history. Based on the proceedings, five of the original seven states have participated in the conferences 18 or more times (Fig. 1). Mississippi participated more times than any of the other southern states outside of the original seven states. Oklahoma and Virginia have had the least representation in the proceedings (Fig. 1). Of the almost 800 total articles and abstracts published, Florida is the leader with 159 followed by Georgia with 97 and Alabama with 93 (Fig. 2). Again leadership and interest from Mississippi is evident by having the most publications outside the original seven states (Figure 2). The lower ranking for Tennessee does not reflect activities of that state. They published separate proceedings of their "Milan No-Till Field Day" tours each of the three times they hosted the conference, as well as the conference proceedings. The field day was considered a part of the conference.

Publications from all states placed more emphasis on crop growth and soil variables compared to emphasis on specific commodities (Fig. 3). The exceptions are Louisiana and Virginia, where the two categories are about equal. When the publications in the proceedings were viewed for four reporting periods of 1978 to 1984, 1985 to 1992, 1993 to 1997, and 1998 to 2002, one could observe changes in research emphasis. For example, among the commodities, greatest emphasis in the early years was on corn and soybean research compared to forages and sorghum (Fig. 4). Research on all these commodities peaked during the 1985 to 1992 period and has begun to decline, with no reports on sorghum during the 1998 to 2002 period. On the other hand, commodities of cotton, peanut, and vegetables received limited attention in the early years but appear to be gaining in interest during the latter periods (Fig. 5). No-till peanut research from Florida and Georgia was reported

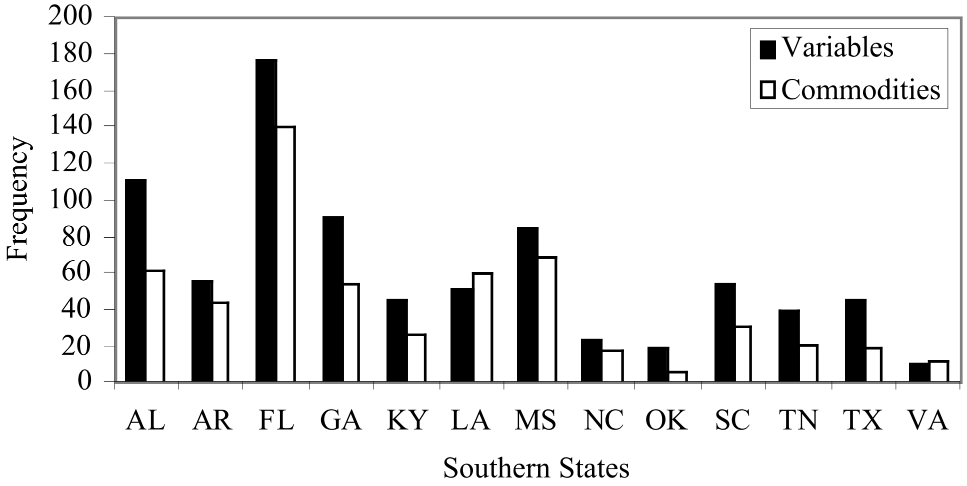

Fig. 3. Proceedings papers for past 25 years with emphasis on crop growth and soil variables *vs.* papers with emphasis on crop commodities.

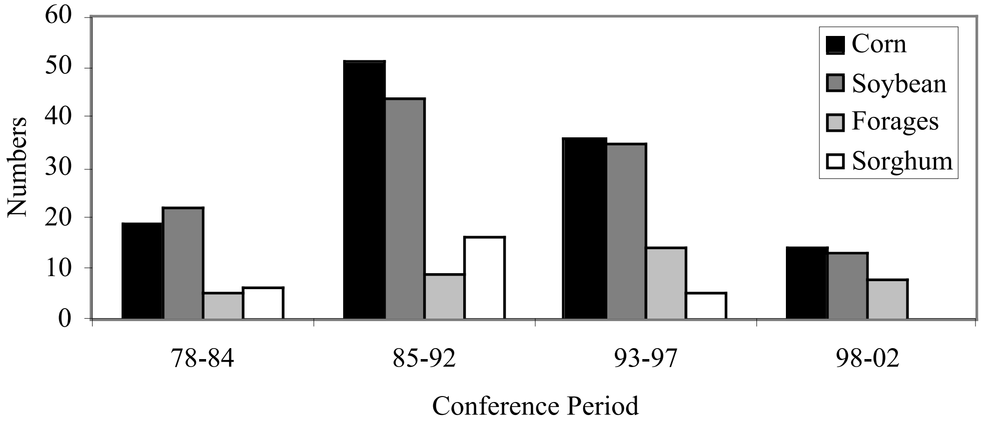

Fig. 4. Proceedings publications with emphasis on corn, soybean, forages, and sorghum for four publishing periods.

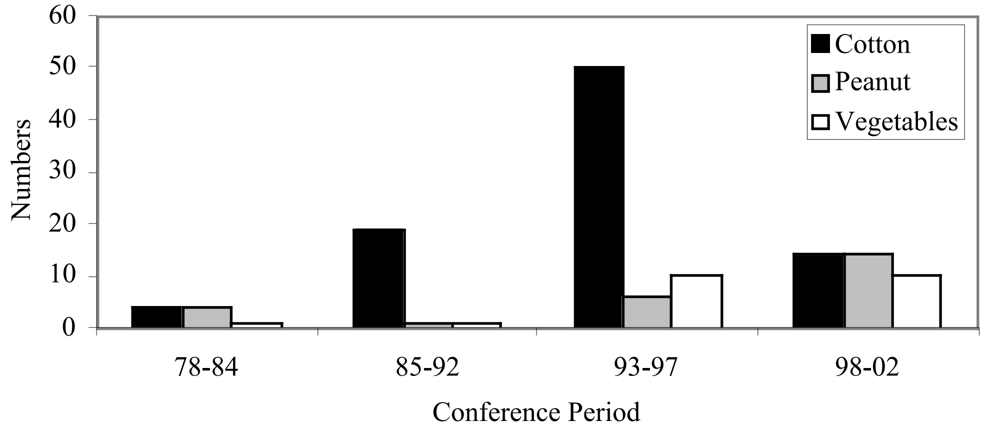

Fig. 5. Proceedings publications with emphasis on cotton, peanut, and vegetables for four publishing periods.

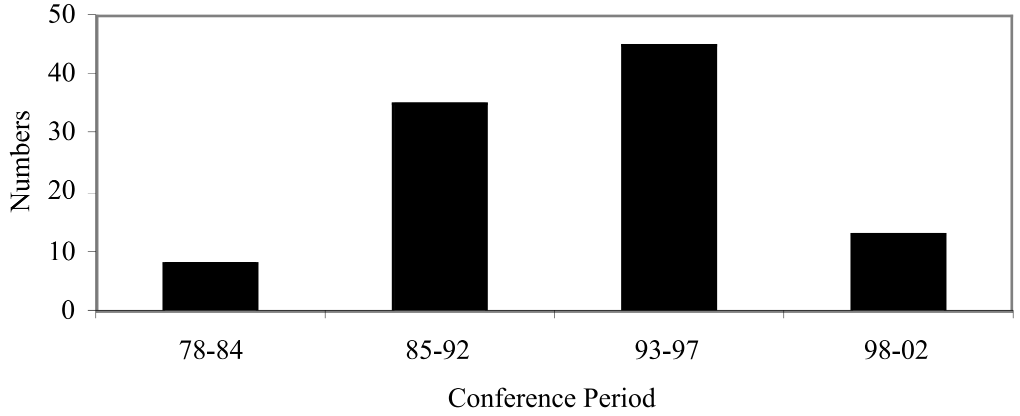

Fig. 6. Proceedings publications with emphasis on winter cover crops and new crops for four publishing periods.

four times in the first seven years but this research was dropped due to lack of farmer interest. It is noted that strip-till peanut is one of the hottest research items today (Fig. 5). The reason for this is just like the application of no-till technology to other commodities over the years, economic survival of the farmers. There has also been a low, but increasing interest in no-till vegetables over the years as well. Published reports on other commodities peaked in the 1993 to 1997 period (Fig. 6). Reports have been published on small grains, winter and summer legumes, and several minor crops.

Reports of experiments comparing forms of conservation tillage with conventional tillage have dominated the variables that impact crop growth (Fig. 7). While many of us believe we have successfully proven that conservation tillage should be considered conventional tillage, the statistics of our reporting in our proceedings shows that we are not yet ready to go all the way. Significant research reports comparing tillage methods are still routinely reported in our proceedings. Research on soil chemical and physical properties and related plant nutrition relationships have received significant priority (Fig. 7). Emphasis on multiple cropping, soil erosion, and water issues appear to be correlated with the interest in tillage variables as well (Fig. 7). Published reports regarding weed control, insects and diseases, including nematodes, are likely not representative of research that has been reported in these areas over the 25-years (Fig. 8). Many weed scientists report their work in state research reports and at their own professional meetings. Greater participation of pest management researchers along with economists would likely have made our goal of information exchange to the public a greater success.

CHALLENGES AND OPPORTUNITIES

We have fought a good fight and have won many races set before us over the past 25 years. We are at the peak of the

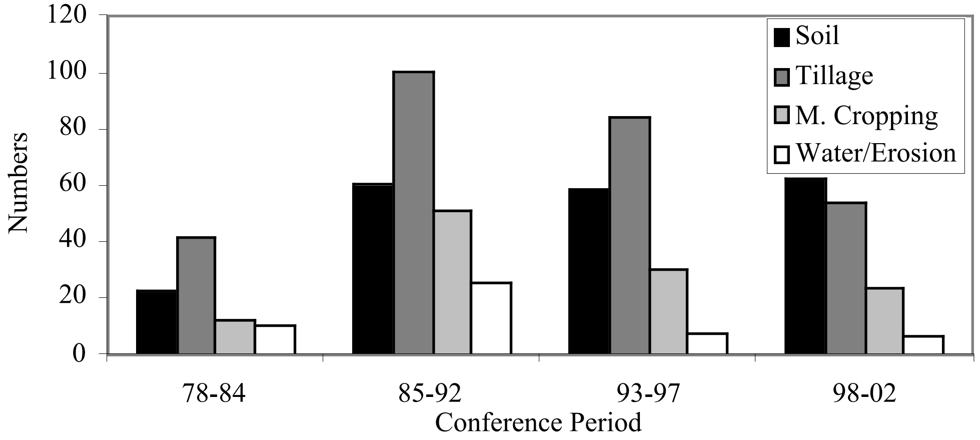

Fig. 7. Proceedings publications with emphasis on soil properties, tillage, multiple cropping systems, water and erosion for four reporting periods.

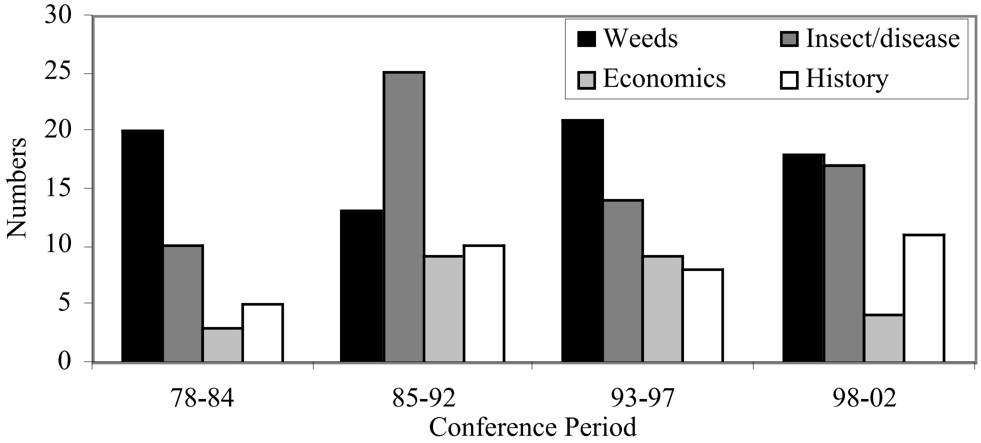

Fig. 8. Proceedings publications with emphasis on pest problems, economics and history for four publishing periods.

new "Conservation Tillage Revolution." We have done an outstanding job of documenting our research findings and in extending that research to the public as evidenced in almost 800 articles in the proceedings of our conferences. In addition, we have held hundreds of field days, short and long courses, lectures, etc, in the promotion of conservation tillage, its possibilities when coupled with multiple cropping, and its environmental and economic advantages. Our research information has been extended worldwide.

Our work in the past has emphasized conservation tillage management for many of the major crops like corn, soybean, grain sorghum, cotton, and forages. We are rapidly expanding conservation tillage for peanut as well. While we can look at the great strides in conversion of land to conservation tillage farming we should ask the question, Why, with all the answers we have now, are there so many farmers still practicing conventional tillage management on these major crops? With few exceptions most vegetable crops have been neglected. Why have we not done more research on conservation tillage vegetables? Why, in most cases, are we still only practicing no-till planting on the summer crops in multiple cropping systems? Over the years we have lost many of the chemicals traditionally used for weed, insect and disease control. Others like Atrazine are being challenged now. Few remain that are approved for use against nematodes. What are our alternatives to chemical pest control in conservation tillage cropping systems? What is the future of precision agricultural technology for conservation tillage farming practices? GMO crops have obviously promoted no-till management and easier control of specific pests. Will the world community become more accepting of these new technologies? Will pest resistance become a major opportunity for solutions as more GMO varieties and crops are introduced. Have we solved all the erosion problems in farming? Which system has the greatest potential for a sustainable agriculture, the highly erosive conventional tillage farming way or conservation tillage farming practices? Do we still have a problem in transferring technology from the researcher to the farm? How well will the new computer technology be utilized to extend information on conservation tillage and its agricultural sustaining principles to the public? As I look at the list of aging, retired, and deceased leaders of these conferences in Table 1, I also note a very good mix of research and extension expertise. Many of us either now hold or have held joint appointments in both research and extension. This mix has aided in extending research to the public. However, I wonder what these aging leaders are doing to help ensure that our organizations will continue to emphasize conservation tillage research and extension efforts when we are gone? Present trends look great for the future of conservation tillage for greater sustainability in agricultural production. The above comments are just a few of the challenges and opportunities that face those of us involved with the Southern Conservation Tillage Conferences for Sustainable Agriculture. Past history of the dust bowl of the midwestern U.S.A, severe erosion from cotton farming in the southern piedmont U.S.A, intensive farming of the sloping land in Parana, Brazil, etc., show that conventional tillage farming is not sustainable; conservation tillage is our hope!

ACKNOWLEDGMENTS

Our accomplishments over the past 25 years have been due to the joint effort by Experiment Stations, Cooperative Extension Services, USDA-ARS scientists, federal and state agencies, and especially the partners from the equipment, chemical, fertilizer, and seed industries. It has been a rewarding and great partnership. Conservation tillage multiple cropping is a part of the Florida FIRST initiative by the Institute of Food and Agricultural Sciences, University of Florida. This paper was supported by the Florida Agricultural Experiment Station and is approved for publication as Journal Series No R-08801.

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CONSERVATION TILLAGE DEVELOPMENT AT THE ABC COOPERATIVES IN PARANÁ, BRAZIL

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ABSTRACT

Soils of Brazil are highly susceptible to degradation and erosion when managed with conventional tillage systems. When native grasslands were cleared and farmed under conventional tillage methods, soil organic matter (SOM) decreased from 4% to 2% in 12 years. Ten years of subsequent no-tillage management brought SOM back up to 5%. The increase in SOM suggested that we could develop systems that not only increase biomass production, but also integrate forage systems in crop rotations. Today, about 40% of Brazil's cultivated land is under conservation tillage. The rapid adoption of conservation tillage was made possible by practical experience, education, and research, as well as the development of new products, such as selective herbicides. Farmers' cooperatives play an important role in research, development, and technology transfer through demonstration fields. They also assist farmers with marketing and the purchasing of supplies. Education is a high priority for the future – to inform producers of the economic and ecological benefits, and to inform consumers of the quality, efficiency, and environmental stewardship made possible by conservation tillage systems.

Fig. 1. Native climax vegetation (pasture and the Paraná pine) and climate in the Campos Gerais region of Paraná state in southern Brazil. Mean rainfall is 75 inches, mean maximum/minimum temperature is 81/55 EF, with median temperature of 68 EF and 3 to 4 killing frosts a year.

INTRODUCTION

This paper describes the performance of conservation tillage systems used in the "Campos Gerais" region in the state of Paraná in southern Brazil, where the ABC Conglomerate of Farmer Cooperatives and my family farm are located. It also describes the successful and rapid adoption of no-till in Paraná and other regions of Brazil.

DEVELOPMENT OF CONSERVATION TILLAGE SYSTEMS

When observing most of Brazil's agricultural areas whether they be the rolling fields in southern Brazil or the plains and savannas of the Cerrado region – it is readily apparent that soils managed under conventional tillage systems are highly vulnerable to erosion and rapid degradation from the action of wind, rain, and sun. These soils require intensive management and the most up-to-date technology to remain fertile. Although the region's conditions allow for multiple crops (the climate in some areas allows up to 3 crops a year), land becomes degraded in a few years when farmed under conventional tillage. This has been witnessed directly by large-scale growers such as myself.

IN E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

Fig. 2. The problem and the solution to farming in this climate and region.

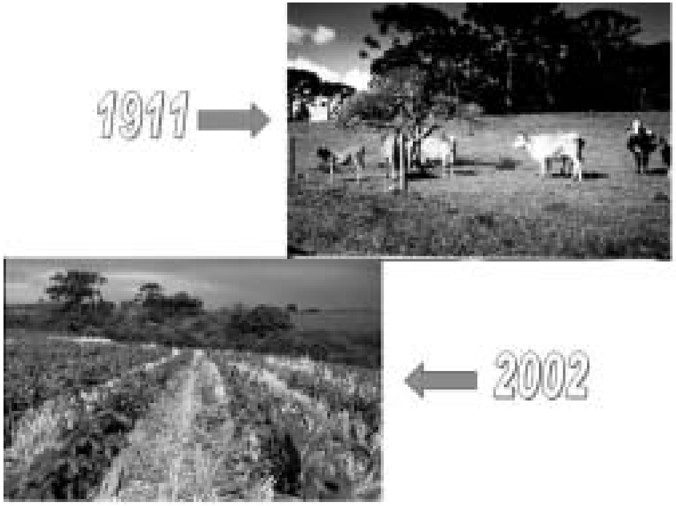

Fig. 3. Evolution of agricultural and soil management systems in southern Brazil.

Nature forced us to either make changes or abandon our land. We initiated several studies, and in 1976, began our first attempts to develop a viable no-till system.

No-till soon showed improvements and significant progress was made in the third year with the introduction of crop rotations and winter cover crops. Our Cooperative's technical department carried out several tests to evaluate the effects of winter cover crops on subsequent cash crops. The benefits of several crops were observed. Black oat (*Avena strigosa* Schreb.) provided an excellent covering with good weed control and deep rooting, while legumes (e.g., *Lupinus* and *Vicia* spp.), supplied life-giving nitrogen, but did not provide sufficient protection to the soil because their residue decomposed quickly. All grass crops increased soil nitrogen and residue/organic matter. These tests assisted us in choosing more appropriate combinations of cover crops. Crop rotation presented itself as a healthy and logical practice that contributed to increased production, preventative diversification, and cost reduction.

When we cleared native grasslands in 1964 under a conventional system, the soil consisted of 3.5 to 4% organic matter (Fig. 5). After 12 years of planting soybean [*Glycine max* (L.) Merr.] and wheat (*Triticum aestivum* L.) under conventional tillage, it declined to between 1.8 and 2.2%.

After just ten years of no-till 1976, soil organic matter content jumped from 1.8 to 5%. The root system that formerly occupied only the upper 25 centimeters of the cultivated soil is now exploring much deeper soil (Fig. 6). The increase in soil water retention allows us to better withstand drought, and reduces the overall severity of environmental fluctuations, resulting in a steady increase in production. Rapid increase in soil organic matter suggested we could develop systems that not only produce sufficient biomass to increase soil organic matter, but could also convert some of this fixed carbon into another source of farm income: e.g., integrating forage systems into a rotation, using cover and green manuring crops to sustain organic matter as well as feed livestock.

Figure 7 clearly shows the learning curve in using the best techniques in conservation tillage. We had ups and downs during the first years, but in 1987 there was a more uniform and linear increase from 4,800 to 8,600 kg ha^{-1} (4,300 to 7,680 lbs A^{-1}), achieved through better soil structure and greater infiltration and storage of water. During this time of

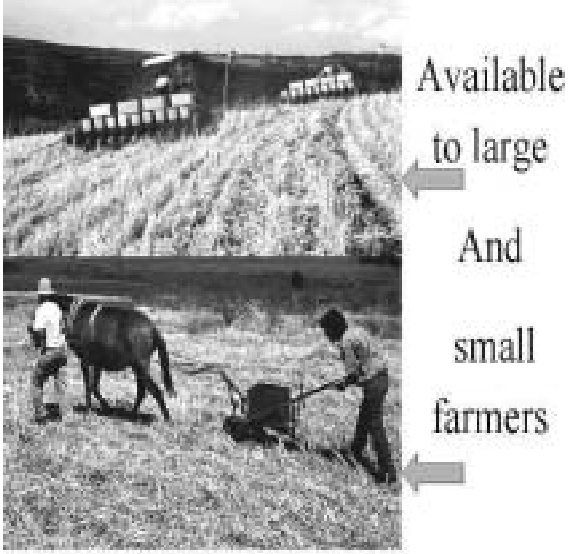

Fig. 4. No-tillage technology has been developed and is transferred to both large and small landholders in the region.

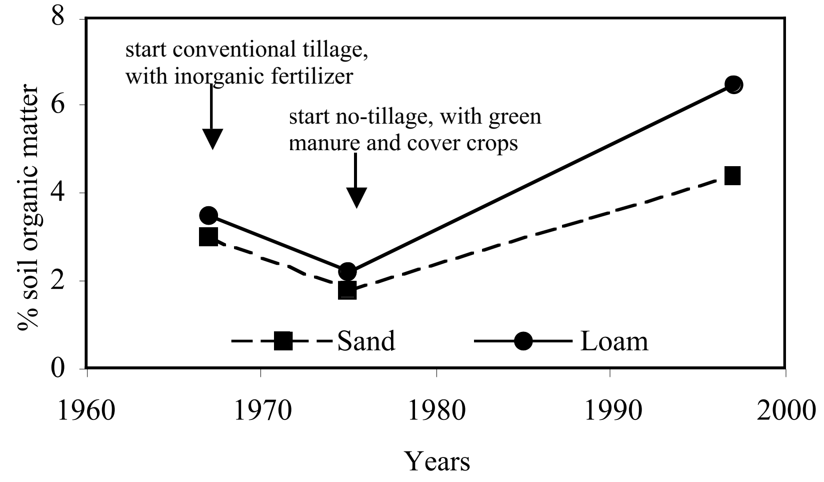

Fig. 5. Change in soil organic matter over time on my farm (Frank'Anna Farm), as affected by soil management strategies. Soil organic matter averaged 3 to 3.5% in native pasture before clearing and conversion to soybean cropping with moldboard plowing in 1968.

increasing production, the corn crop (*Zea mays* L.) exhibited the greatest upswing, because of an improvement in varieties. Soybean yields grew consistently until 1991, when they began to plateau at 2,000 kg ha^{-1} (30 bu A^{-1}) because of a decline in the introduction of new varieties. The production increased after 1991 to 3,300 kg ha^{-1} (49 bu A^{-1}).

Comparing the ABC Cooperative Group which encompasses farms totaling 180,000 ha (445,000 A) and my family farm (1,500 ha or 3,700 A) (Fig. 8), we can see the same tendencies resulting from the introduction of no-till practices. After 7 years, the degraded soil has recovered most of its productivity.

Because of the growing complexity of farming operations, especially as farms become more diverse and integrate livestock and cropping enterprises, it has become necessary to use contract services for many farm operations. This is what we have done on our property. Many types of work, such as transport, silage production, and manure application, have been outsourced to service firms, who perform them in a more professional way, benefiting everyone involved while aiding rural development.

THE ADOPTION OF CONSERVATION TILLAGE IN BRAZIL

Brazil is a relative newcomer to agriculture, especially with respect to soybean production. In spite of the fact that the vast majority of Brazilian fields have been used primarily for livestock, everyone (especially farmers in the USA) knows about the rapid adoption of the Brazilian soybean crop. Today, Brazil cultivates approximately 40 million ha (99 million A) annually, and more than 16 million ha of this cropland (40 million A) are managed under conservation tillage. The many changes producers have had to face in our country have forced a rapid movement towards new and improved farming methods, and younger and more open-minded farmers have been quick to change. In our region of "Campos Gerais", the most significant shift to conservation tillage occurred in 1993, after there had been several producer-sponsored conferences and technical meetings demonstrating research results. The introduction of selective herbicides facilitated production of no-till crops, allowing us to make the most of the short time we have available to plant soybean after harvesting the previous crop.

In order to efficiently convert to no-till, a region must have a competent extension service, technical know-how, and up-to-date research data. Many people believe that our relatively favorable soils and climate are the reasons for the success of conservation tillage in our region. However, successful conservation tillage does not depend on climate and soil types, although these factors certainly impact the outcome of conservation tillage adoption. It depends primarily on the decisions of individual farmers. Harmony and open-mindedness (or lack thereof)can do more good or harm than any environmental factor. At first, some producers resisted the system, but later they became convinced of the need for more efficient tillage practices, and this system was eventually

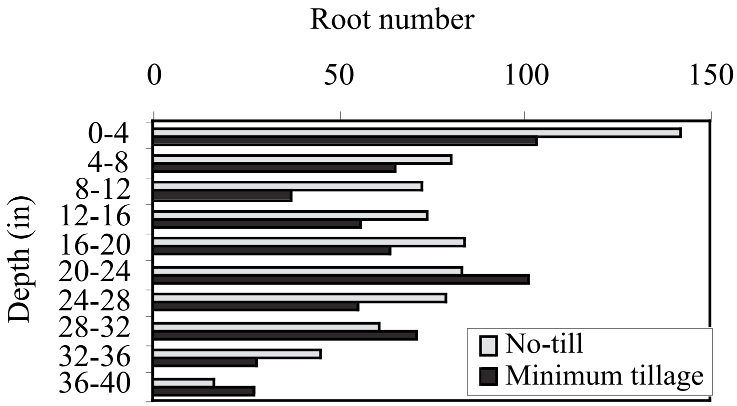

Fig. 6. Crop roots by depth in two fields from Frank'Anna Farm managed with no-tillage or minimum tillage begun in 1976 (from Sa, J.C.M., Fundacao ABC, 1993).

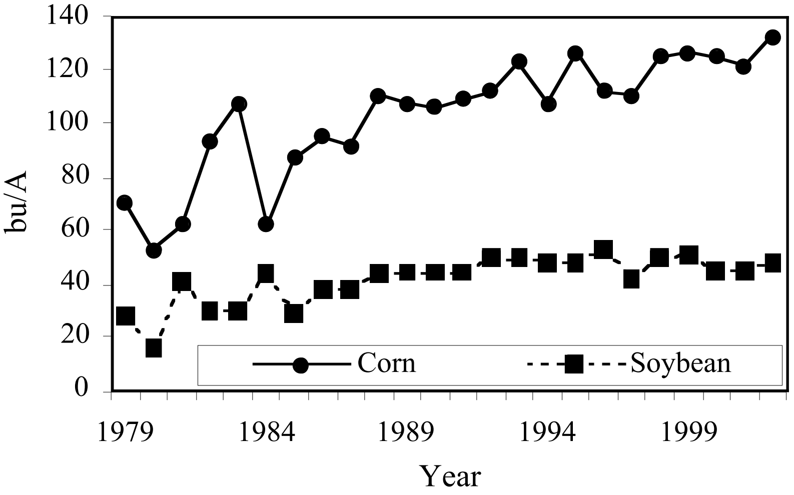

Fig. 7. Increase in corn and soybean yields on Frank'Anna Farm (3,700 A) since adoption of no-tillage. The use of no-tillage in a systems approach not only resulted in greater yields, but over time mitigated the effect of yearly environmental fluctuations on productivity.

adopted by all producers in the region. In my opinion , the soil degradation and loss of productivity caused by conventional tillage in tropical and subtropical regions outweighs any need to prepare the soil. I consider preparing the soil the same as performing surgery: it may be necessary, but only for valid and scientifically supported reasons. Currently, scientific justifications for the general conventional tillage of all soils are few and far between.

DIFFUSION

With the cooperatives *Arapoti* (A) and *Castrolanda* (C), we at *Batavo* (B) have formed our own private research institution, supported by funding from the producers, called the *ABC Foundation*, where research, development, and technology transfer are carried out for the benefit of our constituent producers (Fig. 9). We work in an area about 100 km (62 miles) in diameter, within which we choose four sites to work as demonstration fields, representing the regional micro-climates, in order to obtain information for our producers. The experimental fields have a scope of inference of about 180,000 ha (445,000 A). We conduct applied research on all aspects of production, including variety trials, disease control, insect control, weed control, fertility management, cover crop development, and alternative crop trials. We focus strictly on producer gain (profitability) and omit commercial interests, sharing all information with the farmers in our member cooperatives (Fig. 10).

THE SMALL FARMERS OF BATAVO COOPERATIVE

There are still several small isolated and diversified properties that are not in debt to banks or tied to cooperatives, but they tend not to accept changes, and are gradually becoming obsolete. These are true family farms, where a farmer's son has no other option but to take over his father's farm, and his antiquated ideas along with it.

The *Batavo* Cooperative and *Emater* of Paraná (the state Extension Service) implemented a project that enables a large number of small dairy producers scattered across the state on sloping and less productive soils to obtain corn silage produced locally on more suitable croplands controlled by the Cooperative. These producers can thus begin to focus more on dairy production, increasing production by an average of 16% per year. This partnership is working well and bringing ever-increasing returns to the participants.

This specialization of a farm's activities, conducted in a manner conducive to efficiency and productivity, is also applied off the farm by other organizations; they join their individual efforts to work toward as a larger entity – a Cooperative or Association. This model works to increase returns across all levels of

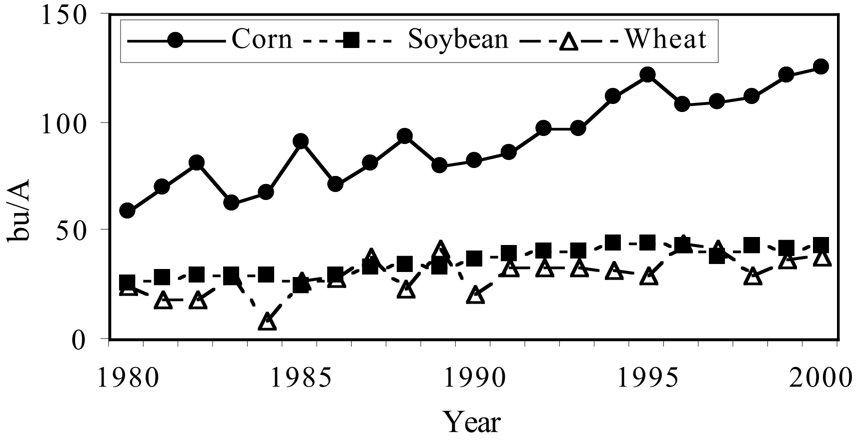

Fig. 8. Mean increase in productivity for the three major crops, corn, soybean, and wheat, produced by members of The ABC Cooperatives. There has been a rapid adoption of no-tillage by members since the early 1990s.

Fig. 9. Producer members of The ABC Cooperatives fund their own applied research and technology transfer service, The Foundation ABC. Research priorities for The Foundation ABC are determined by the producers and research is conducted at four locations representing micro-climate and soil variations of the group's members.

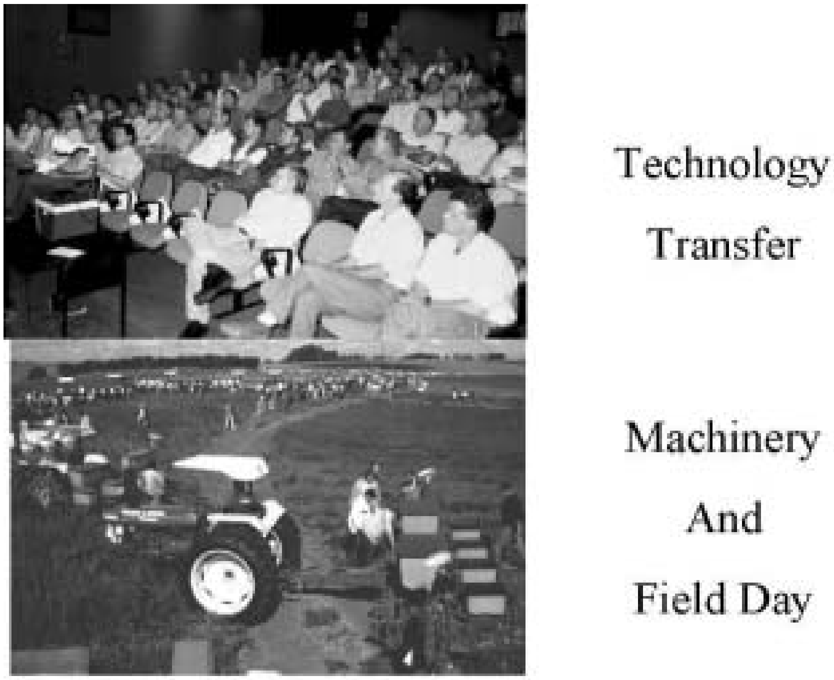

Fig. 10. Producers actively participate in training, field days, and other educational and technology transfer activities carried out by The Foundation ABC. The shared research and technology development focuses on profitability for the producer-members.

Fig. 11. Producing in harmony with nature ensures a better tomorrow. "No-tillage is not only a different technique, but also a matter of survival."

the production chain. The model's success is based on the following philosophy: ***"None of us are as important as all of us together".***

Brazilian farmers, however, often resist changes. They would rather work from sunrise to sunset and well into the night. They carry out their labor with pride, even though they often have to go through hardships just to honor their commitments to their family, their bank, and their community. Before they adopt new farming techniques, they must actually see the benefits. Realizing the benefits of change and cooperation makes producers far more likely to be receptive to change. In order to make this effective and successful, the "win-win" dialogue is essential for the longevity and success of these types of partnerships.

Strategic decisions from increasingly larger agricultural companies focus on corporate profit, and often make life difficult for small producers, because the corporate mentality is not concerned with the families on those properties, who are being deeply affected. These changes beg the questions:

1. What agricultural model will be better in the future?
2. Will there be a place for small producers in the future?

CAPITAL AND TECHNOLOGY

To be successful today, producers must employ modern technology. Those with capital need to seek out and form partnerships with those who have technology. In property-enterprise succession, or in division of property, we must first think on a scale that is economically viable. Many examples of succession exist that didn't reach their objectives. Over time, the division of property needs to transform the estate into parts that use the available technology while achieving a desired scale of production. Not all sons will work in livestock production, yet they can still choose other vocations, receive the same dividends, and maintain the heritage they have been given.

CONCLUSION

The majority of the remaining work in no-till is in educating and encouraging its use: primarily, informing the producer about the economic and ecological advantages that the system offers. We must inform consumers about our products and the high level of quality, efficiency, and environmental stewardship achieved using no-till. It seems odd that organic and biodynamic products have gained the sympathy of the media in recent times. I don't wish to discredit organic products, but in my opinion, you can't call something organic unless it was produced using conservation tillage. By relentlessly tilling the soil, we are opening the door to degradation, and ultimately, compromising our own future. Today, with rapid market globalization becoming ever more apparent, it is necessary to use all available tools for survival, especially as we are competing with an increasing number of subsidized products from First World countries (e.g., the European Union). Because of this, we need to maximize the potential of our existing resources responsibly. Unfortunately, the tendencies we observe in cities, where small commerce is not practical and is replaced by ever larger chain stores (e.g., Wal-Mart in the USA), such as increased capitalism, vertical and horizontal integration, and economies of scale, are also occurring in agriculture and in rural communities.

For today's producer, it isn't enough to produce a suitable volume of goods; he must also pay much attention to the demands of the market and its trends. In developed countries, the consumer demands traceable products and the setting of standards concerning the treatment of animals, grains, and vegetables, as well as their manner of production. The supermarket chains use these differences to their own advantage (and hopefully to the advantage of the producer) in the marketing of agricultural products.

It has been projected that, with the present rate of world population growth, there will be a food shortage by the year 2020. Land is available in limited quantities, so there aren't many possibilities for horizontal growth, and thus, it is necessary to promote vertical growth. This places an even bigger responsibility on our shoulders concerning the management of our soils. Will we leave the individual producer unprepared, without appropriate technologies, degrading his way of life? Or will we instead prepare for him a future of healthy and well-managed soils? Future generations will depend on the attitudes we take on such issues. Our public officials also need to be made aware of this reality and to take part in exploring more options for agriculture.

After much destruction and degradation in the past, we have learned how to produce in harmony with nature, and we now face the new millennium with optimism (Fig. 11). I would like to leave you with the same message that I focused on in a 1981 no-till manual. ***"No-tillage is not only a different technique, but also a matter of survival."***

The challenge now is to convince farmers, not only on a regional basis – as with the *25th Southern Conservation Tillage Conference for Sustainable Agriculture*, but nationally and internationally as well: to gather, discuss, and think about how we can join forces and create the synergy that must exist between farmers, production areas and properties, so that with teamwork, there will be an increase in efficiency and scale, enabling producers to face the challenges and changes of the days ahead successfully – on a local, regional, national, and international level.

PAST, PRESENT, AND FUTURE OF CONSERVATION TILLAGE: U.S.A. FARMER PERSPECTIVE

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In my opinion, the adaptation of conservation tillage in the past has been slow for several reasons:

1. Lack of over-the-top herbicides for our crops, with corn being the exception. Atrazine and Lasso or Dual have provided excellent weed control and still perform well.
2. Lack of equipment to plant in heavy cover crops.
3. Lack of research from our extension service.
4. Farmers have heavily-tilled the soil for years and are reluctant to reduce their tillage.
5. The myth of no till - no yield, no combine bill - is believed to be true by some.
6. The myth that lime won't move through the soil profile over time.
7. Generally speaking, NRCS personnel haven't promoted conservation tillage. There are several NRCS personnel that are avid supporters of conservation tillage and we owe them many thanks.

Presently, there are several reasons for increased conservation tillage:

1. We have good over-the-top herbicides for our major crops. Farmers realize, now, we can control weeds and grasses.
2. Our equipment has been improved through the efforts of farmers, USDA-ARS research and equipment manufacturers. The following are examples:
   a. Moving the coulter farther from the subsoiler;
   b. Raised fin on subsoil points;
   c. Roller to roll down heavy cover crops.
3. The introduction of RR Technology has benefitted cotton farmers in particular.
4. Education of the value of cover crops to our soils:
   a. Increases water holding capacity;
   b. Nutrient recycling;
   c. No water or wind erosion;
   d. Increased beneficial insects.

We still have some areas that need improving, such as more conservation tillage research from our extension services. Also, a lot of NRCS personnel still don't promote the benefits of conservation tillage. Their encouragement would help lead some farmers to adopt conservation tillage. The myths of lower yields, soil must be tilled, (disked, chisel plow, etc.) to form a good seedbed, and lime needs to be incorporated still exist. Also, large acreage farmers think they can't plant in a timely manner.

In the future, as more emphasis is put on a clean environment in the areas of water, soil and air quality, more farmers will move to conservation tillage. We may be even paid to store carbon in our soils.

I think the use of GPS technology will increase conservation tillage acres. With autopilot on tractors, farmers will be able to plant more acres per unit of equipment. Rows could be established in the winter and early spring and large acreage could be planted on a timely basis. With GPS technology, traffic patterns could be established and maintained year to year. Maybe even reduce the need for subsoiling every year. Also, new chemistry herbicides will make weed control in conservation tillage much simpler.

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TWENTY-FIVE YEAR REVIEW OF CONSERVATION TILLAGE IN THE SOUTHERN U.S.: PERSPECTIVE FROM INDUSTRY

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ABSTRACT

Twenty-five years ago, conservation tillage was a concept that many of us had varying degrees of experience and vision of it's potential. Conservation tillage was considered a method to control soil erosion and conserve moisture. There were many barriers including proper planting and spraying equipment, crop protectants for weed, insect and disease control, knowledge of how to apply fertilizers, a negative attitude of "No-Till equal No-Yield" and of course, little expertise. The concept had been introduced over sixty years ago with Edward H. Faulkners Plowman's Folly. Today, through years of agronomic research, extension demonstration, partnerships of industry, farmer and grower experience and much positive publicity, conservation tillage is as commonly accepted in most states as conventional tillage with all major crops. We now have excellent conservation tillage planters, drills and sprayers. We have ten times the crop protectants available to control weeds. Biotechnology has made it simple, affordable, and effective weed control. Fertilizer can now be applied successfully and environmentally acceptable in no-till fields. Attitudes have changed. Farmers who once said they would never no-till now would quit farming if they had to go back to plowing fields. The number and level of experts of conservation tillage is great, but not large enough. We still need more people involved in promoting and refining conservation tillage. During the next twenty five years, we will witness CT mature in growth with many new technologies being introduced by industry to make the agronomic system even easier, more profitable, and environmentally safe.

KEYWORDS

Adoption practices, planting equipment, crop protection, fertilizer use

INTRODUCTION

"You have come a long way Baby" partially describes the development and adoption of conservation tillage in the Southern United States. And I add to this commercial phase "in a relative short period of time." Tremendous strides of success can be and should be shared among all of us in this organization. In the past 25 years, and to some of us, three to four decades, we have seen agricultural crop production in the South transition from preparing our fields for planting from as many as a dozen tillage trips or passes prior to planting to zero. We have the value of 6 and 8 bottom mold board plows being sold in auctions for scrap iron prices. We have seen chisel plows parked and weeds grow up between the shanks, we have 'V' rippers with no tractor large enough to pull them on our farms anymore. We have discs whose blades are changed every few years due to the lack of use and we have young farm labor that does not know how to set the half sweeps on a cultivator. I have a 25 year old son who has asked me if I am ever going to teach him to plow with our old 3 bottom Massey Ferguson mold board plows. He asks, "What is back furrowing?"

According to Doane's Agricultural Research Service last year, the following acres and major crops were produced in conservation tillage and no-tillage. Twenty five years ago, practically no one or no organization documented the change in tillage or the methods of tillage practiced on producing crops. And I use the word "practiced" purposefully, because if we did not till or plow it perfectly the first time we performed it over and over and improved and learned the new and ever evolving Agronomic System. The Tennessee Agricultural Statistics Service started in 1983, through the request and encouragement of the late Tom C. McCutchen, pioneer and leader of no-till at the University of Tennessee Milan Experiment Station (1962-1983). Tennessee leads the South in percentage of acres farmed with no-till technologies, although it is not the largest producer of any particular crop.

The success of conservation tillage in the South and individual states can only be attributed to team work and

IN E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

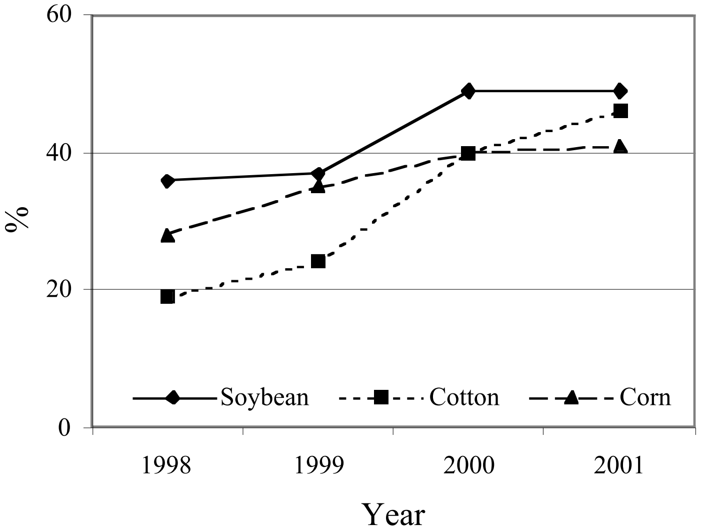

Fig. 1. Percent increase in no-till and conservation tillage acreage for soybean, cotton, and corn in the southern USA. Source: Doane's Agricultural Research Service, 2002.

excellent leadership and partnerships between research, extension, farmers, equipment companies (large and small), crop protectant companies, the fertilizer industry, the ag or farm media, environmental groups and last but not least National Resource Conservation Service and their local Soil Conservation District affiliates as well as ARS.

Success has been achieved in five major areas. These include:

(1) Planting , Seeding and Spray Equipment

(2) Pest control or crop protectants (weeds, insects, disease, rodents)

(3) Fertilizer rate source and placement

(4) Attitude

(5) Degree of expertise

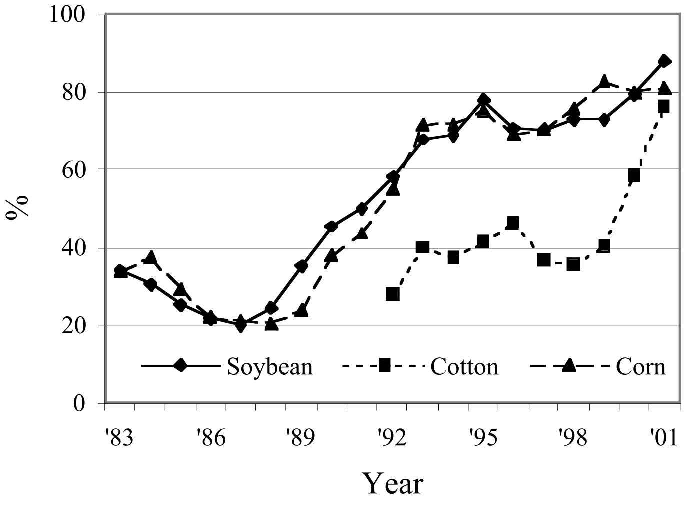

Fig. 2. Growth of conservation tillage (including no till) acreage in Tennessee from 1983 to 2001 for soybean, cotton, and corn. Source: Tennessee Agricultural Statistics Service, Nashville, TN.

PLANTING EQUIPMENT

We all learned early in the trials of no-till that we needed heavier built planting equipment than the '71 model John Deere Flex Planters with shoe or soward type openers. We worked with and tried the Allis Chalmbers. These planters worked with the addition of barrels of water or concrete and available fluted coulters. The AC's planted through fescue sod but were slow (1.5 to 3 mph) for large acreage as growers expanded to row crop production. John Deere introduced the 7100 (3 point hitch) and 7000 (pull type) Max Emerge planter in the mid 70's. The planter with true 'V" disc openers, heavy duty tool bar, heavy duty down pressure springs, 'V' type closing systems with down pressure and the availability of a coulter. These planters cut through reside and cover crops, opened the furrow, placed the seed at a prescribed planting depth, covered the seed for good seed to soil contact, placed fertilizer beside the row and insured excellent stands of no-till and conservation corn, cotton and grain sorghum. At the same time, based on conventional tillage systems and the AC planter, we learned that narrow row spacing, 30 inch or less corn rows and 20 inch or less soybean row spacing, aided in the control of weeds and moisture conservation by quicker shading by the crop canopy. Higher yields were often obtained with reduced row spacing.

In 1977, John Deere introduced the 7100 Soybean Special, conservation tillage planter units on 20 inch spacing to facilitate the advantages of precision planting and narrow rows. International also introduced the off-set double disc openers on its 800 and 900 air seed delivery planters which performed well in no-till. Kinze, Deutz-Allis and White companies introduced heavier-built planters with coulters, openers, and closing systems to enable their customers to direct seed into the roughest of high residue situations. Jerald Hardin and Brown were developing a 'row-till' system or what we now commonly call a rip or strip-till system for the Coastal Plains soil. There were several attachments for different soils and situations with the early strip-till as there still are today. Today there are several manufacturers of strip-till units including Bigham Brothers, Kelly Manufacturing, Powell, Ferguson & PATS.

Conservation tillage drills have advanced as much as precision planters. Tye was one of the first drill manufacturers to build a 'stubble drill' to manage residue and place seed directly into the unplowed soil. This drill was modeled after the "Pasture Pleaser" one of the first forms of no-till, reseeding

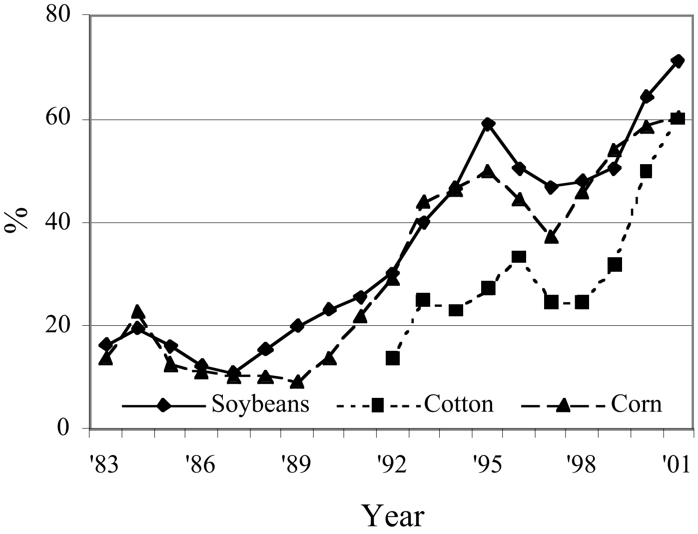

Fig. 3. Percent growth of no till acreage in Tennessee from 1983 to 2001 for soybean, cotton, and corn. Source: Tennessee Agricultural Statistics Service, Nashville, TN.

and renovating pastures without tilling.

The first no-till drills were modified and converted conventional till drills. Many did not hold up to the tough field conditions of no-till. In the mid 80's, most major manufacturers of drills increased the size of the tool bars, used heavier down pressure springs and added gauge wheels for controlling seeding depth on varying soil types. In 1992, John Deere introduced the 750 no-till drill, offering many of the desirable features demanded by growers: variable row spacing, depth control, aggressive for tough soil conditions, and adaptability to plant many different kinds of seed.

Today, most major manufacturers of seeding equipment produce excellent no-till planters and drills. During recent years, economics or profitability has been challenging to agricultural producers. Growers have often not had the capital to purchase new no-till drills and planters. Through the years, those of us dedicated to conservation tillage worked closely with industry that was interested in developing retrofit attachments for planters and drills. The attachments included down pressure springs, seed firming wheels and "rebounders", different types of coulters, residue managers, disc openers, furrow closing systems. We learned early that all mechanical devices must cut and roll through residue, cover crops and no-till soils. Companies leading in the CT attachment industry include Yetter Manufacturing Co., Dawn Equipment Co., Martin Industries, Kelly Manufacturing Co., and others. All of these companies also manufacture CT fertilizer placement attachments.

Today we have a choice and a variety of excellent planters and drills to accomplish successful conservation tillage on all soil types and conditions. "We have come a long way baby."

PEST CONTROL

A close examination of the definition of no-till and conservation tillage reveals that weed control is accomplished by chemicals or crop protectants rather than mechanical tillage. We learned early in our conservation tillage experiences that we must develop weed control systems to ensure success of the planting method. We also learned that an emerging seedling could not tolerate competition from weeds, competition for moisture, nutrients, sunlight and cool soil temperatures. We learned that we must start 'clean' with all vegetation dead or dying.

Weed control has been a challenge. Again, we have come a long way. 'Modern' weed control of the 1950's and 1960's included petroleum-based products that were highly volatile and needed to be tilled or incorporated into the soil, (i.e. Treflan, Eradicane, Sutan, and others). I believe the use of these products actually proliferated tillage to a degree we had never witnessed in history.

Twenty five years ago, we researched and demonstrated available weed control products that did not require soil incorporation or tillage. Pre-plant or "burndown" products included 2, 4-D, Paraquat, Atrazine, MSMA, & Dynap. Each were effective on certain weeds, others only gave partial control. We learned that we could effectively control most weeds in no-till corn with paraquat, 2,4-D, and atrazine as long as we did not have Johnsongrass or bermudagrass and the field received a rain to activate the atrazine with the soil. Soybeans were a different story. The 1970's industry brought us preemergence herbicides that could be surface-applied including Lasso, Dual, Sencor, and Prowl. In 1975, Roundup was introduced offering us the safest broad spectrum "burndown" herbicide we had witnessed. Roundup (non-selective) controlled more weeds including grasses and broadleaves than we had ever experienced. During this same time period we had crop-safe, over-top selective herbicides introduced, including Basagran & Blazer replacing 2, 4-D, Dyanap and Alanap. Good soybean weed control was now possible in no-till soybeans. However, it did take an array of these crop protectants to keep the crops 'clean' or weed free for the entire growing season.

Industry continued in the 1980's to bring excellent products to the conservation tillage farmer. The greatest of these were Accent and Beacon for Johnsongrass and other grass postemergence and weed control in corn. Johnson grass control had been a limiting factor in the expansion of acreage of conservation tillage corn. (note: accelerated growth of NT & CT corn, Figs. 1 and 2,. during 1990s)

Other crop protectants introduced to us in this same time period included the SU or sulfuania urea herbicides, Classic, Canopy for soybeans. Other classes of chemistry introduced were the ALS inhibitors and IMI's The introduction of these herbicides often reduced the number of herbicides and trips of applications.

CT cotton began in the early 1980's. Many of our traditional soil surface herbicides worked well in no-till cotton. Application and timing were critical. Broadcast applications were expensive, but necessary since we were foregoing mechanical cultivation. New grass control products were introduced in the early 1980's, including Poast, Fusilade, Select and Asure. These products provided excellent over - top Johnsongrass control in cotton as well as soybeans. The 1980's were exciting times for the introduction of weed control products effective in CT systems.

The past decade has been even more exciting. During the 1990's, we saw the introduction of Staple, an over-top or post-directed herbicide for seedling cotton. Through genetic engineering, we now have Roundup Ready Soybeans, Roundup Ready Cotton and Roundup Ready Corn for our southern geography. This technology has been the great enabler to bring safe, effective and simple weed control to conservation tillage systems. Most no-till as well as conventional tillage farmers now use only one herbicide, Roundup, for total and season long weed control. Presently over 69 percent of the cotton grown in the US is genetically engineered for Roundup tolerance, or contains the Bollgard insect tolerance gene, or both. Over 70 percent of the soybeans grown are Roundup Ready and growers are purchasing all the Roundup Ready Corn being produced.

Parelleling the development and evaluation of more effective crop protectants for conservation tillage, has been the quest for better spray equipment. We used to find our way about a no-till field at burndown application with a chain marker or guide. We now have foam markers with various colors of foam. We have the availability of GPS guidance systems. We have reduced the amount of water as a carrier of herbicides from 40 gallons per acre for paraquat to 5-10 gallons for Roundup Ultra Max. We now use ounces and grams of products per acre rather than quarts and gallons. We use low volume, low drift, spray equipment technology.

Twenty five years ago, we were building special post-direct herbicide applicators to post-direct 20" soybean rows, apply contract and residual herbicides to the base of cotton plants and shielding the pasts from drift and spray contact from non-selective herbicides sprayed between the rows.

In 1992, plastic hooded sprayers were introduced to the South from Redball, Inc., based in Minnesota. We were able to spray Roundup and other non-selective herbicides "under the hood" and post-direct safer contact and residual at the base of cotton and other crops. Presently there are several major manufacturers of hooded, shielded and post-directed sprayers, most located in the South. These type sprayers have basically eliminated in-season crop tillage or cultivation.

Two of our greatest fears have not developed - insect and disease damage. Twenty-five years ago, many thought that boll weevils, cut worms, grasshoppers and disease complexes would prevent successful conservation tillage. We have found as we change this growing environment we do, occasionally, have infestations of cut worms, grasshoppers, and grubs. Again, industry provided us with products to control the pests and break our barrier of increased insect damage. Genetic engineering such as Bt cotton & corn are offering season- long protection from a broad spectrum of insects.

We have learned that diseases have not been the perceived barrier or demise of CT crop production. Although disease pressure may increase in a CT environment, we have readily-available genetic resistance in varieties, soil- and seed-applied fungicides and insecticides, as well as traditional crop rotations and cover crop benefits. We have often observed less disease pressure in CT condition due to the natural soil microbes increasing as organic matter builds in CT systems. Two years ago, Monsanto introduced brands of Residue proven corn and soybeans. Yes, we have learned what voles are, that snails and slugs will attack corn and cotton, and that fire ant mounds get larger in CT systems. Yet, we have addressed these barriers successfully by re-registering old products and finding new uses for other crop protectants.

FERTILIZER

There are no "short cuts" to effective fertilization practices. Of course, a good fertilization program begins with soil testing. Based on USDA and university research, we have learned that we take our CT soil samples at different depths and our soil testing facilities have adapted. We learned that lime, as well as phosphorus (P) and potassium (K), may be soil-surface-applied in the fall or early spring prior to planting if soil is not eroding from the field. We have learned that we may apply one application of P & K for two crops in the rotation of winter wheat followed by double crop soybeans. We have learned that starter fertilizer may be more beneficial in CT crops than conventional especially when planted early. We have adopted our knowledge of nitrogen sources and loss to volatization to properly apply to each crop. Industry has worked closely with us to develop and manufacture applicators that 'cut and roll' rather than 'drag' through residue. Industry has developed urease inhibitors to slow and lower nitrogen loss when surface applied.

Industry has provided custom application equipment for CT systems to place fertilizer correctly and precisely to the CT crop application. Machine application tires and treads are being changed to help avoid 'cleating' of CT fields prior to planting. Industry is continuing to develop manure applicators for CT with lower soil disturbance.

We have also learned that nitrogen-producing cover crops do not have to be tilled into the soil to contribute nutrients to the primary crop. Effective and efficient nutrient management systems can be accomplished in all CT systems.

ATTITUDE

During the past 25 years, there have been many technological advances in CT systems. We have and know someone in every county or parish of our region practicing cost-effective conservation tillage systems on almost every crop. Crops include corn, soybeans, wheat and grain sorghum as well as peanuts, vegetables, and tobacco. I have seen successful CT on all soil types that normally produce crops. We have learned the many economic, agronomic, and environmental benefits. We have the 'tools'! CT has proven simpler than ever! We have proven yield is not a barrier. We can control erosion cost effectly! The positive list goes on and on! Yet, in a recent survey across the South 30 percent of the growers surveyed stated that 'nothing' would encourage them to adopt CT, they preferred to plow or till. Others gave reasons including:

- Does Not Work on All Soil Types
- Did not Have Equipment
- Past Experience
- Need to Prepare Fields (Straighten Rows)
- Does Not Do No-Till, Prefer Cultivation
- Lower Yields

According to the same survey, factors that would encourage more no-till would be:

- Economics
- Have Equipment
- Better Yields
- Nothing

Industry is working with growers, research, extension, and government to break down these barriers. For example, Monsanto offers these incentives:

- Conservation Tillage Guide
- COE Field Days
- Farm Smart Conferences
- System Sell Brochures
- No-Till Retrofit Equipment Rebates
- Hooded Sprayer Rebates
- Roundup Rewards
- Bottom Line Booster

Attitude is something that we have individual control over everyday. Attitude determines the degree of success or failure of every walk of our lives, our business, our marriage, our church, our research, and our farming system. We have the knowledge, technology, and tools to make CT successful with almost any crop on any soil in any county. We need to continue to be positive and address barriers to CT, adapt new technology to CT and share our expertise with others.

SHARING EXPERTISE

Where would CT be today if we had not shared what we had learned, what we have developed and what we have practiced with others: research with industry, farmers with extension, industry with farmers, etc.? We all believe in CT! One thing that I believe that has slowed and limited adoption is the number of people in the farming communities sharing and promoting CT systems. We need more focus and activity from CT people at the grass roots level. Look where CT has grown and advanced; there is a local leader, an NRCS, an Extension agent, a Milan Experiment Station, an industry representative, an experienced grower, a Farm Smart conference, an annual field day. We need training, cross training, and recruiting. None of us are islands, none of us can do all there is to accomplish for CT. We must continue to work as teams, interdisciplinary work, partnerships and yet work closely with industry and promote those technologies that work in our area's CT system.

THE FUTURE

We are going to see great and rapid changes and new technologies from industry for CT Bollgard II insect protection, enhanced Roundup Ready Cotton (Biotechnology cotton allowing the application of Roundup on more mature cotton), new patented Roundup type products (Mon 007), nematode tolerant cotton, cold tolerant seeds, nitrogen-producing monocotyledonous spcies (corn), additional Roundup-tolerant crops, improved precision planters, and site-specific farming technology adapted to CT.

Almost every product or technology that is brought to the marketplace will work with conservation tillage. Conservation tillage will be of highest priority when new products and technologies are developed by the industry.

Industry will continue to work and partner with government agencies, university research and extension, consultants, and of course, our customers, farmers, and growers. Conservation Tillage is an agronomic system with many interdependent parts, and it is interdisciplinary. Conservation Tillage will continue to grow here and abroad.

MAKING CONSERVATION TILLAGE CONVENTIONAL, BUILDING A FUTURE ON 25 YEARS OF RESEARCH: RESEARCH AND EXTENSION PERSPECTIVE

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ABSTRACT

Although no-till (NT) has shown numerous advantages over conventional tillage methods, the technology has shown relatively slow adoption rates in many regions of the world. In this paper, some of the reasons for slow adoption are analyzed. Mindset is probably among the biggest obstacles to expanded no-till use. Knowledge is also among the main constraints to expanded NT adoption. Although research has generated copious knowledge, this knowledge is often not reaching the farmer. Sometimes conditions for the utilization of technology are not met. Technology diffusion investigations show that farmer-to-farmer extension is one of the most effective ways of achieving rapid adoption of innovations. A greater effort has to be made in creating societal awareness of the many positive effects of NT, not only for farmers themselves but for society as a whole. Research priorities should be directed towards intensifying work with green manure cover crops, crop rotations, biological control of diseases, pests and weeds, soil biology, adaptation of NT to site-specific conditions using a systems approach and on-farm research. The technology should also be developed further for small farmers and research should be done with a greater variety of crops in order to widen the possibilities of crop rotations. Finally a greater effort has to be made in analyzing the economics of NT in a systems approach, taking all on-farm and off-farm benefits of the system into consideration.

KEYWORDS

Technology transfer, crop rotation, economics, cover crops, systems research

CONSTRAINTS TO THE ADOPTION OF NO-TILL

From past research and farmers experience with the no-till system we have learned that crop residues left on the surface protect the soil surface from wind and water erosion, increase the organic matter content of the soil and protect the soil from solar radiation, promoting soil biological activity and bio-diversity, while improving nutrient efficiency, soil structure and water economy. No-till improves water quality and is capable to a large extent of reverting the chemical, physical and biological soil degradation that in extreme cases leads to desertification.

A great wealth of knowledge has been generated on several aspects of the no-till system in the past. It is not the intention of the author of this paper to mention the many research achievements of the past 25 years in this field; this can be done reviewing the literature.

Compared to 25 years ago we have made enormous progress in machinery and herbicide development and much knowledge has been generated (Derpsch 2001a). Why is it that some countries have had relatively slow adoption rates of this technology? While in Brazil, Argentina and Paraguay no-till has been adopted on 45% to 60% of all agricultural land, in the USA the adoption has been only 17.5%. Extremely little adoption has occurred in Europe, Africa and Asia. About 98% of no-till adoption has taken place in the Americas and Australia and only 2% in the rest of the world (Derpsch 2001b).

What are the reasons for the slow adoption in some regions of a technology that has so many advantages and only few disadvantages if any at all? These questions and also future research priorities will be analyzed in this paper.

Mindset is probably among the biggest obstacles to expanded no-till use. Attitudes of farmers that have been plowing the soil for generations are difficult to change. While in general research has been generating adequate technological answers to problems farmers face, we probably have neglected to work on changing the attitudes of rural populations. How could we otherwise explain that a good number of landlords in the USA do not allow their tenants (or fathers do not allow their sons) to use no-till

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because the "dirty trash" on the surface has to be plowed under in order to make the field look clean? Contrary to this an increasing number of landlords in South America do not lease their land unless the tenants use NT.

The idea that the soil has to be plowed to produce a crop is so deeply rooted in many societies in Europe and Asia that it is difficult for these cultures to accept a technology that does away with the plow. The older the tradition of plowing in a society, the more difficult a change seems to be. Also, too many farmers in the USA and around the world still burn their residues, not recognizing the value of crop residues on top of the soil. The best technical research results are of little value if efforts are not made to change attitudes and behavior of farmers, researchers, extension personnel and government officials.

In South America "*we have learned, that if the farmer does not make a radical change in his head and mind, he will never bring the technology to work adequately. We found that this is not only true for farmers but also for technicians,* extension personnel *and scientists as well.* No-till *is so different from conventional tillage and puts everything upside down, that anybody that wants to have success with the technology has to forget most everything he has learned about conventional tillage systems and be prepared to learn all the new aspects of this new production system*" (Derpsch, 2001b)

No-till is probably the "Best Soil Management Practice" for extensive agriculture we know of today. Why is it then that incentives in general still go to curing the symptoms of erosion and bad land management (contour banks, etc.) and incentives seldom are invested in promoting the NT system? Government officials should channel incentives and subsidies adequately, but they only will be able to do this if their attitudes change. "no-till is not a farming practice – it is a concept of the mind" (Rick Bieber, NT farmer, South Dakota). If farmers, technicians, extension personnel, scientists and government officials are not able or willing to change, than it will be difficult to meet the goal of this conference which is *"Making Conservation Tillage Conventional"*.

Knowledge is also among the main constraints to expanded No-till adoption. Despite the fact that knowledge has been generated (Derpsch 2001), this knowledge is not reaching the farmer. Sometimes the problem is that the general knowledge is there, but site specific knowledge is lacking. On station research has generated valuable general knowledge, but at a certain stage, researchers and extension personnel have to go out to the farms and conduct site specific on-farm research and technology development with a systems approach. Also, in many countries extension agents do not know enough about the NT system and consequently are not able to transmit adequate knowledge to the farmer.

Another problem is that all too often knowledge is published in scientific papers and publications and not transformed into a language that is more practical and more accessible to extension personnel and farmers. One part of the problem is the reward system of the scientific community. Scientists in general are rewarded for the number and quality of their publications, but the reward system seldom takes into consideration the adoption of an innovation by farmers. Although a thorough knowledge about the erosion process has been generated in the USA already back in the 1940's when the first photographs of the raindrop impact on a bare soil surface were made by the Naval Research Laboratory together with USDA Soil Conservation Service, it is surprising that even today many researchers, extension personnel and farmers in the USA and elsewhere do not understand this process adequately. Many people still think that one has to loosen the soil by intensive tillage to create big pores and increase water infiltration. **Knowledge is useless if it only is on paper and not in the heads of people**. One problem of course is that the literature generated, even in the last decades, is using outdated information about the alleged benefits of traditional tillage, which in general have been shown to be wrong. The most consistent proof of this is the fact that today more than 67 million ha are being successfully planted into no-till worldwide. An important step is to ensure incorporation of the knowledge accumulated in the NT system in university and college curricula. For this, lecturers need to be trained and new teaching material has to be developed, a task that could well be accomplished by researchers. Today in Brazil for instance there are a number of universities offering degree programs in NT at the graduate level, and many have incorporated NT specialization programs at the undergraduate level (Landers *et al.*, 2001).

CONDITIONS FOR THE UTILIZATION OF TECHNOLOGY

If innovations are to be adopted by farmers, *they* must want to, *they* must know how to, and *they* must be able to follow recommendations. Strategies for the implementation of no-till should carefully consider that *"the results of various diffusion investigations show that* ***most individuals do not evaluate an innovation on the basis of scientific studies of its consequences****, although such objective evaluations are not entirely irrelevant, especially to the very first individuals who adopt. Instead most people depend mainly upon a subjective evaluation of an innovation that is conveyed to them from other individuals like themselves who have previously adopted the innovation. This depen-*

dence on the communicated experience of near-peers suggest that the heart of the diffusion process is the modeling and imitation by potential adopters of their network partners who have adopted previously" (Rogers, 1983).

INFORMATION TO THE GENERAL PUBLIC

Although we have made remarkable technological progress developing no-till, we have failed to inform society as a whole about farmers' contribution to the almost total mitigation of arable land degradation in this system (Landers *et al.*, 2001). Through NT technology we have found a system that is highly economic to farmers and combines agricultural sustainability with natural resource preservation. Despite the fact that a lot has been done in publicizing the enormous impact of tillage on CO_2 emissions to the atmosphere and how NT transforms the soil from a source of carbon dioxide to a carbon sink, the public in general is not aware of these research findings. A much bigger effort has to be made in creating societal awareness about the many positive effects of NT, not only for farmers themselves but also for society as a whole. The downstream benefits of NT adoption are many: NT reduces the impact of soil erosion on roads, waterway, dams, etc., reduces the costs of cleaning drinking water; reduces the cost of electricity generation; increases water infiltration; reduces the risk of flooding; provides greater and more stable yields; allows the production of cheaper food contributing to food security; provides for sustainable rural development that benefits all sectors of society, etc., etc. But, "even if the truth is known, it isn't important unless efforts are made to assure public perceptions are the same" (Beck, 2002).

FUTURE RESEARCH PRIORITIES

There are a number of issues that researchers in general have neglected in the past which need to be addressed more intensively in the future. Research especially needs to be intensified on cover crops, crop rotations, biological controls of diseases, pests and weeds, soil biology and adaptation of the NT system to site-specific conditions using a systems approach and on-farm research. Research should also concentrate on developing the technology further for small farmers and for a greater diversity of crops. Last but not least, researchers should increase their efforts to evaluate the economics of NT.

GREEN MANURE COVER CROPS (GMCC)

The missing element in the no-till system in many regions in the world is the systematic application of Green Manure Cover Crops that enrich crop rotations. Research conducted in Brazil and Paraguay has shown that GMCC's are not only an economic viable option, but that they are indispensable to reduce weed infestation and herbicide costs, reduce diseases and pests, produce the permanent cover needed in the NT system and increase organic matter content of the soil. Therefore, in the NT system it is mandatory that GMCC's are included in crop rotations. In regions were GMCC's are not used research has to select and screen adequate species that can be fitted into specific windows of the farming system. Once it is known which GMCC's can be used in a certain window, research has to study the residual fertilizer effect of these cover crops on the main crops in terms of weed, diseases and pest suppression (or not), increases in yields of cash crops, reduction in nitrogen application rates, etc. Only when this data is available can economists evaluate the economic benefits of cover crops. Without conducting system-approach economic studies over several years, it will not be possible to determine the economic benefits of GMCC's. We have to be aware that farmers in general will only use cover crops when they show economic advantages over the conventional situation. Derpsch *et al.* (1991) showed that soybean [*Glycine max* (L.) Merr.] yielded up to 60% more following black oat (*Avena strigosa* Schreb*.),* a common cover crop in South America, than following wheat (*Triticum aestivum* L.), and that the black oat system demonstrated a quantifiable economic benefit.

CROP ROTATION

A great proportion of no-till still continues to be practiced in monoculture. Monoculture is defined as repeating the same crop each year in the same place. Under this definition, double cropping wheat and soybean is understood as monoculture in South America. Research has to make a larger effort in showing the advantages of crop rotations over monoculture. This needs a systems approach and long term trials (Reeves, 1997), because differences between rotation and monoculture will be greater the longer an experiment is run. A good example is the rotation trial at Rothamsted Experiment Station in the UK, where after a 100 years of experimentation it is shown that wheat in monoculture with 140 kg ha^{-1} N produced about the same (3 tons ha^{-1}) as wheat without N were adequate rotation has been practiced (Boguslawski 1981). Today we know that diseases are one of the biggest problems of NT. This problem can in general be solved using sound crop rotation.

BIOLOGICAL CONTROLS OF DISEASES, PESTS AND WEEDS

No-till increases the potential benefit from using biological controls, allowing a reduction in use of agricultural chemicals. Research has to demonstrate how chemicals can be replaced by biological controls. There are already good examples of efficient biological controls being practiced by farmers. Research in Paraguay has shown that control of the soybean caterpillar *Anticarsia gematalis* with *Baculivirus anticarsia*, is much more effective in the NT system than in conventional tillage (Kliewer *et al.*, 1998). The NT pioneer farmer Herbert Bartz in Rolandia, Brazil, reports not having used post-plant insecticides on soybean for the last 18 years (Landers *et al.*, 2001). Research in Paraguay has also shown it is possible to suppress weeds effectively and economically seeding cover crops or cash crops immediately or as soon as possible after harvesting one crop. In this system it was possible not to apply herbicides at all for 3 years in a row (Vallejos *et al.*, 2001). The potential of reducing weeds with cover crops and adequate management practices has not been sufficiently studied and recognized. More research with a systems approach is needed in this field.

SOIL BIOLOGY

Research has done a fairly good job in understanding and quantifying the effects of tillage systems on chemical and physical soil properties. This has not been the case with respect to biological soil properties. Biological soil processes are probably the most important part of soil fertility and yet we have not been able to come up with a practical and easy method of quantifying biological soil fertility. *"By modifying the structure of the soil ecosystem and the soil-litter interface, NT systems provide the ideal environment for the re-establishment of ecosystem engineers such as earthworms and scarab beetle larvae, of saprophagous and litter transforming organisms such as termites and millipedes and of predator population (pseudoscorpions, centipedes, diplura and spider), thus enhancing the system's natural biological control and regulation mechanisms"* (Brown *et al.*, 2001). Research has to address the issue of soil biology and biological fertility more intensively than in the past.

ADAPTATION OF NT TO SITE-SPECIFIC CONDITIONS USING A SYSTEMS APPROACH AND ON-FARM RESEARCH

This has also been a missing element in many regions. In order to make technology work, adaptive on-farm research is needed. This research has to have a holistic management or systems approach. This means that management decisions and policy techniques need to be based on a broader perspective than has been common in the past (Beck, 2002). Farmers deal with systems, why should researchers continue to ignore this?

SMALL FARMER

While not too long ago it was believed that no-till could only be practiced on big farms with tractors, Brazil and Paraguay have made great progress in developing the NT system for small farmers. Other countries in Latin America, Asia and Africa have to increase their effort in research and development of NT technology for draft animals and also for manual production systems.

RESEARCH WITH A GREATER VARIETY OF CROPS

There are a large number of crops that have proven to grow well in the no-till system, but still there are doubts that some crops like potato (*Solanum tuberosum* L.) and cassava (*Manihot esculenta* Crantz) can grow in this system. In the meantime there are experiences with potato grown in NT in Colombia (Birbaumer, 2000) and cassava grown in NT in Paraguay (Florentìn *et al.*, 2001). Both crops have grown well in this system and farmers obtained higher yields when NT was used as compared to conventional cultivation. Although farmers are already using potato and cassava in the NT system, little research has been done with those crops. Researchers should be encouraged to work with non traditional no-till crops in order to widen the possibilities of crop rotations.

THE ECONOMICS OF THE NO-TILL SYSTEM

Many economic studies have produced misleading results because they have oversimplified evaluations, not taking important aspects of the system into account. Research should increase the effort in evaluating the economics of no-till, avoiding simplistic comparisons of one or two crops. Instead economic studies should have a systems approach and be carried out over several years, considering all aspects of the farming system, not forgetting the value of soil degradation in conventional tillage (erosion, loss of organic matter), the improvement in soil fertility in the NT system (reduction in fertilizer application rates), considering the cost of traditional soil conservation, taking offsite costs of erosion into account, consider the fact that a tractor will last 16 to 20 years in a No-till system as against only 8 to 10 years in the conventional tillage system, that less and smaller tractors are needed, etc., etc.

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CONSERVATION TILLAGE IN ALABAMA'S "OLD ROTATION"

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ABSTRACT

After 106 cropping years, Alabama's Old Rotation experiment (circa 1896) continues to document the long-term effects of crop rotation and winter legumes on sustainable cotton production in the Deep South. For 100 years the experiment was under conventional tillage. However, since 1997, all crops planted on the Old Rotation have benefited from minimum tillage. Coincidentally, record yields of all crops grown on the Old Rotation have been achieved since conservation tillage techniques have been implemented. Long-term yields suggest that winter legumes are just as effective as fertilizer N in producing optimum cotton yields. Yields are also highly correlated with soil organic matter that reflect the long-term treatments. In the past, crop rotation benefits have had a small effect on cotton yields, considering yield levels and crop value. These benefits are apparently enhanced under conservation tillage. Soil quality differences, e.g., aggregation and soil tilth, due to rotations and cover cropping are dramatic and are likely to increase under conservation tillage.

KEYWORDS

Long-term research, winter legumes, cotton, corn, sustainable agriculture, tillage

INTRODUCTION

The "Old Rotation" experiment (circa 1896) on the campus of Auburn University is the oldest, continuous cotton experiment in the world. The test was started in 1896 by Professor J.F. Duggar to test and demonstrate his theories that sustainable cotton production was possible on Alabama soils if growers would use crop rotation and include winter legumes (clovers and/or vetch) to protect the soil from winter erosion and provide nitrogen (N) for the summer crop. The Old Rotation was placed on the National Register of Historical Places in 1988.

Since the centennial cropping year of the Old Rotation (1995), major technological modifications have been implemented in managing this experiment. These include switching to genetically modified crops, almost complete elimination of insecticide use, drastically reducing herbicide use, and switching to conservation tillage instead of conventional moldboard plowing and cultivation. In 2002, another dramatic change is being monitored in the old experiment. Irrigation has been installed such that half of each plot can now be irrigated. This report will highlight yields and observations made during these transition years.

OBJECTIVES

The objectives today are very similar to Professor Duggar's original objective: to determine the effect of crop rotations and winter legumes on sustainable production of cotton in the southern United States. In addition, fertilizer P and K treatments initiated in 1925 allowed early researchers to evaluate the timing of P and K applications to cotton rotation systems. Today, the site is also used as a field laboratory for researchers, students, and visitors interested in long-term, sustainable crop production systems in the southern United States. Since conversion to conservation tillage in 1997, soil quality changes are being monitored.

METHODS

The site is at the junction of the Piedmont Plateau and Gulf Coastal Plain soil physiographic regions. The soil is identified as a Pacolet sandy loam (clayey, kaolinitic, thermic Typic Hapludults). There are 13 plots on one acre of land. Each plot is 136 feet long by 21.5 feet wide with a 3-foot alley between each plot. Originally, each plot was a separate treatment, but today treatments may be described as the cropping systems in Table 1.

Of minor interest today is the timing of fertilizer P and K. Originally, the soil was low in both P and K and the winter legume produced more biomass (and more N) with direct P and K applications. This provided more N for the following cotton crop, resulting in higher cotton yields. Today, all soils test high in P and K and there is no longer a differential

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Table 1. Description of rotation and timing of P and K application treatments for the Alabama "Old Rotation " experiment located on the campus of Auburn University.

Treatments	Plot no.
I. Continuous cotton	
A. No legume/no fertilizer N	1, 6
B. Winter legumes (crimson clover and/or vetch)	2, 3, 8
Timing of P and K aoolication	
(1) Prior to planting cotton	8
(2) Fall application to winter legume	2
(3) Split application: 1/2 to cotton, 1/2 to legume	3
C. 120 lbs N acre^{-1} (as ammonium nitrate)	13
II. Two-year cotton-corn rotation	
A. Winter legumes, no fertilizer N	4, 7
B. Winter legumes + 120 lbs N acre^{-1}	5, 9
Timing of P and K aoolication	
(4) Split application: 1/2 to cotton, 1/2 to legume	all 4 plots
III. Three-year rotation	
Year 1: Cotton then winter legumes	10, 11, 12
Year 2: Corn then small grain for grain	
Year 3: Soybean then winter fallow	

response to the time of fertilizer application although the treatments continue.

All plots have received a total application of 80 lbs P_2O_5 and 60 lbs K_2O per acre per year since 1956. Fertilizer N or legume N is the only fertility variable. Lime is applied to each plot as determined by a soil test to maintain soil pH between 5.8 and 6.5. Soil samples are taken in even-numbered years.

CROP VARIETIES

Crop varieties planted have always been those common varieties recommended and used by growers. However, since 1996, varieties planted and dates harvested reflected new, genetically modified crops that fit well with conservation tillage practices. In 1999, cotton and soybean were both Roundup Ready® varieties and corn was a Liberty Link® variety allowing weed control using only two herbicides.

TILLAGE

All plots were managed with conventional tillage (moldboard plow, flatbed disk or chisel, field cultivate or harrow, and cultivation for weed control) from 1896 through 1996. In 1997, all plots were switched to conservation tillage (spring paratill under the row and plant using no till planter; no mechanical cultivation). A goal was to establish reseeding crimson clover in those plots planted to winter legumes. The following management sequence is now used:

1. Early April: clip winter legumes for dry matter yield.

2. Early to late April: paratill (subsoil) cotton and corn plots; broadcast appropriate fertilizers and/or lime; strip plant corn into clover using row cleaners.

3. Late April to early May: strip plant cotton into mature clover using row cleaners and no-till planter; use Roundup® on cotton or Liberty® on corn to control emerged weeds.

4. Late May/early June: harvest small grain for grain; drill soybean into grain residue; apply Roundup or Liberty as appropriate.

5. Summer: scout cotton and apply appropriate insecticides if necessary.

6. Late August: harvest corn for grain

7. October-November: paratill and plant small grain following corn

8. Early October: harvest cotton; overseed with winter legumes if necessary (plots should have re-seeded and clover seedlings will be emerging at this time); apply fall fertilizer to appropriate plots.

9. Late October: chop cotton stalks when winter legumes are established; harvest soybean.

10. November-March: enjoy football, hunting, and basketball; write reports.

11. February: topdress small grain on plot 10, 11, or 12 with 60 lbs N acre^{-1}

RESULTS (1987 THROUGH 2001)

A NEW ERA BEGINS

The near statewide cotton yield disaster in 1995 prompted Alabama farmers to quickly adopt the new Bollgard genetically modified varieties commercially available for the first time in 1996. This year also opened a century and a new era for the Old Rotation experiment. Since then, only genetically modified cotton with bollworm resistance has been planted on the Old Rotation. Interestingly, no broadcast application of insecticides have been applied to the Old Rotation since then! This contrasts with 8+ applications made annually prior to this new era. Roundup® resistant varieties were introduced in 1997 (soybean) and 1998 (cotton). Since then, only two herbicides have been used, Roundup® on cotton and soybean and Liberty® on corn, and no insecticides have been used since the 1995 season. *Genetically modified crops and conservation tillage introduced a new millenium of crop production unlike anything imagined by Professor Duggar's generation in the 1890s.*

CROP YIELDS

Year to year cotton yields continue to be extremely erratic due to uncontrollable environmental factors, mainly moisture. As an example, annual seed cotton yields since 1896 on plot 3 (cotton with winter legume) are plotted in Fig. 1. Interesting, rarely does one see two really bad years in a row or two very good years in a row. Year-to-year yields are extremely erratic for non-irrigated cotton. However, rarely does an exceptionally high yielding year follow another high yielding year. The same is true for low yielding years. While 1994 and 2001 were two of the highest yielding years on record; 1995 and 2000 were two of the worst. The 5-yr running average gives an indication of yield trends.

In past decades, there seemed to be a slight advantage to rotating cotton with corn or other crops. During the 1990s, this statistical advantage disappeared (Table 2). The highest numerical average (2+ bales per acre) was produced with a cotton-corn rotation using winter legumes plus N fertilizer (plots 5 & 9). Winter legumes (crimson clover) versus fertilizer N resulted in no differences in 10-yr average cotton yields from 1987 through 1996 or in the 5-year average yields since 1997.

Statistically, one should not compare yields from conventionally tilled cotton prior to 1997 and conservation tilled (no till in Table 2) because there are many more variables involved than just tillage. However, of interest is the noted increase in average yields of all crops since conservation tillage began in 1997 (Table 2). Cotton and soybean yields from the disaster year, 2000, were not included in these mean yields. Severe summer drought and late planting of cotton

Table 2. Mean crop yields on Old Rotation, 1986-2001. Cotton lint yields were calculated from seed cotton yields by assuming 38% lint. Mean values followed by the same letter are not statistically different at *P* = 0.10.

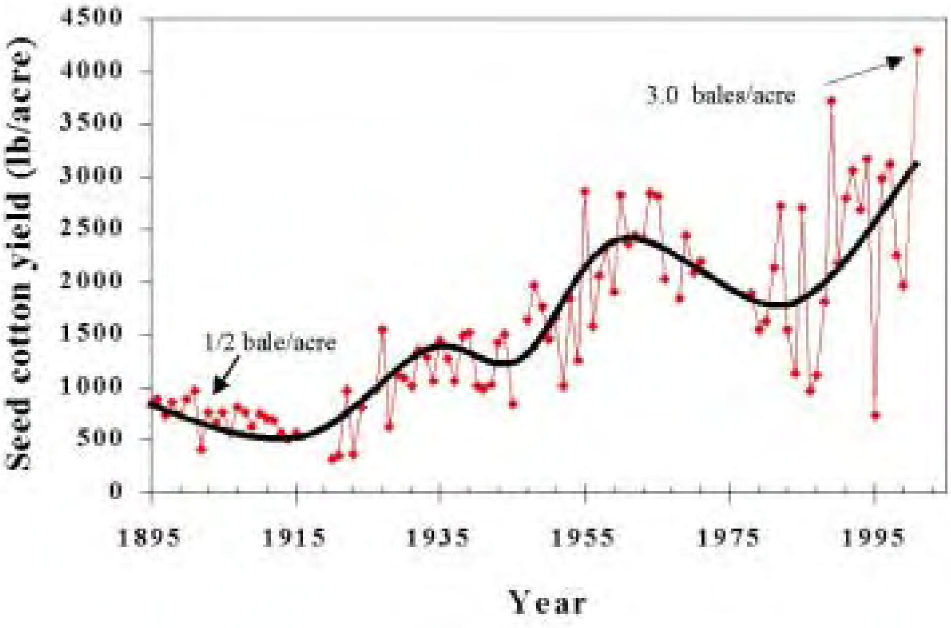
		Cotton lint yields		**Corn grain yields**	
Plot	Treatment	Conv. tillage 1986-95	No tillage 1996-2001	Conv. tillage 1986-95	No tillage 1997-2001
		------lbs per acre----------		--------bushels per acre--------	
1	No N	310 b	360 b	--	--
2	+ legume	770 a	1040 a	--	--
3	+ legume	850 a	890 a	--	--
4 & 7	Cotton-corn + legume	880 a	1000 a	77a	114a
5 & 9	Cotton-corn + legume + 120 N	900 a	1140 a	96a	139a
6	No N	350 b	360 b	--	--
8	+ legume	850 a	1100 a	--	--
10,11, 12	3-yr rotation	830 a	990 a	103a	127a
13	+120 N	700 a	1030 a	--	--
		Small grain (wheat or rye) --------------------------bushels per acre--------------------------			
Plot	Treatment	Conventional tillage 1986-1995		No till 1996-2001	
10,11, 12	3-yr rotation	Wheat=42 (n=2)	Rye=26 (n=6)	Wheat=76 (n=4)	Rye=23 (n=2)
		Soybean --------------------------bushels per acre--------------------------			
10,11, 12	3-yr rotation	31		40	
		Winter legume dry matter yields ------------------------lbs per acre----------------------------			
All plots	Average of all plots	3750		3080	

Table 3. Record non-irrigated crop yields on the Old Rotation.

Crop	Rank	Year	Plot	Record Yield
Cotton	1	2001†	8	1600 lbs lint acre^{-1}
	2	1994	3	1490
	3	1993	9	1270
Corn	1	1999†	11	236 bu acre^{-1}
	2	2001†	5	193
	3	1997†	5	148
Wheat (1961-present)	1	2001†	10	94 bu acre^{-1}
	2	2000†	11	81
	3	1999†	12	79
Oat (before 1960)	1	1958	--	109bu acre^{-1}
	2	1937	--	97
	3	1956	--	87
Rye (1978-present)	1	1981	--	55
	2	1988	--	48
	3	1979	--	40
Soybean (1957-present)	1	1996	12	67 bu acre^{-1}
	2	1992	--	61
	3	1983	--	55
Winter legume	1	1981	11	7250 lbs DM acre^{-1}
	2	2000†	8	6480
	3	1999†	3	6410

† Indicates conservation tillage since 1997.

Fig. 1. Yield for continuous cotton with winter legumes (plot 3) as an example of the yield trends over the 100 years of the Old Rotation.



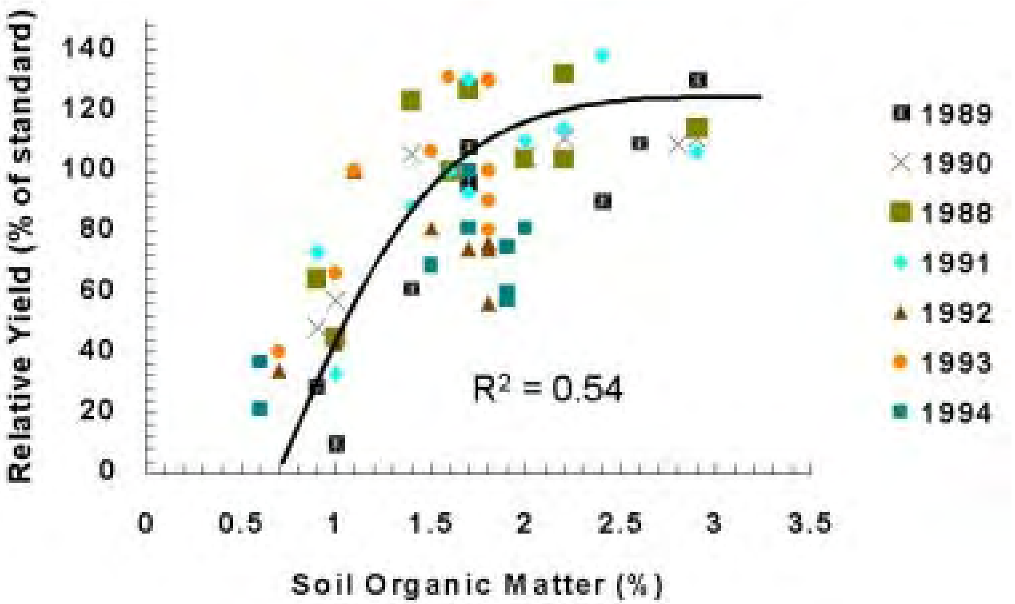
and soybean resulted in no harvestable yield in 2000.

Since switching to genetically modified crops in 1996 and conservation tillage in 1997, record yields of all crops have been produced on the Old Rotation (Table 3). A record 3 bales cotton per acre (1600 pounds lint) was produced in 2001 on a plot which has never received anything but legume N (plot 8). In 1999, a record corn grain yield of 236 bushels per acre was produced on the 3-yr rotation with only legume N. This was attributed to paratilling and residue left on the soil surface, less water runoff and more infiltration, narrow rows (30-inch rows), a high plant population, very high June rainfall during silking and pollination. Paratilling and a cool, dry spring were responsible for three consecutive record wheat yields in 1999, 2000, and 2001. The record soybean yield in 1996 (67 bushels per acre) is attributed to early planted, full-season beans planted into rye stubble and very favorable moisture during pod fill. Due to a late freeze in 1996, the rye crop was not harvested for grain which allowed for early planting of soybean. Normally, soybean is planted after grain harvest in late May or early June.

SOIL QUALITY

Interest in sustainable agricultural systems and soil quality prompted a new look at these factors in the Old Rotation. Surprisingly, little effort has been directed over the past 100 years toward documenting the effects of the cropping systems

Fig. 2. Long-term treatments have resulted in significant differences in soil organic matter (organic C x 1.7 = soil organic matter). These differences are reflected in soil structure, water holding capacity of the plow layer, increased soil buffering capacity, e.g. increased cation exchange capacity, total mineralizable N, etc. Soil organic C was measured in 1988, 1992, and 1994 and regressed against plot yield relative to plot #3 (continuous cotton and winter legumes). There is a definite trend toward higher yields with increased soil organic matter.



on soil organic matter and its effect on yields. Soil organic matter was first measured on plots of the Old Rotation in 1988. Since then, measurements have been repeated in 1992 and 1994. As expected, the long-term treatments have had a dramatic effect on the buildup or depletion of soil organic matter. This is reflected in the yields. Yields in 1988, 1992, and 1994 were closely correlated with soil organic matter measurements (Fig. 2). In 1997, just prior to conversion to conservation tillage, additional soil physical and chemical measurements were taken to serve as a benchmark for future comparisons (Table 3). As crop rotation increased and more biomass was returned to the soil in the form of crop residue, we see increases in soil water holding capacity, hydraulic conductivity (K_{sat}), respiration, total C, total N, cation exchange capacity (CEC), and water-stable aggregates. All these indicate improvements in soil quality.

CONCLUSIONS

After 106 cropping years, the Old Rotation continues to document the long-term effects of crop rotation and winter legumes on sustainable cotton production in the Deep South. Long-term yields suggest that winter legumes are just as effective as fertilizer N in producing optimum cotton yields. Yields are also highly correlated with soil organic matter that reflect the long-term treatments. In the past, crop rotation benefits have had a small effect on cotton yields, considering yield levels and crop value. These benefits are apparently enhanced under conservation tillage. Soil quality differences, e.g., aggregation and soil tilth, due to rotations and cover cropping are dramatic and are likely to increase under conservation tillage. For more information about the Old Rotation and long-term yield records, see the references listed below or check out the web site at

http://www.ag.auburn.edu/dept/ay/cotton.htm

ACKNOWLEDGEMENT

The Old Rotation exits as the world's oldest, continuous cotton plots, and the third oldest continuous field crop experiment on the same site in the United States because of the dedication and cooperation of many individual researchers and administrators at Auburn University. The support of the Alabama Agricultural Experiment Station, Dr. John Jensen, Interim Director, and Dr. Robin Huettel, Associate Director, has been the main reason it has continued to exist. Recently, the USDA Soil Dynamic Laboratory staff and their equipment have played a major role in converting the Old Rotation to conservation tillage. Many students have collected data from the plots that add to our knowledge of soil quality changes. Most of the day-to-day

Table 4. Selected soil physical and chemical measurements made on treatments from the Old Rotation in 1997 before conversion to conservation tillage. Values followed by the same letter are not statistically different at *P* = 0.10.

Treatments	Bulk Density	Soil water	K_{sat}	Soil respiration
Continuous cotton:	----g cm^{-3}----	-----%-----	-inches min^{-1}-	lbs. C A^{-1} day^{-1}
No N/no legumes	1.66	7.69 c	0.37	22 b
+ winter legumes	1.66	7.47 b	0.43	44 ab
+120 lb. N/acre	1.73	9.40 bc	0.04	36 ab
Two-yr rotation:				
+ winter legumes	1.68	10.11 ab	0.57	60 a
+legumes/+120lb N/acre	1.62	11.67 a	0.33	45 ab
Three-yr rotation	1.65	11.47a	1.22	60 a

Treatments	Total C	Total N	C.E.C.	Water stable aggregates
Continuous cotton:	----%----	----%----	--$cmol_c$/kg--	----%----
No N/no legumes	0.50 d	0.02 c	3.1 c	49.8 b
+ winter legumes	0.84 c	0.04 ab	4.3 b	52.2 b
+120 lb. N/acre	0.87 c	0.04abc	5.6a	34.7 c
Two-yr rotation:				
+ winter legumes	0.85 c	0.05ab	4.6 b	53.2 b
+legumes/+120lb N/acre	1.09 b	0.06a	5.4a	48.9 b
Three-yr rotation	1.27a	0.05ab	5.5a	64.1a

work and maintenance is conducted by Mr. Charlie France, Research Technician, who has worked on these plots for over 40 years. The Old Rotation and other long-term experiments in Alabama are partially supported through grower checkoff funds through the Alabama Wheat and Feed Grain Committee and the Alabama Cotton Commission.

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HIGH RESIDUE CONSERVATION TILLAGE SYSTEM FOR COTTON PRODUCTION: A FARMER'S PERSPECTIVE

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ABSTRACT

High residue conservation tillage systems for cotton (*Gossypium hirsutum* L.) production have been proposed as having the potential to be both economically and environmentally sustainable, and research regarding tillage systems has indicated that several advantages may exist for conservation tillage systems compared to conventional tillage systems. However, adoption of new farming systems on a regional scale is difficult unless an individual farmer is willing to take the personal risk and demonstrate the sustainability of the new system on a farm. The John T. Ingram and Sons farm is an example that in 1984 adopted a high residue conservation tillage system. Located on the Coastal Plain soils of Alabama, this farm has been successfully operating as a high residue conservation tillage system from that time to the present and has served as an example for other farmers in the region. The following describes the system presently used on the John T. Ingram and Sons farm and presents their perspective and observations.

KEYWORDS

Strip-tillage, residue management, cotton planter, cover crop.

INTRODUCTION

The development of herbicides in the 1960's provided the ability to produce crops without tillage to control weeds (Baeumer and Bakermans, 1970; Reeves, 1997), which in turn led to the development of cropping systems that limited tillage operations, i.e., conservation tillage systems. Conservation tillage systems have been greatly researched and have been found to provide both potential economic and environmental advantages compared to conventional tillage systems. Over the years, better herbicides and planting equipment have been developed that led to increased adoption of conservation tillage systems across the country. For example in 2002, it is estimated that approximately 70% of cotton production in Alabama will be planted with conservation tillage systems, up from 18.5 % in 1998.

Extensive research has been conducted on developing conservation tillage systems across the country. While this research has contributed to improvements in these farming systems, the wide spread adoption would not have occurred without the pioneering efforts of some individual farmers who were far sighted enough and willing to take the personal economic risk to use conservation tillage systems on a large scale on their farms. In the Coastal Plain of Alabama, John T. Ingram and Sons farm initiated a conservation tillage system in 1984, and is an example of one of these pioneering farms. The objective of this manuscript is to describe in detail the high residue conservation tillage farming system that has evolved on the Ingram farm.

DISCUSSION

The John T. Ingram & Sons farm is located in Marvyn, AL (just south of Auburn, AL). The farm is operated by Tom Ingram and two of his sons, John T. Ingram Jr. and Robert Ingram. Tom Ingram returned from military service in Europe following World War II and graduated from Auburn University on the GI bill. Following graduation, he started to grow cotton on the family farm. Today, Tom Ingram and his two sons' farm comprises approximately 600 acres of cotton. In 1984, the Ingrams initiated a high residue conservation row tillage farming system on 100% of their farm. The conservation tillage systems used by the Ingrams has changed over the years as they have developed better farming techniques and adapted to changing technology. The following is a description of the farming system the Ingrams plan to use this year (2002).

HIGH RESIDUES

Central to the Ingram's conservation tillage system has been the use of high levels of crop residues that are left on the soil surface. Research has shown the benefits of winter cover crops to provide erosion control and to provide crop

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rotation benefits (Reeves, 1994). Benefits such as improved soil physical condition (Folorunso *et al*., 1992; Jackson *et al*., 1993), chemical (Ebelhar *et al*., 1984; Martin and Touchton, 1983; Jackson *et al*., 1993), and biological (Curl, 1963; Barber, 1972; Ries *et al*., 1977) properties have been identified as possible rotation benefits. For example, cover crops can improve soil structure and increase soil water infiltration and storage (Folorunso *et al*., 1992; Jackson *et al*., 1993).

The Ingrams have always used a winter cover crop to provide erosion control for the winter fallow period and to produce a heavy residue for cotton production. They have tried several different plant species over the years, including both non-legume and legume plant species. The legume plant species included clover (*Trifolium incarnatum* L.) and vetch (*Vicia sativa* L.), as well as attempts to plant a winter clover crop that would naturally reseed. The non-legume species included wheat (*Triticum aestivum* L.) and oats (*Avena sativa* L.). Presently, the Ingrams are using rye (*Secale cereale* L.) as their cover crop species because they have found it to be reliable in planting while providing adequate ground cover for soil protection during the winter months (Fig. 1). Rye also exhibits good growth in early spring before killing, which provides a good heavy residue that affords good moisture conservation for the summer growing season. The cover crop is generally killed one month prior to cotton planting (Fig. 2).

Fig. 1. Cover crop of rye planted into cotton stubble, with a 14-inch gap centered on cotton stalks.

Fig. 2. Cotton is planted into killed rye cover crop.

TILLAGE SYSTEM

The cropping system used is a row-till conservation tillage system, which consists of an in-row ripping operation and planting into surface residues from the previous year's crop and cover crop. Cotton is planted on a 40 inch row spacing. In the fall after the cotton is picked, cotton stalks are chopped and left on the soil surface. A grain drill, which has been altered to allow for a 14 inch space centered on the previous year cotton stalks, is used to seed a rye cover crop (Fig. 1). The rye is left to grow during the winter months and is killed with Glyphosate[1] during the first of April (approximately 1 month before planting). Immediately before planting, a ripping operation is performed directly into the previous year's cotton stalks (Fig. 2). The ripping operation uses a subsoil shank to a depth of approximately 16 inches, but causes almost no surface soil disturbance. Cotton is planted into the previous years cotton stalks. By planting into the same row each year, a controlled traffic system is maintained. Research has indicated that using a subsoiler along with controlled traffic can greatly reduce soil compaction that is commonly observed with strict no tillage systems (Raper *et al*., 1994). A John Deere MaxEmerge Plus VacuMeter vacuum precision planter is used for planting at a seeding rate of 1 seed per 4 inches (Fig. 3). Previously, the Ingrams used 3 seeds per hill for planting, but found that large skips could result if they had a seed emergence problem from the loss of just one hill. The planter uses row cleaners with a forward residue mover of their own design (Fig. 4). The residue mover device pushes the standing rye stalks out of the way of the planter and prevents them from becoming entangled in the row cleaner mechanism. This added feature greatly improves planter performance by preventing clogging of the moving parts of the planter. At the rear of the planter (Fig. 3), a spoked wheel row closer is used instead of a solid press wheel row closer. The Ingrams have found that solid wheel closer systems often resulted in levels of soil compression in the immediate area of the seed that obstructs plant emergence. This has not been a problem with the spooked wheel row closures, which has resulted in a more consistent level of soil compression and generates a good soil/seed contact in the sandy soils.

In recent years, the Ingrams have started to eliminate the ripping operation from their cropping system. Last year, only 50% of their farm was ripped and they do not plan to use this tillage operation for planting cotton this year (2002). They believe that improvement in soil

Fig. 3. Cotton planter with spoked wheel row closers.

Fig.. 4. Cotton planter with a forward residue mover.

physical condition and increased soil organic matter with the use of cover crops has improved the soil tilth to the point that subsoil ripping may not be necessary every year. Research into soil bulk density and soil strength support this view. While bulk density has been shown to increase with strict no tillage, lower bulk densities have been reported with no tillage in cropping systems that produce greater amounts of crop residues (McFarland *et al*., 1990). In addition, soil strength measurements have been shown to be reduced when cover crops are used compared to no-till systems using the cotton residue alone (Schwab *et al*., 2002). The Ingrams expect that deep ripping may be necessary in the future due to reconsolidation in the subsoil, but plan to use a soil penitrometer to identify when reconsolidation would be root limiting.

The Ingrams have noticed that the soil temperatures are distinctively cooler in the summer with the heavy residue cover. They believe that these cooler soil temperatures help cotton production during very hot periods of the growing season due to soil moisture conservation from the cooler temperatures and reduced evaporation of soil water from the soil surface. Improved soil moisture conservation due to surface residue cover has been observed in research, due to both a reduction in cultivation and increased soil insulation with the residue (Bradford and Peterson, 2000). Also, the improved soil physical conditions and increased soil organic matter results in increased soil water storage (Reeves, 1994).

In some cases (especially in cold humid climates), yield reductions have been observed with the no-tillage system, which have been attributed to cooler soil temperatures from the residue cover reducing seed germination and slowing seedling growth (Swan *et al*., 1987; Bradford and Perterson, 2000). The Ingrams believe that in addition to providing a guide for controlled traffic, the 14 inch skip in the cover crop planting centered on the cotton row alleviates this potential problem. The skip in the residue cover allows for the sun to warm the soil in the immediate area of the cotton row and helps with seed germination and seedling growth during the critical early growing season (Fig. 5). This concept has been supported with research by Kasper *et al*. (1990); they reported an increase in plant performance when residue was cleared near the row. The Ingrams have not observed any problems with seed germination due to cool temperature. The Ingrams check for soil temperature before planting, but do not believe that there is a substantial difference between when they plant and their neighbors that used conventional tillage.

One of the main benefits to conservation tillage systems is erosion control (Reeves, 1994). The use of cover crop not only provides a cover during the winter months to protect against erosion, it also provides a large amount of residue cover for soil protection during the growing season (Fig. 5). The Ingrams have noticed that runoff water from their cotton fields is nearly clear, unlike the muddy water they observe in the conventionally tilled fields in the area. This observation is backed up in the scientific literature, with conservation tillage systems being found to be very effective in reducing erosion and limiting the amount of nutrients that leave the field in sediment (Angle *et al*., 1984; Gilley *et al*., 1987). A large part of the observed effect is increased soil water infiltration with surface residues. For example, Potter *et al*. (1995) reported

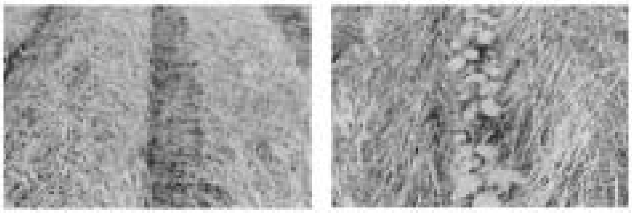

Fig. 5. Cotton is planted into a 14-inch skip in the cover crop, which improves seed germination and seedling growth.

differences in runoff volume and sediment losses between a chisel tillage system and a no tillage system, with sediment losses as much as 30 fold greater with chisel-till. Torbert *et al*. (1999) reported that total sediment lost during a simulated rainfall event was reduced in conservation tillage (0.03 Mg ha^{-1}) compared with conventional tillage (0.67 Mg ha^{-1}), which resulted in a 12-fold increase in nutrient losses associated with sediment.

Soil Fertility

Soil fertility management on the Ingram farm follows Auburn University's soil test laboratory recommendations (Adams *et al*., 1994). Fertilizer applications of P, K, and lime are made from results of soil samples taken each year. Samples are collected from field areas representing approximately 10^{-1}5 acres each. For P and K recommendation, a blended fertilizer application is applied in the spring just before planting. For example, this year an application of 250 lbs acre^{-1} of 14-4-14 blended fertilizer was used. Fertilizer N is applied at a rate of approximately 90 lb/acre (recommended rate for cotton). After application of the blended fertilizer, ammonium nitrate (approximately 200 lbs acre^{-1}) is used to supply the remaining N fertilizer needs.

The use of conservation tillage has been reported to increase short-term N immobilization due to the slower plant decomposition process caused by reduced tillage (Gilliam and Hoyt, 1987; Wood and Edwards, 1992). Often, it is recommended that fertilizer N applications be increased by as much as 25% when using conservation tillage systems (Randall and Bandel, 1991) due to the increased biomass limiting soil N availability to the growing crop. However, the Ingrams have been successful with a 90 lb/acre rate that is the same as that recommended for conventionally tilled cotton. While the increased biomass inputs may cause short term N immobilization, they will also (due to reduced microbial decomposition from not plowing) result in increased soil organic matter. Soil organic matter will greatly improve soil fertility by increasing not only plant available N, P, and K but other micronutrients. It has been reported that winter cover crops can capture and utilize fertilizer that is left over from the previous crop production and reduce nutrient losses through leaching in the winter months (Reeves, 1994). These captured nutrients will become available to the subsequent crops as the plant material decomposes and forms soil organic matter.

It is believed that the length of time that N immobilization would significantly reduce N availability to the point of reducing plant growth is reduced in a well established conservation tillage system. This is due to the improved soil nutrient availability with increased soil organic matter levels with conservation tillage systems. While the influx of new residue would reduce available N, the increased level of total N in the soil makes the cycling time when N is at a limiting level shorter. In addition, since the cover crop is killed one month before planting, there is time for the short term N immobilization to be substantially reduced before cotton plants reach a growth stage where N availability would be a limiting factor for cotton growth. This has been affirmed by research observations in a conservation tillage system study that had been established for 20 years in a heavy clay soil (Torbert *et al*., 2001). In that study, there was no advantage for corn (*Zea mays* L.) production for increased N fertilizer application compared to the conventional tillage system.

Pest Control

Because soil tillage is removed as a means of weed control in conservation tillage systems, weed control is a very important aspect of the crop management. The Ingrams plant 'Round-up-Ready' cotton, which provides early season weed control. They spray over the top with glyphosate at the 4 leaf stage. An additional herbicide (Caporol) application is made with a shielded sprayer at the end of June to capture any late season weeds.

While cultivation is not used for weed control, some benefits are achieved from the use of cover crops and a high residue conservation tillage system. For example, by having a winter cover crop, weeds that become established and contribute to the seed bank during winter and early spring have trouble competing with the rye. In addition, any winter weeds that do establish themselves in the field are killed with the rye before cotton planting and become part of the surface residue. While it is estimated that there is sufficient weed seed stock in cultivated soil to maintaining damaging weed levels for many years, numerous weed seeds depend on tillage to develop conditions favorable for germination. The elimination of plowing greatly reduced the ability of the seeds to reach the soil surface and provide satisfactory conditions where they can germinate (Wiese, 1985).

The Ingrams use Aldicarb at planting (3 lbs acre^{-1} in seed furrow) as a systemic insect control. Additional insect control is accomplished through insect monitoring and additional insecticides are sprayed as needed; however, insect problems rarely reach economic thresholds. The boll weevil eradication program that was established in Central Alabama in the late 1980's has greatly changed insect dynamics in that part of the state. At the present time, boll weevils have been eradicated in the area and this has eliminated the need to spray for boll weevil control. As a result, beneficial insects are not killed and the incidence of pests such as bollworms have been greatly reduced to the point of rarely needing insecticide control.

In addition to the boll weevil eradication, the Ingrams believe that their high residue conservation tillage system has greatly improved the population of beneficial insects and resulted in a great reduction in the need for insecticide applications. The cooler soil temperatures that is afforded by the residue in the inter rows results in a greatly improved environment for beneficial insect survival during the growing season. Fire ants, which have been shown to be a vigilant predator to insects harmful to cotton, are particularly favored by the conservation tillage system, not only by cooler summer temperatures, but also by the elimination of surface tillage greatly reducing the fire ant bed disturbance.

No-till has been shown to increase the incidence of plant diseases (Reeves, 1994). The Ingrams combat this potential problem by using a relatively high rate of fungicide for cotton seedling disease control. At present, they use Ridomil PC application in the seed furrow at planting. The biggest pest for cotton production on the Ingram farm is wildlife. Foraging white tail deer do considerable damage to the cotton crop. Recently, damage to mature cotton bolls by racoons has also become a problem. At present, no effective means of controlling wildlife damage has been developed, and the Ingrams sustain considerable damage to their crops, especially in areas that adjoin extensively wooded terrain.

In addition to pest control, plant growth regulators are used as needed. The Ingram farm is not irrigated and as a result cotton growth only occasionally becomes excessive to the point of needing a plant growth regulator. A defoliant is used to promote leaf drop before harvesting.

CONCLUSION

Cotton yields in the Alabama Coastal Plain varied greatly from year to year in response to weather conditions (especially rainfall during the growing season). In 2001 (a favorable year for rainfall), the Ingram farm produced approximately 2 bales of lint cotton per acre on most of their farm (lower yields were observed in fields with substantial wildlife damage). While lower yields have been realized in years with less favorable weather conditions, over the years the Ingrams believe that their yield levels have become more consistent with the high residue conservation tillage system, especially compared to their conventional tillage neighbors. In addition to stable yield levels, the Ingrams believe that they are improving the overall soil condition on their farm. They have observed much improved soil tilth conditions and a tremendous reduction in erosion losses, which was continuously degrading their farmland before instigating the conservation tillage system. The Ingrams are very satisfied with the high residue conservation tillage systems that they are using on their farm and believe that it is economically sustainable for cotton production in the region (Fig. 6). Research would indicate that this system is also environmentally sustainable compared to conventional farming techniques.

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Fig. 6. High residue conservation tillage affords good cotton growth and seed cotton production.

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DISCLAIMER

CHANGES IN AGRICULTURAL TILLAGE PRACTICES IN MISSISSIPPI FROM 1997 TO 2002

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ABSTRACT

Changes in agricultural land use, tillage systems, and conservation programs have resulted in a meaningful saving of soil resources for Mississippi over the past twenty-five years. Approximately 5,000 acres of cropland has been taken out of production since 1977. Over two thousand acres have gone into the Conservation Reserve Program (CRP) since 1985. It is doubtful that any of these acres will ever return to cropland production. Tillage operations for major field crops have gone from 10 passes across the field before planting in 1977 to less than 2 passes across the field today. Average soil erosion for the state dropped from 5.2 tons per acre in 1982 to 3.7 tons per acre in 1997. Attitudes of producers concerning practices using reduced tillage or no-tillage has moved from the extreme, where intensive tillage was practiced in 1977, to a moderate approach today, where conservation tillage is an acceptable practice for farming.

KEYWORDS

Conservation tillage, Conservation Reserve Program (CRP), soil resources

INTRODUCTION

Agriculture and forestry have played major roles in Mississippi's history. When the state was first settled, people counted on the abundant natural resources for food and shelter. In 1999, it was calculated that one of every five employees in the state had a job related to agricultural or forestry products (USDA-ERS, 1999).

Land grant universities have conducted research that has focused on expanding production while cutting inputs and expenses. At the county level, extension agents and district conservationists provide technical assistance so those land managers may become more adept at protecting the land and water resource base.

Since the mid 1970's, The Natural Resource Conservation Service (NRCS), the Mississippi Extension Service, and the Mississippi Agricultural and Forestry Experiment Station have placed a heavy emphasis on conservation tillage and no-till production. Research on tillage systems has greatly influenced farming methods across the state in the past twenty-five years.

METHODOLOGY

The bulk of data for this report came from the Agriculture Census and National Resources Inventory. Census of Agriculture: Since 1840, the Census of Agriculture has provided information on county, state, and national agricultural production. Uses of the data include implementing farm program policies by Congress and allocating funding for extension service programs, agricultural research, and land-grant universities. Census data provides private industry with the information necessary to increase production and distribution. National Resources Inventory (NRI): The Rural Development Act of 1972 and the Soil and Water Resources Conservation Act of 1977 directed NRCS to collect natural resources data. The purpose of these and other acts was to assess the status, condition, and trends of soil and water, which includes land cover and use, soil erosion, prime farmland, habitat diversity, wetlands, selected conservation practices, and related resources on the nation's non-federal lands. The NRI is designed to produce statistically reliable data at the national, regional, state, and multi-county levels.

DISCUSSION

FARM CHARACTERISTICS

The total number of farms in Mississippi in 1977 were 58,000; by 2002 the farm numbers had decreased by over 27,000. The percentage of farms owned by individuals, families, or family corporations has remained above 90%

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Table 1. Number of farms, average farm size and total acre in farms for Mississippi.

Year	No. of farms	Avg. size (acres)	Total acres
1860[†]	43,000	370	15,000,000
1930[‡]	313,000	55	17,300,000
1977[§]	58,000	259	15,100,000
1997[¶]	31,318	323	10,100,000
2001 (estimated)	30,000	350	10,000,000

[†] USDA , Mississippi Agricultural Statistic Service, Ag Report

[‡] Mississippi Agricultural Statistics Supplement No. 5. Jan 1963

[§] Mississippi Agricultural Statistics 1974-1980 Supplement No. 15

[¶] 1997 Census of Agriculture

since 1982. As the number of farms decreased from 1982, the average age of farm operators increased from 52 to 56 years. Also, the percentage of operators with farming as a principal occupation decreased from 71.7% in 1982 to 40.7% in 1997.

Even though the number of farms and land in farms decreased from1977 to 2002, the average farm size increased by 70+ acres. Farm size in Mississippi has steadily increased since 1930, when the average size of a farm was 55 acres, to 350+ acres in 2002. During this time period the number of farms decreased from 313,000 to 30,000. The total acres in agricultural land have dropped from 15,000,000 acres to 10,000,000 acres during this time period (Table 1.).

CROP LAND USE

Acres by selected land use have been changing over the Over the past 100 years, Mississippi has moved from primarily cotton and corn production to producing a variety of agriculture crops. Soybean, cotton, and corn are the major cultivated croplands in Mississippi for 2001 (Table 2). Nationally, Mississippi ranked fourth in 1997 for cotton acreage and bales produced. For soybean, Mississippi ranked 12th for bushels produced and 11th for acres harvested. Mississippi ranked 5th for rice (*Oryza sativa* L.) in total acres.

From 1982 to 1997, total soil erosion was estimated to decrease from 61,377,989 tons to 31,871,347 tons annually. Average soil erosion per acre decreased from 5.2 tons

Table 2. Land use and annual soil erosion by selected land use in Mississippi.

	1977[†]		1997[‡]		2001[§]	
Land use	Acres	Erosion	Acres	Erosion	Acres	Erosion
	x 1000	est. tons acre^{-1} year^{-1}	x 1000	tons acre^{-1} year^{-1}	x 1000	est. tons acre^{-1} year^{-1}
Corn	250	10.4	419.3	6.1	400	5.5
Sorghum	60	12.4	33.6	5.7	90	5.5
Soybean	3,750	8.0	2295.9	4.3	1,160	4.3
Cotton	1,090	7.8	1280.4	7.9	1,100	6.9
Peanut	7.5	26.3	6.0	8.5	6	6..0
Wheat	140	6.6	106.6	4.3	110	4.3
Rice	112	1.9	239.0	2.3	235	2.3

[†] (est) estimated soil erosion were made using NRI and SCS data for 1977

[‡] 1997 NRI Survey; USDA Ag Report Mississippi Agricultural Statistics Service

[§] NRI 1997 and NRCS data for 2001.

Table 3. Acres and estimated soil erosion for crops grown on hydric soils and highly erodible land in Mississippi. Data for 1977, 1982, and 1997 are based on the 1997 Census of Agriculture. 2001 data are based on estimates.

Crop / Year	Hydric Soils		Highly erodible land	
	Acres	Soil erosion	Acres	Soil erosion
	x1000	tons acre^{-1} year^{-1}	x1000	tons acre^{-1} year^{-1}
Corn				
1977	7.6	†	210.0	21.1
1982	22.4	5.1	127.1	16.3
1997	78.6	4.5	69.2	14.4
2001	80.0	4.3	70.0	12.8
Cotton				
1977	448.5	6.0	206.7	21.3
1982	485.3	5.9	167.4	19.5
1997	436.0	6.1	157.9	18.3
2001	400.0	5.5	140.0	12.0
Rice				
1977	111.0	2.0	†	†
1982	286.1	1.9	†	†
1997	215.4	2.2	†	†
2001	250.0	2.0	†	†
Sorghum				
1977	2.5	3.5	40.0	25.0
1982	6.3	3.3	32.2	22.3
1997	14.8	3.5	6.4	12.6
2001	7.5	3.5	1.3	14.0
Soybean				
1977	1200.0	4.0	990.0	22.0
1982	1633.6	3.8	1024.6	20.5
1997	1430.5	3.4	167.6	13.2
2001	850.0	3.3	145.0	12.0
Peanut				
1977	†	†	1.6	25.0
1982	†	†	1.4	26.3
1997	1.3	6.5	1.7	17.5
2001	1.3	6.5	1.7	17.5
Wheat				
1977	103.0	4.5	77.0	15.0
1982	108.9	4.2	80.9	12.6

† Could not be estimated because of missing census data.

per acre in 1982 to 3.1 tons per acre in 1997. This reduction in total soil erosion was attributed to the decrease in cropland acres. Multiple tillage trips usually associated with sweetpotato (*Ipomoea batata* (L.) Lam) and vegetable production were attributed to the high soil erosion rates for these crops.

SOILS

Within Mississippi, 186 soil series are recognized. Smithdale (fine-loamy, siliceous, subactive, thermic Typic Hapludults) had the most acres with over 3.714 million acres. Pikeville (fine-loamy, siliceous, subactive, thermic Typic Paleudults), rock outcrop, and Frost (fine-silty, mixed, active, hyperthermic Typic Glossaqualfs) had the fewest with 1,300 acres each. Sharkey (very-fine, smectitic, thermic, Chromic Epiaquerts) had the most cultivated and total cropland acres while Talla (fine-loamy, siliceous, active, thermic Glossaquic Natrudalfs) had the fewest cropland acres. Providence (fine-silty, mixed, active, thermic Typic Fragiudalfs) had more acres enrolled in CRP with an estimated average annual soil erosion of 0.5 ton per acre in 1997.

HYDRIC SOILS

Mississippi has over 6.2 million acres classified as having hydric soils (USDA-SCS, 1994). A query of the State Soil Geographic Database (STATSGO) showed that most hydric soils are found in the Delta and near the Pascagoula-Black-Chickasawhay Rivers. Best managed for wetlands, hydric soils are highly productive for agricultural use. Also, hydric soils may sequester C and enhance soil quality with less crop residue management. Approximately 34% of cotton, 62% of soybean, and 90% of rice acres in 1997 were grown on hydric soils (Table 3). Crops grown on hydric soils tended to have less soil erosion when compared to all acres Sharkey is the predominant hydric soil in the state with 1,284,300 acres. Of this, 910,900 acres were in cropland during 1997. Approximately 17.8% of nut crops, 25% of soybean, and 45.7% of rice acres were planted on a Sharkey soil in 1997 (data not shown). The NRI does not include hydric inclusions.

HIGHLY ERODIBLE LAND

Highly erodible land (HEL) can serve as an environmental indicator. As more HEL is used for agricultural production, soil erosion can increase,

Table 4. Acres and annual soil erosion, irrigated acres, and acres developed by 1997 of prime farmland in Mississippi (NRI, 1997).

Land use	Acres	Soil loss	Acres irrigated
	x1000	tons $acre^{-1}$ $year^{-1}$	x1000
Corn	351.7	5.0	52.6
Cotton	1027.6	7.4	185.1
Rice	203.2	2.4	203.2
Sorghum	23.2	5.5	2.7
Soybean	1769.2	3.9	526.3
Peanut	4.7	9.0	†
Wheat	88.4	4.5	24.1

and thus, decreasing soil quality. Between 1982 and 1997 the number of acres of HEL has decreased by 655.3 thousand acres (Table 3). A decrease in soybean acres of HEL was a leading reason. Mississippi had 500,000 acres of soybeans in 1952, 3,750,000 acres in 1977, and 2,300,000 acres in 1997. Generally, soil erosion decreased with each land use from 1977 to 2002 for HEL. Loring (fine-silty, mixed, active, thermic Oxyaquic Fraqiudalfs), found mainly in the Brown Loam, had 222,800 acres of HEL in 1997 (data not shown). Of this, 157,500 acres were in cropland.

Prime farmland

Prime farmland is defined as land with the best combination of physical and chemical characteristics for food, feed, forage, fiber, and oilseed crop production and is also available for these uses (USDA-NRCS, 1999). According to STATSGO, Mississippi had 6.2 million acres that could be classified as prime farmland (Code 1). Soils in the Delta and the Brown Loam are classified as prime farmland only when protected from flooding or not frequently flooded during the growing season (Code 3).

Delta soils Sharkey, Alligator (very-fine, smectitic, thermic Chromic Dystraquerts), Dundee (fine-silty, mixed, active, thermic Typic Endoaqualfs), and Forestdale (fine, smectitic, thermic Typic Endoaqualfs) are the top four soils with the most acres of potential prime farmland and cropland on prime farmland (data not shown). Of the prime farmland soils with 2,000 plus acres, Memphis (fine-silty, mixed, active, thermic Typic Hapludalfs) and Loring had the highest soil erosion rates, 14.5 and 10.5 tons $acre^{-1}$ $year^{-1}$, respectively. In 1997, approximately 80, 77, and 85% of the total acreage of cotton, soybean, and rice were planted on prime farmland, respectively. Soil erosion associated with these crops tended to be less on prime farmland than on all acres (Table 4).

Conservation practices

Conservation practices such as terraces, filter strips, and grassed waterways help improve water quality by reducing the amount of sediment and attached pesticides reaching water bodies. The average use of fluometuron and norflurazon in Mississippi is among the highest in the nation (USGS, 1998). Research in the state has shown that filter strips can reduce loss of these compounds by at least 63% (Rankins *et al*., unpublished data). In another study, loss of metribuzin and metolachlor from runoff was less than 3% of the total amount applied, or half that of the unfiltered check, when tall fescue (*Festuca arundinacea* Schreb.) was used as a filter strip (Tingle *et al*., 1998).

Conservation tillage

Conservation tillage (CT) (>30% residue after planting) has been shown to have agronomic, economic, and environmental benefits; however, land operators in Mississippi have planted only approximately 25% of cropland acres with CT from 1992 to 1997 (CTIC, 1997). Mississippi ranked 31st nationally in percentage of acres planted using CT and 6th in the Southeast.

Over half of double-cropped soybean was planted using CT from 1992 to 1997 (CTIC, 1997). Conservation tillage acres for corn, one of the crops easiest to grow with CT, were less than 30%. Research in the state has shown that highly erosive crops such as cotton (Stevens *et al*., 1992; Bloodworth and Johnson, 1995), peanut (*Arachis hypogea* L.) (Bloodworth and Lane, 1994), and sweetpotato (Bloodworth and Lane, 1994) can be successfully grown with CT; however, less than 9% of acres for these crops were planted using CT in 1997. With a drastic downturn in the agriculture economy, a large number of producers are converting to no-till farming as a means of survival.

Annual crop yields of long-term no-till soybean (*Glycine max*) and conventional-till soybean at Holly Springs, Mississippi were summarized for a 16-year period, 1984-1999. McGregor *et al*. (1992), McGregor *et al*. (1999), and Cullum *et al*. (2000) indicated probable trends for increasing soil losses with time under conventional-till history and minimal soil losses with time for no-till history. Differences and trends in crop yields between no-till and conventional-till soybean on a soil overlaying a fragipan were recorded over the 16-year period. Crop yield results and computations with the revised universal soil loss equation indicate that soil loss from conventional-till soybean on fragipan soils reduces long-term crop productivity, while the soil resource base is maintained on these soils under no-till soybean. No-till crop productivity under no-till also is maintained at a higher level than under conventional-till. Although poor soybean yields from both no-till and conventional-till were produced during several years, the sustained trend for lower yields from conventional-till as compared to no-till indicated an adverse effect of excessive erosion and tillage on soil productivity. Continued erosion of the soil overlying a fragipan soil creates an environment where crop yields cannot be maintained even under optimum climatic growing conditions.

Crop rotation

Crops are commonly grown in a rotation in order to reduce pest competition, improve soil conditions, and reduce soil erosion. To date, the NRI is the only statistically reliable national survey that records cropping history. For each inventory year, land cover use is recorded for the preceding three years thus providing data for four years. A query was conducted from the 1997 NRI to determine acres in either a monoculture or a crop rotation cropping practice. Acres and average soil erosion for each crop and cropping practice are presented in Table 5.

Essentially, all rice in Mississippi was in a four-year crop rotation while 78% of cotton was grown in a monoculture practice. Soybean acres were evenly split between the two practices. Soil erosion for each cultivated crop in a rotation tended to decrease except for rice**.**

Corn is a popular rotation crop since it can be easily grown with CT, increases soil organic matter, and decreases soil erosion. Acreage of corn in 1997 rotated with cotton, rice or soybean tended to increase from 1994 to 1996. Acres classified as land not planted decreased during the three years prior to 1997 except for corn and sorghum. Soybean was the crop most commonly used in a rotation.

CONCLUSION

Demand for a readily available and safe supply of food and water is projected to increase. Therefore, Mississippi must continue to conserve its natural resources. Many of the acres taken out of cropland production were entered into the CRP, thus reducing sediment in lakes and rivers. Implementing various conservation practices and management options such as buffer strips and precision farming help decrease nutrient and pesticide runoff. Research by the Mississippi Agricultural and Forestry Experiment Station, USDA-ARS Soil Sedimentation Laboratory, USDA-NRCS Plant Material Center and advances in equipment, technology, and herbicides have proven CT is a viable alternative for reducing costs while maintaining crop yields. Adoption of CT practices began to stagnate in the state in the mid 1990's. With a downturn in agricultural commodity prices in the late 1990's and continuing in the 2000's, CT has increased rapidly during this period. Cropland development has been on a downward trend since 1987, but efforts should be made to conserve irrigated cropland and prime farmland. Mississippi is a leader in funds spent for agricultural and forestry research for developing conservation practices. Programs and demonstration projects from agencies such as the MSU-Extension Service and NRCS have greatly enhanced the dissemination of research data and practices over the past twenty-five years.

Table 5. Acres and average annual soil loss for crops in a monoculture or four-year crop rotation cropping practice in Mississippi, 1997 (Source: NRI 1997).

	Monoculture		Crop rotation	
Crop	Acres	Soil los	Acres	Soil los
	x 1000	tons acre^{-1} year^{-1}	x 1000	tons acre^{-1} year^{-1}
Corn	89.7	6.6	329.6	6.0
Cotton	1002.3	8.3	275.1	6.4
Rice	3.7	1.8	235.4	2.3
Sorghum	9.5	6.6	24.1	5.4
Soybean	1151.4	4.5	1144.5	4.0
Wheat	21.2	6.8	85.4	3.6

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A WHOLE-FARM ECONOMIC ANALYSIS OF NO-TILLAGE AND TILLED CROPPING SYSTEMS

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ABSTRACT

Cotton, corn, grain sorghum, soy, and wheat-soy doublecrop productivity were measured on an upland site with chisel tillage (CT) and no-tillage (NT) during a 10 year crop management study. An integer programming model was developed to allocate resources among different crop enterprises with different tillage systems on a whole farm basis with the objective of maximizing profits. This model was used to study optimal resource use as farm size increased. Labor for machine operation was treated as a finite resource and Conservation Reserve (CRP) at $35 acre-1 was included as a default option. Results were sensitive to commodity prices and crop productivity. In the whole farm analysis, NT was the dominant choice; cotton was the most profitable crop and displaced CRP at 400A with $.58 lint prices. Economies of scale were evident as profits increased with subsequent 100A increments as fixed machinery and labor costs did not increase. Worker productivity became limiting for NT cotton above 500A and at 800A the model switched to corn handled by one worker. In the CT system, cropping was not initiated below 500A with corn and grain sorghum as the crop choices. Worker productivity in NT systems in terms of acreage managed was approximately double that for CT. As acreage increased, other crop enterprises were added. Net returns for NT cropping were greater than for CT at equivalent land areas. Whole farm analysis offers a means of crop enterprise comparison that can assess benefits of conservation tillage in terms of both worker productivity and profitability.

KEYWORDS

Conventional tillage, no-tillage, integer programming, commodity pricing

INTRODUCTION

Economics drives the adoption or rejection of new agricultural practices. Crosson *et al.* (1986) addressed farmer adoption of conservation tillage practices and stated, "In the future, as in the past, farmers' decisions to adopt reduced tillage will be made primarily on their calculations of its economic worth". Crosson *et al.* (1986) noted that field operations are eliminated as conservation or no-tillage is adopted, leading to reduced labor for field operations and less equipment for pre-plant land preparation. Reduced investment in equipment results from eliminated operations and using smaller, less expensive tools and power equipment. This in turn reduces fixed costs for equipment and interest on investment. Pesticide amounts, especially herbicides, are increased as tillage operations are eliminated and these increased costs offset some of the savings in equipment and labor. Crosson *et al.* (1986) states, "The value to the farmer of the time saved depends on the value he or she places on alternative uses of time, such as other farm work, off-farm employment, or increased leisure. Clearly the value will be different for different farmers but for most, if not all, it will be positive."

The potential for expanding operations or adding enterprises with the same labor and equipment has rarely been considered in published analyses. The main reason for this neglect is methodological. The method of partial budgeting is most frequently used to evaluate the profitability of technology innovations, including alternative tillage systems. Partial budgeting is essentially a comparison of the net change in costs and returns between alternative systems, with the key assumption that all other costs and returns are unchanged. The approach also assumes that hourly labor to perform field operations is neither limiting nor slack. This assumption is unrealistic since many farms hire full-time seasonal or annual labor. While differences in fixed equipment costs can be evaluated using partial budgeting, the comparisons are often not robust because they are made, often implicitly, on the basis of a single farm scale. Equipment is assumed to be used efficiently, regardless of

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farm size. In actuality, partial budget comparisons should vary across farms with different acreage and fixed equipment and labor resources.

Innovations in tillage systems require modeling in a representative, whole farm framework where land, labor and capital are considered finite resources and successful operators are those who use these most efficiently. To address both economic and management questions, crop production research was initiated in the deep loess area of northern Mississippi in 1987 by the USDA ARS National Sedimentation Laboratory cooperatively with The Mississippi Agricultural and Forestry Experiment Station. Objectives included development and evaluation of systems that would reduce off-site sediment movement and preserve long-term productivity by minimizing soil loss, while offering growers a profit potential.

MATERIALS AND METHODS

An upland site occupied by grassland was selected and prepared by applying lime and fertilizer to satisfy needs indicated by soil tests, tilling the experimental blocks (10), and planting wheat for winter cover with the first crops in 1988. Soils on the site were dominantly Grenada silt loam (Fine-silty, mixed, active, thermic Oxyaquic Fraglossudalfs), but included small amounts of associated Memphis (fine-silty mixed, thermic Typic Hapludalf) and Loring (fine-silty, mixed, thermic Typic Fragiudalf) silt loams. Memphis soil has no restrictive horizon, while Grenada and Loring soils contain a restrictive pan at the 18 to 22 in. depth. Depth to pan is commonly less because of erosion during prior use. Crops included cotton, grain sorghum, soybean, and wheat in a doublecrop system with soybean. Corn was included in a separate experiment begun in 1989. Tillage systems included CT (chisel plow, disk 2x, smooth, plant, cultivate postemergence 2x), NT (spray, plant, harvest), and two reduced tillage systems. Initially, all crops except wheat and doublecrop soybean were planted in 36 inch rows. After 1992, all soybean was drilled in 10 inch rows. NT cotton included a wheat cover crop which increased the surface residue, soil protection, and cost of production (~$20 per acre). In the first phase of the study (through 1992), NT management proved suitable for all crops. In 1993, corn replaced grain sorghum and reduced tillage systems were changed to NT. One of the NT cotton systems utilized winter weed growth for cover rather than a planted cover crop. By the third year, crop yields reached 95 percent parity with the long term NT system with wheat cover. Because of favorable productivity and reduced cost, this system was used in the analysis described below. Earlier publications from these management studies included cotton production (Triplett *et al*., 1996). Monthly precipitation records as well as greater details on cultural practices are available in earlier publications (Dabney *et al*., 1993, Triplett *et al*., 1996).

In the whole farm analysis, the calendar was divided into 13 4-wk periods with assignment of optimum planting and harvest timing for crops. Days suitable for field operations in each period (Spurlock *et al*., 1995) were coupled with equipment performance rates to calculate potential crop acreage per worker. The Revised Universal Soil Loss Equation was used to calculate soil loss potential for different crops and tillage practices. These were applied to systems to determine compliance with soil loss restrictions and eligibility for Farm Program payments. Since this is an upland site with significant erosion potential, soil was left undisturbed following harvest and all tillage operations were performed within one month of planting. Number of years for each system, mean crop yields, and operations performed for different crop management systems during the life of the study are shown in Table 1. Crop yields and historic commodity prices were used to calculate gross returns for crop and tillage combinations. Initial labor was supplied by the operator with returns to land, labor, and management representing operator earnings. When all available operator time was committed and economic conditions were favorable, additional labor for machine operation was hired for an entire year at $20,000 per worker. Costs of inputs and fixed costs for equipment necessary for crop production were entered into the General Algebraic Model System and the selection of crops, equipment inventory, and labor hired that maximized profits was solved for specified acreages. Entering the land into the Conservation Reserve Program at $35 per acre was included as the default option.

RESULTS

Crops selected, input costs, labor hired, machinery costs, and returns for various acreages in the whole farm analysis are shown in table 2. Commodity prices are average for the last 5 years of the study. The model selected the CRP option until available area for cropping reached 400A. Before this point, the purchase of one tractor and rotary cutter to maintain the CRP acreage was designated. No-tillage cotton was selected initially as the most profitable crop and was first produced at 400A. Profits increased markedly ($23K to $43K) when acreage increased to 500A, because the fixed machinery cost ($58K) remained constant. The fixed cost of cotton harvest equipment is a major component of the cotton machinery budget. At 515A, time became limiting during harvest season for one worker, and CRP was selected to complete the 600A increment. At 800A, the program shifted to NT corn with one worker, time demands decreased, profit per acre increased, and the equipment budget was less than for the smaller acreage of cotton. At 900 and 1000A, time became limiting for corn planting and a NT corn-soybean rotation was chosen with

Table 1. Cropping system, average tillage operations performed, and yield. Insecticide applications and harvest operations not shown. Yields are express as lbs lint acre^{-1} for cotton, cwt acre^{-1} for grain sorghum, and bu acre^{-1} for corn and soybean. The numbers in parenthesis are years of data collected for yield in each system.

Crop	Tillage, crop culture	Yield
Cotton, cv	Chisel, 2spread, 1.7disk, bed, do-all, plant, 2spray, 3cult, shred	612 (9)
Cotton, ridge	2Spread, NTplant, 2 spray, 3 cult, shred	598 (4)
Cotton, min	2 Spread, mulch finisher, NT plant, 2 spray, 2 cult, shred	658 (4)
Cotton, NT,wh	2Spread, NTplant, 3 spray, shred, drill cover	716 (9)
Cotton, NT	2Spread, NTplant, 3 spray, shred	616 (5)
GS, cv	Chisel, 2spread, disk, plant, spray, 2cult	39.6 (5)
GS, ridge	2 Spread, Ntplant, spray, 3 cult	34.5 (5)
GS, min	2 Spread, mulch finisher, Ntplant, spray, 2 cult	36.1 (5)
GS, NT, vetch	2 Spread, Ntplant, 2spray, drill cover	42.4 (5)
GS, NT, wh.sb	2 Spread, Ntplant, 2spray, drill wheat	43.2 (5)
Cn, cv	Chisel, disk, 2spread, plant, 2spray, 2 cult	128 (5)
Cn,NT,ve	2 Spread, 2 Spray, Ntplant, drill vetch	111 (5)
Cn,NT,wf	2 Spread, NT plant, 2.6 spray	120 (5)
Cn,NT,wh,sb	2 Spread, NT plant, 2.6 spray, drill cover	131 (5)
Cn,NT,wh,ct	2 Spread, NT plant, 2.6 spray, drill cover	128 (5)
Sb.cv	Chisel, 1.4 disk, spread, plant, 1.5 cult, 2 spray	25.5 (10)
Sb.rt	Spread, plant, 3.2 cult, 1 spray	26.9 (5)
Sb.mt	Spread, mulch finisher, plant, 3 cult, 1.4 spray	25.7 (5)
Sb.NT.wf.sb	Spread, drill, 4.4 spray	31.4 (5)
Sb.NT.wh.sb	Spread, drill, 3.1spray, drill	24.3 (10)
Sb.NT cn.wh.	Spread, drill, 3.1 spray	22.7 (5)
Sb.NT.gs wh.	Spread, drill, 3.1 spray	28.1 (5)

NT doublecrop wheat-soybean occupying the additional acreage. Although less profitable than corn, doublecrop wheat-soy occupied underutilized time periods and was produced with the same equipment used for the corn-soy sequence. Labor demands are high for all crops during planting and harvest seasons. While crop enterprises with different planting and harvest seasons may utilize labor most effectively, these may not be cost effective at smaller acreages because of increased equipment investment. As acreage is increased, other crop enterprises are added and labor is used more effectively. At 5000A, the cropping mix was approximately half cotton with corn and soy comprising the other half.

Although the model did not choose tilled systems at any acreage amounts, NT was disabled in the program, and solutions for tilled management were made for a series of acreages (Table 3). In the CT solutions, cotton did not appear at any time, reflecting lower CT cotton yields in the production study (Table 1). Crop production was not initiated until the 500A level. Corn and grain sorghum were chosen as crops and were managed by a single machine operator with a net of $26 per acre. Of interest, corn was limited to 451A because of time constraints for land preparation and planting, and grain sorghum occupied the remaining area. Both crops utilized the same planting and

Table 2. Solutions that maximize profits at various acreages. Costs and returns in $ x 1000s. Per acre returns in $. Assumed commodity prices are $ 0.58 per pound of cotton, $ 2.38 per bushel of corn and $ 5.95 per bushel of soybean.

Total Acres	300	400	500	600	700	800	900	1000	2000	5000
CRP	300			85	185					156
Cotton		400	500	515	515				1500	2118
Corn						800	420	420	500	1363
Soybean							420	420		1363
Doublecrop							61	161		
Gross $(K)	2	185	232	240	240	213	229	254	830	1678
Profit $(K)	4	23	43	49	52	62	80	92	201	554
AMTA	8	11	14	17	20	23	25	26	56	141
Var. Input		102	128	131	132	125	119	133	461	903
Var. Mach	--	14	17	18	18	11	13	16	59	111
Fix Mach	6	58	58	58	58	38	41	41	126	172
Total Mach	6	72	76	76	76	49	54	57	184	282
Payroll	0	0	0	0	0	0	0	0	40	80
$ acre^{-1} net	13.5	57	86	82	75	78	89	92	100	111
T.mach hrs		670	838	864	864	450	484	570	2790	4958
Mach $ acre-^{1}	20	180	152	127	109	61	60	57	92	56

harvest equipment but at different time periods. In the NT solution (Table 2), one machine operator had time to manage 800A corn. At 700A and 800A, soy replaced grain sorghum and corn remained at 445A. Shifting production to soy required the purchase of a drill, reflected in the fixed machinery cost. At 1000A, the most profitable solution involved all corn but required the employment of two additional workers. At 5000A, corn occupied 4966A, sorghum 34A, and 10 machine operators were employed.

DISCUSSION

With lower cotton prices, corn and/or soy may be the first crop selected (data not shown). The program selected NT production in almost all cases. Contributing factors included increased cotton yield with NT, favorable yields for corn and soys with NT, compliance with farm program restrictions on erosion, and greater worker productivity because of fewer operations during planting season. In some analyses with CT yields high enough to favor this system initially, the program would switch to NT as acreage increased and time became limiting, rather than hire an additional machine operator. NT corn requires approximately 0.56 hr per acre of machine time, while NT cotton requires 1.68 hr per acre during crop production, respectively. Tilled corn production required 1.1 hr per acre, essentially double the time for NT production. Since time requirements for harvest are similar in both systems, the increase is entirely during the planting season when time available for field work is also limiting for NT, which has fewer operations. Per acre net returns for tilled systems were half those of NT. Contributing factors included no AMTA payments, greater machine costs for production of like crops, and greater labor requirements for tilled systems. While AMTA payments contribute measurably to net income, they represent less than half the difference at smaller acreages.

The integer programming approach allows for a comparison of crop enterprises that evaluates conservation tillage in terms of both worker productivity and profitability. The analysis is sensitive to farm size, commodity prices, and labor availability. Farm gross income represents a product of commodity prices and crop yield, neither of

Table 3. Solutions that maximize profits for tilled systems at various acreages. Costs and returns are in \$ x 1000 and per acre returns in \$. Assumed commodity prices are \$ 0.58 per pound of cotton, \$ 2.38 per bushel of corn, \$ 5.95 per bushel of soybean, and \$ 3.91 per cwt grain sorghum.

Total Acres	400	500	600	700	800	900	1000	2000	3000	5000
CRP	400				2	900				
Cotton										
Corn		451	451	445	445		1000	1440	3000	4966
Soybean				255	353			660		
GrainSorg		49	149							34
Gross \$(K)		132	148	159	170	6	277	464	831	1381
Profit \$(K)		13	17	21	24	22	31	102	178	321
AMTA	11	0	0	0	0	25	0	0	0	0
Var. Input		65	74	76	82	0	135	222	406	675
Var. Mach		10	12	15	17	0	20	42	62	104
Fix Mach	6	44	44	47	47	8	50	57	65	82
Total Mach		54	56	62	64	8	70	99	127	186
Payroll \$	0	0	0	0	0	0	40	40	120	200
\$ acre^{-1} net	19	26	29	29	30	25	31	52	59	64
T.mach hrs		558	667	764	866	0	1118	2188	3356	5593
Mach \$ acre-^{1}	15	108	93	90	80	9	70	50	42	37

which are under complete control by producers. Rather, gains in profitability derive mostly from improved management of production costs. Results from this analysis clearly demonstrate that NT systems more effectively utilize resources of land, labor, and capital. Because of different harvest machine requirements, producers are unlikely to change from cotton production to corn or soy based on minor shifts in commodity prices. However, the relative mix of crops (corn, soy, doublecrop soy following wheat), which employ similar equipment for production, could be adjusted based on commodity price, projected yield, land available for production, and labor supply.

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MAKING NO-TILL "CONVENTIONAL" IN TENNESSEE

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ABSTRACT

No-till production has become the conventional system for corn, soybean and cotton in Tennessee. No-till is now used on 60 percent of the cotton, 65 percent of the corn and 70 percent of the soybean acreage in the state. This success is the result of improved weed control technology combined with a sustained research and extension effort spanning over 30 years. This effort was a response to some of the most serious soil erosion problems in the USA. Today soil erosion rates on cropland have been reduced by more than half from 1977 levels. Crop yields have increased, and soil quality has improved.

KEYWORDS

Soil erosion, conservation compliance, farm bill, adoption.

INTRODUCTION

No-till is truly the "conventional" tillage system for Tennessee row crops. No-till is now used on 60 percent of the cotton, about 65 percent of the corn and about 70 percent of the soybean acreage in Tennessee. The reasons for this widespread use are related to the historical problems of soil erosion and summer drought.

Most upland soils in Tennessee have silt loam Ap horizons, which are low in organic matter. Surface soil organic matter content is often less than one percent in tilled fields. Annual tillage destroys the structure of these soils and removes the mulch cover from crop residue. In the past, cropped fields were intensively tilled using chisel plows, moldboard plows and disk harrows. This system resulted in very high levels of soil erosion on sloping lands. The average rate of erosion for all cropland in Tennessee in 1977 was 15 tons acre^{-1} year^{-1}, and on upland soils it was much higher, sometimes exceeding 50 tons acre^{-1} year^{-1}. Most of the highly erodible cropland soils are either Fragiudalfs with fragipans in the subsoil, or Paleudults and Paleualfs with clayey subsoils. These high rates of erosion over a period of years have reduced the depth of soil above these unfavorable subsoil layers. The result is a loss of water storage capacity, and a permanent loss of crop yield potential (Rhoton, 1990).

The high rate of runoff of rainwater associated with this erosion also decreased yield, due to drought. Growing season rainfall in combination with stored soil water from the winter is normally sufficient for successful crop production in Tennessee, on soils with 2 feet of rooting depth or more, but there is not much excess water. If a high proportion of water from rain runs off the field, the probability of yield loss from drought is greatly increased.

Farmers and researchers have long been aware of this situation, but before 1960, tillage was necessary to control weeds. Conservation systems that could adequately control erosion were available, including terracing, rotation with forages, and contour strip-cropping. However, these systems were not widely adopted. They were costly to farmers, either in terms of expense of installation (terraces) or in terms of less intensive, less profitable farming systems (rotation and contour strip cropping). These near-term costs exceeded the long-term benefits, in the opinion of farmers. Therefore, these systems were never used to the extent necessary to adequately control erosion. The development of effective herbicides between 1960 and 1980 changed the situation. When it became possible to control weeds without tillage, researchers at the University of Tennessee and in surrounding states began to develop practical systems of no-till and minimum tillage (Mueller and Hayes, 1996).

No-till has many advantages over traditional systems of soil and water conservation for Tennessee conditions. First, no-till, when combined with high residue cropping systems, is much more effective in control of erosion than traditional systems. Use of contour terraces in cotton production will reduce soil erosion by 50 to 60 percent, but use of no-till with a winter cover crop will reduce erosion by 90 percent. No-till with residue also enhances infiltration and reduces runoff of growing season rainfall compared to traditional systems.

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The no-till system allows the continued use of intensive cropping systems while controlling erosion. Use of no-till does not add significant cost in most cases, and may be less costly for some crops. The possibilities of controlling erosion and increasing yield without additional production cost made no-till a very desirable alternative to traditional conservation systems.

DEVELOPMENT AND ADOPTION OF NO-TILL SYSTEMS

Research in reduced tillage and no-till systems was begun at the University of Tennessee in the late 1950's by Henry Andrews and his graduate students (Andrews and Peters, 1967; Graves, 1996). Attempts at farmer adoption began between 1965 and 1970.

In this early period, there were many problems. Planting equipment of the time was designed to operate in soft, tilled soil (Graves, 1996). It was inadequate for proper seed placement and coverage in firm, untilled soils, and it did not operate well if there was crop residue present on the soil surface. Herbicides had made no-till possible, but initially there were relatively few herbicides available and there were many weed species that could not be controlled without tillage. In particular, johnsongrass (*Sorghum halepense*) was a major limitation on the use of no-till in Tennessee from 1960 to 1980 (Graves, 1996; Mueller and Hayes, 1996).

In addition to these problems, there were other concerns and uncertainties in this early era. These included soil compaction, adequacy of surface application of lime and fertilizer, buildup of insects and diseases, and concerns about accumulation of a thick, unmanageable layer of mulch over time.

During the period from 1960 to 1980, great progress was made in all of these areas. Effective no-till planters were developed. These planters were heavier, to increase durability and to improve penetration of seed placement mechanisms in firm soils. They included a mechanism for slicing through crop residue to prevent accumulation of plant material on the planter frame. Normally, this was a disk coulter mounted in front of the seed placement mechanism in each row. Seed was placement was accomplished by disk openers following the coulter. Adequate soil-seed contact and coverage of the seed was accomplished by covering mechanisms with narrow, firm press wheels and large amounts of down-pressure. By 1980, commercial row planters were available which could successfully place seed in untilled soil in most situations. Improved drills were also becoming available.

At the same time, the number of herbicides available to farmers for use on major crops increased greatly in the period from 1970 onward. By 1985, a wide spectrum of herbicides made no-till production of corn, soybeans and cotton feasible in almost all situations in Tennessee. The most notable of these were the post-emergence grass control herbicides (fluaziflop, sethoxydim, clethodim, quizalofop), which made control of johnsongrass possible in no-till cotton and soybean (Mueller and Hayes, 1996). In the 1990's, advances in biotechnology lead to another important advance: the development of glyphosate-tolerant cotton and soybeans. This greatly simplified the control of weeds in no-till systems and led to increased use of no-till in both crops.

Soil compaction was a major concern in the early years. Most farmers and many researchers and Extension personnel believed that compaction would be a major problem in long-term no-till. This thinking was influenced by the results of subsoiling and compaction research from the Coastal Plain, which showed serious compaction problems on the sandy soils commonly found there, and a distinct advantage when deep tillage was utilized.

Experimental results and farmer experience had clearly shown by the early 1980's that soil compaction was not a major problem in the silt loam and silty clay loam soils that make up much of Tennessee's cropland. Research in tilled systems showed no yield advantage in subsoiling or other deep tillage as compared to shallow tillage (Mullins *et al*, 1974; Tyler and McCutchen, 1980). Studies comparing no-till and tilled systems found that soil compaction was not a problem in no-till systems. Soil physical properties were at least as favorable for root development in no-tilled as in tilled systems and often were better (Tyler *et al*, 1983), and yields generally equaled those from tilled systems, including deep tillage.

There was a general belief in the early 1970's that surface application of lime and phosphorus would not be adequate to maintain soil pH and soil nutrients at optimum levels without occasional mixing by tillage. However, research showed that surface application of lime and of P and K without incorporation was adequate for optimum yield, even over long periods in continuous no-till (Howard and Tyler, 1987; Howard et al, 1996). Rates of lime, P and K recommended for tilled systems were adequate for no-till as well.

With regard to nitrogen, it was found that when solid urea or urea-ammonium nitrate was applied to the soil surface, reduced yields were obtained due to volatilization losses. Surface applied ammonium nitrate was found to be equal to injected nitrogen (Howard and Tyler, 1989). Therefore, injected UAN, surface applied ammonium nitrate or anhydrous ammonia became the recommended system for nitrogen fertilization of no-till corn and soybean.

Legume cover crops were found to provide the equivalent of 50 to 70 pounds per acre of nitrogen to succeeding no-till crops (Duck and Tyler, 1996). However, because of economics and problems of timely establishment, systems utilizing legumes have not been widely adopted.

Insects and disease were major concerns of researchers in the early years of no-till research. Research and experience have shown that insect and disease problems are no greater in no-till than in tilled systems. However, the problems may be different. Damage from nematodes, for example, is often less in no-till, while diseases caused by organisms that live in decaying crop residue may be worse. (Lentz *et al*, 1996; Tyler *et al*, 1983; Tyler *et al*, 1987).

By the late 1970s, researchers had developed practical, sustainable systems of no-till production for major crops that were ready for commercial adoption. At this point, the Extension Service and the Soil Conservation Service began major efforts to encourage adoption of no-till. These efforts included field days, on-farm demonstrations, public meetings, publications and incentive payments to farmers, as well as one-on-one direct contact with growers.

The Conservation Compliance provisions of the 1985 Farm Bill gave no-till a considerable boost in Tennessee, especially in cotton production. These provisions required the adoption of improved erosion control methods in highly erodible land to remain eligible for USDA program benefits. Since the majority of cropland in Tennessee falls in the highly erodible category, Tennessee farmers were heavily impacted. Conservation Compliance did not require no-till as the erosion control method, but the cost advantages of no-till compared to other methods of erosion control quickly became apparent, and most farmers in Tennessee chose to use no-till to meet this requirement. After this policy began to be seriously enforced in 1991, adoption of no-till increased quickly for a few years.

As a result of research, extension and government efforts, no-till has been widely adopted as a production system on Tennessee farms. Table 1 shows the proportion of the areas of corn, soybeans and cotton planted using no-till from 1983 until 2001. From this table, three major stages of adoption become apparent. The first stage, prior to 1990, represents early adoption by more advanced farmers. This phase reached 10 to 20 percent of the planted area. During the period from 1990 to 1995 there was a rapid increase in no-till use. This was a result of Conservation Compliance, increasing confidence of farmers in the system, and the development of improved post-emergence herbicides. The development of effective post-emergence herbicides for control of johnsongrass in corn (nicosulfuron, primisulfuron) was especially important. In this phase of adoption, use of no-till reached 45 to 50 percent of planted area in corn and soybean, and 25 percent to 30 percent in cotton. In the 1998 to 2001 era, glyphosate-tolerant GMO varieties became widely available for cotton and soybean. This greatly simplified no-till weed control, and has led to another large increase in adoption, up to 60 to 70 percent of planted area.

Table 1. Percentage of the area of major Tennessee crops planted using the no-till system, 1985-2001. No data were available for cotton production prior to 1992. Source: Tennessee Agricultural Statistics Service

Year	Corn	Soybean	Cotton
1985	13	16	–
1986	11	12	--
1987	10	11	--
1988	10	15	--
1989	9	20	--
1990	14	23	--
1991	22	26	--
1992	29	30	14
1993	44	38	25
1994	46	44	23
1995	50	55	27
1996	45	50	33
1997	37	47	24
1998	46	48	24
1999	54	50	32
2000	58	65	53
2001	65	71	61

It is interesting to note that from the time research first began around 1960, 15 to 20 years were required to develop commercially viable systems, and another 15 to 20 years were required before the new technology was adopted on half of the planted area. The success of no-till in Tennessee is a classic example of the Land Grant approach to agricultural production problems. A problem was identified (soil erosion), a viable solution was developed through research (no-till), and the solution was adopted on the land as a result of Extension education programs.

TOM MCCUTCHEN AND THE MILAN NO-TILL FIELD DAY

No story of no-till in Tennessee can be complete without mention of Tom McCutchen and the Milan No-Till Field Day (Dore, 1996). The Milan Experiment Station was established in 1963, with the specific objective of conducting field-scale research in cropping systems of western Tennessee. Tom McCutchen, who had been a county agent in Obion County, became its first superintendent. Tom was greatly concerned by the soil erosion he observed in West Tennessee fields. In the mid 1960's, he became convinced that no-till was the best solution, and he began work in developing no-till systems. In the early years, he was virtually on his own, facing skeptical farmers, researchers and administrators. But he persevered and as the technology improved more and more people came to agree.

By 1981, commercially viable systems of no-till corn and soybeans had been developed at Milan. The University was ready to promote no-till as the solution to soil erosion, so Tom staged the first Milan No-Till Field Day in July 1981. This event drew 2,000 in its first year, and grew steadily for the next 15 years until attendance reached 11,000 in 1995. The Milan Field Day is world famous, and has been a major factor in the adoption of no-till in the United States.

Tom McCutchen met an untimely death in 1983, but his work lives on. His successor, John Bradley, continued and expanded the work in no-till and the Field Day, becoming an internationally recognized no-till authority. The tradition continues today under Blake Brown. This year, for the 22nd year in a row, everyone involved in row crop production in western Tennessee knows exactly where he will be on the fourth Thursday in July.

ADVANTAGES OF NO-TILL PRODUCTION FOR TENNESSEE

CROP YIELDS

On cropland with high yield potential (generally gently sloping to level, with deep, well-drained soils), yields of major crops from no-till are about the same as from conventional tillage (Graves *et al.*, 1993; Hoskinson and Gwathmy, 1996). Initially, there was concern that yield would eventually decline in continuous no-till systems, due to compaction, disease, insect infestation, depletion of phosphorus, or acidification of the soil. These concerns have proven to be unfounded in Tennessee. Table 2 shows yield of cotton at the Milan Experiment Station under no-till and tilled conditions from 1983 to 1993. While in any one year, the yield from either no-till or conventional tillage may be higher, the long term average is about the same. In general, no-till yields tended to increase relative to tilled yields over time.

Table 2. Cotton yield from tilled and no-till systems planted in residue from the previous crop. Milan, Tennessee, USA, 1983-1993

Year	No-till	Tilled
	---- kg lint ha^{-1} -----	
1983	599	590
1984	1158	1480
1985	1185	1151
1986	894	875
1987	1193	1104
1988	859	773
1989	943	773
1990	736	910
1991	1144	978
1992	1478	1381
1993	841	618
11 yr. average	1003	967

SOIL EROSION

The initial purpose for development of no-till systems was for soil erosion control. No-till is quite effective in controlling erosion as long as there is adequate surface cover from crop residue or cover crops. For individual storm events at certain times during the growing season, the reduction in erosion from no-till can exceed 95 percent. For example, at the Milan Experiment Station in western Tennessee on June 11, 1981, a single large rainfall event of 64 mm resulted in soil loss of 26 Mg ha^{-1} on tilled soybean plots, compared to 0.4 Mg ha^{-1} on no-tilled plots. In five simulated rainfall events in 1982 (generated using a sprinkling rainfall simulator) soil loss from a no-till soybean system totaled 0.8 Mg ha^{-1} compared to 10.4 Mg ha^{-1} from a tilled system (Shelton *et al.*, 1983) The Revised Universal Soil Loss Equation predicts soil loss reduction of 50 to 90 percent from use of no-till in cropping systems in Tennessee. Experimental results confirm large reductions in erosion.

Table 3. Effect of tillage systems on the organic matter content of the upper 6 inch depth of a western Tennessee soil in soybean production.

Soil depth	No-till	Tilled
--- inches ---	---- g kg^{-1} soil ----	
0 - 3	24	11
3 - 6	12	13
0 - 6	15	13

SOIL ORGANIC MATTER CONTENT AND SOIL QUALITY PARAMETERS

No-till systems increase soil organic matter content in the layers near the soil surface over a period of time (Tyler *et al.*, 1983). Table 3 shows the organic matter content of the Ap horizon (0-6 inches) of a silt loam soil in western Tennessee after five years of no-till soybean production as compared to a tilled soil. The increase is concentrated near the surface. This is very important to the infiltration of rainwater. The higher organic matter content near the surface promotes more stable soil aggregates with stable macropores, which are resistant to closing by surface soil sealing under raindrop impact. This promotes higher infiltration rates and less runoff through the growing season.

Comparison of a 25-year no-till field at Milan to a tilled field showed higher infiltration rates, greater aggregate stability, and many more earthworms in no-till soil. Bulk densities of the upper 3 inches were the same (Seybold *et al*, 2002). Earthworm populations increased from negligible in tilled to over 100 per m^2 in no-till. Aggregate stability and infiltration rate were an order of magnitude higher in no-till.

MANAGEMENT FACTORS

No-till production requires less labor for tillage, planting and in-season weed control. The total investment in machinery is less over the long run. The power requirements are lower, and the hours of machinery use are lower. Less fuel is required as well.

No-till helps with timeliness of operation as well. Under Tennessee conditions, there is a relatively short period of time in spring (April-May) suitable for successful planting of warm season crops. The days available for land preparation and planting are reduced by rain during this period. No-till production eliminates the need to use some of these days for seedbed preparation, allowing all suitable days to be used for planting. This assists with timely planting in years when rainfall is above normal in the spring.

Because of more stable structural aggregates, no-till soils have better trafficability at harvest time as well. This also allows for timelier machine harvest when the fall period (September-November) is unusually rainy.

CONTINUING CONCERNS IN NO-TILL IN TENNESSEE

WEED CONTROL

With the development of a wide range of herbicides and glyphosate-resistant varieties over the past 30 years, weed control is no longer a major obstacle to use of no-till in cotton, corn or soybeans. However, it is a limitation in many other crops, especially vegetables, which occupy a small total planted area. Herbicide choices are very limited for many of these crops, and hand weeding is usually required. Apparent glyphosate resistance is appearing in marestail in Tennessee fields, threatening the sustainability of continuous glyphosate tolerant crops in no-till.

INADEQUATE BIOMASS FOR MULCH FOR EROSION CONTROL

Effective control of erosion in no-till requires the production of enough plant biomass to form a mulch layer on the soil surface that will persist until the next crop is established. This is a problem in some cropping systems that produce relatively little biomass. It is also a problem in systems where all of the biomass is removed at harvest, such as corn silage. This problem can be overcome by changing to a cropping system with more biomass, or by using cover crops, which are grown in the interval between crops for the purpose of providing biomass for surface mulch. Lack of residue is a particular problem in continuous cotton. Even with no-till, residue cover is inadequate for erosion control on slopes of more than 4 percent (Denton and Tyler, 1997). Cover crops or rotations are needed, but economic factors continue to limit the effectiveness of these systems.

DISEASE AND INSECTS

Experience in Tennessee has shown that disease and insect problems are not usually increased in no-till as compared to tilled systems. There may be problems, however, with diseases that persist in the residue of crops if those crops are grown continuously, or if the residue from the crop persists throughout the cropping sequence. This has been a problem in Tennessee with wheat. While some farmers here had success with no-till wheat, in general yields have been lower than in minimum tilled systems. In part, this is due to disease.

INADEQUATE PLANTING EQUIPMENT

Adequate planting equipment is still a problem for transplanted crops, and for small grains (wheat, barley, etc.) if there is a large amount of residue cover. For small farmers, the expense of no-till planting equipment is a significant barrier to use. This has been overcome in some cases by using cooperatives to purchase equipment for rental.

SUMMARY

In Tennessee, no-till has proven to be a very successful production system. It has allowed intensive crop production on highly erodible land with little soil erosion. Costs of production are not increased, and may be lower in some cases. Yields of crops have been maintained or increased. Soil quality has improved. The widespread soil degradation occurring on hundreds of thousands of acres in western Tennessee in 1975 had been greatly reduced, with average erosion rates dropping by 60 percent or more. No-till has become conventional in Tennessee.

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Table 1. Percentage of the area of major Tennessee crops planted using the no-till system, 1985-2001. (no numbers are available for cotton before 1992)

CONSERVATION TILLAGE TOMATO AND COTTON PRODUCTION SYSTEMS IN CALIFORNIA

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ABSTRACT

Despite increases in conservation tillage (CT) production in other regions of the US during the past decade, less than 0.3% of the acreage in California's San Joaquin Valley is currently farmed using CT practices. Preplant tillage operations typically account for 18 – 24% of overall production costs for annual crops grown in the West Side region of the San Joaquin Valley (SJV). An average of about 9 to 11 tillage-related passes are routinely done during the fall-spring period to *prepare* the soil for summer cropping. These passes represent not only considerable energy, equipment and labor costs, but recent research indicates that tillage reduces soil organic matter (SOM) and emits considerable respirable dust as well. Because SOM is widely regarded as an important attribute of good soil quality and long-term productivity, interest has been growing over the last several years, in developing alternative production systems that reduce costs while at the same time improve the soil resource through greater carbon sequestration. Conservation tillage systems may serve to increase SOM levels, reduce production costs and improve air quality in this critically important agricultural production region. The University of California's Conservation Tillage Workgroup, in conjunction with several Central Valley farmers, has recently initiated a number of research and demonstration evaluations of a variety of CT approaches for crop rotations of this region. Results from these studies are quite preliminary, but have served to reveal a number of new research directions for further evaluations of these alternative systems in California.

KEYWORDS

Soil preparation cost, soil organic matter, dust, Central Valley, San Joaquin Valley

INTRODUCTION

Although the term "conservation tillage" (CT) technically denotes a range of crop production alternatives that typically leave a minimum of 30% of the soil surface covered by residues from previous crops (Reeder, 2000), the development and adoption of CT systems for California's very diverse cropping systems is likely to spawn many tillage system variants that do not fully reflect the classic model systems that have been developed in other regions. Through a wide range of university and public agency research and demonstration activities, as well as private sector trials, there has been a well documented, and rather dramatic increase in interest and innovation related to reduced tillage crop production alternatives during the last five years in California's Central Valley (CT 2001 Proceedings, 2001). This interest has resulted from a number of interrelated factors.

Recent escalating diesel fuel costs (CEC, 2000) have, first of all, resulted in sharp declines in net farm income and threaten long-term economic viability in many Central Valley crop production regions (USDA Economic Research Service, 2000). A medium-sized row crop farm of 4,000 acres in this region may have weekly diesel fuel costs of upwards of $12,000 (Personal communication, Anonymous). Cutting diesel fuel use from 75 to 35 gallons per acre has been identified as a 2001 production target in the northern San Joaquin Valley (Personal communication, Anonymous). Reducing production costs has thus become a compelling and critical goal of growers throughout this region of California, which has historically been an area of phenomenal productivity (Calif. Dep't. Food and Agriculture, 1990).

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There is also a body of research evidence from other regions of the United States (largely untested yet in California, however) suggesting that conventional tillage practices disrupt soil aggregates exposing more organic matter to microbial degradation and oxidation (Reicosky, 1996) and are one of the primary causes of tilth deterioration (Karlen, 1990) and subsurface compaction (Personal communication, Taylor) over the long-term. Finally, because intensive tillage typically leads to decreased soil carbon (C) via gaseous CO_2 emissions (reviewed by Reicosky *et al.*, 1995), and because there is concern that this C source has been a significant component in the historic increase in atmospheric CO_2 (Wilson, 1978; Post *et al.*, 1990) and the potentially associated greenhouse effect (Lal *et al.*, 1998), there is increased interest in investigating cropping systems opportunities for mitigating these emissions. While these factors have gained greater "currency" in recent years, the fundamental motivation for reducing tillage remains economic; California growers are investigating a range of minimum tillage options primarily for reducing production costs.

CT RESEARCH AND INFORMATION DEVELOPMENT INITIATIVES

To respond to the needs for information on reduced tillage production alternatives, the University of California's Division of Agriculture and Natural Resources established the Conservation Tillage Workgroup in 1998 to develop knowledge and exchange information on CT production systems and to coordinate related research and extension education programs. Current Workgroup membership includes over 80 University of California researchers, USDA Agricultural Research Service and Natural Resource Conservation Service scientists, farmers, private industry affiliates and other public agency representatives. The Workgroup's 1998, 2000, and 2001 conferences, which were held as two back-to-back daylong sessions in Five Points and Davis in each year and which focused on successful conservation tillage systems in other parts of the US, have been attended by over 850 participants. Workgroup member research and demonstration sites have expanded from one in 1996 to over twenty in 2001.

CONSERVATION TILLAGE AND HERBICIDE RESISTANT CROPS

Running parallel to these CT research and extension education efforts has been the use of transgenic herbicide tolerant crops throughout a number of production valleys in California. Production of herbicide tolerant cotton in the San Joaquin Valley, for instance, began with about 500 experimental acres planted in 1997, and has increased steadily to upwards of 250,000 acres in 2001 (Vargas *et al.*, 2001), with adoption expected to increase in the future. Acreage shifts within the herbicide tolerant lines have favored those varieties that are closely related to existing successful Acala parentage. Potential benefits of transgenic cotton result from reduced hand weeding costs, elimination of one or more in-season weed cultivations for standard bed planting systems, as well as irrigation levee establishment costs for ultra narrow row cotton which can be flood irrigated (Personal communication, H.Wu). To date, however, transgenic seed technologies have not been coupled with production practices that reduce intercrop tillage, at least at any wide scale, primarily because of current postharvest cotton plowdown regulations for pink bollworm management. Other issues related to these transgenics, including weed resistance and crop yield and quality concerns, are the focus of considerable ongoing study (Vargas *et al.*, 2001).

TILLAGE REDUCTION OPPORTUNITIES IN SAN JOAQUIN VALLEY COTTON AND PROCESSING TOMATO ROTATIONS

In the fall of 1999, we began a four-year comparison study of conservation tillage and conventional tillage practices with and without winter cover crops in cotton and tomato rotations in Five Points, CA at the University of California's West Side Research and Extension Center. The study consists of a 3.23 hectare field experiment with four replications of these tillage / cover crop systems and both crops in each year.

To date, this study has demonstrated that planting and harvesting crops with conservation tillage systems is possible given some equipment modifications and that yields can be maintained relatively close to those of standard tillage in CT crop residue environments. Data from our 2001 tomato harvest indicate that yields in the CT ± cover crop systems were similar to those in the standard till plots

Table 1. Yield of processing tomato and cotton for the 2001 crop year.

Tillage / cover crop	Processing Tomatoes	Cotton
	tons acre^{-1}	bales acre^{-1}
Standard Tillage		
No cover crop	60.1	3.6
Cover crop	63.4	2.8
Conservation Tillage		
No cover crop	64.4	3.2
Cover crop	60.5	3.0

with an elimination of six tillage operations following last year's cotton crop in the CT plots relative to the standard till systems (Table 1).

2001 cotton yields were reduced 11 and 18% in the CT – cover crop and CT + cover crop systems, respectively, relative to the standard tillage control system, however, there was an elimination of 8 or 9 tillage operations in the CT systems relative to the ST approach. Estimated resource use per acre (hours of labor and gallons of fuel) indicate the possibility of the CT systems to reduce these inputs relative to standard till systems, however, these data are quite preliminary and are subject to further analysis. Longer-term implications of these reduced till regimes in terms of soil compaction, water use, profitability, soil carbon sequestration, insects and diseases are being evaluated as the study progresses through a four-year cycle.

OTHER CONSERVATION TILLAGE INITIATIVES IN CALIFORNIA

During the last two years, there have been a number of other CT evaluation projects that have been initiated in California. These range from a large-scale UC Davis campus-based comparison of reduced and standard till systems for crops common to the Southern Sacramento Valley that is being conducted by a large group of UCD researchers, UC Cooperative Extension Farm Advisors, and farmers, to smaller-scale farm demonstrations of reduced till planting and postharvest cotton management systems in Riverdale, CA in the Central San Joaquin Valley.

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EXPERIENCES WITH CONSERVATION TILLAGE AND NO TILL IN AUSTRIA

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ABSTRACT

Soil erosion is a major threat to the resource soil. The objective of this 8 yr-field study was to compare different tillage systems with respect to runoff, soil loss, nutrient, and pesticide transport. Three different tillage systems were compared: 1) conventional tillage (CT), 2) conservation tillage with cover crop (CS), and 3) no-till with cover crop (NT). No significant differences in total runoff during growing season were measured between the three tillage practices. Overall average annual soil loss ranged from 0.82 to 3.13 tons acre^{-1}, with the highest amount for conventionally tilled plots and the lowest for no-till plots. Nutrient losses from April to October were 8.4 lbs acre^{-1} yr^{-1} for CT, 5.4 lbs acre^{-1} yr^{-1} for CS, and 2.7 lbs acre^{-1} yr^{-1} for NT. Corresponding values for phosphorus were 4.1, 1.9, and 1.0 lbs acre^{-1} yr^{-1}. Conservation tillage and no-till management were able to reduce pesticide losses between 23 and 99 %.

KEYWORDS

Conservation tillage, no till, soil erosion, runoff, nutrients

INTRODUCTION

Soil erosion is a major threat to the functions a soil should fulfill. Especially the productivity, storage, and filtering functions are damaged by loss of topsoil. Therefore, land use and soil management should be carried out in a sustainable way, protecting the existing soil and water resources. In Austria, the use of conservation and no tillage is increasing. In the eastern part, where most of the cropland is located, approximately 10-15% of the agricultural land is managed with conservation tillage.

The objective of this study was to compare different tillage systems with respect to runoff, erosion, nutrient and pesticide movement, and biological soil properties. In 1994 a field experiment was started at two different locations in Austria. In 1997 a third location (Pixendorf) was added to the research program. Three different management practices were compared: 1) conventional tillage (CT), 2) conservation tillage with cover crops during winter period (CS), and 3) no-till with cover crop (NT). Crop rotation during the investigation period was corn-small grains at Pyhra and Pixendorf and corn-small grains-sugar beet-small grains-sunflower-small grains at Mistelbach.

MATERIALS AND METHODS

The experiments were carried out on plots of three agricultural schools in the eastern part of Austria, where land is used mainly for agriculture (Fig. 1). Mistelbach is situated 60 km north of Vienna in the so-called “Wine Quarter”. This region consists of rolling hills and is one of the warmest but also driest parts of Austria. The second experimental site is located in Pyhra about 80 km west of Vienna. This region is located in the foothills of the Alps. The landscape is characterized by gentle to fairly steep slopes. Pixendorf is located approximately 50 km west of Vienna on slopes of the so-called Tullnerfeld. Long term average precipitation and air temperature of the sites and values during the experimental period are given in Table 1.

The soils in Mistelbach and Pyhra are classified as Typic Argiudolls, while the soil in Pixendorf is an Entic Hapludoll. Soil textures range from silt loam to loam. Clay content ranges from 10.3 to 25.1%, silt content from 42.6 to 64.2%, soil organic carbon content (SOC) from 1.2 to 1.4%, and cation exchange capacity (CEC) from 8 to 15 cmol kg^{-1} (Table 2). Physical and chemical properties of each soil were determined with the following methods: dispersed particle size distribution measured with a wet sieving and pipette method, soil organic carbon (SOC) measured by the modified Walkley-Black method (Klute, 1986), pH in $CaCl_2$ (Klute, 1986), cation exchange capacity (CEC) determined by the barium chloride dihydrate method (Page *et al*., 1982), calcium carbonate content determined by the HCl treatment (Page *et al*., 1982), total nitrogen analyzed by the Kjeldahl method, and total phosphorus determined by ammoniummolybdat using extraction with $K_2S_2O_8$ solution (DIN 38.405, 1983).

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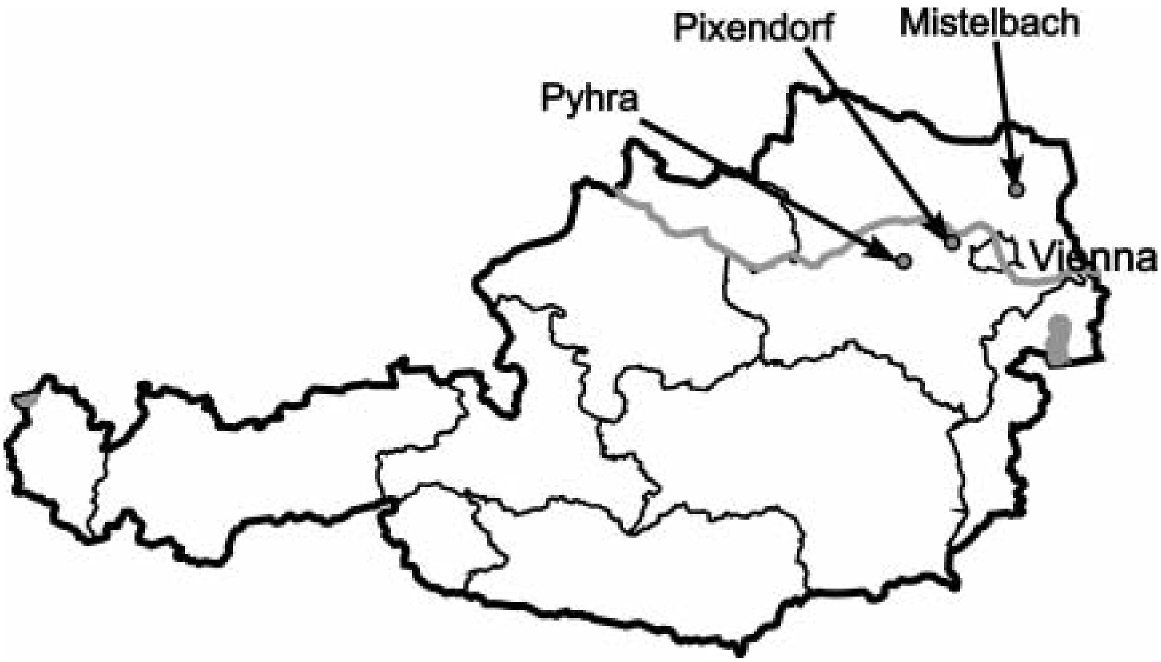

Fig. 1. Location of investigation sites in Austria

Table 1. Average monthly and annual precipitation and mean monthly and annual temperature for Mistelbach (1994-2001), Pyhra (1994-2001) and Pixendorf (1997-2001)

	J	F	M	A	M	J	J	A	S	O	N	D	Avg
							Precipitation, inch						
Mistelbach	1.00	0.79	1.53	1.50	2.74	3.72	4.56	2.35	3.56	1.30	1.46	1.42	26.2
Pyhra	1.20	1.70	2.55	2.70	4.13	3.78	4.57	3.91	4.20	2.22	2.79	2.22	36.0
Pixendorf	0.89	0.97	1.40	1.48	3.15	3.44	5.35	2.30	3.21	1.62	2.17	1.72	27.7
							Air temperature, °F						
Mistelbach	30.1	33.4	40.3	49.6	59.1	63.9	67.8	68.0	58.4	50.4	39.5	31.1	49.3
Pyhra	30.5	35.1	41.0	48.6	58.3	63.1	66.3	65.9	57.0	49.2	39.1	31.9	48.8
Pixendorf	32.2	38.6	43.8	50.7	60.1	63.9	65.8	67.3	57.1	51.6	40.2	33.9	50.4

Table 2. Main physical and chemical properties of investigated soils.

Soil	Sand	Silt	Clay	OC	pH	CEC	$CaCO_3$	Ntot	Ptot
	---------------- % ----------------					cmol kg^{-1}	-------------- % ------------		
Mistelbach	12.8	64.2	23.0	1.3	8.1	15	9.2	0.16	0.08
Pyhra	32.3	42.6	25.1	1.4	7.1	8	0	0.16	0.08
Pixendorf	27.6	62.1	10.3	1.2	8.1	8	21.2	0.15	0.06

Table 3. Characteristics and application rates of used pesticides (Hornsby *et al.*, 1996)

	Pesticide				
Characteristic	Rimsulfuron	Bromoxynile	Tribenuron	Metamitron	Pendimethalin
T (days)	31	7	10	30	171
Koc (mL g^{-1})	35	10000	46	100	111
Solubility (mg L^{-1})	< 10	0.08	280	1820	0.3
Appl. rate (oz acre^{-1})	0.07 – 0.15	1.61 – 5.18	0.21 – 0.34	7.00	20.0

The study design consisted of 9.8 ft (Mistelbach) and 13.1 ft wide (Pyhra and Pixendorf) and 49.2 ft long runoff plots for each management variation. The incline of hill slopes varied between 6 and 16%. Runoff and sediments were collected after each erosive rainstorm event. Precipitation and air temperature were measured in 5 min intervals with an automatic data logging system.

Representative runoff and sediment samples were taken for physical and chemical analyses. Nitrate concentrations in runoff were measured by the UV absorption method described by Navonne (1964). Ammonium concentrations were analyzed using Na-nitroprussid, Na-salicylate, and dichlorisocyanuracid solutions (Oenorm ISO 7150, 1985). Phosphate contents were determined by the ammoniummolybdat method (DIN 38.405, 1983).

Soil, pesticide, and rainfall characteristics influence timing, amount of pesticide loss (Leonard, 1990), and the dominating transporting agent of that pesticide. Pesticide persistence (T) and sorption properties (Koc) influence the time they stay near the application site and whether they will be adsorbed to sediment or remain in the solution phase. Pesticide persistence determines, in part, the probability of loss by runoff, and in what form the loss will occur (in solution/runoff water or adsorbed to sediment). Percentage of pesticides in runoff and on sediment will depend not only on sorption properties, but also on processes controlling runoff and sediment production during a rainfall event.

All used pesticides are slightly to very slightly mobile, expressed by sorption coefficients (Koc) between 35 and 10000 (Table 3). The half-lives (T) of pesticides range between 7 and 171 days. Therefore, Bromoxynile and Tribuneron are readily degradable, while Metamitron is fairly degradable, and Rimsulfuron and Pendimethalin are slightly degradable. Between 0.07 and 20.0 oz acre^{-1} of pesticides were applied per year.

In characterizing soil quality, biological properties have received less emphasis than chemical and physical properties, because their effects are difficult to measure, predict, and/or quantify. Soil microbial biomass is an important component of the soil organic matter that regulates transformation and storage of nutrients. The effects of tillage, crop rotations, and soil type on organic C and nutrient turnover can be assessed by following nutrient pools and activity associated with the soil microbial biomass. The toxicity of pollutants and the degradation of organic compounds (like pesticides) can be monitored following changes in the soil microbial biomass.

Soil samples were taken from March 20 to October 29, 2001, in monthly intervals at depths of 0-6 in and 6-12 in. Samples have been sieved through a 2 mm-sieve, and then water content was adjusted to 50-60% of the maximum water holding capacity. Microbial activity was estimated with at least one replication using five procedures: 1) substrate induced respiration (SIR; Anderson and Domsch, 1978), 2) soil respiration (SR; Isermeyer, 1952; modified after Jaeggi, 1976), 3) actual (AN) and potential nitrification (PN; Berg and Roswall, 1985), and 4) enzymatic dehydrogenase activity (DHG; Thalmann, 11968).

SIR represents the potential activity of soil organisms, while soil respiration (SR) represents the actual situation influenced by climate, physical and chemical soil properties, and agricultural practices. The dehydrogenase enzyme systems fulfill a significant role in the oxidation of soil organic matter as they transfer hydrogen from substrates to aceptors (Tabatai, 1982). The result of the essay of dehydrogenase activity will show the average activity of the active population (Skujins, 1976).

RESULTS

RUNOFF AND SOIL LOSS

Since the beginning of the experiment in 1994, 16 (Mistelbach) to 35 (Pixendorf) rainfall events produced runoff during the growing seasons. Not all of these events led to soil erosion. Depending on soil management, 75 to 82% of these events were erosive in Mistelbach, while 48 to 62% were erosive in Pyhra and 57 to 82% in Pixendorf. Data show that soil erosion is an extreme event process. At all sites, only two rainfall events (app. 7 to 12% of all runoff producing events) led from 66 to 96% of total soil loss.

For conventional tillage long-term average surface runoff during growing season ranged between 0.66 (Mistelbach) and 0.90 inches (Pixendorf). Corresponding values for conservation tillage were between 0.46 and 1.00 inches and between 0.59 and 1.00 inches for no-till plots (Fig. 2). In

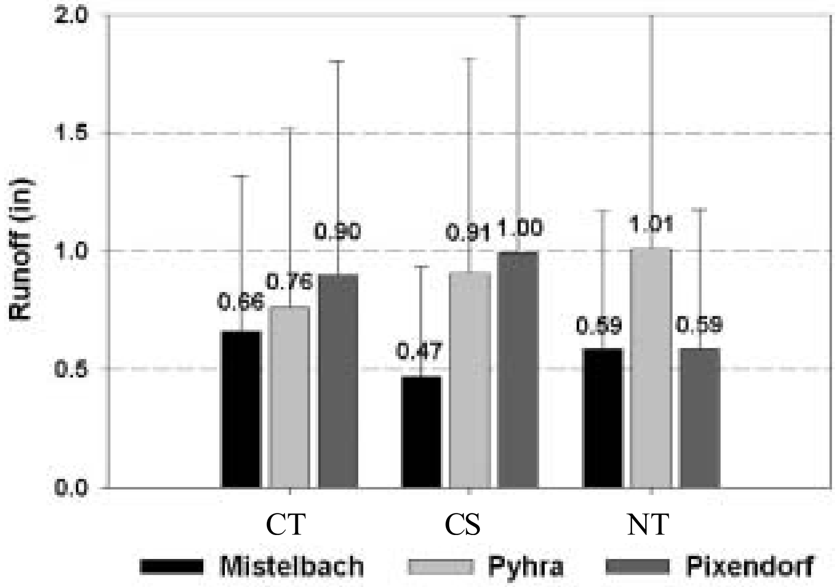

Fig. 2. Average runoff from CT, CS, and NT plots for all investigated sites.

Pyhra and Pixendorf, average runoff from CS was numerically higher than from CT. Compared to CT, NT plots had higher runoff in Pyhra but lower runoff in Mistelbach and Pixendorf. Statistical analyses showed no significant differences in runoff between investigated treatments.

Although average runoff did not significantly differ between management treatments, significant differences in soil loss could be determined. At each site, highest annual soil losses were measured from conventional tilled plots, while lowest soil erosion was measured from no-tilled plots. Average annual soil loss from CT ranged from 2.53 (Pixendorf) to 10.33 tons acre^{-1} (Mistelbach; Fig. 3). CS and NT led to soil losses between 0.69 and 2.94 tons acre^{-1} and 0.10 to 1.78 tons acre^{-1}, respectively. Compared to CT, conservation tillage with cover crops reduced soil loss by 36 to73 % and no till by 65 to 96%. This reduction can mainly be explained by the impact of organic matter on the soil surface. Plant residues of former crops and cover crops protect the soil surface against the impact of raindrops and increase the flow path on the field, thereby reducing flow velocity and , thus, the kinetic energy and shear stress of runoff water.

NUTRIENT LOSSES CAUSED BY SOIL EROSION AND RUNOFF

Due to no significant differences in runoff between the treatments, differences in nitrogen and phosphorus losses between the three soil management treatments were mainly related to amount of soil loss. Therefore, highest losses in total nitrogen (Ntot) and total phosphorus (Ptot) were observed from CT plots, and lowest from NT plots (Table 4). In Mistelbach yearly N-losses ranged from 0 to 147 lbs acre^{-1}, in Pyhra from 0 to 90 lbs acre^{-1}, and in Pixendorf from 0.3 to 22 lbs acre^{-1}. On a long-term basis, between 5.5 and 32.1 lbs N acre^{-1} are lost with CT between 1.8 and 9.2 lbs N acre^{-1} with CS, and between 0.6 and 7.0 lbs N acre^{-1} with NT. As phosphorus is mainly adsorbed to soil particles, P losses are highly related to amount of sediment yield. With CT, between 3.3 and 20.8 lbs P acre^{-1} per year are transported off the field (attached to soil particles and dissolved in runoff). P-losses from CS plots ranged between 1.0 and 5.2 lbs acre^{-1} and between 0.1 and 3.6 lbs acre^{-1} yr^{-1} from NT plots.

Besides N and P, another main soil quality parameter, organic carbon (OC), was transported off the field. At all sites sediment contained the same to 1.2% higher OC-contents than *in situ* soil. This results in organic carbon losses by soil erosion up to 225 lbs acre^{-1} per year (Table 4). Losses of organic carbon reduce filter and buffer ca-

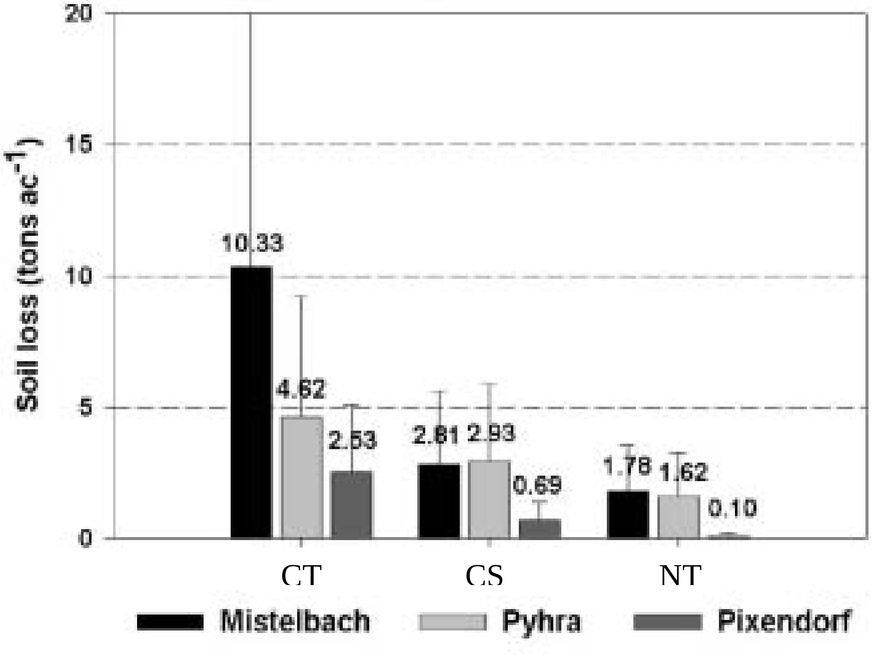

Fig. 3. Average soil loss from CT, CS, and NT plots for all investigated sites

Table 4. Average annual losses of total nitrogen (Ntot), total phosphorus (Ptot) and soil organic carbon (SOC) in lbs acre^{-1}

	Mistelbach			Pyhra			Pixendorf		
Parameter	CT	CS	NT	CT	CS	NT	CT	CS	NT
Ntot	31.12	9.15	6.98	12.08	10.68	4.63	5.52	1.75	0.58
Ptot	20.79	5.21	3.55	6.20	3.67	2.08	3.31	1.03	0.13
SOC	224.8	83.5	57.6	115.2	80.9	47.9	69.9	18.8	3.7

Table 5. Percentage of applied pesticides lost in solution (runoff) and adsorbed to sediment .

Losses	CT	CS	NT
By runoff	1.94	0.46	0.20
By sediment	3.69	1.28	2.38
Total	5.63	1.74	2.58

pacity of the soil, diminish soil fertility, and increase the potential of soil and groundwater contamination by pollutants.

Pesticide losses

For the Mistelbach site, average percentages of pesticides lost in runoff and on sediment were calculated from 1.74 to 5.63% (Table 5). Yearly values range from 0 to 23.1% (CT), 8.3% (CS) and 12.8% (NT), respectively. The results show that besides pesticide characteristics, the timing of erosive rainfall influences the amount of pesticide losses from the field. The highest losses were measured in 1994, when an extreme erosive event occurred only 10 days after pesticide application.

All used pesticides can be classified as slightly mobile to very slightly mobile. Therefore they are highly attached to sediments and transported with the eroded soil. For all treatments, percentage of pesticide losses caused by soil loss was always higher than that caused by runoff. Between 1.3% and 3.7% of the applied pesticide amount was leaving the plot adsorbed to sediments, while 0.2 to 1.9% was lost in solution. Conventional tillage caused the highest losses and conservation tillage the lowest.

Soil biological properties

Table 6 gives an overview of average values of substrate induced respiration (SIR), soil biomass-C, soil respiration (SR), and actual and potential nitrification (AN and PN) as well as dehydrogenase activity (DHG). Assuming a respiration coefficient of 1, soil biomass-C can be assessed by:

1 mg CO_2 / 100 g DM . h = 20.6 mg biomass-C / 100 g DM

Investigated parameters show higher values in 0-6 in soil depth than in 6-12 in. This is due to better aeration and higher temperatures in this layer. For a soil depth of 0-6 in, NT treatment shows highest values for all investigated soil biological parameters. Significantly higher values of SIR, SR, AN, PN, DHG, Ntot and OC exist only for the Pixendorf site. For Mistelbach and Pyhra, an increase also can be seen. Differences compared to CT are not significant. When comparing biomass-C and organic C, it can be seen that between 4.3 and 8.6% of soil organic carbon consists of living biomass. CS and NT always have higher Cmic/OC-ratios than conventional treatment.

Crop production

For a corn-small grains-crop rotation, CS and NT had no negative effects on the yield. In years with extreme erosive events CS and NT had even positive impacts on the yield because of less or no crop damage. Only for sugar beets, a yield decrease of 16% was determined when using no till.

SUMMARY AND CONCLUSIONS

In a field study the impact of different tillage practices on runoff, sediment yield, and nutrient and pesticide loss was investigated. The different soil management systems had no significant impact on runoff. Conservation tillage (CS) and no-till (NT) with cover crops are successful practices to reduce soil erosion. Compared to conventional tillage, conservation tillage with cover crops reduced soil loss by 33-70% and no-till by 63-96%. Reductions in total nitrogen ranged between 11-70% for CS and 62-92% for NT. Corresponding values for total phosphorus were 41-70% (CS) and 67-97% (NT), respectively. Pesticide losses decreased by 23-99% when using CS and NT. Reduced tillage systems, together with cover crops during the winter, are able to increase soil quality without negative effects on crop yields.

Table 6. Average values of investigated soil biological parameters (March 20 – October 29, 2001).

Parameter /	Mistelbach			Pyhra			Pixendorf		
depth	CT	CS	NT	CT	CS	NT	CT	CS	NT
Soil organic carbon content (%)									
0 – 6 in	1.35	1.33	1.40	1.11	1.16	1.60 *	0.75	0.91 *	1.06 *
6-12 in	1.17	1.16	1.19	1.07	1.05	1.19	0.72	0.69	0.72
Substrate Induced Respiration (mg CO_2/100 g DM.h)									
0 – 6 in	4.50	4.28	5.07	2.51	2.94	3.88 *	2.91	4.00	4.40 *
6-12 in	3.54	3.82	3.73	2.05	2.59	2.37	2.55	2.70	2.70
Soil Respiration (mg CO_2/ g DM. 24 h)									
0 – 6 in	0.23	0.25	0.26	0.10	0.10	0.09	0.14	0.17 *	0.19 *
6-12 in	0.21	0.24	0.22	0.06	0.08	0.07	0.14	0.15	0.15
Soil Biomass-C (mg Biomass-C/ 100 g DM)									
0 – 6 in	92.7	88.2	104.4	51.7	60.6	79.9 *	59.9	82.4	90.6 *
6-12 in	72.9	78.7	76.8	42.2	53.4	48.8	52.5	55.6	55.6
Cmic / OC (%)									
0 – 12 in	6.6	6.7	7.0	4.3	5.2	4.6	7.6	8.6	8.2
Total Nitrogen content (%)									
0 – 6 in	0.16	0.16	0.17	0.15	0.16	0.18 *	0.11	0.12 *	0.13 *
6-12 in	0.15	0.14	0.14	0.13	0.14	0.15 *	0.10	0.10	0.10
Actual Nitrification (ng N/g DM.24 h)									
0 – 6 in	120.6	105.6	137.1	28.7	35.6	32.9	102.9	133.2 *	140.2 *
6-12 in	111.6	105.1	88.7	25.7	31.4	20.9	85.0	80.0	81.9
Potential Nitrification (ng N/g DM. 5h)									
0 – 6 in	568.4	468.5	609.1	434.6	492.3	720.1	260.7	396.9	508.7 *
6-12 in	424.3	385.7	352.4	402.1	473.5	625.5 *	196.4	186.7	192.7
Dehydrogenase Activity (ug TPF/ g DM 16 h)									
0 – 6 in	20.23	16.56	22.91	10.25	16.13	19.60	13.98	21.90	29.35 *
6-12 in	10.78	13.63	11.83	13.39	10.38	10.00	12.83	10.86	11.33

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Sod-Based Systems

SOIL ORGANIC CARBON CONTENT OF A TYPIC ARGIUDOLL IN URUGUAY UNDER FORAGE CROPS AND PASTURES FOR DIRECT GRAZING: EFFECT OF TILLAGE INTENSITY AND ROTATION SYSTEM

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ABSTRACT

Reduced information exists regarding tillage intensity effect on soil carbon (SOC) in rotation systems that combine forage crops and pastures grazed directly. A 72 ha experiment comparing 4 soil use intensities (SUI) was installed in 1995 in Uruguay on a Typic Argiudol. SUI were Continuous Cropping (CC): double crop of C3 grasses in winter and C4's in summer, Short Rotation (SR): 2 years idem CC and 2 years of biannual grass and legume pasture, Long Rotation (LR): 2 years idem CC and 4 years of perennial grass and legume pasture, and Permanent Pasture (PP): natural pasture overseeded with perennial legumes. There are no synchronic replications, but yearsare the replications for statistical analysis. Experimental units occupy 6 ha, containing all rotations phases synchronically. Conventional experiments with RCB design are conducted annually inside CC and in the experimental units of SR and LR in the first crop following the pasture; treatments are tillage intensities (Conventional: CT, Reduced: RT, and No-Till: NT). SOC is determined annually in composite samples collected 0-15 cm depth. Results showed that under CC, SOC decreased 24%, 12% and 7.5% from 1995 to 1999 with CT, RT and NT, respectively. Using NT, SOC was 12-20% and 23-30% higher in SR and LR, respectively, compared with CC. Compared with PP, SOC was 11% and 14% higher in SR and LR, respectively. It is concluded that CC for intensive animal production is not sustainable, even with NT. Forage Crop-pasture rotations, however, were demonstrated to maintain and improve SOC, being sustainable.

KEYWORDS

Soil Organic Carbon, Conservation Tillage, No-Till, Crop-Pasture Rotations

INTRODUCTION

Uruguay, located in South America between 30 and 35 degrees of latitude, has an important experience in integrating crops and pastures in rotations systems. The area served by the Experimental Station INIA-Treinta y Tres, in Eastern Uruguay, represents 30% of the country. The dominant soils are Typic Argiudols with low to moderate soil fertility (1.5 to 2% SOC). They occupy a landscape of gently sloping hills of modest altitude, where the erosion risk is moderate to high. Also, because of a strongly developed argillic B horizon, these soils are sometimes poorly drained. Because of their natural limitations, they are between land capabilities III and IV in the USDA Land Capability Classification. Because of their limitations for grain crop production, natural livestock pastures are the predominant production system in this area. The adoption of No-Till technology started during the 90's, allowing the development of more intensive animal production systems based on forage crops and pastures rotations.

Soil organic carbon is recognized as the main soil quality indicator (Doran and Parkin 1994; Reeves, 1997; Seybold *et al.*, 1997). Mid and long term effects of tillage and rotation on SOC in grain crops production systems have been extensively reported (Diaz, 1992; Reeves, 1997). Results from the oldest long-term experiment in South America (started in 1962 in INIA-La Estanzuela, Uruguay) indicate that continuous cropping with conventional tillage results in a continuous SOC decline, but in crop-pasture rotations SOC declines during the arable cropping cycle but is recovered during the planted pasture cycle. These opposite effects tend to lead to a long term SOC equilibrium, despite a small downward trend (Diaz, 1992). The SOC recovery produced by pastures improves nitrogen availability (reducing the need of fertilizers) and soil physical conditions for the following crop phase of the rotation (García Préchac, 1992). The rotations of crops and pastures also have an important effect in reducing the long term average annual erosion (Terra and García Préchac, 2001), because half of the time the soil remains covered suffering no tillage.

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Little information is available in rotation systems that combine forage crops and pastures grazed directly. In these conditions, due to animal utilization or harvesting for hay or silage, the amount of biomass incorporated into the soil (conventional tillage) or left as residue on the surface (no-till) is less than in the systems where grain harvesting is the only biomass exported during the crop cycle of the rotations.

Soil compaction in the top 10-15 cm caused by livestock trampling also can be a problem in the adoption of NT by farmers. Results of Ernst and Siri (2000) suggest that RT for the first crop following the pastures is necessary to achieve the same crop yield as with CT during the rest of the cropping cycle using NT. No tillage is needed, however, if it is possible to have enough fallow time between the herbicide application and the first crop planting. There is evidence of this fallowing effect on better soil N availability (Terra and García Préchac, 2001) and reduced surface compaction (Ernst, not published, cit, by García Préchac *et al.,* 2002).

The objective of the present paper is to present SOC results evaluating the effect of rotations, including forage crops and pastures for direct grazing, with different tillage and cropping intensities.

MATERIALS AND METHODS

A 72 ha experiment was installed in 1995 on a Tipic Argiudol at the Palo a Pique experimental unit of the National Institute of Agriculture Research (INIA) located in Eastern Uruguay. The experiment compares the following four soil use intensities (SUI) for livestock production.

Continuous Cropping (CC)

Double annual forage crop of oats (*Avena sativa*) mixed with annual ryegrass (*Lolium multiflorum*) in winter and sorghum (*Sorghum bicolo*r) or foxtail millet (*Setaria italica*) in summer.

Short Rotation (SR)

Two years of CC followed by two years of a pasture of annual ryegrass and red clover (*Trifolium pratense*).

Long Rotation (LR)

Two years of CC followed by four years of a pasture including orchardgrass (*Dactylis glomerata*), white clover (*Trifolium repens*), and birdsfoot trefoil (*Lotus corniculatus*).

Permanent Pasture (PP)

This is a natural pasture which was overseeded every four years with ryegrass, white clover, and birdsfoot trefoil.

The experiment does not have synchronic replications, but all phases of the rotations are present simultaneously; there are 12 experimental units of 6 ha, where livestock grazes directly. For the statistical comparison of the 4 soil use intensities, years were taken as replications in a Randomized Complete Block (RCB) design. The results that are going to be presented come from three years: 1998, 1999, and 2000.

Despite all 6 ha, experimental units were managed with no-till in smaller areas inside them. Short mid-term analytical experiments were conducted comparing the effects of different tillage intensities: Conventional: (CT), Reduced (RT), and No-Till (NT). These experiments were arranged in RCB design with 4 replications. CC has contained one of these analytical experiments since 1995, with the same treatments applied to the same plots that were planted with forage crops twice a year. Identical experiments were conducted in 1998 and 1999 in the experimental units of SR and LR, corresponding to the first winter crop following the pasture cycle of the rotation. In SR and LR after this first crop, all the following crops were NT planted. Excessive soil degradation observed from 1995 to 1998 was the reason to exclude CT from the experiment in 1999.

Composite soil samples were collected in the fall from the top 15 cm in the 12 experimental units of the experiment that compared the 4 SUI. In each one of these units there was a selected 0.5 ha sampling area chosen for identical soil characteristics, including landscape position. The composite sample in these cases came from 15 2.5 cm diameter soil cores taken randomly in the sampling area.

In the 0.04 ha plots of the analytical experiments comparing tillage intensities, the composite soil samples were made of 10 subsamples taken randomly in all the plots' surface. The sampling in these experiments was made at the planting of the winter crop and after the following summer crop harvesting. SOC was determined using the Walkey and Black technique (Nelson and Sommers, 1982).

Data analysis was performed using SAS PROC GLM (SAS Institute, 1996). In the experiment comparing SUI, the treatment sum of squares was partitioned into three orthogonal contrasts of one degree of freedom: CC *vs.* other treatments, PP *vs.* SR and LR, and SR *vs*. LR.

In the experiments comparing tillage intensities on three different previous uses (CC, 2 yr. Pasture in SR, and 4 yr. Pasture in LR) in 1998 and 1999, a combined analysis was made using Blocks nested into Previous Use as the error term to test the previous use effect. The independent contrasts were: CC *vs*. Pastures, and 2 yr (SR) *vs*. 4 yr. (LR) pastures. In 1998 Tillage intensities independent contrasts were: CT vs. RT and NT, and RT vs. NT; in 1999 the only tillage intensity contrast was RT vs. NT. The interaction (Previous use x Tillage intensities) contrasts were the combinations of the indicated Previous Use and Tillage intensities contrasts.

When presenting and discussing the results, the indication of significant differences were based in the contrasts with equal or smaller probability of greater F than 0.05. The LSD's are presented as an indication of the experimental error, not to be used for means comparisons.

RESULTS AND DISCUSSION

The SOC means from 1998 thru 2000 were CC: 1.48%, PP: 1.6%, SR: 1.78%, and LR: 1.82%; the LSD was 0.2%. The independent contrasts indicated that CC had significantly lower SOC than the average of the other SUI. PP had significantly lower SOC than the average of the two crop-pastures rotations, and there were no significant difference between SR and LR.

The results of the Tillage intensity experiment inside CC are presented in Fig. 1. The general trends, best described (higher R^2) by quadratic functions, show SOC decline for the three tillage intensities, but these declines were different between treatments. Referred to the SOC before the experiment started, the reductions in the last measurement were 7.5%, 12% and 24%, in NT, RT and CT, respectively.

Because of the low return of biomass to the soil in CC, due to grazing of the winter crops and harvesting for hay or silage of the summer crops, it is conceivable to have some SOC reduction even with NT. It should be noted that the magnitude of SOC reduction in CC with NT in both experiments is very close. In the SUI experiment, the SOC under PP is representative of the initial value under natural pasture; the reduction under CC, compared with PP was 8%. Because of greater soil organic matter oxidation and soil erosion, a greater SOC decline with increased tillage intensity should be expected , as the results indicate.

Contrasting with CC, the SOC in the crop-pasture rotations is expected to be higher, but the results show that SOC in these rotations was even higher than in PP. The explanation for such result should be that the Carbon balance in the crop-pasture rotations is higher than in PP. The results of the Tillage intensity experiments in 1998 and 1999, presented in Table 1, indicate the same trend. At the planting of the winter crop in 1998, the combined analysis of the 3 experiments showed lower SOC in CC than in the experiments on pastures, and that in the experiment started on the 4 year pasture, the SOC was higher than in the one started on the 2 year pasture. The effect of the tillage intensity Treatments in the 3 experiments shows significantly higher SOC in NT than in the tilled treatments and no difference between them. The significant results at the 1999 winter crop planting also indicate that CC had the lower SOC and that between the two previous pasture uses, SOC was higher in LR than in SR. Between the two tillage treatments used in 1999, NT had higher SOC than RT. In both years the interaction contrasts were not significant.

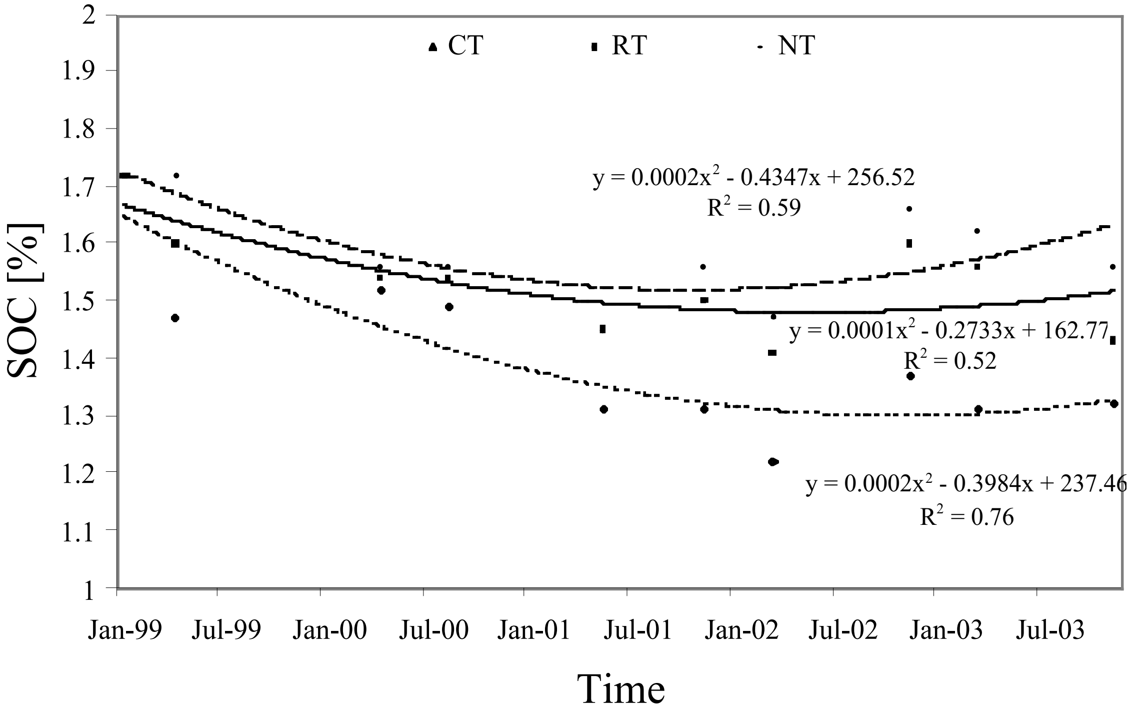

Fig. 1. Soil Organic Carbon content evolution with time in an experiment at the at the Palo a Pique experiment station in Eastern Uruguay comparing three tillage intensities, in continuous forage cropping.

Table 1. The effect of three soil use intensities (SUI) and three tillage intensities effect on soil organic carbon (SOC %) in the 0-15 cm depth during winter cropping season in two years.

SUI ➔	CC				SR				LR				LSD for	
Tillage Intensity:	CT	RT	NT	SUI MEAN	CT	RT	NT	SUI MEAN	CT	RT	NT	SUI MEAN	SUI	Tillage Intensity
1998 SOC%	1.44	1.56	1.68	1.56	1.71	1.67	1.85	1.74	1.86	1.93	2.02	1.94	0.21	0.08
1999 SOC%	1.31	1.56	1.62	1.50	-	1.63	1.75	1.69	-	1.99	2.23	2.11	0.29	0.14

CONCLUSIONS

SOC decreases with tillage intensity, independently of the previous SUI. SOC was higher under NT and lowest under CT. In a highly biomass extractive system like CC, even with NT there is some SOC decline.

The inclusion of seeded pastures in rotation with forage crops increases SOC, independently of the tillage intensity used. The results indicate that the inclusion of productive pastures in the rotations can determine that the carbon balance will be higher than in natural pastures of modest productivity, reaching higher SOC content.

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INTEGRATING NO-TILL INTO LIVESTOCK PASTURES AND CROPS ROTATION IN URUGUAY

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ABSTRACT

Uruguay has a temperate sub-humid climate; C3 and C4 grass pastures are its primary vegetation, occupying 80% of the surface area (39.8 million acres). Beef, wool, and dairy are the main products. Crops occupy a portion of the remaining 20%, mainly on Argiudols and Vertisols, rotating with seeded grass and legume pastures. Continuous cropping (CC) with conventional tillage (CT) proved not to be sustainable because of decreasing soil productivity. Productivity recovery during seeded pasture periods made crops-pastures rotation (CPR) the dominant crop production system from the 1960s. The adoption of CPR is explained by better and more stable returns from year to year. But soil degradation remained important during the crops cycle of the crops-pastures rotation with conventional tillage. Farmers' and technicians' interest in no-till (NT) to reduce this problem, lower prices of herbicides, appearance of regionally made no-till planters, and agronomic research solving problems of no-till under Uruguayan conditions, are the explanations for no-till's adoption during the 1990s. in 1999/2000, 52.5% of the crop-producing farms and 25% of the dairy farms used it. This paper presents research results regarding the transition period from conventional tillage to no-tillage, and soil compaction and soil organic carbon (SOC) content in the crops-pastures rotation with no-tillage. It concludes by discussing the relative sustainability of continuous cropping vs. crops-pastures no-till based systems.

KEYWORDS

Soil quality, soil compaction, soil organic carbon, no-till, pasture crop rotation

INTRODUCTION

Uruguay is located in South America, between 30 and 35° latitude. Annual mean rainfall varies between 40 inches in the south to 55 inches in the northeast. Daily mean temperature varies from 55 ˚F in winter to 77 ˚F in summer. Winters are cold, but the soils are not frozen; summers are hot. Monthly average rainfall distribution is fairly uniform, but potential evapotranspiration is driven by solar radiation, thus during fall and winter water is abundant, and during late spring and summer it may be deficient. The country's total surface area is around 39.8 million acres. Natural and regenerated natural pastures, composed largely of C4 and C3 perennial and annual grasses, occupy around 80% of the area. Crop production involves less than 20%, mainly on Argiudols and Vertisols, and is done in rotation with planted grass and legume pastures.

From the times of the Spanish domination, livestock production formed the basis of Uruguayan economy, greatly influencing the national culture. Livestock production has evolved from bovine cattle for leather exploitation to beef and leather production. During the mid nineteen century, sheep for wool and beef were also introduced, and during the twentieth century, dairy cattle became an important component of animal production. Because of the country's climate, all animal production is made in the open field, by direct grazing of natural and planted pastures.

CROPS-PASTURES ROTATION WITH TILLAGE

Field crops production with conventional tillage was used from the times of the European settlement in a relatively small area surrounding the city of Montevideo. Despite its effect on soil degradation due to erosion and soil organic matter loss, the technology of rotating field crops with planted pastures began in the 1960s. The elements that led to the adoption of crops-pastures rotation were the recognition that forage production of natural pastures was limiting the country's animal production, leading to the idea

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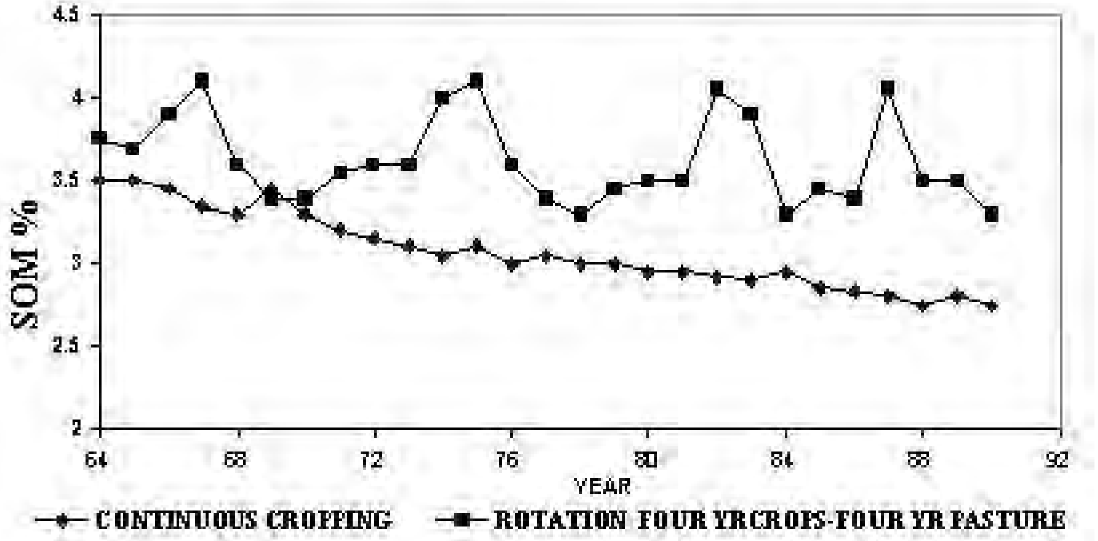

Fig. 1. Evolution of soil organic matter content from 1964 thru 1990, in two contrasting soil use systems with conventional tillage (Díaz Roselló, 1992).

of supplementing natural pastures by planting or interseeding grass and legume pastures to increase forage production, following the New Zealand model. Literature from the UK (Low *et al.*, 1963) presented evidence of improved soil organic matter content, soil nitrogen availability, and soil structure-related properties, after a period of grass and legume seeded pastures, rotated with arable crops, and that these changes had favorable productive effects on the crops that followed.

National programs promoted the planting of grass and legume pastures and the interseeding of legumes in pastures dominated by natural grasses, with the aid of phosphorus (P) fertilization. In the area of predominant natural pastures, the impact of these programs during the 1960s and 1970s was limited, with more interseeding of legumes than planting of new pastures by elimination of natural ones with tillage. Conventional tillage proved to be very risky in terms of soil erosion, and imposed a period of low forage production and utilization because of the slow initial growth of the planted perennial species. But in the smaller area of field crops production, the planting of grass and legume pastures was progressively adopted, in order to recover the productivity of soils degraded by years of continuous cropping. The performance of the planted forage legumes was generally good, because despite the degradation caused by tillage, the continuous cropped soils had higher P availability, due to moderate fertilization of crops. Consequently, the leading farms began to combine field crops production on soils where fertility was recovered after a period of planted pastures, with beef cattle fattened on these productive pastures. The technology of planting the pastures together (in the same planting operation) with the last crop of the crops cycle became very successful because of the savings of time, cost, and soil degradation.

Long-term experiments supported these processes. The oldest one started in 1962 at the Experimental Station INIA-La Estanzuela; it is still in operation, with changes during the 1980s to include reduced tillage and no-till. Reviews were done at the beginning of the 1990s (Dìaz Roselló, 1992; García Préchac, 1992a; Fernández, 1992). The total grain production of the period 1963-1989 in the crops-pastures rotation was between 59 and 63% of the ones in continuous cropping. As the crops cycle in the rotations occupies half the time, it means crop productivity per acre was increased between 18 and 26%. The higher crop productivity is a consequence of better soil quality, as seen in Fig. 1. It shows a continuous decline of the Ap horizon's soil organic matter content in continuous cropping, but in the crops-pastures rotation the soil organic matter content lost during the arable cropping cycle is recovered during the planted pastures cycle, despite a small trend of soil organic matter content decline in the long term. The soil organic matter recovery in the pastures cycle improves N availability (reducing the need of nitrogen (N) fertilizers) and soil structure. The last was documented in 1978 by soil bulk density measurements (García Préchac, 1992a) that increased from 1.12 to 1.28 Mg m^{-3} from the first to the fourth crop of the crops cycle, and decreased back to 1.2 Mg m^{-3} after 3 years of seeded pastures.

The reduction of tillage operations by half in the crops-pastures rotation than in continuous cropping, and less need of N fertilizers, translated to lower average cost during the period 1963-1989 (Fernandez, 1992). As the gross income was similar or higher in crops-pastures rotation than in

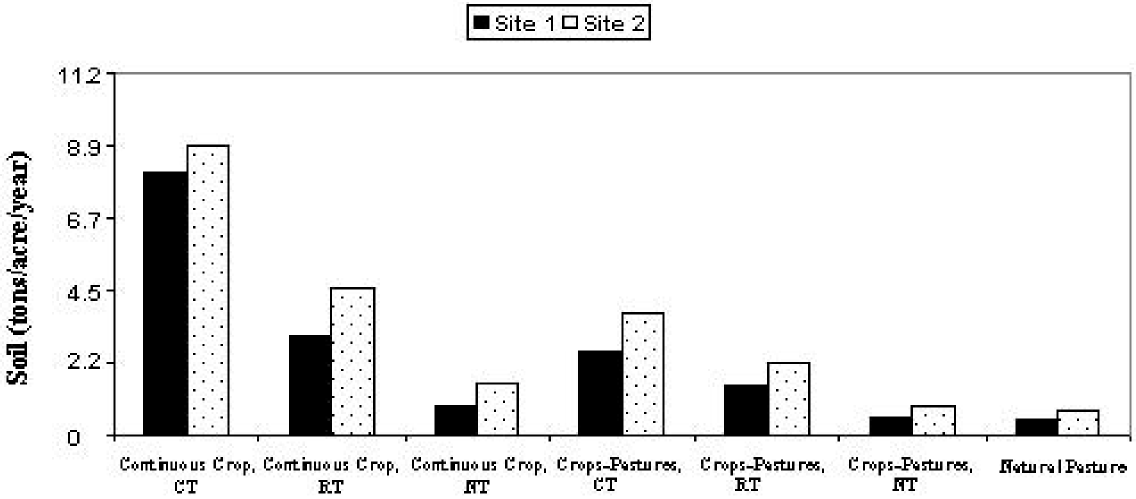

Fig. 2. Annual mean soil erosion of contrasting cropping intensities (continuous crop and crops-pastures rotation) and soil tillage [no-tillage (NT), reduced tillage (RT) and conventional tillage (CT)] in two locations, measured in Wischmeier runoff plots. Site 1, La Estanzuela, from 1984 to1990, (Sawchik and Quintana, cit. by García Préchac, 1992b); Site 2, Palo a Pique, from 1993 to 2000, (Terra and García Préchac, 2001).

continuous cropping, because of higher crop productivity and the addition of beef production, the gross margin of the crops-pastures rotation was higher (in 1990, CPR: $ 120 per acre vs. CC: $70 per acre). Also, because of greater product diversity (grain and beef vs. only grain), the crops-pastures rotation is economically a more buffered system than continuous cropping (Gross Margin Coefficient of Variation: CPR 73% vs. CC 95%), and is better able to support inter annual variations in prices of products and inputs.

Annual average soil erosion, measured in two soils during 6 years with runoff plots (Fig. 2), show the great soil conservation benefits of the crops-pasture rotation, independent of tillage intensity (García Préchac, 1992b; Terra and Garcìa Préchac, 2001). Nevertheless, the need to reduce erosion that is generated during the crops cycle with conventional tillage is important to farmers and technicians, even when contour cropping is used. The switch from conventional tillage to reduced tillage improves the soil conservation level, but the use of no-till combined with crops-pastures rotation generated soil erosion results similar to pristine natural pasture, being the state-of-the-art in terms of soil conservation during the last decade.

CROP - PASTURE ROTATION WITH NO-TILL

The use of no-till became important in Uruguay in the early 1990s and has been growing in percent of farms participating (Ernst *et al.*, 2001; Scarlato *et al.*, 2001). Driving this process were pioneer farmers concerned with soil erosion and degradation during the arable crops cycle of the crops-pastures rotation; as they became interested in conservation tillage they formed AUSID, an organization pro no-till that started contacts with similar organizations in the region (Brazil, Argentina, Chile and Paraguay), shared their experiences, and demanded research on the new technology. Roundup's® patent ended and the competition with other glyphosate-based herbicides lowered the price of this vital input to no-till. Brazilian and Argentinean no-till planters appeared in the market at competitive prices. Research was developed to solve the problems of the new technology inside the particular ecological and productive conditions of Uruguay. But undoubtedly, the increasing adoption is being boosted by the lower total cost of no-till (between 10 and 30%, according to FUCREA, a national Farmers non-governmental organization), because the reduction in tillage, machinery, and operative costs compensates for the need to use more herbicide.

Among the differences of the Uruguayan production systems with the ones in most countries with no-till experience is the crops-pastures rotation, including direct grazing, and therefore soil surface compaction by cattle trampling. Also, in the more intensive animal production systems like dairy production, not only the pastures are grazed, but also most of the crops, in particular during winter when soil water content is high. In addition, the crops that are not grazed are harvested for hay or silage, leaving very little residue on the soil surface. Thus the sustainability of these intensive animal production systems, even under no-till, is in the pasture's return of biomass to the soil during its cycle in the crops-pastures rotation (Terra and García Préchac, 2002).

Figure 3 gives insight into no-till use of different crops

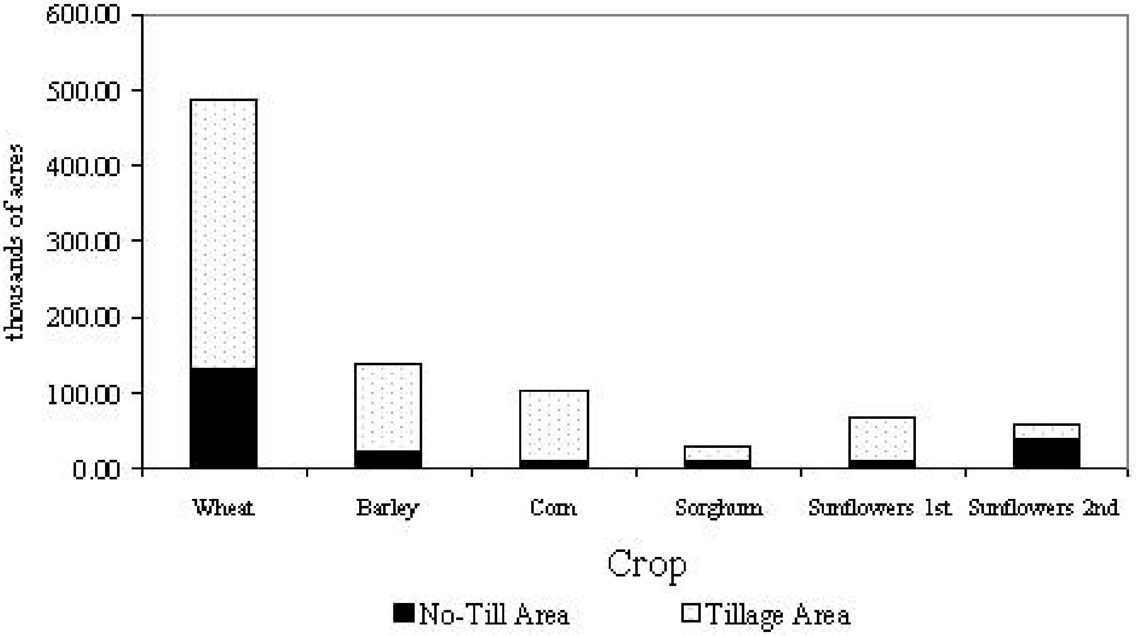

Fig. 3. No-tillage use in different crops during the 1999-2000 cropping season in Uruguay (20% of the population sampled in 2000, DIEA, 2001).

planted in 1999-2000. The main winter crop is wheat (*Triticum aestivum* L.); it shows higher no-till utilization than barley (*Hordeum vulgare* L.), the second crop in importance. The difference between these crops is that barley production is financed by the malt industry, which also dictates the technology to be used by farmers. As the industry has doubts about barley's no-till production performance, it has not yet recommended no-till as the main soil management procedure to be used.

Among summer crops, there is a striking difference in no-till use between full season crops, corn (*Zea mays* L.) and sunflower (*Helianthus annuus* L.) first, and second crops (sunflower 2nd) in an annual double-cropped sequence. Full season crops are planted in the spring, and in Uruguay they share some of the problems known in the U.S. Corn Belt, related to lower soil temperature and N availability early in the spring season. But in the case of corn, most of it is planted for silage in the crops-pastures rotation on dairy farms. In the cropping sequence used on these farms, corn is planted following an annual winter crop for direct grazing of dairy cows. Usually, as winter is the most limiting forage-producing season, dairy farmers continue using winter crops up to the beginning of the spring. This leads to: 1) low soil cover, 2) low soil-available N and water, 3) surface compacted and trampled soil, and 4) short time in fallow to recover water and N availability and to improve soil tilth.

It follows that no-till is being used both as occasional and as integral soil management technology. The latter is the case on farms where the whole operation is done using no-till. The study by Scarlato *et al.* (2001) was in the area of the country where crop production is concentrated. The use of no-till included 35% of the farms, but when referring only to crop-producing farms (there are also livestock farms, based only on pastures), the use of no-till is 52.5%. But only 10% of these farms were using no-till as integral soil management strategy. In a study by Ernst *et al.* (2001), 25% of dairy farmers used no-till, but 15% were using it as part of an integral management system. In the study by Scarlato *et al.* (2001), the planting of pastures in the crops-pastures rotation was done in 80% of the cases using no-till. Thus, the available information indicates that the use of no-till in Uruguay has been easier in systems where full season summer crops are less used in the crops cycle of the rotation. Actually, the study by Ernst *et al.* (2001) on dairy farms showed less use of corn for silage in the integral no-till farms than in the rest of the farms studied.

THE TRANSITION

The transition from conventional tillage to no-till is the most difficult period for the adoption of the new technology. Farm and research results from the first half of the 1990s (Fig. 4) indicated lower crop yield with no-till than with conventional tillage or reduced tillage during the transition period (Ernst, 2000). No-till inherits the problems of conventional tillage in the areas of the country where crops and dairy production are concentrated. In the crops-pastures rotation with conventional tillage, the end of the pasture cycle is mostly determined by bermudagrass (*Cynodon dactylon* L. Pers.) infestation. This weed is a perennial rhizome C4 grass, introduced to the country to stabilize

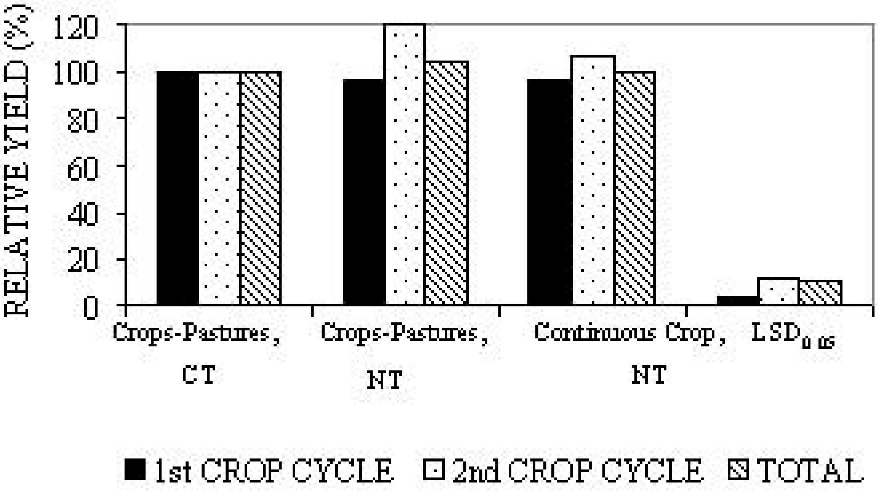

Fig. 4. Difference between conventional (CT) and no-tillage (NT) relative crop yields in the transition period (1st. Cycle); after the systems with no-tillage are more stabilized (2nd. Cycle), and mean of two cycles (Ernst, 2000).

railroad slopes at the end of the 1800s. It occupies the N enriched niches in the pastures left by death of legumes during summer droughts, and competes successfully with most of the commonly used species in the pastures. Its productivity is low because most of its biomass is dedicated to producing subterranean organs, and because the aerial part is killed by the first winter frosts. Bermudagrass, when present, is very competitive with all crops and pastures from the spring thru the fall. Tillage is effective in reducing its presence, as are glyphosate applications, but the amount of growing points underground saves bermudagrass from being totally controlled by any means. No-till farmers experience, as well as long-term experiments, demonstrate that repeated herbicide application and crops competition for light, progressively reduces this weed's presence in no-till systems. But in the transition from conventional to no-till systems, particularly when crops begin to be no-till planted on bermudagrass-invaded pastures (the most common situation), its huge underground biomass with high C:N ratio takes a long time to decompose and sequesters a lot of soil N in the process. Also, this underground biomass holds together soil aggregates; this effect, together with surface compaction due to grazing, results in poor soil tilth.

Figure 4 shows that the yield trends in the first cropping cycle of the rotations were reversed in the second cycle. Despite the fact that the second cycle reflects the effect of less bermudagrass, one reason for this is that during the first cropping cycle, results indicated the need of enough fallow time between the first and heaviest glyphosate application to the pasture and the crop planting, especially when an old pasture with bermudagrass is treated. If the herbicide treatment is to be effective, an important chemical fallow time is needed for the decomposition of the underground biomass, in order to free fixed soil N and to have soil aggregates separate, resulting in good soil physical condition.

Ernst (2000) reported no differences between wheat yields in the following contrasts in an experiment: 1) no-till in crops-pastures vs. continuous cropping, 2) corn vs. soybean (*Glycine max* (L.) Merr.) as previous crop, 3) no-till vs. conventional tillage, averaged over continuous cropping and crops-pastures. But when the contrast was between long or short chemical fallow of herbicide-treated old pastures (treatment on March 10 vs. April 23), the yield of no-till wheat planted on June 15 was significantly higher in the long fallow period (2779 vs. 1334 lbs per acre). Terra and Garcìa Préchac (2001) reported that, after perennial pastures, soil NO_3-N content in the upper 6 inches of soil at oat (*Avena sativa* L.) planting, was significantly higher in no-till plots with 70 days of chemical fallow (35 ppm) compared with no-till plots with 15 days of chemical fallow (10 ppm), and did not differ with tilled plots (33 ppm) with the same fallow time.

One common compaction problem in soils under conventional tillage is the presence of plowpans. The transition to no-till inherits this problem. The problem is eventually eliminated with time because root growth into the compacted layer generates channels, deposits organic matter, and attracts biological activity. Experimentally, the use of the paraplow has been very effective in alleviating soil compaction for no-till planting (Martino, 2001). This researcher found positive response in 11 out of 14 experiments conducted, with crop yield increases of 102, 36, 29, and 14% in corn, sunflower, barley, and wheat, respectively.

When no-till technology began, information in the literature indicated that N fertilizer application with no-till would be more than with conventional tillage, because of lower N mineralization and higher losses in no-till. A long-term experiment was started in 1995 on a pasture very close to natural conditions, but with some bermudagrass infestation (Terra and García Préchac, 2001). The experiment compared no-till with reduced till and conventional tillage, keeping the same treatments in the same plots for 5 years, planting forage crops in an annual double cropping system for direct grazing or total harvesting (hay or silage). The results did not show significant production differences

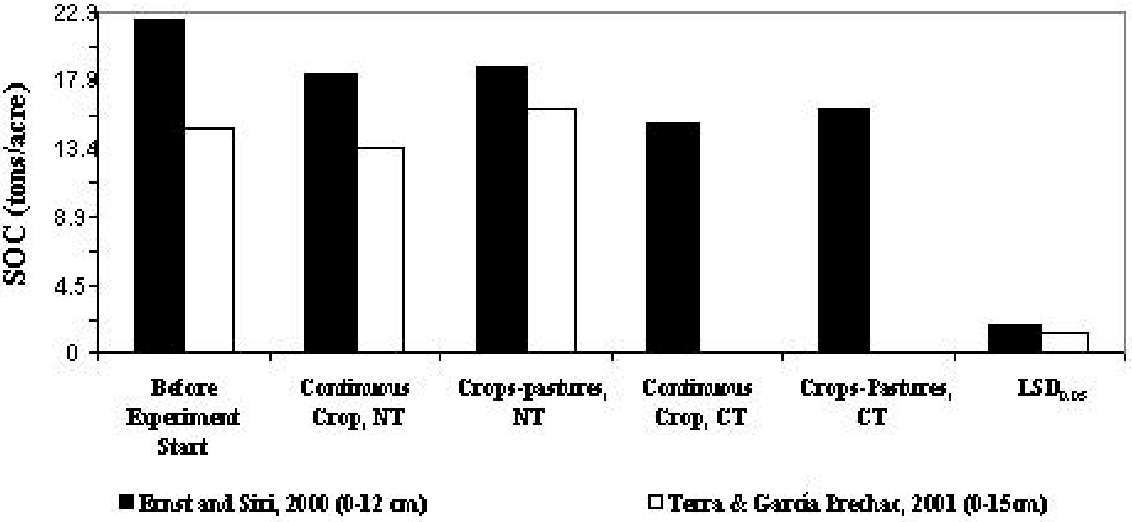

Fig. 5. Soil organic carbon (SOC) content of two experiments after one cycle of crops-pastures rotation vs. continuous cropping; in one case comparing no-tillage (NT) vs. conventional tillage (CT), and in both cases comparing to values before experiments started.

between tillage treatments or significant interaction between the tillage treatments and four rates of fertilizer N. Soil NO_3-N evolution during this period showed that the main factor generating variation was climate, with low levels during wet periods and higher levels during dry periods.

Soil Compaction

Soil compaction has been a matter of concern as it relates to no-till technology. A history of tillage use has created the impression that the only way to deal with soil compaction is tillage. Nevertheless, scientific information indicates that the main cause of soil compaction (among other consequences of soil degradation), in the medium and long term, is tillage. For example, as the crops cycle of the crops-pastures rotation advances, with more crops and tillage operations, the state of the physical properties is progressively deteriorated (García Préchac, 1992a). Conversely, as the soil is not tilled and it recovers soil organic matter content, the expectation is to have better soil structure.

If no-till is compared with conventional tillage in the short term, the soil close to the surface is more compacted under no-till (Terra and García Préchac, 2001). But at the bottom of the tilled layer, soil compaction is greater in the tilled treatments. In terms of traffic from animal grazing, and therefore, for forage utilization, this situation favors no-till. The authors report that the forage was between 10% and 30% better used by animals in no-till, compared with conventional tillage, depending on the winter soil water excess. Tillage treatments were equally grazed during winter, and the ground was prepared for no-till planting of a summer crop late in the spring. However, the results of the summer crop (grain sorghum (*Sorghum bicolor* (L.) Moench) did not show significant differences.

Two years of no-till experiments comparing the effects of different sheep stocking rates as applied to the winter forage crops, on the production of the following summer crops (sorghum and foxtail millet (*Setaria italica* L.)) did not show significantly different production, despite the differences in soil strength that were found after the winter grazing period (Terra and García Préchac, 2001).

Summarizing the results it can be said: 1) no-till planted winter forage crops can be better utilized by animals than conventional planted ones; 2) if soil is tilled for the winter forage crops, the winter grazing eliminates the effects and the following no-till summer crops are not benefited; 3) with the range of winter grazing pressures used in these experiments, no differential effects were found on the performance of the summer crops that followed.

Soil Quality

Soil organic carbon content is well known as the main soil quality indicator (Reeves, 1997). Figure 5 presents the results of two experiments. The one by Ernst and Siri (2000) started in 1993 on a very fertile Argiudol with a previous long history of use under crops-pastures rotation with conventional tillage. The SOC content of this soil at the beginning was around 12% below its content under natural pasture. The crops were harvested for grain, leaving the residues on the surface (no-till) or buried by plowing (conventional till). The experiment by Terra and García

Préchac (2001), started in 1995 on an Argiudol of low fertility, with SOC similar to the same soil under natural pastures due to insignificant crop history of 5 years in the 1980s and long-term pasture after that. The crops were directly grazed [oat-annual ryegrass (*Lolium multiflorum* Lam.) mixture] or harvested for hay (foxtail millet) or silage (corn, grain sorghum); thus, the biomass return is much lower than in the first experiment.

Results in the Ernst and Siri (2000) experiment show that under no-till the SOC remained close to the original value, while with conventional till, continuous cropping lost 20% and crops-pastures 14% of the original value; the difference between the last two systems, the expected one, was not significant. Thus, the conclusion after 7 years is that with no-till, independent of rotation with pastures, the original SOC content is maintained. It should be pointed out that the crops-pastures rotation in this case is 3 years of crops and 3 years of pastures. In the Terra and García Préchac (2001) experiment, after 4 years, continuous cropping with no-till lowered the original SOC content 7.5%, while crops-pastures rotation with no-till had 6% more SOC than the original content (more details in Terra and García Préchac, 2002).

SUSTAINABILITY

Sustainability of agricultural production systems depends on control of soil erosion and the level of soil organic carbon. We conclude that crops-pastures rotation with no-till are sustainable soil use and management systems under the Uruguayan ecological and productive conditions, even when most of the aerial biomass production is harvested and exported by direct grazing or as hay or silage. When crops are harvested only for grain and residue is left *in situ*, despite some soil erosion (about half of the soil loss tolerance of 3.5 tons $acre^{-1} yr^{-1}$), SOC indicates that continuous cropping with no-tillage could be possible. Consideration should be given to other benefits of the crops-pastures rotation, such as a more diversified system, with more buffer power against climatic and economic inter annual variations. Also, the use of agrochemicals and their potential environmental impact can be greatly reduced, as the crops-pastures rotation uses them only during the crops cycle, this is half the time, as compared with continuous cropping.

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INFLUENCE OF GRAZING TIME AND HERBICIDE KILL TIME ON GRAIN YIELD OF SORGHUM IN A NO-TILL SYSTEM

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ABSTRACT

We evaluated the effect of length of fallow period after application of glyphosate herbicide to kill oats (*Avena sativa* L.) planted for grazing. We also evaluated grazing management practices on the subsequent emergence, growth and yield of grain sorghum (*Sorghum bicolor* (L.) Moench) planted for grain in a no-till system. Grazing increased soil resistance to penetration in the top 2 inches by 9% and increased availability of NO_3-N in the top 8 inches of soil significantly as the length of fallow period increased. The number of grain sorghum plants and their growth were reduced significantly when the fallow period was less than 20 days or greater than 40 days. When the fallow period was only 19 days, the NO_3-N concentration and grain sorghum stand was affected by the amount of oats stubble present. Grain yield was related to the number of plants that survived.

KEYWORDS

Soil compaction, oat winter pastures, fallow duration.

INTRODUCTION

The utilization of winter crops followed by the planting of summer crops is a common practice in agricultural and livestock production systems in Uruguay. The effect of grazing on the subsequent crop was studied by Devoto and Gonzáles (1999), who found that resistance to soil penetration in the top 2 inches increased significantly from 0.99 to 1.5 Mpa when the sheep stocking rate was increased from 24 to 73 lambs acre^{-1}. Díaz-Zorita *et al.* (2002) reported similar changes for sites used for grazing either with or without tillage.

When summer crops are established without tillage operations, it is common to have planting problems, which lead to reductions from 20% to 50% in grain production (Martino, 1994; Martino, 1998) and are associated with reduced plant survival and rate of crop growth. The biggest problems have been encountered in corn (*Zea mays* L.) and sunflower (*Helianthus annuus* L.), followed by grain sorghum and soybean (*Glycine max* (L.) Merr.) (Scarlato *et al.*, 2001).

The problems in the planting and growth of crops planted immediately after the harvest of another crop have been attributed to the presence of phytotoxic compounds liberated by the previous crop or generated during the decomposition of roots and stubble on the surface. Phytotoxic compounds are liberated directly with rainfall leaching of the residue, or indirectly as products and subproducts of microbial activity during the decomposition of the stubble. Phytotoxic potential lessens as the crop residues age, according to Martín *et al.* (1990).

The residues of oats, rye (*Secale cereale* (L.) , Swedish turnip (*Brassica na*pus L. var. napobrassica (L.) Rchb.) and colza (*Brassica napus* L. var. Napus) reduced the later growth of weeds for prolonged periods of time (Almeida *et al.*, 1985; cited by Floss, 2000). With oat residues, the soil remained free from grass and broadleaf weeds for 85 days. Kimber (1973) and Raimbault *et al.* (1991) found that the phytotoxic compounds produced by the residues of alfalfa (*Medicago sativa* L.), peas (*Pisum arvense* L.), oats, perennial ryegrass (*Lolium perenne* L.) and wheat (*Triticum aestivum* L.) occurred mainly in the first stages of decomposition. Acetic, propionic, and butyric acid, frequently associated with allelopathy, which occurs during the decomposition of wheat straw, increased gradually for 12 days and then declined (Tang and Waiss, 1978). The oat biomass showed allelopathic control on a number of plants, establishing an inhibiting effect directly or indirectly on plants and also on microorganisms (Floss, 2000). Roth *et al.* (2000) attributed the lower yield of wheat after grain sorghum to the presence of phototoxins. The negative effects were eliminated with tillage and with sorghum-fallow-wheat rotation. In both cases, the phytotoxic effect would be lessened by increasing the rate or time of decomposition. Evaluating leguminous plants and with rye as cover crops, Ross *et al.* (2001) quantified the phytotoxic

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effects on the number and growth of weeds during the subsequent fallow period. The effect was greater and more prolonged in low fertility soils.

Ernst *et al.* (2001) succeeded in improving the emergence and survival of crops planted without tillage in old pastures by lengthening the period between herbicide application and planting of the next crop. These authors found a greater content of water and NO_3-N in the soil and less resistance to penetration at the time of planting the summer crop when this fallow period exceeded 45 days. This resulted in a significant improvement in emergence and initial growth. The authors attributed these results to the reduced loss of water from the soil by transpiration and to the termination of the decomposition of roots and above ground residues, permitting the accumulation of nutrients and the reduction of phytotoxic compounds produced by the previous crop or during the period of decomposition.

The object of this study was to evaluate the effect of the date of herbicide application and the date of the end of grazing of oats on the planting, growth, and yield of grain sorghum in a sequence of oats-sorghum without tillage.

MATERIALS AND METHODS

The experiment was conducted in Uruguay (32 °S, 56 °W) on typical Brunosol Eutrico soil with 2.4% organic C and 15 ppm of phosphorus (Bray I) in the top 8 inches of soil. Rainfall between May and September was 93% higher than the historical average, with 27 inches falling during this period. The experimental area was planted with a sequence of crops without tillage beginning in 1997. On 8 March 2000, oats were planted; the grazing treatments imposed are shown in Table 1. After grazing, 29, 16 and 41 lbs acre^{-1}, of N was added as urea to the oats cover crop in treatments 1, 3, and 4, respectively.

Table 1. Grazing date, grazing duration, and animal weight during each grazing period. Young bulls with an average weight of 880 lbs were used.

No.	Date	Duration	Animal weight Daily	 Total
		- days -	lbs acre^{-1} day^{-1}	lbs acre^{-1}
1	5/11	7	2141	14987
2	6/29	3	2890	8670
3	7/21	5	2105	10525
4	8/19	6	1998	11988

On 28 August, five grazing treatments were imposed to the oats, which are shown in Table 2. On 29 September, after 34 days of the growth of the oats, treatment I employed grazing with 1492 lbs acre^{-1} of live-weight for 6 days (8952 lbs acre^{-1} in total). Grain sorghum (Pioneer 8586 hybrid) was planted on 21 November using a John Deere 750 direct planter. The distance between rows was 15 inches. The grain sorghum was harvested on 4 April, 2001

The quantity of oats dry matter at the time the glyphosate herbicide was applied was determined (Mannetje, 1978). Before the planting of the grain sorghum crop, soil penetrometer resistance was measured at two depths (0-2 inch and 2-4 inch), taking 30 random measurements per plot. The NO_3-N concentration and water content was measured at planting and at the V6 stage of grain sorghum, on 0-8 inch soil samples (28 Dec, 2000). The number of seedlings surviving 15 days after planting in 60 ft of row per plot (3 furrows of 20 ft) was counted. On 28 December, 30 plants per plot were taken at random and dry weight, height (inches), state of development using the Haun scale, and N concentration (Kjeldhal) were measured. At harvest, the number of ears meter^{-2}, the weight of a thousand grains, and the grain yield were quantified.

Table 2. Description of treatments.

	Treatment no. I	 II	 III	 IV	 V
Date of last grazing	9/29	8/24	8/24	8/24	8/24
Days of oats growth before grazing	34	-	-	-	-
Days between last grazing and application of glyphosate	35	29	35	53	69
Date of glyphosate application	11/2	9/22	9/28	10/17	11/2
Days between herbicide application and sorghum-planting	19	59	53	35	19

Table 3. Rainfall (inches) between 24 August, 2000 and the blooming of grain sorghum.

	Treatment no.				
	I	II	III	IV	V
Until glyphosate application	9.7	4.4	4.4	6.7	9.7
Glyphosate application-seeding	1.0	6.3	6.3	3.9	1.0
10 days before seeding	1.0	1.0	1.0	1.0	1.0
10 days after seeding	2.6	2.6	2.6	2.6	2.6

The experiment design used was a completely randomized design with three replications. The size of the plot was 5382 ft. The results were analyzed using the GLM procedure of the Statistical Analysis Systems (SAS, 1996). Separation of measurements was done using the $LSD_{0.05}$.

RESULTS AND DISCUSSION

Table 3 shows the rainfall that occurred in different phases of the experimental period. Rainfall distribution ensured that water in the soil profile in all the treatments was recharged. The rainfall measured 10 days prior and 10 days after planting totaled 3.5 inches, so rainfall cannot be considered a limiting factor for planting conditions. During the growing season, rainfall exceeded crop demand.

Oats pasture

There was a significant relationship between the days of fallow and the concentration of NO_3-N in the first 8 inches of the soil profile (Fig. 1).

When the period of oats growth was increased from 29 to 69 days (treatments II to V), the herbicide application was made on an increasing quantity of oats dry matter, and consequently the residue went from 1026 to 4558 lbs acre^{-1} with a lower initial N concentration (2.4 and 1.4% of oats dry matter, respectively). In treatment I, on 29 September there was additional grazing, and 1277 lbs acre^{-1} of oats dry matter was consumed. The oats growth period of 47 days produced a similar quantity of residue than treatment IV (1606 and 2105 lbs acre^{-1}, respectively), but with 3.6% N concentration so that its lower concentration of NO_3-N at

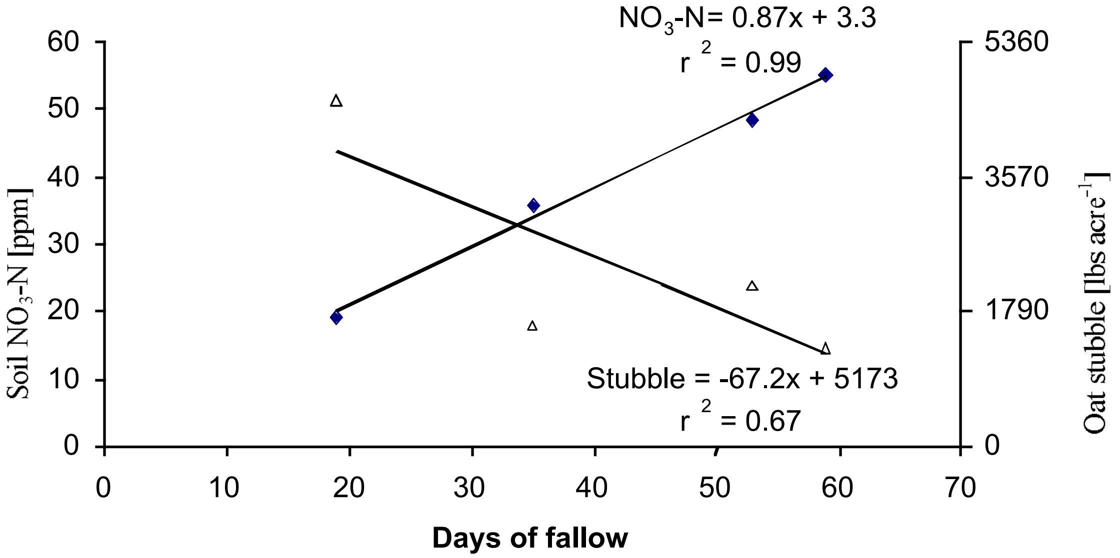

Fig.1. Effect of days of fallow on the quantity of oats stubble and NO3-N concentration in the soil profile at grain sorghum planting (treatments II, III, IV and V, only).

Table 4. Soil moisture (0 – 8 inches) and penetrometer soil resistance at time of grain sorghum planting.

	Treatment no.					
	I	II	III	IV	V	Avg
Soil moisture, %	21.1 a	23.0 a	23.1 a	22.0 a	22.1 a	22.2
Penetration resistance, kg cm^{-2}						
0 - 2 inches	2.27 a[†]	2.06 b	2.05 b	1.93 b	2.08 b	2.08 A[‡]
2 – 4 inches	2.09 a	1.88 b	1.83 b	1.78 b	1.92 b	1.90 B

[†] Treatment means followed by the same lower case letter are not significantly different based on LSD$_{0.05}$.

[‡] Overall depth means were different based on LSD$_{0.05}$

planting would be explained by the shorter fallow period. Comparing treatments I and V with the same fallow time (19 days), the differences in NO$_3$-N at planting would be the result of the different quantities of oats stubble and concentrations of N. The results agree with those reported by Ernst (2000), Alvarez *et al.* (2001), and Ernst *et al.* (2001), who defined a minimum fallow time of 40 to 50 days to permit the decomposition of above ground residues and to accumulate N and water in the soil. In this case, treatments did not show significant differences in the soil moisture by rainfall occurring between 24 August and 21 November.

There were significant differences in resistance to soil penetration between the two depths that were evaluated (Table 4).

Resistance to penetration was 9% greater in the top inch of the soil profile, independent of the treatments (average 2.08 *vs.* 1.90 kg cm^{-2}) (Table 4). This profile of resistance to soil penetration is similar to that found by other authors following grazing. Treatment I significantly increased resistance to soil penetration at both depths that were evaluated. Given that there were no differences in soil moisture, differences must be attributed

Table 5. Number of grain sorghum plants 15 days after planting, availability of NO$_3$-N, plant dry matter, plant height, nitrogen content, N amount per plant, plant dry matter per acre and N uptake of grain sorghum at V6.

	Treatment no.				
Response variable	I	II	III	IV	V
Stand, plants ft^{-2}	172 b[†]	211 ab	216 a	174 b	128 c
Measurements taken at V6					
Soil NO$_3$-N (ppm)	4.4	6.1	6.2	6.9	4.8
Plant dry matter, g	6.9 a	9.7 a	10.1 a	6.4 a	3.6 b
Plant height, inches	21.5 a	25.2 a	24.9 a	22.0 a	16.5 b
N plant, %	2.6 b	3.3 a	3.2 a	3.0 a	3.2 a
N-amount, g plant^{-1}	0.18 b	0.32 a	0.32 a	0.19 b	0.12 c
Plant dry matter, lbs acre^{-1}	976 b	1707 a	1772 a	960 b	385 c
N uptake, lbs acre^{-1}	25.4 b	56.3 a	56.7 a	28.8 b	12.3 c

[†] Means within a row followed by the same letter are not significantly different based on LSD$_{0.05}$.

Table 6. Treatment effects on sorghum grain yield and yield components.

	Treatment no.				
	I	II	III	IV	V
Ears plants^{-1}	1.0 a	0.85 b	0.75 b	0.94 a	0.92 a
Ears yard^{-2}	19 a	20 a	18 a	18 a	13 b
Weight 1000 grains (oz)	0.74 ab	0.68 b	0.68 b	0.70 b	0.78 a
Grain yield, lbs acre^{-1}	4666 a	4746 a	4646 a	4571 a	3792 b

† Means within a row followed by the same letter are not significantly different based on LSD$_{0.05}$.

to the affect of additional 47 days of growth following grazing before planting. Although the effect of direct grazing has been recorded at greater depths than those evaluated in this study (Touchton *et al.*, 1989), the greatest effect occurred in the top depth of the soil profile.

GRAIN SORGHUM

Treatments II and III produced the same number of plants yard^{-2}, exceeding I and IV by 16% and V by 57% (Table 5).

At the V6 stage, grain sorghum crops had less growth per plant and per unit of surface in the treatment with longer growth time for oats and less time between the application of the herbicide and grain sorghum planting (treatment V). The effect on the grain sorghum dry matter production and N uptake was similar. On the other hand, treatment I, which showed the greatest soil penetrometer resistance in the top four inches of soil was intermediate, producing 34% more plants than treatment V, but 25% less than the best treatments (II and III). Unlike treatment V, it did not negatively affect individual growth or N uptake. Treatments I and IV did not differ from each other. The results showed a negative effect from a greater quantity of oats stubble combined with reduced fallow time on the planting and initial growth of grain sorghum. Given that moisture at planting and the rains that occurred during the ten days afterwards cannot be considered as limits for the planting process, and that the concentration of NO$_3$-N, although lower, was not below the critical level, the effects must be attributed to other factors, including the presence of phytotoxicity. As is mentioned by Tang and Waiss (1978) and Floss (2000), the negative effects on the planting and growth of crops planted immediately after the death or the harvest of oats lessen with decomposition time and are directly related to the quantity of stubble that is present. On the other hand, in the treatment with five days of oats grazing (V), while there was increased soil penetrometer resistance compared to all the other treatments, which received four days of grazing, grain sorghum behaved similar to the treatment that left a similar quantity of oats stubble (IV). The only quantitative difference between these two systems was the concentration of NO$_3$-N in the top eight inches of soil at the time the grain sorghum panting, which might be explained by the reduced fallow period (19 days *vs*. 35 days, respectively).

The only treatment that negatively affected the yield of grain sorghum was number V (Table 6). Treatments I and IV succeeded in compensating for the lower number of initial plants with a greater number of ears per plant and greater grain weight. An excessive quantity of oats stubble combined with reduced fallow time negatively affected the planting, growth, and yield of the grain sorghum (V). While additional grazing (treatment I) reduced the number of plants meter^{-2}, it did not affect growth, which under conditions of high water availability allowed for problems with planting to be compensated. Under normal moisture conditions in which the possibilities of compensating for the lack of plants are less, treatments II and III with 50 to 60 days of fallow would permit the accumulation of water and N and optimize the planting process and the subsequent growth of the grain sorghum.

CONCLUSIONS

There was a negative relationship between days of fallow period and soil NO$_3$-N concentration in the top 8 inches of the soil. When the fallow period was only 19 days, NO$_3$-N concentration was reduced by increasing oat stubble. Grazing increased soil penetrometer resistance in the top 2 inches of soil, especially when grazing was close to grain sorghum planting. The emergence and initial grain sorghum growth was reduced by large amounts of oats stubble and a shorter fallow period. With this management, the grain yield was 816 lbs acre^{-1} less than with a fallow period of 35 to 50 days.

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PERENNIAL FORAGE IN ROTATION WITH ROW CROPS IN THE SOUTHEAST

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ABSTRACT

The Southeast U. S. farming community has been a region in transition for the last 15 years and has seen a continuous cycle of crops with the highest potential return. Low crop prices, yields, and uncertain weather led growers to change from a wheat/ soybean and corn system to cotton to rotate with peanuts. This required the development of an entire infrastructure system to support cotton along with specialized harvesting equipment. During this transition period, many growers went out of business or much of the farm land was planted to trees for long term investments as jobs were secured off farm. The challenges to agriculture today is to cut production costs while increasing yield to bring profit back to the farm since crop prices for most commodities have fallen by 25% or more during the last 15 years. Good management is required to produce better yields. Research during the last half of the 20th century shows the value of rotating cash crops with sod. By starting out farming with a high proportion of the farm in sod, less initial capitalization is required for small tractors and tillage equipment and yield of crops grown behind sod is often 50% or higher than continuously grown row crops. Research from Auburn, Florida and Georgia has shown the impacts of bahiagrass on pests, water infiltration, rooting depth, and subsequent yield of crops grown after bahiagrass. The main objection from growers is that it can't work in their farming operations. A recently developed business model by the University of Florida shows that it is easily adapted to southern farms with or without livestock and becomes more profitable each year with total profits being 3 or 4 times higher after the system is fully implemented in the 4th year.

KEYWORDS

Sod, perennial pasture, conservation tillage, rotation, soil health.

HISTORY

The Southeast is one of the most diverse crop production areas in the U.S. All of the major crops as well as pasture grasses can be grown, with lower average yields for corn and soybean than in the Midwest while wheat yields are near the national average. Cotton and peanut are traditional row crops for the area and competition comes from other Southern areas or over seas. The fertile soils of the mid west were in native grasses that built up organic matter and improved soil structure for many years prior to plowing and cropping corn and soybean. The Southeast, by contrast, had native forest and small areas that had been cleared by Indians where some grass encroached. As these small patches of bluestem and switch grass were not large enough for many animals, they were soon overgrazed and replaced with broomsedge and other less desirable grasses. Other parts of the U.S. developed livestock production from grasses and legumes introduced from Europe to supply needs of cities in the Northeast and for export. Agriculture in the South was primarily cotton and tobacco with limited livestock production to supply local needs. Soils of the Southeast are generally infertile as compared to much of the U.S. and continuous row cropping further degraded these soils. Improved pastures and beef and dairy production did not begin in the South until the 1930's and 40's, when Dr. Glen Burton and others began breeding and releasing new grass varieties.

The Southeast typically has an average annual rainfall of 48-65 inches per year. Most row crops require about 25 inches of rain or irrigation to produce high yields. However, crops yields are limited each year by periods of insufficient rain for optimum crop growth and yield. It has been reported that Florida has more available groundwater than any other state in the nation, yet crop yields are reduced substantially almost every year from lack of moisture. During the last three years of drought, many counties in high population areas instituted water rationing to prevent the water table from dropping lower and contaminating fresh water with salt water intrusion. Can anything be done to overcome the effects of droughts on crops except to irrigate? It is known that rotation with perennial sod crops will increase organic matter content, water infiltration, improve soil structure, and decrease erosion to a much

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higher level than any of the winter annual cover crops which have been shown to be better than summer annuals. Winter annual cover crops do very little to enhance soil quality because of their short duration and fast degradation. Much of the research data in the 20th century looked at these cover crops as green manure crops that were turned under for nitrogen benefit or nematode suppression. Recent advances with herbicide tolerant crops have allowed crops to be planted directly into the standing cover crops. These winter cover crops seem to be better erosion control inhibitors than for increasing soil health. Perennial grasses in all regions of the U.S. and in other countries have been shown to have a major impact on yield (Rogers and Giddens, 1957). This has also been the testimony from growers in the South who plant after bahiagrass and pay a premium for land coming out of perennial grass sods. Do sod crops make enough difference on following crops to over come drought effects and make this systems approach profitable? There is little current research in literature to show the benefits of a sod based rotation, but available data show that individual crops yields can be increased 50-100%. Many peanut producers use irrigation, but it has often been noted that non-irrigated peanuts after bahiagrass are higher yielding than irrigated peanuts even in drought years. Why have we not developed a cropping system that incorporates the advantages of bahiagrass in a system that equals yields of irrigated crops? I believe that there are many answers to that question, but the main one is that the system has never been put together by researchers to show growers that a sod based system can be used successfully with less risk and higher returns. Since best soil quality is obtained after permanent grass crops, best crop yields are obtained immediately behind these grass sod crops because they are taking advantage of the soil characteristics improved by the sod. Cooper and Morris, 1973, put it in context when they described a wheat- sod based rotation by saying that the primary function of sod is to put “heart back into the land”. Cash crops get the first consideration on farms while the output from animals or hay produced from the sod crop is a by product of sound row cropping. Sod crops cannot be justified solely for their contributions to the following row crops, but they must be considered as they have a much lower cost structure and risk factor than do row crops. Row crops alone carry a much higher cost structure from equipment and yearly input costs than do pastures and require bigger equipment if all acreage is devoted to row crops with none being in sod. Therefore, if sod is a part of a farming operation, it must make a contribution for hay, grazing or in another manner to help pay expenses as land value and crop inputs continue to increase.. Virginia research showed that winter annual cover crops did not contribute to improved water holding capacity while perennial grasses did. Mid west data (Bartholomew, 1957) showed that sod crops were the most effective at maintaining organic matter content of any crop. Many years of research in Europe and long term studies of over 100 years at the Morrow plots in Illinois and the MacGruder plots in Oklahoma have shown that the best soil quality is after many years of perennial grass sod and that soil quality and fertility degrade over many years in continuous crops organic matter leveling out after 70-80 years of degradation, and crop yields being mained by increased inputs. Organic matter content of many of these soils are around 4% when initially taken out of sod crops and degrade to around 1-1.5% at which level a crop rotation of corn- soybean or wheat can maintain (Boman, et. al, 1996). However, these crops cannot increase organic matter content above 1-1.5%.

Legume crops result in temporary increases in soil N but degrade more rapidly than grass crops and in the long term contribute less to soil health than do perennial grasses

Green manure cover crops or those grown for strip tilling into have little influence on soil organic matter but can play a significant role in moderating soil temperature and reducing evaporation and soil erosion, thereby helping to maintain soil quality. Where cover crops are incorporated into the soil, degradation is enhanced and little benefit is derived in the South. Even forest soils lose their supply of organic matter rapidly when cultivated.

At least a century of data shows that soil health is improved by having a sod based cropping system and that following crop yields are improved enough to make this system a must for those desiring to stay in row crop production. A recent economic model using today prices with support from the farm bill shows the profitability of getting back to where we were in a farming system in the last century. So the question that needs to be asked is how we can afford not to look at this sod based system for row crops in the South. The rotation which we propose can be started without diminishing farm profits, and profits at the end of year 4, when the system is fully implemented, can be double or triple those of conventional cropping systems. We have all components of a good farming system with conservation tillage to reduce erosion, fuel use and labor, herbicide resistant crops to make farming more consistent and less expensive and time consuming and sod based rotations to increase yield. This system approach allows for any number of crops and will have to be considered to remain viable in the future as we compete in global markets and under adverse weather conditions. Tri-state work is underway to document and verify that this system can make a significant impact on the farm economy.

IMPACT

Perhaps the most important aspect of the sod based system is improving yield while improving soil health (Reeves, 1997). Much of the farmland in the Southeast suffers from a hardpan layer starting at 6-8 inches depth and continuing to 14 inches (Kashirad, *et al.*, 1967; Campbell, *et al.*, 1974). This has a dramatic effect on crop management. Even with irrigation, it is very difficult to effectively manage water stress because the hard pan prevents deep penetration of the water and plant roots. Under these conditions water has to be applied frequently, increasing labor and equipment costs and decreasing water use efficiency. Elkins *et al.* (1977) calculated that given an evapotranspiration rate of 1/3 inch of water per day, available water of 1 inch per foot of soil, and plant rooting depth of 6 inches, plants will experience water stress after only 3 days without rainfall. However, if the rooting depth was 5 feet, the plant would not experience water stress until 30 days after rainfall (Table 1). This table may actually underestimate the value of the deeper rooting systems because many soils in the Southeast have increased water holding capacities at deeper depths.

Using weather data from Ward *et al.*(1959), Elkins *et al.* (1977) determined that for the average Coastal Plain Soil - (for the most part a coarse-textured sandy soil with low water holding capacity), a crop with a rooting depth of 30 cm will experience 60 drought days during May through August in 5 out of 10 years. However, if rooting depth were 5 feet deep, the crop would experience only 11 drought days.

Table 1. Days without plant water stress following rainfall for different rooting depths.. The available water was 1 inch per 12 inches of soil, and the evapotranspiration 0.33 inch day^{-1} (after Elkins *et al.*, 1977)

Rooting depth	Days without water stress
---- inch ---	-------- d -------
6	3
9	5
12	6
24	12
36	18
48	24
60	30

Water extraction is not the only factor dramatically affected by rooting depth. Nutrient extraction is also greatly enhanced when rooting depths are increased. This not only increases the use efficiency of fertilizers applied, but also decreases the potential for contamination of groundwater with nitrates and other farm chemicals. Long *et al*, 1983 found that cotton following 3 years of continuous Bahiagrass sod rooted more deeply than that planted in continuous cotton, allowing the cotton in the bahiagrass-cotton rotation to extract water and nutrients from lower soil depths. This resulted in a reduced amount of N, K, and Ca in the soil solution at the lower depths and an increase in K and Ca in the cotton plants. They reported a 33% increase in yield of seed cotton (1420 lbs acre^{-1} vs. 1900) in the cotton plots that followed 3 years of Bahiagrass. There was a continued trend toward higher yields after 5 years of Bahiagrass sod, but this was not statistically significant. They also found that the cotton following Bahiagrass sod had an increase in the number of roots at 24 inches depth. In the continuous cotton, there was an average of 0.5 roots per 10 in^2, whereas in the cotton following sod they reported 20 roots per 10 in^2.

Increases in water and nutrient extraction and deep root growth in crops following Bahiagrass sod is attributed to the effect that the deep penetrating roots of the grass have on soil structure, especially soil pore size. Again, Long *et al.* (1983) found a seven fold increase in pore sizes greater than 1.0 mm in the dense soil layer below the plow depth. They concluded that the dense soil layer had been penetrated by the bahiagrass roots and that, after the decay of the roots, pores were left that were large enough for the cotton roots to grow through. They also reported an increase in water and nutrient extraction at greater soil depths. Especially significant, in considering the potential for nitrate leaching, is the fact that they found that NO_3-N in the soil solution at 67 inches depth was only 10 ppm in plots following Bahiagrass, but 40 ppm in plots under continuous cotton (100 lbs. N ha^{-1} was applied to the crop).

We expect that the need for irrigation will be reduced several ways. First, bahiagrass will not need as much irrigation as the row crops (10 vs. 20 inches), and half of the land will be in bahiagrass. Second, the increased water infiltration will reduce the need for irrigation in row crops. Finally, the increased root depth and density will make the row crops more efficient at extracting deeper water. There is extensive literature on the potential benefits of bahiagrass sod for controlling nematodes. Norden *et al.* (1977) reported that the greatest change in reducing nematodes was realized after only one year of Bahiagrass sod, and although peanut yields and quality increased with increasing years in sod (up to 7 years), the greatest increase in yield was after only one year. Dickson and Hewlett (1989) reported in Florida that population levels of the nematode *Meloidogyne arenaria* were reduced during the early part of the growing season, but returned to high levels in peanuts following one year of bahiagrass. Still, they reported a yield increase of 6.6 fold in peanuts following bahiagrass (1,691 lbs. acre^{-1} vs. 737) with no nematocides applied, and a 9.7 fold increase (2,479 lbs. acre^{-1}) in yield in peanuts following Bahiagrass and also treated with 1,3-dichloropropene. Rodriguez-Kabana *et al.* (1988), reported that *M. arenaria* populations remained low during the entire growing season in Alabama, reducing populations by 41% in peanuts following only one year of bahiagrass as compared to plots in continuous peanuts. They also reported an increase in peanut yield of 27% in plots following one year of Bahiagrass. After 2 years of bahiagrass, Rodriguez-Kabana *et al.* (1991) found that *M. arenaria* populations were reduced to non-detectable levels and recorded an increase in soybean yields of 114%.

By rotation with row crops, there is the opportunity to control weeds that may have invaded the pasture and replant new or different varieties of grass.

CONSERVATION TILLAGE

The value of conservation tillage is nearly as important to a sustainable cropping system as is the value of rotation (Reeves, 1994; 1997). In recent years the development of precision planters, subsoilers, and varieties resistant to herbicides has allowed for widespread adaptation of conservation tillage practices. Although no-till practices are being used in many cropping systems, strip till is compatible with cotton and peanut production (Pudelko *et al.* 1997; Pudelko *et al.* 1995) and has been proven over a wide area by growers. At this time our experience with no-till is that seed placement (both spacing and depth) with peanut and cotton, even with the most advanced planters, is still difficult at best

Most of the information on water usage by cover crops is from studies of winter cover crops. Usually there is a significant increase in water efficiency. For example, Lascano *et al.* (1994) reported from Texas that the increased evapotranspiration efficiency in cotton after winter wheat resulted in a 35% increase in lint yield with a reduction in soil water evaporation 40% less in wheat residues than in bare soil. Field water balance studies by Baumhardt *et al.* (1993) related increased soil water content due to increased residue cover from a winter wheat crop to increased rain infiltration. However, cover crops and sod crops must be managed effectively to realize the full benefits of the practice. An important aspect in winter cover crops is to kill the crop early enough and efficiently enough so that it does not compete with water needed for starting the new crop. For example, Baumhardt and Lascano (1999) did not recommend their terminated wheat-cotton system for the Texas South Plans because of the lack of water available for the cotton crop. If the cover crop is not killed, there may be continued competition for water and/or nutrients (Pedrosa De Azevedo *et al.*, 1999). This also can occur when converting from sod to row crop if it is not killed effectively (Wilson and Okigbo, 1982).

PLANT PESTS

Early and late peanut leaf spot alone account for over $70 acre^{-1} or more of inputs in fungicides. Boll rot in cotton has been identified as a major yield limiting factor, most likely due to high N rates accompanied by high humidity and temperature.

The impact of conservation tillage and rotation practices on plant disease is extremely complex and often very site dependent. Often times, below ground and above ground diseases are affected (Bailey, 1996; Ward *et al.*, 1997). There is also clear evidence that tillage practices affect other control measures, including biological (Kim *et al.*, 1997) and chemical (Wheeler *et al.*, 1997). Several observations indicate that there will be a significant shift in the quality and quantity of the epidemics in each of the crops/cropping systems, however crop rotation may help to ameliorate the potential increase in disease pressure due to the increased survival of pathogens on surface debris (Bockus and Shroyer, 1998). Double row peanuts has been reported to help reduce the negative impact of tomato spotted wilt virus, but can also increase the severity of pod rot pathogens and sclerotinia blight (Hollowell *et al.*, 1998; Butzler *et al.*, 1998). While there have been numerous studies on the impacts of crop rotation and minimum tillage on plant pathosystems, there are still many gaps in our knowledge of how these practices will impact row crop production in the southeastern U.S. For example, the use of minimum till practices was originally thought to possibly increase disease pressure, however experience has shown that some diseases in peanuts are actually reduced (Wiatrak *et al.*, 2000).

A similar situation exists with weeds. Although specific weeds may be better controlled with the integration of herbicide resistant crops, in the longer term the weed populations may shift to other weed species, which could be more or less detrimental than the ones they replaced. Rotation with sod will help ameliorate this (Patterson *et al.*, 1996; Reeves *et al.*, 1996; Reeves *et al.*, 1997).

The impact of the cropping systems on insects should be minimal. The dominant effect will be due to the Bt resistance incorporated into the cotton. One potential impact will be the possible overwintering of insects in plant debris in the conservation tillage plots. However, crop rotation will help minimize the potential damage from insects.

Recent studies have analyzed tillage systems and pesticide use in the Corn Belt (Fuglie, 1999), rotations (Funk *et al.,* 1999), cotton in rotation with soybean under three tillage practices (Stark *et al.*, 1996), and fertilizer rates and yield responses in feed grains (Atwood and Helmers, 1998). Overall, the research implies that such a system should be analyzed within a crop management and economic framework. Fuglie (1999), for example, noted that with no-till herbicide use was about equal to that under conventional tillage, but that insecticide use increased. Funk *et al.* (1999), on the other hand found a trade-off between insecticide and herbicide use, but looked only at corn-soybean rotation and did not include tillage. Atwood and Helmers (1998) discussed the yield and protein content decline of feed grains caused by restricting timing and level of nitrogen applications in order to control nitrate contamination. In 1996, Stark *et al.* summarized results from a 1987-1991 experiment. They found that in terms of yield and net returns, full tillage in a cotton-soybean rotation, each preceded by triticale, gave better results than row-till and no-till systems. In that experiment pest control varied by tillage method and fertility levels were to levels recommended by the Georgia Cooperative Extension Service. The experiment reported by Stark *et al.* is the most complete, but an analysis of a complete system suitable for the Southern Coastal Plain for ultra narrow row cotton is lacking. None of the research, however, analyzed a sod-based rotation with rotation-tillage-pesticide-fertilizer in the system.

INTEGRATED PEST MANAGEMENT

The major changes in pesticide use in a sod based system, other than the reduction in area of both peanuts and cotton, is the need to kill the bahiagrass in the fall of its second year and a reduction in peanut leafspot sprays from 6 to 3. A reduction in the need for nematicides would be expected, but about 50% of the farms would still use aldicarb or thimet to control thrips on cotton. However, those that use a peanut variety resistant to tomato spotted wilt virus (which is vectored by thrips) will not need aldicarb, as the bahiagrass will eliminate the need to control the nematodes.

The cost for pesticides for growing conventional peanuts and cotton are calculated to be \$120 acre^{-1} and \$37, respectively. In the bahiagrass rotation, the cost for pesticides bahiagrass is \$10 per acre to kill it with glyphosate in the fall before peanuts. No other pesticides will be needed for bahiagrass. For peanuts in rotation, the pesticide cost is reduced to \$70 per acre because of the reduction in leafspot sprays and need for aldicarb. In cotton the cost per acre remains the same, \$37 per acre. In this rotation, the annual cost for pesticides is slightly less than half of the conventional system.

Growers know that crops must be rotated to control pest and increase yields. They know, also that sod-based rotations can often increase yields even more, even doubling cotton yields (Elkins *et al.*, 1977). When combined with advances in IPM and minimum till technology, it is possible to develop an economic and environmentally sustainable row crop rotation system for farmers in the Southeast that will allow more profit for farms of all sizes including smaller farms.

Primary considerations for a successful rotation must include the reduction of costs of inputs (both economically and environmentally), the increase or at least maintenance of the soil health, and an increase in the economic output of the acreage farmed. The cropping systems and farming practices developed must have a high degree of sustainability to be effective. Research projects should encompass multi disciplines and embrace modern IPM practices, recent genetic technology, precision planting equipment, precision agriculture tools, and minimum or no-tillage systems and, most importantly, sod-based rotations for dramatic yield increases.

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COMPARISON OF PLANTING EQUIPMENT FOR SOD-SEEDED RYEGRASS

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ABSTRACT

Fall planted winter annuals yield less when overseeded, compared with the growth achieved with plowing and disking. The objective of this study was to compare planting equipment which provided various levels of residue and soil disturbance. Ryegrass was planted in a bermudagrass pasture with: 1. Tye no-till drill, 2. Tarver no-till drill, 3. Broadcast following Hay-King subsoiler, or 4. Broadcast. Establishment of ryegrass with the Tarver resulted in an initial stand (30 days after planting, DAP) of 74%, compared with 25% for ryegrass established with the Tye, and only 10% for ryegrass broadcast seeded. At 60 DAP, ryegrass stands were 86% when planted with the Tarver, 70% with the Tye, and 53% when broadcast. Ryegrass plant height and ground cover were also greater with the Tarver, compared with the Tye or Broadcast. There were no differences between N fertilizer sources. There was a 2.3 fold difference between the early fall yield of ryegrass seeded with the Tarver, compared with the early fall ryegrass yield planted with the Tye.

KEYWORDS

Ryegrass establishment, planting method, sod-seeding.

INTRODUCTION

Annual Ryegrass (*Lolium multiflorum*) is overseeded in the fall into warm season grass pastures on thousands of acres throughout the southeastern U.S.A. by various techniques. A common method is to broadcast seed (usually mixed with fertilizer) directly on top of the pasture with or without light discing and cultipacking. Some producers use a grain drill or a drill designed for no-till seeding of winter annuals. However, without tillage, early yield of ryegrass is greatly reduced compared with ryegrass seeded into a prepared seedbed (Coats, 1957; Dudley and Wise, 1953; Lang, 1989; Lang *et al*., 1992; Lang and Elmore, 1995; Lang *et al*., 1997; Cuomo *et al*., 1999; Elmore and Lang, 2000). Previous work has focused on improving fall growth of sod-seeded ryegrass and other winter annuals with little success. It was essential to remove the growth residue of the summer grass (Cuomo *et al*., 1999), but a herbicide burn-down has not been necessary if the summer grass is cut for hay late in the fall or cattle graze the summer grass (Lang, 1989; Brock *et al*., 1992; Ingram *et al*., 1993; Lang and Elmore, 1995; Lang *et al*., 1997; Elmore and Lang, 2000). Sod-seeded ryegrass did not respond proportionally to fertilizer-N up to 150 lbs N acre^{-1}, compared with ryegrass sown into a prepared seedbed (Lang and Elmore, 1995). There is a need for technology, which improves fall growth for sod-seeding winter annuals into summer grass pastures. The objectives of this study were to compare planting equipment and nitrogen source on fall seeded ryegrass sown into a bermudagrass pasture.

MATERIALS AND METHODS

The experiment was located within a heavily grazed 25-acre bermudagrass dominated pasture (Table 1) on an Oktibbeha soil (Very-fine, smectitic, thermic Chromic Dystruderts). Soil test P and K were medium to high; pH was 6.2. 'Marshall' ryegrass was planted without an herbicide burn-down at 35 lbs acre^{-1} on September 27, 2001 with a Tarver drill, Tye drill, broadcast following a Hay King subsoiler, or broadcast. Ryegrass plots planted with the Tarver drill and Tye drill received nitrogen fertilizer at 65 lbs N acre^{-1} as ammonium nitrate (34–0-0), urea (30-10-10), or liquid N-Sol. Plots Broadcast planted received N-Sol as the N-Source. A unique feature of the Tarver Drill was that fertilizer was placed below the seed during planting. Fertilizer as 34-0-0 or 30-10-10 was broadcast following seeding with the Tye drill. N-Sol was applied following planting within all planting methods. Nitrogen treatments were reapplied in December, 2001, February, 2002, and April, 2002. Each treatment plot was 24' wide and 300' long planted along the contour of the field and replicated three times. Three transects along each 300' length were established perpendicular to the replications in order to account for field variation within the large treatment plots.

Ryegrass was evaluated for stand, ground cover, and botanical composition by visual techniques. Plant height was determined with a floating cardboard attached to a meter stick. Yield was calculated by harvesting a known area with a Carter forage harvester following dry matter determination. Data were analyzed with SAS and calculated in order to perform comparisons between 'Drill vs. Broadcast', 'Tarver vs. Tye', 'Liquid N vs. Dry N within Drill', and '34-0-0 vs. 30-10-10 within Drill' treatments.

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Table 1. Characterization of initial botanical composition on October 2, 2001

Equipment / N- Treatment	Bermuda Stand	Dallisgrass Stand	Sward Height	Residue Thickness
	---------- %	------------	--- inch --	†
Tarver 34-0-0	87	7	3.1	3.4
Tarver 30-10-10	83	11	3.2	3.2
Tarver N-Sol	84	8	3.7	3.1
Tye 34-0-0	90	7	3.8	3.2
Tye 30-10-10	80	13	3.8	3.2
Tye N-Sol	85	17	2.8	3.6
Hay King N-Sol	92	5	3.2	3.7
Broadcast N-Sol	84	13	3.3	3.3
LSD (0.05)	12	12	1.0	0.9
Linear contrast				
Drill vs Broadcast	NS	NS	NS	NS
Tarver vs Tye	NS	NS	NS	NS
Liquid N vs Dry w/Drill	NS	NS	NS	NS
34-0-0 vs Urea w/Drill	NS	NS	NS	NS

† Residue thickness scored on a scale of 1 to 10, where 1 = least amount of residue and 10 = most.

RESULTS AND DISCUSSION

The plot area was uniform in terms of botanical composition: short, with a low level of top growth (Table 1). Ryegrass stands established rapidly in plots planted with the Tarver drill, moderate when planted with the Tye drill, and slow when broadcast seeded (Table 2). By early December, ryegrass stand was similar in plots planted with the Tarver or Tye, but stand of broadcast seeded ryegrass was less (Table 3). Ryegrass stand was similar for all planting methods by February (data not shown).

Fall growth of ryegrass was superior when planted with Tarver drill as compared with the Tye drill or broadcast (Table 3). There were no differences between N fertilizer sources. The 2.3 fold difference between the early fall yield of ryegrass seeded with the Tarver, compared with the early fall ryegrass yield planted with the Tye, is in the low range (2x to 10x) of previous work comparing ryegrass growth sown into a prepared seedbed with ryegrass sod-seeded with a Tye Drill (Lang and Elmore, 1995; Elmore and Lang, 2000). The Tye is equipped with a single coulter and double disk openers, which cut 1-2" deep and leaves a narrow slit through the sod. The Tarver drill has a slicing coulter which cuts 2.5" deep followed by a ripping shank that penetrates 3/4" wide and 5.5" deep leaving a mini-prepared seedbed within the sod (Tarver, 1997), which provided 137% more early fall ryegrass growth compared with the Tye planter (Table 3).

Previous work has shown that the fall growth suppression with sod-seedings of ryegrass disappears in the spring (Lang, 1989; Lang and Elmore, 1995; Elmore and Lang, 2000). A similar pattern occurred in the current study (Table 4). Ryegrass yield was generally similar in February and April in plots seeded with the Tarver as compared with those planted with the Tye. Yield of ryegrass. Broadcast seeded was lower than ryegrass planted with either drill, but there was no advantage to using the Hay King subsoiler to establish ryegrass. Stand and yield of bermudagrass will be measured during the summer of 2002 in order to determine any long term effects of the various ryegrass planting methods.

Table 2. Initial Ryegrass stand, height and ground cover (GC) on November 1, 2001.

Equipment / N- Treatment	Ryegrass Stand	Ryegrass Height	Ryegrass GC
	--- % ---	--- inch---	--- % ---
Tarver 34-0-0	71	7.1	10
Tarver 30-10-10	80	7.9	10
Tarver N-Sol	70	7.6	8
Tye 34-0-0	37	4.1	5
Tye 30-10-10	19	4.6	4
Tye N-Sol	16	3.2	3
Hay King N-Sol	13	4.1	2
Broadcast N-Sol	5	2.0	1
LSD (0.05)	28	2	3
Linear contrast			
Drill vs Broadcast	***	***	***
Tarver vs Tye	**	**	**
Liquid N vs Dry w/Drill	NS	NS	NS
34-0-0 vs Urea w/Drill	NS	NS	NS

**, *** $P =$ 0.01 and 0.001, respectively

Table 3. Ryegrass stand and yield on December 4, 2001.

Equipment / N- Treatment	Ryegrass Stand	Ryegrass Yield
	--- % ---	lbs acre^{-1}
Tarver 34-0-0	87	875
Tarver 30-10-10	81	800
Tarver N-Sol	88	1013
Tye 34-0-0	80	571
Tye 30-10-10	72	222
Tye N-Sol	63	357
Hay King N-Sol	55	338
Broadcast N-Sol	33	86
LSD $_{(0.05)}$	26	572
Linear contrast		
Drill vs Broadcast	**	*
Tarver vs Tye	*	*
Liquid N vs Dry w/Drill	NS	NS
34-0-0 vs Urea w/Drill	NS	NS

*, ** $P =$ 0.05 and 0.01, respectively

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Table 4. Yield of sod-seeded ryegrass as influenced by planting equipment and nitrogen source.

Equipment / N- Treatment	12-4-2001	2-22-2002	4-10-2002	Total
	------------------------	lbs acre^{-1}	----------------------	
Tarver 34-0-0	875	1052	3139	5066
Tarver 30-10-10	800	1052	3324	5176
Tarver N-Sol	1013	1103	4233	6349
Tye 34-0-0	571	993	3138	4702
Tye 30-10-10	222	927	3628	4777
Tye N-Sol	357	528	2939	3824
Hay King N-Sol	338	594	2112	3044
Broadcast N-Sol	86	306	2121	2513
LSD $_{(0.05)}$	572	385	893	1994
Linear contrast				
Drill vs Broadcast	*	**	**	**
Tarver vs Tye	*	**	NS	**
Liquid N vs Dry w/Drill	NS	NS	NS	NS
34-0-0 vs Urea w/Drill	NS	NS	NS	NS

*, ** $P =$ 0.05 and 0.01, respectively

ESTABLISHMENT OF NATIVE GRASSES INTO FESCUE SOD

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ABSTRACT

Cool-season perennial grass production declines rapidly during the hot summer months. This poor productivity is of special concern to forage producers who rely on a continuous supply of herbage. Establishment and obtaining a reasonable stand are problems associated with native grasses. A field experiment was initiated to evaluate the influence of disking, herbicide, and spring burn treatment combinations on stand population and vigor of four warm-season grasses. Treatments included a fall herbicide, spring herbicide, fall/spring herbicide, fall herbicide-spring disk, spring herbicide-spring disk, fall/spring herbicide-spring disk, fall herbicide-spring burn and an untreated control. The existing tall fescue (*Festuca arundinacea* Schreb.) vegetation was sprayed with glyphosate [*N*-(phosphonomethyl) glycine] at 1 qt a.i. acre^{-1}. The grass species were 'Kaw' big bluestem (*Andropogon gerardii* Vitman), 'Alamo' switchgrass (*Panicum virgatum* L.), 'Pete' eastern gamagrass [*Tripsacum dactyloides* (L.) L.], and 'Lometa' Indiangrass [*Sorghastrum nutans* (L.) Nash]. Visual assessments for plant density (%) were recorded in November of each year and for plant vigor and remaining tall fescue at the end of the third growing season. The data indicate that plant populations increased from Year 1 to Year 3 for combinations containing a disk treatment. Treatments without disk tillage did not produce a reliable stand of native grasses. The range of stand response for disk treatments (67-100%) was greater than the range for treatments without disking (0-25%). Stand populations for switchgrass and Indiangrass were higher than for other species (Year 3). Higher vigor ratings for grass species resulted from treatments in which a disk operation was conducted.

KEYWORDS

Native grasses, establishment, fescue eradication, herbicide, cultivation

INTRODUCTION

One of the major grasses used in forage programs in the mid-south is tall fescue. Tall fescue is characterized by early spring growth and is normally productive in the spring, early summer and again during the fall. A forage base that does not contain summer grazing can be detrimental to the performance of animal daily gain and performance. Perennial native warm-season grass species may offer an opportunity to provide much needed grazing during the hot, dry portion of the growing season (Rehm, 1984). Native grasses are also recommended for reseeding marginal cropland to improve available forage, conserve soil, and provide wildlife habitat (Beran *et al*., 2000).

Methods of establishment for native grasses into tall fescue sod may make this conversion of cool- to warm-season species more acceptable. Vassey *et al*. (1985) concluded that atrazine would facilitate good stand establishment under stress conditions or when inadequate equipment is used for seeding switchgrass. Burning or combining burning with atrazine to control prairie threeawn offered little advantage over atrazine alone applied in March (Engle *et al*., 1990). Samson and Moser (1982) used atrazine and glyphosate to suppress cool-season vegetation before seeding with reduced tillage techniques. Herbicides were used to control weeds and cool-season species allowing for the growth and expansion of warm-season species (Waller and Schmidt, 1983).

Because grass plantings require one or more growing seasons to become suitable for grazing, optimum densities of initial plants are needed to minimize the length of time for stand establishment. Two growing seasons were necessary for the establishment of switchgrass and flacidgrass (*Pennisetum flacci* L.) in North Carolina (Burns *et al*., 1984). Rapid ground cover is desirable in all new grass plantings. Sparse seedling stands frequently do not develop adequate ground coverage until tillering gives rise to additional plants. Poor initial stands may never become dominant because of weed and undesirable grass competition (Launchbaugh and Owensby, 1969). Concerns of forage producers about seed cost and difficult stand establishment (McKenna and Wolf, 1990) have limited the popularity and use of switchgrass. Possible reasons for stand failure or thin and uneven stands may be less

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favorable soil moisture and poor success in weed control. (Vassey *et al*., 1985).

The ability to influence the acceptance of native grasses would be increased with lower input establishment methods and a greater degree of success in obtaining a viable stand. This study was initiated to develop a reliable method to establish native warm-season grass species. The objectives of this study were to determine the effects of combinations of timing glyphosate applications, a spring burn, and dishing on stand response and plant vigor of four native warm-season grass species.

METHODS AND MATERIALS

The study was conducted at the Booneville Plant Materials Center, Booneville, AR, on sites previously established to tall fescue. The experimental design was a split-plot arrangement of a randomized complete block design with three replications. Main plots were preplant treatments and sub-plots were grass species. The main plot treatments were fall herbicide, spring herbicide, fall/spring herbicide, fall herbicide-spring disk, spring herbicide-spring disk, fall/spring herbicide-spring disk, fall herbicide-spring burn and an untreated control. Plot areas receiving a herbicide application were prepared by spraying existing vegetation with glyphosate [*N*-(phosphonomethyl) glycine] at 1 qt a.i. acre^{-1}.

The sub-plot grass species were ‘Kaw’ big bluestem, ‘Alamo’ switchgrass, ‘Pete’ eastern gamagrass, and ‘Lometa’ Indiangrass. Grass species were established using pure live seeding rates based on existing recommendations of 8, 8, 10, and 8, lbs acre^{-1} for big bluestem, switchgrass, eastern gamagrass, and Indiangrass, respectively. The north-south oriented rows were spaced 9 in. apart and drilled using a Kincade Plot Planter. The seeding date was 1 April. The plots were established on a Taft silt loam (fine-silty, siliceous, thermic Glossaquic Fragiudults) soil and were 12 ft by 20 ft. An initial soil test was obtained and soil pH was about 6.0. The plots were fertilized in the spring prior to planting with 80 and 150 lbs acre^{-1} P and K, respectively. No N was applied before or at seeding of the establishment year to limit weed growth and competition (Krueger and Curtis, 1980). In Year 1, after establishment of the study, N at 60 lbs acre^{-1} was surface-applied in the spring and each subsequent year. Once established, all plots were burned 1 March of each successive year. Visual assessments of plant density (0=no plants to 100%=solid stand) were made in November of each year. Plant vigor (1=poor to 10=best) and tall fescue (%) within each grass species sub-plot was assessed at the end of the third growing season.

RESULTS AND DISCUSSION

Relationships between tillage treatments and stand response for native grass species (Year 1, after establishment) are found in Table 1. The range of stand response for eastern gamagrass (25-33%) to tillage treatments with no spring disk was generally greater than for other grass species (0-25%). The fall herbicide-spring burn resulted in a higher percentage of plants for all species than for treatments that did not receive a spring disk. The spring disk regardless of the timing of a herbicide treatment produced a greater number of native grass plants than other treatment combinations. The range of stand response for grass species to disk treatments for switchgrass was lower (50-58%) compared to gamagrass (67-83%), big bluestem (67-75%), or Indiangrass (75-92%).

Table 1. Effect of herbicide application timing and spring tillage operation on stand response of native warm-season grasses in year 1.

Herbicide application	Spring operation	Gama grass	Big bluestem	Switch grass	Indian grass	Mean
		------------------------ % ------------------------				
Fall	----	25	0	0	0	6 b
Spring	----	25	8	8	8	12 b
Fall + spring	----	25	8	8	8	12 b
Fall	disk	83	75	58	75	73 a
Spring	disk	75	75	50	92	73 a
Fall + spring	disk	67	67	50	83	67 a
Fall	burn	33	25	17	25	25 b
Control		8	0	0	0	2 b
Mean		43 a	32 a	24 a	36 a	

Means averaged across species for stand response indicated that the fall herbicide-spring disk (72.8%), spring herbicide-spring disk (73.0%) and fall/spring herbicide-spring disk (66.8%) were similar.

Stand response means, averaged across species, for Year 2 (Table 2) were similar to Year 1 for fall herbicide (6.3%), spring herbicide (12.3%), fall/

Table 2. Effect of herbicide application timing and spring tillage operation on stand response of native warm-season grasses in year 2.

Herbicide application	Spring operation	Gama grass	Big bluestem	Switch grass	Indian grass	Mean
		------------------------	%	------------------------		
Fall	----	25	0	0	0	6 c
Spring	----	25	8	8	8	12 c
Fall + spring	----	33	8	8	25	19 c
Fall	disk	92	92	83	100	92 a
Spring	disk	75	83	50	100	77 ab
Fall + spring	disk	75	67	50	92	71 b
Fall	burn	33	25	17	25	25 c
Control		8	0	0	0	2 c
Mean		46 a	35 a	27 b	44 a	

spring herbicide (12.3%), fall herbicide-spring burn (25.0%), and control (2.0%). Stands of gamagrass and Indiangrass (Year 2) increased 8 and 17 percentage points, respectively, compared to the first year after establishment for the fall/spring herbicide treatment and values for big bluestem and switchgrass remained similar.

Greatest stand increases between Year 1 Year 2 occurred for the fall herbicide-spring disk tillage treatment. Means averaged across species for stand increases between Year 1 and 2 were greater for fall herbicide-spring disk (72.8 and 91.8%, respectively) compared to spring herbicide-spring disk (73.0 and 77.0%) and fall/spring herbicide-spring disk (66.8 and 71.0%). The fall herbicide-spring disk treatment produced a stand increase of 25 percentage points for switchgrass and Indiangrass compared to a 9-percentage point increase for eastern gamagrass.

At the end of Year 2 stand responses for Indiangrass were 100% for the fall herbicide-spring disk and spring herbicide-spring disk treatments. The fall herbicide-spring disk treatment produced an average cover of 92% for eastern gamagrass and big bluestem and was similar to Indiangrass with a fall/spring herbicide-spring disk. There were no big bluestem, switchgrass, or Indiangrass plants observed in the fall herbicide or control treatments at the end of Year 2.

Generally, in the fall of Year 3 (Table 3), there was no change in plant populations compared to Year 2 for eastern gamagrass, big bluestem, switchgrass, or Indiangrass with fall herbicide, spring herbicide, fall/spring herbicide or control treatments. Exceptions to this were for Indiangrass and gamagrass for the spring herbicide and fall/spring herbicide treatments, respectively. Small decreases in plant numbers were observed for all species with a fall herbicide-spring burn treatment. Stand response for Indiangrass, at the end of year 3 was 100% for all treatments that contained a disk treatment. The spring herbicide-spring disk treatment resulted in an increase in native plants for gamagrass, big bluestem, and switchgrass in Year 3. The spring herbicide-spring disk and fall/spring herbicide-spring disk produced the greatest increase in plant numbers for switchgrass (50

Table 3. Effect of herbicide application timing and spring tillage operation on stand response of native warm-season grasses in year 3.

Herbicide application	Spring operation	Gama grass	Big bluestem	Switch grass	Indian grass	Mean
		------------------------	%	------------------------		
Fall	----	25	0	0	0	6 cd
Spring	----	25	8	8	17	15 c
Fall + spring	----	25	8	8	25	17 c
Fall	disk	92	92	100	100	96 a
Spring	disk	67	67	92	100	82 a
Fall + spring	disk	75	67	75	100	79 ab
Fall	burn	17	20	15	20	18 b
Control		0	0	0	0	0 cd
Mean		41 a	33 a	37 a	45 a	d

Table 4. Effect of herbicide application timing and spring tillage operation on vigor of native warm-season grasses and % tall fescue in year 3.

Herbicide application	Spring operation	Gamagrass	Big bluestem	Switchgrass	Indiangrass	Tall Fescue
		-------------- Vigor rating -------------				-- % ---
Fall	----	1.7	0.0	0.0	0.0	50
Spring	----	2.7	1.0	1.0	1.3	50
Fall + spring	----	2.3	1.3	0.0	2.0	0
Fall	disk	6.7	7.0	7.7	6.7	0
Spring	disk	5.0	5.7	7.0	7.7	0
Fall + spring	disk	5.7	6.0	7.7	6.3	0
Fall	burn	1.7	1.3	0.0	2.3	10
Control		0.0	0.0	0.0	0.0	85

percentage points) from Year 2 to Year 3. Means averaged across species for stand response between Year 2 and 3 were similar for fall herbicide-spring disk (91.8 and 96.0%, respectively) and spring herbicide-spring disk (77.0 and 81.5%) and lower than the fall/spring herbicide-spring disk (71.0 and 79.3%) treatment.

Stand vigor ratings were assessed at the end of the third growing season after the year of establishment (Table 4). Higher vigor ratings for grass species resulted from treatments in which a disk operation was conducted. Vigor response of grass species to treatments without a disk ranged from 1.0 to 2.7 and these were lower than for species with a disk treatment that ranged from 5.0 to 7.7. Means averaged across species for vigor were higher for the fall herbicide-spring disk (7.0) compared to the spring herbicide-spring disk (6.4) and fall/spring herbicide-spring disk (6.4) treatments.

The percent tall fescue remaining at the end of the third growing season was greater for the control (85%) than for the fall herbicide or spring herbicide (50%). No tall fescue remained in the fall/spring herbicide or disk treatments.

CONCLUSIONS

These data provide evidence that a spring application glyphosate may reduce tall fescue and other plant competition to enhance stand establishment of native grasses. It also emphasizes the importance of providing limited soil disturbance to provide adequate seed soil contact. At the conclusion the third year, acceptable stands of eastern gamagrass, big bluestem, switchgrass and Indiangrass were achieved with a fall or spring or fall/spring herbicide application with a spring disk. The best stand in the third year after establishment was obtained with a fall herbicide-spring disk and this treatment was better than the spring herbicide-spring disk and the fall/spring herbicide-spring disk. A 100% stand of Indiangrass was obtained with a spring disk regardless of the timing of the herbicide application. The fall herbicide-spring disk produced a 100% stand of switchgrass by end of Year 3. The other five treatment combinations (without a disk treatment) resulted in stands equal to less than 25%.

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A MULTI-STATE PROJECT TO SUSTAIN PEANUT AND COTTON YIELDS BY INCORPORATING CATTLE IN A SOD BASED ROTATION

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ABSTRACT

The number of commercial farms in the southeastern United States is decreasing at an alarming rate. Escalating costs of production, reductions in the value of commodities, and stagnant yields have caused many in the farm community to sell out or plant pines on land previously in row crops. Main production limitations in the Southeast are infertile, compacted, droughty soils and pests. The primary objective of this project is to develop an economically and environmentally sustainable sod based- row crop production system appropriate for the biological and social conditions of the southeastern United States. Bahia or bermuda sod can add organic matter to infertile soils for better nutrient and water holding capacity. Bahiagrass also reduces nematode populations, and both bahia and bermuda can reduce other pests. Grass roots grow through the compacted soil layer, allowing subsequent row crop roots to penetrate the compacted layer for access to deeper water and nutrients. When following bahia or bermuda grass, root growth of row crops is often 10 times deeper than in conventional cropping systems. Most growers agree that sod based rotations with bahia or bermuda grass will increase yield of crops by 50-100%. When economic analyses are done on cotton and peanut in a sod based rotation (bahia-bahia-peanut-cotton), profits are about twice as great as in a conventional peanut-cotton-cotton or peanut-cotton rotation. Income is further increased and diversified if cattle are pastured on the Bahiagrass.

KEYWORDS

Integrated pest management, conservation tillage, bahiagrass, southeastern United States

INTRODUCTION

The number of commercial farms in the southeastern United States is decreasing at an alarming rate. There are many reasons for this including droughts and low prices, but the ultimate problem is that there has been little or no incentive for the industry to develop and utilize a farming system that reduces costs and dramatically increases yield even in drought years. Escalating costs of production, reductions in the value of commodities, and stagnant yields have caused many in the farm community to sell out or plant pines on land previously in row crops. The primary objective of this project is to develop an economically and environmentally sustainable sod-based row crop production system appropriate for the biological and social conditions of the southeastern United States This project will deliver a viable production system for small farms in the 100 to 800 acre range, and will obtain higher yields at less cost. These farms include family farms as well as a large number of minority and presently under funded farmers.

Main production limitations in the Southeast are infertile, compacted, droughty soils and pests. There is a low cost way to markedly reduce the impact of each of these limitations, and that is using a sod based rotation of bahia or bermuda grass in the cropping system. Bahia or bermuda grass adds organic matter to infertile soils for better nutrient and water holding capacity, while grass roots grow through the compacted soil layer allowing subsequent row crop roots to move through the compacted layer for access to more water and nutrients. Bahiagrass also reduces nematode populations, even after only one year (Norden, *et al.*, 1977, Rodrígues-Kábana, *et al.*, 1988). Water in the soil profile is conserved and utilized by subsequent crops, since rooting of row crops is often 10 times deeper following bahia or bermuda grass than in conventional cropping systems. Long and Elkins (1983) found that cotton following 3 years of continuous bahiagrass sod rooted more deeply than that planted in continuous cotton, allowing the cotton in the bahiagrass-cotton rotation to extract water and nutrients from lower soil depths. This could result in as little as 1/10th the current water use for irrigation, alleviating

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some of the water problems currently being debated in Tri-state water talks. They reported a reduced amount of N, K, and Ca in the soil solution at the lower depths and an increase in K and Ca in the cotton plants. Especially significant in considering the potential for nitrate leaching, is the fact that they found that NO_3-N in the soil solution 66 inches deep was only 10 ppm in plots following bahiagrass, but 40 ppm in plots under continuous cotton (100 lbs N acre-1 was applied to the crop).

The increases in water and nutrient extraction and deep root growth in crops following bahiagrass sod is attributed to the effect that the deep penetrating roots of the grass have on soil structure, especially soil pore size. Long and Elkins (1983) found a seven fold increase in pore sizes greater than 0.04 Perennial Forage in Rotation with Row Crops in the Southeast inches in the dense soil layer below the plow depth. They concluded that bahiagrass roots had penetrated the dense soil layer and that after the decay of the roots, pores were left that were large enough for the cotton roots to grow through. They also reported an increase in water and nutrient extraction at greater soil depths.

We expect that the need for irrigation will be reduced several ways. First, the bahiagrass will not need as much irrigation as the row crops (10 inches *vs.* 20 inches), and half of the land will be in bahiagrass. Second, the increased water infiltration will reduce the need for irrigation in row crops. Third, the increased root depth and density will make the row crops more efficient at extracting deeper water. Finally, the rotation may increase organic matter, which has many positive impacts on farming systems (Reeves, 1977).

Most growers agree that sod based rotations with bahia or bermuda grass will increase yield of crops by 50-100%. State average yield of peanut in the Southeast is about 2,500 pounds per acre, but yields after bahiagrass are often 3,500-4,500 lbs per acre. When economic analyses are done on cotton and peanut in a sod based rotation, profits are about two times greater as in a conventional peanut-cotton-cotton rotation.

Crop rotation has been a viable means of pest control since agriculture began. Although experience and research data show that the yield of cotton and peanuts can be increased significantly when rotated with other row crops, we also know that sod based rotations can often increase yields even further. When combined with advances in minimum till technology, we feel it is now possible to develop an economic and environmentally sustainable row crop rotation system for farmers in the Southeast while reducing equipment costs, labor, and pesticide use.

Primary considerations for a successful rotation must include the reduction of costs of inputs (both economically and environmentally), the increase or at least maintenance of the soil health, and an increase in the economic output of the acreage farmed, even in the global economy. The cropping systems and farming practices developed must have a high degree of sustainability to be effective. This project will address these needs from several fronts, including adaptation of modern IPM practices, utilization of the most advanced genetics available, precision planting equipment, precision agriculture tools, minimum or no-tillage systems and, most importantly, the introduction of sod based rotations to give dramatic yield increases and improved economics of production.

Although growers and scientists realize the merits of a sod based cropping system, no practical steps have been brought forward to implement it. A business model is currently being delivered to growers and scientists to better define the advantages of the system along with conservation tillage aspects of crop production. This project will verify the model. The concept will be taken to farms for further verification and promotion. We expect this system to add $100-200 per acre profit to the 3 million acres of cotton and peanut being grown in Florida, Alabama and Georgia. This increased profit will result from less inputs and higher yield on smaller acreage of row crops. After considering the multiplier effect, the total impact resulting from this rotation is expected to infuse 3-6 billion more dollars into the rural economy.

The yield benefits of several years of bahia or bermuda grass on cotton and peanut as well as other row crops cannot be matched by increased use of fertilizer or pesticides. Better soil health and water quality are by- products of this sod based rotation system and will be verified in this project. This joint (Florida, Alabama, and Georgia) project will simulate the production environment of integrated systems, monitoring yield, pests, and soil quality factors such as organic matter and carbon sequestering, compaction, water quality, and nutrient movement.

Peanuts and cotton are major cash crops for the southeastern region of the United States. Yields of most row crops have remained level for the past 25 years because of poor rotations and use of inputs such as irrigation and pesticides which help keep yields high even under unfavorable production conditions. Both are dependent in large part upon government support programs that change regularly, with the present Farm Bill expiring in 2002. The future value of the peanut and cotton crops in the Southeast will be affected as the support programs are revised and as a result of direct competition from imports and shifting production areas within the United States, especially with more peanuts in Texas. The domestic price of peanut and cotton may be forced downward to international price levels. The expected shift in the price of peanuts will force surviving farmers to adopt a more economical system of farming. To do that with sustainable practice requires a whole farm systems level approach.

The major objectives of the this project are:

1. Develop and compare the economic and environmental benefits of conventional and sod based farming systems using conservation tillage systems,
2. Quantify the positive impact that sod based rotations have on soil health, pest reduction, and sustainable farm production, and
3. Refine and promote production practices in a sod based rotation which results in significant yield increases associated with decreased inputs.

MATERIALS AND METHODS

FIELD PLOTS

The specific objectives will be met through the establishment at five sites (one each in Alabama and Georgia and three in Florida) of a 4 year rotation experiment. At each site a conventional peanut-cotton-cotton (Florida and Georgia) or peanut-cotton (Alabama) rotation will be compared to a bahia-bahia-peanut-cotton rotation. Farm sized plots (40 acres) will be used to best simulate the production environment, especially yield and insect, nematode, disease, and weed interactions. This will also provide an excellent teaching environment for demonstration of the equipment, crops, and production practices. The crop management will be conservation tillage systems utilizing the most advanced strip till equipment, genetics, and farming and animal production practices. Best management practices appropriate for each site will be used during the cropping season, but treatments in each trial will be consistent. Detailed data will be taken on all farming practices as well as crop performance and economic costs. There will be a core data set consisting of abiotic, biotic, and economic factors that will be consistent across all systems.

Two sites will harvest the bahiagrass as hay. At the Quincy, Florida and the Tifton, Georgia site, a 1/4 acre replicated plot field design will be used. The cropping sequences will be conventional peanut-cotton-cotton compared to bahia-bahia-peanut-cotton-winter wheat. Each will be grown under full conservation tillage systems. At Quincy, plots will be split for irrigated and nonirrigated trials. At Tifton, all plots will be irrigated. Bahiagrass and conventional systems were established at these locations in 1999, and 2002 will be the first planting of peanuts after 2 years of rotation.

Three sites will harvest the bahiagrass by grazing cattle. All will be under irrigation. At Headland, Alabama a 50 acre site will be established with 2 replicated plots of the bahia-bahia-peanut-cotton rotation and two plots with a conventional peanut-cotton-peanut-cotton rotation. A stocker operation will be used to graze the sod and winter cover crops of wheat and/or oats that will be used for winter grazing. At Marianna, Florida two (one at the North Florida Research and Education Center and one on a commercial farm) 120 acre sites under center pivot irrigation will be divided into 40 acre plots and planted to the bahia-bahia-peanut-cotton rotation. Both sites will use a cow-calf operation on the second year of bahiagrass.

All pests will be managed with standard IPM practices, genetically resistant varieties where available, and biological and cultural controls. We will use Bt and herbicide resistant varieties whenever possible.

PLANT DATA

Data collection will be consistent at each site. Microclimate data, management practices and costs, crop data, and pest data (including control strategies) will be recorded for each system. Nematodes will be monitored with preplanting and post harvest soil samples for each crop. Insects in cotton will be monitored weekly until the pinhead square stage and then twice weekly, examining 10 plants per plot. On peanuts, the foliage feeding insects will be sampled weekly with a beat-cloth technique. Root-peg-pod feeding insects will be monitored by digging 5 plants and examining the pegs, pods, and roots. Wheat will be scouted weekly for aphids and disease.

Disease assessment and pathogen population monitoring will be done on a regular basis in each of the crops. In cotton, boll rot and hard lock will be quantified in each system as it is anticipated that the taller plants in the sod based system may lead to a denser canopy, resulting in higher humidity and possibly increased boll rot. Seedling stands will also be examined for damping off diseases by determining the incidence of damping off and the pathogen responsible. In peanuts, plants will be examined weekly for early and late leaf spot, Tomato Spotted Wilt (TSW), Sclerotinia, and Cylindrocladium Black Rot (CBR) by examining 10 consecutive plants at 4 different sites in each plot. Yield of cotton and peanuts will be collected and analyzed for quantity and quality. Specific harvest dates will depend upon the growing conditions, but harvest will be done at the optimum time. Bahiagrass hay will also be harvested and quantified.

Market prices at harvest will be used to determine economic returns. Extension Enterprise Budgets will be modified to account for limitations associated with the experimental design (i.e. plots smaller than production fields) so that the economic data can be extrapolated to real farm conditions.

Dry matter samples of total biomass for each crop, including bahiagrass cuttings, will be collected and analyzed for C and N in order to calculate inputs of C and N to the soil.

SOIL DATA

A consistent core set of data to determine the impact of cropping and tillage systems will be collected at all sites. Baseline soil quality data (physical and chemical) will be collected before starting the experiment in 2002 and at the end of the experiment in 2004/2005. Data collected will include wet aggregate stability determinations (0-2 inch depth), water infiltration, total soil carbon and total N at depths of 0-2, 2-6, and 6-12 inches. Particulate and mineral-associated C, which represents the transient and resistant soil C pools, respectively, will be determined following the techniques of Camberdella and Elliott (1992). Soil microbial biomass will be determined at the same time as C and N by the fumigation method (Jensen *et al*., 1996). Soil pH will be determined using a 1:1 soil/water ratio. For non-sod crops, bulk density measurements to a 4-inch depth immediately after planting will be taken within the row using the core method (Blake and Hartge, 1986).

ANIMAL DATA

Animal data will include the costs and returns associated with the animal production aspect of the study. Weight gain, herd health, and costs associated with the animals will be analyzed. Weight gain and reproduction efficiency will be recorded for each herd.

RESULTS AND DISCUSSION

The economics of rotation to a non cash crop are confounding. Although income is lost because of the reduction in area of the most economically important crop, expenses are reduced if the rotation crop requires fewer inputs and also results in the need for fewer inputs for the cash crops. For example, in our proposed rotation system, we assume that in a 200 acre farm in the bahiagrass rotation, there would be 100 acres of bahiagrass (50 acres one year old and 50 acres 2 years old), 50 acres of cotton, and 50 acres of peanuts. We expect the increase in yield in the peanuts and cotton to be 50% following the bahiagrass, and that the bahiagrass sod would produce about 5 tons per acre of hay the second year to be sold for $2.50 per 50 lb square bale. We also assume that the farm has 40 tons of quota peanut that would sell for $618 per ton and the additional at $300 per ton. The cost of establishing, maintaining and harvesting the bahiagrass is estimated at $210 per acre and the cost of producing the peanuts and cotton is estimated at $370 per acre. These are estimates based on average year expenses and returns. When returns and expenses are totaled, the farm practicing the bahiagrass rotation realizes an average profit of $35,500/year whereas the farm with no bahiagrass realizes less than $15,700 profit per year (Table 1). A 200 acre farm grazing cattle on the bahiagrass can realize a profit of nearly $45,000. The major factors in increased profit are a reduction in production costs of the crops (nearly $7,000) and the sale of the bahiagrass as hay or the cattle operation.

Obviously a critical aspect of this system is the increase in yield as a result of the bahiagrass; however, the grower community has experienced such increases in yields for years. They will pay a premium to rent land in bahiagrass, and regularly the top state peanut producer from Alabama, Georgia, or Florida reports they followed bahiagrass. This study will document the growers' experiences and determine the mechanisms responsible for the increase. At present, growers search to rent land in bahiagrass rather than integrating it into their own farm.

Another critical aspect of the economics of the project is the potential income generated from the bahiagrass sod. In the present economics model, the sod is harvested for hay as either 1,000 lb roles or 50 lb square bales, and marketed as such. Presently, the large roles sell for about $25, whereas the square bales sell for $2.50. Thus, the economics obviously favors the square bales; however, more work is required and a market for the bales must be available. In this study we will also develop information on the feasibility, including labor demands and economics, of putting cattle on the 2 year old bahiagrass and possibly in the late summer and fall on the 1 year bahiagrass. We have had a lot of interest in this information, as many of the small row crop farmers in the southeastern United States also have small herds (less than 100 head) of cattle. The Florida site will conduct the study as a cow-calf operation, whereas the Alabama site will begin with a stocker operation. We expect that the addition of the cattle may affect the nutrient status of the soil, but that the larger benefits of the sod rotation will not be affected. Other sites at Florida and Georgia will not have cattle and the sod will be harvested as hay.

The major changes in pesticide use, other than the reduction in area of both peanuts and cotton, is the need to kill the bahiagrass in the fall of its second year (we will use glyphosate at 1 qt per acre) and a reduction in peanut leafspot sprays from 6 to 3. We also anticipate a reduction in the need for nematicides, but expect about 50% of the farms will still use aldicarb or thimet to control thrips on cotton. However, those that use a peanut variety resistant to tomato spotted wilt virus (which is vectored by thrips and the reason they must be controlled) will not need aldicarb, as the bahiagrass will eliminate the need to control the nematodes.

The cost for pesticides for growing conventional peanuts and cotton are calculated to be $141 per acre and $37 per acre, respectively. In the conventional farming system with 200 acres in a 3 year rotation, any given year will have 66 acres in peanuts and 134 acres in cotton for a total farm cost of $14,256.

In the bahiagrass rotation, the cost for pesticides for bahiagrass is $7.50 per acre or $375 on the 50 acres to kill it with glyphosate in the fall before peanuts. No other pesticides will be needed for bahiagrass. For the peanuts in rotation, the pesticide cost is reduced to $95 per acre because of the reduction in leafspot sprays and aldicarb application. In the cotton the cost per acre remains the same, $37 per acre. In the bahiagrass rotation, the annual cost for pesticides in the 50 acres of peanuts will be $4,756 and in the cotton, $1,325. In sum, the total cost for pesticides in the grass rotation will be $6,600, as compared to $14,250 in the conventional farming system, a reduction in costs of over $7,500.

Crop rotation has been a viable means of pest control since agriculture began. When combined with advances in IPM and minimum till technology, we feel it is now possible to develop an economic and environmentally sustainable row crop rotation system for farmers in the Southeast while reducing pesticide use, equipment costs, and labor. The systems approach used in this project will help assure that the delivered information will be appropriate for rapid implementation and adoption by the grower community.

This project directly addresses the plight of small row crop farmers in the Southeast. By integrating sod based rotations on small farms, it will be possible to stop the economic and environmental decline ruining many individual farmers and small rural communities. The proposed farming system will increase farm profitability, increase soil health, decrease the need for some inputs (including water and pesticides) and diversify the economic base of the small farm. This is a multi-state (Alabama, Georgia, Florida), multi-institutional (Auburn University, University of Georgia, University of Florida, and the United States Department of Agriculture), and multi-disciplinary (agronomy, entomology, soil science, weed science, plant pathology, nematology, animal science, economics) project that effectively integrates agricultural research, extension and education. The major impact will be directed to the small and mid-sized farms in the southeastern United States, but the principals and practices developed will be largely scale neutral and will apply to row crop production world wide, especially in areas where soil conservation is critical and farm resources are low. The delivery of an effective row crop production system that is economically and ecologically viable and competitive with world market prices will have a tremendously positive impact on the many rural farm-based communities in the Southeast.

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Table 1. Income and expenses associated with a bahiagrass sod rotation and traditional peanut- cotton rotation. This model and the assumptions within it can found at http://nfrec.ifas.ufl.edu/Marois/Index.html.

Crop	Yield	Acres	Costs	Revenue	Profit
Conventional rotation (peanut-cotton-cotton)					
Cotton	650 lbs	134	49574	59228	9654
Peanut	2500 lbs	66	30995	37030	6035
	Total	200	80569	96258	15689
Bahiagrass rotation (bahia-bahia-peanut-cotton)					
Cotton	975 lbs	50	20204	33150	12946
Peanut	3750 lbs	50	24826	40405	15579
Bahia 1-yr	2 tons	50	10572	10000	-572
Bahia 2-yr	5 tons	50	17401	25000	7599
	Total	200	73003	108555	35552
Bahiagrass rotation with cattle					
Cotton	975 lbs	50	20204	33150	12946
Peanut	3750 lbs	50	24826	40405	15579
Bahia 1-yr	2 tons	50	10572	10000	-572
Cattle	68 calves	50	27794	44681	16887
	Total	200	83397	128236	44840

Table 2. Pesticide use and costs in conventional and bahiagrass rotations. This model assumes a 200-acre farm with conventional rotation of cotton-cotton-peanuts and the bahiagrass rotation phase of a bahiagrass-bahiagrass-peanuts-cotton rotation.

	Conventional Peanuts Size = 66 acres			Bahiagrass Rotation Peanuts Size = 50 acres		
Product	Rate/ acre	Cost/ acre	Total cost	Rate/ acre	Cost/ acre	Total cost
Glyphosate	1 pt	3.75	248	2 pt	7.50	375
2-4-D	1 pt	1.50	99	0 pt	0.00	0
Dinitroanaline	2 pt	5.00	330	1 qt	5.00	250
Paraquat	10 oz	2.25	149	10 oz	2.25	113
Bentazon	13 oz	6.00	396	13 oz	6.00	300
2-4-D Butryl	1 pt	4.38	289	1 pt	4.38	219
Chlorimuron	0.5 oz	2.50	165	0.5 oz	2.50	125
Chlorothalonil	4 x 1.5 pt	30.00	1980	2 x 1.5 pt	30.00	1500
Azoxystrobin	2 x 3 pt	75.00	4950	3 pt	37.50	1875
Aldicarb	3.5 lb	10.50	693	0 lb	0.00	0
	Total	141	9298	Total	95	4756

	Conventional Peanuts Size = 134 acres			Bahiagrass Rotation Peanuts Size = 50 acres		
Glyphosate	4 pt	15.00	2010	4 pt	15.00	750
2-4-D	1 pt	1.50	201	1 pt	1.50	75
Aldicarb	3.5 lb	10.50	1407	3.5 lb	10.50	525
Orthene	2 pt	10.00	1340	2 pt	10.00	500
	Total	37.00	4958	Total	37.00	1850

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Nutrient Management

LONG TERM APPLICATION OF POULTRY BROILER LITTER TO COTTON AND CORN

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ABSTRACT

Poultry broiler litter has been applied to crops on a Coastal Plain soil (fine-loamy, siliceous, thermic Typic Kandiudults) since 1991 in Alabama. Variable N rates from 0 to 240 lbs acre-1 were applied based upon the total N content of poultry broiler litter and compared to fertilizer N rates as ammonium nitrate. Conventionally tilled cotton was produced 1991-1994; conservation tilled corn was planted 1995-1997; and conservation tilled cotton has been planted since 1998 to evaluate surface applications and residual effects of broiler litter on cotton. The relationship between the N rates (N) and relative N availability (y) based on the crop yield can be described by linear equation: $y=71.58+0.15N$ ($r=0.66^*$, $n=22$). Residual effect of broiler litter the year following application produced 30 to 50% cotton lint yield and 25 to 65% corn grain yield relative to the current season's application. General observations suggest that N availability from broiler litter is similar whether surface applied as in conservation tillage systems or incorporated as in conventionally tilled systems.

KEYWORDS

Manure, broiler litter, poultry litter, cotton, corn, nitrogen availability, nitrogen fertilization

INTRODUCTION

Alabama produces almost 3 times more poultry broiler litter (by weight) as commercial fertilizers used. In regions of intensive poultry production, most broiler litter is over applied to pastures and hayfields creating potential nutrient enrichment of surface and ground waters. Row crop farmers have been reluctant to use broiler litter on their crops, especially cotton. Reasons may include:

- Perception among cotton producers that manure-N sources would produce excessive vegetative growth and late maturity of cotton.
- Suspicion that animal manures may introduce weed seed into prime cotton land.
- Lack of extensive published, applied research with manures on cotton.
- Most cotton land is often remote from the smaller farms where poultry is produced
- Availability of broiler litter may not coincide with optimum time of fertilizing cotton at planting in the spring.
- Reluctance of cotton producers to change successful production practices.

In 1990, an experiment began at the Tennessee Valley Research and Education Center in North Alabama to address concerns about the use of broiler litter on cotton. This experiment was discontinued after the 1993 growing season (Mitchell *et al*., 1995. Broiler litter on cotton. 1995 Proc. Beltwide Cotton Conf. p. 1338-1339. Nat. Cotton Council. Memphis, TN.). An identical experiment was started at E.V. Smith Research Center in Central Alabama in 1991 and has continued with modifications for over 10 years. Today, it is one of the longest running, continuous experiments in the U.S. with poultry manure on crops.

The objectives of the experiment over the years have been to:

1) evaluate broiler litter as a source of N for cotton and corn;
2) determine the availability of N in broiler litter compared to ammonium nitrate fertilizer;
3) determine if plant growth regulators would be needed to control excessive vegetative growth of cotton fertilized with broiler litter;
4) determine the residual effects of broiler litter on cotton and corn production and soil properties; and
5) demonstrate to area producers the practicality of using broiler litter as an alternative fertilizer for cotton.

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Table 1. Mean values of broiler litter on an as-sampled basis (n = 11) that was used in test from 1991 through 2001.

Analysis	Mean	SE	Min.	Max.
Moisture, %	24.4	9.20	14.4	38.5
Ash, %	27.3	6.70	20.5	37.4
Total N, %	2.98	0.63	2.04	4.14
NH_4-N, %				
P_sO5, %	3.92	0.40	3.37	4.75
K_2O, %	2.80	0.53	1.80	3.56
Ca, %	2.43	0.24	2.01	2.89
Mg, %	0.54	0.05	0.47	0.60
Cu, mg kg^{-1}	508	154	300	751
Zn, mg kg^{-1}	401	86	250	562
Mn, mg kg^{-1}	439	138	310	669
Pb, mg kg^{-1}	14	6.00	9	21
B, mg kg^{-1}	51	10	39	71

METHODS

The site of the experiment is on the Field Crops Unit of E.V. Smith Research Center in Central Alabama. The site is in the Upper Coastal Plain soil physiographic region and the soil is mapped as a Norfolk fine sandy loam (fine-loamy, siliceous, thermic Typic Kandiudults).

Conventionally tilled cotton was grown from 1991-1994, corn from 1995-1997, and conservation tilled cotton since 1998. The experiment contains 11 treatments replicated 4 times. Treatments are different rates of broiler litter or ammonium nitrate based solely upon the TOTAL N in the material.

All broiler litter is broadcast just prior to planting at a rate based upon the TOTAL N concentration in the litter (Table 1); ammonium nitrate rate is split with 1/2 applied at planting and 1/2 applied as a sidedress. All treatments except broiler litter treatments receive 60 pounds P_2O_5 and 60 pounds K_2O per acre as concentrated superphosphate and muriate of potash, respectively, just prior to planting.

When conventionally tilled cotton was planted (1991-1993), Pix® (mepiquot chloride) was used on half of the broiler litter treatments to determine if a plant growth regulator was needed. Approximately 8 total ounces per acre were applied in multiple applications. This treatment was dropped when conservation tilled corn was planted in 1995 and conservation tilled cotton in 1998. Residual broiler litter treatments in 1995-2001 received no additional fertilization the year after application. Since 1995, the broiler litter treated plots and residual broiler litter plots have rotated.

Conventional tillage included using a moldboard plow, disk, field cultivator, and cultivator to control weeds. Plots were winter fallowed, and all nutrients were incorporated just prior to planting under conventional tillage. Conservation tillage followed winter rye planted as a cover crop; all nutrients were surface applied just prior to planting into rye residue after spraying with glyphosate. All rows were in-row subsoiled to 35 cm every spring just prior to planting. There was no mechanical cultivation. Yields were estimated by harvesting the two center rows in each 8-row plot.

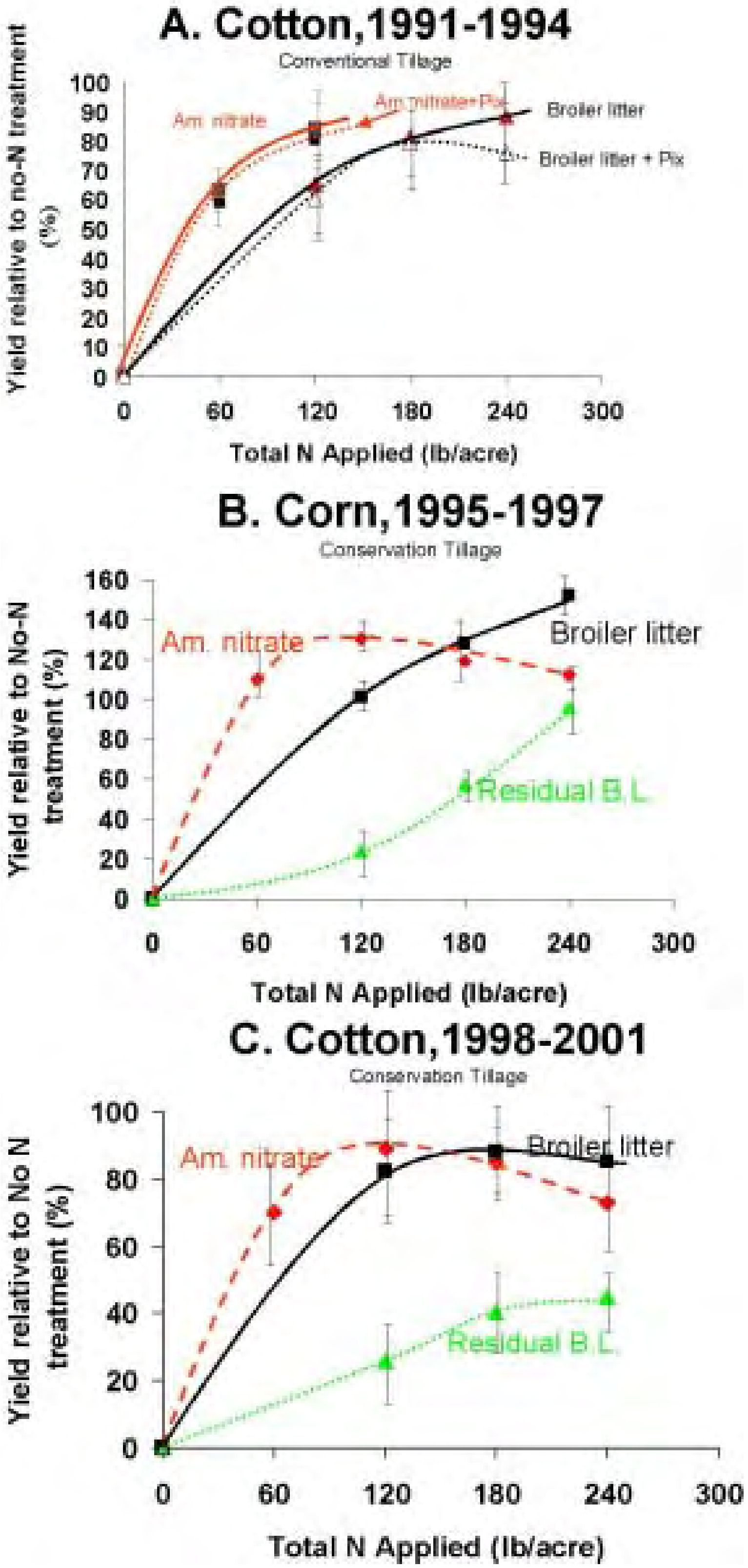
RESULTS

Because this is a non-irrigated study, yields varied considerably from year to year depending upon rainfall (Table 2). However, high cotton lints yields are near 2 bales per acre

Table 2. Highest average cotton and corn yields produced on this study by year, 1991-2001.

Year	Highest yield	Treatment
Cotton, conventional tilled (lbs lint $acre^{-1}$)		
1991	1200	Broiler litter @ 180 lbs N $acre^{-1}$
1992	990	Broiler litter @ 240 lbs N $acre^{-1}$
1993	911	Broiler litter @ 180 lbs N $acre^{-1}$
1994	990	Am. nitrate @ 120 lbs N $acre^{-1}$
Corn grain, conservation tilled (bu $acre^{-1}$)		
1995	70	Broiler litter @ 240 lbs N $acre^{-1}$
1996	133	Am. nitrate @ 120 lbs N $acre^{-1}$
1997	153	Broiler litter @ 240 lbs N $acre^{-1}$
Cotton, conservation tilled (lbs lint $acre^{-1}$)		
1998	855	Am. nitrate @ 120 lbs N $acre^{-1}$
1999	1020	Broiler litter @ 120 lbs N $acre^{-1}$
2000	812	Broiler litter @ 240 lbs N $acre^{-1}$
2001	1520	Broiler litter @ 240 lbs N $acre^{-1}$

Fig. 1. Average cotton lint and corn grain yields relative to the no-N check as affected by total N rate applied as ammonium nitrate and poultry broiler litter. Residual B.L. is the relative yield the year following broiler litter application where no additional fertilizer was applied.



with the exception of 1998 and 2000. Over 3 bales per acre were produced in 2001 using the highest rate of broiler litter. Corn grain yields were very good for Central Alabama in two of the three years. Mean yields are presented in Tables 3 and 4.

In general, the total N in broiler litter is only slightly less available to crops compared to nitrogen from ammonium nitrate fertilizer. Under conventionally tilled cotton from 1991-1994 (Figure 1a.), we needed between 180 and 240 pounds total N as broiler litter to produce the same cotton lint yield as 120 pounds N per acre as ammonium nitrate. These first years of the study seemed to support Alabama Cooperative Extension recommendations that about 2/3 of the total N in broiler litter would be available to the crop the year it was applied. The plant growth regulator, Pix®, had no significant affect on cotton yield.

In 1995 when conservation tilled corn was planted, we began rotating the treatments receiving broiler litter so we had 1-yr residual broiler litter treatments. Ammonium nitrate treatments were increased to match the total N applied in broiler litter. The average over three years of corn indicated that about 160 pounds total N in broiler litter (surface applied at planting) was needed to produce the same corn yield as 120 pounds N as ammonium nitrate in split applications (Figure 1b.) There is significant carryover of N from broiler litter treatments into the second year. Although the presidedress soil nitrate test failed to detect any residual nitrate-N to a depth of 2 feet (data not shown) the crop was certainly able to respond to residual N. However, residual N from the highest broiler litter application rate the previous year failed to produce yields equivalent to 60 pounds N per acre as ammonium nitrate.

Surprisingly, nitrogen availability is about the same whether it is surface applied as in conservation tillage or incorporated as in conventional tillage. In fact, from 1998-2001 we needed about 140 pounds N as broiler litter surface applied to produce the same cotton yield as 120 pounds N as ammonium nitrate. We see a similar pattern

Table 3. Mean cotton lint yields for conventionally -tilled cotton, 1991-1994.

N source	Total N	Cotton yield†	
	-- lbs acre^{-1}--	-----lbs lint acre^{-1}---	
No N	0	550	d
Am. nitrate	60	840	bc
Am. nitrate	60 + Pix	840	bc
Am. nitrate	120	940	abc
Am. nitrate	120 + Pix	940	abc
Broiler litter	120	880	abc
Broiler litter	120 + Pix	850	bc
Broiler litter	180	960	a
Broiler litter	180 + Pix	950	ab
Broiler litter	240	970	a
Broiler litter	240 + Pix	940	abc

†Means followed by the same letter are not significantly different at $P = 0.05$.

of residual N from broiler litter on cotton yield, although cotton is not as responsive to N as corn.

When all data for the 11-yr experiment are combined in an attempt to estimate an availability factor for broiler litter for cotton and corn, we found that at about 186 pounds total N, the availability of N from broiler litter is the same as that from ammonium nitrate (Fig. 2). High rates of broiler litter seem to enhance crop growth above and beyond what can be explained by nitrogen fertility alone. This has been documented before and may be attributed to increased soil organic matter, improved soil physical condition, enhanced growth of beneficial soil microorganisms, control of certain soil borne pathogens e.g. nematodes, plant growth regulators produced by decomposing broiler litter, *et cetera*. At a N rate of 120 pounds N per acre, which is the recommended N rate for non-irrigated corn in Alabama and is the optimum N rate as ammonium nitrate for cotton on this site (Fig. 1), the N availability factor for broiler litter is 90%.

Fig. 2. Nitrogen availability from poultry broiler litter compared to ammonium nitrate for cotton and corn, 1991-2001.

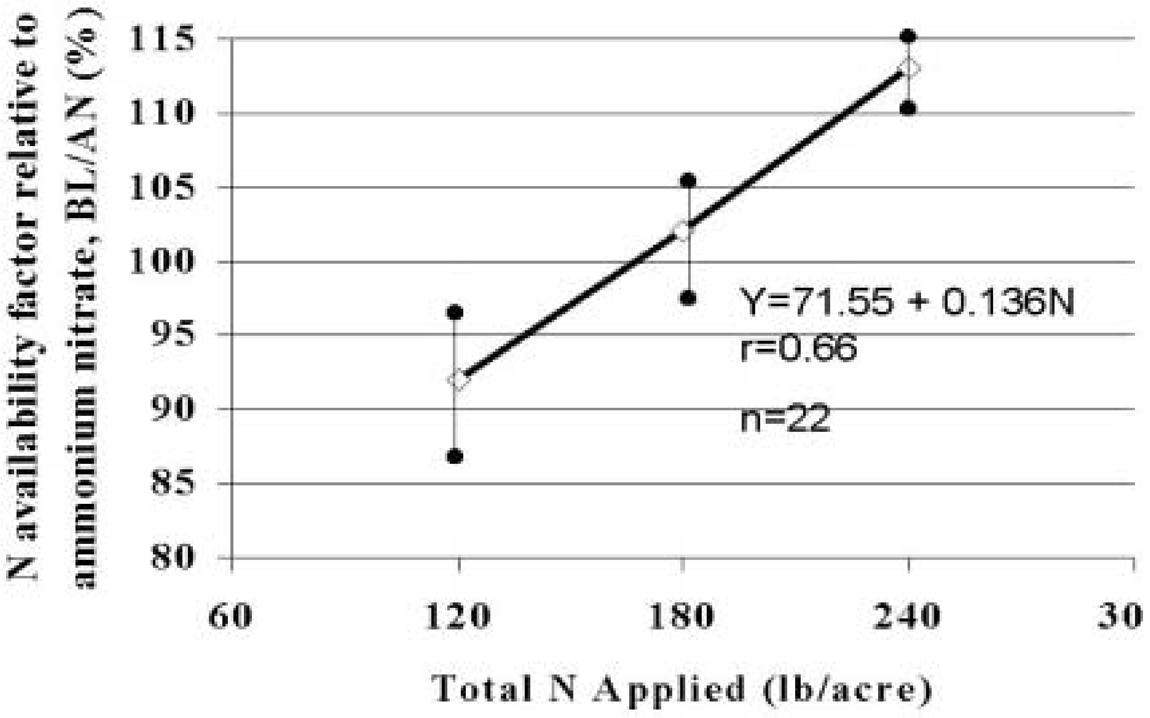


Table 4. Mean yields for conservation-tilled corn (1995 - 1997) and cotton (1998- 2000)

N source	Total N rate	Corn, 1995-1997*		Cotton, 1998-2001†	
	--- lbs acre^{-1} --	----- bu acre^{-1} -----		---- lbs lint acre^{-1} --	
No N	0	46	e	540	c
Am. nitrate	60	99	bc	940	a
Am. nitrate	120	107	ab	1030	a
Am. nitrate	180	103	abc	990	a
Am. nitrate	240	98	bc	940	a
Broiler litter	120	107	ab	990	a
Broiler litter	180	103	abc	1020	a
Broiler litter	240	117	a	1040	a
Broiler litter	120 Residual	58	e	680	b
Broiler litter	180 Residual	73	d	760	b
Broiler litter	240 Residual	89	c	780	b

†Means followed by the same letter are not significantly different at $P = 0.05$.

CONCLUSIONS AND RECOMMENDATIONS

Over ten years of research with broiler litter on cotton and corn on a Central Alabama Coastal Plain soils have demonstrated that broiler litter can be used as the sole N source for cotton. Broiler litter may all be applied at planting and rates can be based upon the total N in broiler litter. Rates do not need adjusting when surface applied and not incorporated as in conservation tillage systems. Residual N from broiler litter on cotton is small but significant. On fields that have not received previous applications of broiler litter, assume a N availability factor of 2/3. However, because of the residual effect of N two years after application, long-term availability factors will be around 90% at recommended N rates.

LINT YIELD ADVANTAGES OF NO-TILL AND POULTRY LITTER-BASED COTTON/RYE CROPPING SYSTEM IN A SOUTHERN PIEDMONT SOIL: A FIVE-YEAR DATA SET

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ABSTRACT

Cotton [*Gossipium hirsutum* (L.)] is a dominant crop in the Southeast. It is largely grown using conventional tillage and fertilizers. Georgia and bordering states produce about 42% of the poultry in the United States, but only a small percentage of the litter is utilized as fertilizer. We measured and compared cotton yield from conventional tillage (CT) and no-till (NT) plots fertilized either with ammonium nitrate as conventional fertilizer (CF) or poultry litter (PL) from 1996 to 2000 near Watkinsville, GA. The soil was a Cecil sandy loam (fine, kaolinitic thermic Typic Kanhapludult), a dominant soil series in the Southern Piedmont. The four treatments CTCF, CTPL, NTCF, and NTPL were replicated three times on twelve nearly level (0-2% slope) 30 ft by 100 ft plots. Rye [*Secale cereale* (L.)] was the winter cover crop. Mean lint yields over five years in lbs acre^{-1} were: 971 for NTPL, 915 for NTCF, 753 for CTPL, 686 for CTCF, 943 for NT, 719 for CT, 862 for PL, and 800 for CF. Statistically significant (P = 0.05) yield differences were: NTPL > CTCF by 42%, NTCF > CTCF by 34%, NTPL > CTPL by 29%, NTCF > CTPL by 22%, and NT > CT by 31%. Drought during first bloom to peak bloom reduced yield and negated all treatment effects in the fourth year and reduced yield in the fifth year. It is possible to increase cotton productivity in the Southern Piedmont by adopting no-till and fertilizing with poultry litter instead of tilling and fertilizing conventionally.

KEYWORDS

Conservation tillage, no-till, poultry litter, Cecil sandy loam

INTRODUCTION

The Southern Piedmont lies in southeastern USA extending along the eastern face of the Appalachian Mountains from Virginia to Alabama and covering approximately 40.7 million acres. Soil erosion has been a serious problem in the region as a result of over 200 years of intense row crop agriculture (Bruce and Langdale, 1997). Much of the row crop agriculture is conventionally tilled and fertilized. The soils have relatively low fertility and organic matter, are highly erodible and easily compacted by rainfall and machine traffic (Carreker *et al*., 1977). The soils, however, are responsive to good management practices, including adequate levels of nutrients, and cropping systems that restore organic matter and soil structure increase available water and reduce machine traffic, such as those under conservation tillage. Conservation tillage has many benefits such as soil and water conservation, lower production costs, higher yields, and greater production efficiency (CTIC 1998; Domitruk and Crabtree, 1997; Langdale *et al*., 1992).

Cotton and poultry production are of great economic importance in the Southeast. In Georgia, for example, cotton acreage increased from about 0.3 million in 1987 to about 1.4 million in 1996 (Rodekohr and Rahn, 1997). Poultry production is a growing agribusiness in Georgia worth about $10 billion annually (Rodekohr and Rahn, 1997). The poultry enterprise produces large quantities of litter annually. Poultry litter is typically applied to pasture and crop land because of its nutrient value (Moore *et al*., 1995) and because it is considered to be environmentally safe to do so (Edwards and Daniel, 1992). However, only a small percentage is applied to crop land. Reasons for this include: limitations of timely availability of poultry litter for application to row crops; perceived risk due to variability in nutrient content compared to conventional fertilizers; and insufficient information on its impact when used in conservation tillage and on different crops.

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The Southern Piedmont has a favorable climate, including 200 to 250 frost-free-days and abundant and generally well-distributed annual rainfall, that supports production of a wide range of crops that include cotton. However, short-term summer droughts that can lead to yield reduction are common. Cotton under conventional tillage is more at risk of suffering moisture stress during these drought periods because of factors such as crusting, pore size distribution and connectivity, which reduce soil water reserves. Conservation tillage often creates a more favorable soil water regime by improving surface soil properties that favor more infiltration and conduction of water to lower soil profile and, consequently, a higher reserve of soil water (Fawcett *et al*., 1994). Conservation tillage systems are recommended for cotton production on highly erosive soils (Bradley, 1995).

Adoption of conservation tillage for major crops such as cotton and soybeans has risen in the Southeast in recent times. According to CTIC (2000), about 20% of the cotton and 58% of the soybeans in the Southeast are now under no-till, a form of conservation tillage. Nationally, approximately 37% of crops were planted with conservation tillage in 2000. Research evaluating the performance of cotton managed under contrasting tillage and nutrient sources is limited in the Southern Piedmont. The objective of this research was to evaluate and compare lint yield from no-till and conventionally tilled cotton fertilized either with poultry litter or ammonium nitrate on a Cecil soil, the dominant soil series in the Southern Piedmont.

MATERIALS AND METHODS

Experimental Site and Soil

The experiment was conducted from 1996 to 2000 at the USDA-ARS, J. Phil Campbell, Sr., Natural Resource Conservation Center, Watkinsville, Ga (83°24' W and 33°54' N) on 12 subsurface-drained and instrumented plots, each 30 ft by 100 ft, located on nearly level (0-2% slope) Cecil sandy loam (fine, kaolinitic thermic Typic Kanhapludults). Typic Kanhapludults cover about two-thirds of approximately 34.8 million acres available for cropping in the Southern Piedmont (Langdale *et al*., 1992). Endale *et al*. (2002) give details for climate and soil characteristics of the research site.

Tillage and Fertilizer Treatments

The experiment was laid out as a randomized complete block split-plot design with three replications. Conventional tillage (CT) and no-tillage (NT) were main plots. Fertilizer subplots consisted of ammonium nitrate as conventional fertilizer (CF) or poultry litter (PL). The CT consisted of a 12 in. deep chisel plowing to break possible hard pans, followed by a one to two diskings to a depth 8 in., and a subsequent disking to 3 in. to smooth the seed bed. The only soil disturbance in NT was a coulter disk for planting. NT treatments have continued on the same plots since the fall of 1991.

Fertilizer rates were targeted at 54 lbs available N acre^{-1}. This amounted to an application of 2 tons acre^{-1} (30% moisture) for poultry litter. Mineralization of N in poultry litter was assumed to be 50% (Vest *et al*., 1994) during the cotton season. A specially designed spreader was used to apply fresh litter that was brought to the research site and kept under cover for no more than two weeks. Soil tests were used to determine P and K needs and rates. All N, P and K fertilizers were applied one to two days before cotton planting each year.

Cropping System and Operations

Details for cropping system and operations are given in Endale *et al*. (2002). These are summarized in this section. The cropping system consisted of rye (cv. Hy-gainer) grown from November to May as a cover crop, followed by cotton grown from May to November. Light disking was carried out in CT plots in November, two to three days prior to planting rye. Ammonium nitrate (50 lbs N acre^{-1}) and potassium chloride (40 lbs K acre^{-1}) were applied on all plots and incorporated by light disking in CT but not NT plots. Glyphosate [N-(phosphonomethyl) glycine] was applied to kill the rye about two weeks prior to cotton establishment. Rye produced 2680 to 4465 lbs of dry matter residue acre^{-1}.

Cotton pesticides were: aldicarb [2-methyl-2-(methylthio) propionaldehyde o-(methylcarbamoyl) oxime], fluometuron [N,N-dimethyl-N‘-(3-trifluoromethyl-phenyl) urea], and pendimethalin [N-(1-ethylpro-pyl)-3,4-dimethyl-2,6-dinitrobenzenamine]. Except for aldicarb, which was applied at the same time as planting, fertilizers and pesticides were applied one to two days before planting and were incorporated into the soil by light disking in CT and applied only to the soil surface in NT plots.

The early-maturing ‘Stoneville 474’ cotton cultivar was planted in 34-inch rows at three to four plants per foot in 1996 and 1997. Planting dates were 30 May 1996, 14 May 1997, 14 May 1998, 16 May 1999, and 24 May 2000. Harvesting was on 1 November 1996, 4 November 1997, 12 November 1998, 10 November 1999, and 16 November 2000.

Additional chemical and mechanical means were used to control persistent sporadic weeds after cotton emergence. Vegetative growth of cotton was controlled on all plots in 1996 and 1997 with the growth regulator mepiquat chloride

[Mepiquatchloride: N,N-dimethyl-piperidinium chloride]. Due to persisting drought conditions, mepiquat chloride was not applied after 1997. Dimethipin [2,3-dihydro-5,6-dimethyl-1,4-dithiine 1,1, 4-tetraoxide)], a defoliant, and ethephon[(2-chloro ethyl)phosphonic acid], a boll opener, were also used two weeks prior to harvest. Cotton was hand harvested first for yield determination and the rest was mechanically harvested. Stalks were shredded after harvest with a rotary mower. Yield was expressed as lint as 40% of seed cotton weight and at 10% moisture.

DATA ANALYSIS

Data were analyzed using the MIXED procedure of SAS (Littell *et al*., 1996). Degrees of freedom were calculated using the SATTERTH option in the MODEL statement. In addition, yield was analyzed as repeated measures for years, with Heterogeneous Compound Symmetry (CSH) error structure providing the best fit of variance and covariance among the residuals. All significant differences are reported at $P = 0.05$.

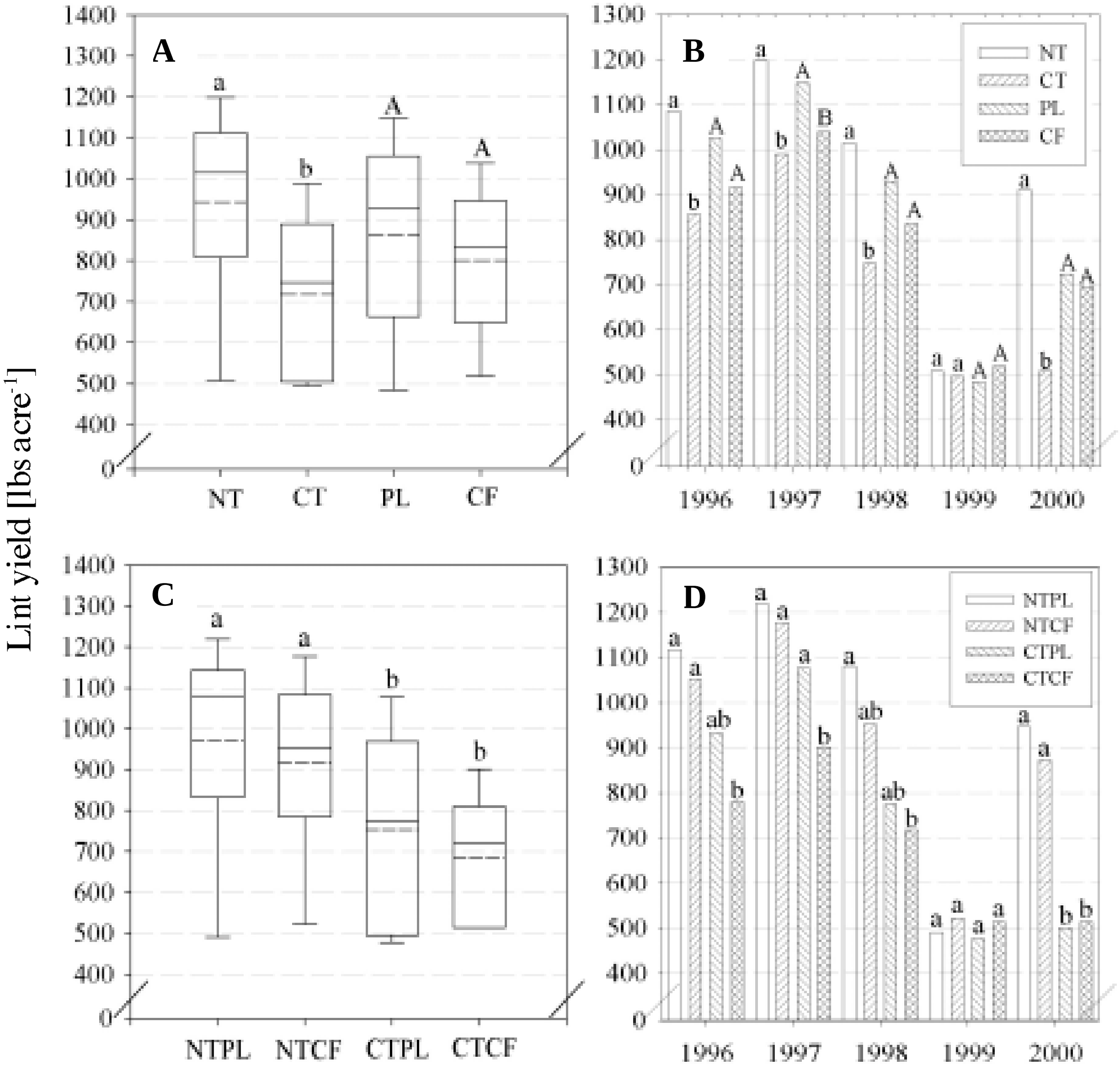

Fig. 1. Lint yield from 1996 to 1999: (A) boxplots with the five years average shown as dashed lines inside a box; (B) average yield per year. Treatments with the same letters above the boxes and bars are not significantly different at $P = 0.05$ (lower case letter show differences between NT and CT, and upper case letters between PL and CF); (C) boxplots with the five years average shown as dashed lines inside a box; (D) average yield per year. Treatments with the same letters above the boxes and bars are not significantly different at $P = 0.05$.

RESULTS

MEAN YIELDS

Mean yields over five years from NT, CT, PL and CF are shown in Fig. 1A and for individual years in Fig. 1 B. Similarly, Figs. 1C and D show mean yield from NTPL, NTCF, CTPL and CTCF over 5 years and for individual years, respectively. Statistical differences at $P = 0.05$ are indicated by letters above the boxplots and bars in both figures. Lower case letters are used to compare NT with CT and upper case letters for PL with CF in Figs. 1A and B. Yields between two treatments with the same letter above the boxplots or bars are not significantly different. Variance was smallest in CTCF. The other 3 treatments had similar variances that were about 2 to 3 times that of CTCF.

YIELD COMPARISONS

NT vs. CT

Yield was 21 to 79 % significantly greater from NT than from CT each year, except in 1999 (Fig. 1B). The greatest difference was in 2000. Yield from NT was 31% significantly greater over five years (Fig. 1A). Drought in 1999 suppressed yield in all treatments and negated treatment differences. Endale *et al.* (2002) attribute this to 35 days of drought, which coincided approximately with first bloom to peak blooming period, when the plant was most susceptible to water stress but received only 0.78 in. of rainfall. Rainfall during the equivalent 35 days period for the other four years varied from 3.8 to 7.8 in. Endale *et al.* (2002) reported that during the first four years of research including 1999, 88 to 93% of the yearly yield variation per treatment could be explained by the rainfall amount during this 35-day critical period. This period will be referred to as “week 10 to 14” henceforth.

PL vs. CF

Yield from PL was 4 to 12% higher than CF except in 1999, when CF yielded 7% more lint (Fig. 1B). These differences were not significant except in 1997, where PL yielded 11% more than CF. This could help explain the fact that, although not significant at $P = 0.05$, the 7% difference between PL and CF over five years (Fig. 1A) is significant at $P = 0.1$.

NTPL vs. NTCF

PL did not cause a significant yield difference over CF in the NT treatments in individual years or over five years (Figs. 1C and D). Nevertheless, yield from NTPL was 4 to 13% higher than that from CTCF except in 1999, when NTCF yielded 6% more lint. Over five years NTPL yielded 6% more than NTCF (Fig. 1C).

NTPL vs. CTPL

NT had variable effects on yield in plots receiving PL (Figs. 1C and 1D). Over five years, NTPL produced 29% significantly greater lint than CTPL (Fig. 1C). In 2000, yield was 89% significantly higher from NTPL. In 1996 and 1997 NTPL had greater yield by 13 and 39%, respectively, but the differences were significant at $P = 0.1$ and not at $P = 0.05$. In 1999 NTPL produced only 3% more lint than CTPL.

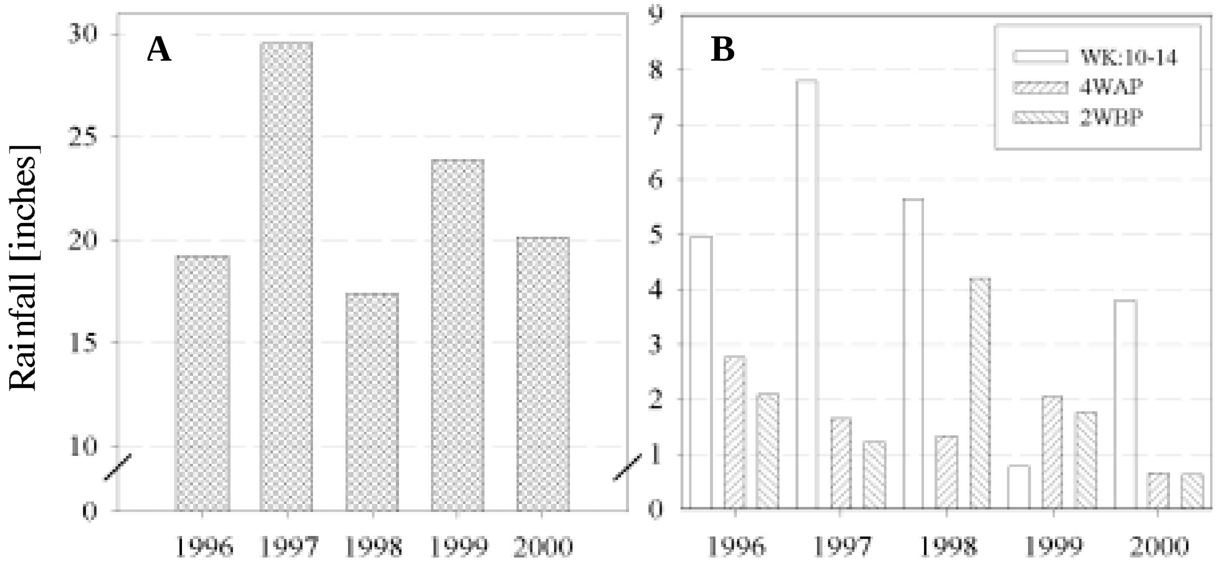

Fig.2. Rainfall during various periods of cotton growth from 1996 to 2000: (A) for weeks 1 to 20; (B) for weeks 10 to 14 [WK:10-14], for 4 weeks after planting [4WAP], and for 2 weeks before planting [2WBP].

NTPL vs. CTCF

The greatest yield differences were observed between NTPL and CTCF. Yields were significantly greater by 35 to 84% from NTPL in four of the five years and 42% greater over five years (Figs. 1C and D). The greatest difference was in 2000. The 1999 drought suppressed yield differences that year. In fact, CTCF produced 4.7% more in 1999 but the difference was not significant.

NTCF vs. CTPL

NTCF produced 9 to 22% more lint than CTPL from 1996 to 1999 but none of the differences were significant (Fig. 1D). In 2000, however, NTCF produced 74% significantly more; and, as a result, yield over five years was 22% significantly greater from NTCF than CTPL.

NTCF vs. CTCF

The second greatest yield differences were between NTCF and CTCF. In four of the five years, NTCF produced 30 to 70% significantly higher yield than CTCF, with the greatest difference occurring in 2000. In 1999, however, yield was only 1.6% higher from NTCF. Over five years, yield was 33% significantly higher from NTCF.

CTPL vs. CTCF

CTPL produced 8 to 20% more lint than CTCF during the first three years of which only the 1997 difference was significant. CTCF actually produced 7.8% more in 1999 and 2.6% more in 2000, but none of these differences were significant.

RAINFALL PATTERNS

The timing or distribution as well as the total amount of rainfall are important in determining yield. To attempt to explain the temporal variation in yield in our research, rainfall patterns are presented in Fig. 2A and B. Rainfall for the first 20 weeks of the cotton season is presented for each year in Fig. 2A. Rainfall during the 20- week period varied between 15 and 20 in. from 1996 to 2000. The differences do not reflect the corresponding yield differences. In fact, 1999 received the second highest rainfall during the 20 weeks. Rainfall during two critical periods of growth: first bloom to peak bloom (weeks 10 to 14) and germination and early stand establishment are presented in Fig. 2B. Rainfall in the two weeks before planting, and during the first four weeks are critical for germination and stand establishment. After week 4, differences between the cumulative rainfall became smaller among the years. In 2000, rainfall was about 0.63 in. each in both the two weeks before planting and the four weeks after. Rainfall in the equivalent period of the other years varied from1.34 to 4.21 in. (2 to 6 times).

DISCUSSION

DROUGHT

The Southeast has been dominated by a harsh drought that started in mid-1998. Cotton is generally considered as one of the most drought tolerant field cops in the Southeast. However, large yield reductions occur when there is water deficit from first bloom to peak bloom period, and loss of yield may not be recovered even if the deficit is lifted at a later date (Sweeten and Jordan, 1987). As indicated, severe water deficit occurred in 1999 from week 10 through 14 of the cotton-growing season. This coincided approximately with the period of first bloom to peak bloom. Rainfall in inches in ascending order during this critical period was: 0.78 for 1999, 3.80 for 2000, 4.97 for 1996, 5.66 for 1998, and 7.81 for 1997 (Fig. 2B). Not only was yield drastically curtailed in 1999 compared to other years, but all treatment differences were negated too (Figs. 1B and D). A linear regression of these rainfall amounts with mean yields for the equivalent years per-treatment indicated that 77 to 93 % of the year-to-year yield variation for each treatment could be explained by the rainfall received during week 10 to 14. The coefficients of determination (r^2) were: 0.91 for NTPL, 0.93 for NTCF, 0.77 for CTPL, and 0.78 for CTCF (Fig. 3A and D).

The rainfall in 2000 during week 10 to 14 was the second lowest of the five years. Although the NT treatments were able to take advantage of this 3.8 in. rainfall and improve the yield over 1999, this did not happen with CT, which had yield close to the 1999 level. This was partially due also to dry conditions during planting and the germination period, which hindered germination more in the CT than NT treatments. In fact, some replanting was necessary in some areas in five of the six CT plots even though we were forced to irrigate all plots with about 0.35 inches of water during the first 10 days after planting to avoid total loss. Replanting meant that during harvesting some of the CT cotton might not have been quite ready. It also confounds the issue of critical period when planting date is staggered. As shown in Fig. 2B, rainfall in 2000 during a six-week period beginning two weeks before planting was only 1.3 inches.

In order to relate the combined effect of dry period early in the season and during blooming to yield, we did a non-linear regression of yield as a response variable to water supply during weeks 10 to 14 and weeks 1 to 4. The data fitted well an equation of the form

$$\mathbf{Z = a + bx + cy}$$

where Z is the mean yield, x is the rain for weeks 10 to 14, and y is the rain for weeks 1 to 4. The R^2 values were: 0.96 for CTCF, 0.98 for CTPL, 0.95 for NTCF, and 0.89 for NTPL. We were thus able to explain 96 to 98% of the yield variation for the CT treatments with this model. Recall that we could only explain 77 to 78% of the variation with a model utilizing the rain of weeks 10 to 14 only. We see also that this model fits the data a little better for NTCF. The model did worse for NTPL.

Soil Water Use and Yield Response

No-till systems can be used to reduce the negative impact of dry periods on cotton production. NT-based systems develop surface and subsurface soil physical conditions that lead to favorable soil water regimes. Endale *et al*. (2002) showed that change in soil water content during the 1998 cotton crop season of this research, an indicator of cotton water uptake, was highest in NTPL followed by NTCF, CTPL, and CTCF in that order.

Managing cotton in NT and fertilizing with either PL or ammonium nitrate has distinct yield advantages over conventionally tilled and fertilized cotton except in the years of severest water deficit. In this research, average yields during the first three years of adequate rainfall were above 1050 lbs acre^{-1} in NTPL and NTCF compared to 800 lbs acre^{-1} for CTCF. The yield advantage was greatest in NTPL. Although yield was reduced in all treatments in 1999 and 2000 due to water limiting conditions, yield differences between treatments considering all years were greatest in 2000 (70 to 89%). It appears that in 2000, the NT more than the CT-based systems were able to take advantage of the little irrigation during the first week for better and sustained germination, and the limited water supply during the

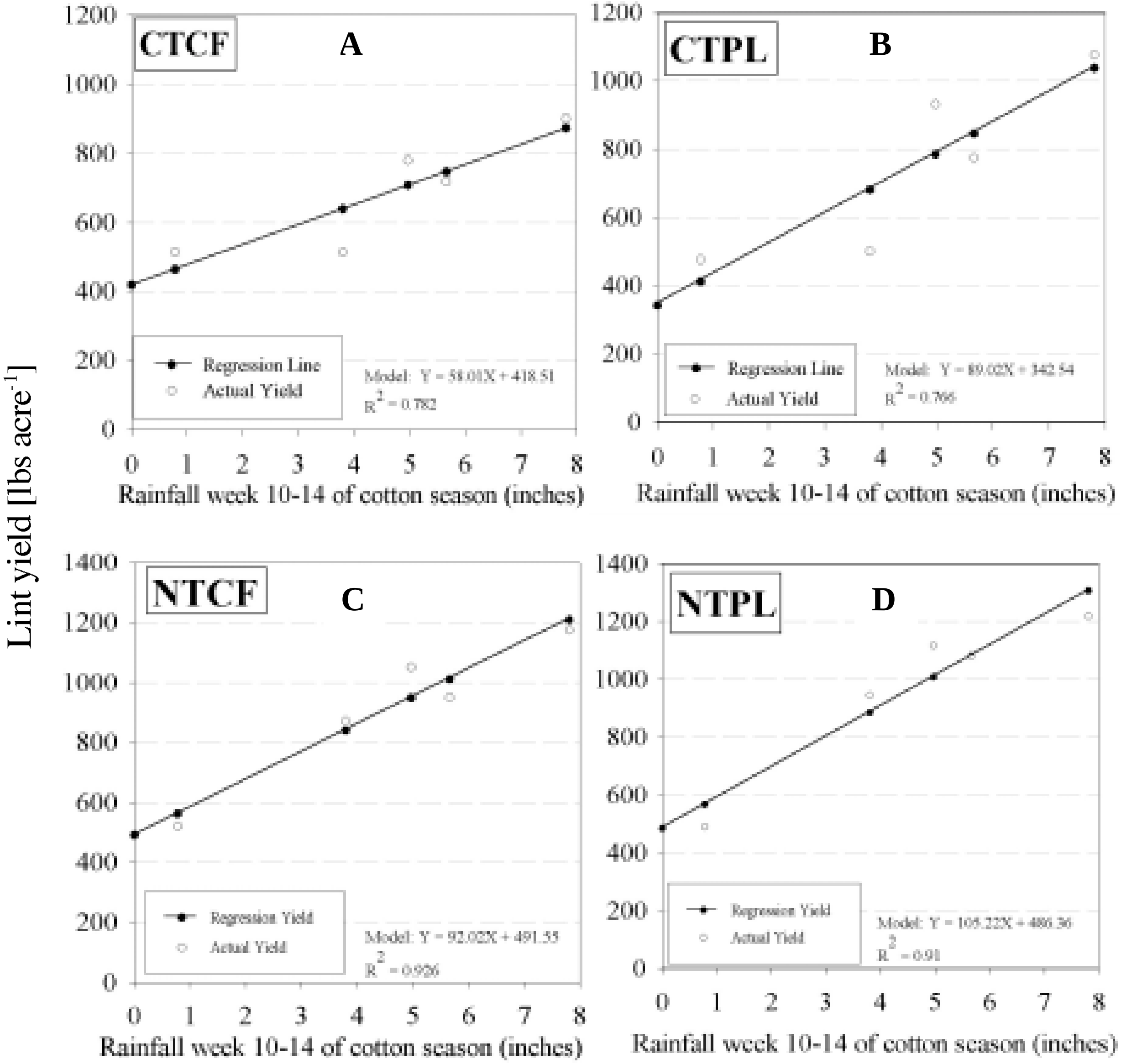

Fig 3. Linear regression of rainfall amount during weeks 10 to 14 of the cotton season versus yield from 1996 to 2000: (A) for CTCF; (B) for CTPL.; (C) for NTCF; and (D) for NTPL

blooming period. The CT-based systems were severely affected on both counts and did not perform as well. Although we used $P = 0.05$ to indicate statistical significance, actual P-values were < 0.001 for all differences in 2000, and as a result P-values were < 0.01 over the five year period. The yield advantage of poultry litter alone over ammonium nitrate is limited.

NT not only provides additional insurance during all but the severest droughts against crop failure, the yield advantage in normal years more than compensates for yield suppression in dry years so that the long-term yield advantage is maintained. This research showed that even where, in two of five years, water was moderately to severely limiting, average yields over the whole period were statistically greater in the NT-based systems. Although yield differences have been presented primarily from the statistical point of view, higher yields of the NT-based systems that were not statistically significant may, nevertheless, have positive economic implications if yield variances and/or cost of production for NT is lower. Yield variance over five years was higher in NT in this research.

CONCLUSIONS

Our five years of research showed that cotton managed under no-till and fertilized with poultry litter or ammonium nitrate has a superior yield return than that of conventionally tilled and fertilized cotton in the Southern Piedmont. A no-till and poultry litter based cotton can produce up to 50% more lint compared to conventionally tilled and fertilized cotton. Similarly, no-till cotton can produce up to 34% more lint than conventional tillage cotton when both are fertilized with ammonium nitrate. These advantages can be even higher during periods of water deficit, except in years of severest deficit. The yield advantages in years of favorable water regime more than makes up for the lack of or reduced differences in water stressed years.

The use of poultry litter as a fertilizer source in cotton production would, in addition to enhancing yield in no-till systems, also create a useful outlet for the large amount of litter produced from the poultry industry in the southeastern United States. Adoption of no-till and poultry litter use in cotton production should, however, also take into account potential build up of nutrients over time and possible environmental degradation. A good nutrient management plan should always be included in the farming system.

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STRIP-TILL COTTON YIELD IN SIX DOUBLE CROPPING SYSTEMS

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ABSTRACT

The objective of this research was to determine adaptability and yield of strip-till cotton (*Gossypium hirsutum* L.) in combination with six winter crops in double cropping systems. Six winter crops were planted in a randomized complete block design in the fall of 2000. Winter crops were wheat (*Triticum aestivum* L.) cv. 'Flemming', rye (*Secale cereale* L.) cv. 'Wrens 96', oat (*Avena sativa* L.) cv. 'Chapman', lupin (*Lupinus angustifolius* L.) cv. ' Tiftblue 78', vetch, (*Vicia villosa* roth.) cv. 'Common Hairy', and crimson clover (*Trifolium incarnatum* L.) cv 'Dixie Resseding'. The small grain seed harvest was in mid May 2001 followed by bailing the small grain straw. The three legumes were left undisturbed. Six varieties of cotton were randomized and strip-tilled on 31 May 2001 into the winter crop plots as sub plot treatments, allowing the testing of the varieties in six double cropping systems. Varieties included 'Delta Pine 5690', 'Delta Pine 5690 RR', 'Delta Pine 655 BG/RR', 'Delta Pine 5415', 'Delta Pine 5415 RR', and 'Delta Pine 458 BG/RR'. Crops were irrigated, fertilized according to soil test, and pests were controlled using best management practices. Cotton was hand harvested and samples were ginned to determine lint yield. Data collected included seed cotton and lint yield, plant height, and final plant population. Cotton data was analyzed as a split-plot with winter crops as main treatments and cotton varieties as sub treatments with six replications. The average of the six varieties showed that all double cropping systems were equal in seed-cotton (lint + seed) yield and cotton seed (delinted seed) yield except for double cropping with crimson clover (lowest yield). Lint yield averaged across all cropping systems showed that Delta Pine 458 BG/RR had the greatest yield (1270 pounds/acre) and the lowest yield was for Delta Pine 655 BG/RR (1102 pounds/acre). The highest lint yield was obtained with cotton double cropped after oat for Delta Pine 458 BG/RR (1415 pounds/acre) and after rye for Delta Pine 5415 RR (1420 pounds/acre). Final plant populations were significantly higher in double cropping systems with the three small grains compared to double cropping systems after the three legumes. Based on these results the best double cropping system was oat or rye followed by Delta Pine 458 BG/RR.

KEYWORDS

Gossypium hirsutum L., winter cover crops, small grains, winter legumes, cultivars

INTRODUCTION

Increased global competition requires US farmers to become more efficient in their farming practices. The best way to improve a grower's financial condition is through research that will lead to improved competitiveness for U.S. growers by learning ways to reduce or improve effectiveness of inputs and/or increase yield (Baldwin, 1998). Upland cotton is a source of oil and fiber for humans and protein for livestock (Lee, 1984; Cassman, 1993). It is valued in the billions of dollars to the U.S. economy (Goodell, 1993). This crop is steadily increasing in importance in the Southeast and in recent times especially in Florida (Gallaher and Brecke, 1999).

Conservation tillage is increasingly becoming conventional due to savings to farmers in fuel, labor, equipment, time, etc. and at the same time improves the environment. Because of the huge decreases in soil erosion, soil water and nutrients are also conserved which results in improved plant growth. Approximately 300 million acres of cropland is now under conservation tillage management in the U.S., of which a significant portion is strip-till cotton (Mitchell, 1996). Refinement of conservation tillage management is important in order to maximize crop growth and productivity.

Past research on strip-till cotton in Florida has resulted in the refinement of N fertility management. Gallaher's (unpublished data) research for the past four years has concluded that nitrogen fertilizer should be applied in three splits in sandy soils to ensure crop utilization and avoidance of leaching from heavy rainfall events. During dry years 90 lbs N acre^{-1} (with irrigation) and 120 lbs N acre^{-1} during years of heavy rainfall events were needed to maximize lint yield. Research at Quincy, Florida has shown cotton yields to respond to 120 lbs N acre^{-1} (Wiatrak *et al*., 1999). We have also tested several cotton varieties (Gallaher, 1999) and weed control strategies (Edenfield *et al*., 1999) under

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strip-till management. Some studies pointed to high yielding varieties adapted to Florida like Delta Pine 5415 RR (RR = Roundup Ready gene variety) (Gallaher, 1999). Selecting the proper variety, using the proper research supported nitrogen management, and knowing the best crop rotation for pest management (Edenfield, *et al.*, 1999; McSorley and Gallaher, 1993; 1999; Munro, 1987) can result in significant yield increases. The objective of this research was to determine adaptability and yield of strip-till cotton in combination with six winter crops in double cropping systems.

MATERIALS AND METHODS

The experimental site was located at the University of Florida, IFAS Plant Science Research and Education Center near Citra, FL. Six double cropping systems with strip-till cotton were established in 2001 at this site and consisted of wheat, rye, oat, lupin, vetch, and crimson clover followed by cotton. Winter crops were planted at recommended rates into a minimum tillage seedbed on 20 November 2000. Seed of six varieties of cotton were obtained for succession planting which involved two families of genetically altered cotton. The first family of varieties consisted of Delta Pine 5690, Delta Pine 5690 RR, and Delta Pine 655 BG/RR (BG = *Bacillus thuringiensis* –Bt gene variety). The second family of varieties consisted of Delta Pine 5415, Delta Pine 5415RR, and Delta Pine 458 BG/RR. In mid May 2001 the three small grain crops were harvested for seed and the straw was baled. Legume crops were dying and were left undisturbed in the plots. Cotton was strip-tilled into the stubble of the small grains and the cover of the legumes on 30 May 2001. Crops were irrigated as needed. Fertilization was applied based on soil test recommendations and included 60 pounds lbs N acre^{-1} at planting of cotton. Cotton following the small grain crops received an extra 30 lbs N acre^{-1} sidedressed when the cotton was 12 inches tall. A 50 square foot section of each of the 175 square foot plots was harvested by hand. Seed-cotton (lint + seed), lint, and seed (delinted seed) yields were determined. Percent lint was determined using a 0.5 pound subsample from each of the 216 plots by use of a small laboratory tabletop gin. Statistical analyses were conducted on the split plot experiment with winter cover crops as main effects and the six varieties of cotton as sub effects. A bale of lint cotton was assumed to weigh 480 pounds. The experiment was replicated six times.

Table 1. Cropping system and cotton cultivar response for seed cotton yield (lint plus seed) and lint yield of strip-till cotton at Citra, FL, 2001.

Cotton	Winter Crop System						
Variety	Wheat	Rye	Oat	Lupin	Vetch	Crimson	Average
	-------Seed cotton yield, lbs acre^{-1} -------						
DP 5690	3099	3062	3126	2819	2726	2542	2896 A[†]
DP 5690 RR	2800	3208	3316	2533	2417	2549	2804 AB
DP 655 BG/RR	3113	3138	3165	2321	1955	2045	2623 B
DP 5415	2963	3268	3314	2590	2903	2167	2868 AB
DP 5415 RR	2449	3452	2974	2946	2631	2432	2814 AB
DP 458 BG/RR	3086	3203	3389	2887	3039	2669	3046 A
Average	2918 XY[‡]	3222 X	3214 X	2683 XY	2611 XY	2400 Y	
	------- Lint yield, lbs acre^{-1} -------						
DP 5690	1317	1254	1292	1185	1131	1083	1210 AB
DP 5690 RR	1175	1323	1381	1057	995	1090	1170 AB
DP 655 BG/RR	1350	1305	1327	964	810	856	1102 B
DP 5415	1252	1352	1408	1082	1222	916	1205 AB
DP 5415 RR	1044	1420	1213	1242	1105	1027	1175 AB
DP 458 BG/RR	1267	1330	1415	1185	1276	1148	1270 A
Average	1234 XYZ	1330 XY	1339 X	1119 XYZ	1089 YZ	1020 Z	

[†] Cotton cultivar averages not followed by the same letter (ABC) are significantly different at $P = 0.05$, based Duncan's Multiple Range Test.

[‡] Winter crop system averages not followed by the same letter (XYZ) are significantly different $P = 0.05$, based Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Seed cotton yields were equal for all double cropping systems except for cotton following crimson clover (Table 1). Yield of seed cotton tended to be best following rye and oat and lowest following crimson clover. All varieties gave equal yield with the exception of DP 5690 and DP 458 BG/RR, which gave higher seed cotton yield compared to DP 655 BG/RR (Table 1). No differences were found among winter cropping systems or varieties of cotton for percent lint. Lint yield was similar among the systems that included wheat, rye, oat, and lupin, all of which were greater than lint yield following crimson clover (Table 1). There appeared to be a trend for lint yield to be higher following the small grains compared to the legumes. Delta Pine 458 BG/RR had greater lint yield compared to DP 655 BG/RR. Seed yield (data not shown) tended to follow the same pattern as that of seed cotton yields with yield following crimson clover being the lowest compared to following rye and oat. Delta Pine 5690 and Delta Pine 458 BG/RR had greater seed yield compared to Delta Pine 655 BG/RR. Delta Pine 5690 and Delta Pine 458 BG/RR were taller varieties (data not shown) compared to Delta Pine 655 BG/RR and Delta Pine 5415 RR. Final plant population at harvest time (data not shown) was greater following the small grain crops compared to double cropping following the three legume crops. Final plant populations tended to be greater for Delta Pine 5690, Delta Pine 5415 RR, and Delta Pine 458 BG/RR. The variety with the lowest population at harvest time was Delta Pine 5415 RR.

CONCLUSIONS

All winter crops grew well and five of the six were easily established where they had never been grown before. First year establishment of crimson clover was more difficult compared to the other legumes.

1. These six double cropping systems worked well in north Florida where they had never been established before. The big question is the sustainability of each without some type of summer crop rotation to disrupt weeds and diseases including nematodes that may become established.
2. The six varieties of cotton in this study are all adaptable to north Florida.
3. Lint yields among varieties ranged from 1100 to 1270 lbs acre^{-1} and represents 2.3 to 2.6 bales acre^{-1} (480 pound bales) when averaged over all the six double cropping systems. However, yields close to three bales per acre were observed for some varieties following rye or oat. Lint yield tended to be lower following the legumes compared to the small grain crops and yield following crimson clover tended to be the lowest. This was likely due to poor establishment and growth of crimson clover in some replications and thus a limitation in N production that would be available to the cotton.
4. There were differences in final plant populations among varieties, but this does not readily explain why Delta Pine 655 BG/RR tended to have the lowest yield. Further experimentation is needed to attempt to explain this. However, plant populations were significantly lower following the three winter legumes compared to the three small grains. This may be due to the differences in crop residue management and possibly the difference in seed placement for germination. However, this too will need further investigation.
5. Based on these results the best double cropping system was oat or rye followed by Delta Pine 458 BG/RR.

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MAKING "DIFFERENT" LIMING AND FERTILIZATION PRACTICES ON CONSERVATION TILLAGE "CONVENTIONAL"

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ABSTRACT

Fertilizing and liming practices for conservation tillage systems need to be adjusted compared to conventional tillage systems. Four "different" practices for conservation tillage and the reasons for the differences are discussed. These include 1) getting off to a good start, since there is no opportunity for incorporating lime and fertilizer with tillage, 2) soil sampling by depth and row pattern, since there can be stratification and in-row differences of pH and nutrients, 3) using starter fertilizers, since there is a better chance of response and 4) adjusting nitrogen management, since cover crops can either tie up or provide N.

KEYWORDS

Soil sampling, nutrient management, liming, starter fertilizer

INTRODUCTION

Conservation tillage of row crops continues to gain popularity in South Georgia and throughout the Southeast. Along with the increase in "strip-till" cotton and peanut acres come a number of new questions from growers, about how surface applications of lime and fertilizer can be effective, accurate soil sampling strategies, use of starter fertilizers, and the application of fertilizers to small grain cover crops.

Some say that conservation tillage systems should be limed and fertilized in the same manner as conventional tillage systems. While I agree that basic soil fertility requirements are the same for both systems (for example, you still need to maintain proper soil pH and supply essential plant nutrients), I also firmly believe there are a number of liming and fertilization practices that should be done differently in conservation tillage systems to assure their success. These "different" practices are not necessarily new, but merely variations of practices that have been done in conventional tillage systems for years. Like many other aspects of the conservation-tillage system (for example, weed control), fertilization and liming practices simply need to be approached differently and adjusted accordingly.

The four "different" liming and fertilization practices in conservation tillage that will be discussed in this paper are 1) the need for a good start, 2) soil sampling, 3) use of starter fertilizers and 4) nitrogen management. All four of these practices apply to cotton, whereas only the first two apply to peanuts.

THE NEED FOR A GOOD START

Before converting a given field from conventional to conservation tillage, proper soil pH and nutrient levels (especially P and K) should be established throughout the plow layer. This involves taking a soil sample to plow depth (usually 8 to 10 inches) and incorporating any lime and fertilizer that is recommended. Basically, this may be the "last chance" to incorporate any lime or fertilizer and correct deficiencies deep in the soil profile.

This is important because lime and some fertilizer nutrients (such as phosphorous) move very slowly into the soil profile. Therefore, if proper levels of lime and fertilizer are present throughout the profile at the start, these levels can be maintained with surface applications of lime and fertilizer. In this way, lime and fertilizers can work to maintain soil nutrients, even though they are not "worked in." The consequences of not starting the process properly can be quite drastic. For example, if a pH or nutrient problem deep in the soil profile is not corrected before starting conservation tillage, it cannot be fixed quickly with surface applications of lime or fertilizer. If this type of problem is discovered after conservation tillage is started, there may not be any other solution than to incorporate the lime or fertilizer with deep tillage and, in essence, start over completely.

In a related situation, a grower may have started with good levels of pH and nutrients throughout the plow layer, but after several years of conservation tillage, problems develop that are deep and severe enough that, again, it might require deep incorporation and basically starting over to correct them. The best way to avoid both

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situations described above is to sample soils in conservation tillage systems differently than in conventional tillage systems. This will be discussed in the following section.

SOIL SAMPLING

Soil under conservation tillage should be sampled more frequently and according to old row patterns, but above all, should be sampled at different depths.

In conventionally tilled systems, the recommendation is to sample soils to plow depth. In conservation tillage systems, the recommendation is to take shallow and deep soil samples separately. This system, developed by growers, involves taking a shallow soil sample (2 to 3 inches deep) and then a deep sample (down to 6 or 8 inches) — from the same hole! Samples from different depths are stored and analyzed separately.

The main reason for sampling as described above is to detect a drop in pH in the shallow sample so it can be corrected with surface applications of lime before it extends too deep into the profile.

In conservation tillage systems, acidity will develop at the soil surface first and then work its way down into the profile. This is largely due to surface applications of nitrogen fertilizers on crops such as cotton and corn. Sometimes, after lime as been surface applied in conservation tillage systems, the pH in the shallow sample will be above the target pH. This is not necessarily a problem, since again, surface applications of nitrogen will usually soon lower the pH in the shallow sample.

The main focus of the deep sample is, again, pH. If a low pH is detected in the deep sample (for example, 5.5), it may actually limit crop growth, and require correction by tilled-in lime. This situation may be avoided by taking the shallow sample separately.

A regular plow-depth sample will not necessarily detect this type of pH problem. There may be a pH drop (for example, 5.5) in the top two inches, but soil from the deep sample is well within the normal range (for example, pH 6.2). A regular plow depth sample would integrate both readings and indicate a pH of 6.0, whereas the problem may lie only at the surface, and could be corrected without tillage.

This difference in pH between the shallow and deep soil samples is called stratification. Stratification can also occur with fertilizer nutrients. Since it is relatively immobile (like lime), phosphorous (P) usually stratifies in conservation tillage systems. It is common to see a buildup in P levels in shallow samples (as compared to deep samples) in conservation tillage systems. This should not be an agronomic problem, i.e. lead to problems with crop production. Phosphorous does not usually out-compete other essential plant nutrients (except zinc) when P levels are elevated. High P levels may, however, contribute to dissolved P in runoff water, leading to eutrophication of stream, a water quality concern. On the other hand, conservation tillage dramatically reduces the amount of soil erosion and thus the amount of P that reaches surface water associated with eroded soil.

Another advantage of taking shallow soil samples in conservation tillage is that it can be used to help monitor the "pegging zone" for peanut production. Many were concerned about a buildup of potassium (K) in strip-till peanuts when in rotation with strip-till cotton. The fear was that potash surface-applied to cotton would carry over and interfere with calcium in the "pegging zone", the top 2-3 inches of soil where peanuts peg and pods develop. This has not turned out to be a great problem, possibly due to K movement past the pegging zone, especially after the peanuts are dug and the pegging zone is disrupted. Even though a shallow soil sample can help monitor potash in the pegging zone, this sample is usually taken in the fall or early winter. This should not replace taking a true pegging zone soil sample after peanut emergence when needed.

After taking shallow and deep soil samples as described above, a conservation tillage grower usually must determine which sample to lime or fertilize by. There is no doubt that the grower should use the shallow sample to guide any liming program. There is less certainty in determining which sample to use in planning fertilizer applications. For agronomic (crop production) purposes, and to be conservative, one would fertilize by the deep sample, since it will, in all likelihood, be lower in nutrients, especially P. However, as mentioned earlier, as P builds up in the soil it may begin to threaten the environment. What is needed is solid research to address this issue of P stratification and fertilizing, with both agronomic and environmental considerations in mind. In the future, a grower may have medium levels in the deep sample that would call for P fertilizer. The shallow sample, on the other hand, may be high in P and not call for any fertilizer. The question, ultimately, is whether P near the surface will provide the crop with enough P to grow properly. Until this question is answered, the grower is advised to lime by the shallow sample and fertilize by the deep.

There is also some question as to whether most samples should be taken between the planted rows, or in the old "drill" (where the row was planted). The current recommendation is to take more samples between the rows than in the drill. As a rule of thumb, a grower should take 10 samples between the rows for every one taken in the drill. If starter fertilizers are used, samples taken from the drill may hit an old starter band and be concentrated in elements such as P (since 10-34-0 is a common starter fertilizer used) Also, if the same row pattern is maintained in conservation tillage, roots from the crop can actually concentrate or "draw" elements such as P and K into the drill area. In a worst-case scenario, if all the samples are taken from the drill, the results may indicate adequate levels of nutrients (especially P and K), whereas, in reality, the samples where taken from an old starter band, where nutrient levels are higher. This is a "false high," where actual nutrient levels are much lower than the samples indicate. Proportionally, there is a greater volume of soil in between the rows than under the narrow band around the drill. This is yet another reason to take more samples in between the rows. If an alternating row pattern in is used in strip-till, the chances of accumulating a "false high" due to crop roots drawing nutrients to the drill are reduced, but a starter fertilizer band could still be encountered. Therefore, the recommendation to take more samples in the old "middles" still holds true.

Finally, the frequency of sampling must be considered. Currently, UGA recommends that row crop farmers sample soil every field year. According to recent county agent surveys, most growers are already following this recommendation. Sampling every year should be sufficient for conservation tillage just as in conventional tillage. However, if a grower samples less frequently than this in conventional tillage (for example, every other year) and then switches to conservation tillage, then frequency should be increased to every year, as recommended. This sampling pattern is intended to catch the drop in pH in the shallow soil sample before the problem migrates into the deep soil, requiring tillage. Coastal Plain soils are poorly buffered (sandy, low CEC, low organic matter) and therefore, pH can drop fairly rapidly, even in conventional tillage systems. This condition is even more dangerous in conservation tillage systems, where nitrogen can only be applied to the surface.

STARTER FERTILIZERS

There is no official UGA recommendation on the use of starter fertilizers in conservation tillage systems, because there are no research data that indicate a consistent yield response. However, growers are encouraged to consider starters, especially for conservation tillage corn and early-planted (April) cotton. Soil temperatures are usually low enough at these planting times to facilitate a response to starter fertilizers, especially those containing phosphorous. It is well documented that soil P mineralization and availability are limited when soil temperatures are low. Therefore, starter fertilizers such as ammonium polyphosphate (10-34-0) that contain P are often used.

A recent study in Georgia comparing different starter fertilizers for cotton production indicated that both soil type and weather conditions at planting should be considered when choosing a starter fertilizer (Bednarz *et al*, 2000). Although this study was conducted with conventional tillage, it is interesting to note that the only statistically significant cotton yield responses were measured when the crop was exposed to cool weather for an extended period of time, immediately following planting. Also, the best starter fertilizer contained P on a site that is known to fix soil P and contained N+S on a site that was much sandier and is known to have frequent sulfur deficiencies. Growers planting conservation tillage corn or cotton are encouraged to use a starter fertilizer containing P if soil test levels are medium or low. If soil test levels of P are high, then a N only or N+S starter may be the best choice.

Growers using poultry litter when strip tilling these crops also question the use of starter fertilizer. This question is a valid one, since poultry litter contains significant amounts of N, P and S. The litter may be spread one to two months in advance of planting, and soil temperatures during corn planting and early planted cotton should still be low, so there still may be a need for starter fertilizer in these situations. Current research must be conducted to confirm this theory.

Current research data is also lacking in the evaluation of different placements and rates of starter fertilizer in conservation tillage. UGA recommends that cotton growers use a "2 by 2" (2 inches to the side and 2 inches below the seed) placement and not exceed 15 lbs N acre^{-1}. There is significant interest in spraying starter fertilizer in a band behind the planter press wheels, or approximately 10 inches under the seed, in the subsoil shank. Growers believe they can put out more N and P with these placements. However, the fertilizer is not concentrated near the seed in either of these placements, and the "starter effect" may be lost. Some cotton growers have also tried to increase the rate of N in the starter in a 2 x 2 placement. In the past, 10 gallons acre^{-1} of 10-34-0 was commonly used as a starter treatment. However, this only gives 10 lbs N acre^{-1}, and current recommendations for cotton call for 20 to 30 lbs N acre^{-1} in the pre-planting period. Many growers have tried to "spike" 10-34-0 with liquid N (UAN) or UAN+S combinations. Unfortunately, this can cause severe burn and under certain conditions, (hot, dry, and sandy soil) can result in the need for replanting. A better way to supply the recommended amount of pre-plant N to cotton under conservation tillage would be to include some N in pre-plant K applications to supplement that contained in the starter. This broadcast N can also help to nullify tie-up of soil N by small grain cover crop residue.

The economics of using starter fertilizers in have only been studied under conventional tillage. In the study mentioned above (Bednarz *et al*), 23 out of 30 individual comparisons (treatments by locations by years) gave higher net returns, as compared to an untreated check. Again, this study was conducted using conventional tillage so, it is assumed that greater yield response and economic returns would result from conservation tillage, where the soil would be even cooler. When nutrient input (N, P and/or S) is factored into the complete fertility program, any additional cost is largely due to application costs.

NITROGEN MANAGEMENT

When using a winter cover crop for conservation tillage cotton, which most growers do, nitrogen must be managed differently than in conventional tillage systems. The majority of strip-till cotton growers in South Georgia use a small grain cover crop, such as rye, wheat, or oats. When cotton follows a small grain cover crop, the total nitrogen rate must be increased by 25 %, to compensate for N tie-up by decomposing small grain residue. When this additional N is not applied, N deficiency on young cotton (soon after emergence) has been observed. The best time to apply this additional N is by broadcasting before planting, at planting, or soon after planting. Broadcast is preferred over banding in order to replenish N across the entire rooting zone. Since all recommended potash is applied at planting, this extra N can easily be applied with the potash or with an N-P-K complete, or "base" fertilizer. Trying to supply this additional N by increasing the N rate in starter fertilizer can lead to burn and stand loss. Again, no more than 15 lbs N acre^{-1} should be used in starter fertilizer applications, even in a "2 by 2" placement.

A number of strip-till cotton growers, especially those who have been practicing conservation tillage a number of years, and have learned how to plant into heavy residue, apply some additional nitrogen to the small grain winter cover crop in early spring (February). The question then arises as to whether this additional application can be included in the total N budget for the cotton that will follow. Preliminary research in both Georgia and Alabama indicate that this N will not be available for the subsequent cotton crop. This does not necessarily mean that the early spring application was wasted. The additional N on the small grain will generate more residue, which in turn can increase soil organic matter and all the benefits that come with it. These benefits, however, are harder to assign an exact dollar value, and are not collected immediately. Therefore, fertilizing a cover crop will not pay off immediately, but will be beneficial in the long run.

Rye is the most popular winter cover crop in South Georgia. Growers have often taken advantage of the option to utilize the cover for winter grazing of cattle. In this case, the cover crop is also usually fertilized with N during the winter and early spring. A grower who grazes cattle on winter rye should still increase N application for cotton, because N becomes tied up in the rye, cattle, and the manure cycle, and will not be evenly distributed across the field. Even though cattle will remove most of the visible biomass, there will still be significant amounts of residue (roots and crowns) to tie up soil N.

Since Georgia is the number one poultry producer in the USA, poultry litter (manure) is commonly used as a fertilizer for crops. For row crops in South Georgia, poultry litter is best used as a complete fertilizer, and is commonly applied at 2 ton acre^{-1} just prior to planting. For strip-till cotton growers using small grain cover crops, it is important to apply the litter just prior to, or after, the cover crop is terminated (usually 30 days in advance of planting with a burndown herbicide). If poultry litter is applied to the small grain cover crop earlier, such as in mid-February, the small grain cover crop may tie up most of the nitrogen just as if commercial inorganic fertilizer N was used. Again, if the goal is to grow more residue, then fertilizing the cover crop with poultry litter in February is a good idea. However, the N applied in February will not be available to the subsequent cotton crop.

Most growers doubt that poultry litter will work in a conservation tillage system and question this practice just as they question surface application of lime and fertilizer. They are concerned that all N in poultry litter will be lost to the air by volatilization. It is estimated that only 10 % more N is lost from surface litter than that which is incorporated. This value should even be lower if the poultry litter is applied before the strip till operation or if it rains soon after applying the litter. Therefore, poultry litter should work well with strip till corn and cotton. Peanuts and soybeans should not receive poultry litter applications, since they are both legumes and fix their own nitrogen.

A small number of growers in South Georgia are experimenting with legume winter cover crops, such as crimson clover, hairy vetch, and lupin, to provide nitrogen to a subsequent strip-till cotton crop. In an on-farm study in Cook County, GA, a crimson clover cover crop provided all but 30 lbs N acre^{-1} for a subsequent cotton crop. Since an early maturing clover variety was used, it reseeded. After three years of reseeding the study was repeated and it was found that the clover provided all the N needed by the cotton. However, the potential for building nematode populations or having early spring insect infestations (especially cutworms) are a cause for concern. Although more research is needed to address these issues, this system looks promising.

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INFLUENCE OF NITROGEN AND TILLAGE ON COTTON

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ABSTRACT

Nitrogen (N) is an important nutrient for cotton growth and development. The objective of the experiments conducted from 1995 to 1997 at the North Florida Research and Education Center (NFREC) near Quincy, FL was to determine the influence of N application (0, 60, 120, and 180 lbs N acre^{-1}) on 'DP 5409' cotton (*Gossypium hirsutum* L.) planted in strip and conventional tillage. The results showed no significant difference between tillage systems for the N uptake on leaves, bolls, and the whole plant, except higher uptake for stems from strip than conventional tillage. Generally, increasing the N fertilization increased the uptake of this element. Higher N (NO_3-N) content in the soil was obtained from strip than conventional tillage at the depth of 36-48 inches and higher N rates significantly increased N content in the soil. Cotton grown in strip tillage gave higher lint yields as compared to conventional tillage, but applying more than 60 lbs N acre^{-1} did not significantly increase yield. Higher N efficiency was obtained with low N application on cotton. Higher lint yield increases were obtained from conventional than strip tillage for the application levels of 0-60 and 0-120 lbs N acre^{-1}. This was due to lower yields from treatments with no N application on conventional than strip tillage.

KEYWORDS

Conservation tillage, rotation, soil health, nitrogen, N uptake

INTRODUCTION

In the U.S.A., strip tillage (minimum tillage) for crop production is mainly used to reduce soil erosion. Minimum tillage also increases soil organic matter, soil moisture, and improves soil structure, which results in increased yield of plants (Hargrove, 1990). Minimum tillage into previous crop residue may significantly reduce water erosion, especially on areas that are highly erodible (Hutchinson *et al.*, 1994). Minimum tillage influences the chemical, physical and biological aspects of soils and these changes depend on the soil quality and climate conditions (Gordon *et al.*, 1990). According to Nabors and Jones (1991) using minimum tillage protects cotton during emergence against injury from wind and sand. Minimum tillage saves soil moisture due to less evaporation (Philips and Young, 1973) and decreased surface water flow (Yoo and Touchton, 1989). However, increased permeability may increase the N flow from soil (Philips, 1980; Tyler and Thomas, 1977), increase denitrification (Olson *et al.*, 1979; Gilliam and Hoyt, 1987), and immobilization of N (Gilliam and Hoyt, 1987). The effect of minimum tillage and N rates on cotton growth in Florida has not been determined.

The purpose of this study was to determine the influence of strip and conventional tillage, and N rates on cotton growth and yields in northwest part of Florida.

MATERIALS AND METHODS

PLOT PREPARATION

Field research with cotton was conducted during 1995 - 1997 on a Dothan sandy loam (fine, loamy siliceous, thermic Plinthic Kandiudults) at the North Florida Research and Education Center / University of Florida in Quincy. The soil profile depth of 1 ft. contained 97 ppm K, 24.7 ppm P, 68 ppm Mg, 318 ppm Ca, and 0.5 ppm NO_3-N. Cotton cultivar 'DP 5409' was planted in strip and conventional tillage with N rates of 0, 60, 120, and 180 lbs N acre^{-1}. The study area was sprayed with glyphosate [N-(phosphonomethyl) glycine] at 1.5 qt acre^{-1} 2 weeks before planting. The rows in strip-till sections were ripped about 38-cm deep with a Brown Ro-till implement (Brown Manufacturing Co., Ozark, AL). On the conventional section, a disk-harrow was used (3 times). The disked soil was then sub-soiled, and then s-tine harrowed (2 times).

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Plant culture

Cotton was planted in 3 ft. row spacing at the rate of 4 seed per ft of row with KMC planters (Kelly Manufacturing Co., Tifton, GA). Each plot was 12 ft. wide by 20 ft. long and consisted of four rows. Cotton was sprayed with fluometuron [1,1-dimethyl-3-(α, α, α-trifluoro-*m*-totyl)urea] at 2 pt acre^{-1} and pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) at 2 pt acre^{-1} after planting and direct sprayed with fluometuron at 2 pt acre^{-1} and MSMA (monosodium salt of methylarsonic acid) at 2 pt acre^{-1} 3 weeks later. Four weeks after planting, N fertilizer in the form of ammonium nitrate was applied on cotton plots. The rate of 180 lbs N acre^{-1} treatment was divided into 2 applications with 120 lbs N acre^{-1} applied four weeks after planting and additional 60 lbs N acre^{-1} applied three weeks later. Cotton was defoliated with thidiazuron (N-phenyl-N'-1,2,3-thiadiazol-5-ylurea) at 0.166 lbs acre^{-1} and ethephon (2-chloroethyl phosphonic acid) at 1.4 pt acre^{-1} and ethephon plus cyclanilide [(2-chloloethyl)phosphoric acid plus 1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid] at 1.5 pt acre^{-1} and Agridex oil at 1 pt acre^{-1} when 60 to 70% of the cotton bolls were open. The cotton was picked by hand 2 to 3 weeks after defoliation.

The field experiments were static and conducted as split - plots with four replications. Biometric measurements were conducted on 10 plants taken from each plot.

Weather data was obtained from the weather station in Quincy (30° 36' N latitude and 84° 33' W longitude) located at 245 ft. above sea level.

All results were analyzed using ANOVA, GLM, and REG procedures of SAS (SAS Institute, 1985 a, b). Analyses of linear and quadratic regression were added to the analysis of variance.

RESULTS AND DISCUSSION

Yield of cotton depend on N acquired by plants (Doss and Scarsbrook, 1969; Oosterhuis *et al.*, 1983). Constable and Rochester (1988) showed that the amount of N acquired by cotton, without N fertilization, was from 22.7 to 92.3 lbs N acre^{-1}. According to Hern (1981) total N uptake, especially irrigated, may be up to 205 lbs N acre^{-1}, and half of it is removed with harvested yield. Even with the N immobilization under minimum tillage (Rice and Smith, 1984), strip tillage with leaving plant residues on the top of the soil, showed better utilization of applied N (Torbert and Reeves, 1994).

Our research showed that among analyzed plant parts, N uptake was higher from strip than conventional tillage for stems only (Table 1). There was no significant difference between tillage systems for the N uptake by leaves, bolls, and in the whole plant. Table 2 shows the influence of N application on N uptake in cotton. Increasing the N rate increased the uptake of this element. Highest uptake of N was obtained with the application of 180 and 120 lbs acre^{-1}. Significantly lower N uptake was received from the treatment with no N application on cotton.

According to calculated regressions, increasing the N rate by 1 lbs increased the N uptake by 0.336 lbs N acre^{-1}, where 0.192 lbs was allocated for bolls, 0.096 lbs for leaves, and 0.048 lbs for stems (Table 3).

Evaluating the N content in the soil, Lamb *et al.* (1985) found that soil had a better ability to hold N where plowing was done as compared to minimum tillage for the first few years, but these differences get smaller later. Eck and Fanning (1962) and Johnson *et al.* (1974) showed that higher accumulation of NO_3–N on clay soil occurred after

Table 1. Influence of tillage on nitrogen uptake.

Tillage	Stems	Leaves	Bolls	Whole plant
	--------------- lbs acre^{-1}			-------------
Strip-till	11.6	26.2	63.3	100.9
Conventional	10.0	23.5	58.7	92.2
LSD$_{(0.05)}$	1.52	NS	NS	NS

Table 2. Influence of fertilization on nitrogen uptake.

N rate	Stems	Leaves	Bolls	Whole plant
lbs acre^{-1}	----------- lbs acre^{-1}			-----------
0	6.1	15.2	40.4	61.7
60	9.4	22.5	57.5	89.4
120	13.1	29.5	72.0	114.6
180	14.5	32.0	74.0	120.5
LSD$_{(0.05)}$	1.52	4.06	13.3	18.9

Table 3. Functions of nitrogen production in cotton 120 days after planting

Parts of plant	Regression	Determination Coefficient
Stems	$y = 6.44 + 0.048N$	$r^2 = 0.97$
Leaves	$y = 16.2 + 0.096N$	$r^2 = 0.96$
Bolls	$y = 43.7 + 0.192N$	$r^2 = 0.91$
Whole plant	$y = 66.3 + 0.336N$	$r^2 = 0.94$

plowing than after leaving plants residue on the top of the soil. Fenser and Peterson (1979) showed that lower accumulation of NO_3–N in soil with minimum tillage than after plowing.

According to our studies, significantly higher soil N (NO_3-N) content was obtained from strip than conventional tillage at the depth of 36-48 inches and there was no significant difference between tillage systems at 0-12, 12-24, 24-36 inch, and the total soil depth (Table 4). Higher N rates significantly increased the N content in the soil at the measured levels. The N content at 0-48 inch depth was 101.5 and 101.0 lbs acre^{-1} with the application of 0 and 60 lbs N acre^{-1}, respectively, 107.2 and 118.3 lbs acre^{-1} with 120 and 180 lbs N acre^{-1}, respectively (Table 5).

Table 4. Influence of tillage on nitrogen content in the soil.

Tillage	Depth level (inch)				
	0-12	12-24	24-36	36-48	0-48
	-------------------- lbs acre^{-1} --------------------				
Strip-till	27.1	26.3	27.4	28.6	109.4
Conventional	26.5	25.9	26.0	26.4	104.8
LSD$_{(0.05)}$	NS	NS	NS	1.41	NS

Table 5. Influence of fertilization on nitrogen content in the soil.

N rate (lb/a)	Depth level (inch)				
	0-12	12-24	24-36	36-48	0-48
lbs acre^{-1}	---------------------- lbs acre^{-1} ----------------------				
0	25.5	24.6	25.0	26.4	101.5
60	26.3	26.1	24.7	23.9	101.0
120	26.6	27.4	27.3	25.9	107.2
180	28.7	26.4	29.5	33.7	118.3
LSD$_{(0.05)}$	1.56	1.42	1.37	1.78	2.94

Research conducted in 1987-92 (Hutchinson *et al.*, 1993) showed that yields of cotton grown in minimum tillage were similar to yields obtained from conventional tillage. Burmester *et al.* (1997) showed that yields may vary in different years comparing minimum and conventional tillage. According to Matocha and Barber (1992) and Smart and Bradford (1996), different tillage and fertilization have a direct effect on cotton yield. Many experiments show that cotton yields from minimum tillage are lower or similar to yields from conventional tillage (Brown *et al.*, 1985; Stevens *et al.*, 1992; Burmester *et al.*, 1993; Hutchinson, 1993).

The optimum N rate lies within the range of 31 to 120 lbs N acre^{-1} (Howard and Hoskinson, 1986; Lutrick *et al.*, 1986; Maples and Frizzel, 1985; Phillips *et al.*, 1987; Thom and Spurgeon, 1982; Touchton *et al.*, 1981). According to research conducted by Gordon *et al.* (1990), for cotton grown in strip-tillage, the optimum rate of N to get maximum yield is 76.5 lbs N acre^{-1}.

Our studies showed that cotton grown in strip tillage gave 6.3% higher lint yields as compared to conventional tillage, but applying more than 60 lbs N acre^{-1} did not significantly increase the yield (Table 6). For conventional tillage, yields were lower with application of 180 lbs N acre^{-1} as compared to yields with the application of 60 lbs N acre^{-1}.

Agricultural efficiency was calculated by dividing the differences between the lint yields by N rates. The productivity of 1 lbs N changed from 3.35 and 4.48 lbs lint acre^{-1} with the application of 60 lbs N acre^{-1} to 1.37 and 1.17 lbs acre^{-1} with 180 lbs N acre^{-1} for strip and conventional tillage, respectively (Table 7). Higher N productivity was obtained with low N application on cotton. Higher lint yields increases were obtained from conventional than strip tillage for the application levels of 0-60 and 0-120 lbs N acre^{-1}. This was due to lower yields from treatments with no N application on conventional than strip tillage.

Table 6. Influence of tillage and nitrogen rates on lint yield.

Tillage	N rate (lbs acre^{-1})				
	0	60	120	180	Mean
	---------------------- lbs acre^{-1} ----------------------				
Strip-till	1136	1337	1307	1382	1291
Conventional	1033	1302	1282	1244	1215
Mean	1084	1319	1295	1313	-

LSD$_{(0.05)}$ for tillage - 23.1 lbs acre^{-1}
LSD$_{(0.05)}$ for N rates - 32.9 lbs acre^{-1}
LSD$_{(0.05)}$ for interaction - 46.3 lbs acre^{-1}

CONCLUSIONS

Nitrogen uptake was higher from strip than conventional tillage for the stems only. Increased N rate increased the uptake in plants with highest uptake from the application of 180 and 120 lbs acre^{-1}. Increasing the N rate by 1 lbs increased the N uptake by 0.336 lbs N acre^{-1}. Significantly higher N (NO_3-N) content was obtained from strip than conventional tillage at the depth of 36-48 inches and higher N rates significantly increased the N content in the soil at the measured levels. Cotton grown in strip tillage gave higher lint yields as compared to conventional tillage, but applying more than 60 lbs N acre^{-1} did not significantly increase the yield. Higher N productivity was obtained with low N application on cotton and higher lint yields increases were obtained from conventional than strip tillage for the application levels of 0-60 and 0-120 lbs N acre^{-1}.

Table 7. Efficiency of nitrogen fertilization on lint yield increase.

Tillage	Level of N fertilization (lbs acre^{-1})				
	0-60	0-120	0-180	60-120	120-180
Strip-till	3.35	1.43	1.37	-	1.25
Conventional	4.48	2.07	1.17	-	-

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NITROGEN MANAGEMENT FOR COTTON GROWN IN A HIGH-RESIDUE COVER CROP CONSERVATION TILLAGE SYSTEM

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ABSTRACT

Over 70% of the cotton (*Gossypium hirsutum* L.) in the Tennessee Valley of northern Alabama is currently raised using conservation tillage techniques. High-residue small grain cover crops are becoming a common tool in these systems, but N immobilization may occur causing previous N recommendations to be obsolete. A replicated 3-year field study was initiated in 1999 in the Tennessee Valley of Alabama on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult) to test a factorial arrangement of N source (ammonium nitrate and urea-ammonium nitrate), N rates (0, 40, 80, 120, 160 lbs N acre^{-1}), N application timing (all at planting and 50-50 split between at planting and first square), and N application method (banded or broadcast) for cotton grown in a high-residue rye (*Secale cereale* L.) conservation system. Preliminary results suggest that 120 lbs N acre^{-1} may be needed to optimize yields (781 lbs lint acre^{-1} in 2000 and 1026 lbs lint acre^{-1} in 2001). Generally, highest yields were obtained when N was applied at planting (803 lbs lint acre^{-1} in 2000 and 957 lbs lint acre^{-1} in 2001). Ammonium nitrate applications resulted in greater yields when broadcast at planting while UAN applications resulted in greater yields when banded, regardless of application timing. At current prices for AN and UAN, the preliminary data suggest the most efficient and economical practice for cotton grown in high-residue conservation systems would be to apply 120 lbs N acre^{-1} as UAN in a banded application at planting.

KEYWORDS

Conservation tillage, cover crop, N source, N application, UAN, ammonium nitrate, N application method

INTRODUCTION

Nitrogen recommendations for cotton were developed for conventional tillage systems. For the most part, these recommendations were based upon N and C degraded soils as a result of tillage for extensive periods of time (Martens, 2001). The recommended rate of N for cotton in the Tennessee River Limestone Valley soils of northern Alabama ranges from 30 to 90 pounds N per acre (lbs N acre^{-1}), with 60 lbs N acre^{-1} used as an average (Mitchell *et al*, 1991; Monks and Patterson, 1996). Continuous cotton production, which has little crop residue, has caused soil degradation, erosion, and loss of organic matter in these soils (Schwab *et al*, 2002). Studies show that soil erosion from Alabama crop lands with conventional tillage can be as much as 10 tons per acre per year, which results in a soil loss of 0.10 inches per year. Alabama data suggests that soybean yield [*Glycine max* (L.) Merr.] could drop 35% within 20 to 30 years with this rate of soil loss (Monks and Patterson, 1996). A corresponding decrease in cotton production could seriously jeopardize the profitability of cotton production in Alabama.

Approximately 70% of the farmers in the Tennessee Valley region of Alabama currently use conservation tillage in cotton (Patterson, personal communication, 2002). The main two methods they use are planting into the old cotton stubble, or planting into a cereal cover crop. Planting into the cotton stalks is easier for plant establishment, but may increase compaction problems and reduces lint yield (Burmester *et al*, 1993; Raper *et al*, 2000; Schwab *et al*, 2002). Producers in the Tennessee Valley are increasingly using more high-residue cereal cover crops (>4,000 lbs residue acre^{-1}).

Bauer and Bradow (1993) state that rye offers many benefits as a cover, as it is easy to kill with herbicides, easy to establish, and provides intensive ground cover, even if planted late (Brown *et al*, 1985). Raper *et al* (2000) also found that a rye cover crop was the most critical factor in increasing yields of conservation tillage cotton on this soil type.

Integration of cover crop residue into production systems increases microbial activity and alters the amount and

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seasonality of available inorganic N, affecting N use efficiency (Jackson, 2000). Two common N sources, urea-ammonium nitrate liquid 32% N (UAN) and ammonium nitrate 34% N (AN) are used in cotton cropping systems. Urea-ammonium nitrate liquid 32% N is generally cheaper at \$120 per ton (\$0.188 per lb N) (Limestone Farmers Cooperative, personal communication, 2002), easy to handle and apply, does not require special equipment, and herbicides can be mixed with it during application. It has a few disadvantages as it can scorch plant foliage, salt out at low temperatures, and may become bulky to store (Alabama Certified Crop Advisor Program, 2002). Ammonium nitrate works well as a top-dressing but is more expensive at \$195 per ton (\$0.287 per lb N) (Limestone Farmers Cooperative, personal communication, 2002) and very hygroscopic so it may cause caking problems or present an explosion hazard. Research by Touchton and Hargrove (1982) showed that AN is more efficient than UAN in conservation tillage systems, as UAN may be more susceptible to the urease enzyme concentrated in crop residue, causing more N loss as ammonia to the atmosphere (Bovis and Touchton, 1998).

Nitrogen application method also influences crop N use efficiency. Touchton and Hargrove (1982) showed that banding UAN resulted in higher yields and N uptake in no-till corn (*Zea mays* L.), when compared to broadcast treatments. Another study by Johnston and Fowler (1991) found that dribble banded UAN showed higher responses to yield than broadcast UAN in no-till wheat (*Triticum aestivum* L.). However, a study by Bell *et al* (1998) showed that banded and broadcast N-P-K fertilizer resulted in similar cotton yields.

Nitrogen application timing also affects cotton N use efficiency. The peak time that N is needed is mid-bloom through boll set (Monks and Patterson, 1996). Mullins and Burmester (1990) found that most nutrient accumulation occurs 63 to 98 days after planting, with leaf N concentrations decreasing as the season progresses. Monks and Patterson (1996) stated that only half of N should be applied at planting, with the remainder prior to first bloom. A study by Ebelhar *et al* (1996) showed a significant increase in cotton yield when N was 50-50 split at planting and pinhead square formation. However, research by Howard *et al* (2001) showed that splitting UAN, 50% at planting and 50% six weeks later, resulted in higher yields in only one of eight years.

It is likely that high-residue conservation tillage techniques will initially require higher N rates due to immobilization of N and loss from ammonia (NH_3) volatilization. Monks and Patterson (1996) expect total fertilizer N rates to be increased from 60 lbs acre^{-1} to 90 lbs acre^{-1} in the Tennessee Valley, but no research has been conducted to verify this rate. The objective of this research is to determine the most efficient combination of N rate, method, application timing, and source for high-residue conservation tillage cotton systems in the Tennessee Valley in northern Alabama.

METHODS AND MATERIALS

This experiment was initiated in November of 1999 at the Tennessee Valley Research and Extension Center of the Alabama Agricultural Experiment Station, in Belle Mina, AL with the planting of a rye cover crop. The soil type is a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult), the major type in the region. The experiment design is a factorial arrangement of two N sources (UAN and AN), two N application times (at planting and 50% at planting/50% at first square), two N application methods (broadcast and banded), and four N rates (40, 80, 120, and 160 lbs N acre^{-1}) in a randomized complete block of 4 replications. A 0-N control is also included. The varieties used are ‘Elbon’ Rye and ‘SureGrow 125 BG/RR’ cotton.

Phosphorous, potassium, and lime are applied prior to planting the fall crop based on Auburn University test recommendations. Compaction can become a problem for this soil (Schwab *et al.*, 2002), thus, each year plots are deep tilled to the 18-inch depth using a Paratill® bent-leg subsoiler (Bigham Brothers Inc., Lubbock, TX 79452) immediately following the planting of the rye cover crop, in early November. Equipment used in this experiment is guided using a Trimble AgGPS Autopilot® automatic steering system (Trimble, Sunnyvale, CA 94088), with centimeter level precision. This insures that the equipment compaction is kept off the cotton row. This guidance system allows the banded application of N to be placed in the same location each time it is applied. The rye is terminated in mid-April using glyphosate at the labeled rate. A roller/crimper is then used to roll down the cover crop (Ashford *et al*, 2000). Cotton is planted in early May using a 4-row unit vacuum planter set on 40-inch rows at a rate of 5 seed per foot. All cotton production practices are followed as outlined by the Alabama Cooperative Extension Service.

Initial N applications are made immediately following planting of cotton using a drop spreader equipped for broadcast or banded applications for AN and a sprayer rig for UAN. The second application of the 50-50 split N is applied at first match head square formation. To account for the border effect of alleys, 2.5 feet are cut off each end of the plot using a rotary mower before harvest. The center two rows are harvested with a spindle picker equipped with a sacking unit.

Prior to termination, rye biomass is sampled by collecting two 0.25 m^2 per plot. The residue is dried at 131°F (55°C) until all moisture is removed and weighed to determine dry matter per acre. Approximately 30 g of subsample is ground through a 1 mm screen on a rotary mill. Total C and N by dry combustion using a Fisons 1500 NCS® nitrogen/carbon analyzer (Fisons Instruments, Beverly, MA 01915) is determined on subsamples. At first square, leaf chlorophyll from 25 of the upper most expanded leaves in each plot are read with a Minolta 502 SPAD® chlorophyll meter (Spectrum, Plainfield, IL 60544). Nitrogen concentrations from the leaf blade/petiole combination is then determined by dry combustion. Chlorophyll meter readings from 25 of the upper-most expanded leaves are taken again when the cotton is at 1st flower and mid-bloom. Petioles are separated from leaf blades and analyzed for NO_3-N using an ion selective electrode combination, while leaf blades are again analyzed for N using the combustion technique. The harvested cotton is subsampled and ginning percentage is determined before being sent to the USDA classing office (USDA, Pelham, AL 35124) for high volume instrumentation (HVI) analysis.

Analysis of variance (ANOVA) is conducted prior to determination of Fisher's protected least significant difference (LSD) values using the SAS statistical package® (SAS Institute, 2001). A significance level of $P = 0.10$ was established *a priori*. Only cotton yield and leaf N at 1st bloom data from the 2000 and 2001 seasons are presented in this paper.

RESULTS

2000 Season

In 2000, lint yield ranged from 547 lbs acre^{-1} (0-N check plots) to 1043 lbs acre^{-1}. A significant interaction occurred between N timing x N rate x N application method (Table 1). All N rates significantly increased yield over the 0 N check. When N was broadcast at planting, highest yield was obtained with the 160 lbs N acre^{-1} application (960 lbs acre^{-1}), and rates of 40-120 lbs N acre^{-1} were similar in yield. When N was banded at planting, highest yields (946 lbs acre^{-1}) were obtained with the 120 lbs N acre^{-1} rate, with a trend for reduced yields at the 160 lbs N acre^{-1} rate. Too much N will harm cotton as the plants grow excess vegetation, which reduces fruit load and lint yield (Gerik *et al*, 1994). When N was split applied, regardless of application method (broadcast or banded), there was no response to N application rate other than a yield increase over the 0 N control. However, yields were generally greater for broadcast applications than for banded applications when N was split applied.

At first flower, N source and N rate significantly affected leaf N concentration. Ammonium nitrate applications had higher leaf N (3.88%) than did UAN (3.78%). The 40 lbs N acre^{-1} rate had lower leaf N% (3.64%) than the other three rates (3.86%, 3.87%, and 3.96, for 80, 120, and 160 lbs N acre^{-1} respectively), as expected. Although significantly different, they were all within the sufficiency level of 3.50 to 4.50% N at first bloom (Jones *et al*, 1991). All treatments were in the sufficiency level except the 0 N check plots (3.16%) and UAN broadcast application of 40 lbs N acre^{-1} at planting (3.34%). These plots yielded 547 and 762 lbs lint acre^{-1}, respectively.

2001 Season

In 2001, cotton lint yield ranged from 572 lbs acre^{-1} (0-N check) to 1135 lbs acre^{-1}. There were several significant interactions in this crop season. There was a N source x N method interaction (Table 2). Ammonium nitrate application resulted in greater yield (1014 lbs acre^{-1}) when broadcast, but UAN application yielded higher when banded (1006 lbs acre^{-1}). Rain may affect urea efficiency (Bovis and Touchton, 1998). No rain fell after fertilization in 2000, but within 12 hours of application in 2001, 0.38 inches fell

Table 1. Effect of N application timing, method, and N rate (lbs acre^{-1}) on cotton lint yield for a high-residue conservation system in the Tennessee Valley of Alabama in 2000.The no N check yielded 572 lbs acre^{-1}.

	Broadcast N-rate				Banded N-rate			
Application timing	40	80	120	160	40	80	120	160
	lbs acre^{-1}							
At planting	767	733	725	960	717	739	946	839
Split†	700	812	790	791	663	742	663	750
$LSD_{0.10}$	132							

† Split = 50% N at planting, 50% N at 1st square.

Table 2. Effect of N source and N method on cotton lint yield for a high-residue conservation system located in the Tennessee Valley of Alabama in 2001. The no N check yielded 572 lbs acre^{-1}.

N Source	Banded	Broadcast
	------------ lbs acre^{-1} ------------	
AN	877	1014
UAN	1006	944
LSD$_{0.10}$	56	

after the at-planting and 0.92 inches after first square applications. It is expected that the banded UAN performed better than when broadcast as the N was more concentrated near the cotton root system (Touchton and Hargrove, 1982).

There was an application timing x N rate x application method interaction in 2001 (Table 3) . Nitrogen rate did not affect yield when broadcast at planting, except when compared to 0 N check plots (572 lbs acre^{-1}). Broadcast split applications at 80 lbs N acre^{-1} and greater yielded higher than the 40 lbs N acre^{-1} rate. Banded at planting N increased yields with 120 lbs N acre^{-1} (1029 lbs acre^{-1}) over 80 lbs N acre^{-1} (839 lbs acre^{-1}).

There was also a N source x N method x N application timing interaction (Table 4). Urea-ammonium nitrate liquid banded at planting (1053 lbs acre^{-1}) out performed AN banded at planting (840 lbs acre^{-1}), but AN broadcast at planting (1035 lbs acre^{-1}) out performed the UAN broadcast at planting (913 lbs acre^{-1}). When N was split, there was no yield response; yields were equivalent regardless of N source and method.

Table 3. Effect of N application timing, method, and N rate (lbs acre^{-1}) on cotton lint yield for a high-residue conservation system in the Tennessee Valley of Alabama in 2001.The no N check yielded 572 lbs acre^{-1}.

	Broadcast N-rate				Banded N-rate			
Application timing	40	80	120	160	40	80	120	160
	---------------lbs acre^{-1} ---------------							
At planting	912	985	1006	980	819	839	1029	1129
Split[†]	896	1004	1026	1020	838	958	1042	913
LSD$_{0.10}$				112				

[†] Split = 50% N at planting, 50% N at 1st square.

Table 4. Effect of N application time, N-method, and N-source on cotton lint yield for a high-residue conservation system located in the Tennessee Valley of Alabama in 2001. The no N check yielded 572 lbs acre^{-1}.

	Broadcast N-source		Banded N-source	
Application timing	AN	UAN	AN	UAN
	---------------lbs acre^{-1} ---------------			
At planting	1035	913	840	1053
Split[†]	995	976	912	964
LSD$_{0.10}$		80		

[†] Split = 50% N at planting, 50% N at 1st square.

The N source x N method interaction revealed broadcast AN (3.43%) increased leaf N compared to banded AN (3.33%). Ammonium nitrate broadcast also resulted in greater leaf N concentrations (3.43%) than when UAN was broadcast (3.26%). There was a linear response to N rate when N was applied at planting (Table 5). Split applications resulted in an increase in leaf N from the 40 lbs N acre^{-1} (2.92%) to the 80 lbs N acre^{-1} (3.54%), but no increase after that. There was also a N application timing x N source x N rate interaction (Table 6). At planting, AN rates of 120 (3.60%) and 160 lbs N acre^{-1} (3.81%) had greater leaf N than lower rates. Urea-ammonium nitrate source resulted in a linear response to N rate when applied at planting. The highest N rates (120 and 160 lbs N acre^{-1}) were generally the only plots without a N deficiency, regardless of source. There was also a N source x N method x N rate interaction (Table 7). Broadcast AN resulted in a linear response to N rate, while banded AN resulted in increased leaf N only with N rates greater than 80 lbs acre^{-1}. The reason for the greater leaf N concentrations for UAN applications of 40 lbs N acre^{-1} is unclear, but may be related to reduced plant size and a concentration effect.

Table 5. Nitrogen leaf percentage at the first bloom cotton stage for application timing and N rate in a high-residue conservation system located in the Tennessee Valley of Alabama in 2001. The N-concentration of the no N check was 2.65% N.

Application	N rate			
timing	40	80	120	160
At planting	2.95†	3.06†	3.50	3.69
Split‡	2.92†	3.54	3.55	3.63
$LSD_{0.10}$	0.110			

† Insufficient leaf N at first bloom.

‡ Split = 50% N at planting, 50% N at 1st square.

CONCLUSIONS

Lint yield and leaf N at 1st bloom data suggest that 120 lbs N acre^{-1} may initially be needed for cotton grown in high-residue (>4,000 lbs residue acre^{-1}) conservation systems in the Tennessee Valley. We speculate that N requirements may not be as high for systems with less residue and that N requirements may be reduced over time in high residue systems as soil C and N pools reach new equilibriums. Nitrogen applied at planting generally resulted in greater lint yields (803 lbs lint acre^{-1} in 2000; 957 lbs lint acre^{-1} in 2001) for both sources (UAN and AN) compared to split applications (739 lbs lint acre^{-1} in 2000; 962 lbs lint acre^{-1} in 2001). Ammonium nitrate applications resulted in greater yields when broadcast compared to banding, while efficiency of UAN application was increased when banded. Using 120 lbs N acre^{-1}, at a cost of \$0.19 per lb N for UAN (\$22.80 per acre) and \$0.28 per lb N for AN (\$33.60 per acre), producers can save \$10.80 per acre by using UAN rather than AN. Applying all N at planting saves trips across the field, reducing operating costs and compaction. Banding all UAN at planting may help producers maximize cotton yield and profit in high-residue conservation systems in the Tennessee Valley.

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Reference to trade or company name is for specific information and does not imply approval or recommendation of the company by the USDA or Auburn University to the exclusion of others that may be suitable.

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Table 6. Nitrogen leaf percentage at the first bloom cotton stage for application timing, N source, and N-rate (lbs acre^{-1}) in a high-residue conservation system located in the Tennessee Valley of Alabama in 2001. The N-concentration of the no N check was 2.65% N

	AN rate				UAN rate			
Application timing	40	80	120	160	40	80	120	160
	%							
At planting	3.02†	2.96†	3.60	3.81	2.88†	3.15†	3.39†	3.57
Split‡	2.93†	3.47†	3.53	3.72	2.91†	3.24†	3.57	3.54
LSD$_{0.10}$	0.155							

† Insufficient leaf N at first bloom.

‡ Split = 50% N at planting, 50% N at 1st square.

Table 7. Nitrogen leaf percentage at the first bloom cotton stage for N-source, N-application method, and N-rate (lbs acre^{-1}) in a high-residue conservation system located in the Tennessee Valley of Alabama in 2001. The N-concentration of the no N check was 2.65% N

	Broadcast N-rate				Banded N-rate			
Source	40	80	120	160	40	80	120	160
	lbs acre^{-1}							
AN	3.00†	3.37†	3.52	3.83	2.94†	3.06†	3.62	3.70
UAN	3.93	2.93†	3.50	3.42†	3.87	3.21†	3.46†	3.69
LSD$_{0.10}$	0.155							

† Insufficient leaf N at first bloom.

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CONSERVATION TILLAGE AND POULTRY LITTER EFFECTS ON COTTON AND CORN YIELDS: FIVE YEAR RESULTS

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ABSTRACT

The adoption of conservation tillage in the production of cotton (*Gossypium hirsutum* L.) in northern Alabama has been hindered by the poor emergence, reduced seedling growth, delayed maturity, and reduced yield that have been attributed to conservation tillage systems. The objectives of this study were to evaluate the effects of tillage (no-till, mulch-till, conventional till), cropping system (cotton winter fallow without cover crop, cotton with winter rye (*Secale cereale* L.) cover crop) and N source (poultry litter, ammonium nitrate) on growth parameters and yield of cotton and corn in north Alabama. Cotton lint yield under no-till (NT) was 24%, 7%, 24%, and 8% greater than that under conventional till (CT) in 1997, 1998, 2000, and 2001, respectively. Cover cropping increased cotton lint yields by 6 to 12% compared to cotton winter fallow cropping in 2000 and 2001. Poultry litter (PL) at 100 kg N ha^{-1} gave similar cotton lint yield to ammonium nitrate (AN) whereas at 200 kg N ha^{-1}, lint yields were significantly greater than those at 100 kg N ha^{-1} in the form of AN or PL. Residual N from PL applied to cotton in 1997 and 1998 produced up to 17.3 Mg ha^{-1} of corn biomass (includes 7.1 Mg ha^{-1} of corn grain yield) without additional fertilizer. Poultry litter applied to cotton also increased corn grain quality which was shown by up to 100% increase in grain N content compared to the 0N treatment. These treatments would be appropriate for use in the southeastern U.S.A. where soil erosion is a problem and the disposal of PL from the large poultry industry poses an environmental problem.

KEYWORDS

Conventional tillage, mulch tillage, cropping systems,

INTRODUCTION

The adoption of conservation tillage for cotton production in some counties of north Alabama still lags behind that of other parts of the state. Cotton in northern Alabama is largely grown under conventional tillage, which typically includes shredding cotton stalks followed by primary tillage with moldboard or chisel plow in the fall, spring disking or harrowing, and inter-row cultivation for weed control during the cotton growing season. These tillage operations make the soil susceptible to erosion and hasten the depletion of soil organic matter (Bordovsky *et al.*, 1998). No-till can reduce tillage operations by as many as six to eight operations, which reduces equipment, fuel and labor costs, and increases equipment life and profits. In addition, no-till can reduce soil erosion while maintaining or increasing soil productivity (Triplett *et al.*, 1996). However, some farmers who have tried to adopt conservation tillage systems for cotton production in compliance with the 1985 and 1990 Farm Bills (Federal Register, 1987; Food, Agriculture, Conservation, and Trade Act, 1990) have encountered problems. Cotton seedlings are generally weak, and conservation tillage can result in poor seedling establishment and poor crop growth due to soil compaction, resulting in static or reduced cotton yields (Schertz and Kemper, 1994).

Use of cover crops such as winter rye or organic manure such as poultry litter (PL) in conservation tillage systems may improve cotton seedling emergence, growth and yield. Legumes are often unsuitable for use as cover crops in no-till cotton production in north Alabama, because they are difficult to kill, thus delaying cotton planting and reducing yields. In addition, the toxic ammonia produced by legumes can be most injurious to cotton seedlings. Winter rye displays more vigorous growth, winter hardiness, and mulch persistence than any legume cover. Winter rye cover crops may also reduce leaching losses of residual N fertilizer (Kelly *et al.*, 1992; Nyakatawa *et al.*, 2001a) that could contribute to ground water pollution.

Poultry litter is a relatively inexpensive source of nutrients, particularly N and P. Application of PL to croplands is an

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environmentally friendly way of disposing of the large quantities of PL produced on the multitudinous poultry farms in the American South. An abundant supply of PL is available from the sizable poultry industry in the intensive cotton producing areas of northern Alabama. Therefore, the cotton-producing Tennessee Valley region of northern Alabama could benefit greatly from the use of PL fertilizer. Corn is becoming an important crop for the southeastern USA, especially when grown in rotation with cotton, the major cash crop of this region. Rotating cotton with rye and corn breaks the life cycles of cotton's major pests and diseases, and supplies additional residue to increase soil organic matter. The objectives of this study were to evaluate the effects of no-till and mulch-till with winter rye cover cropping and PL on cotton and corn grown in rotation on a Decatur silt loam soil in North Alabama.

MATERIALS AND METHODS

A field experiment involving soil and crop management strategies for Upland cotton production was initiated at the Alabama Agricultural Experiment Station in Belle Mina, Alabama (34^{o} 41' N 86^{o} 52' W) on a Decatur silt loam soil (clayey, kaolinitic thermic, Typic Paleudults) in 1996.

Treatments and Design

The treatments consisted of three tillage systems: conventional till, mulch-till, and no-till; two cropping systems: cotton-winter fallow (cotton in summer and fallow in winter), and cotton-winter rye sequential cropping(cotton in summer and rye (*Secale cereale* L.) in winter); three N levels: 0, 100, and 200 kg N ha^{-1}; and two N sources: ammonium nitrate and fresh poultry litter. Ammonium nitrate was used at one N rate (100 kg N ha^{-1}) only. The experimental design was a randomized Complete Block design with 4 replications. Plots were 8 m wide and 9 m long, totaling 8 rows of cotton, 1 m apart. Conventional tillage was accomplished by moldboard plowing in November and disking in April. A field cultivator was used to prepare a smooth seedbed after disking. On mulch-till plots, a field cultivator was used before planting to destroy and shallowly incorporate rye residue. A no-till planter was used to place seeds in the untilled soil of the no-till plots.

The N content of the poultry litter was determined by digesting 0.5 g samples using the Kjeldhal wet digestion method (Bremner and Mulvaney, 1982) and followed by N analysis using the Kjeltec 1026 N Analyser (Kjeltec, Sweden). The amounts of poultry litter to supply 100 and 200 kg N ha^{-1} were calculated each year based on the N content of the poultry litter. A 60% adjustment factor was used to compensate for the N availability from poultry litter during the first year. Poultry litter was broadcast by hand and incorporated to a depth of 5 to 8 cm by pre-plant cultivation in the conventional and mulch-till systems. In the no-till system, the poultry litter was surface-applied. Ammonium nitrate and poultry litter were applied to the plots 1 day before cotton planting. The experimental plots received a blanket application of 336 kg ha^{-1} of a 0-20-20 fertilizer to nullify the effects of P and K applied through poultry litter.

Crop management

The winter rye cover crop (cv. Oklon) was planted in fall

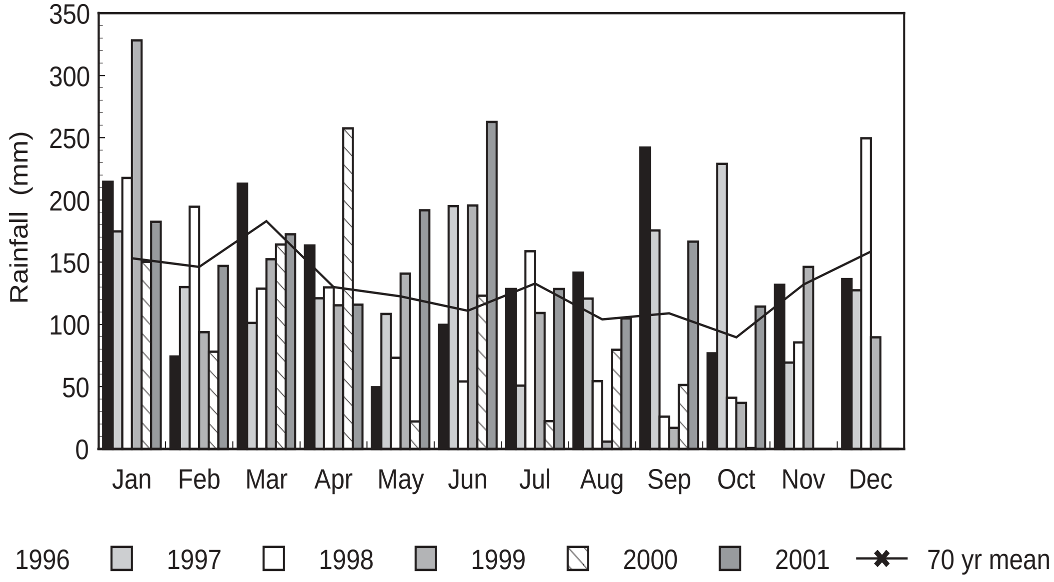

Fig. 1. Total monthly rainfall (mm) and 70-yr mean.

and killed by Roundup herbicide (glyphosate) about 7 days after flowering in spring. A Tye no-till grain drill (Glascock Equipment and Sales, Veedersburg, IN) was used to plant the rye cover crop at 60 kg ha^{-1}. Cotton (cv. Deltapine NuCotn 33B) was planted in all plots at 16 kg ha^{-1}, using a no-till planter. A herbicide mixture of Prowl (pendimethalin) at 2.3 L ha^{-1}, Cotoran (fluometuron) at 3.5 L ha^{-1}, and Gramoxone Extra (paraquat) at 1.7 L ha^{-1} was sprayed on all plots before planting in May for weed control. In addition, all plots received a band application of 5.6 kg ha^{-1} Temik (aldicarb) for early-season control of thrips. During the season, a cultivator was used for weed control in the conventional till system, while spot applications of Roundup using a knapsack sprayer were used to control weeds in the no-till and mulch-till systems. Aphids were controlled by spraying Bidrin (dicrotophos) at 0.4 kg ha^{-1}, and bollworms were controlled with Karate (cypermethrin). A growth regulator (Pix, at 0.8 kg ha^{-1}) was applied to cotton to reduce vegetative growth 2.5 months after planting. The cotton was defoliated with a mixture of Finish at 2.3 L ha^{-1} and Def at 0.6 kg ha^{-1} two weeks before the first harvest. Corn (cv. Dekalb 687^{TM}) was planted in all plots using a no-till planter in spring of 1999 and 2002, at a plant population of 30,000 plants acre^{-1}. When the corn was about 15 cm tall, each plot was sub-divided lengthwise into three sub-plots, each 3 m long with 8 rows of corn, 1 m apart. Three N treatments (0, 100, and 200 kg N ha^{-1}) were randomly applied to the sub-plots in each main plot. Nitrogen, in the form of AN (34% N) was evenly broadcast by hand in each sub-plot when the soil was moist, five weeks after corn planting.

DATA COLLECTION

Seed cotton yield was determined by mechanically harvesting open cotton bolls in the four central rows of each plot. Lint yield data were determined by multiplying the seed cotton yield by the ginning percent. At physiological maturity, five corn plants were randomly selected from the four central rows of each plot and cut at ground level. The leaves and stems were dried to constant weight in an oven at 65^{o}C and weighed. Seed weights were adjusted for a moisture content of 15.5%. The weight of the stalks was combined with that of the stems. Each of the grain, leaf, and stem samples were ground to pass through a 2 mm sieve with a Wiley mill (A.H. Thomas Co., Philadelphia, PA). The samples were analysed for total N content using Kjeldhal wet digestion. Nitrogen uptake of the grain, leaf, and stem samples was calculated by multiplying the percent total N by the sample weight, expressed in kg ha^{-1}. Corn grain yield was obtained by manually harvesting ears in the two center rows of each sub-plot. The ears were shelled using a small-plot combine and yield was calculated after adjusting for seed moisture content as before. Rainfall data (Fig. 1) were taken from an automatic weather station at the Experiment Station.

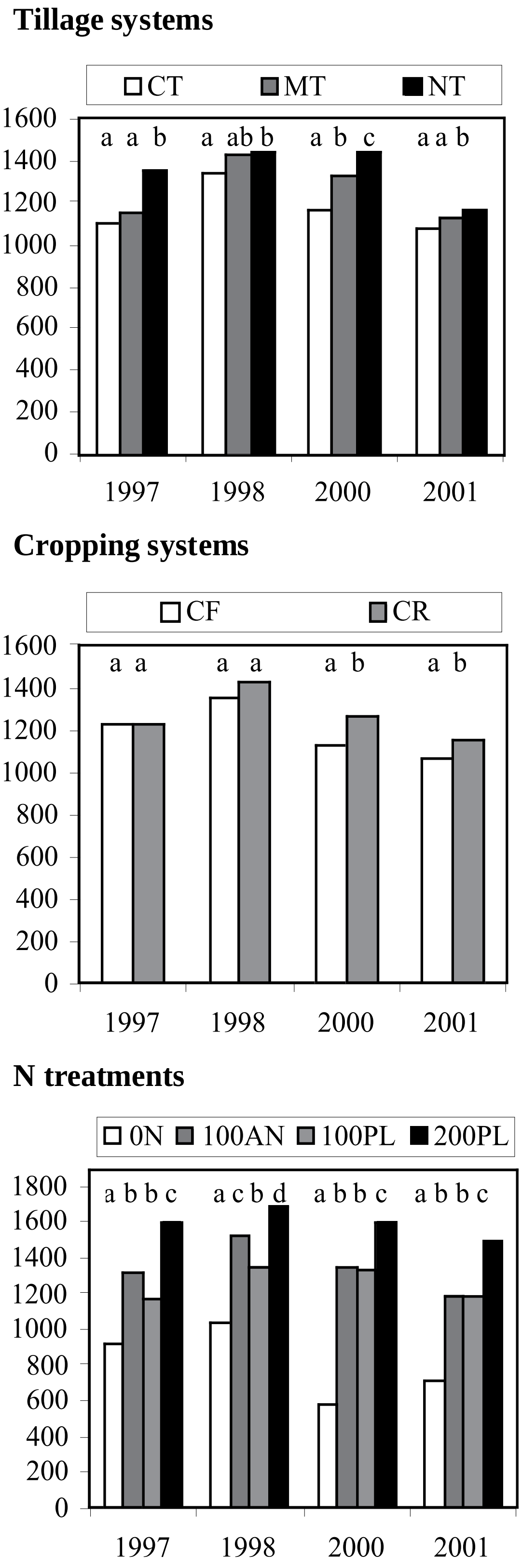

Fig 2. Effect of tillage system, cropping system, and N treatment on seed cotton yield.

Table 1. Means for grain and stover yield of no-till corn as influenced by three applied rates of N (0, 10 and 200 kg N ha^{-1}) in plots previously cropped to cotton under conventional till (CT),mulch-till (MT), no-till (NT) systems, with N from ammonium nitrate (AN) and poultry litter (PL), Belle Mina, AL, 19 (Significance levels of contrast analyses given in parenthesis)

	Tillage treatments applied to cotton from 1996 to 1998		
	CT	MT	NT
Contrast	---------------------------- Stover yield (Mg ha^{-1}) -----------------------------------		
0 vs 100	6.8 vs 13.7 (***)	6.2 vs 15.0 (***)	7.6 vs 15.2 (***)
0 vs 200	6.8 vs 16.0 (***)	6.2 vs 17.8 (***)	7.6 vs 18.9 (***)
100 vs 200	13.7 vs 16.0 (*)	15.0 vs 17.8 (NS)	15.2 vs 18.9 (**)
	-------------------------------- Grain yield (Mg ha^{-1}) ---------------------------------- ----		
0 vs 100	5.2 vs 9.5 (***)	5.2 vs 10.4 (***)	5.9 vs 9.3 (***)
0 vs 200	5.2 vs 11.6 (***)	5.2 vs 10.2 (***)	5.9 vs 11.2 (***)
100 vs 200	9.5 vs 11.6 (**)	10.4 vs 10.2 (NS)	9.3 vs 11.2 (***)

	N sources applied to cotton from 1996 to 1998			
	0N	100AN	100PL	200PL
Contrast	------------------------------- Stover yield (Mg ha^{-1}) ---			
0 vs 100	6.4 vs 13.2 (***)	6.8 vs 15.6 (***)	6.9 vs 12.6 (***)	10.2 vs 18.4 (*)
0 vs 200	6.4 vs 15.7 (***)	6.8 vs 17.6 (***)	6.9 vs 17.8 (***)	10.2 vs 21.3 (**)
100vs 200	13.2 vs 15.7 (**)	15.6 vs 17.6 (***)	12.6 vs 17.8 (***)	18.4 vs 21.3 (NS)
	------------------------------------- Grain yield (Mg ha^{-1}) ------------------------------------- -----			
0 vs 100	4.6 vs 9.7 (***)	5.2 vs 9.7 (***)	5.9 vs 9.5 (***)	7.1 vs 8.8 (NS)
0 vs 200	4.6 vs 12.6 (***)	5.2 vs 11.3 (***)	5.9 vs 10.5 (***)	7.1 vs 10.1 (*)
100vs 200	9.7 vs 12.6 (***)	9.7 vs 11.3 (**)	9.5 vs 10.5 (NS)	8.8 vs 10.1 (NS)

*, **, *** significant at 0.05, 0.01, and 0.001 levels, respectively

STATISTICAL ANALYSIS

The data were analysed using the General Linear Model procedures of the Statistical Analysis System (SAS, 1987). Main effects of the treatment factors were determined by contrast analysis procedures. Regression analysis was used to determine the response functions of corn yield to N from PL.

RESULTS AND DISCUSSION

COTTON

Cotton lint yield under no-till (NT) was 24%, 7%, 24%, and 8% greater than that under conventional till (CT) in 1997, 1998, 2000, and 2001 respectively (Fig. 2). Improved soil moisture conservation in NT plots was largely responsible for improved lint yields in this system. Results from our study are similar to the findings of Harmen*et al.* (1989), who found a significant increase in cotton lint yield under no-till compared to conventional till on a Sherm clay loam soil in Texas. Cover cropping increased cotton lint yields by 6 - 12% compared to cotton winter fallow cropping in 2000 and 2001 (Fig. 2). Poultry litter (PL) at 100 kg N ha^{-1} generally gave similar cotton lint yield to ammonium nitrate (AN), whereas at 200 kg N ha^{-1}, lint yields were 25 - 38% significantly greater than those at 100 kg N ha^{-1} in the form of AN or PL. Soil moisture measurements in the top 7 cm of the soil taken during the first 4 days of cotton seedling emergence showed a greater volumetric soil moisture content in NT plots compared to CT plots with or without PL (Nyakatawa and Reddy, 2000). Poultry litter improved soil water holding capacity of the soil which resulted in higher soil moisture content in NT and PL plots during dry spells. Residues left at the surface and the mulch provided by PL under NT reduced loss of soil moisture by evaporation which resulted in higher yields in NT and PL plots (Nyakatawa *et al.*, 2001b).

CORN

Application of N at 100 or 200 kg N ha^{-1} to corn in 1999 to plots previously under CT, MT or NT cotton from 1996 to 1998 increased corn stover yield by over 100% compared to no N application (Table 1). In 1999, N applied to

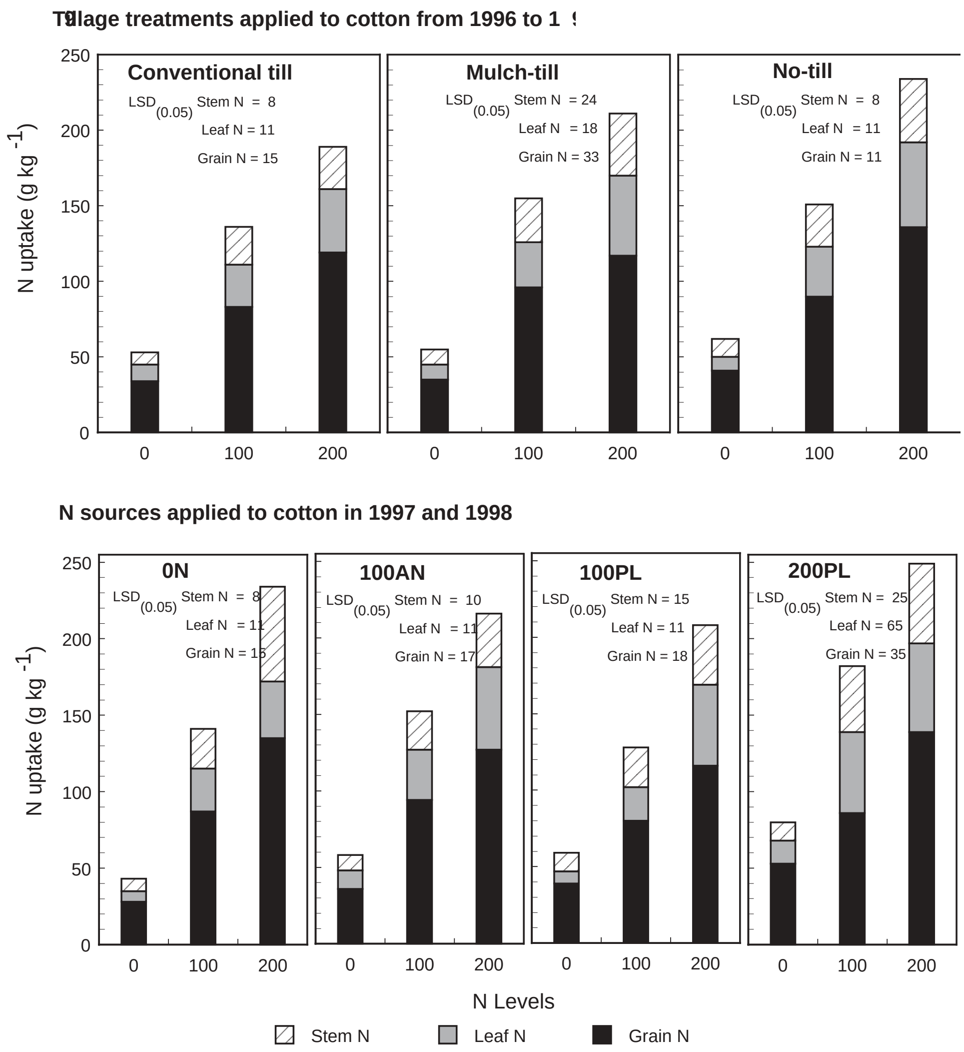

Fig. 3. Effect of tillage system (upper panels) and N-treatment (lower panels) on N uptake of cotton.

corn at 200 kg N ha^{-1} gave significantly greater stover and grain yield, compared to the 100 kg N ha^{-1} N level in plots previously under CT or NT, but not in plots previously under MT. The response of corn stover yield to the 200 kg N ha^{-1} treatment compared to the 100 kg N ha^{-1} N in 1999 was greater in plots previously under NT cotton ($P = 0.01$) compared to that in plots previously under CT cotton ($P = 0.05$). Similar results for the response of corn grain yield to the 200 kg N ha^{-1} treatment in plots previously under NT and CT cotton were significant by $P = 0.001$ and $P = 0.01$, respectively, compared to 100 kg N ha^{-1} treatment. The greater N uptake with N applied to corn in 1999 in plots previously under NT suggests a greater yield potential by corn in plots previously under NT cotton. Our results show that residual N from PL applied to cotton at 100 or 200 kg N ha^{-1} in 1997 and 1998 was capable of meeting about half of the N requirements of the following corn crop in 1999. In addition to reducing costs of fertilizer, this will reduce the amount of nitrate N available for leaching and pollution of surface and ground waters.

At 0, 100, and 200 kg N ha^{-1} levels of 1999, corn grain N concentration in plots previously under NT cotton was, respectively, 21%, 8%, and 14% greater than that in plots previously under CT (Table 1). This suggests that NT applied to cotton from 1996 to 1998 increased corn grain quality compared to CT. Nitrogen applied to the corn crop in 1999 increased grain N uptake at each of the previous 0N, 100AN, 100PL or 200PL N cotton treatments of 1997 and 1998 (Fig. 3). At the 0 kg N ha^{-1} level of 1999, plants in plots which previously received 100PL in 1997 and 1998 under cotton had 14% and 39% higher leaf and grain N concentration, respectively, than those which previously had not received N (Fig. 3). Similar figures for the 200PL treatment of 1997 and 1998 were 114% and 89%, respectively. However, at 100 or 200 kg N ha^{-1} level applied to corn in 1999, there were generally no significant differences in leaf and grain N concentration among the N treatments of 1997 and 1998 (Fig. 3), which suggest that readily available inorganic N satisfied corn N needs.

Quadratic response curves for corn stover yield to N levels applied to corn in 1999 show no gains in stover yield at N levels beyond 200 kg N ha^{-1} in plots which previously received 0N, 100AN and 200 PL (Fig. 4). However, in plots which previously received 100PL, corn stover yield increased linearly with N applied in 1999. Corn grain yield increased linearly with N applied in 1999 in plots which had previously received 100PL or 200 PL under cotton in 1997 and 1998 (Fig. 4). These results suggest that corn in plots which previously received PL under cotton may give higher grain yield at N rates above 200 kg N ha^{-1}. Residual N from PL applied to cotton that slowly becomes available to the corn crop may reduce the amount of N needed to increase corn yields under NT system, thereby reducing nitrate pollution of surface and ground waters.

CONCLUSIONS

Results from our study indicate that NT significantly increased yields of cotton. Poultry litter at 100 kg N ha^{-1} gave similar lint yields to AN. However, at 200 kg N ha^{-1} lint yields were significantly greater than those at 100 kg N ha^{-1} from AN or PL. The PL previously applied to cotton also increased grain and stover yields of corn in1999, which was grown in the same plots following two years of cotton. Inorganic N application to corn in 1999 showed that residual N from PL applied to cotton in 1997 and 1998 was capable of meeting part of the N requirements of the corn, which can reduce N fertilizer costs for the corn and the potential leaching of excess nitrate N. In practical terms, NT, cover cropping, and surface application of PL at 200 kg N ha^{-1} into crop residues will be useful for soil moisture conservation in cotton and corn production systems in the southeastern USA, where erosion is a problem, abundant PL is available, and its disposal is becoming a problem.

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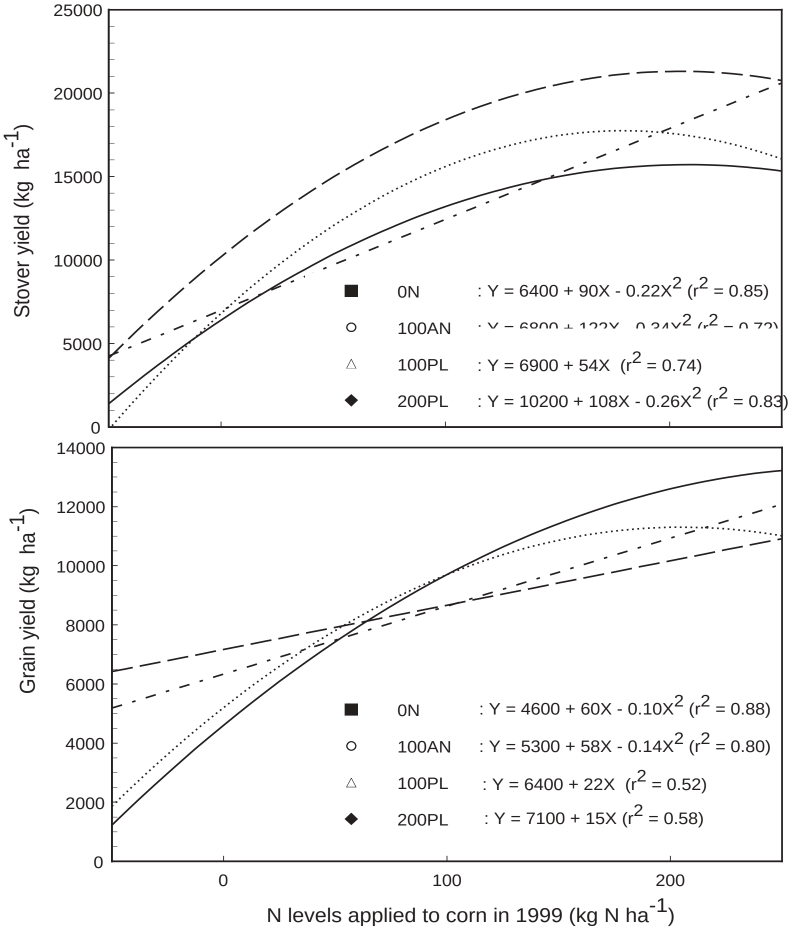

Fig. 4. response functions of corn stover and grain yield to levels of inorganic N (0, 100, 200 kg N ha-1) as influenced by ammonium nitrate (AN) and poultry litter (PL) applied to cotton in 1997 and 1998 at Belle Mina, AL.

YIELD AND NUTRIENT UPTAKE OF TROPICAL FORAGES RECEIVING POULTRY LITTER

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ABSTRACT

Mississippi requires that all poultry facilities generating dry litter or waste must obtain a permit. An essential requirement in the permitting process is a "Waste Utilization Plan". The plan's main function is to determine the total amount of land needed to utilize nutrients generated by each animal unit. Application rates and required acreage are based on soil type and the nutrient removal capacity of the plant species receiving land applied poultry litter. Nutrient removal capacity is the product of nutrient concentration in the plant tissue and dry matter yield. Nine warm season grass species and one legume were planted April 27, 2000 at the North Mississippi Branch Station in Holly Springs. The study site soil is classified as a Grenada Silt Loam with a 0-2% slope. Species were separated into two classes based on nitrogen (N) use, high or medium. Plots were machine harvested and weighed, and sub samples were taken for laboratory analyses. Dry matter yield, phosphorus (P) uptake, and N uptake were determined for each species. In this study there seemed to be no correlation between yield and litter rates among species of forages. It did show, as one might expect, that the N and P uptake increased as yield increased. There was a similar pattern in N and P uptake among cutting dates and yield. There were several instances of high CVs in the first cutting as well as significant yield differences among varieties, each of which can be explained by newly established plots.

KEYWORDS

Animal waste disposal, water quality, N uptake, P uptake

INTRODUCTION

Mississippi currently ranks fourth in the nation in broiler production behind Georgia, Arkansas, and Alabama. According to the Mississippi Agriculture Statistics Service, Mississippi placed over 722 million broiler chicks in 1998. Broiler production is integrator-controlled from egg production to final processing of the mature bird. The farmer has responsibility over daily management including periodic removal of poultry litter manure and bedding. The Mississippi poultry industry currently generates approximately 500,000 tons of poultry litter each year (Bagley and Evans, 1995).

Water quality impacts from land-applied litter are dependent on many variables: soil, rainfall, climate, plant species, shallow *versus* concentrated flow, application rate, waste characteristics, and many others (Edwards and Daniel, 1991). In an attempt to limit potential adverse environmental effects, the Mississippi Department of Environmental Quality requires permits. An essential requirement in the permitting process is a "Waste Utilization Plan".

The Natural Resources Conservation Service (NRCS) is charged with supplying technical support for these plans. The plan's main function is to determine the total amount of the land needed to utilize nutrients generated by each animal unit. Application rates and required acreage are based on soil type and nutrient removal capacity of the plant species receiving the land applied poultry litter. Nutrient removal capacity is the product of nutrient concentration in plant tissue and dry matter yield.

Results from a survey of 25 NRCS field offices and 125 poultry producers in Mississippi showed that 97% of poultry litter is land-applied. The most commonly used forages were bermudagrass and bahiagrass. Total land acreage needed to properly utilize the nutrients in the poultry could be reduced if other higher yielding plant materials were available to poultry producers. However, information is lacking on nutrient removable potential of various non-traditional forage species in the Southeast.

METHODS AND MATERIALS

In the spring of 2000 nine warm season grass species and one legume were planted at the North Mississippi Branch Station in Holly Springs, Mississippi to evaluate yield response to surface applied poultry litter (Table 1). The

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Table 1. Poultry litter application, dry matter and nutrient yield and nutrient uptake for nine tropical forages fertilized with poultry litter. Not all entries received the same rate of poultry litter, thus application rate is confounded with species..

	Litter	Dry matter yield			Yield		Uptake	
Species and cultivar	applied	6/19/01	9/14/01	TOTAL	N	P	P_2O_5	N
	tons acre^{-1}	---------------------------- lbs acre^{-1} ------------------------------						
Bermudagrass								
Common	2.9	1354	3165	4519	160	217	23	43
Summerall 007	5.5	859	3430	4289	302	407	25	42
Pensacola Bahiagrass	2.9	1013	3629	4642	160	217	25	52
Alamo Switchgrass	5.5	2727	5129	7856	302	407	31	76
Gamagrass 9062680	5.5	1948	4437	6385	302	407	29	57
Weeping Lovegrass	2.9	1889	4046	5935	160	217	27	50
Johnsongrass	5.5	1350	3688	5038	302	407	24	42
Tropical sunn hemp	2.9	†	3398	3398	160	217	13	111
Caucasian bluestem	2.9	954	3763	4717	160	217	20	39
Dallisgrass	2.9	796	2641	3437	160	217	17	42
Mean		1432	3997				23	55
LSD		1066	NS				3.2	NS
CV, %		50	31				15	77

† Tropical sunn hemp, the only dicotyledoneous species evaluated, was harvested only once.

experiment design was a randomized complete block with three replications. Each plot was twelve feet by six feet with an alley between and beside other adjacent plots. Forage varieties were established either by seed, sprigs, or transplants. Pensacola Bahiagrass (*Paspalum notatum* Fl¸gge), Common Bermudagrass (*Cynodon dactylon* (L.) Pers.), Dallisgrass (*Paspalum dilatatum* Poir.), tropical sunn hemp (*Crotolaria juncea* L.), and weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees var. *curvula* Nees) were established from seed planted in three rows on 3-ft. centers. Bermudagrass cv. Sumerall 007 sprigs were planted in a grid pattern with a total of 15 sprigs per plot. Alamo switchgrass (*Panicum virgatum* L.), Eastern Gamagrass (*Tripsacum dactyloides* (L.) L.), and Caucasian Bluestem (*Bothriochloa caucasia* (Trin.) C.E. Hubb.) transplants were planted in a grid pattern. The entire plot area was furrow-irrigated daily until all seeded plots had emerged and sprigs and transplants had propagated. Additional irrigation was done until soil moisture was adequate for plant survival. Plots were regularly checked for weeds until adequate ground cover had been achieved. Poultry litter was applied in the spring of 2001 to each plot according to N rates. Two poultry litter rates of 5.5 tons and 2.9 tons per acre were used to achieve 302 and 160 lbs. of N per acre (Table 1). The litter had a pH of 6.92, 26.4% moisture, 3.26% N, and 4.93% P_2O_5. This is equivalent to 55 lbs N and 45 lbs P ton^{-1} wet weight or as it is applied.

Plots were harvested twice during the summer of 2001 by cutting a three-foot swath in the center of each plot with a mower-equipped bagging system. Biomass from each plot was weighed in the field, a sub sample was taken at this time as well. The sub sample was weighed and then oven dried at 110 ˚C. Final dry weights were recorded after samples did not vary more than one percent from the first dry weight. Each dried sample was ground in a Wiley Mill to pass a 25-mesh screen, and analyzed for N and P.

RESULTS AND DISCUSSION

In this study there appeared to be no correlation between yield and the two litter rates among species of forages (Table 1). The results show that N and P uptake increased with increasing yield. There was a similar pattern in N and P uptake among cutting dates and yield. Coefficients of variation (cv) were high for the first cutting and there were significant yield differences among species, which can be explained by growth differences during establishment. There were no significant yield differences among species in the second cutting and there was a lower CV.

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Pest Management

EFFECTS OF WINTER AND FALL COVER CROPS ON PLANT-PARASITIC NEMATODE POPULATION DEVELOPMENT

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ABSTRACT

Combinations of winter and fall cover crops were evaluated for the management of plant-parasitic nematodes. The winter cover crops examined were rye (*Secale cereale*) and narrow-leafed lupin (*Lupinus angustifolius*) and the fall cover crops were soybean (*Glycine max*), cowpea (*Vigna unguiculata*), sorghum-sudangrass (*Sorghum* bicolor x *S. sudanense*), sun hemp (*Crotalaria juncea*), and corn (*Zea mays*). A summer crop of corn was planted in between the winter and fall cover crops. Nematode population densities were determined before and after each cropping season. Both rye and narrow-leafed lupin suppressed the population development of *Meloidogyne incognita* and *Pratylenchus* spp. during the winter crop season. However, this effect was eliminated after one cropping cycle of the summer crop, corn. During the fall cropping season, plant-parasitic nematode populations increased in general, however, plots previously in winter narrow-leafed lupin had higher population densities of *M. incognita* than plots that had winter rye ($P = 0.05$). All the fall cover crops tested had lower *M. incognita* levels than corn ($P = 0.05$). Sorghum-sudangrass and corn supported the highest population densities of *Paratrichodorus minor* and *Mesocriconemella* spp. Sun hemp suppressed all the plant-parasitic nematodes present including *Helicotylenchus dishystera* and *Pratylenchus* spp. as compared to corn ($P = 0.05$). Therefore, rye was more effective in the winter, whereas sun hemp, 'Iron Clay' cowpea, and 'Hinson Long Juvenile' soybean have good potential as fall cover crops for nematode management.

KEYWORDS

Conventional tillage, legumes. Grasses, narrow-leafed lupin, *Lupinus angustifolius* L, tropical sunhemp, *Crotalaria juncea* L

INTRODUCTION

Conservation-tillage has shown many benefits in crop management including reduced soil erosion, moderate soil temperature, conservation of soil moisture (Gallaher, 1977) and machinery energy, and some crops such as rye (*Secale cereale* L.) can even suppress weeds (Shilling et al., 1995). However, no-till practices have failed to suppress most plant-parasitic nematodes compared to cover crop rotation (McSorley and Gallaher, 1993; Cabanillas *et al*., 1999) except for *Pratylenchus* spp., which are usually higher in conventional-tillage plots than in no-tillage plots (McSorley and Gallaher, 1994). In fact, population densities of some nematodes increased in no-till compared to conventional-till plots (Fortnum and Karlen, 1985). Limitations of a one cover crop rotation cycle are the resurgence of nematode populations at the end of the subsequent cash crop cycle, making the subsequent crops prone to nematode damage (McSorley, 1999) or accumulation of plant-parasitic nematode population densities over time (McSorley *et al*., 1994). Although leaving the soil fallow could overcome the nematode problem, volunteer weeds during the fallow period might maintain or even increase some plant-parasitic nematodes. Strategies to improve cover-cropping systems for crop management are under investigation. This research proposed to incorporate winter and fall cover crops in a triple-cropping system to improve nematode management by cover crops.

Rye as a winter crop maintained population densities of *Meloidogyne arenaria* (Neal) Chitwood (McSorley, 1994). In the southeastern U.S., low temperatures in the winter may limit the nematode reproduction, thus using rye, as a winter crop would be beneficial. Although planting legumes in the winter can improve soil nitrogen, most winter legume cover crops such as crimson clover (*Trifolium incarnatum* L.), white clover (*T. repens* L.), or alyceclover (*Alysicarpus* vaginalis (L.) D.C.) are highly susceptible to *Meloidogyne* spp. and other plant-parasitic nematodes (McSorley and Gallaher, 1991; Quesenberry *et al*., 1986; Taylor *et al*., 1986). A potential winter legume that is less

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susceptible to plant-parasitic nematodes is narrow-leafed lupin (*Lupinus angustifolius* L.) (McSorley and Gallaher, 1994; Ferris *et al*., 1993).

In the fall, a number of cover crops are adapted to growing conditions in Florida and the Southeast. For example, some sorghum (*Sorghum bicolor* (L.) Moench) cultivars were effective in reducing population densities of *M. incognita* (Kofoid & White) Chitwood (McSorley and Gallaher, 1991) but were not effective against *Paratrichodorus minor* (Colbran) Siddiqi and *Belonolaimus longicaudatus* Rau (Crow *et al*., 2001; McSorley *et al*., 1994; McSorley, 1996). A summer legume cover crop such as 'Iron Clay' cowpea (*Vigna unguiculata* (L.) Walp.) suppressed *M. incognita* as compared to weed treatment at the beginning of the first cash crop, tomato (*Lycopersicon esculantum* Mill.), but this effect did not persist into a spring vegetable crop (McSorley *et al*., 1999). Sun hemp (*Crotalaria juncea* L.) is another legume cover crop that recently gained recognition for nematode management (Wang *et al*., 2002).

Our objective is to examine the nematode population development in a triple-cropping system involving winter crops, a summer crop of corn (*Zea mays* L.) as a cash crop, followed by fall cover crops. Our goal is to improve the nematode suppressive effect of cover crops in a conservation-tillage system.

MATERIALS AND METHODS

A triple-crop system under a combination of conventional and conservation-tillage practice was set up at the University of Florida Plant Science Research Center, Marion County, FL. A field experiment was conducted in a 2.75 acres site previously planted to pasture. The soil is Arredondo fine sand, consisted of 91.3% sand, 3.5% silt, and 5.2 % clay, with an organic matter content of 1.3%, and a pH of 5.8. A mixture of *Helicotylenchus* spp., *Meloidogyne incognita*, *Mesocriconemella* spp., *Paratrichodorus minor*, and *Pratylenchus* spp. were present at this site.

The summer cash crop, corn, was in rotation with winter and fall cover crops. Two winter cover crops tested were 'Wrens 96' rye (*Secale cereale* L.) planted into a conventional tillage seedbed at 60 lbs acre^{-1}, and 'Tift Blue' narrow-leafed lupin planted at 30 lbs acre^{-1}. The winter cover crops were planted in late November 2000. Individual plots were 2800 ft^2. The experimental design was a randomized complete block with 6 replications. March 21, 2001, the above ground biomass of winter crops was harvested, leaving roots and a stubble height of about 2 inches. The field was prepared for the summer corn crop by which the weeds and crop residues were killed with 0.82 lbs glyphosate a.i. acre^{-1}. 'Florida IRR' experimental corn was no-till planted in rows 10 inches apart (50,000 seeds acre^{-1}). Corn was harvested on June 28, 2001, and the field was prepared for fall crops in which the weeds were sprayed with glyphosate (0.82 lbs a.i. acre^{-1}) then no-tilled with a Tye drill seed planter. Five fall cover crops—soybean (*Glycine max* (L.) Merr. 'Hinson Long Juvenile', 420,000 seeds acre^{-1}), cowpea ('Iron Clay', 420,000 seeds acre^{-1}), sorghum-sudangrass (*Sorghum bicolor* x *S. sudanense* (Piper) Stapf 'Cow Chow', 420,000 seeds acre^{-1}), sun hemp ('Tropic Sun', 260,000 seeds acre^{-1}), and corn ('Florida IRR', 50,000 seeds acre^{-1}) were planted as subplots in each of the winter crop treated plot. Each subplot was 560 ft^2 in size. Thus the experiment became a 2x5 (winter crop x fall crop) split-plot experiment. The biomass of these fall cover crops was then harvested on 3 October 2001.

Rye and narrow-leafed lupin were fertilized with 122 lbs N, 28.5 lbs P_2O_5, 89 lbs K_2O, 7 lbs Mg, 14 lbs S per acre at planting. Prior to corn planting, field plots were sprayed with pre-emergence herbicide, atrazine, at 2.2 lbs a.i. acre^{-1}, and carbofuran was applied at 0.44 lbs a.i. acre^{-1} to control lesser cornstalk borer (*Elasmopalpus lignosellus* Zeller). Summer corn and the subsequent fall crops received a total of 211 lbs N, 52 lbs P_2O_5, 193 lbs K_2O, 12 lbs Mg, 25 lbs S per acre applied at 3 intervals for each crop. Foliar insecticide, methomyl, was applied several times during summer corn and cover crops seasons at 0.26 lbs a.i. acre^{-1} and the field was irrigated with overhead irrigation as needed.

Soil was sampled from each plot at the beginning and end of each crop to estimate initial and final population densities of nematodes. Six soil cores of 1" diam. to 8" depth from each plot were composited to form a sample. Nematodes were extracted from a subsample of 0.2 pt. by the centrifugal-floatation method (Jenkins, 1964). At harvest of each crop, above ground plant biomass was removed, dried, and expressed as dry matter yield per acre.

Nematode counts were log-transformed ($\log_{10}$ [x+1]) before the analysis of variance (ANOVA) using Statistical Analysis System (SAS Institute, Cary, NC), but untransformed means are presented in tables. Data collected after winter crop and summer corn were subjected to one-way ANOVA whereas data collected after fall crop were subjected to split-plot (2 x 5) ANOVA where the winter cover crop treatment was the main plot, and the fall cover crop treatment was the subplot. Means were separated by Waller-Duncan *k*-ratio (*k*=50) where appropriate.

RESULTS AND DISCUSSION

The initial population densities of plant-parasitic nematodes in this site were very low. Both rye and narrow-leafed lupin maintained the low population densities of root-knot (*Meloidogyne incognita*), and lesion (*Pratylenchus* spp.)

Table 1. Effects of winter cover crops on plant-parasitic nematode population densities (0.2 pt soil) in a triple crop system. Data are means of 6 replications

Winter crop	Nematodes per 0.2 pt soil				
	Meloidogyne incognita	*Helicotylenchus dihystera*	*Paratrichodorus minor*	*Mesocricone-mella* spp.	*Pratylenchus* spp.
		-------------------- March, 2001-----------------------			
Rye	0[z]	2	6	16	0
Lupin	0	13 *	2 *	13	0
		-------------------- July, 2001------------------------			
Rye	24	71	36	58	1
Lupin	22	50	41	97	1
		-------------------- October, 2001---------------------			
Rye	18	36	15	36	3
Lupin	48 *	33	22	36	2

* indicated that values for rye and lupin on that date are significantly different at $P = 0.05$ according to the analysis of variance.

nematodes at undetectable levels 4 months after the winter crop planting (Table 1). However, narrow-leafed lupin had higher numbeof spiral nematodes (*Helicotylenchus dihystera* [Cobb] Sher) than the rye, whereas rye had higher number of stubby-root nematodes (*Paratrichodorus minor*) than narrow-leafed lupin(P = *0.05*). At 4 months after summer corn planting (July, 2001), these phenomena were eliminated. During the fall cropping season, plant-parasitic nematode populations increased in general. Plots planted to narrow-leafed lupin during the previous winter had higher population densities of *M. incognita* than plots with rye (P = *0.05*) regardless of the fall crop treatments (Table 1). This is due to the fact that plant-parasitic nematode reproductive rates increased in the summer. Some of the fall crops were hosts of the plant-parasitic nematodes present in the field. Rye might have a better suppressive effect on *M. incognita* and *P. minor* than the narrow-leafed lupin during the winter, but this effect was not observed until the nematode population was magnified over the summer on the corn crop.

During the fall, the cultivars of sorghum-sudangrass, sun hemp, soybean, and cowpea tested suppressed *M. incognita* as compared to corn (P= *0.05*, Table 2). These results were consistent with previous research (McSorley and Gallaher, 1991; McSorley, 1999; Wang *et al*., 2002). The result from soybean, the ‘ Hinson Long Juvenile’ is a poor host to *M. incognita* and *P. minor* is a new information and should be explored due to its cash crop value. Although soybean ‘Hinson Long Juvenile’ is very susceptible to *H. dihystera*, this nematode is not very damaging to most crops, including corn and soybean. Sun hemp was the most effective cover crop tested here, resulting in statistically lowest

Table 2. Effects of fall cover crops on plant-parasitic nematode population densities (0.2 pt soil). Data are means of 6 replications.

Fall crop	Nematodes per 0.2 pt soil				
	Meloidogyne incognita	*Helicotylenchus dihystera*	*Paratricho-dorus minor*	*Mesocricone-mella* spp.	*Pratylenchus* spp.
Soybean	13 b[†]	95 a	9 b	11 b	2 bc
Cowpea	3 b	13 bc	7 b	8 b	4 a
Sorghum-sudangrass	20 b	26 bc	32 a	93 a	2 bc
Sunn hemp	6 b	10 c	3 b	18 b	0 c
Corn	124 a	30 ab	42 a	50 a	6 ab

[†] Values followed by the same letters are not different according to Waller-Duncan k-ratio (k=100) t-test.

populations of all plant-parasitic nematodes in this field including *H. dihystera* and *Pratylenchus* spp. This is contradictory to the results from Kenya where another species of *Crotalaria* was found to be a good host for these two nematode genera (Desaeger and Rao, 2000). This could be because of a difference in the nematode susceptibility among *Crotalaria* species. Although sorghum-sudangrass suppressed *M. incognita* effectively, it is a good host to *P. minor* and *Mesocriconemella* spp. (Table 2) similar to previous reports (McSorley, *et al*., 1994; McSorley and Dickson, 1995). Continuous planting of corn resulted in the highest population densities of all the plant-parasitic nematodes in this field (Table 2), indicating that double cropping of corn will create future nematode problems that might not be manageable by winter cover crop alone.

CONCLUSION

A triple cropping system offered more opportunity for nematode management than the more common double-cropping systems practiced in the subtropical climate of Florida. Planting rye in the winter maintained low plant-parasitic nematode population densities. Sun hemp, 'Iron Clay' cowpea and 'Hinson Long Juvenile' soybean have good potential as fall cover crops for nematode management in addition to their nitrogen improvement properties.

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CROP ROTATION EFFECTS ON NEMATODE POPULATIONS

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ABSTRACT

Crop rotations are an effective method of improving yields. One benefit of alternating crops within a field is nematode suppression. In Louisiana, many fields are infested with root-knot [*Meloidogyne incognita (Koifoid and White)*], reniform [*Rotylenchus reniformis* (Linford and Oliveira), and soybean cyst (*Heterodera glycines* Ichinohe) nematodes. Nematodes can cause plants to be less thrifty and hypersensitive to stress, resulting in yield decline. Nematodes can be controlled for a limited duration with chemicals that can be expensive and highly toxic. Host plant resistance is another alternative to controlling nematode populations; however, this option is often limited by the lack of high-yielding, resistant cultivars available to producers. Most studies involving nematode control with crop rotation have been for less than five years and can not account for alterations in soil properties caused by long-term crop sequences, which may affect nematode population dynamics. The objective of this study was to compare the effectiveness of cropping sequences involving cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), grain sorghum [Sorghum bicolor (L.) Moench], and wheat (*Triticum aestivum* L.) for control of nematode populations. Cropping sequences established in 1982 were evaluated for nematode population densities. The test site was managed with conventional tillage and practices recommended by LSU. Five sampling dates during 1999-2002 were taken from 6-in cores and assayed for nematode infestation. Data indicated grain sorghum was the best alternative as a non-host crop in fields with mixed reniform and root-knot populations. Corn was a good non-host for reniform nematodes but proved to be a host plant for root-knot nematodes. Winter and spring weed species may also contribute to boosting root-knot nematode populations that were previously suppressed by non-host crops.

KEYWORDS

Root-knot nematode, reniform nematode, soybean cyst nematode, cropping systems, crop rotation

INTRODUCTION

Alluvial soils of the lower Mississippi Delta region in Louisiana are often infested with root-knot (RKN), reniform (REN), and soybean cyst (SCN) nematodes. Infected crops generally are slightly stunted and may show signs of potassium deficiency (Shepherd *et al*., 1988b; Blasingame, 1994). If growing conditions for the crop are less than ideal, nematode infestation may exacerbate plant stress.

Economic losses attributed to nematodes can be immense. In Louisiana, an estimated 87,000 bales of cotton were lost in 2000 because of nematode damage (Blasingame, 2001). Nationwide in the same year, nematodes cost cotton producers nearly 800,000 bales. The range of REN infestation appears to be worsening in Louisiana. Overstreet and McGawley (2000) reported that in two of the leading cotton producing parishes, Richland and Franklin, the incidence of samples with REN had increased by nearly twenty-fold over the last twenty years.

Control of nematodes is difficult and expensive. Chemical control has been somewhat successful with the use of Temik™ (aldicarb) and Telone II™ (Gazaway *et al*., 2001; Lorenz *et al*., 2001; Overstreet *et al*., 2001). Unfortunately, these chemicals can be expensive, highly toxic, and provide only short-term nematode suppression.

An alternative method of controlling nematode populations has been the use of host plant resistance. Several soybean lines exist with excellent SCN and REN resistance (Robbins *et al*., 2000; Long and Todd, 2001). Varying levels of resistance to RKN has also been identified in soybean germplasm (Luzzi *et al*., 1994). Several experimental cotton genotypes have been developed with resistance to RKN (Shepherd, 1974; Shepherd *et al*., 1988a). In 1991, cotton cultivar 'LA 887' was released and possessed partial resistance to root-knot nematodes (Jones *et al*., 1991). Cotton cultivar 'Acala NemX', released in 1995, was the first commercial cultivar with complete resistance to RKN (Oakley, 1998). Unfortunately, few commercial cotton breeding companies dedicate resources for development of RKN resistant cultivars, which leaves producers with

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limited options for fields infested with the nematodes. Little progress has been made in developing REN resistant cotton cultivars.

A third alternative to suppressing nematodes is the practice of crop rotation. Studies indicate that excellent control of soybean cyst nematode can be achieved by rotating SCN resistant soybean cultivars with corn (Howard *et al*., 1998; Long and Todd, 2001; Chen *et al*., 2001). Crop damage from RKN and REN can be mitigated by rotating to a nonhost crop for at least one year (Goodell and Eckert, 1998; Overstreet, 1998; Mueller, 1999; Gazaway *et al*., 2000). After a season of growing a susceptible crop host, nematode levels will again be restored to pre-rotation levels. Winter cover crops supposedly have little effect on spring populations of REN (Overstreet *et al*., 2001; Gazaway *et al*., 2000).

Most crop rotation studies that monitored nematode populations have been for less than five years. It is not known how cropping sequences continued for a longer period of time will affect nematode populations in the lower Mississippi Delta.

METHODS AND MATERIALS

Fourteen cropping sequences including cotton (CT), corn (CN), grain sorghum (GS), soybean (SY), and wheat (WT) have been evaluated at the LSU AgCenter's Northeast Research Station near St. Joseph, LA. The study was initiated in 1982 on Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent). Experimental design was a randomized complete block with four replications. Plot size was 16-rows (40-in. centers) X 50 ft. All plots are managed with conventional tillage practices and were not irrigated. During the winter and spring, native weed species were allowed to grow unchecked. All cultivars have been the most recent to be recommended by LSU for commercial production in Louisiana.

Soil was sampled Sept. 1999, Sept. 2000, Sept. 2001, Dec. 2001, and April 2002. Ten cores at 6-in. depths were taken from each plot. Samples were then sent to the LSU Plant Pathology Department in Baton Rouge, LA, for nematode assessment. Nematode populations are reported as nematodes per 500 cm^3 soil. Nematode data were analyzed using the GLM procedures of SAS (1989). Fisher's protected LSD at a significance level of 0.05 was used to separate means.

RESULTS AND DISCUSSION

The most common nematode species found was RKN (Table 1). Cotton, corn, and to a lesser extent soybean and wheat were susceptible to RKN. Grain sorghum did not support RKN populations at a detectable level and appears to be the most promising rotation choice for suppression. Grain sorghum consistently eliminated RKN from areas previously planted to cotton and soybean. After a year back to cotton or soybean, RKN populations were restored to the pre-rotation level. These results are similar to scenarios associated with REN and crop rotation (Overstreet, 1998; Gazaway, 1999; Mueller, 1999). The spring 2002 sampling from the CT-GS-SY cropping scheme, in which grain sorghum was planted in 2001, indicated the presence of

Table 1. Cropping sequence effect on root-knot nematode (500 cm^3 of soil).

Crop	Fall 1999		Fall 2000		Fall 2001		Winter 2001		Spring 2002	
Scheme	Crop	RKN	Crop	RKN	Crop	RKN	Crop	RKN	Crop	RKN
CT	*CT*	3840	*CT*	560	*CT*	950	*CT*	160	*CT*	295
SY	*SY*	0	*SY*	420	*SY*	40	*SY*	0	*SY*	325
CN	*CN*	160	*CN*	747	*CN*	120	*CN*	40	*CN*	80
GS	*GS*	0	*GS*	0	*GS*	0	*GS*	0	*GS*	0
CN-CT	*CT*	1813	*CN*	300	*CT*	960	*CT*	200	*CT*	40
CN-SY	*SY*	27	*CN*	107	*SY*	650	*SY*	160	*SY*	1200
CT-SY	*SY*	373	*CT*	27	*SY*	75	*SY*	35	*SY*	80
GS-CT	*CT*	3840	*GS*	0	*CT*	560	*CT*	0	*CT*	920
GS-SY	*SY*	107	*GS*	0	*SY*	0	*SY*	0	*SY*	40
CT-CN-SY	*SY*	27	*CT*	0	*CN*	835	*CN*	80	*CN*	280
CT-GS-SY	*SY*	93	*CT*	427	*GS*	0	*GS*	0	*GS*	80
CT-CT-SY	*SY*	40	*CT*	0	*CT*	240	*CT*	80	*CT*	0
CT-CT-CN	*CN*	3840	*CT*	0	*CT*	960	*CT*	40	*CT*	220
SY-WT	*SY*	0	*SY*	13	*SY*	120	*WT*	40	*WT*	80
Mean		1011		186		394		60		260
LSD$_{(0.05)}$		n.s.		n.s.		n.s.		n.s.		n.s.

Table 2. Cropping sequence effect on reniform nematode (500 cm^3 of soil).

Crop	Fall 1999		Fall 2000		Fall 2001		Winter 2001		Spring 2002	
Scheme	Crop	REN	Crop	REN	Crop	REN	Crop	REN	Crop	REN
CT	*CT*	0	*CT*	3733	*CT*	1600	*CT*	2840	*CT*	3610
SY	*SY*	0	*SY*	0	*SY*	0	*SY*	0	*SY*	40
CN	*CN*	0	*CN*	0	*CN*	0	*CN*	0	*CN*	0
GS	*GS*	0	*GS*	0	*GS*	0	*GS*	0	*GS*	0
CN-CT	*CT*	0	*CN*	0	*CT*	0	*CT*	250	*CT*	640
CN-SY	*SY*	0	*CN*	0	*SY*	0	*SY*	0	*SY*	0
CT-SY	*SY*	0	*CT*	0	*SY*	5080	*SY*	1680	*SY*	80
GS-CT	*CT*	0	*GS*	0	*CT*	0	*CT*	0	*CT*	0
GS-SY	*SY*	0	*GS*	0	*SY*	0	*SY*	0	*SY*	0
CT-CN-SY	*SY*	0	*CT*	0	*CN*	0	*CN*	0	*CN*	0
CT-GS-SY	*SY*	0	*CT*	0	*GS*	0	*GS*	0	*GS*	0
CT-CT-SY	*SY*	0	*CT*	0	*CT*	0	*CT*	0	*CT*	0
CT-CT-CN	*CN*	0	*CT*	0	*CT*	0	*CT*	40	*CT*	0
SY-WT	*SY*	0	*SY*	6613	*SY*	0	*WT*	0	*WT*	0
Mean		0		739		477		344		312
LSD$_{(0.05)}$		n.s.		n.s.		n.s.		n.s.		n.s.

Table 3. Cropping sequence effect on soybean cyst nematode (500 cm^3 of soil).

Crop	Fall 1999		Fall 2000		Fall 2001		Winter 2001		Spring 2002	
Scheme	Crop	SCN	Crop	SCN	Crop	SCN	Crop	SCN	Crop	SCN
CT	*CT*	0	*CT*	0	*CT*	0	*CT*	0	*CT*	0
SY	*SY*	0	*SY*	0	*SY*	15	*SY*	0	*SY*	10
CN	*CN*	0	*CN*	0	*CN*	0	*CN*	0	*CN*	0
GS	*GS*	0	*GS*	0	*GS*	0	*GS*	0	*GS*	0
CN-CT	*CT*	0	*CN*	0	*CT*	0	*CT*	0	*CT*	0
CN-SY	*SY*	0	*CN*	0	*SY*	0	*SY*	0	*SY*	0
CT-SY	*SY*	0	*CT*	0	*SY*	0	*SY*	0	*SY*	0
GS-CT	*CT*	0	*GS*	0	*CT*	0	*CT*	0	*CT*	0
GS-SY	*SY*	0	*GS*	0	*SY*	0	*SY*	0	*SY*	0
CT-CN-SY	*SY*	0	*CT*	0	*CN*	0	*CN*	0	*CN*	0
CT-GS-SY	*SY*	0	*CT*	0	*GS*	0	*GS*	0	*GS*	0
CT-CT-SY	*SY*	0	*CT*	0	*CT*	0	*CT*	0	*CT*	0
CT-CT-CN	*CN*	0	*CT*	0	*CT*	0	*CT*	0	*CT*	0
SY-WT	*SY*	0	*SY*	0	*SY*	0	*WT*	0	*WT*	0
Mean		0		0		1		0		1
LSD$_{(0.05)}$		n.s.		n.s.		n.s.		n.s.		n.s.

RKN. This may have been the result of RKN finding hosts among native weed species during the winter and spring.

The second most common nematode species in the study was REN (Table 2). Incidence of REN was more sporadic than RKN and may be the result of sensitivity to fluctuating conditions in the upper 6-in. soil profile (McSorley, 1998). Data suggests that cotton and soybean were excellent host species. These findings are congruent with previous research (Starr, 1998; Kinloch, 1998). Corn and grain sorghum, considered good rotation choices for REN control (Mueller, 1999; Gazaway, 2000), drove REN populations below detectable levels. REN in cotton-grain sorghum rotations were not detected and were never detected in the soybean-cotton rotation, which is contrary to expectations (Overstreet, 1998). There may have been an interaction with soil properties and REN in these cropping schemes that impaired REN fecundity (Howard *et al*., 1998; Zhao, 2000).

SCN were only detected in areas planted in continuous soybean (Table 3). The plant host range of SCN is very limited (Noe, 1998). Soybean grown in rotation with any of the other crops, including the double-cropped wheat, appeared to substantially reduce SCN.

CONCLUSIONS

Grain sorghum appears to be the best non-host rotation option especially in fields with mixed populations of RKN and REN. Samples from plots planted to grain sorghum consistently were free from all detectable nematode infestations. Moreover, the benefit of grain sorghum in suppression of REN to cotton and soybean was slightly better than was observed from corn. SCN were invariably controlled with crop rotation.

Further investigations are needed into the dynamics of soil properties and vitality of nematode populations. In addition, weed species that are hosts to RKN and REN need to be identified and control measures devised to ensure the advantages of crop rotation are preserved for as long as possible.

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IMPACT OF STRIP-TILL PLANTING USING VARIOUS COVER CROPS ON INSECT PESTS AND DISEASES OF PEANUTS

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ABSTRACT

A research project is ongoing at the Wiregrass Research and Extension Center in Headland, AL to evaluate the impact of cover crops in a minimum till planting and its effects on insect pests and diseases of peanuts. The tests were conducted in a standard field with a cotton/ peanut rotation and consisted of eight winter cover crop treatments arranged in a randomized complete block design with four replications. The eight treatments were wheat, rye, oats, fallow, ryegrass, wheat/ryegrass, rye/ryegrass, and oats/ryegrass. The first half of each plot (A portion) was treated with Lorsban and the second half of each plot was untreated. Stand counts were made on the third row of each plot, and Tomato Spotted Wilt Virus (TSWV) ratings were made in the two middle rows of each plot. White mold disease ratings were made from the four middle rows (two Lorsban and two untreated rows). Three-cornered Alfalfa Hopper (TCAH) damage was determined from terminal samples taken from these same four rows. Yields were taken from the middle four rows of each plot (A and B). Further testing will be ongoing to study the long term effects of the rotation and its effects on insects, disease, and yield.

KEYWORDS

Conservation tillage, minimum tillage insecticides

INTRODUCTION

Peanuts (*Arachis hypogaea*) are a major crop in the southeastern United States and are very important to the state of Alabama. In 2001, 199,000 acres of peanuts were planted in Alabama yielding an average of 2,750 lbs per acre. Because of their importance to Alabama, some of the biggest challenges facing peanut growers are how to adequately control insects and diseases and how to increase yield. Strip-till planting is a method that is slowly becoming acceptable as an alternative way to plant peanuts. Strip-till planting involves planting peanuts in soil that was planted during the winter with cover crops and planting in the crop debris left on the surface from the cover crops. Strip-till planting is a conservation management system that includes these elements: 1) maintaining crop residue 2) managing better nutrients, 3) getting a good stand and 4) decreasing disease pressure and insects. The benefits of using a strip-till planting method vary from year to year, but in most instances, decreases in disease incidence and insect damage have been observed resulting in increases in yield.

Strip or no-till planting differs from conventional tillage in that conventional tillage refers to the sequence of operations that are most commonly used to prepare a seedbed and produce a crop (Dickey *et al.,* 1992). Reduced tillage generally refers to any system that is less intensive and less aggressive than conventional tillage and can refer to a number of different systems (Dickey *et al.,* 1992).

One of the results of using a no-till or reduced-till program is the effect that it has on insect populations. Tillage practices have an impact on all types of soil organisms and may affect them either directly or indirectly. It has been observed that insects that spend part of their life cycle in the soil may develop more slowly in a reduced till planting, because the residue from the cover crops can moderate soil temperature (Steffey *et al.,* 1992). Among the various insects that may be affected are corn ear worn, lesser corn-stalk borer, and three cornered alfalfa hopper (TCAH). In addition, tobasso thrips (*Frankliniella fusca*) populations may also be reduced resulting in less tomato spotted wilt virus (TSMV) damage. Tillage practices may also change weed densities that may have an impact on both beneficial insects and insect pests. In addition to tillage practices, crop rotation can have an effect on insect populations.

Another positive impact that occurs from the use of a conservation tillage program is the reduction in diseases that have been observed. Because conservation tillage

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generally reduces soil temperature and conserves soil moisture, they may or may not have any effect on potential severity of the disease. Crop diseases that are favored by cool wet soils may be more of a concern than those that are favored by higher soil temperatures (Scott *et al.,* 1992). Diseases affected by strip-till planting include leaf spot diseases caused by *Cercospora arahidicola* and *Cercosporidium personatum,* white mold (WM) caused by *Sclerotium rolfsii*, and Tomato spotted Wilt Virus (TSWV). Researchers in Georgia have shown that in fields using strip-till planting, there was a 25 percent decrease in leaf spot diseases compared to fields using conventional tillage. There was also less TSWV damage in these same fields (Yancey, 2002).

One of the biggest challenges facing farmers using strip-till planting is getting a good stand. The recommended seeding rate is the same as for conventional tillage of 6 seed per foot of row. When comparing yields using the various planting methods, results seem to vary. In Florida, some conventional fields outperformed strip-till, but at other locations strip-till planted peanuts outperformed conventional tillage (Yancey, 2002). In a previous study conducted in Alabama in 1983 (Hartzog and Adams, 1984), similar results were obtained. In some locations, strip tillage had some effect on yield, while at other locations the conventional tillage fields gave better results.

Because of the variability observed using a strip-till or minimum-till planting, a long-term research project is ongoing to study the effects of crop rotation in a strip-till planted peanut field. The purpose of this study is to look at the long-term results from strip-till peanuts and to determine the effects that this type of planting method has on control of diseases and insects and its subsequent effect on yield, and to establish a consistent pattern in fields where strip-till planting is occurring over many years

MATERIALS AND METHODS

This research project was begun in 2000 at the Wiregrass Research and Extension Center in Headland, AL. Peanuts were planted in a field that was previously planted with cotton and a peanut/cotton rotation was followed. The soil type was a Dothan sandy loam that was conducive to growing peanuts in southeast Alabama. Peanut cultivar ‘Georgia Green’ was used in all plantings, and both in 2000 and 2001 peanuts were planted during the last week of April. Plots were arranged in a randomized complete block design with four replications.

Plots consisted of eight rows 60 feet in length, and eight treatments were involved in the test consisting of various winter cover crops. These included wheat, rye, oats, fallow, ryegrass, wheat/ryegrass, rye/ryegrass, and oats/ryegrass. Peanuts were planted into the plots after these cover crops were killed with herbicide. The plots were divided into subplots with the first four rows of each plot treated with Lorsban and the second four rows of each plot remaining untreated. Plots were maintained throughout the growing season, and all eight rows were treated for diseases following the recommendations of the Alabama Cooperative Extension System.

Approximately two weeks after emergence, stand counts were made from the third row of each plot. Prior to inversion, TSWV counts were made in the two middle rows of each plot. White mold hit counts were made from the four middle rows of each plot-two Lorsban treated rows and two untreated rows. Terminal samples were also taken from these rows to determine TCAH damages which was defined as the number of girdled stems per 25 terminals.

Table 1. Insect and disease data taken from minimum-till peanut test, 2001.

	Disease Ratings		Insect Damage
Forage System	TSWV[†]	White Mold[‡]	TCAH[¶]
Wheat	6.5 a[§]	1.5 a	19.8 a
Rye	2.6 a	3.5 a	20.3 a
Oats	3.9 a	2.5 a	14.3 a
Fallow (no forage)	4.3 a	4.8 a	16.3 a
Ryegrass	2.5 a	2.5 a	15.5 a
Wheat/Ryegras	5.8 a	6.3 a	24.8 a
Rye/Ryegrass	3.3 a	3.8 a	23.5 a
Oats/Ryegrass	2.8 a	6.0 a	15.5 a
$LSD_{0.05}$	5.1	5.3	11.6

[†] TSMV counts were made from the middle two rows of each plot on 8/30/01

[‡] White Mold counts were made on 9/7/01 as the number of disease loci per 120 ft of row (1 locus = 1 ft of consecutive symptoms and signs of the disease).

[¶] 25 terminal samples were taken on 9/6/01 to determine TCAH girdling damage.

[§] Numbers within columns followed by the same letter do not differ significantly according to Fisher’s protected least significant difference at *P* = 0.05.

Plots were inverted, left to dry for two to three days and then combined. Yield results were taken from the middle four rows of each plot and separated into Lorsban and untreated sub plots. All data was analyzed utilizing analysis of variance (SAS, Cary, NC).

RESULTS

Disease and insect ratings that were taken in 2001 (Table 1) from the different plots showed very little differences. None of the plots showed any significant differences in the disease and insect ratings. For TSWV, the number ranged from a low of 2.5 in the ryegrass plots to a high of 6.5 in the wheat plots. White mold results also showed that none of the plots were significantly different from each other even though the wheat plots had fewer hits than the other plots. For TCAH damage none of the plots gave significantly better results, but the numbers from the oats plots were lower than any of the other plots and the numbers from the wheat/ryegrass plots showed the greatest damage. When insect totals were compared for soil insects and foliage feeders during the summer, lowest numbers were observed for soil insects in the rye/ryegrass plots that were significantly different from the ryegrass only plots. For foliage feeders, the lowest numbers were observed in the oats plots and these were significantly different from both the wheat and rye/ryegrass plots (Table 3).

In 1999, yield data was taken from the plots to determine what effects that winter cover crops had on the final results. Yield data taken showed that none of the plots were significantly different from each other and there was very little variation within the plots (Table 2). Even though there was no significance among the plots, the yields taken from the ryegrass plots consistently gave the highest yield totals, and the yields from the oats plots were consistently lower. Yields from the no forage plots decreased each year.

In 2000, a severe drought occurred at the station and throughout the southeast with rainfall totals much below historical means. As a result, yield totals were much lower than the previous year due to the plots being located in a area where no irrigation was available. Even though yield totals were lower than the previous year, significant differences did occur among the plots. Yield totals ranged from a high in the wheat cover of 2093 lbs acre^{-1} to a low in the oats/ryegrass plots of 1095 lbs acre^{-1}.

Yield from the no forage plots were reduced from the previous year and were significantly better than the oats/ ryegrass and significantly less than the wheat plots.

In 2001 rainfall totals returned to more historical averages for the area and this was reflected in the yield results, which were much above totals from both 1999 and 2000. As in the previous year, yield taken from the oats/ ryegrass plots were the lowest observed and the yield from the rye plots gave the highest totals. Overall results from the no forage plots continued to show a decrease in relation to the other plots, but only the rye plots gave significantly higher yields.

Table 2. Peanut yield from minimum-till plots for the 1999 – 2001 crop years**.** Yield were calculated from harvest area of 6 x 60 ft

Forage System	1999	2000	2001
Wheat	3824 a	2093 a	5203 abc
Rye	3842 a	1797 ab	5687a
Oats	2868 a	1249 de	5512 ab
Fallow (no forage)	3884 a	1682 bc	4943 bcd
Ryegrass	3866 a	1615 bc	4737 cd
Wheat/Ryegras	3588 a	1561 bc	5191 abc
Rye/Ryegrass	3860 a	1482 cd	5445 ab
Oats/Ryegrass	3600 a	1095 e	4537 d
$LSD_{0.05}$	1064	305	623

In two out of three years, yield results from the rye plots were the highest overall and in 2000 only the wheat plots

Table 3. Soil insect and foliage feeder counts from minimum-tillage plots during summer 2001.

Forage system	Soil Insects	Foliage Feeders
Wheat	2.25 ab	12.00 a
Rye	1.75 ab	9.75 a
Oats	1.50 ab	3.50 b
Fallow (no forage)	2.50 ab	7.75 ab
Ryegrass	4.25 a	7.00 ab
Wheat/Ryegras	2.00 ab	7.75 ab
Rye/Ryegrass	1.25 b	9.50 a
Oats/Ryegrass	2.00 ab	7.00 ab
$LSD_{0.05}$	3.0	5.3

gave higher results, but they were not significant. In 2001, the yield total for the rye/ryegrass plots was higher than the other plots and was significantly better than the ryegrass plots and the oats/ryegrass plots. After three years of data, results indicate that the no forage plots have declined each year.

DISCUSSION

Minimum tillage practices are gaining popularity in the peanut growing regions of the United States. Research will continue to be done to determine the effectiveness of these practices and whether or not the impact on insect pests and diseases and yield will make it economically feasible for growers. Yields have also varied from year to year and from field to field with no conclusive trend in either direction. In some years conventional tillage has given better results in controlling pests and diseases and in other years minimum tillage fields gave better results.

Because of the inconclusive nature of the previous studies, more work needs to be done to determine the long-term impact that tillage systems have on peanuts. This includes the effects on insects and diseases, but more importantly the impact on yield, which to the grower is the bottom line in any type of system. Studies will be ongoing at the Wiregrass Research and Extension Center to determine the impact of tillage and rotation on long-term peanut production.

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ANNOYING TRENDS IN STRIP-TILLAGE WEED CONTROL IN PEANUT: WHAT ARE OUR OPTIONS?

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ABSTRACT

Controlling Texas panicum in peanut has been troublesome to growers attempting to implement strip-tillage production practices. Studies were conducted from 1999 to 2001 in Georgia to develop Texas panicum management systems in strip-tillage peanut production. The experimental design was a split-plot with four replications. Main plots were preemergence (PRE) herbicides for annual grass control; ethalfluralin (Sonalan®) (0.75 lbs a.i. acre-1), pendimethalin (Prowl®)(1.0 lbs a.i. acre-1), metolachlor (Dual®) (2.0 lbs a.i. acre-1), alachlor (Lasso Microtech®) (3.0 lbs a.i. acre-1), dimethenamid (Frontier®) (1.2 lbs a.i. acre-1), and a nontreated PRE control. All plots were irrigated immediately after PRE applications to activate herbicides. Sub-plots were postemergence (POST) graminicides applied 28 days after peanut emergence; sethoxydim (Poast Plus®) (0.20 lbs a.i. acre-1), clethodim (Select®) (0.09 lbs a.i. acre-1), and a nontreated POST control. None of the PRE herbicides alone adequately controlled Texas panicum in strip-till peanut production, even with optimum activation with irrigation. Both sethoxydim and clethodim consistently controlled Texas panicum, regardless of PRE treatments. While POST graminicides effectively controlled Texas panicum in strip-till peanut production, their use to the exclusion of PRE herbicides would leave small-seeded dicot weeds, such as Florida pusley, uncontrolled. Growers who choose to use irrigated strip-till peanut production need to use a properly timed POST graminicide for Texas panicum control in addition to traditional dinitroaniline herbicides. This additional cost needs to be factored into crop production budgets.

KEYWORDS

Panicum texanum, pre-eemergence,herbicides, post emergence herbidides, herbicide injury

INTRODUCTION

Texas panicum (*Panicum texanum* Buckl.) is among the most common and troublesome weeds of southeastern peanut (*Arachis hypogaea* L.) (Webster 2001). Texas panicum is also considered to be among the most costly weeds in peanut (Buchanan *et al*. 1982), with losses primarily due to yield reductions from competition, excessive harvest losses, and costs of control.

Ethalfluralin and pendimethalin are the two dinitroaniline herbicides registered for use on peanut grown in the southeastern U. S. and are the primary means to control annual grasses in conventional tillage peanut production (Brecke and Currey 1980; Chamblee *et al*. 1982; Grichar 1991; Grichar *et al*. 1994; Prostko *et al*. 2001). Traditionally, both are applied preplant incorporated (PPI), although registrations have been recently amended to allow preemergence (PRE) applications, activated with sprinkler irrigation (Anonymous 2001a, 2001b). Ethalfluralin and pendimethalin applied PPI or PRE effectively control Texas panicum in conventional tillage systems and neither herbicide is overly injurious to peanut (Grichar and Colburn 1993; Johnson and Mullinix 1999; Johnson *et al*. 1997).

Peanut production in the U. S. using conservation tillage practices has recently increased (Sholar *et al*. 1995). Conservation tillage minimizes water and wind erosion which can be significant in the southeastern peanut producing region. Conservation tillage is also attractive because conventional tillage requires multiple tillage operations in rapid succession, which can be complicated by skilled labor shortages, weather delays, and logistical complications. In contrast, conservation tillage offers growers significant time and labor savings in the spring planting season by rescheduling tasks to other times year. Furthermore, recent trials have shown incidence of spotted wilt disease (tomato spotted wilt tospovirus) in peanut is significantly less in conservation tillage than in conventional tillage (Johnson *et al*. 2001), adding further incentive for growers to alter their peanut production strategy.

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The most common conservation tillage variant in the southeastern peanut production region is strip-tillage into a small grain cover crop such as rye (*Secale cereale* L.). The seedbed preparation implement has in-row subsoil shanks, multiple gangs of fluted coulters to cut cover-crop debris, and ground-driven crumblers that till a band approximately 12 in wide. Crops are seeded with planter units tandem-mounted on the tillage implement or as a separate operation.

With the widespread acceptance of strip-tillage peanut production come new questions regarding Texas panicum control. Grichar and Boswell (1987) showed that one of the limiting factors to profitable strip-tillage peanut production was annual grass control. Similarly, Wilcut *et al*. (1990) were not able to adequately control Texas panicum in non-irrigated conservation-tillage peanut production using dinitroaniline herbicides alone. Adequate control in their trials came with either paraquat or sethoxydim POST following dinitroaniline herbicides applied PRE. It is plausible that the lack of timely rainfall or irrigation for herbicide activation may have reduced activity of the dinitroaniline herbicides evaluated in their trials. Grichar *et al*. (1994) evaluated several herbicides for overall weed management in irrigated strip-tillage peanut and determined that pendimethalin applied in a band and crudely incorporated with crumblers on the strip-tillage implement did not adequately control Texas panicum. Chloracetamide herbicides used in their study were ineffective in controlling Texas panicum. POST graminicides are highly efficacious in controlling Texas panicum and other annual grasses (Prostko *et al*. 2001), but neither provide residual control of grasses nor control small-seeded dicot weeds.

With the increasing acceptance of strip-tillage peanut production in the southeastern coastal plain, systems need to be developed for Texas panicum control. Therefore, trials were initiated in 1999 to develop systems for Texas panicum control in strip-tillage peanut production.

MATERIALS AND METHODS

Irrigated field studies were conducted at the Attapulgus Research Farm near Bainbridge, GA (1999 and 2001) and the Coastal Plain Experiment Station Ponder Farm near Tifton, GA (2000), both units of the University of Georgia - Tifton Campus. Soils at Attapulgus were a Lucy loamy sand (loamy, kaolinitic, thermic Arenic Kandiudults) and a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) at the Ponder Farm. Soils at Attapulgus were 88% sand, 8% silt, 4% clay, and 0.9% organic matter and 88% sand, 6% silt, 6% clay, and 0.5% organic matter in 1999 and 2001, respectively. Soil at the Ponder Farm was 90% sand, 6% silt, 4% clay, and 0.7% organic matter. Soils at both locations were representative of soils in the southeastern U. S. peanut production region.

The experimental design was a split-plot with treatments replicated four times. Main plots were residual herbicides applied PRE; ethalfluralin (0.75 lbs a.i. acre-1), pendimethalin (1.0 lbs a.i. acre-1), metolachlor (2.0 lbs a.i. acre-1), alachlor (3.0 lbs a.i. acre-1), dimethenamid (1.2 lbs a.i. acre-1), and a nontreated PRE control. Chloracetamide herbicides were included in the trial since they are widely used for grass control in conservation tillage systems in other crops. All PRE herbicides were applied immediately after planting and irrigated (1.2 cm) with a center-pivot within twelve hours of application. Sub-plots were POST graminicides; sethoxydim (0.20 lbs a.i. acre-1), clethodim (0.09 lbs a.i. acre-1), and a nontreated POST control. POST graminicides were applied 28 days after emergence (DAE), with an additional application made 42 DAE in 2000. The additional applications were made in 2000 due an unusually large density of Texas panicum. A crop oil concentrate adjuvant was included with all POST graminicides at 1.0% by vol. Herbicides were applied with a tractor-mounted CO_2 plot sprayer calibrated to deliver 25 gal acre-1 at 30 lbs per inch^2 with flat fan nozzle tips. Plots were two rows wide by 20 ft long, with rows spaced 36 in apart.

Plots were seeded with rye at 56 lbs acre-1 using a grain drill in the fall after the preceeding crop harvest. In early April, the rye cover was killed with glyphosate (Roundup Ultra®) (1.0 lbs a.i. acre-1). Seedbeds were formed with a two-row strip-tillage implement (Kelley Manufacturing Company; 80 Vernon Drive; Tifton, GA 31794) that prepared a 12 in seedbed and planted to peanut with a vacuum planter (ATI., Inc.; 17135 West 116th St.; Lenexa, KS 66219) in a separate operation. Georgia Green (1999 and 2000) and C-99R (2001) peanut were seeded in early May each year at a rate of 100 lbs acre-1. After seeding peanut, the entire experimental area was treated with paraquat (0.5 lbs a.i. acre-1) to control emerged weeds. This treatment was not tank mixed with any PRE herbicides. All plots were maintained free of dicot weeds throughout the season with one POST application of pyridate (Tough®) (0.9 lbs a.i. acre-1) plus 2,4-DB (Butoxone®) (0.25 lbs a.i. acre-1) and handweeding as needed.

Parameters measured were visual estimates of Texas panicum control and peanut injury compared to the nontreated control taken 90 days after planting and peanut yield. Visual ratings are based on a percentage scale from 0 (no crop injury or weed control) to 100 (crop death or complete weed control). Texas panicum densities were high in 1999 and 2001 (>1 plant per foot^2) and extraordinarily high in 2000 (>2 plants per foot^2). Peanut yields were measured by digging, inverting, air curing, and combining peanut using commercial two-row equipment. Yield samples were mechanically cleaned to remove foreign material, with yields reported as cleaned farmer stock peanut.

All data were subjected to analysis of variance, with means separated using Fisher's protected LSD ($P = 0.05$). Arcsine transformations of visual injury and weed control ratings did not change the results of the analysis of variance, therefore nontransformed data are presented.

RESULTS AND DISCUSSION

Analysis of variance indicated no significant interactions between PRE herbicides and POST graminicides for Texas panicum control, and only main effect means are presented. However, there was a significant interaction between PRE herbicides and POST graminicides for peanut yield. In addition, there was no year by treatment interactions for any of the parameters, therefore all data were pooled across years.

TEXAS PANICUM CONTROL

Less than 76% control of Texas panicum was noted with dinitroaniline and chloracetamide herbicides in strip-tillage peanut production (Table 1). This is in contrast to previous research in conventional tillage systems where ethalfluralin and pendimethalin applied PPI or PRE effectively controlled Texas panicum (Prostko et. al. 2001). In this current study, PRE herbicides were activated with irrigation within twelve hours of application and still failed to adequately control Texas panicum. Wilcut *et al.* (1990) found sequential applications of either paraquat or sethoxydim POST following dinitroaniline herbicides applied PRE were needed for adequate Texas panicum control in their non-irrigated strip-tillage trials. In our trials, neither ethalfluralin nor pendimethalin PRE in strip-tillage peanut adequately control Texas panicum, despite activating PRE herbicides with irrigation. Previous research supports the inability of chloracetamide herbicides to adequately control Texas panicum in strip-tillage peanut production (Grichar *et al.* 1994).

Marginal control of Texas panicum is unacceptable in peanut production. Peanut has a long growing season and subterranean fruiting which complicates harvest and any Texas panicum escaping control will likely cause significant harvest losses. While there has been no research on Texas panicum interference with peanut to quantify yield losses, it is widely felt that annual grasses escaping initial control efforts significantly reduce yield (Chamblee *et al.* 1982). Accordingly, neither dinitroaniline nor chloracetamide herbicides should be recommended as the sole means for Texas panicum control in strip-tillage peanut due to their poor efficacy.

Sethoxydim and clethodim effectively controlled Texas panicum when applied 28 DAE (Table 2). The lack of significant interaction between PRE herbicides and POST graminicides shows that properly used POST graminicides alone are fully capable of adequately controlling Texas panicum, which is consistent with other research (Grichar *et al.* 1994; Prostko *et al.* 2001; Wilcut *et al.* 1990). However, there are disadvantages to relying exclusively on POST graminicides for Texas panicum control to the exclusion of dinitroaniline herbicides. Dinitroaniline and chloracetamide herbicides control an array of small seeded dicot weeds, including Florida pusley (*Richardia scabra* L.), and POST graminicides will not control dicot weeds. In addition, POST graminicides at the rates registered for use on peanut will not provide residual control of annual grasses, including Texas panicum. Furthermore, sequential applications may be needed to control later emerging weeds or escapes from extremely heavy infestations, which occurred in the 2000 trial. Sequential applications add to the cost of peanut production, which is contradictory to the current urgency to reduce production costs. Logically, it is prudent to have complimentary management options for potentially devas-

Table 1. Texas panicum control in strip-tillage peanut production with preemergence herbicides; 1999 to 2001. Data pooled over POST graminicide treatments and years.

PRE herbicide	Rate	Control
	lbs ai acre^{-1}	----- % ------
Ethalfluralin	0.75	70
Pendimethalin	1.0	75
Metolachlor	2.0	67
Alachlor	3.0	71
Dimethenamid	1.2	66
Nontreated PRE	–	58
$LSD_{0.05}$		14

Table 2. Texas panicum control in strip-tillage peanut production with postemergence graminicides; 1999 to 2001. Data pooled over PRE graminicide treatments and years.

PRE herbicide	Rate	Control
	lbs ai acre^{-1}	----- % ------
Sethoxydim	0.20	90
Clethodim	0.09	91
Nontreated POST	–	22
$LSD_{0.05}$		26

tating weeds like Texas panicum, instead of relying on only a single herbicide that may fail.

A possible explanation for the poor control of Texas panicum with ethalfluralin and pendimethalin PRE in strip-tillage peanut production is the presence of germinated, but non-emerged, Texas panicum seedlings at the time of treatment. Uptake of dinitroaniline herbicides is primarily through roots and emerging shoots (Appleby and Valverde 1989; Ashton and Crafts 1981). However, Parker (1966) showed that trifluralin was more inhibitory to grain sorghum [*Sorghum bicolor* (L.) Moench] when absorbed through roots than emerging shoots. Dinitroaniline herbicides are generally considered to be immobile in the soil (Weber 1990). In a strip-tillage system, dinitroaniline herbicides will be concentrated in the extreme upper portions of the soil profile and Texas panicum, a large seeded annual grass, may be able to germinate below the zone where dinitroaniline herbicides are located. In this case, emerging shoots pass through treated soil, whereas developing roots would be below the herbicide treated soil. In contrast, conventional tillage systems would have freshly tilled soil from incorporation that mechanically controls emerging Texas panicum and disperses the herbicide deeper in the soil profile where roots, as well as emerging shoots, absorb the herbicide. This theory is also the basis on which direct-seeded cucurbit crops are more tolerant of dinitroaniline herbicides applied PRE than PPI (Grey *et al*. 2000a, 2000b).

It is also possible that the presence of cover debris adsorbs dinitroaniline herbicides, reducing efficacy. Dinitroaniline herbicides are readily adsorbed by organic matter, which has traditionally limited their use to mineral soils (Weber *et al*. 1990). It is possible that the presence of rye straw mulch, although not finely pulverized by mowing or decay, intercepts and adsorbs ethalfluralin and pendimethalin reducing efficacy in strip-tillage peanut production.

VISIBLE INJURY

Peanut exhibited no visible injury symptoms from any of the herbicide treatments throughout the study (data not shown). Similarly, time of peanut emergence was not affected by PRE herbicide treatments. These results are in agreement with previous research that showed dinitroaniline herbicides applied PRE are not overly injurious to peanut (Johnson and Mullinix 1999; Johnson *et al*. 1997).

PEANUT YIELD

Peanut yield response to Texas panicum control in strip-tillage systems generally mirrored the Texas panicum control data (Table 3). Peanut yields were greater in plots that relied on PRE herbicides followed sequentially by POST graminicides for Texas panicum control than those using PRE herbicides alone. Relying exclusively on PRE herbicides in strip-tillage peanut production for Texas panicum control reduced yields by allowing escaped Texas panicum to interfere with peanut growth and yield. Exclusive use of POST graminicides protected peanut yield loss due to Texas panicum interference. However, maintenance weed control, including handweeding, prevented the confounding presence of uncontrolled small seeded broadleaf weeds in these trials. If peanut producers using strip-tillage

Table 3. Effects of Texas panicum management in strip-tillage peanut production on yield; 1999-2001.

PRE herbicide	POST herbicide	Yield
		lbs acre^{-1}
Ethalfluralin		
	Sethoxydim	2570
	Clethodim	2970
	Nontreated POST	1940
Pendimethalin		
	Sethoxydim	3100
	Clethodim	3210
	Nontreated POST	2280
Metolachlor		
	Sethoxydim	3100
	Clethodim	3340
	Nontreated POST	1780
Alachlor		
	Sethoxydim	3080
	Clethodim	3090
	Nontreated POST	2000
Dimethenamid		
	Sethoxydim	2840
	Clethodim	2740
	Nontreated POST	1870
Nontreated PRE		
	Sethoxydim	2420
	Clethodim	2420
	Nontreated POST	1510
$LSD_{0.05}$		710

choose to rely exclusively on POST graminicides for Texas panicum control they should also plan control of dicot weeds with other facets of their weed management system.

These results show the potential for serious difficulties in managing Texas panicum in irrigated strip-tillage peanut production. Dinitroaniline herbicides, the traditional means to control Texas panicum in conventional tillage systems, do not adequately control the annual grass in strip-tillage peanut production, despite irrigation to activate the herbicides. POST graminicides effectively control Texas panicum, but their exclusive use will not control small seeded dicot weeds that are controlled by PRE herbicides, perhaps complicating the overall weed management system. The most effective system to control Texas panicum in strip-tillage peanut will feature either ethalfluralin or pendimethalin PRE, followed by a POST application of either sethoxydim or clethodim. The additional cost of the seemingly obligatory POST graminicide treatment in strip-tillage peanut production should be factored into any decision that a grower makes when deciding on the type of tillage system.

Despite the reduction in efficacy of dinitroaniline herbicides in strip-tillage peanut production, these herbicides still have a clear niche and should not be overlooked by growers. While dinitroaniline herbicides do not adequately control Texas panicum in strip-tillage production systems, they control many small seeded broadleaf weeds (W. C. Johnson, III, unpublished data). Furthermore, ethalfluralin and pendimethalin cost approximately $5.70 and $4.70 per acre, respectively, which are among the least costly herbicide inputs in peanut production (E. P. Prostko, unpublished data). In contrast, cost of alternatives such as the chloracetamides, are much greater, ranging from $11.70 to $15.80 per acre. Despite the reduced efficacy in strip-tillage systems, the inexpensive cost of dinitroaniline herbicides insures their continued use in irrigated strip-tillage peanut production.

FUTURE RESEARCH

Field trials were initiated in 2002 to determine if seeding rate of the rye cover crop affects efficacy of residual and postemergence herbicides used in strip-tillage peanut. It has been speculated that the rye cover crop may adsorb some preemergence herbicides. It has also been observed that very heavy densities of rye shields weeds from postemergence herbicides. These trials will possibly indicate the optimum cover crop seeding rate from a weed management perspective. Complimentary greenhouse and plant growth chamber trials will be initiated to quantify the adsorption of preemergence herbicides by rye straw and effects on emergence of weed seedlings.

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RESPONSE OF DRYLAND CONSERVATION TILLAGE PEANUTS TO FUNGICIDES

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ABSTRACT

Due to the increase in acreage of conservation tillage peanuts, these trials were developed to determine the response of dryland conservation tillage peanuts to fungicide. For 3 years (1999-2001) chlorothalonil (Bravo WeatherStik applied at 1.1 lbs ai acre-1) and tebuconazole (Folicur 3.6F applied at 0.20 lbs ai acre-1) applications were made on scheduled intervals of 14 and 21 days, with the number of spray schedules ranging from 3-7. Treatments also included a non-treated control. Peanuts were planted into rye stubble, which had been harvested with a grain combine that included a straw spreader. During 2000 and 2001, leaf spot ratings using the Florida 1-10 scale were taken at least 135 days after planting. During 2000, leaf spot was significantly lower in treatments where 7 applications of chlorothalonil had been applied and where 4-7 applications of tebuconazole had been made. During 2001, leaf spot was significantly lower than the control in all applications and schedules of fungicides. In 2000 and 2001 leaf spot tended to be lower as the number of applications increased with both fungicides. During 1999 and 2000, there was no difference in yield between fungicides and spray schedules. However in 2001, yield was significantly higher than the control where 5 applications of tebuconazole had been applied. When combining all 3 years, tebuconazole tended to yield higher than chlorothalonil and the control.

KEYWORDS

No-till, leafspot

INTRODUCTION

Early leaf spot [*Cercospora arachidicola* S. Hori), late leaf spot (C*ercosporidium personatum* (Berk. & M. A. Curtis) Deighton], and southern stem rot (*Sclerotium rolfsii* Sacc.) are critical yield limiting diseases of peanut (*Arachis hypogaea* L.) in the southeastern U.S. as well as in most areas of the world where peanut is grown. These diseases account for combined losses and cost of control that may exceed $80 million in a single year in Georgia alone (Kemerait, 2000). Although crop rotation is effective for reducing the severity of all three, management of these diseases is largely dependent upon multiple applications of various fungicides. Since the mid-1970's, chlorothalonil has been the standard fungicide for leaf spot management. Additional options became available for leaf spot management in 1994 with the registration of the ergosterol biosynthesis inhibiting fungicide tebuconazole for use on peanut. This fungicide is effective against both leaf spot diseases and provides significant suppression of southern stem rot (*Sclerotium rolfsii*) and Rhizoctonia limb rot (*Rhizoctonia solani*). In 1997, azoxystrobin was also registered for use of two sprays on peanut for control of leaf spot diseases, southern stem rot and Rhizoctonia limb rot. All of these fungicides are recommended for use in spray regimes utilizing two or more fungicides with applications every 14 d beginning approximately 30 d after planting. In 2000, an estimated 55% of the peanut crop in Georgia was grown with some form of irrigation. Production on non-irrigated fields, commonly referred to as "rain-fed" or "dryland" production, still represents a huge acreage.

When a suitable host and inoculum are present, development of the leaf spot diseases is dependent largely upon available moisture. A rain-event based application timing schedule has been developed that can help ensure that fungicide applications are applied only when they are needed (Jacobi *et al*., 1995). Brenneman and Culbreath (1994) showed that AU-Pnuts was also effective for timing sprays of tebuconazole for management of southern stem rot. Most of the fungicide response work, however, has been conducted using irrigated fields under conventional tillage practices. In recent years, fungicide response in non-irrigated fields has not been characterized as well as that in irrigated fields. In addition, in recent years the percentage of peanut grown using some form of conservation tillage has

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risen to approximately 20% of the Georgia peanut crop. Monfort *et al*. (2001) showed that strip-tillage practices in irrigated fields delayed or suppressed epidemics of early leaf spot and could reduce the number of fungicides required for leaf spot management from 7 in conventional tillage to 4 in strip-tillage. However, fungicide response in dryland conservation tillage peanut has not been characterized. The objective of these experiments was to determine the leaf spot and yield response of dry-land conservation tillage peanuts to varying numbers of applications and timing regimes of standard labeled fungicides, chlorothalonil and tebuconazole.

MATERIALS AND METHODS

The plot area for these experiments was a Tifton loamy sand located at the Coastal Plain Experiment Station, University of Georgia in Tifton, Georgia. The objective of these experiments was to determine the response of dryland conservation tillage peanuts to fungicides. Two adjacent plots under sustainable/no-till practices were selected to set up the trials that used rye (cereal rye) and grain sorghum as rotational crops for peanuts. In the spring of 1999 one plot was planted with peanuts while the other was planted with grain sorghum. The plots were rotated each year developing a rye-grain sorghum- rye-peanut rotation in which the seed was harvested from the rye (25 bu acre^{-1} avg.) and grain sorghum 50 (bu acre^{-1} avg.). Each year 600 lbss of 10-10-10 analysis fertilizer was applied to the rye while 150 pounds of ammonium nitrate (34% N) was applied to the grain sorghum. A Tye no-till drill was used each year to plant 2 bushels of rye per acre. A Monosem no-till drill retrofitted with a 12" in-row subsoiler between the fluted coulter and Yetter row cleaner was used to plant the grain sorghum (6 seed/ft) and peanuts on a 36" row pattern.

‘Georgia Green’ peanuts were used for the trial in which a randomized complete block design with 6 replications was used for fungicide applications of chlorothalonil (Bravo WeatherStik) applied at 1.1 lbs ai acre-1, and tebuconazole (Folicur 3.6 F) was applied at 0.20 lbs ai acre^{-1} with differing intervals and schedules (Table 1). Fungicide applications started 40 days after planting with leaf spot ratings using the Florida 1-10 scale, where 1 = no leaf spot and 10 = plants completely defoliated and killed by leaf spot (Chiteka *et al*., 1988) taken 135 days after planting. The harvesting date was determined by using a hull scrape test (Williams and Drexler, 1981).

During 1999, ‘Georgia Green’ peanuts were no-tilled 6 seeds foot^{-1} into rye stubble on May 31st. Peanuts were fertilized with 300 pounds per acre of 0-7-28, which was split into 2 applications applied in an 8" band in July. 1000 pounds per acre of gypsum was broadcast on July 20th. Although no insecticides were applied, post emergence herbicides were selectively applied throughout the growing season for weed control. Fungicides were applied according to protocol beginning on July 10th. Rainfall totaling 16.54 inches was received from June through October. Peanuts were dug on November 2nd, harvested November 8th, dried, cleaned, and weighed.

During 2000, ‘Georgia Green peanuts were no-tilled 6 seeds foot^{-1} into rye stubble on May 26th. On June 20th, 300 pounds per acre of 0-7-28 was applied on the surface in an 8" band. 1000 pounds per acre of Gypsum was broadcast to the surface on August 8th. Although no insecticides were applied, herbicides were selectively applied post-emergence throughout the growing season for weed control. Fungicides were applied according to protocol beginning on July 6th. Leaf spot ratings were taken on October 6th using the Florida 1-10 scale. Rainfall totaling 18.20 inches was received from June through October. Peanuts were dug on October 12th, harvested October 20th, dried, cleaned and weighed.

During 2001, after applying 1000 pounds per acre of limestone in February, ‘Georgia Green’ peanuts were no-tilled 6 seeds foot^{-1} into rye stubble on June 1st. Gypsum was broadcast at 1000 pounds per acre on July 18th. Although no insecticides were applied, herbicides were selectively applied post-emergence throughout the growing season for weed control. Fungicides were applied according to the protocol beginning on July 10th. Leaf spot ratings were taken on October 12th using the Florida 1-10 scale. Rainfall totaling 17.86 inches was received from June through October. Peanuts were dug on October 23rd, harvested October 30th, dried, cleaned and weighed.

RESULTS AND DISCUSSION

During 2000 leaf spot was significantly higher in non-treated peanuts than in treated peanuts (Table 2). Chlorothalonil with 4 applications and tebuconazole with 3 applications had significantly higher leaf spot than all other fungicide application schedules. Chlorothalonil with 3 applications was significantly higher in leaf spot than chlorothalonil with 7 applications and tebuconazole, which was applied in 4 to 7 scheduled applications. During 2001 leaf spot was also significantly higher in non-treated peanuts than in treated peanuts. Chlorothalonil with 3 and 4 applications along with tebuconazole in 3 applications was significantly higher in leaf spot than other application schedules. Chlorothalonil with 5 to 7 applications and tebuconazole with 4 to 7 applications had significantly lower leaf spot than other application schedules. When averaging both years, leaf spot was higher in the non-treated peanuts than where fungicides were applied. Leaf spot was significantly reduced when chlorothalonil was applied in 5 to 7 applications and tebuconazole was applied in 4 to 7 applications.

Yield response of dry-land conservation tillage peanuts to fungicides are presented in Table 3. In 1999 and 2000 there was no significant difference in yield among the nontreated, chlorothalonil and tebuconazole treatments. Number of applications and schedules also did not provide any significant difference in yield. In 2001, yield for plots treated with 5 applications of tebuconazole was significantly higher than the non-treated, while there was no significant difference between the fungicides or application schedules. However when averaging all three years, yields from plots treated with tebuconazole were significantly higher than the control when 4, 5, and 7 applications were applied. No significant difference was seen between fungicides or application schedules. Yield response to chlorothalonil would be primarily due to effects of this fungicide on foliar diseases, primarily early leaf spot in this test. Yield response to tebuconazole could be due to effects on foliar diseases, soilborne diseases, such as southern stem rot, or a combination of both. Southern stem rot did not cause noticeable damage in these tests, and plots were not rated for this disease. Previous reports of the effects of tillage systems on southern stem rot indicate that reduced and conventional tillage practices have no consistent effect on this disease (Johnson *et al*., 2001). Relative yield response to applications of tebuconazole would be expected to be greater in conventional or conservation tillage fields in which southern stem rot would occur at higher incidence.

Decisions on fungicide applications may become increasingly difficult for producers of dryland conservation tillage peanuts. Fungicide applications significantly reduce leaf

Table 1. Fungicide application schedule.

Treatment	Application no.						
	1	2	3	4	5	6	7
	------------ No. of weeks after planting ----------						
Nontreated	--	--	--	--	--	--	--
Chlorothalonil (7 applications on a 14 day schedule)	5	7	9	11	13	15	17
Chlorothalonil (6 applications on a 14 day schedule)	5	7	9	11	13	15	--
Chlorothalonil (5 applications on a 14 day schedule)	5	7	9	11	13	--	--
Chlorothalonil (4 applications on a 21 day schedule)	5	8	11	14	--	--	--
Chlorothalonil (3 applications on a 21 day schedule)	5	8	14	--	--	--	--
Tebuconazole (7 applications on a 14 day schedule)	5	7	9	11	13	15	17
Tebuconazole (6 applications on a 14 day schedule)	5	7	9	11	13	15	--
Tebuconazole (5 applications on a 14 day schedule)	5	7	9	11	13	--	--
Tebuconazole (4 applications on a 21 day schedule)	5	8	11	14	--	--	--
Tebuconazole (3 applications on a 21 day schedule)	5	8	14	--	--	--	--
Chlorothalonil/Tebuconazole alternate (4 applications on a 21 day schedule)	5	8	11	14	--	--	--

Table 2. Effect of fungicides on peanut leaf spot disease in a dry-land conervation tillage system. Means within a column followed by the same letter are not significantly different based on Duncan's Multiple Range Test at *P* = 0.05.

Treatment	2000	2001	Average
Nontreated	5.2 A	6.6 A	5.9 A
Chlorothalonil (7 applications on a 14 day schedule)	2.2 D	2.6 E	2.4 D
Chlorothalonil (6 applications on a 14 day schedule)	2.5 CD	2.5 E	2.5 D
Chlorothalonil (5 applications on a 14 day schedule)	2.6 CD	2.4 E	2.5 D
Chlorothalonil (4 applications on a 21 day schedule)	4.0 B	4.9 B	4.4 B
Chlorothalonil (3 applications on a 21 day schedule)	3.1 C	4.9 B	4.0 BC
Tebuconazole (7 applications on a 14 day schedule)	2.4 D	3.0 DE	2.7 D
Tebuconazole (6 applications on a 14 day schedule)	2.2 D	2.2 E	2.2 D
Tebuconazole (5 applications on a 14 day schedule)	2.4 D	2.6 E	2.5 D
Tebuconazole (4 applications on a 21 day schedule)	2.5 D	2.6 E	2.5 D
Tebuconazole (3 applications on a 21 day schedule)	3.8 B	4.0 BC	3.9 BC
Chlorothalonil/tebuconazole (4 applications on a 21 day schedule)	---	3.7 CD	3.7 C

spot but may not always significantly increase yield. The maximum amount of leaf spot acceptable and the application and cost of fungicides are major decisions with which producers will be faced. In the future, it will be more critical than ever for growers to be aware of the disease history of each field in planning disease management programs. Response to fungicide applications varies with water available for both infection by the pathogen and for the plant to produce yield. A rainfall-based decision tool such as AU-pnuts could be especially useful in dryland conservation tillage fields to help ensure that fungicide applications are needed and to increase the likelihood of economic yield response to the fungicide inputs.

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Table 3. Effects of fungicides on dry-land conservation tillage peanut yields. Means within a column followed by the same letter are not significantly different based on Duncan's Multiple Range Test at $P = 0.05$.

Treatment	1999	2000	2001	Average
	------------------ lbs acre^{-1}	----------------		
Nontreated	1210 A	1640 A	2683 B	1844 B
Chlorothalonil (7 applications on a 14 day schedule)	1389 A	1915 A	2887 AB	2064 AB
Chlorothalonil (6 applications on a 14 day schedule)	1416 A	1918 A	2768 AB	2034 AB
Chlorothalonil (5 applications on a 14 day schedule)	1404 A	1944 A	2952 AB	2100 AB
Chlorothalonil (4 applications on a 21 day schedule)	1370 A	1891 A	2827 AB	2029 AB
Chlorothalonil (3 applications on a 21 day schedule)	1322 A	1811 A	2821 AB	1984 AB
Tebuconazole (7 applications on a 14 day schedule)	1476 A	2051 A	2951 AB	2159 A
Tebuconazole (6 applications on a 14 day schedule)	1325 A	1786 A	3045 AB	2052 AB
Tebuconazole (5 applications on a 14 day schedule)	1328 A	2092 A	3244 A	2221 A
Tebuconazole (4 applications on a 21 day schedule)	1470 A	2036 A	3042 AB	2183 A
Tebuconazole (3 applications on a 21 day schedule)	1455 A	1906 A	2927 AB	2096 AB
Chlorothalonil/Tebuconazole alternate (4 applications on a 21 day schedule)	1325 A	-----	2913 AB	2119 AB

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GLYPHOSATE IMPACT ON IRRIGATED AND DRYLAND ROUNDUP READY™ COTTON

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ABSTRACT

Over the past few years, the capability to apply glyphosate over-the-top of cotton for controlling weeds has been realized on a commercial level with Monsanto's development of Roundup Ready™ technology. Since perhaps 90% of the cotton acreage in Alabama is planted to this system, it was our goal to understand the effects that glyphosate might have when applied according to the manufacturer's label directions. This study was conducted in 1999 and 2000 at the Tennessee Valley Research and Extension Center in north central Alabama on a Decatur silt loam. A stacked gene cotton variety (DPL 458) was planted in late April each year using conventional procedures. Main plots were sprinkler irrigated individually for maximum yield or were left as dryland. Glyphosate subplots included four treatments: 1.) untreated, 2.) 1.0 quart acre^{-1} formulated material applied postemergence over-the-top at the 4-leaf stage (POST), 3.) 1.0 quart acre^{-1} post-directed to pre-bloom cotton (DIR), and 4.) 1.0 quart acre^{-1} applied POST and DIR. Data collection included cotton yield, plant mapping, and fiber quality from first and second position bolls from 30 plants in each plot. Glyphosate applications had no effect on earliness, overall yield, growth and reproductive parameters, number of reproductive nodes, or fiber quality (except for micronaire on node 14 in 2000). Irrigation increased yield and number of reproductive nodes/plant. Irrigation also had a positive effect on plant growth and fiber quality compared to cotton produced under dryland conditions.

KEYWORDS

Roundup Ready cotton, weed control, herbicide tolerant, cotton physiology, drought stress

INTRODUCTION

Cotton weed control has changed over the past five to seven years with the introduction of glyphosate tolerant, Roundup Ready™ cotton varieties (McClelland *et al*., 1996). The Roundup Ready technology has provided producers with an effective, inexpensive weed control system for managing grass and broadleaf weeds (Faircloth *et al*., 2001). Acceptance of this system has resulted in the replacement of most older, conventional herbicide based operations. With conservation tillage increasing in cotton production in Alabama, the Roundup Ready technology has enabled producers to control weeds without the expenses associated with cultivation and generally without visible crop injury (Dugger and Richter, 2000). This technology also allows cotton to germinate and become established in an herbicide-free soil environment that often causes some level of seedling damage.

The objectives of this study were: 1) to evaluate the overall effect of glyphosate applications on cotton yield and development and 2) to evaluate the effect of glyphosate applications when applied under adequate moisture and drought situations.

MATERIALS AND METHODS

Field experiments were conducted in 1999 and 2000 at the Tennessee Valley Research and Extension Center in north central Alabama. The soil at this location is a Decatur silt loam with 1.0 % organic matter and pH 6.1. Experimental areas were maintained according to Alabama Cooperative Extension System recommendations. The test was maintained weed-free for the duration of the study using labeled rates of trifluralin (preplant incorporated), fluometuron plus pyrithiobac applied preemergence, or cultivation. 'Deltapine 458' stacked gene cotton was planted in mid-April both years.

Plot size was eight, 38-inch rows by 50 ft long. Treat-

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Table 1. Monthly irrigation and rainfall from emergence in late April through to late bloom in mid-August for 2000 and 2001.

	2000		2001	
Month	Irrigation	Rainfall	Irrigation	Rainfall
	------------------- mm		----------------------	
April	0	40	0	13
May	0	119	24	19
June	0	166	96	80
July	76	93	255	45
August	70	0	29	34

ments were in a factorial arrangement in a completely randomized experimental design with four replications. There were four glyphosate treatments: 1.) untreated, 2.) 1.0 lbs a.i. acre^{-1} applied postemergence at the 4-leaf cotton stage, 3.) 1.0 lbs acre^{-1} post-directed at the pre-bloom cotton stage, and 4.) 1.0 lbs acre^{-1} applied at the 4-leaf and pre-bloom cotton stages. Irrigation treatments were established by irrigating for maximum yield or by maintaining cotton under dryland conditions. Irrigation scheduling was based on the evapo-transpiration rate as determined by an on-site weather station (Table 1).

Data collection included earliness (open and closed boll counts per 16 row feet), lint yield and quality by node and treatment, and growth and reproductive parameters using traditional plant mapping procedures. Cotton was machine-harvested in early October or mid-September in 1999 and 2000, respectively. Data were subjected to ANOVA and means separated using Fisher's protected LSD test at the 5% level. Data were averaged across years, irrigation, or glyphosate treatment where appropriate except where interactions occurred.

RESULTS AND DISCUSSION

EFFECTS ON COTTON GROWTH AND REPRODUCTIVE DEVELOPMENT

Internode length, plant height, number of reproductive nodes/plant, boll retention on the first fruiting position, or boll retention on the second fruiting position data were pooled due to absence of year interactions or glyphosate effects. Irrigation had a positive affect on all measured parameters of plant growth (Table 2). Internode length and plant heights were increased in irrigated compared to dryland plots. An increase in yield potential for irrigated cotton was reflected by an increase of 3 reproductive nodes/plant. Irrigation also increased boll retention at the first and second fruiting position.

Table 3. Effect of irrigation on boll opening and seed cotton yield. Data were pooled over years and glyphosate treatment due to absence of interactions and glyphosate main effect. Open bolls were counted when most mature treatment reached 65% open.

Moisture	Open bolls	Yield
	-- % --	--lbs acre^{-1} --
Dryland	65	1655
Irrigated	17	3464
LSD $_{0.05}$	5	107

Table 2. Effect of irrigation on plant height, internode length, reproductive nodes, and boll retention at the first and second fruiting positions. Data were pooled over years and glyphosate treatments due to absence of interactions and glyphosate main effect.

Measurement	Dryland	Irrigated	LSD $_{0.05}$
Internode length, cm	3.9	4.8	0.6
Plant height, cm	71	109	10
Reproductive nodes, no. plant^{-1}	16	19	1
Retention on first position, %	47	55	3
Retention on second position, %	14	28	4

EFFECTS ON EARLINESS AND COTTON YIELD

Open and closed boll counts and seed cotton yield data were pooled over years and glyphosate treatments due to an absence of interaction and effect. Irrigation had the greatest effect on boll maturity (percent open) when compared to the dryland plots (Table 3). Dryland plots were 65% open compared to 17% for irrigated cotton. Moisture

Table 4. Effect of irrigation on cotton fiber quality. Data were pooled over years and glyphosate treatments due to absence of interactions and glyphosate main effect.

Node no.	Micronaire	Dryland	Irrigated	LSD $_{0.05}$	Dryland	Irrigated	LSD $_{0.05}$
		------------- cm -------------			----------- g tex^{-1} -----------		
7	3.9	2.74	2.84	0.06	29.5	30.1	NS
8	4.0	2.69	2.92	0.06	28.4	30.9	1.1
9	4.2	2.67	2.87	0.05	27.5	29.5	1.6
10	4.2	2.67	2.87	0.04	27.2	29.6	1.6
11	4.2	2.67	2.84	0.05	27.2	29.9	1.6
12	4.2	2.82	2.84	NS	27.6	30.1	1.7
13	4.1	2.62	2.84	0.05	27.5	30.8	1.7
14	GLY[†]	2.82	2.84	NS	27.3	30.5	1.7
Whole plant	4.1	2.67	2.84	0.03	27.8	30.2	1.2

[†] GLY, the main effect for glyphosate was significant at $P = 0.05$.

Table 5. Effect of glyphosate treatment on micronaire at node 14.

Rate	Stage	Method	Micronaire
Untreated control			4.3
1 lbs acre^{-1}	4-leaf	POST[†]	3.9
1 lbs acre^{-1}	Pre-bloom	DIR[‡]	4.0
1 lbs acre^{-1}	4-leaf & pre-bloom	POST, DIR	3.8
LSD $_{0.05}$			0.3

[†] POST, postemergence over-the-top of 4-leaf cotton.
[‡] DIR, postemergence directed

stress can cause cotton to cutout and open earlier than cotton that does not experience the same stresses. As in our study, irrigation in north Alabama has been shown to dramatically increase seed cotton yield (Huber *et al*., 1999).

EFFECTS ON COTTON FIBER QUALITY BY NODE

Micronaire was not affected by any treatment in any year except at node 14, where a glyphosate main effect was recorded (Tables 4 and 5). Micronaire was highest in the untreated cotton compared to cotton treated with glyphosate (Table 5). However, the differences were not in the range of discounts according to industry standards. Since fiber length and strength were not affected over years or by glyphosate treatment, these data were pooled (Table 4). Irrigation resulted in longer fiber measurements recorded on all nodes except 12 and 14, where no differences were recorded. The overall average for length was also higher in irrigated cotton. Strength was higher (above node 7) when irrigated cotton was compared to dryland cotton.

CONCLUSIONS

Since over 90% of the cotton acreage in Alabama utilizes the Roundup Ready technology, it was important to determine if cotton is affected by glyphosate applied according to the manufacturer's label and if stress influences those effects. Our results indicate that glyphosate, when applied according to label directions, had no effect on overall yield, growth, reproductive structure, or fiber quality. Irrigation increased yield, total number of reproductive nodes on each plant, and boll retention. Overall, irrigation had a positive effect on plant growth and fiber quality.

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IMPACT OF COTTON ROTATION AND TILLAGE INTENSITY AT VARYING PHOSPHORUS FERTILITY ON CERTAIN SORGHUM INSECTS AND GRAIN YIELD

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ABSTRACT

With depressed grain prices and rising production input costs, grain sorghum [Sorghum bicolor (L.) Moench] producers are challenged to utilize alternate production methods to improve profitability. This study was initiated to extrapolate results of earlier small-plot research on cropping systems/tillage and soil fertility to larger field scale plots and further evaluate cultural and soil management practices for profitable production of grain sorghum. Objectives of this research include investigations of fossil fuel saving tillage practices, possible yield enhancing crop rotations and varying levels of fertilizer P and micronutrients, Fe and Zn, on grain sorghum production. The influence of these cultural management practices on certain sorghum insects was also evaluated. The experimental site was a Clareville clay loam (hyperthermic, Pachic Argiustoll) located west of Robstown, TX at the Perry Foundation. Conventional tillage (7-8 tillage trips; 6-10" tillage depth) was compared with minimum tillage (3-4 trips; 3" maximum depth) under both continuous sorghum cropping and a sorghum: cotton (Gossypium hirsutum L.) yearly rotation. The major blocks, cropping systems, and sub-blocks, tillage systems were evaluated at three P fertilization rates. Micronutrients, Fe and Zn, were included at the high P rate in the minimum tilled (MT) treatment. First year results for sorghum following cotton compared to sorghum following sorghum showed a 30 percent grain yield increase when averaged across all tillage and fertilizer variables. With severe moisture stress in the second year, the rotation benefit decreased to a statistically non-significant 13 percent. Early season plant growth differences in favor of reduced tillage failed to translate into final grain yield differences due to moisture stress prior to physiological maturity. Although sorghum head insect counts varied due to treatment, conclusive evidence of treatment effect is not offered at this time without additional data collection. Data collection for all parameters will continue for at least two years since changes in soil quality require many years to reach equilibrium and influence crop productivity.

KEYWORDS

Sorghum bicolor (L.) Moench, Tillage intensity, Cotton rotation, Phosphorus fertility, Insects.

INTRODUCTION

Improved crop yields and reduced production costs are vital to increased profitability in grain sorghum [Sorghum bicolor (L.) Moench] production in the South. Crop rotation and tillage management can have significant impact on soil quality parameters and subsequent crop yields. Changes in both soil chemical and physical properties require many years to reach near equilibrium and, therefore, long-term studies are needed to properly evaluate the effects of rotation and changing tillage systems on soil quality. Small plot research (Matocha and Stearman, 1989) showed substantial enhancement in crop yields due to crop rotation. Reduction in tillage in the Southeast USA (Motta, *et al.*, 2000) and the Southwest USA (Cripps and Matocha, 1987; Matocha *et al.*, 1998) has been shown to improve soil chemical and physical quality parameters.

Other work (Matocha and Sorenson, 1987; Matocha *et al.* 1987) has shown that fertilization techniques can affect crop yields under conservation tillage systems. Also, grain sorghum appears to respond better to certain forms of phosphate fertilizer than other sources (McCray and Matocha, 1988). Changes in soil microbial populations have been noted due to fertilization and sorghum cropping sequences (Barber and Matocha, 1994).

In the past, use of alternative tillage systems such as minimum and no-till has been slow in adoption in the Southwest but recent interest has expanded. The objective of our research was to evaluate the influence of a cotton: sorghum rotation compared to continuous sorghum on grain head insects numbers and final grain yields under conservation tillage and varying P fertilization.

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MATERIALS AND METHODS

This research was initiated in the fall of 1999 with yield data collected in years 2000 and 2001. The experimental site is located some nine miles west of Robstown, Texas, on a Clareville sandy clay loam soil. In this large field experiment, crop rotation was the main blocks and tillage treatments were evaluated as sub-blocks while soil fertility variables were considered as split-plots within each of the blocks. Each of the two tillage systems (conventional and minimum-till) was evaluated under continuous sorghum as well as a 1:1 cotton-sorghum rotation. A field at the Perry Foundation Farm (location described above) was selected which had been split into sorghum and cotton production with equal fertilizer application during the 1999 season. This allowed sorghum planting in the 2000 season on previous year's cotton land and a comparison with continuous sorghum on adjacent land in the same field and soil type.

The conventional tillage system (CT) involved 6-8 tillage operations per year (6-10" depth) and was compared with a minimum-till system (MT), which reduced tillage operations to 3-4 per year with tillage depth restricted to 3 inches or less.

Both tillage and crop rotation systems were evaluated at three levels of phosphorus (P) fertilizer (0, 20, 40 lbs P_2O_5 acre^{-1} in 2000; 0, 10, 20 lbs P_2O_5 acre^{-1} in 2001). In addition, the high P rate with the MT system was studied further with supplemental zinc (Zn) and iron (Fe) fertilization individually as well as both micronutrients in combination. Nitrogen (N) was blanketed to all treatments except the fertilizer control at a soil test recommended rate (80 lbs N acre-1) for 5500 lbs acre^{-1} grain yield. All fertilizer materials were applied as liquids in January 2000 and 2001, using a knifing mechanism that allowed banding to an approximate depth of three inches below and five inches to the side of seed placement. A randomized complete block design was utilized with three replications.

Gaucho insecticide treated grain sorghum hybrid, DK-52 (medium maturity) was planted on February 25, 2000, into seedbeds with marginal soil moisture. Seeding rate was 94,000 seed acre^{-1} in 30-inch rows. Each plot consisted of 12 rows with 250-foot row lengths.

Yield parameters for sorghum measured at harvest included grain moisture, bushel test weight and grain yield weight. Drought hastened maturity of the sorghum, which was harvested on June 23 using a grain combine, and weigh wagon.

Soil samples from selected areas in the experimental field were collected for chemical analyses prior to treatment initiation in 1999. Sampling will continue on a biennial schedule.

In the second year, crop rotation, soil fertility, and tillage treatments were studied at two seeding densities (approximately 60,000 and 75,000 seed acre-1). Both tillage systems and crop rotations were evaluated at reduced levels of P fertilizer during the 2001 season. These rates were reduced to 0, 10, and 20 lbs P_2O_5 acre^{-1} because of substantial carryover of P from the previous droughty season. As was the case in 2000 in the MT system, the high P rate was studied further with supplemental Zn and Fe fertilization individually, and in combination. Nitrogen (N) was blanketed to all treatments except the fertilizer control at the same rate used in 2000.

In the second year, planter-box insecticide treated grain sorghum hybrid, DK-52 (medium maturity) was planted in all treatments in March 2001, into seedbeds with marginal soil moisture.

Tillage and crop rotation effects on abundance of soil inhabiting insects such as southern corn rootworm, grubs and borers were assessed in both years by visual inspection of early damage to sorghum plants. Later, three insect samples were taken every other week over a 5-week period from May 15 to June 14, in both years. Samples were taken using the beat bucket method and consisted of 10 sorghum heads each. Insect data recorded included densities of headworm (*Helicoverpa zea*), rice stinkbug (*Oebalus pugnax*) and a total count of natural enemies, mainly predators. Most of the predators were ladybugs (*Scymnus* sp.), insidious flower bugs (*Orius insidiosis*), fire ants (*Solenopsis invicta*), green lacewings (*Chrysopa carnea*), damsel bugs (*Nabis* spp.), and spiders. Cocoons of one *Cotesia* parasitoid species were also observed.

Appropriate statistical analyses were performed on all collected field data. Sufficient yield response data is not available at this time so economic analyses for determining profitability of the production systems are not included in this paper.

RESULTS AND DISCUSSION

FIRST-YEAR GRAIN YIELDS

Yield levels for the first year (2000 season) were considered satisfactory especially since only 5.9 inches of precipitation were recorded for the period following planting through physiological maturity. This represents approximately 60% of the long-term average. Grain yields ranged from a high of 3522 to a low of 2290 lbs acre-1. Average yield for all 24 treatments was 3007 lbs acre-1. Sorghum grown in rotation with cotton averaged 3384 lbs acre^{-1} across tillage and fertility regimes while continuous sorghum produced average grain yields of 2605 lbs acre-1. This reflected a 30% increase in yield due specifically to crop rotation. The benefit from rotation appeared consistent within tillage systems and for most fertilizer rates.

As would be expected for the early phase of the project, yields remained largely unchanged due to tillage intensity. However, yield trends with continuous sorghum appeared lower for MT compared to CT at low P fertilizer rates. This effect was not evident when sorghum followed cotton. Additions of P fertilizer in general, either with or without micronutrients Zn and Fe had little effect on grain yields even though initial soil test levels measured medium.

INSECT EVALUATIONS

Damage to sorghum plants by soil inhabiting insects was monitored by visual inspection with no evidence of damage recorded in either year. Sorghum head insect counts were made at two dates (mid-May and June 1). Sorghum completed its blooming cycle during the first 7 days in May. Primary insects counted were headworms, rice stink bugs, and predators. At the mid-May insect count, data indicated only small and largely non-significant differences in numbers of all three insects due to tillage. However, in the early June counts, differences due to cropping system and fertilizer treatment became apparent. Stink bug numbers ranged from 0.33 to 21 per 10 heads. This was generally below what is considered the economic threshold so spraying was not initiated. However, the crop rotation effect produced substantial variation in numbers of stink bugs. Significantly greater numbers of stink bugs were recorded across most treatment variables in sorghum following cotton compared to continuous sorghum. However, insect counts two weeks later, June 1, showed large increases in headworms, stink bugs and predators. The headworm numbers were still below threshold levels, but stink bugs increased to an average range of 14 to 59 per 10 heads depending upon treatment variable and were above the economic threshold. Insecticide spraying for stink bugs was not required, however, because sorghum grain had just matured past the stage where stink bugs were no longer a yield affecting factor.

SECOND-YEAR GRAIN YIELDS

Grain yields for 2001 were drastically reduced by drought and approximated 33 percent of expected normal yields. Only 3.61 inches of precipitation were recorded for the period following planting through physiological maturity. This represents approximately 37% of the long-term average. Grain yields ranged from a high of 2025 to a low of 1108 lbs acre^{-1} with both extremes measured with the lower plant density. Average yields for the 24 treatments were 1482 and 1476 for the high and low plant densities, respectively. Sorghum grown in rotation with cotton averaged 1574 lbs acre^{-1} across tillage, fertility regimes and population treatments, while continuous sorghum produced average grain yields of 1384 lbs acre-1. or approximately 14% less than sorghum grown in rotation. The benefit from rotation appeared consistent within tillage systems and for most fertilizer rates. Further breakout of yields within the MT systems showed an approximate 430 lbs acre^{-1} (34%) increase from rotation at the higher plant populations.

Grain sorghum response to P fertilizer was variable with tillage intensity and cropping system. A statistically non-significant 320 lbs acre^{-1} grain yield increase was measured from 20 lbs P_2O_5 acre^{-1} in the MT and continuous sorghum system. However, sorghum following cotton produced 627 lbs acre^{-1} (significant at $P = 0.05$) more grain with P fertilizer and the CT tillage system. As P fertilizer rates increased, there appeared to be better response to rotation under CT as compared to the MT system. As was the case in the initial year of this study, no yield improvement was recorded from Fe and Zn fertilization.

Grain yields remained largely unchanged due to tillage variables, although moisture readings down to 24 inch depths showed a positive influence from MT earlier in the growing season. However, abnormally high air temperatures and essentially no rainfall during critical stages of plant growth resulted in severe drought stress which masked the earlier substantial plant growth response from the MT system and prevented manifestation of increases in final grain yields.

INSECT EVALUATIONS

As was described for the first year, damage to sorghum plants by soil inhabiting insects was monitored by visual inspection with no evidence of damage recorded. Headworms were only present during the first two sampling periods, with average densities per head during sampling period 1 (0.87) being significantly greater than sampling period 2 or 3 (0.10 and 0, respectively). Although tillage had no effect on headworm densities, rotation and fertilizer treatment did significantly affect headworm densities, but only during sampling period one. During sampling period 1, headworm densities were greater on sorghum planted in rotation with cotton (1.07 per plant), than for continuously planted sorghum (0.67 per plant). A significant interaction between tillage and fertilizer treatments on headworm numbers was also measured at this time. In CT plots, there were significantly less headworms in the N + 0 P treatment than in the 0 N-0 P, N + 10 lbs P, or N + 20 lbs P treatments.

Rice stinkbugs were only significantly affected by fertilizer treatments in MT plots, and this affect was different depending on the type of rotation. In the sorghum: cotton rotation plot the no N-no P treatment had significantly more rice stinkbugs than did the N + 20 lbs P treatment or the N + 20 lbs. P + zinc treatment. Generally, there appeared to be a trend of fewer rice stinkbugs with increasing rates of P fertilization.

The only variable that significantly affected predator density was tillage. Natural enemy density (4.94 per head) was greater in the CT system than in the MT treatment (4.00 per head). Also, there was no significant correlation between predator density and either headworm or rice stinkbug densities.

CONCLUSIONS

The first two years of this research project have demonstrated that rotation of grain sorghum with cotton in alternate years can influence grain productivity and profitability. Rotation improved profits by $24.00 per acre in the first year. Drought stress conditions especially in the second season may have suppressed treatment response. Reduced tillage had shown to be a large factor in early season growth of sorghum due to treatment effect on improved soil moisture in the second year, but severe drought in late season prevented changes in final grain yields. Although this research appears to suggest a relationship between sorghum headworm/rice stinkbug pressures and crop rotation and P fertilization, additional studies are needed for conclusive evidence of this association. Additional years of treatment evaluations are needed before conclusive economic evidence of profit maximizing levels of tillage/rotation/fertility can be developed.

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AN EVALUATION OF CLEARFIELD RICE PRODUCTION ON A STALE SEEDBED

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ABSTRACT

Red rice (*Oryza sativa* L.) is the most troublesome weed in rice in the southern United States. It is the same genus and species as commercial rice varieties, and there have been no selective herbicides developed to control red rice in an established rice crop until Clearfield rice was commercialized by BASF in 2002. Clearfield rice is tolerant to the herbicide Newpath (imazethapyr), and Newpath provides very effective control of red rice and other important rice weeds. A study was conducted in Louisiana in 2000 and 2001 to compare the Clearfield rice system and the Newpath herbicide with a standard variety and an Arrosolo (propanil plus molinate) herbicide program in drill-seeded conventional and stale seedbeds. Newpath was applied sequentially with preemergence and postemergence applications. Rates were 0.063 lbs **acre^{-1} followed by 0.063 lbs acre^{-1} or 0.094 lbs acre^{-1} followed by 0.032 lbs acre^{-1}. Arrosolo was also applied sequentially with early postemergence and late postemergence applications at a rate of 3.0 lbs acre^{-1} followed by 3.0 lbs acre^{-1}. An unsprayed weedy check was included for each system. Grain yields were not affected by tillage either year. In 2000, control of barnyardgrass (*Echinochloa crus-galli* L.), annual sedge (*Cyperus compressus* L.), and broadleaf signalgrass [*Bracharia platyphylla* (Griseb.) Nash] were similar for the Newpath and Arrosolo programs. Grain yields were also similar, and all herbicide programs significantly outyielded the unsprayed weedy controls. In 2001, weed infestations were minimal, and grain yields were similar for both herbicide programs and the weedy controls. Low levels of weed infestations affected net returns above direct production costs, and in 2000, yield increases due to weed control were not large enough to cover herbicide and application costs in the conventional tillage system with either herbicide program. With the stale seedbed, both herbicide programs increased returns above costs, and net returns exceeded the weedy checks. In 2001, neither herbicide program provided returns above those of the weedy checks, regardless of tillage. This study suggests that herbicide-tolerant rice technology, such as the Clearfield system, will be most beneficial in situations where difficult-to-control weeds, such as red rice, need to be managed. Herbicide programs need to be tailored to crop needs in either system to maximize production and increase net returns above costs.**

KEYWORDS

Newpath, Arrosolo, barnyardgrass, red rice, herbicide tolerance

INTRODUCTION

Herbicide-tolerant rice technology is now a reality with the commercialization of Clearfield rice by BASF. Clearfield rice is tolerant to the herbicide Newpath, whereas red rice and numerous other common rice weeds are not. This system reflects a significant advancement in rice weed control, especially in red rice control, since it provides for the first time an opportunity to control red rice in established commercial rice. This will allow rice cultural systems to shift from predominantly water seeding to drill seeding, and this change is expected to mitigate environmental concerns associated with water-seeded production practices (Feagley *et al*., 1992). There is also potential for increased stale seedbed acreage with this system. Concerns with Clearfield rice include lower yield potential than the more popular standard varieties (Bollich *et al*., 2000; Bollich *et al*., 2001), increased production costs due to the new technology (higher seed costs and herbicide costs), the need for companion herbicides to broaden the weed spectrum of Newpath (Dillon *et al*., 2000; Pellerin *et al*., 2001a; Pellerin *et al*., 2001b; Masson and Webster, 2001), and the feasibility of Clearfield rice production when red rice is not a yield limitation.

The objective of this study was to compare a Clearfield rice system and Newpath herbicide with a standard variety and an Arrosolo herbicide program in drill-seeded conventional tillage and stale seedbed systems.

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MATERIALS AND METHODS

An experiment was conducted in Crowley, LA, at the Rice Research Station in 2000 and 2001 on a Crowley silt loam (Typic Albaqualf, fine, montmorillonitic, thermic). A randomized complete block with a factorial arrangement of two tillage systems, five herbicide treatments (including an untreated weedy control for each herbicide system), and four replications were used. Conventional tillage was compared with a stale seedbed in a drill-seeded cultural system. Phosphorus and potassium (60 lbs acre^{-1} each) were incorporated in the fall, and conventional and stale seedbeds were completely tilled prior to establishment of each rice crop. The test area was allowed to become stale over the winter months. One month prior to seeding, the stale seedbed was sprayed with 1 qt acre^{-1} Roundup (1.0 lbs ai acre^{-1}) and 2 pt acre^{-1} (1.0 lbs ai acre^{-1}) 2,4-D to terminate winter vegetation. The conventional seedbed was again tilled in the spring immediately before planting. An Arrosolo herbicide system with a standard variety was compared with a Clearfield variety and Newpath herbicide. Cypress and Cocodrie were planted as the standard varieties in 2000 and 2001, respectively. In the Clearfield system, CF501 and CL141were planted as the herbicide-tolerant varieties in 2000 and 2001, respectively. Arrosolo herbicide was applied as a sequential treatment of 2 qt acre^{-1} (3.0 lbs ai acre^{-1}) early postemergence (EP) plus 2 qt acre^{-1} late postemergence (LP) to the standard varieties. Newpath herbicide was applied sequentially as a 4 oz acre^{-1} (0.063 lbs ai acre^{-1}) preemergence (Pre) plus 4 oz acre^{-1} postemergence (Po), and sequentially as a 5 oz acre^{-1} (0.094 lbs ai acre^{-1}) Pre plus 3 oz acre^{-1} (0.032 lbs ai acre^{-1}) Po to the Clearfield varieties. The experiment was flush irrigated as needed until the 4-leaf growth stage. Nitrogen (165 lbs acre^{-1}) as urea was surface applied, and a permanent flood was established 1 to 2 days later. After main crop harvest and additional 75 lbs acre^{-1} nitrogen was applied and the experiment was immediately flooded for ratoon crop production. Standard agronomic practices (insect and disease control) were conducted according to current recommendations. Weed control (barnyardgrass, broadleaf signalgrass, and annual sedge 5 weeks after seeding) and main crop and ratoon crop grain yields were determined. Data were analyzed using SAS anova procedures, and treatment means were separated using Fisher's Protected LSD (P = 0.05). Returns above costs for herbicide treatments were estimated for each tillage system each year and were based on a tenant share arrangement.

RESULTS AND DISCUSSION

Weed control ratings for 2000 are shown in Table 1. Barnyardgrass control was higher with conventional tillage

Table 1. Influence of tillage and herbicide program on weed control in Clearfield and Cypress rice for the 2000 crop year. The tillage x herbicide interaction was non-significant (P = 0.05) for every response variable.

		Barnyardgrass		Signalgrass		Annual sedge	
Herbicide program	Rate/timing†	Conv	Stale	Conv	Stale	Conv	Stale
	------ lbs acre^{-1} ------	------------------- % control ----------------------					
Arrosolo	3.0 EP + 3.0 LP	95	68	95	83	95	86
Newpath	0.063 Pre + 0.063 Po	95	93	95	95	95	94
Newpath	0.094 Pre + 0.032 Po	95	70	95	71	95	71
Arrosolo check	--	11	0	11	0	11	0
Newpath check	--	0	0	0	0	0	0
C.V., %		34.0		32.0		31.7	
Tillage mean							
Conventional		59		59		59	
Stale		46		50		50	
LSD $_{(0.05)}$		12		ns		ns	
Herbicide mean							
Arrosolo	3.0 EP + 3.0 LP	81		89		91	
Newpath	0.063 Pre + 0.063 Po	94		95		94	
Newpath	0.094 Pre + 0.032 Po	83		83		83	
Arrosolo check	--	6		6		6	
Newpath check	--	0		0		0	
LSD $_{(0.05)}$		18		18		18	

†EP = early postemergence, LP = late postemergence, Pre = preemergence, Po = postemergence.

than with the stale seedbed, but control of broadleaf signalgrass and annual sedge were similar. There were no differences in weed control among the three herbicide programs for any of the weeds rated. All herbicide programs controlled weeds greater than 80%. Injury was observed with Arrosolo and Newpath but was less than 15% (data not shown). Grain yields were not influenced by tillage (Table 2). Arrosolo and the two Newpath treatments significantly increased grain yields over the unsprayed controls, and main crop grain yields were similar. Ratoon crop grain yields were significantly higher with Arrosolo and with the unsprayed Cypress control. These differences were due to the higher yield potential of Cypress and not weed control or injury. Total grain yield with Arrosolo was significantly higher than with Newpath only when Newpath was applied at a sequential rate of 5 oz followed by 3 oz. All herbicide programs significantly outyielded their respective unsprayed controls.

Weed control ratings for 2001 are shown in Table 3. Weed infestation levels were low in 2001. Although weed control was significantly higher with herbicide application when compared with the unsprayed controls, overall weed control was lower than in 2000. Tillage had no effect on weed control. Tillage also had no effect on grain yields (Table 4). Main crop, ratoon crop, and total grain yields were similar for all herbicide programs and the unsprayed controls. Lack of weed infestation resulted in no advantage in applying herbicides in 2001. Yield potential was also similar between the Clearfield variety CL141 and Cocodrie planted in 2001.

An economic analysis of results from the 2-year study was conducted and is shown in Table 5. Net returns per acre above direct production costs were estimated for both years of the study for a tenant rice producer paying a 30 percent crop share for land and water. Producer share of rice yields were valued in both years at the loan rate (\$6.50 cwt^{-1}). Direct production costs per acre were estimated for the conventional tillage and stale seedbed production system and included expenses for seed, fertilizer, chemicals, custom application, fuel, labor, repairs, and interest on operating costs. Net returns were generally lower in the 2000 test compared with 2001 due to additional insecticide and fungicide treatments applied. Cost differences between the Clearfield production system and the standard Arrosolo herbicide program in the study were primarily related to herbicide material cost and seed cost. Herbicide material costs (excluding application charges) were approximately \$30 acre^{-1} for the Newpath treatment compared with \$26 acre^{-1} for the Arrosolo treatment. Rice seed costs for Clearfield were \$46 cwt^{-1} compared with \$16 cwt^{-1} for conventional Cypress and Cocodrie varieties. In tests conducted in 2000, the Arrosolo plots yielded higher

Table 2. Influence of tillage and herbicide program on grain yield (12% moisture) of Clearfield and Cypress rice for the 2000 crop year. The tillage x herbicide interaction was non-significant (*P* = 0.05) for every response variable.

		Main crop		Ratoon crop		Total	
Herbicide program	Rate/timing[†]	Conv	Stale	Conv	Stale	Conv	Stale
	------ lbs acre^{-1} ------	------------------------ lbs acre^{-1} ----------------------					
Arrosolo	3.0 EP + 3.0 LP	7241	7342	2475	2576	9716	9917
Newpath	0.063 Pre + 0.063 Po	7127	7731	1778	1954	8905	9685
Newpath	0.094 Pre + 0.032 Po	7463	7485	1772	1833	9235	9318
Arrosolo check	--	6676	6289	2543	2528	9219	8816
Newpath check	--	6945	6597	1733	1772	8678	8369
C.V., %		6.14		11.10		5.64	
Tillage mean							
Conventional		7091		2060		9151	
Stale		7089		2132		9221	
LSD $_{(0.05)}$		ns		ns		ns	
Herbicide mean							
Arrosolo	3.0 EP + 3.0 LP	7292		2525		9817	
Newpath	0.063 Pre + 0.063 Po	7429		1866		9295	
Newpath	0.094 Pre + 0.032 Po	7474		1802		9277	
Arrosolo check	--	6483		2535		9018	
Newpath check	--	6771		1752		8524	
LSD $_{(0.05)}$		446		239		532	

[†] EP = early postemergence, LP = late postemergence, Pre = preemergence, Po = postemergence.

Table 3. Influence of tillage and herbicide program on weed control in Clearfield and Cocodrie rice for the 2001 crop year. The tillage x herbicide interaction was non-significant (*P* = 0.05) for every response variable.

		Barnyardgrass		Signalgrass		Annual sedge	
Herbicide program	Rate/timing[†]	Conv	Stale	Conv	Stale	Conv	Stale
	------ lbs acre^{-1} ------	------------------- % control ----------------------					
Arrosolo	3.0 EP + 3.0 LP	74	70	85	80	83	80
Newpath	0.063 Pre + 0.063 Po	79	75	85	80	85	83
Newpath	0.094 Pre + 0.032 Po	75	73	83	83	85	85
Arrosolo check	--	0	0	0	0	0	0
Newpath check	--	0	0	0	0	0	0
C.V., %		12.92		6.73		5.31	
Tillage mean							
Conventional		46		51		51	
Stale		44		49		50	
LSD $_{(0.05)}$		ns		ns		ns	
Herbicide mean							
Arrosolo	3.0 EP + 3.0 LP	72		83		81	
Newpath	0.063 Pre + 0.063 Po	77		83		84	
Newpath	0.094 Pre + 0.032 Po	74		83		85	
Arrosolo check	--	0		0		0	
Newpath check	--	0		0		0	
LSD $_{(0.05)}$		6		3		3	

[†] EP = early postemergence, LP = late postemergence, Pre = preemergence, Po = postemergence.

Table 4. Influence of tillage and herbicide program on grain yield (12% moisture) of Clearfield and Cocodrie rice for the 2001 crop year. The tillage x herbicide interaction was non-significant (*P* = 0.05) for every response variable.

		Main crop		Ratoon crop		Total	
Herbicide program	Rate/timing[†]	Conv	Stale	Conv	Stale	Conv	Stale
	------ lbs acre^{-1} ------	----------------------- lbs acre^{-1} ----------------------					
Arrosolo	3.0 EP + 3.0 LP	7647	6820	1697	1483	9344	8303
Newpath	0.063 Pre + 0.063 Po	6960	7208	1898	1871	8858	9080
Newpath	0.094 Pre + 0.032 Po	7134	7143	1741	1584	8875	8726
Arrosolo check	--	7238	7173	1880	1479	9118	8652
Newpath check	--	6659	7267	1860	1856	8519	9123
C.V., %		8.83		15.35		7.44	
Tillage mean							
Conventional		7128		1815		8943	
Stale		7122		1654		8777	
LSD $_{(0.05)}$		ns		ns		ns	
Herbicide mean							
Arrosolo	3.0 EP + 3.0 LP	7233		1590		8823	
Newpath	0.063 Pre + 0.063 Po	7084		1885		8969	
Newpath	0.094 Pre + 0.032 Po	7139		1662		8801	
Arrosolo check	--	7206		1679		8885	
Newpath check	--	6963		1858		8821	
LSD $_{(0.05)}$		ns		ns		ns	

[†] EP = early postemergence, LP = late postemergence, Pre = preemergence, Po = postemergence.

estimated net returns above direct costs per acre than the Clearfield plots due primarily to significant yield differences, as well as the higher seed and herbicide costs for the Clearfield system. Yield increases from the application of Newpath herbicide were not large enough to cover herbicide and application costs in the conventional tillage test but did offset added costs in the stale seedbed tests, as net return for both Newpath treatments exceeded the check. In the 2001 tests, yield increases for both the Arrosolo and Newpath treatments were not large enough to offset additional herbicide treatment and application costs.

CONCLUSIONS

Weed infestations were moderate to very light in 2000 and 2001, respectively. There were few differences in weed control between herbicide programs and between tillage systems. Grain yields were significantly higher in 2000 when herbicides were applied; but in 2001, weed control had no effect on grain yields. In Louisiana, it is very uncommon to maximize both grain yield and net returns without a successful weed control program. Since the primary objective of this study was to compare two different weed control technologies, standard applications were made each year with no regard to weed infestation level. In 2001, especially since weed infestation levels were minimal, a single application of herbicide with the standard variety, and possibly a less expensive one, would have improved net returns in that system. With the Clearfield technology, Newpath is labeled specifically to be applied sequentially with two 4-oz applications. This is especially critical for red rice control. In commercial fields where red rice infestation are not yield limiting, it is questionable whether Clearfield technology will be profitable. With any rice weed control program, it is important to tailor the herbicides to weeds present and to consider weed size when determining both application rate and timing if high grain yields and maximum economic returns are expected.

Table 5. Net returns above direct production costs for conventional tillage and stale seedbed rice production with Clearfield and Arrosolo herbicide programs. Returns above costs assume that the tenant share of the rice yield (70%) is valued at loan rate ($6.50/cwt).

Herbicide program	Herbicide rate	Total grain yield	Returns above costs
		--- lbs acre-^{1} --	--- $ acre-^{1} ---
Conventional Tillage- 2000			
Newpath	0.063 Pre + 0.063 Post	8905	10.93
Newpath	0.094 Pre + 0.032 Post	9235	23.23
Newpath control	--	8678	42.44
Arrosolo	3.0 EP + 3.0 LP	9716	69.25
Arrosolo	--	9219	86.14
Stale Seedbed- 2000			
Newpath	0.063 Pre + 0.063 Post	9685	21.52
Newpath	0.094 Pre + 0.032 Post	9318	7.63
Newpath control	--	8369	3.38
Arrosolo	3.0 EP + 3.0 LP	9918	58.11
Arrosolo	--	8817	50.45
Conventional Tillage- 2001			
Newpath	0.063 Pre + 0.063 Post	8858	61.97
Newpath	0.094 Pre + 0.032 Post	8875	62.71
Newpath control	--	8519	89.37
Arrosolo	3.0 EP + 3.0 LP	9344	108.28
Arrosolo	--	9118	135.38
Stale Seedbed- 2001			
Newpath	0.063 Pre + 0.063 Post	9079	55.94
Newpath	0.094 Pre + 0.032 Post	8727	44.15
Newpath control	--	9123	100.89
Arrosolo	3.0 EP + 3.0 LP	8303	54.63
Arrosolo	--	8652	106.67

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Soil Quality

INTERPRETING THE SOIL CONDITIONING INDEX

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ABSTRACT

The Soil Conditioning Index (SCI) is a tool for organic matter prediction used by the Natural Resources Conservation Service (NRCS) that utilizes the effects of climate, tillage, and erosion on organic matter decomposition at various geographic locations. The three components of the SCI include (1) the amount of organic material returned to the soil, (2) the effects of tillage and field operations on soil organic matter decomposition, and (3) the effect of predicted erosion associated with the management system. The SCI gives an overall rating based on these components. The original intent of this predictive tool assumed that a negative rating would indicate soil organic matter degradation, a zero would mean status quo, and a positive number would mean an increase in soil organic matter. The objectives of this study were to generate SCI ratings for plots in long-term carbon studies in several regions of the country and interpret the ratings compared to actual organic matter trends. Results show carbon gains correlated with positive SCIs and losses with negative SCIs. The accuracy of the predicted rate of change was better for the east (0.76) than the west (0.56). In both regions, further division on a state basis improved prediction of rate of change. The SCI may need regional calibration with additional research for differences in internal drainage. This study indicated favorable potential for the SCI to predict trends in organic matter content for conservation planning and carbon sequestration.

KEYWORDS

Soil erosion, soil quality, soil organic matter, regional assessment

INTRODUCTION

For much of its history, NRCS (formerly SCS) worked primarily with erosion on agricultural and other lands. Predictive tools such as the Universal Soil Loss Equation (USLE) and the Wind Erosion Equation (WEQ) enhanced conservation for erosion control. As the mission of the agency was broadening to include other resources – soil, water, air, plant, and animal – new planning tools were needed for the multi-resource concerns.

One area of concern is the degradation of soil quality as influenced by management. The Soil Conditioning Index (SCI) is an organic matter prediction tool used by the Natural Resources Conservation Service in conservation planning (NRCS, 2001) to ensure that organic matter is improving based on the application of conservation practices. Practices such as Conservation Crop Rotation (328) and Residue Management (Mulch Till – 329B, No-till – 329 A, and Ridge Till – 329 C) include standards that have criteria to maintain or improve soil organic matter content as predicted by the use of the SCI. With the potential for carbon-based programs in the upcoming farm bill and the interest in carbon sequestration, NRCS field offices need a simple, easy-to-use method to estimate trends of organic matter as influenced by management.

MATERIALS AND METHODS

The SCI estimates the combined effect of three components on trends of organic matter. Soil organic matter trends are assumed to be an indicator of improvement or degradation of soil quality. The formula for the SCI is SCI = OM + FO + ER where:

OM IS ORGANIC MATERIAL OR BIOMASS

This component accounts for the effect of biomass returned to the soil. Organic material from plant or animal sources may be grown and retained on the site or imported to the site.

FO IS FIELD OPERATIONS:

This component accounts for the effect of field operations that stimulate organic matter breakdown. Tillage, planting, fertilizer application, spraying, and harvesting crush and shatter plant residues, as well as aerating or compacting the soil all affect and increase the rate of residue decomposition and the placement of organic material in the soil profile.

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Map ID: 3848
For proper interpretation, see Explanation of Analysis for this map at our web site. Search for "USDASOTC" to locate our map index.

U.S. Department of Agriculture
Natural Resources Conservation Service
Resource Assessment Division
Washington DC December 1996

ER IS EROSION:

This component accounts for the effect of removal or sorting, or both of surface soil material by sheet, rill, or wind erosion processes that are predicted by water and wind erosion models. It does not account for the effect of concentrated flow erosion such as ephemeral or classic gullies. Erosion contributes to loss of organic matter and decline in long-term productivity.

A soil texture correction factor was added to the original SCI based on findings from carbon measurements on different soil textures (Norfleet, unpublished). The Revised Universal Soil Loss Equation (RUSLE) decomposition functions are used in the model to estimate relative rates of plant residue decomposition at different locations. Climate at each location is expressed as average monthly precipitation and average monthly temperature.

Soil Conditioning Indices were generated and compared from long-term experiments that had been reported to gain or lose carbon. Certain Land Resource Region Groups, LRRs (Figure 1) were used for a representative sample of the country (Soil Conservation Service, 1981). We selected long-term carbon experiments of 10 or more years with the exception of Athens, GA (six years). Table 1 lists the location, years of duration at time of measurements, LRR Group, crops grown, tillage systems, and key references used to obtain data for the experiments.

We converted all carbon findings from the experiments to percent because of the inconsistencies found in the experimental data reported (i.e. bulk densities not reported at the end of experiments or not reported at all). Soil information and field operations described in the references were used to estimate soil losses using the revised soil loss equation (RUSLE).

RESULTS AND DISCUSSION

In the Western USA experiments (Figure 2), carbon gains began with a positive number as indicated by the intersect line at zero. The correlation between carbon gains and SCIs was not as solid for the west compared to the east (R^2 of 0.56 and 0.76, respectively, Figures 2 and 3). Although the correlation was lower, the SCIs in the west accurately predicted carbon trends and none of the systems estimated a loss where there was none. A negative SCI was always associated with a negative carbon trend. In the west region, further division on a state basis improved prediction. When the states were divided out independently, the R^2 improved (Figures 4, 5, and 6). Thus, to be useful in predicting rate of change, the SCI may need regional

Table 1. Crops, tillage and references from long-term carbon studies.

Location	Yrs	LRR	Crops	Tillage	References
Pendleton, OR	55	B	Wheat-fallow	Conventional	Ramussen and Parton, 1994
Akron, CO	10	G	Wheat-fallow	Conventional/ No-till	Halvorsen et al., 1997
Bushland, TX	30	H	Wheat fallow/ Continuous wheat	Sweep/One-Way sweep	Unger, 1982
Bushland, TX	10	H	Wheat/sorghum	Stubble mulch/No-till	Potter et al., 1998
Crossville, AL	10	N	Corn-wheat cover crop, soybean-wheat cover crop, corn wheat cover-soybean-wheat cover crop	Conventional/ No-till	Edwards et al., 1992
Lexington, KY	15	N	Corn-rye cover crop	Conventional/ No-till	Ismail et al., 1994
South Charleston, OH	28	M	Corn	Conventional/ No-till	Mahboubi et al., 1993
Athens, GA	6	P	Soybean/sorghum with rye or clover cover crop	Conventional/ No-till	Hendrix et al., 1997
Florence, SC	14	P	Corn/wheat-soybean and wheat/cotton	Conventional/ No-till	Hunt et al., 1996

calibration with additional research for differences in rainfall and decomposition in regions receiving less than 35 in (889 mm) annually. Although the current model of SCI accounts for texture, additional research may be necessary for differences in drainage.

The Eastern USA carbon studies showed more accuracy with the model as reflected by the R^2 (Figure 3). All of the studies in the east had cover crops or were double-cropped except the corn study in Ohio. The cover crops and double crops accounted for more organic material in the rotations along with the fact that most of the experiments were on level ground (low erosion), which resulted in mostly positive SCIs. By adding the soil texture correction, the SCI began to predict gains with a positive SCI, whereas before the SCI needed to be at 0.18 before OM gains were seen. The soil texture correction also improved the accuracy of predictions in conventional tillage when higher residues were produced and erosion rates were low.

CONCLUSION

As NRCS and other conservation planners begin using the SCI as an organic matter maintenance tool, it is important that they consider the entire system that the three sub-factors of the SCI represent, and how they combine to form an overall SCI. Since this comparison was done from experimental plots, erosion was not a determining factor to the SCI since they tend to be on more gentle slopes. This was reflected in the higher scores (higher = less erosion) for the erosion sub-factor in the SCIs (not shown). Most of the problems seen in this study were with conventional tillage systems that generated positive SCIs but had negative carbon trends. We expect better correlations on land with slopes greater than 2% where the lower erosion scores will contribute to a lower SCI. However, if conservationists are seeing positive SCIs that are near zero, but soil degra-

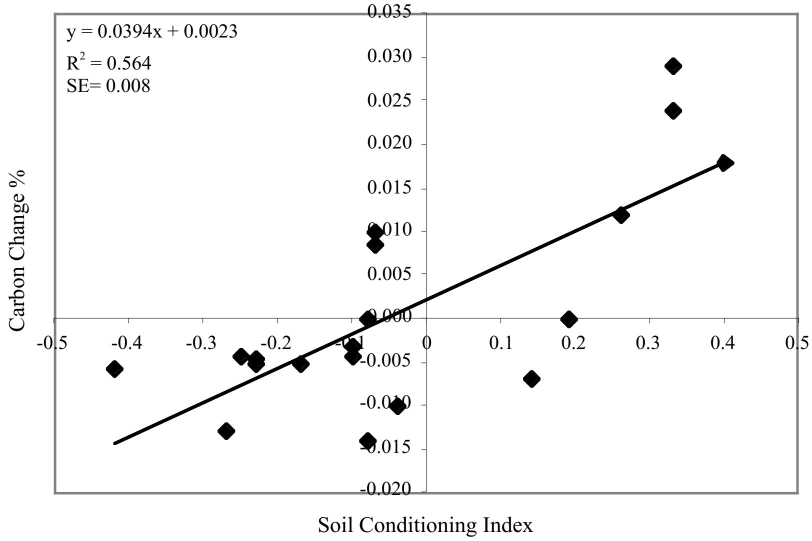

Fig. 2. Soil Conditioning Index vs % Carbon Change for the Western USA.

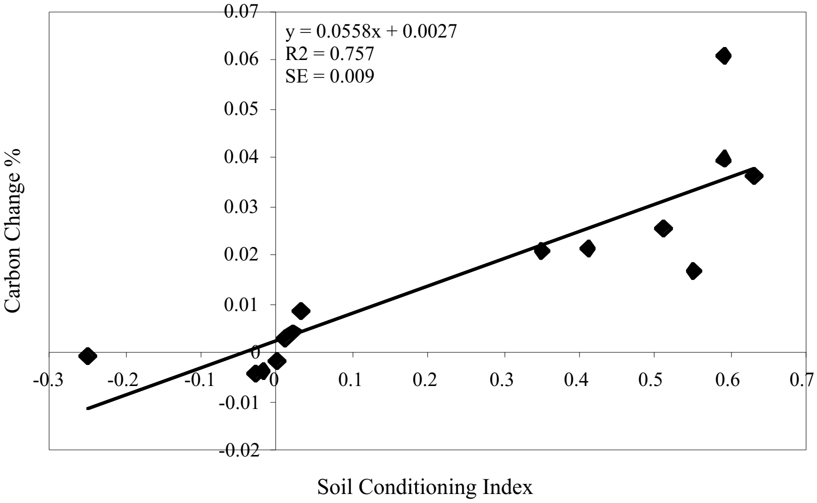

Fig. 3. Soil Conditioning Index vs % Carbon Change for the Eastern USA.

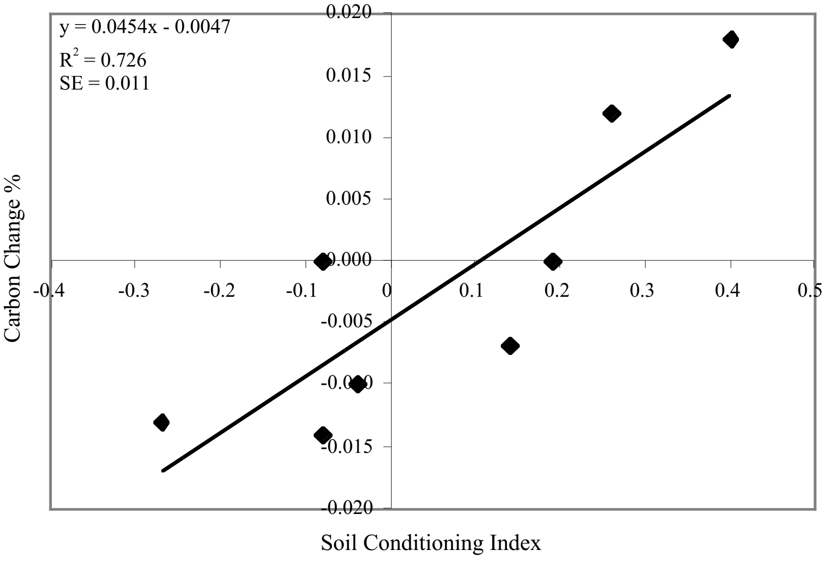

Fig. 4. Soil Conditioning Index vs % Carbon Change for Texas

dation is still evident, then further inventory of the resources may be needed. Based on comparison of SCIs with these long-term carbon studies, we found the following: (1) In the Western and Eastern USA, positive trends of carbon follow positive SCIs; (2) negative SCIs were associated with negative carbon trends in both the west and the east; (3) The R^2 in the west improved when we separated the data by states; and (4) problems with the model associated with conventional tillage on flatter slopes were corrected by adding texture to the model. The SCI may need calibration for certain regions especially in the west. More studies from different regions are needed.

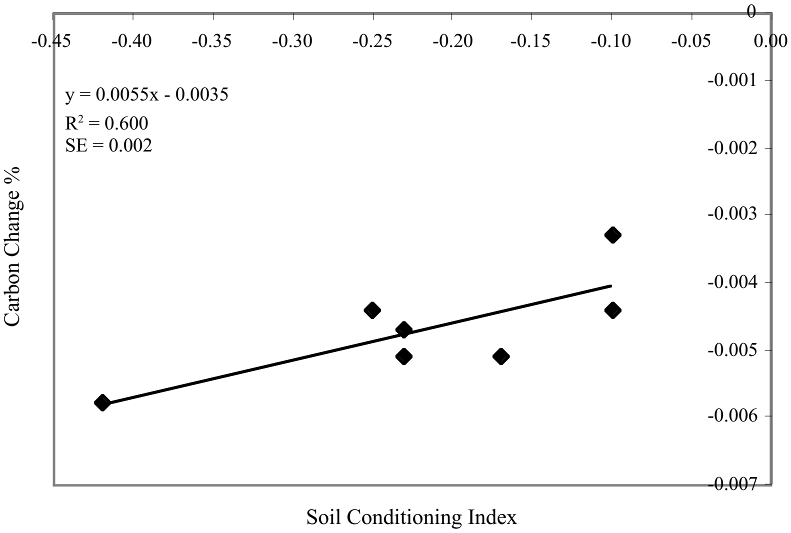

Fig. 5. Soil Conditioning Index vs % Carbon Change for Oregon.

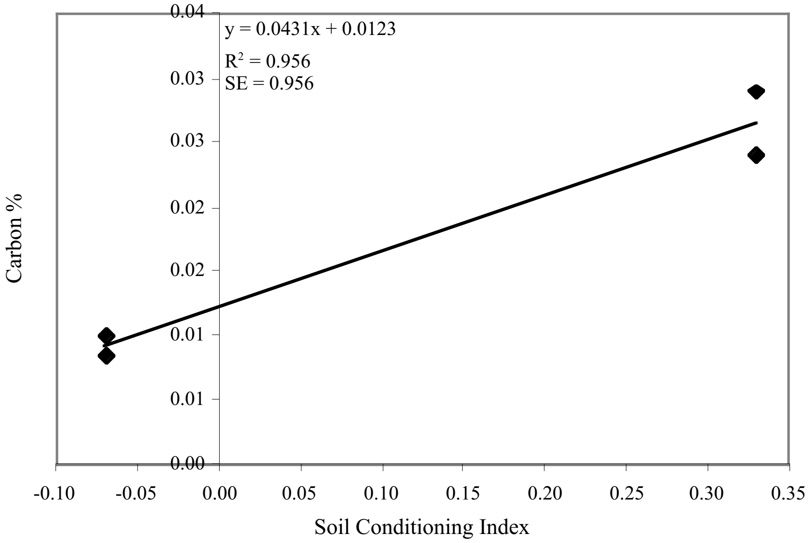

Fig. 6. Soil Conditioning Index vs % Carbon Change for Colorado.

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SHOWING FARMERS THE DIFFERENCE: MEASURING SOIL QUALITY IN CONSERVATION TILLAGE AND CONVENTIONAL FIELDS USING THE NRCS SOIL QUALITY TEST KIT

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ABSTRACT

Although many farmers have reported noticeable differences in their fields and soils after several years of conservation tillage, there is little on-farm data available in Georgia comparing soil quality in fields under conservation vs. conventional tillage. The Georgia Soil Management Team was formed in 1999 to help educate farmers and agricultural professionals on soil quality. This group has used the NRCS Soil Quality Test Kit to begin to gather this type of data and make it accessible to farmers. We have collected data for three years in seven Georgia counties with the Test Kit measuring infiltration, bulk density, and water stable aggregates, and also sending soil samples to the Soil, Plant, and Water Laboratory at the University of Georgia for carbon and routine nutrient analysis. The data reflect a range of surface soil textures, years in conservation tillage, and conservation tillage practices. Generally, the conservation tillage fields have higher percent carbon, water stable aggregates and infiltration rates than comparable conventional fields. These data have been presented and discussed at several Georgia Conservation Tillage Alliance Meetings and other educational settings. We hope to gather more data over the next several years in order to continue the development of this on-farm database, which can benefit growers and educators alike.

KEYWORDS

Soil management, water infiltration, bulk density, soil structure

INTRODUCTION

Farmers who have used conservation tillage practices for several years often report improvements in soil tilth, reduced crusting, and decreased runoff, all of which can result in improved crop quality and production. This anecdotal information is often discussed in Conservation Tillage Alliance Meetings where growers gather to learn from each other's experiences, but there is little on-farm data on soil characteristics to validate the growers' reports. Although there is a large body of research data available on the effects of conservation tillage on soil characteristics, information from a nearby county or farm is sometimes more effective in illustrating the benefits.

The Georgia Soil Management Team was formed in 1999 to help educate farmers and agricultural professionals about the importance of soil quality. This group has used the NRCS Soil Quality Test Kit to compare selected soil quality characteristics in fields with similar soils using either conservation or conventional tillage. We hoped to develop a database that would show farmers the differences in soil quality under different management systems and over time. We also hoped the Soil Quality Test Kit would be used by other groups such as 4-H students.

METHODS

Information for the database has been gathered since 1999 by visiting a Georgia county or group of counties in the late fall or early winter after harvest and before planting preparation. The County Extension Agent and/or the NRCS conservationist was contacted and asked to recommend farmers using conservation tillage who might want to participate. Once a farmer's field was selected, County Soil Survey maps were used to identify the dominant soil series. A nearby farm with soils in the same soil map unit using conventional tillage was also sampled for comparison. For example, if we selected a strip till cotton field in Coffee County, we would use the Coffee County Soil Survey to determine the mapped soil series in the field and find a nearby conventional cotton field with the same surface soil texture and with the same soil series mapped as a contrast-

IN E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

ing management for that soil series. Farm field locations were noted on road maps so the site could be revisited.

Once a field was selected, we looked for a representative area with about a 50-foot radius in the field with similar surface soil texture, slope, and growth characteristics. All the subsampling and replicate sampling were conducted within that radius. Subsampling sites were randomly selected within the sampling area..

A subset of parameters was selected to evaluate the various aspects of soil quality. Bulk density and infiltration were measured as an indicator of the physical component of soil quality. Routine soil nutrient analysis for pH and available Ca, K, Mg, Mn, P, and Zn, as well as percent C were analyzed as indicators of chemical soil quality. Water stable aggregates were run as an indicator of biological activity.

Bulk density was measured using the ring method in the NRCS Soil Quality Test Kit Guide (NRCS, 1999). Four bulk density samples were collected in each field's sampling area: two samples collected in-row, two samples in the middles, and an average bulk density calculated for the area. Infiltration was measured using the NRCS Soil Quality Test Kit Guide twice in-row and twice in the middles, and an average was calculated (NRCS, 1999). The procedure was performed twice in each ring to obtain both a dry and wet infiltration rate. The wet infiltration is reported in the database.

Composite soil samples (six or more subsamples) were collected from the soil surface (0-6 in) for routine soil analysis at the University of Georgia's Soil, Plant, and Water Laboratory. Soil test P, Ca, K, Mg, Mn, and Zn were extracted with Mehlich I solution (AOAC Method 968.08, Cunniff,1996) and analyzed on an emission ICP by EPA 200.7 (USEPA, 1994). A composite soil sample was also collected from the surface (0 - 0.5 in) for carbon analysis. Total soil carbon was analyzed on a LECO analyzer (Nelson and Sommers, 1996). This was converted to percent organic matter using a 1.724 multiplier. Soil pH was determined on a 2.5:1 soil/water paste (Thomas, 1996).

Water stable aggregates were determined using the NRCS Soil Quality Test Kit method. Four subsamples were collected from the soil surface (0-6 inches) and an average percentage calculated for the area.

RESULTS

A total of 21 fields from seven counties in Georgia have been sampled since the fall of 1999. The counties from which we have data are Brooks, Coffee, Houston, Jenkins, Macon, Randolph, and Tift. Soil series mapped on the sites were Cowarts/Carnegie, Faceville, Norfolk, Orangeburg, Pelham, and Tifton. Most of the fields had a sandy or loamy sand texture in the soil surface.

Cotton was grown during the previous growing season in most fields, but several had strip till peanuts. The number of years a field had been in conservation tillage ranged from one to 18. Because conservation tillage is a growing practice in Georgia, a higher number of fields sampled had only been in conservation tillage for one to three years (Fig. 1). We also found differences in what was considered conservation tillage in several counties. Most of the growers whose fields we sampled had converted to a conservation tillage system, which included strip tilled cotton into a winter cover crop, usually rye (CTS - 8 fields). There was a group of growers who strip tilled cotton or peanuts into a winter cover, but harrowed the fields before the winter cover was planted (CT/FT - 7 fields).

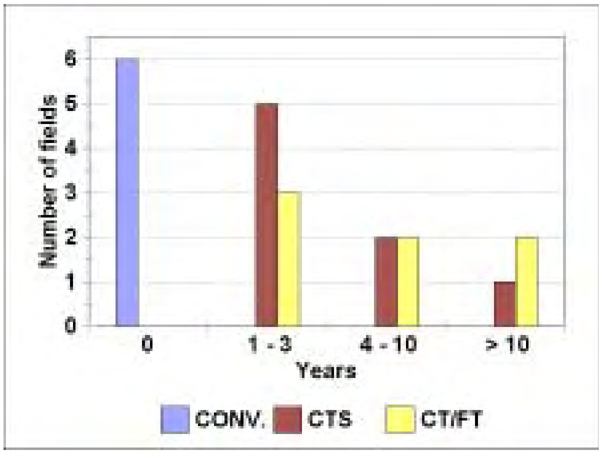

Fig.1. Distribution of the fields sampled for the soil quality database by years in conservation tillage. Consevation tillage with winter cover crop (CTS), summer strip-till/ fall tillage (CT/FT), or conventional tillage (CONV).

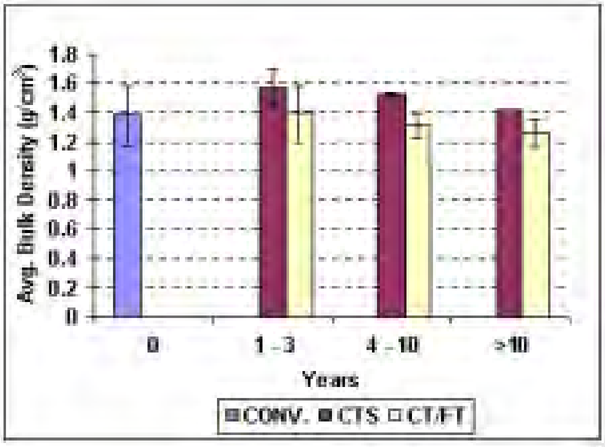

Fig. 2. Average bulk densities measured with the NRCS Soil Quality Test Kit in conventional (CONV), conservation tillage with winter cover (CTS) and summer strip-till/ fall tillage (CT/FT).

Bulk density in the soil surface of the CTS or CT/FT fields is similar to that of the CONV, though there may be a trend of decreasing bulk density with time in conservation tillage (Fig. 2).

We present infiltration as the number of minutes required for one inch of water to move into the soil (Fig. 3). This measurement illustrates to the farmer that water is unlikely to puddle in the CTS fields. All these measurements were taken in the late fall and early winter. Due to the extended drought conditions, most soils were very dry. Only one measurement (CTS 4-10 years group) was taken under wet conditions.

As expected, the variability of this measurement was very high (Fig. 3). However, the time to infiltrate one inch of water tended to decrease with the number of years in CTS or CT/FT. The relatively high average for the CTS 4-10 years group is due to longer infiltration times in the middles of the one field measured under wet conditions. In some cases, water infiltrated very quickly in the CONV. system; however, these measurements were made after the field had been harrowed and no rainfall had occurred. After rainfall, these fields would typically have a crust which would decrease infiltration.

Organic matter in the top 0.5 inch of the soil ranges from less than 1% to over 3.5 % (Fig. 4). The fields in the CTS generally had higher soil organic matter than CONV, but the average for CTS is lower than for CT/FT. The lower average for CTS is probably due to the fact we have more fields in this group that have used conservation tillage for one to three years, and these fields are just beginning to rebuild soil organic matter. In the few samples that we have, we see an increase in water stable aggregates with the amount of time in CTS while the CT/FT appears to hold steady (Fig 5).

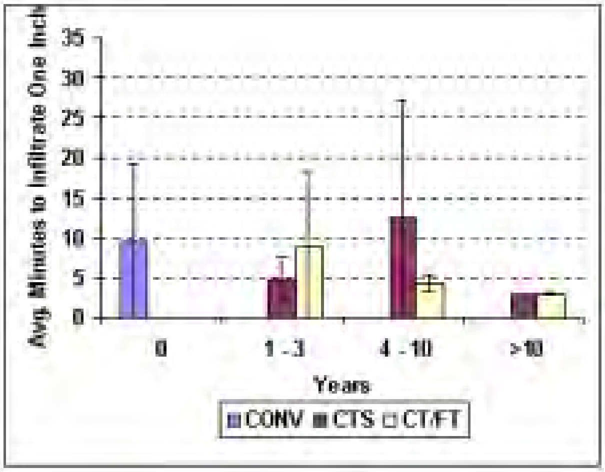

Fig. 3. Average amount of time it takes for one inch of water to infiltrate the soil measured with the NRCS Soil Quality Test Kit in conventional (CONV), conservation tillage with winter cover (CTS) and summer strip-till/ fall tillage (CT/FT).

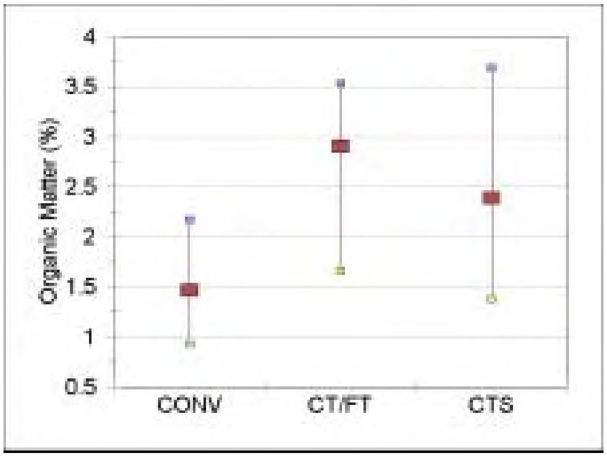

Fig. 4. Range of organic matter in conventional (CONV), conservation tillage with winter cover (CTS) and summer strip-till/ fall tillage (CT/FT).

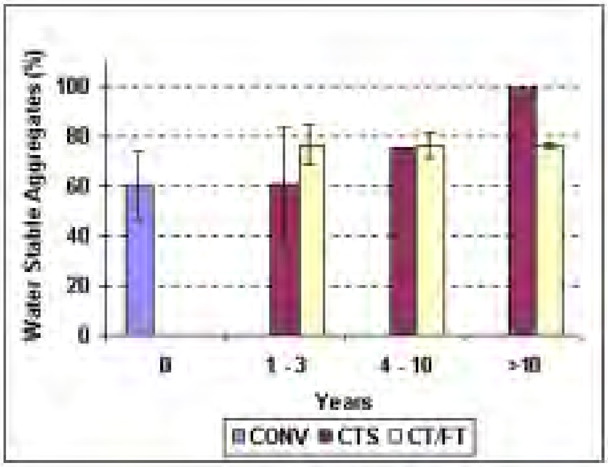

Fig. 5. Average water stable aggregates measured with the NRCS Soil Quality Test Kit in conventional (CONV), conservation tillage with winter cover (CTS) and summer strip-till/ fall tillage (CT/FT).

DISCUSSION

The information has been shared with over 400 farmers and 190 agricultural professionals at such meetings as the Georgia Conservation Tillage Alliance annual meeting, the Southern Sustainable Agriculture Research and Education Professional Development Program / Southern Sustainable Agriculture Work Group Annual Meeting, Conservation Tillage Workshops, and the National Association of County Agricultural Agents National Meeting. Growers have been very interested in the results from their farm and how they compare to other farms using conventional tillage. The process has helped increase farmer awareness about soil quality and how it may relate to changes they are experiencing in their fields.

The Soil Quality Test Kit has also been used with the Coffee County 4-H group. Middle and high school students measured various soil quality parameters in conservation tillage fields and compared the results to conventional tillage fields. Students presented their results and why their variable would be important to the group.

The data has been used as a springboard to discuss the link between soil quality and water quality, and to discuss how improvements in infiltration and soil water storage with increases in soil quality helps make better use of rainfall and more efficient use of irrigation water resources. Education on these issues are becoming more critical in Georgia as the state policies are beginning to address the fact that water is becoming a scarce resource. We hope to continue collecting data every fall and return to the fields we have measured after about four years to see if we can document trends.

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MANAGEMENT EFFECTS ON CLAY DISPERSIBILITY OF A RHODIC PALEUDULT IN THE TENNESSEE VALLEY REGION, ALABAMA

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ABSTRACT

Conventional tillage coupled with monoculture cotton (*Gossypium hirsutum* L.) production has resulted in declining soil quality in the Tennessee Valley Region. However, conservation tillage systems that have been shown to increase soil quality are increasingly more common. Surface horizons in the region have appreciable silt and clay, which are mostly composed of quartz, kaolinite, hydroxy-interlayered vermiculite, and Fe oxides. Similar clay mineralogical suites have been shown to be dispersive under certain conditions, which can degrade soil physical properties. We evaluated the clay dispersibility of these soils cropped to cotton in: 1) a no-till system without a cover crop (NT), 2) a no-till system with a rye (*Secale cereale* L.) cover crop (NTC), 3) a no-till system with a rye cover crop and fall paratilling (NTCP), and 4) a conventional tillage system (CT). Soils consisted of fine, kaolinitic, thermic Rhodic Paleudults. Water dispersible clay (WDC), extractable Fe forms, and soil organic carbon (SOC) were evaluated for surface samples. Particle size distribution (PSD) and mineralogy of *in situ* soil, runoff sediment, and WDC were also evaluated. Increased clay amounts were recovered when samples had dithionite extractable Fe removed (Fe_d) compared to soil organic matter removal. The WDC quantities were positively correlated with SOC (%), which was higher under reduced *versus* conventional management and negatively correlated with Fe_d (%) and water stable aggregates (%). The aggregate of data suggests Fe oxides play a more vital role in clay aggregation than SOC in these soil systems. Particle size and mineralogy of runoff sediment collected under simulated rainfall was similar to *in situ* soil, suggesting models depicting erosion and nutrient runoff can be developed using *in situ* soil as a surrogate for sediment characterization.

KEYWORDS

Water dispersible clay, Ultisols, conservation tillage

INTRODUCTION

In recent years, reduced tillage systems have become common in the Tennessee Valley region of Alabama. These soils are mostly Ultisols with surface horizons possessing appreciable silt and clay particles. Quartz dominates the sand and coarse silt fractions, and kaolinite and hydroxy-interlayered vermiculite are found in the fine silt and clay fractions. Relatively high quantities of Fe oxides are found in both surface and subsurface horizons.

Similar soil mineralogical systems have been shown to possess appreciable quantities of water dispersible clay (WDC) under certain conditions (Miller and Baharuddin, 1986; Miller and Radcliffe, 1992; Chiang *et al*., 1994). Water dispersible clay has been correlated with erodibility (Bajracharya *et al*., 1992) and relatively high quantities of WDC results in soil crusting (Chiang *et al*., 1994), which decreases infiltration (Zhang and Miller, 1996). Studies have established WDC quantities are correlated with total clay content, soil organic matter content (SOM), dithionite extractable Fe and Al content, exchangeable cations, pH, and ionic strength (Goldberg *et al*., 1990; Miller *et al*., 1990; Brubaker *et al*., 1992; Heil and Sposito, 1993).

Due to the importance of water dispersible particles to soil properties, this study was undertaken to: 1) develop an understanding of the interactions of management systems on the dispersion characteristics of surface soils in the Tennessee Valley Region, and 2) characterize sediment and dispersed particles from these soils.

MATERIALS AND METHODS

Our research site was located at the Belle Mina Experiment Station in the Tennessee Valley Region of Alabama. Soils possessed fine-textured surface horizons, and were classified as fine, kaolinitic, thermic Rhodic Paleudults (Table 1). Soils are moderately to severely eroded due to historical conventional tillage management during inten-

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sive cotton (*Gossypium hirsutum* L.) monocropping. However, since 1996, conservation tillage management systems using cover crops are now predominant in the region. The study site was part of a long-term experiment (1995 to present) evaluating conservation *versus* conventional tillage management systems cropped to cotton in a RCB design with four replications (Schwab *et al*., 2002). We selected four treatments (plots are 8 m wide x 15 m long) consisting of no-till without a cover crop (NT), no-till with a rye (*Secale cereale* L.) cover crop (NTC), no-till with a rye cover crop and fall paratilling (NTCP), and a conventional tillage system (CT) that consisted of disking and chisel plowing in the fall, followed by disking and leveling in the spring.

For deep pedon characterization, soils were sampled by horizon according to National Cooperative Soil Survey Standards. Particle size determination, cation exchange capacity, exchangeable cations, extractable Al, base saturation, and pH were analyzed according to standard techniques (Soil Survey Investigations Staff, 1996).

Soils were composite (≈ -20) sampled at the 0-1 cm depth in the four replications of the selected treatments. Soil organic carbon (SOC) was measured using dry combustion (Yeomans and Bremner, 1991). Organically bound Fe was extracted with sodium pyrophosphate (Fe_p), non-crystalline (poorly crystalline and organically bound) Fe was extracted with acid ammonium oxalate (Fe_o), and total Fe oxides and organically-bound Fe were extracted with dithionite-citrate-bicarbonate (Fe_d) (Jackson *et al*., 1986). Particle size was determined with: 1) SOM removed (using H_2O_2), 2) Fe_d removed, and 3) both SOM and Fe_d removed (Kilmer and Alexander, 1949). The WDC was measured using the method of Miller and Miller (1987). The WDC was measured using both distilled H_2O (H_2O_d) and well water used during rainfall simulation experiments (H_2O_{TV}) [pH=7.41, EC= 0.17 dS m^{-1}, total electrolyte concentration (TEC)=2 mol_c m^{-3}, Ca=33.2 ppm, Na=1.7 ppm].

Water stable aggregates (WSA) (0-3 cm) were determined for composited (5) samples for the first and third replication using the method of Kemper and Rosenau (1986). The first and third replications were chosen to coincide with rainfall simulation experiments (first replication in the fall, third replication used in spring, see Truman *et al*., in review).

Rainfall simulation experiments were conducted during November, 1999 on duplicate 1-m^2 plots placed within the first replication (Truman *et al*., in review). Briefly, rainfall was applied to duplicate plots within each treatment at a target intensity of 50 mm h^{-1} using an oscillating nozzle rainfall simulator. Rain was applied for 1 h, paused for 1 h, and then resumed for 1 additional h. Runoff sediment was collected at an outlet placed on the corner of each plot.

Runoff sediment, WDC (from first replication), and *in situ* soil samples (from first replication) were fractionated into fine (0-0.2µm) and coarse clay (0.2-2 µm) after organic matter removal using standard techniques (Jackson, 1975). Oriented clay fractions were examined by XRD using these treatments: Mg-saturation / ethylene glycol solvation @ 25C, Mg-saturation @ 25 C, K-saturation @ 25C, 300C, and 550C. Magnesium-saturated clay fractions were analyzed using thermogravimetric analyses (TGA). Hydroxy-interlayered vermiculite (HIV) and quartz (Qtz) quantities were estimated using the techniques of Karathanasis and Hajek (1982).

RESULTS AND DISCUSSION

The 0-1 cm depth in these soils possessed appreciable clay (Table 2). Overall, for particle-size measurements with SOM removed (standard procedure), the CT plots possessed slightly higher clay than all of the NT treatments,

Table 1. Soil characterization data for the Tennessee Valley site (fine, kaolinitic, thermic Rhodic Paleudult). Values for Ca, Mg, K, and Na are NH_4OAc extractable bases, values for Al are the KCl extractable quantity, ECEC is the effective cation exchange capacity, CEC is the cation exchange capacity, pH is the pH in 1:2 soil:water, and BS is the base saturation.

Horizon	Depth	Sand	Silt	Clay	Ca	Mg	K	Na	Al	ECEC	CEC	pH	BS
	-- cm --	--------- %		---------	-------------------- cmolkg^{-1}						--------------------		- % -
Ap1	0 –19	15.3	54.2	30.5	3.36	0.42	0.63	0.01	0.07	4.49	8.91	5.10	49.6
Ap2	19-30	12.7	51.8	35.5	4.14	0.49	0.59	0.01	0.06	5.29	10.01	5.52	52.2
Bt1	30-46	10.0	39.4	50.6	3.36	0.44	0.41	0.02	0.85	5.08	11.87	4.62	35.6
Bt2	46-110	10.0	36.3	53.7	2.20	0.45	0.25	0.01	1.15	4.06	10.49	4.44	27.7
Bt3	110-150	9.1	27.9	63.0	1.38	0.52	0.26	0.01	2.21	4.39	10.90	4.10	19.9

reflecting the more thorough mixing of surface and subsurface soils and possibly a slightly higher degree of erosion for CT treatments. In the southeastern region, eroded soils typically have finer-textured surface horizons due to the exposure of argillic horizons and the mixing of these clay-rich subsurface horizons with surface horizons through tillage (Olson *et al*., 1994).

Many studies have shown the role SOM plays in clay aggregation, which is partly attributed to clay-organic interactions facilitated through cation bridging (Oades, 1989). However, for these soils, the amount of clay recovered increased when Fe_d was removed compared to SOM removal (Table 2). In fact, recovered clay quantities were similar with Fe_d removed compared to having both Fe_d and SOM removed (Table 2). These data suggest Fe_d plays a more substantial role in aggregating clay minerals in these soils than SOM. The Fe_d is composed of "free" Fe oxides, which consist of crystalline (hematite, goethite), poorly crystalline (ferrihydrite and other forms), and organic Fe forms. The high proportion of Fe_d compared to Fe_o (poorly crystalline) and Fe_p (organic forms) suggests much of the free Fe is in crystalline oxide form (Table 2). At the resident pH of these soil systems (5 to 6), Fe oxides possess an appreciable (+) charge (ZPC from 6.5-7.5), thus promoting the bridging of (-) charged phyllosilicate surfaces (e.g., kaolinite has a ZPC from 3.5-5). Although in many surface soils SOM plays a large role in clay aggregation, our data suggests in these soil systems (>2.5% Fe_d on a whole-soil basis) Fe oxide minerals play a more substantial role.

Overall, an average of 14% (H_2O_{TV}) to 18% (H_2O_d) of the clay fraction was water-dispersible (Table 2). Brubaker *et al*. (1992) analyzed soils from eight orders and found an average of 34% of the clay fraction was water-dispersible. Our soils have relatively less WDC overall, likely due to the high quantities of Fe oxides in these soil systems. The slightly greater amount of WDC using H_2O_d is likely due to a combination of lower total electrolyte concentration (TEC) for this treatment, and the relatively higher Ca in the H_2O_{TV} treatment causing a slight decrease in the double layer and slightly reduced dispersion. It has been suggested in highly weathered systems with low TEC, such as mimicked with the H_2O_d treatment, repulsive forces between clays result in increased dispersion (Kaplan *et al*., 1996).

No relationship existed with regard to H_2O_d dispersible clay quantities and SOC or Fe_d (Fig. 1a and b). However, the H_2O_{TV} dispersible clay quantities increased with increasing SOC (r^2=0.65) and decreased with increasing Fe_d (r^2=0.35) (Fig. 1c and d). Studies have indicated in some systems, SOC may enhance dispersion by decreasing Ca activities while increasing negative charges on clay colloids (Oades, 1984). For these soils, increasing Fe oxide quantities resulted in a general decrease in WDC. We also found WDC was exponentially related to percent water stable aggregates (WSA), suggesting WDC should be included in soil quality data sets (Figure 2).

The runoff sediment was similar in texture to *in situ* soil (Table 3). Similarities in texture between sediment and soil is consistent with results obtained by Meyer *et al*. (1992) and Shaw *et al.* (in review) for other Southeastern soils.

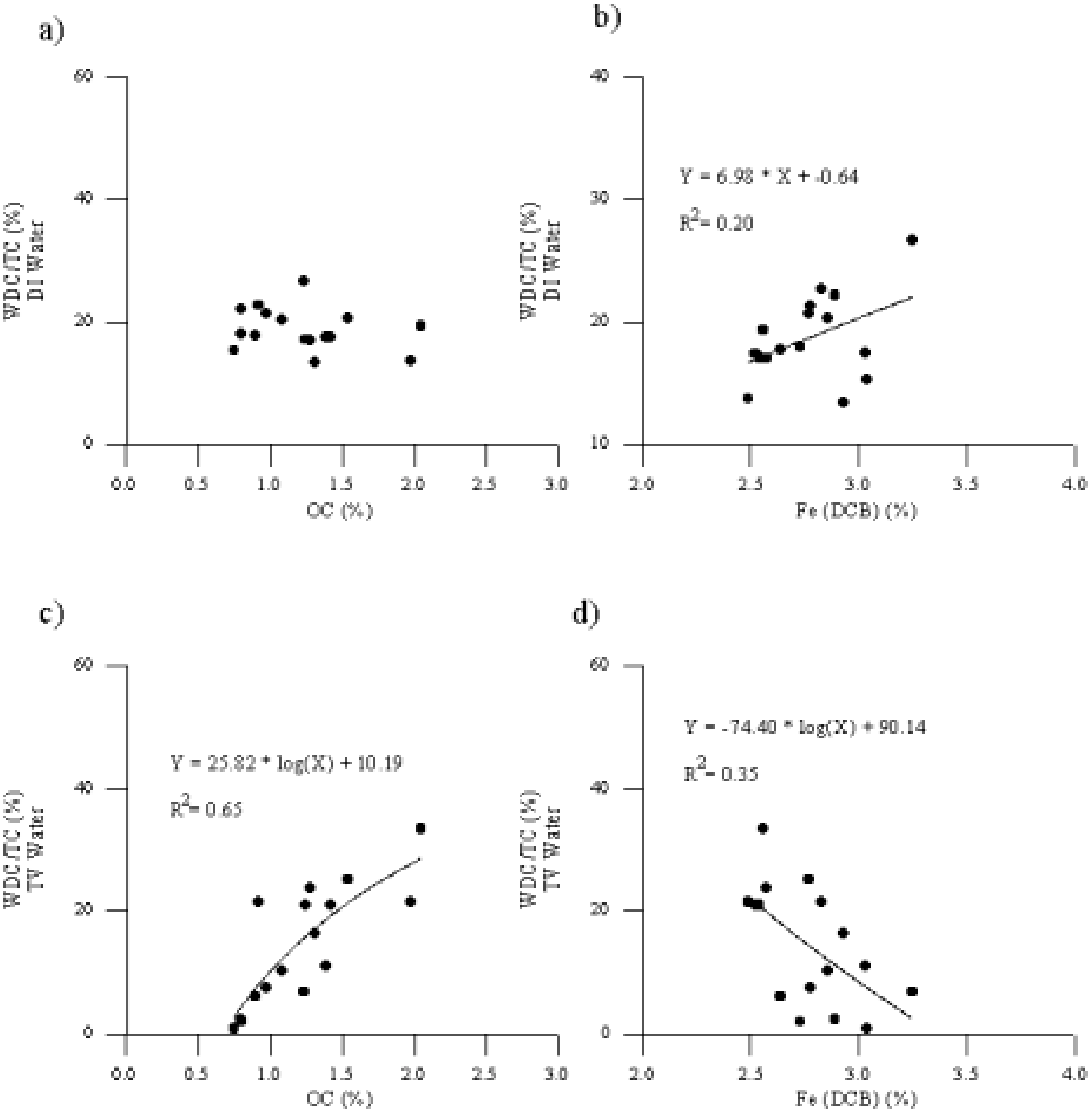

Fig. 1. Relationship between a) water dispersible clay (WDC)/total clay (TC) and SOC (%) for DI water, b) WDC/TC and DCB Fe (%) for DI water, c) WDC/TC and OC (%) for TV water, and d) WDC/TC and DCB Fe (%) for TV water. TV water composition described in methods.

Analyses of the clay mineralogy of the *in situ* soil, runoff sediment, and WDC suggest little enrichment of specific clay minerals in transported *versus in situ* soil. Similar quantities of kaolinite, hydroxy-interlayered vermiculite (HIV), quartz, and Fe_d were observed between the soil, sediment, and WDC (Table 4). These data suggest models depicting off-site nutrient movement do not need to incorporate enrichment ratios for specific particle size separates and minerals, i.e., characterization of *in situ* texture and mineralogy adequately reflect sediment size characteristics and mineralogical composition.

CONCLUSIONS

Increasing amounts of dispersible clay has been shown to decrease infiltration as well as generally degrade soil physical properties. It is widely accepted that in many soil systems, increases in SOM resulting from conservation tillage systems generally result in increased infiltration rates. Results from a companion study (Truman *et al.*, in review) suggested minimal differences in infiltration between the CT, NT, and NTC treatments of this experiment, which may be due to the clay dispersion phenomena shown in this study. Infiltration rates were greatly increased in the no surface tillage systems with non-inversion deep tillage

Table 3. Particle-size of soil and sediment collected during a rainfall simulation experiment on first replication. Numbers in parentheses are standard deviations of means.

	Soil			Sediment		
Treatment†	Sand	Silt	Clay	Sand	Silt	Clay
	%					
NT	6.8	74.3	19.0	4.5(0.8)	71.8(0.3)	23.7(1.1)
NTC	8.0	72.4	19.6	4.2(0.6)	65.2(1.2)	30.5(1.8)
NTCP	11.6	58.8	29.6	8.0(0.2)	61.9(1.5)	30.1(1.3)
CT	10.5	56.2	33.3	8.4(0.4)	57.1(2.9)	34.5(2.4)

†NT = no tillage, NTC = no tillage with cover crop, NTCP = no tillage with cover crop and fall paratilling, CT = conventional tillage.

Table 4. Comparison of mineralogical composition of clay (< 2 µm) fraction between *in situ* soil, runoff sediment, and WDC. Mineral quantities averaged over all treatments for first replication. Recovered mineral quantities normalized to 100%. Numbers in parentheses are standard deviations of mean.

	0 - 0.2 µm				0.2 - 2 µm			
	Kao	HIV	Qtz	Fe_d	Kao	HIV	Qtz	Fe_d
	%							
Soil	49.1(3.5)	42.2(3.1)	0.0(0.0)	8.7(0.4)	37.8(2.6)	43.0(3.9)	13.0(6.2)	6.2(0.6)
Sediment	44.5(1.9)	45.0(2.0)	0.0(0.0)	10.5(1.0)	34.7(1.6)	44.6(2.5)	12.3(1.0)	8.4(1.5)
WDC	44.9(1.8)	46.1(2.5)	0.0(0.0)	9.0(1.0)	31.9(4.4)	45.3(1.2)	15.6(3.9)	7.2(0.7)

† Kao=kaolinite, HIV= hydroxy-interlayered vermiculite, Qtz=quartz, Fe_d = dithionite extractable Fe.

(NTCP), which suggests the mechanical disruption induced by deep tillage overwhelms surface soil WDC effects on infiltration. Corollary relationships observed in a study of Southeastern Coastal Plain soils (Shaw *et al.*, in review) between SOM, water stable aggregates, and infiltration were not evident in these soils. Future work should evaluate the effects of liming and other amendment applications for stabilizing organic matter and refining reduced tillage systems in this region.

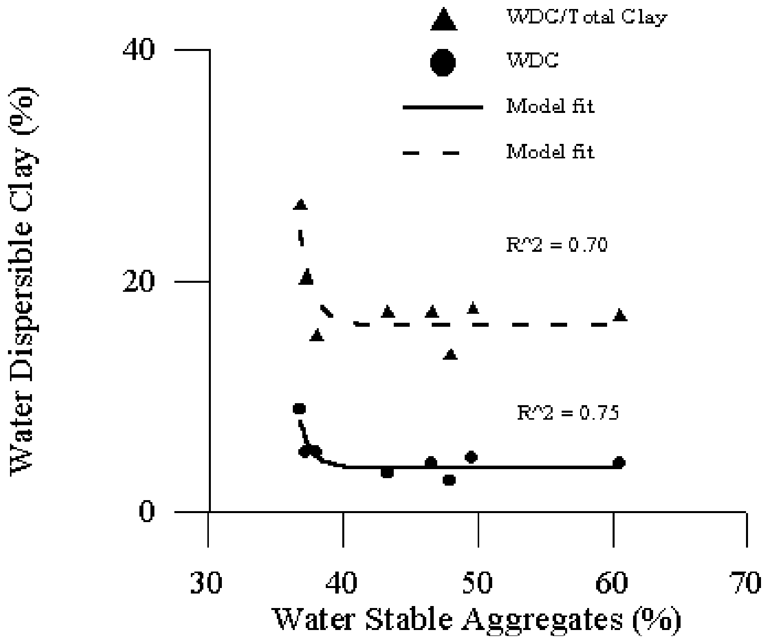

Fig. 2. The relationship between water stable aggregates and water dispersible clay for the first and third replications.

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QUANTIFYING RESIDUE COVERAGE VIA SATELLITE REMOTE SENSING PLATFORMS

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ABSTRACT

Arable lands in conservation tillage may serve as an appreciable sink for soil organic carbon (C) and impact global C pools. Throughout the Southeastern U.S., reduced tillage systems using high residue cover crops are increasingly common. Current methods of estimating residue cover are time and labor intensive, however, remote sensing (RS) may prove a more expedient method of determining residue cover as it relates to soil quality, C dynamics and near-surface soil characteristics. The objective of this study was to use Ikonos satellite imagery to evaluate *in situ* **crop residue. In April of 2001, residue plots (15 m x 15 m) were established at the Wiregrass (Coastal Plain) and Sand Mountain (Appalachian Plateau) Experiment Stations in AL. Soils consisted of fine-loamy, kaolinitic, thermic Plinthic Kandiudults at Wiregrass and fine-loamy, siliceous, thermic Typic Hapludults at Sand Mountain. Residue treatments of 0%, 10%, 20%, 50%, and 80% wheat (*Triticum aestivum* L.) were replicated 3 times at each site. Soil moisture, straw moisture, and residue decomposition were monitored, and digital photos were collected during periods of data acquisition. Treatment differences were observed at the Sand Mountain site using a combination of near infrared (NIR) and red spectra. Results indicate reliable estimates of residue cover using Ikonos satellite data were significantly affected by soil type, soil moisture and residue decomposition.**

KEYWORDS

Ikonos, wheat, visible, near infrared, conservation tillage

INTRODUCTION

Managing crop residue enhances soil quality primarily through the accumulation of soil organic C (SOC). Keeping in mind more than a third of United States' agricultural lands have been classified as highly erodible, residue management can effectively decrease erosion (USDA, 1991; McMurtrey *et al*., 1993). Residue cover improves infiltration and soil aggregation t,hus reducing off-site transport of nutrients and pesticides (Lal, 1989; USDA, 1995).

Beyond improvements to soil quality, arable lands may be an appreciable C sink and key component in the reduction of CO_2 emissions. Soil C reserves store nearly twice the C in vegetation and 1.5 times the amount of atmospheric C (Rice, 2000). The Intergovernmental Panel on Climate Change (1995) estimates 20% of greenhouse gas emissions come from arable lands (Lal, 1997). Consequently, small changes in SOC reserves may impact the global C budget. Increased levels of SOC associated with conservation tillage systems have been shown to range from as much as 0.5 to 1.0% over a ten-year period (Rice, 2000). However, very small changes can be difficult to detect and vary significantly over short distances.

Residue management and conservation tillage practices necessitate an accurate and time-efficient way to monitor changes in residue cover. Traditional line-transect methods are time-and labor-intensive, but RS may prove to be a valuable new tool in residue cover assessments. Recent field studies show RS has had some success in differentiating among soil and residue spectra. Aase and Tanaka (1991) utilized spectrophotometer and infrared thermometer data to quantify varying degrees of residue cover under wet and dry conditions in the Great Plains. Results showed reflected energy could be used to detect differences among 0, 33, and 66% cover, but no differences were seen between 66 and 100% cover. More importantly, under moist conditions, thermal infrared (TIR) data more accurately quantified residue cover. In a separate study, McNairn and Protz (1993) developed a normalized difference index based on corn residue and thematic mapper bands to evaluate *in situ* residue treatments. Despite some success, little field work exists regarding currently available high resolution RS.

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RATIONALE AND OBJECTIVES

The use of conservation tillage systems in conjunction with efforts to reduce greenhouse gas emissions from America's arable lands necessitates streamlining current residue assessment strategies. Newly available high resolution satellite imagery has not been evaluated with regard to *in situ* residue measurements. The goals of this study were to: 1) evaluate the spectral reflectance of crop residue via the Ikonos multispectral sensor and, 2) determine the threshold for detection of near-surface soil characteristics under variable residue cover.

MATERIALS AND METHODS

Two distinct physiographic provinces within Alabama were assessed to determine the utility of satellite imagery to evaluate residue cover. In April of 2001, several residue plots (15 m x 15 m) were established at the Wiregrass and Sand Mountain Experiment Stations of AL. Soils classified as fine-loamy, kaolinitic, thermic Plinthic Kandiudults at Wiregrass and fine-loamy, siliceous, thermic Typic Hapludults at Sand Mountain. Treatments consisted of five residue cover rates (0%, 10%, 20%, 50%, and 80%) and plots were arranged in a completely randomized design. Total mass per treatment was calculated based on the amount of residue necessary for complete ground coverage. Fistula bags were used to monitor residue decomposition. Bags were filled with straw to reflect treatment, staked within each plot, and collected on a bimonthly basis. Straw was dried and ground to pass a 1-mm sieve and total C was measured via a Leco CHN-600 analyzer (Leco Corp., St. Joseph, MI).

Soil samples were collected prior to residue applications to determine near surface soil properties. Soils were air-dried and sieved to pass a 2-mm sieve. Analyses included total C, dithionite-citrate extractable iron (Jackson et al., 1986), and particle size distribution (Kilmer and Alexander, 1949). Total C samples were further ground to pass a 1-mm sieve prior to combustion. During satellite data acquisition, soil surface samples were collected for gravimetric soil moisture content. Digital photographs were taken along with satellite imagery to estimate residue cover. Cover estimates were made using a supervised classification routine in ERDAS Imagine 8.4.

Remotely sensed images were acquired via the Ikonos satellite. Ikonos orbits the earth in a sun synchronous orbit at an altitude of 681 km, with a revisit time of two to three days. The sensor on board Ikonos possesses a multispectral scanner equipped with three visible (VIS) (0.45-0.52, 0.52 – 0.60, 0.63 – 0.69 µm), one NIR (0.76 – 0.90 µm), and one panchromatic (PAN) band (0.45 – 0.90 µm). Spatial resolution ranges from 1 m for the PAN band to 4 m for the VIS and NIR bands. Multispectral satellite data were acquired at the Sand Mountain site on 18 May 2001, 7 July 2001, and 14 February 2002. Acquisitions were made at the Wiregrass location on 13 May 2001 and 19 February 2002. Data was collected on days having less than 10% cloud cover, as close to solar noon as possible. These results reflect analyses based on raw digital values (DV).

Individual bands were stacked by site using ERDAS Imagine 8.4 prior to analysis. Plots were extracted using a subset function and pixels exported in ASCII format. Each plot consisted of 9 pixels. Average and coefficient of variation (% CV) were calculated within each plot. Outliers within plots having greater than 10% CV were excluded.

RESULTS AND DISCUSSION

Soil analysis confirmed uniformity of near surface soil properties by site. Soils contained 0.53% SOC, 0.25% iron, 79.6% sand, 12.6% silt, and 7.9% clay at Wiregrass and 0.57% SOC, 0.21% iron, 55.5% sand, 37.8% silt, and 6.7% clay at Sand Mountain. These values are generally representative of surface horizon properties for soils in these regions.

Literature suggests residue spectral response increases without inflection throughout the VIS and NIR, differing from soil spectral response only in magnitude of reflected energy (Baumgardner *et al*., 1985; Aase and Tanaka, 1991; Daughtry *et al.*, 1995). However, spectral analyses of Ikonos data showed residue spectra peaked at approximately 0.76 µm with inflection points at 0.45, 0.52, and 0.63 µm. Comparing inflection points, the greatest difference in the amount of reflected energy was observed between 0.76 and 0.63 µm, suggesting a band ratio comprised of these wavelengths may be useful in differentiating among residue treatments.

Correlations were evaluated to determine the extent to which a relationship existed between VIS/NIR energy and decomposing residue. Results were highly variable between sites, indicating differences in soil type strongly affect this relationship. Sandy epipedons characteristic of the Wiregrass site were similar in spectra to residue. Thus, spectral response patterns associated with cover rates were not easily separable from bare soil spectral response (Figure 1). By contrast, results from Sand Mountain showed significant correlations with residue were observed in the red and NIR regions of the spectrµm. A NIR to red band ratio analysis produced a significant correlation (r = -0.49, *P* = 0.10) with residue cover in May and a strong relationship (r = -0.65, *P* = 0.01) existed between reflected red energy and cover rate during the February acquisition. Concurrent with February data acquisition, moist surface soils (gravimetric water content = 13.6%) may have contributed to the highly significant correlation observed in the red region of

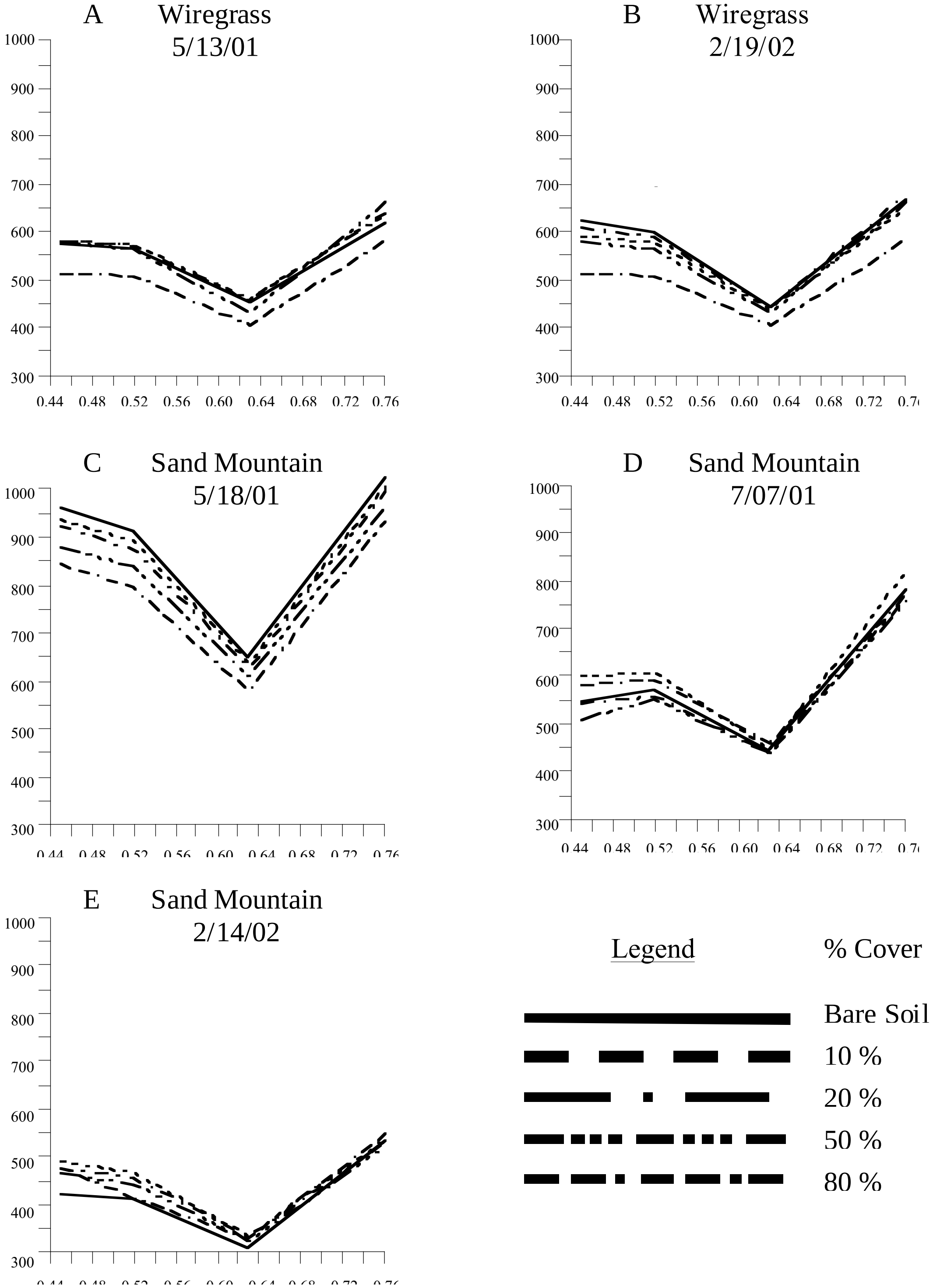

Fig.1. Spectral response curves for each treatment based on percent cover and digital value. (A) Wiregrass study site 5/13/01, (B) Wiregrass study site 2/19/02, (C) Sand Mountain study site 5/18/01, (D) Sand Mountain study site 7/07/01, and (E) Sand Mountain study site 2/14/02.

the spectrum. Results agree with previous studies that report mixed results due to differences in soil type, soil moisture, and residue decomposition. Daughtry *et al.* (1995) was unable to differentiate among residue cover using VIS/NIR data. In their case, Daughtry *et al.* (1995) utilized a variety of crop residues, which had been air-dried and ground, against soils representing 14 suborders. However, an earlier report by McMurtrey (1993) showed red and NIR energy simulated to match thematic mapper bands successfully estimated residue cover. Later reports from Daughtry

Table 1. Regression parameters for digital values versus % residue cover for the Wiregrass and Sand Mountain study sites.

Site Date	Wavelength From	 To	Slope	Intercept	r^2	P = 0.10
	-------- µm	-------				
Sand Mountain						
5/14/05	0.45	0.52	0.216	902	0.01	0.69
	0.52	0.60	0.305	853	0.03	0.58
	0.63	0.69	0.209	614	0.03	0.52
	0.76	0.90	0.104	980	0.01	0.80
	0.45	0.90	0.110	871	0.01	0.76
	0.76	0.63	-0.0004	1.60	0.24	0.07
7/8/05	0.45	0.52	0.226	548	0.02	0.64
	0.52	0.60	0.260	567	0.16	0.47
	0.63	0.69	0.248	437	0.16	0.14
	0.76	0.90	0.052	774	0.00	0.93
	0.45	0.90	-0.009	588	0.00	0.98
	0.76	0.63	-0.0009	1.78	0.03	0.53
2/15/06	0.45	0.52	0.001	465	0.00	0.99
	0.52	0.60	0.007	446	0.00	0.99
	0.63	0.69	0.024	326	0.00	0.93
	0.76	0.90	-0.523	539	0.54	0.00
	0.45	0.90	-0.442	451	0.12	0.23
	0.76	0.63	-0.002	1.67	0.09	0.31
Wirgrass						
5/14/05	0.45	0.52	0.166	593	0.01	0.76
	0.52	0.60	0.010	579	0.00	0.98
	0.63	0.69	-0.045	462	0.01	0.78
	0.76	0.90	0.215	646	0.01	0.68
	0.45	0.90	-0.180	567	0.01	0.69
	0.76	0.63	0.0006	1.40	0.06	0.38
2/20/06	0.45	0.52	0.070	581	0.00	0.91
	0.52	0.60	0.007	567	0.00	0.99
	0.63	0.69	0.013	431	0.00	0.96
	0.76	0.90	0.035	646	0.00	0.95
	0.45	0.90	-0.056	560	0.00	0.92
	0.76	0.63	0.000	1.50	0.00	0.98

(2001) also found NIR and red spectra effectively distinguished among cover rates. As stated earlier, differences in results between data acquisitions may be due to variable decomposition rates of straw. During the decomposition process spectral response patterns necessarily change with changes in straw composition. During tissue chlorophyll loss, spectral response is greatest between 0.4 to 0.8 µm, as residues absorb incoming blue light and reflect green and red. Presence of water at this stage masks absorbance features in the NIR associated with lignin and cellulose features (Elvidge, 1990) As decay progresses, spectral response patterns shift to longer wavelengths due to the increasing percentage of lignin and cellulose present (Elvidge, 1990). Relative comparisons of spectral response curves between data acquisitions generally agree with this observation (Figure 1).

A linear relationship was observed between reflected energy in the NIR and red portions of the light spectrum at the Sand Mountain study site (Table 1). During the May acquisition, a weak relationship ($r^2 = 0.24$ at $p = 0.10$) existed using the NIR to red ratio, and significant treatment differences were limited to bare soil and 20% cover rates (Table 2). February data revealed an $r^2 = 0.54$ at $p = 0.10$ with significant differences among treatments occurring primarily between bare soil and 80% cover. No treatment differences were observed between 10, 20, 50 or 80% cover rates ($p = 0.05$) (Table 2). It appears soil water content during the February acquisition was a key factor in differentiating between bare soil and 80% cover rates.

Based on the spectral response curve for bare soil, estimates were made to determine where soil spectral features attenuate with increasing residue cover. Threshold

Table 2. Least significant differences ($P = 0.05$) observed between residue treatments within a wavelength at Sand Mountain.

	Wavelength (um)		Residue cover, % of area				
Date	From	To	0	10	20	50	80
	----- µm ------		-------------------------------- D.V. ----------------------------				
Sand Mountain							
5/14/05	0.45	0.52	607 A	608 A	568 A	577 A	627 A
	0.52	0.60	587 A	589 A	561 A	569 A	592 A
	0.63	0.69	465 A	467 A	452 A	456 A	464 A
	0.76	0.90	655 A	668 A	619 A	641 A	678 A
	0.45	0.90	577 A	582 A	537 A	540 A	574 A
	0.76 /	0.63	1.405 A	1.427 AB	1.368 B	1.406 AB	1.461 AB
7/8/05	0.45	0.52	575 AB	574 AB	494 C	537 CB	596 A
	0.52	0.60	588 A	581 AB	533 B	571 AB	604 A
	0.63	0.69	448 AB	441 AB	428 B	445 AB	464 A
	0.76	0.90	802 A	782 A	729 A	773 A	797 A
	0.45	0.90	605 A	597 A	556 A	575 A	606 A
	0.76 /	0.63	1.793 A	1.775 A	1.704 A	1.738 A	1.718 A
2/15/06	0.45	0.52	465 A	438 A	326 A	533 A	439 A
	0.52	0.60	422 A	419 A	431 A	448 A	441 A
	0.63	0.69	313 A	333 A	222 A	326 A	325 A
	0.76	0.90	546 A	549 B	532 AB	524 AB	513 B
	0.45	0.90	446 A	442 A	442 A	436 A	428 A
	0.76 /	0.63	1.775 A	1.651 A	1.596 A	1.607 A	1.581 A

residue cover rate at which soil spectral features were no longer detectable occurred between 20 and 50% coverage. Furthermore, soil spectral response consistently declined with increasing cover at both locations and all data acquisitions (Figure 1). Differences in soil and residue spectral response patterns are slight, and differ primarily in the magnitude of reflected energy.

CONCLUSION

Multispectral Ikonos imagery did not reliably evaluate% residue cover at either site. Perhaps results were limited by spatial resolution, since studies using ATLAS airborne imagery under the same conditions indicated RS could differentiate among residue treatments (Sullivan *et al.*, 2002). Although differences were observed throughout the spectrum, differences in residue cover were most consistent using Atlas TIR bands. Furthermore, Atlas data were adjusted for atmospheric conditions whereas Ikonos results were limited to raw digital values.

Ikonos data was able to differentiate among residue cover rates at the Sand Mountain site alone, suggesting soil type and other edaphic factors may be an overriding factor in the ability of RS to detect residue cover. Data indicate freshly applied residue can best be observed using a NIR to red ratio, but it appears the red region of the light spectrum was more sensitive to decomposing straw under wet conditions associated with the February acquisition. In this case, treatment differences were greatest between bare soil and 80% cover rates.

As residue cover increases, the ability to detect soil spectral response patterns greatly diminishes. Losing soil spectral response may be an important consideration with respect to soil survey and natural resource inventory applications of remotely sensed data. Threshold residue cover at which soil spectral response weakened occurred between 20% and 50% residue cover. Data show this relationship held as residue decomposed over the course of one year.

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USING THE CENTURY MODEL TO SIMULATE C DYNAMICS IN AN INTENSIVELY MANAGED ALABAMA ULTISOL

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ABSTRACT

Increasing soil organic carbon (SOC) storage is essential for improving soil quality and mitigating greenhouse gas emissions. Studies have shown that cultivated soils in the Southeastern USA have substantial potential for sequestering SOC. The use of validated models to simulate soil management effects on the SOC pool is critical for growers, researchers, and policy makers. We evaluated the ability of the CENTURY model to simulate SOC dynamics in a tillage and crop rotation experiment (ca. 1988) located in Milstead, central AL. Soils consisted of coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults. Tillage treatments included surface tillage (no tillage and conventional tillage) and subsurface tillage (one-time subsoiling on narrow centers, annual in-row subsoiling, and no subsoiling) cropped to a corn (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) rotation with a winter crimson clover (*Trifolium incarnatum* L.) cover crop from 1988 to 1996. From 1997 to 2001, plots were planted to three different crop rotations that basically consisted of either a corn-cotton (*Gossypium hirsutum* L.) rotation or continuous cotton with one or two biomass producing cover crops each year. Significant differences (P = 0.10) in SOC existed between many of the tillage-rotation treatments. The average SOC for the conventional tillage plots was 6.6 tons C acre^{-1} (14.8 Mg C ha^{-1}), which CENTURY overestimated by 57%. The average SOC for the no surface tillage plots was 8.2 tons C acre^{-1} (18.4 Mg C ha^{-1}), which CENTURY overestimated by 32%. CENTURY overestimated SOC for most treatments, did not simulate the magnitude of the differences between the treatments, but did simulate the general trend in SOC dynamics within certain rotations. The aggregate of data suggests changes in SOC occur more rapidly than CENTURY simulates for Southeastern USA cropping systems.

KEYWORDS

CENTURY, soil organic carbon, conservation tillage, Ultisols.

INTRODUCTION

Soil organic carbon (SOC) is critical for assessing soil quality. Studies have shown that in most environments, SOC improves soil aggregation and structure, increases infiltration, prevents surface crusting, reduces erosion, and improves crop productivity (Reeves, 1997). Soil organic matter can also serve as a source or a sink for atmospheric carbon, helping to mitigate greenhouse gas emissions.

Modeling can be used to estimate SOC storage in soils under different agricultural management practices. CENTURY is an empirical model that was originally developed to model long-term C, N, P, and S dynamics in grassland systems (Parton *et al.*, 1987; Smith *et al.*, 1997). CENTURY has been has been modified to include forest, savannah, and agricultural systems. Major input variables include monthly average maximum and minimum air temperature, monthly precipitation, lignin content of plant material, plant N, P, and S content, soil texture, atmospheric and soil N inputs, and initial soil C, N, P, and S pools (Parton *et al.*, 1992). Soil organic matter is divided into three pools: active, slow, and passive, and litter is split into two pools: metabolic and structural, based on lignin content (Smith *et al.*, 1997). Theoretically, the active pool is microbial and labile SOC that turns over in < 5 years, the slow pool is relatively more resistant and has a turnover period of 20 to 40 years, and the passive pool is relatively stable (Parton *et al.*, 1987).

CENTURY has been successfully used to model SOC dynamics in long-term experiments in several climates (Smith *et al.*, 1997). Some researchers have found CENTURY to be more accurate for croplands and grasslands as compared to forested systems (Kelly *et al.*, 1997). Parton and Rasmussen (1994) found that observed versus CENTURY simulated SOC levels were similar ($R^2 = 0.77$) for a long-term wheat (*Triticum aestivum* L.)-fallow-residue management experiment in Oregon. These authors con-

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cluded the model could predict SOC change within 5% for 57 % of the time. Gisjman *et al.* (1996) found CENTURY did not simulate C, N, and P well in grassland savannahs comprised of Colombian Oxisols. These authors provided suggestions for improving the model for these tropical regions. There has been little validation of this model in cropping systems and soils of the Southeastern USA.

Our goal was to validate the CENTURY model for Southeastern crop management systems. We used a long-term (ca. 1988) experiment in central Alabama with a diverse tillage and crop rotation history to evaluate the model.

METHODS AND MATERIALS

FIELD EXPERIMENT

We used CENTURY to model SOC in an experiment established in 1988 as described by Reeves *et al.* (1992), Lee *et al.* (1996), and Reeves and Delaney (2002). The experiment was located at the E.V. Smith Research Center of the Alabama Experiment Station, near Shorter, AL. Soils were described, sampled, and characterized according to standard techniques (Soil Survey Investigations Staff, 1996), and were composed mostly of Compass sandy loam (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) (Table 1).

The experiment was established to evaluate tillage, equipment trafficking, and crop rotation effects on crop yields and soil quality. The trafficking component was conducted from 1988 to 1996, however, Lee *et al.* (1994), found trafficking had no significant effect on SOC, thus, traffic effects were not included in our simulations. Tillage treatments consisted of a surface and a subsurface tillage component. The surface tillage treatments were conventional tillage (disked, chisel plowed, disked, and field cultivated every spring) and no surface tillage. The subsurface tillage treatments included a one-time complete disruption that consisted of subsoiling on 10-inch centers, annual in-row subsoiling, and no subsurface tillage. From 1988 to 1996 the plots were planted in a corn -soybean rotation with a winter crimson clover cover crop.

From 1997–2001, the plots were planted in various cropping rotations (Table 2). Subsurface tillage was modified so that all treatments were non-inversion deep-tilled with a Paratill® (AgEquipment Group, Lockney, TX 79241) or subsoiler annually; surface tillage regimes remained the same as 1988-1996. Rotation 1 consisted of sunn hemp (*Crotalaria juncea* L.)-wheat (*Triticum aestivum* L.)- cotton (*Gossypium hirsutum* L.)-lupin (*Lupinus albus* L.) and crimson clover mix-corn rotation. Rotation 2 consisted of a black oat (*Avena strigosa* Screb.) and rye (*Secale cereale* L.) mix-cotton-lupin and clover mix-corn rotation. Rotation 3 consisted of a continuous cotton-black oat and rye mix rotation. These rotations were placed in two year cycles and were planted in two phases in order to have each phase of the rotation present each year. Since 1997, a portion of the cotton was planted as ultra narrow row (UNR, 8- inch drill). We did not account for this in the simulations. Further discussion of treatments can be found in Reeves and Delaney (2002).

Table 1. Soil characterization data for a sampled pedon for the E.V. Smith sites. CEC is the cation exchange capacity and ECEC is the effective cation exchange capacity.

Hor	Depth	sand	silt	clay	Ca	Mg	K	Na	Al	CEC	ECEC
	cm	pct < 2 mm			<-----------------------$\text{cmol}_c\ \text{kg}^{-1}$						----------------------->
		coarse-loamy, siliceous, subactive, thermic Plinthic Paleudult									
Ap1	0-7	82.8	14.1	3.1	0.60	0.44	0.08	0.00	0.12	2.39	1.25
Ap2	7-30	82.1	16.4	1.4	0.86	0.42	0.04	0.00	0.12	1.78	1.45
BE	30-44	72.5	18.5	9.0	0.92	0.82	0.12	0.04	0.11	2.81	2.02
Bt	44-62	69.4	17.4	13.2	1.26	1.40	0.19	0.12	0.19	3.17	3.16
Btv	62-82	74.6	16.5	8.9	0.63	0.57	0.10	0.06	0.26	2.30	1.63
B/E	82-94	75.4	17.5	7.2	0.21	0.25	0.04	0.01	1.25	1.45	1.76
Btvx1	94-114	74.0	16.4	9.7	0.19	0.18	0.06	0.02	1.94	2.02	2.39
Btvx2	114-150	72.9	14.2	12.9	0.20	0.17	0.06	0.00	2.47	2.88	2.91

Table 2. The three crop rotations in two phases (1997-2001) for a Compass loamy sand in east-central, Alabama. The years listed are the first three years of the rotation; rotations were repeated through 2001. Planting and harvesting dates are approximate. UNRC is ultra narrow row cotton.

		Rotation					
		1		2		3	
Year	Month	a	b	a	b	a	b
1997	Aug.	Sunn Hemp					
	Sept.						
	Oct.			Oat-Rye	Lupin-Clover	Oat-Rye	Oat-Rye
	Nov.		Lupin-Clover				
	Dec.	Wheat					
1998	Jan.						
	Feb.						
	March						
	April						
	May		Corn	Cotton	Corn	Cotton	
	June						
	July	Cotton (UNRC)					Cotton (UNRC)
	Aug.						
	Sept.		Sunn Hemp		Oat-Rye		
	Oct.						
	Nov.	Lupin-Clover		Lupin-Clover		Oat-Rye	Oat-Rye
	Dec.		Wheat				
1999	Jan.						
	Feb.						
	March						
	April						
	May	Corn		Corn	Cotton	Cotton	
	June						
	July		Cotton (UNRC)				Cotton (UNRC)
	Aug.						
	Sept.						
	Oct.						

CENTURY MODELING

The values for the soil parameters for the CENTURY model (texture and bulk density by horizon) were obtained from soil characterization data (Table 1). Weather data were obtained from the National Climactic Data Center for Milstead, AL (NOAA, 2002). The SOC pools were initialized [SOC=7.1 tons C acre^{-1} (16.0 Mg C ha^{-1})] using data from a neighboring conventional tillage experiment and the SOC was partitioned according to the CENTURY 4 parameterization workbook (Pulliam, 1996).

Parameterization files are used to provide input values for the model. These files assign quantitative values to processes such as harvesting or cultivating for running the simulations. CENTURY possesses readily accessible parameter files (ASCII text files) by which input values can be modified. The sunn hemp and the lupin-clover mix were not originally in the model, therefore, parameterization files were created for these cover crops. We modified the biomass production levels and C:N ratio for sunn hemp according to Mansoer *et al.* (1997) and lupin-clover mix according to Noffsinger *et al.* (1998) and Odhiambo and Bomke (2001). We used the oat parameters to simulate the oat-rye mixture and the grass-clover pasture parameters to simulate clover. We also modified tillage operation parameter files to more adequately represent tillage operations. Disking operations were simulated by modifying the cultivator parameters so that more surface litter was incorporated. The parameters for plowing were used to simulate chisel plowing.

Table 3. Measured SOC and CENTURY simulated SOC for a Compass loamy sand in east-central, Alabama. NT is no surface tillage, CT is conventional tillage, NS is no subsoiling, 1XCD is one time complete disruption, AS is annual in-row subsoiling. Rotations are defined in Table 2.

Surface tillage (1988-2001)	Subsurface tillage (1988-1996)	Rotation (1996-2001)	Measured SOC		CENTURY output SOC	
			tons C A^{-1}	Mg C ha^{-1}	tons C A^{-1}	Mg C ha^{-1}
NT	NS	1a	8.1	18.1	11.0	24.7
NT	NS	1b	8.4	18.8	11.5	25.8
NT	NS	2a	7.6	17.0	11.3	25.3
NT	1XCD	1a	7.8	17.6	11.0	24.6
NT	1XCD	3a	8.3	18.6	10.0	22.4
NT	1XCD	3b	9.5	21.3	10.0	22.4
NT	AS	2a	8.3	18.7	11.3	25.3
NT	AS	2b	6.3	14.2	11.3	25.3
NT	AS	3a	9.5	21.2	9.9	22.3
CT	NS	1a	6.3	14.2	10.6	23.8
CT	NS	1b	6.3	14.2	11.2	25.0
CT	NS	2a	6.3	14.1	11.0	24.6
CT	1XCD	1a	6.0	13.4	10.6	23.8
CT	1XCD	3a	6.9	15.5	9.6	21.6
CT	1XCD	3b	6.9	15.3	9.6	21.6
CT	AS	2a	6.3	14.1	9.4	21.1
CT	AS	2b	6.3	14.1	11.3	25.3
CT	AS	3a	8.1	18.1	9.9	22.3
$LSD_{0.10}$			1.4	3.1		

MODEL VALIDATION

Soil organic carbon was composite sampled in each plot for the 0-5 and 5-20 cm depths. Samples were air-dried, crushed, and carbon was measured using dry combustion (Yeomans and Bremmer, 1991). Bulk density was measured at the 0-5 and 5-20 cm depths using the method of Blake and Hartge (1986). The simulations were run from 1988 to 2001, and output was compared to measured SOC values.

RESULTS AND DISCUSSION

Significant differences (*P* = 0.10) in SOC concentrations existed between many of the treatments (Table 3). Similar to other findings, when averaged overall, the no tillage systems had higher SOC levels (8.2 tons C acre^{-1}) than the conventional tillage systems (6.6 tons C acre^{-1}) (Table 3). Further discussion of treatment effects on the SOC pools for this experiment can be found in Reeves and Delaney (2002).

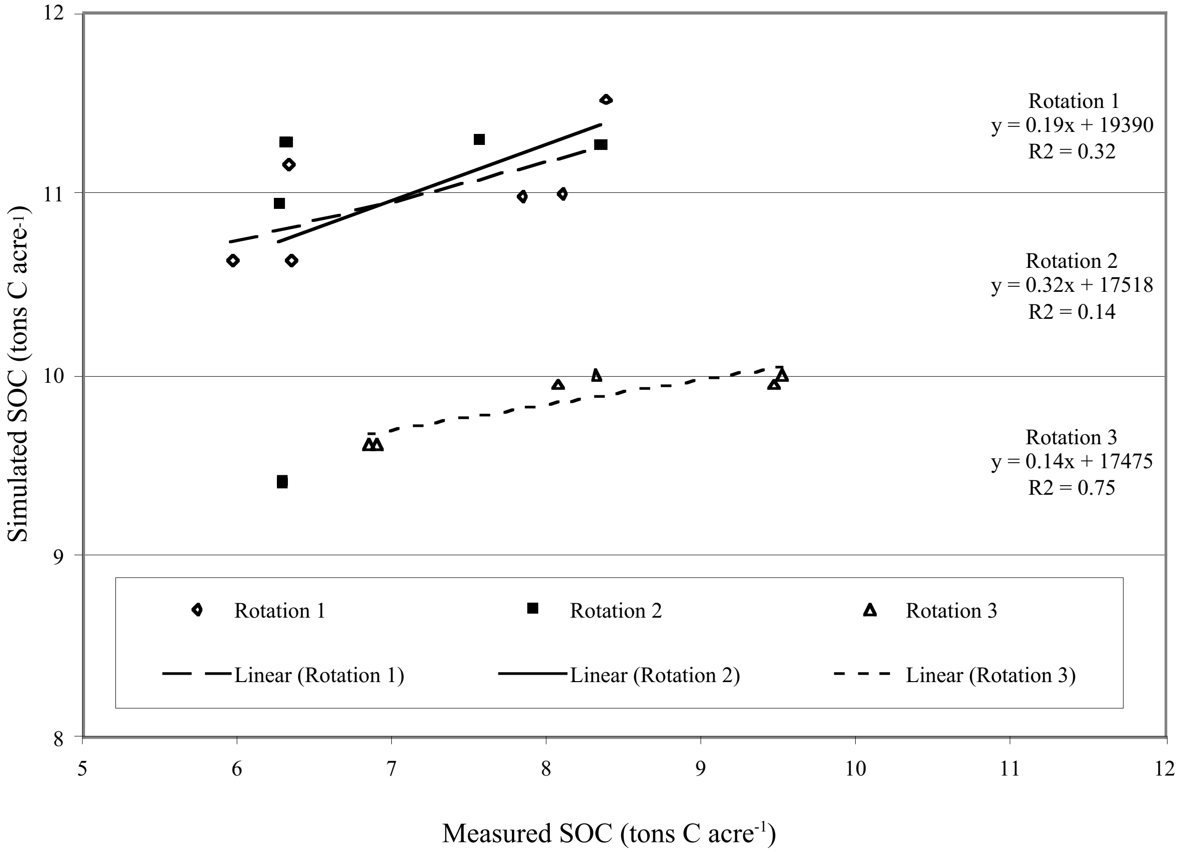

Fig. 1. Measured versus CENTURY simulated SOC by Rotation. Rotations are given in Table 2.

The average CENTURY output for the conventional tillage plots was 10.4 tons C acre^{-1} (23.2 Mg C ha^{-1}), which is 57% higher than the average of the measured values (6.6 tons C acre^{-1}). The average CENTURY output for the no surface tillage plots was 10.8 tons C acre^{-1} (24.2 Mg C ha^{-1}), 32% above the average of the measured values (8.2 tons C acre^{-1}). In addition, when measured SOC values were compared to simulated SOC data, a fairly high Root Mean Square Error (RMSE) was observed (3.5 tons C acre^{-1}). Our findings indicate that CENTURY overestimated SOC for most treatments.

Differences in CENTURY's ability to simulate SOC trends as affected by tillage within each rotation were evident (Figure 1). CENTURY simulated trends in tillage effects most accurately within rotation 3 ($R^2 = 0.75$), which was the most simple rotation consisting only of a cotton-oat and rye cover crop rotation. In addition, CENTURY more accurately depicted SOC quantities within rotation 3 [RMSE=1.9 tons C acre^{-1} for rotation 3 versus 3.9 and 4.2 tons C acre^{-1} for rotation 1 and 2 (see table 2 for rotations), respectively]. These findings suggest that as cropping system becomes more diverse and/or intensive, the accuracy of CENTURY output decreases.

Century estimated SOC to within the LSD (1.4 tons C acre^{-1}) for treatments with the highest SOC. For the no surface tillage treatment in rotation 3a, measured SOC was 9.5 tons C acre^{-1} (21.2 Mg C ha^{-1}), which CENTURY estimated to be 9.9 tons C acre^{-1} (22.3 Mg C ha^{-1}). Similarly, for the no surface tillage within rotation 3b, SOC was 9.5 tons C acre^{-1} (21.3 Mg C ha^{-1}), which CENTURY estimated as 10.0 tons C acre^{-1} (22.4 Mg C ha^{-1}). On the treatment with the lowest SOC (conventional tillage within rotation 1a), CENTURY overestimated the SOC by 78%.

CONCLUSIONS

CENTURY overestimated SOC in most of the treatments for this tillage/rotation experiment. The model simulated most accurately the treatments with the highest SOC levels (no surface tillage), but did not do well with the SOC levels found in conventional tillage plots. CENTURY output showed as much difference between the crop rotations as between tillage treatments; however, measured data suggested significant differences in SOC between tillage treatments. Despite these errors, CENTURY can accurately model SOC trends within certain cropping systems.

Overall, we feel the model could be improved by: 1) providing a chronological output of agronomic operations based on user input and, 2) adding additional crop (in particular, cover crops) and tillage parameter sets necessary to simulate many Southeastern management systems.

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LAND USE BIODIVERSITY INDEX AS A SOIL QUALITY INDICATOR

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ABSTRACT

Decreases in land cover diversity can lead to decreases in soil quality. This study proposes using the National Resources Inventory (NRI) to develop a biodiversity index as a biological indicator of soil quality. Index values for Major Land Resource Areas in the southeastern United States were calculated using land-use based upon whether the Primary Sampling Unit was either 1) all cropland, 2) multi-cropped, 3) cropland with at least one non-cropland use, or 4) cropland having some vegetative diversity (cover crop, buffer strip, etc.). Forestland and range/pasture land-uses provided high biodiversity index values for most of the southeastern United States. Cropland enrolled into the Conservation Reserve Program was attributed with the increase from 1982 – 1997 of those acres with a score of 4. Irrigated cropland tended to have lower index values than non-irrigated cropland. Corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Max.] seed yields tended to decrease as index values increased. Using the NRI did show promise for developing a biodiversity index.

KEYWORDS

Southeastern USA, soil resources, row crops, soil quality

INTRODUCTION

Approximately 20,000 plant species worldwide are used by humans for food and medicines (Pimental *et al*., 1997). However, market conditions have reduced the number of major crops to less than 15. Currently, rice, corn, and wheat comprise 60% of the world's food supply (Wilson, 1988). It is this monoculture production style or lack of land cover diversity that has led to nutrient leaching loss, invasion by weedy species, and high incidences of diseases and pests – all of which decrease soil quality.

Conserving land cover diversity helps in organic waste disposal, N_2-fixation, biological control of pests, plant pollination, and agriculture sustainability. Increases in human population and activities are decreasing natural habitats that many species require for their existence. Some threats to United States agriculture are the results of the loss of pollinators and natural enemies of pests. Effective policies and conservation programs must be implemented to protect land cover diversity for a safe and protective environment for future generations.

Soil quality is comprised of three properties: physical, chemical, and biological. Indicators are needed that relate to soil functions. Although it is impossible to assess changes in all soil properties, tracking changes in a select set could serve as indicators of changes in soil quality.

Cover crops play a major role in conservation technology. Cover crops reduce soil erosion, improve soil aggregation, recycle nutrients, and suppress weed growth. Cover crops also reduce incidence of insects and pathogens by increasing biodiversity. This study proposes a biodiversity index as part of the biological aspect of soil quality at the field level and higher.

METHODOLOGY

The NRI offers a reliable method for determining biodiversity. It is a statistically designed survey to track trends in land cover use with over 300,000 of Primary Sampling Units (PSUs) (Nusser and Goebel, 1997). Land cover use is collected at several points within each PSU. Using the NRI, a diversity index for the field level up to a broader scale (state, regional, etc.), was developed.

Data from the NRI (1982, 1987, 1992, and 1997 inventory years) were used to estimate biodiversity at the Major Land Resource Area (MLRA) scale. Scoring was as follows:

1=all points within a PSU on cropland with the same crop (cultivated and non-cultivated)

2=all points within a PSU on cropland (cultivated and non-cultivated) with at least one different crop

3=all points within a PSU on cropland (cultivated and non-cultivated) with at least one point with a non-cropland land cover/use (range, pasture, or forest)

4=all points within a PSU on cropland (cultivated and non-cultivated) with at least one point having veg-

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etation diversity [Conservation Reserve Program (CRP), cover crop, buffer strip, etc.].

Scores for each PSU were weighted according to acres at each point. The sum of all PSUs within each MLRA was then divided by the number of PSUs to determine an index value.

RESULTS

The NRCS has divided the 13 southeastern states into two regions. The South Central region includes Arkansas, Louisiana, Oklahoma, and Texas with the Southeast region covering the remaining nine states. For this study, areas outside these two regions but still within a MLRA were included in the analyses.

Range-, crop-, and forestland are the three major land cover types in the southeastern United States (USDA-NRCS, 2000). In 1997, total acres (million) were 163.4, 150.9, and 148.6 for range, crop, and forest, respectively. Total acreage decreased for all three land-uses from 1982 to 1997. Acres (16.6 million) enrolled in the CRP were a major factor for the decrease of cropland acreage.

Forestland and rangeland/pasture are the dominant land-uses in the Southeastern and South Central States, respectively (USDA-NRCS, 2000). Therefore, these sections had most of their respective MLRAs with index values greater than 2.75 during 1982 – 1997 (Table 1).

The total number of acres with a score of 3 or less declined from 1982 to 1997 while the number of acres with a score of 4 increased (Table 2). This increase was attributed to the CRP and USDA's efforts to promote buffer strips.

As might be expected, irrigation tends to increase the number of acres of a particular crop grown in an area. This increase, in turn, decreases land cover diversity. Irrigated cropland tended to have low diversity index scores (data not shown). Soil loss on irrigated, non-irrigated, and total cropland is shown in Table 3. As diversity index values increased from 1.45 to 2.50, soil loss generally decreased. Erosion on irrigated cropland was generally less than for non-irrigated cropland.

Corn and soybean data from the Census of Agriculture were analyzed to estimate influence of diversity on seed yield at the national level. Generally, yields decreased as diversity increased (Table 4). These decreases were attributed to fewer acres under irrigation.

CONCLUSIONS

This method suggesting a land cover diversity index did show a relationship to soil quality. Cropland with little land cover diversity (monoculture or all cropland with no conservation practice or vegetative diversity) tended to have higher soil loss. This was especially true for irrigated cropland.

Additional studies with this index will include evaluating soil cover factors (C-factor in the Universal Soil Loss Equation and V-factor in the Average Annual Wind Erosion Equation) recorded in the NRI. Bloodworth *et al.* (unpublished data) determined critical soil cover factors for sequestering soil carbon. Therefore, this index could be used to identify areas, which are increasing biodiversity and sequestering soil carbon.

Table 1. Total acres by diversity index value ranges, 1982-1997. The diversity index value is explained in the methodology section.

Diversity Index value	Year 1982	1987	1992	1997
	----------------------------	acres	----------------------------	
1.45 - 2.00	16,136,600	8,914,900	0	288,400
2.00 - 2.25	301,300	6,519,600	14,296,300	13,641,700
2.25 - 2.50	8,002,300	7,298,200	6,813,800	6,459,500
2.50 - 2.75	7,069,500	3,036,600	1,449,000	1,347,600
2.75 - 3.00	81,072,100	82,136,200	80,712,400	77,359,900

Table 2. Total acres by biodiversity index value, 1982-1997. The diversity index value is explained in the methodology section.

Year	Diversity index value 1	2	3	4
	----------------------------	acres	----------------------------	
1982	12,297,800	5,432,900	94,851,100	0
1987	10,564,500	5,495,300	91,830,800	14,900
1992	9,020,900	5,162,600	89,063,500	24,500
1997	9,888,900	4,729,800	91,277,400	83,800

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Table 3. Soil loss for irrigated and non-irrigated cropland, by land cover diversity score, 1982-1997. The diversity index value is explained in the methodology section.

Index	Irrigated	Non-irrigated	Total
	-------- tons acre^{-1} year^{-1} -------		
1982			
1.45 - 2.00	11.4	18.0	15.4
2.00 - 2.25	3.9	6.2	6.1
2.25 - 2.50	4.9	14.2	10.3
2.50 - 2.75	13.9	17.2	16.3
2.75 - 3.00	5.6	8.1	7.8
1987			
1.45 - 2.00	†	†	†
2.00 - 2.25	19.1	29.8	25.1
2.25 - 2.50	6.2	12.8	10.2
2.50 - 2.75	2.6	3.0	3.2
2.75 - 3.00	8.7	10.8	10.5
1992			
1.45 - 2.00	†	†	†
2.00 - 2.25	8.0	11.0	9.7
2.25 - 2.50	3.6	9.1	6.5
2.50 - 2.75	2.1	25.5	2.2
2.75 - 3.00	7.9	8.2	8.5
1997			
1.45 - 2.00	5.1	3.8	3.8
2.00 - 2.25	11.3	13.3	12.3
2.25 - 2.50	3.4	6.4	5.0
2.50 - 2.75	2.3	2.0	2.1
2.75 - 3.00	6.5	7.2	7.2

† Soil loss not estimated

Table 4. Corn and soybean seed yield as influenced by land cover/use diversity, 1982-1997. The diversity index value is explained in the methodology section.

Index	Corn	Soybean
	--------- bu acre^{-1} ---------	
1982		
1.45 - 2.17	100.2	29.3
2.17 - 2.50	101.6	30.8
2.50 - 2.66	87.5	23.5
2.66 - 2.85	88.8	28
2.85 - 3.00	83.3	24.2
1987		
1.45 - 2.17	115.1	33.8
2.17 - 2.50	112.0	31.2
2.50 - 2.66	99.0	28.2
2.66 - 2.85	100.2	30.5
2.85 - 3.00	89.1	27.5
1992		
1.45 - 2.17	114.4	32.7
2.17 - 2.50	118.6	32.7
2.50 - 2.66	87.9	28.8
2.66 - 2.85	104.2	30.4
2.85 - 3.00	91.5	27.4
1997		
1.45 - 2.17	112.5	35.2
2.17 - 2.50	117.0	35.6
2.50 - 2.66	106.9	34.3
2.66 - 2.85	115.7	33.2
2.85 - 3.00	105.9	28.2

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EFFECTS OF TILLAGE SYSTEMS ON SOIL MICROBIAL COMMUNITY STRUCTURE UNDER A CONTINUOUS COTTON CROPPING SYSTEM

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ABSTRACT

Soil management practices affect soil microbial communities, which in turn influence soil ecosystem processes. In this study, the effects of conventional and no-tillage practices on soil microbial communities were examined under continuous cotton (*Gossypium hirsutum* L.) systems on a Decatur silt loam soil. Soil samples were taken in February, May, and October of 2000 at depths of 0 to 3, 3 to 6, 6 to 12, and 12 to 24 cm. The no-till treatment had significantly higher soil organic carbon and microbial biomass carbon contents in the surface layer than the conventional till treatment. Microbial community structure, as indicated by the phospholipid fatty acid (PLFA) profile, was analyzed using principal components analysis; analysis of variance (ANOVA) on the first two principal components (PCs) was performed to assess the effects of tillage and sampling time. PLFA profiles clearly shifted over time and along soil depths. ANOVA on PC 1 revealed that both month x depth and tillage x depth interactions were significant. The response of PC 1 was different for conventional till and no-till treatments, as well as for the late season and the two early season samples. The influential fatty acids to the first two PCs were 10Me16:0, *i*15:0, and *cy*19:0 which are signature bacterial PLFAs, suggesting that the observed differences may result from the shift of bacterial populations. These results indicate that microbial communities associated with conventional tillage and no-tillage continuous cotton systems were dissimilar and the tillage effect varied by soil depths and over time. The use of culture-independent methods, such as PLFA profile analysis, allows us to better characterize the changes of the microbial community under different management systems and may provide insights into how conservation tillage improves soil quality and sustainability.

KEYWORDS

Phospholipid fatty acid (PLFA) profile, soil carbon, microbial biomass carbon

INTRODUCTION

Soil management practices affect soil microbial communities, which mediate many processes essential to the productivity and sustainability of soil. Until very recently, conventional tillage has been the predominant method of land preparation in the southeastern US, where continuous cotton has been grown for decades on soils with low inherent fertility, susceptible to aggregate disruption, crusting formation, and erosion (Miller and Radcliffe, 1992; Reeves, 1994). Lately, more and more farmers have adopted conservation tillage systems. It is well-known that no-till practices increase soil organic matter content in the surface layer, improve soil aggregation, and preserve the soil resources better than conventional till practices. Changes in soil physical and chemical properties associated with different tillage practices have been studied extensively (Blevins and Frye, 1993; Reeves, 1997); however, characterization of the soil microbial community lags behind.

There is increasing interest in the management of the biological component of soil to improve soil quality and sustainability. Amounts or types of organic inputs to soils, as well as the environmental conditions, can influence microbial biomass, population function, and community composition. In this study, we used the phospholipid fatty acid profile to characterize microbial communities developed under conventional till and no-till treatments in a kaolinitic soil cropped to cotton. The objective of the study was to determine the effects of conventional and no-tillage practices on soil microbial community structure, as indicated by phospholipid fatty acid (PLFA) profiles under continuous cotton systems.

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MATERIALS AND METHODS

Field experiment and soil sampling

Soil samples were collected from a long-term cotton tillage and rotation experiment located at the Tennessee Valley Research and Extension Center, Belle Mina, Alabama, USA. The experiment is a randomized complete block design with four blocks and nine treatments. The soil type is a Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudults). The soil was sampled from two winter fallow continuous cotton (*Gossypium hirsutum* L.) treatments subjected to conventional tillage and no-tillage. Conventionally tilled plots were established in 1979 and no-till plots in 1988 from previously conventionally tilled plots. Conventional tillage involved chisel plowing in the fall and field cultivation in the spring prior to planting. No-till cotton was planted into the cotton stubble of the previous year. Fertilizers, insecticides, herbicides, and defoliants were applied according to Auburn University recommendations.

The soil was sampled in February, May, and October of 2000. Ten 3.9-cm diameter soil cores (0-24 cm deep) were collected randomly from 1000 ft^2 (50’ x 20’) individual plots. The soil cores were divided into four depths (0-3, 3-6, 6-12, and 12-24 cm), composited by depth, and passed through a 4-mm sieve. After a thorough mixing, subsamples were taken for water content, microbial biomass determination by the chloroform fumigation incubation method, and extraction of lipids. Field moist soil samples were stored at 4°C for no more than 2 weeks before microbial biomass determination and no more than 4 weeks before lipid extraction.

Laboratory Analysis

Soil samples taken in February were air-dried and used for total carbon determination using a C/N analyzer (Fisons Instruments, Beverly, MA). Since there is no appreciable carbonate carbon in this inherently acidic soil, the total carbon content is equivalent to the soil organic carbon (SOC) content. Microbial biomass carbon (MBC) was determined by the fumigation-incubation method according to Horwath and Paul (1994). Biomass carbon was calculated using a conversion factor of 0.41 without the subtraction of a control (Voroney and Paul, 1984; Franzluebbers, *et al*., 1999).

Field moist soil samples were used for PLFA analysis according to a procedure modified after Findlay and Dobbs (1993) and Bossio and Scow (1998). Duplicate soil samples (4 g dry weight) were extracted in 19 ml of a single-phase mixture (1:2:0.8, v/v/v) containing chloroform, methanol and citrate buffer (0.15 M, pH 4). The phospholipids were separated from neutral and glycolipids using silicic acid column chromatography and then subjected to a mild alkaline methanolysis to obtain the fatty acid methyl esters (FAME). Samples were dissolved in appropriate amounts of hexane containing 19:0 methyl ester as an internal standard and analyzed using a Hewlett Packard 5890 gas chromatograph equipped with a 25-m HP Ultra 2 capillary column and a flame ionization detector. Fatty acid peaks were identified using the MIDI peak identification software (MIDI, Inc., Newark, DE) and bacterial fatty acid methyl ester standards (Matreya, Inc., Pleasant Gap, PA). Identification of the FAMEs was confirmed by gas chromatography mass spectrometry using a Varian Saturn 4 Ion Trap GCMS system.

PLFA compositions were analyzed with SAS software using principal components analysis (PCA). All samples were analyzed for PLFA profiles using a set of 22 fatty acids indicative of various taxonomic groups of soil microorganisms. Analysis of variance (ANOVA) on the first two principal components was performed to assess the effects of tillage, soil depth, and sampling time.

RESULTS AND DISCUSSION

The tillage treatments greatly affected soil organic carbon and microbial biomass carbon (Table 1). SOC content was more than twice as high in the surface layer of the no-till

Table 1. Soil organic carbon and microbial biomass carbon from conventional and no-till plots of a long-term cotton tillage and rotation experiment in Belle Mina, Alabama.

Tillage treatment	Depth			
	0-3 cm	3-6 cm	6-12 cm	12-24 cm
Soil organic carbon, mg g^{-1}				
Conventional	8.3	9.3	6.4	5.4
No-till	18.8	10.0	6.5	6.1
LSD$_{(0.05)}$	0.9	0.9	0.9	0.9
Biomass carbon, µg g^{-1}				
Conventional				
February	236.7	181.8	117.8	73.9
May	266.2	155.5	101.5	66.8
October	221.2	164.5.	113.2	62.9
No-till				
February	380.3	161.7	96.8	78.5
May	632.9	184.8	107.9	73.2
October	387.8	187.3	104.1	74.8
LSD$_{(0.05)}$	35	35	35	35

treatment compared to the conventional-till treatment (18.8 vs. 8.3 mg g^{-1}). The differences in SOC between the two tillage treatments were not significant at three lower depths. SOC in no-till plots decreased sharply with increasing soil depth. There was a significant increase in SOC at the second sampling depth compared to the surface layer (9.3 vs. 8.3 mg g^{-1}) for conventional-till plots; thereafter, soil organic carbon declined linearly with depth. The increase in SOC at the second sample depth may reflect the density of cotton root growth and/or buried residues with plowing. These results support the findings that no-till practice results in increased SOC at the surface layer (Edwards *et al*., 1992; Wander *et al*., 1998; Motta *et al*., 2001; Ding *et al*., 2002).

Microbial biomass carbon ranged from 63 to 266 µg g^{-1} in conventionally tilled soils and 73 to 633 µg g^{-1} in no-till soils for all sampling depths and months (Table 1). The percentages of SOC as biomass carbon ranged from 1.17 to 3.21% in conventionally tilled plots and 1.20 to 3.37% in no-till plots and the values decreased as soil depth increased. No-till soils contained significantly higher amounts of MBC than conventionally tilled soils at the surface layer for all sampling months (Table 1). Surface MBC content under no-till treatment was 61, 138, and 75% greater than under conventional till treatment in February, May, and October, respectively. Under both tillage systems, the highest MBC content was observed in May, probably due to the combined effect of nitrogen fertilizer application in the spring and the rhizodeposition of cotton roots. MBC contents decreased with increasing soil depths, as did SOC (Table 1). The largest changes occurred between the surface layer and lower depth, irrespective of the sampling month. Change in biomass carbon was most pronounced for the no-till treatment at the surface layer sampled in May, which was at least twice as large as for other months. Our results agree with previous reports that higher levels of MBC are found near the soil surface under no-tillage compared with conventional tillage and similar or lower levels at lower depths (Granastein *et al*., 1987; Franzluebbers *et al*., 1994; Motta *et al*., 2001).

Table 2. PLFAs receiving loadings > |±0.2| on the first two principle components. The principal component analyses were carried out using 22 marker PLFAs. Soil samples were taken at four depths in February, May, and October 2000.

PC 1		PC 2	
Fatty acid	Loading	Fatty acid	Loading
10Me16:0	.72	*i*15:0	-.71
*cy*19:0	.38	*cy*19:0	.35
18:1ω9*c*	-.26	18:1ω9*c*	.26
18:1ω7*c*	-.26	18:1ω7*c*	.26
18:2ω6*c*	-.23	*a*15:0	-.24
*i*15:0	.20	10Me16:0	.21

PLFA profiles of 22 fatty acids were analyzed using principal components analysis. The first two principal components (PCs) accounted for 65% and 11% of the total observed variance. The PCA plot of the first two PCs showed that October data formed a cluster, whereas data points for February and May were intermixed (data not shown). PLFAs 10Me16:0, *cy*19:0, 18:1ω9*c*, 18:1ω7*c*, 18:2ω6c, and i15:0 were influential fatty acids to PC 1 with 10Me16:0 having the largest loading of 0.72 (Table 2). The PLFA with the highest loading (-0.71) for PC 2 was *i*15:0; other major contributors included *cy*19:0, 18:1ω9*c*, 18:1ω7*c*, *a*15:0, and 10Me16:0 (Table 2). PLFAs 10Me16:0, *cy*19:0, 18:1ω7*c*, i15:0, and *a*15:0 have been reported as marker PLFAs for bacteria with 10Me16:0, i15:0, and *a*15:0 being indicators of Gram-positive bacteria and *cy*19:0 and 18:1ω7*c* of Gram-negative bacteria (Paul and Clark, 1996; Findlay and Dobbs, 1993). PLFAs 18:1ω9*c* and 18:2ω6c have been identified as signature PLFAs for fungi (Paul and Clark, 1996; Findlay and Dobbs, 1993). The relative abundance (mole percentage) of these PLFAs was comparable under no-till and conventional till systems (data not shown). The ratio of *cy*19:0 to 18:1ω7*c,* which describes community response to anaerobic conditions (Guckert *et al*., 1986), increased with increasing soil depths and was higher in no-till soil at lower depths. This suggests that microbial community structure shifted as its surrounding physical and chemical environment was altered by the tillage system.

ANOVA of PC 1 revealed that both month x depth and tillage x depth interactions were significant at P≤d 0.1 (data not shown). There was no significant tillage x depth x month interaction. The response of PC 1 was different for conventional till and no-till treatments. There was a strong linear response in PC 1 to depth for conventional tillage, whereas the response was nonlinear for no-tillage (Fig. 1A). The month x depth graph shows clearly that the late season (October) samplings differed from the two early-season (February and May) samplings (Fig. 1B). PC 1 showed a strong relationship with depth, and thus could be renamed the “depth response” variable indicating the cause of the observed variation. The only significant effect revealed by ANOVA for PC 2 was month ($P = 0.047$); therefore, PC 2 could be called the “time variable”. PLFAs with dominant loadings for both PC 1 and PC 2 were Gram-positive bacterial markers (10Me16:0 and *i*15:0), suggesting that

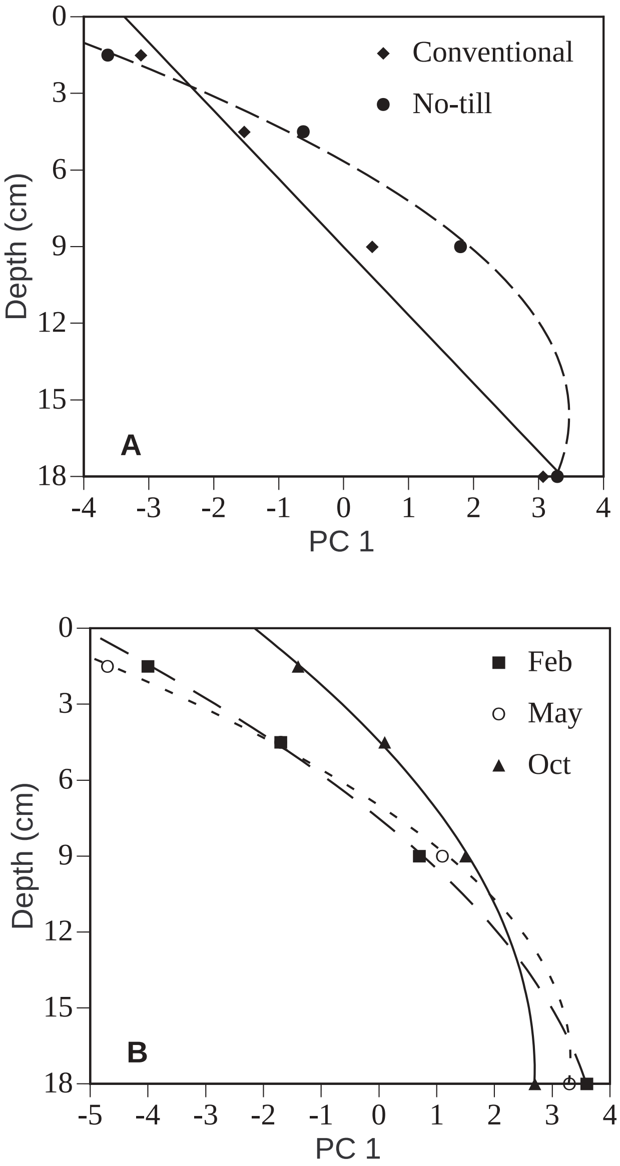

Fig. 1. Responses of the first principal component to increasing soil depth for tillage treatments (A) and sampling months (B) from a continuous cotton field. The principal components analysis was based on all three sampling dates and 22 fatty acids. The regression equations for tillage treatments are: PC 1 = 0.368 depth - 3.317 (R^2 = 0.981) for conventional tillage; PC 1 = -0.0352 $depth^2$ + 1.097 depth – 5.08 (R^2 = 0.997) for no-tillage (quadratic). The regression equations for sampling months are: PC 1 = -0.019 $depth^2$ + 0.82 depth -5.11 (R^2 = 0.999) for February; PC 1 = -0.034 $depth^2$ + 1.16 depth - 6.37 (R^2 = 0.999) for May; PC 1 = -0.016 $depth^2$ + 0.57 depth - 2.18 (R^2 = 0.998) for October.

differences in microbial community structure between tillage systems and sampling months may result from the shifts of bacterial populations. These results support previous observation of eubacterial groups affected by tillage (Calderon *et al*., 2001). Drijber *et al*. (2000) observed that for wheat-fallow cropping system, marker PLFA for arbuscular mycorrhizal fungi (16:1ω5) was important in discriminating no-till and plow treatments.

CONCLUSIONS

No-till practice resulted in significant increases in soil organic carbon and microbial biomass at the surface layer, as well as changes in the soil microbial community. The tillage effect on microbial community varied by soil depths and over time. The use of culture independent methods, such as PLFA profile analysis, allows us to better characterize the changes of the microbial community under different management systems and may provide insights into how conservation tillage practice improves soil quality and sustainability.

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MICROBIAL RESPONSES TO WHEEL-TRAFFIC IN CONVENTIONAL AND NO-TILLAGE SYSTEMS

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ABSTRACT

Traffic-induced soil compaction and tillage systems can impact the productivity and sustainability of agricultural soils. The objective of this study was to assess the response of soil microbial populations to wheel-traffic in two tillage systems on a Norfolk loamy sand (Typic Kandiudults; FAO classification Luxic Ferralsols). Experimental variables were with and without traffic under conventional tillage (disk harrow twice, chisel plow, field cultivator-planter) *vs.* no-tillage employed in a split-plot design with four replications; main plots were traffic and subplots were tillage. Soil samples were collected from 0-2 and 2-4 cm depths, sieved (2 mm), and used to assess soil water content, microbial biomass nitrogen (N), dehydrogenase, and microbial characterization using phospholipid ester-linked fatty acid (PLFA) analysis. Traffic increased soil water content, had little effect on microbial biomass N, and increased microbial activity (no-till plots only) likely due to increased amounts of residue. Soil water content, microbial biomass N, PLFA estimates of microbial biomass, and microbial activity were all consistently higher in no-till compared to conventional tillage plots. Data from this study suggest that conventional tillage results in a lower, more static, possibly more mature community of microbes, while the microbial community under no-till appears to be a younger, more viable growing population. Finally, these data suggest that overall soil quality, at least in the surface soil layer, is improved in agricultural systems employing no-till operations.

KEYWORDS

Dehydrogenase, microbial biomass, phospholipid fatty acid, residue management, soil compaction

INTRODUCTION

Traffic-induced soil compaction can negatively impact crop productivity due to restrictions in root growth. It has also been suggested that compaction may affect soil microbial populations, impacting the decomposition of plant materials and the subsequent cycling of nutrients required for plant growth (Dick *et al.*, 1988). Lee *et al.* (1996) reported higher levels of microbial biomass carbon associated with trafficked compared with non-trafficked areas.

Reduced soil productivity and increased erosion associated with intensive tillage operations have prompted interest in reduced-tillage and no-tillage farming practices. In no-till systems, plant residues remain on the soil surface (as opposed to being incorporated during tillage operations) thereby slowing decomposition, which results in higher levels of soil C and N (Holland and Coleman, 1987; Wood and Edwards, 1992). Generally, tillage events result in a large (albeit temporary) increase in microbial biomass and/ or activity due to the physical incorporation of organic substrates into the soil (Lynch and Panting, 1980; Lee *et al.*, 1996). However, following tillage, measures of microbial communities tend to be higher under no-till conditions due to the generally more favorable soil conditions (Lee *et al.*, 1996). Adoption of no-tillage farming systems may enhance soil quality, in part through their impacts on soil microbes.

Soil microbial populations may act as early indicators of changes in soil quality as they can respond much more rapidly to perturbations than other indicators such as soil C or N (Kennedy and Papendick 1995). The size and activity of the soil microbial population is critical to overall soil use and sustainability. Soil organisms contribute to the maintenance of soil quality through their control of many key processes, such as decomposition, nutrient cycling and availability, and soil aggregation. These processes affect erodibility, water infiltration, water storage, and carbon sequestration (Kennedy and Papendick 1995). Understanding the interactive effects of wheel-traffic and tillage systems and their impact on microbial responses is crucial

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for proper management and the improvement of highly degraded soils in the Southeastern U.S. The objective of this study was to assess the response of microbial populations to wheel-traffic in two tillage systems on a coarse textured soil.

MATERIALS AND METHODS

STUDY SITE AND DESIGN

This research was conducted as part of a continuing, long-term, traffic/tillage study (previously detailed by Reeves *et al.*, 1992; Torbert *et al.*, 1996) on a Norfolk loamy sand at the E.V. Smith Research Center of the Alabama Agriculture Experiment Station in east central Alabama, USA (N 32° 25.461, W 85° 53.403). The soil is highly compactable and has a well developed hard pan at the 18-30 cm depth. Soil bulk density in the hard pan ranges from 1.51 to 1.76 Mg m^{-3} with a predominance of sand in the profile. Other soil and residue properties for this study site have been previously described (Reicosky *et al.*, 1999).

Crop rotation consisted of corn (*Zea mays* L.) in 1993, followed by a winter cover crop of crimson clover (*Trifolium incarnatum* L.) and soybean (*Glycine max* (L.) Merr.) in 1994 also with a winter cover crop of crimson clover. The aboveground soybean non-grain biomass averaged 3400 kg ha^{-1} the previous fall and was not readily apparent at the start of this study due to overwinter decomposition. Cover crop was terminated with a burn-down herbicide [glufosinate-ammonium]. Fertilizer and lime recommendations were based on standard soil testing recommendations.

The experimental layout and design were previously described in detail by Reeves *et al.* (1992). Experimental variables were with traffic *vs*. without traffic and conventional tillage (disk harrow twice, chisel plow, field cultivator) *vs*. no-tillage. Thus, there were four combinations of traffic and tillage arranged in a split-plot design with four replicates; main plots were traffic and subplots were tillage.

Conventional spring tillage included disking twice to 10-12 cm, chisel plowing to 15-18 cm, and field cultivation to 10 cm. All plots received 25 mm of irrigation water on 4 April, 1995 (Day of Year (DOY) 94) between the disking and chisel plow operations (Reicosky *et al.*, 1999). The no-tillage treatment required no surface tillage. In both conventional and no-till plots, an eight-row (76 cm row width) no-till planter was used immediately behind the field cultivator to simulate the planting operation (planters were not loaded with seed). The planter was equipped with interlocking steel-fingered row cleaners set to float just above the soil surface to skim excessive residues from a 10 cm band width over the planting row.

All tillage and planting operations for the without traffic plots were done with an experimental wide-frame tractive vehicle (6.1 m wide) described by Monroe and Burt (1989). In the trafficked plots, a 4.6 Mg tractor with tires (470 mm x 970 mm) inflated to an average pressure of 125 kPa immediately followed the wide-frame tractive vehicle to simulate tractor traffic in a field operation.

SOIL SAMPLING AND MICROBIAL ANALYSIS

Soil samples from 0-2 and 2-4 cm depths were collected using a 17 mm diameter soil probe prior to spring tillage operations (DOY 90) and following disking (DOY 93), chisel plowing (DOY 94), and cultivator/planting operations (DOY 95), for a total of four sampling periods. Approximately 500 g soil was collected by systematic sampling in an “M” pattern across each plot at each sampling period. Soils were sealed in plastic bags and stored on ice until transported to the laboratory for analysis.

Soils were sieved (2 mm) and divided into four alliquots: one for determination of soil water content, one for determination of microbial biomass nitrogen (N), one for determination of dehydrogenase activity, and one sent to the laboratory of Dr. David C. White for microbial characterization, including phospholipid ester-linked fatty acid (PLFA) analysis (White *et al.*, 1996). Soil water content was determined by placing approximately 1 g fresh soil weight into an aluminum weighing pan, oven drying at 105°C for three days, and recording the oven dry weight; percent soil water content was calculated as: ((fresh weight - oven dry weight)/oven dry weight) x 100). Three replicate soil samples were used for each plot.

Microbial biomass N was determined using chloroform fumigation/extraction techniques as described by Horwath and Paul (1994). 50 g fresh soil was placed into 125 ml flasks. Flasks were placed into vacuum desiccators with 50 ml chloroform, and a vacuum was placed on the desiccator until the chloroform boiled (22 mm Hg). The desiccator was then sealed and incubated (25 C) for 24 hr. Following removal of the chloroform, desiccators were flushed with clean air a minimum of 6 times. Soil samples were removed, 50 ml of 0.5M K_2SO_4 added to each flask, and flasks were placed on a rotary shaker at 200 rpm for 30 min. The resulting soil suspensions were then filtered through Whatman No. 42 filter paper in plastic funnels with the solution captured in 50 ml plastic vials. Vials were capped and frozen until N determination using standard Kjeldahl procedures was completed. Nitrogen was also determined on a replicate set of non-chloroform incubated soil samples following K_2SO_4 extraction; microbial biomass N was calculated as incubated N minus non-incubated N and expressed as ug N per gram soil dry weight. Three replicate soil samples were used for each plot at each sampling date.

Dehydrogenase activity, a measure of microbial respiration and a reliable index of microbial activity in soil (Stevenson, 1959), was determined from modified procedures described by Tabatabai (1982). Sieved soil (1 g) was placed in test tubes (15 x 100 mm), covered with 1 ml of 3% aqueous (w/v) 2,3,5-triphenyltetrazolium chloride, and stirred with a glass rod. After 96 hr incubation (27°C), 10 ml of methanol was added to each test tube, and the suspension was vortexed for 30 sec. Tubes were then incubated for 1 hr to allow suspended soil to settle. The resulting supernatant (5 ml) was carefully transferred to clean test tubes using Pasteur pipets. Absorbance was read spectrophotometrically at 485 nm, and formazan concentration was calculated using a standard curve produced from known concentrations of triphenyl formazan. Dehydrogenase activity was expressed as g formazan per gram soil dry weight. Three replicate soil samples were used for each plot at each sampling date.

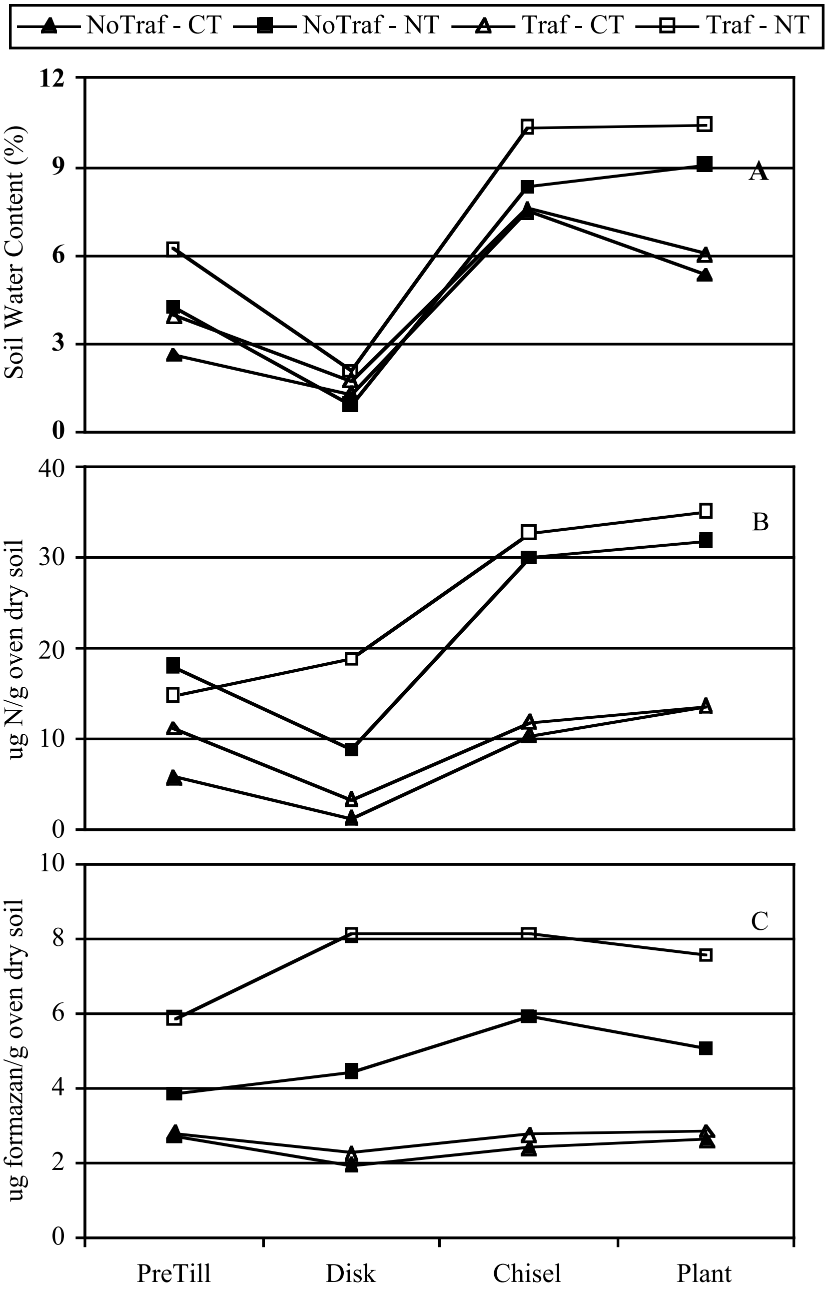

Fig. 1. Interactive effects of traffic (NoTraf = no traffic; Traf = traffic) and tillage system (CT = conventional tillage; NT = no-tillage) on soil water content (A), soil microbial biomass nitrogen (B), and dehydrogenase (C). Sampling periods on the X-axis are prior to spring tillage (PreTill), following disking (Disk), following chisel plowing (Chisel), and following cultivator/planter operation (Plant).

DATA ANALYSIS

Data from the three replicate samples were averaged prior to analysis. All analyses were performed using the mixed procedure of the Statistical Analysis System (Littell *et al.*, 1996). Error terms appropriate to the split-plot design were used to test the significance of main effects variables and their interactions. In all cases, differences were considered significant at the $P = 0.05$; values which differed at the $0.05 < P < 0.15$ level were considered trends.

RESULTS AND DISCUSSION

Soil microbial measurements were consistently higher in the 0-2 compared to the 2-4 cm depth. Further, as no effect of treatment variables and no interactions were observed on any of the soil microbial assays or on soil water content at the 2-4 cm depth, all data presented herein deal exclusively with the 0-2 cm soil depth.

Soil water content was significantly higher in trafficked than non-trafficked areas prior to spring tillage ($P = 0.03$) and following disking ($P = 0.01$); traffic had no effect on soil water content at the final two sampling periods, which occurred following irrigation (Fig. 1). Compaction due to wheel traffic can reduce soil porosity (Torbert and Wood, 1992) and may have decreased water movement through the soil profile. No-till plots had higher soil water content than conventional plots prior to tillage ($P = 0.01$), following chisel plowing ($P = 0.06$) and the cultiva-

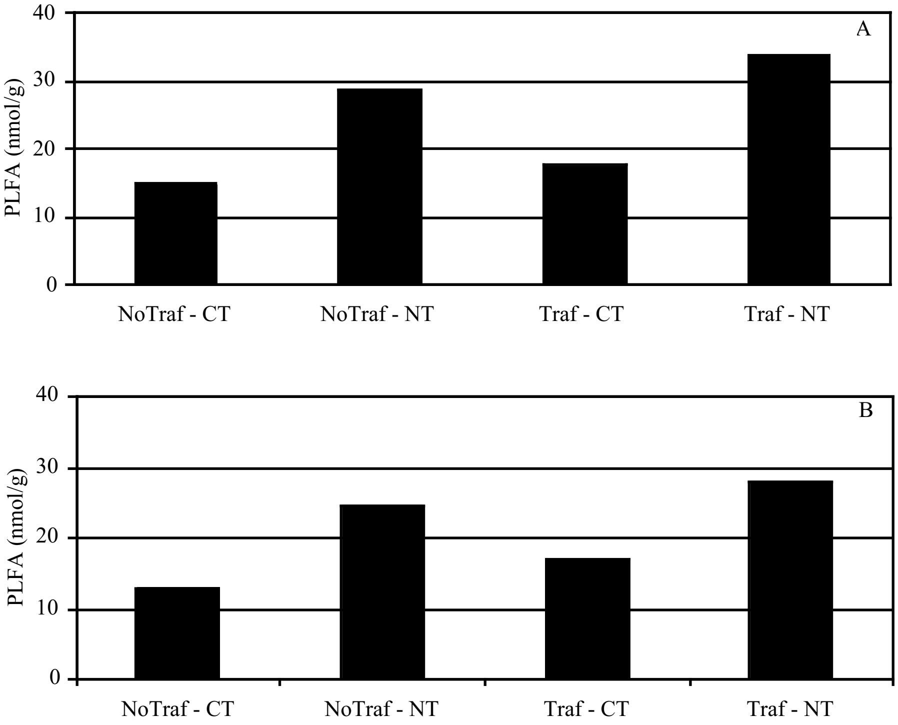

Fig. 2. Interactive effects of traffic (NoTraf = no traffic; Traf = traffic) and tillage system (CT = conventional tillage; NT = no-tillage) on microbial biomass estimates based on phospholipid ester-linked fatty acid (PLFA) analysis following disking (A) and chisel plowing (B).

tor/planting operation ($P = 0.01$); soil water content was not different following disking due to the fact that the soil was extremely dry at this time (1.5%). Higher soil water content in no-till plots is likely a result of extra residue from no-till operations, which can reduce evaporative soil water loss (Bradford and Peterson, 2000). There was no interaction between traffic and tillage on soil water content at any sampling period. Soil water content decreased up to the irrigation event, increased following irrigation, and then began to decrease in conventional tillage plots, but remained high in no-till plots. Again, this is most likely due to lowered water loss resulting from increased residue in no-till plots.

Traffic had little effect on microbial biomass N at any sampling period (Fig. 1); however, there was a trend ($P = 0.08$) for trafficked areas to have higher microbial biomass N following the disking treatment. Similarly, Lee *et al.* (1996) observed higher microbial biomass carbon in trafficked compared with non-trafficked areas following tillage operations. Soil compaction can decrease available pore space, which slows the rate at which organic substrates are incorporated into and released from microbial biomass (van der Linden *et al.*, 1989). Microbial biomass N tended to be higher ($P = 0.12$) in no-till plots prior to spring tillage. Higher microbial biomass under no-till treatment has been previously reported (Lynch and Panting, 1980) and is likely due to increased amounts of surface residue and its impacts on soil moisture retention. Generally, microbial biomass increases following tillage events (Lynch and Panting, 1980; Lee *et al.*, 1996). However, in the present study, concurrent measurements of microbial biomass N were consistently higher ($P < 0.01$, in all cases) in no-till compared with conventional tillage plots. The extremely low soil water content following disking likely restricted microbial response to this tillage operation (Fig. 1). A similar explanation for a lack of response in soil CO_2 efflux following disking was reported by Reicosky *et al.* (1999). Microbial biomass N increased in all plots following irrigation and subsequent tillage operations; however, the increase was much greater in no-till compared to conventional tillage plots. Again, the effects of no-till on soil water content and surface residues are most likely responsible for this increase in microbial biomass N. No traffic by tillage interactions was observed for microbial biomass N at any sampling period.

Microbial respiration, as determined by the dehydrogenase assay, can reflect changes in the size of the microbial population and/or changes in the respiratory activity of a given population size in response to changes in the soil environment. Microbial activity tended to remain relatively stable over time in the conventional tillage plots, indicating little impact of tillage events on either population size or respiratory activity (Fig. 1). Significant traffic by tillage interactions for microbial activity were observed at all sampling periods except following chisel plowing; traffic had no effect in the conventional tillage plots, but this measure was significantly higher in trafficked areas compared with non-trafficked areas in the no-till plots ($P = 0.01$ prior to tillage and following disking and cultivation/planting; $P = 0.07$ following chisel plowing). The increase in microbial respiration following the final two tillage events reflected the increase in microbial biomass, which occurred following irrigation. No-till plots generally exhibited significantly higher microbial activity than conventional tillage plots in both trafficked ($P < 0.01$, in all cases) and non-trafficked areas ($P = 0.01$ to 0.09); however, the difference due to tillage system tended to be greater in the trafficked areas. The higher soil water content and greater

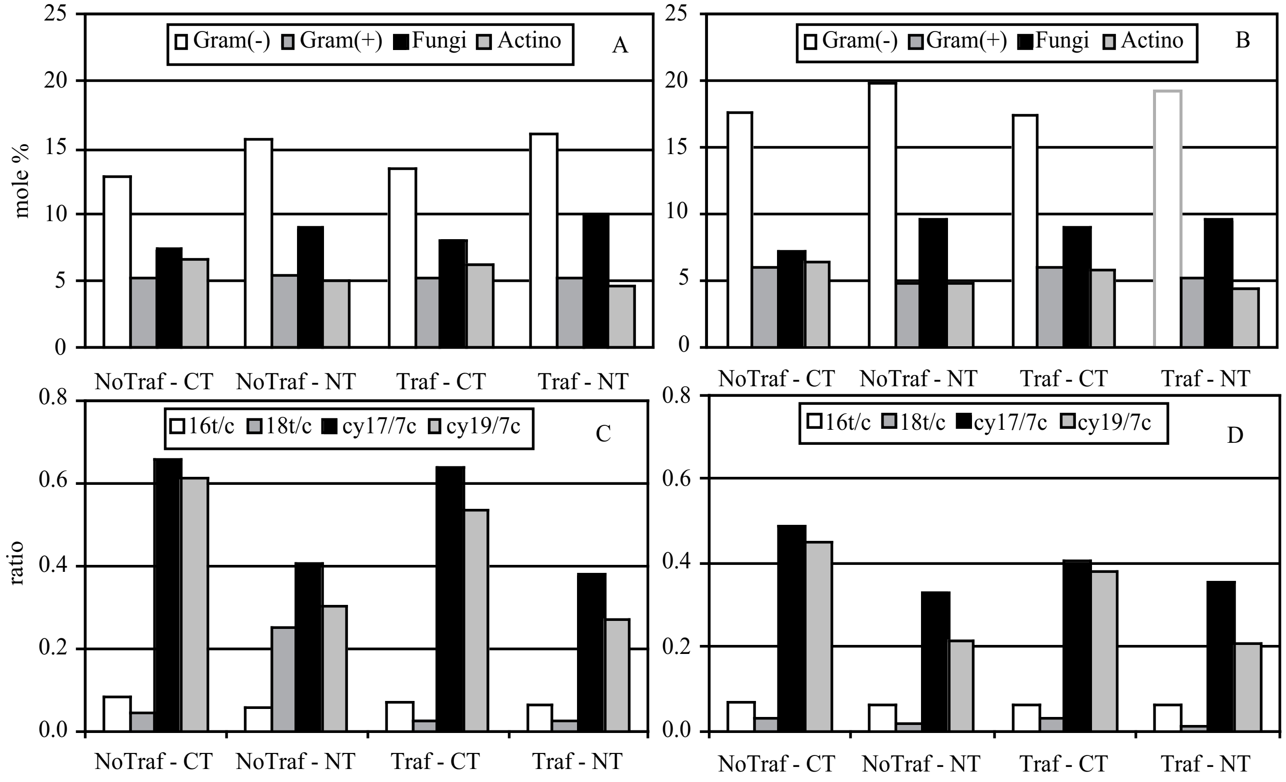

Fig. 3. Interactive effects of traffic (NoTraf = no traffic; Traf = traffic) and tillage system (CT = conventional tillage; NT = no-tillage) on relative microbial community composition (Gram(-) bacteria, Gram(+) bacteria, fungi, and actinomycetes) following disking (A) and chisel plowing (B) based on phospholipid ester-linked fatty acid (PLFA) analysis and on microbial physiological status following disking (C) and chisel plowing (D) using ratios of specific phospholipid fatty acids.

amounts of residue in no-till plots are the most likely reasons for the higher microbial activity in these plots.

Soil samples were analyzed for PLFA for the sampling periods following disking and chisel plowing only (Fig. 2). Conventional tillage reduced PLFA estimates of microbial biomass compared with the no-till treatment; PLFA estimates of microbial biomass were not affected by traffic. PLFA estimates of microbial biomass were highly correlated with both microbial biomass N and dehydrogenase activity at both sampling periods ($r^2 = 0.95$). PLFA analysis also demonstrated subtle shifts in microbial community composition due to differences in tillage systems (Fig. 3). No-till plots tended to have higher populations of Gram(-) bacteria but lower populations of actinomycetes; Gram(+) bacteria and fungi were not significantly affected by tillage treatments. Associated with the increased biomass and relative percentage of Gram(-) bacteria, ratios of specific PLFAs suggested a decrease in the stress ratios for this functional group. No-till practices produced lower cyclopropyl/monoenoic precursor ratios, which generally correspond to a viable growing population. Conversely, higher ratios (as seen in conventional plots) are typically associated with old or stationary phase organisms. Further, it has been shown that release of CO_2 per unit microbial biomass is higher for "young" compared with "mature" sites (Anderson and Domsch, 1990). These factors might aid explanation of the dehydrogenase data discussed previously. That is, the low and stable microbial activity under conventional tillage might reflect a mature microbial population in a stationary phase of growth, while the increase under no-till would reflect a younger, more viable growing population. PLFA ratios tended to decrease in conventional plots between the disking and chisel plowing treatments, possibly suggesting a change in the microbial population toward a more active phase of growth as a result of tillage.

Although soil quality is a very broad term relating to the chemical, physical, and biological properties of soil (Seybold *et al.*, 1997), the size and activity of the soil microbial population is critical to overall soil use and sustainability (Kennedy and Papendick 1995). Soil organisms contribute to the maintenance of soil quality through their control of many key processes (e.g., decomposition, nutrient cycling and availability, and soil aggregation) and may act as early indicators of changes in soil quality (Kennedy and Papendick 1995). Microbial data from this study suggest that overall soil quality has improved, at least in the surface layer, in agricultural systems employing no-till operations.

CONCLUSIONS

Traffic increased soil water content prior to the irrigation event but had little effect on microbial biomass N. Traffic increased microbial activity only in no-till plots, which was likely a result of increased amounts of residue in these plots in conjunction with the more favorable soil moisture conditions. The largest differences in microbial response observed in this study occurred between the conventional tillage and the no-till systems; soil water content, microbial biomass N, PLFA estimates of microbial biomass, and microbial activity were all higher in no-till compared to conventional tillage plots. It was expected that tillage operations would increase soil microbe populations and/or activity, and while an increase in microbial biomass N was observed following chisel plowing, it is likely that the low soil water content prior to irrigation and during disking restricted this response. Data from this study suggest that conventional tillage results in a lower, more static, possibly more mature community of microbes, while the microbial community under no-till appears to be a younger, more viable growing population. Finally, it appears that overall soil quality has improved, at least in the surface layer, by using no-till farming practices.

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LAND USE EFFECTS ON SOIL QUALITY PARAMETERS FOR IDENTICAL SOIL TAXA

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ABSTRACT

Near-surface or use-dependent soil properties are relatively dynamic and can change over a few years time. These manageable, use-dependent properties are critical to soil quality. Past studies have documented land use effects on near-surface soil properties without ensuring soil taxa were identical. Our objective was to evaluate soil quality differences due to land use in taxonomically identical soils. Research sites were located at the Sand Mountain Research Center (SMRC) and E.V. Smith Research Center (EVS) of the Alabama Agricultural Experiment Stations. Soils were classified as fine-loamy, siliceous, subactive thermic Typic Hapludults at SMRC and coarse-loamy, siliceous, subactive, thermic Typic Paleudults at EVS. Experiments were conducted in long term conventional and conservation tillage plots, pastureland, and woodland areas. Investigated parameters included: bulk density (Db), water stable aggregates (WSA), saturated hydraulic conductivity (Ksat), soil water retention (SWR), soil strength, water dispersible clay (WDC), soil organic carbon (SOC), total nitrogen (TN), and soil microbial biomass C. Results at SMRC indicated that the conventional tillage system had lower values of WSA, SWR, SOC, TN, and soil microbial biomass C as compared to the other systems. At SMRC, WSA in the conventional tillage system were 28, 25, and 24% lower than pastureland, woodland, and the conservation tillage system, respectively. Similarly, SWR in the conventional tillage system was 19, 23, and 11% lower than pastureland, woodland, and the conservation tillage system, respectively. Pastureland had higher WSA, Db, and soil strength. Woodland had the highest SOC, TN, microbial biomass C, and Ksat. At EVS, the conventional and no-tillage systems had lower WSA, WDC, and microbial biomass C and higher Db and SWR compared to woodland. Pastureland had higher SWR, SOC, TN, and soil microbial biomass C than woodland. The conservation tillage system had higher WSA, SWR, TOC, TN, and microbial biomass C and lower Ksat, and WDC compared to the conventional tillage system. At EVS, WSA in the conventional tillage system were 14, 26, and 12% lower than pastureland, woodland, and the conservation tillage system, respectively. In addition, the woodland had lower values of SOC and TN compared to the pastureland and conservation tillage systems. Our data at EVS suggests that loblolly pine (*Pinus teada* L.) plantation management did not improve soil quality relative to croplands. In general, the aggregate of data suggested that intensive soil cultivation resulted in reduced soil quality at both sites. Our data showed differences in near-surface soil properties that resulted from land use systems in taxonomically similar soils. Variation in near-surface properties resulting from land use suggests further work is needed to enhance soil map unit interpretations.

KEYWORDS

Soil quality, land use, soil taxa, use-depedent soil properties, soil.

INTRODUCTION

Knowledge of the land use impacts on soil quality is necessary for sustainable agricultural production. Sustainability is related to soil quality, which is defined as, "the capacity of a specific kind of soil to function, within natural or managed boundaries, to sustain plant and animal productivity, maintain or enhance air and water quality, and support human health and habitation" (Karlen, 1997). The soil's ability to function as a component of an ecosystem may be degraded, aggraded, or sustained as use-dependent properties change in response to land use and management. For example, conservation tillage practices generally result in higher amounts of soil organic matter (SOM), reduced erosion, increased infiltration, increased water stable aggregates, and greater microbial biomass C when compared to conventional tillage systems (Reeves, 1997). Some studies have shown that when woodland is converted to

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pastureland, soils are subject to compaction and subsequently decreased porosity (Deuchare *et al.,* 1999). Conversely, when pasture is converted to woodland, infiltration increases with increasing forest age (Carter *et al*., 1998).

Soil taxonomy emphasizes subsurface properties and de-emphasizes near-surface soil properties because of their dynamic nature. The dynamic nature of near-surface soil properties requires the evaluation of land use effects on soil systems for better characterization of soil map units. Near-surface soil properties impact many soil interpretations, thus it is essential to understand the variability of use-dependent soil properties in taxonomically similar soils. Our main objectives were to: 1) evaluate land use effects on soil chemical, physical, and biological properties in taxonomically identical soils to assess soil quality, and 2) define ranges in near-surface soil properties impacted by variation in soil management strategies.

MATERIALS AND METHODS

STUDY SITES

The study sites were located in two physiographic regions of the Southeastern USA. Sand Mountain Research Center (SMRC) is located near Crossville, AL, and E. V. Smith Research Unit (EVS) is located near Shorter, AL. Soil laboratory characterization was conducted to ensure soils were taxonomically similar. Soils at SMRC are located on the Appalachian plateau, are formed over sandstone, and classified as fine-loamy, siliceous, subactive, thermic Typic Hapludults. Soils at EVS are located in the Coastal Plain, are formed from fluvial sediments, and classified as coarse-loamy, siliceous, subactive, thermic Typic Paleudults.

At the SMRC site, tillage experiments have been established for 12 years with treatments consisting of rotational cropping-no tillage, continuous cropping-no tillage, rotational cropping-conventional tillage, and continuous cropping-conventional tillage. Rotational cropping means that both conventional and no-tillage systems were under a rotational cropping system. Continuous cropping indicates that both conventional and no-tillage systems were under a continuous cropping system. The cropping systems were a continuous corn (*Zea mays* L.) -wheat (*Triticum aestivum* L.) treatment, and the rotational system was composed of a corn-wheat-soybean [*Glycine max* (L.) Merr.]- wheat (wheat for cover crop only) rotation. Pastureland consisted of bahiagrass (*Paspalum notatum* L.), and woodland consisted of mixed forest. The EVS tillage experiments were started in 1988 with cropland treatments consisting of conventional tillage and no-tillage. The cropping system consisted of corn-soybean rotation with a crimson clover (*Trifolium incarnetum* L.) cover crop every winter until 1996. The cropping system was then changed to ultra-narrow row crop cotton (*Gossypium hirsutum* L.) with black oat (*Avena strigosa* L.) or lupin (*Lupinus albus* L.) cover crop for 2 years. The cropping system was then modified to black oat cover during winter of 1998-1999 and sorghum-sudan grass [Sorghum x drummondii (Nees ex Stend.) Millsp. and Chase] during summer of 1999. The cropping system was then changed to ryegrass (*Lolium perenne* L.) during winter of 1999-2000, sorghum-sudangrass during summer, and black oat during winter of 2000-2001. Pastureland consisted of bermudagrass (*Cynodon dactylon* L.), and woodland consisted of a loblolly pine (*Pinus taeda* L.) plantation.

The treatments were in a completely randomized design with four replications. Soil samples were collected in December 2000, June 2001, and December 2001 at both sites. Samples for Db, SWR, WDC, Ksat, SOC, and TN were taken in June 2001. Samples for WSA and soil strength were taken in December 2000, June 2001, and December 2001. Microbial biomass samples were taken in June, October, and December of 2001.

FIELD MEASUREMENTS

Bulk density was measured using the core method (Blake and Hartge, 1986). Saturated hydraulic conductivity (K_{sat}) was determined by the borehole method developed by Amoozegar and Warrick (1986). Soil penetrometer measurements were determined using a Rimik® CP 20 recording cone penetrometer (Agridry Rimik Pty Ltd, Queensland, Australia, 4350).

LABORATORY MEASUREMENTS

Water stable aggregates were measured using the wet sieving technique (Kemper and Rosenau, 1986). Water dispersible clay was measured using the micropipette method (Soil Survey Laboratory Manual, 1996). Soil water retention at 0.33 and 15 bar tension was determined using a pressure plate (Klute, 1986). The microbial biomass C was measured using the chloroform incubation fumigation method (Alef and Nannipieri, 1995), and soil organic carbon (SOC) and total nitrogen (TN) were determined using dry combustion (Yeomans and Bremner, 1991). Conventional statistics (ANOVA) were used to assess treatment differences, and only differences at the $P = 0.05$ callbacks.

RESULTS AND DISCUSSION

BULK DENSITY

Significant differences in bulk density (Db) existed between treatments at the 0-2 in and 0-6 in depth for both sites (Table 1). At SMRC, Db (0-2 in and 0-6 in) was highest for pastureland and lowest for woodland. No difference for Db existed between no-tillage and conventional tillage systems at the 0-6 in depth. Previous research (Edwards *et al*., 1992) on similar soils found lower Db in the no-tillage treatment than in the conventional systems. Other research (Radcliffe *et al*., 1988) found higher surface Db in the no-tillage *vs*. conventional tillage. At EVS, pastureland had higher Db (0-2 in) followed by no-tillage and conventional tillage systems.

AGGREGATE STABILITY

Significant differences in % WSA existed at both sites (Table 1). The conventional tillage systems had lower % WSA than the other land use systems at both sites. Our results are generally in agreement with Wood (1977) and Bruce (1990). The WSA were positively correlated with SOC at SMRC and weakly correlated at EVS. Tisdall and Oades (1982) suggested that correlations between SOC and aggregate stability are not always strong because only part of the SOC fraction is involved with aggregate stability.

SOIL WATER RETENTION

Soil water retention was significantly affected by land use at both sites (Table 1). For the SMRC site, the conventional tillage treatments had lower soil water retention than the other land use systems. No significant differences were observed between woodland, rotational cropping- no-tillage, and pastureland treatments. For the EVS site, no-tillage had higher soil water retention than conventional tillage and woodland.

Table 1. Average bulk density, water stable aggregates, and soil water retention as affected by long-term land use within taxonomically similar soils in the Appalachian Plateau and Coastal Plain region of AL.

		Bulk density[§]		Water stable aggregates[¶]	Water retention[#]	
				Depth (in)		
		0-2	0-8	0-2	0-8	
Site[†]	Land Use[‡]				0.33bar	15bar
		-----g cm^{-3}-----		---%---	---cm^3 cm^{-3}----	
SMRC	Pastureland	1.44	1.26	52.2	0.21	0.06
	Woodland	1.12	1.13	50.4	0.22	0.08
	Rotational cropping- no tillage	1.43	1.34	49.7	0.21	0.07
	Continuous cropping- no tillage	1.36	1.37	47.2	0.19	0.06
	Rotational cropping- conventional tillage	1.37	1.34	37.7	0.17	0.05
	Continuous cropping- conventional tillage	1.31	1.33	37.3	0.17	0.05
LSD $_{0.05}$		0.078	0.065	4.54	0.02	0.01
EVS	Pastureland	1.49	1.47	36.2	0.13	0.04
	Woodland	1.33	1.46	42.1	0.11	0.03
	No tillage row crop	1.42	1.33	35.1	0.13	0.03
	Conventional tillage row crop	1.4	1.31	31.0	0.12	0.04
LSD $_{0.05}$		0.04	0.06	2.58	0.01	0.006

[†] SMRC = Sand Mountain Research Center located near Crossville, AL; E.V. Smith Research Unit located near Shorter, AL.

[‡] Land use= SMRC: pastureland consisted of bahiagrass, woodland consisted of mixed forest, no-till and conventional tillage systems possessed both continuous corn-wheat and corn-wheat-soybean-wheat in rotation. EVS: pastureland consisted of bermudagrass, woodland consisted of managed loblolly pine plantation, no-till and conventional tillage systems consisted of continuous corn, corn-soybean rotation and cotton cover crops consisted of sorghum-sudangrass during summer 1999, ryegrass during winter of 1999-2000, sorghum-sudangrass during summer 2000 and black oat cover during winter of 2000-2001.

[§] bulk density data for June 2001.

[¶] water stable aggregates are averaged over three sampling dates.

[#] water retention data for June 2001.

Tollner (1984) found less available water in a no-tillage system, while Mapa (1995) found higher soil water retention in reforested systems. Our forested system is a managed pine plantation at the EVS site, thus our results differ from Mapa (1995).

Water dispersible clay

Significant differences in water dispersible clay existed between treatments at SMRC but not at EVS at the 0-2 in depth (Table 2). The conventional tillage system had higher WDC at SMRC when compared with the other land use systems. For the EVS site, though no significant differences existed between the treatments, no-tillage and conventional tillage treatments had lower WDC than pastureland and woodland at the 0-2 in and 0-8 in depths. These results are in general agreement with Shaw *et al.* (2002), who found WDC to be highly correlated with SOC in sandy coastal plain surfaces dominated by low activity clays.

Hydraulic conductivity

Hydraulic conductivity was highest in woodland and lowest in pastureland at SMRC, while no significant differences were observed in Ksat at EVS between pastureland, woodland, and conventional tillage treatments. Hydraulic conductivity was lowest for the no-tillage system at EVS (Table 2). Our results are in general agreement with Wood (1977).

Soil strength

Analysis of the penetrometer data was confined to the 0-8 in depth. Significant differences in mean soil strength averaged over this depth existed between the treatments at both sites (Table 2). At SMRC, measurements taken in June 2001 showed the highest average cone index existed in the pastureland and no-tillage

Table 2. Average water dispersible clay, Ksat, and soil strength as affected by long-term land use within taxonomically similar soils in the Appalachian Plateau and Coastal Plain region of AL.

		Water dispersible clay[§]		Ksat[¶]	Mean soil strength[#]		
		Depth (in)					
		0-2	0-8	0-6	0-8		
Site[†]	Land Use[‡]				Dec-00	1-Jun	1-Dec
		------%-----		-cm hr^{-1}-	---MPa--	--MPa--	--MPa--
SMRC	Pastureland	53.0	80.0	1.2	nd[††]	2.45	1.63
	Woodland	33.0	66.0	4.7	nd	1.76	1.43
	Rotational cropping- no tillage	48.0	71.0	4.7	1.36	2.21	1.64
	Continuous cropping- no tillage	47.0	64.0	4.0	1.48	2.06	1.79
	Rotational cropping- conventional tillage	69.0	66.0	2.3	1.72	1.44	1.38
	Continuous cropping- conventional tillage	57.0	65.0	2.5	1.84	1.48	1.42
LSD $_{0.05}$		19.2	11.8	2.2	0.32	0.25	0.31
EVS	Pastureland	63.0	66.0	5.1	2.68	2.21	3.09
	Woodland	52.0	55.0	6.7	1.92	2.27	2.69
	No tillage row crop	47.0	47.0	3.0	0.82	0.93	0.84
	Conventional tillage row crop	48.0	50.0	5.6	0.91	1.05	0.70
LSD $_{0.05}$		31.1	22.8	1.9	0.23	0.19	0.35

[†] SMRC= Sand Mountain Research Center located near Crossville, AL; E.V. Smith Research Unit located near Shorter, AL.

[‡] Land use= SMRC: pastureland consisted of bahiagrass, woodland consisted of mixed forest, no-till and conventional tillage systems possessed both continuous corn-wheat and corn-wheat-soybean-wheat in rotation. EVS: pastureland consisted of bermudagrass, woodland consisted of managed loblolly pine plantation, no-till and conventional tillage systems consisted of continuous corn, corn-soybean rotation and cotton cover crops consisted of sorghum-sudangrass during summer 1999, ryegrass during winter of 1999-2000, sorghum-sudangrass during summer 2000 and black oat cover during winter of 2000-2001.

[§] water dispersible clay data for June 2001.

[¶] saturated hydraulic conductivity measurements taken for June 2001.

[#] soil strength measurements taken in December 2000, June 2001, and December 2001.

[††] nd= indicates no data

treatments. At EVS, the highest cone index readings were recorded in the pastureland and woodland. No difference in average cone index existed between no-tillage and conventional tillage at the EVS site.

Soil organic carbon, nitrogen, and soil microbial biomass C

Significant differences existed in SOC and TN between treatments at both sites (Table 3). At SMRC, the no-tillage and pastureland systems had higher SOC (0-2 in) than the conventional tillage systems. At EVS, SOC and TN (0-2 in) were highest for pastureland. The soil organic carbon in the pastureland and no-tillage systems was significantly higher than the conventional tillage system. Our results are in general agreement with Wood (1991) and Reeves (1997), who found decreasing SOC in intensively cultivated soils. Biologically active soil organic carbon is one of the most sensitive indicators of soil quality (Molina, 1994) as it impacts the physical, chemical, and biological processes in soil, and thus provides a relatively rapid measure of the impact of these systems on soil quality (Fenton, 1999).

Soil microbial biomass C was significantly different at both sites for the 0-2 in depth (Table 3). For SMRC, microbial biomass C (0-2 in) was highest for woodland compared to pastureland, no-tillage, and conventional tillage. The conventional tillage system had significantly lower microbial biomass C compared to continuous cropping-no-tillage and pastureland for the SMRC site. These results are in general agreement with Carter (1998) and Saviozzi (2001). At EVS, microbial biomass C (0-2 in) was highest for pastureland compared to woodland, no-tillage, and conventional tillage systems. Similar to the SMRC site, conventional tillage had lower microbial biomass C than no-tillage.

Table 3. Average soil microbial biomass C, soil organic carbon (SOC), and total nitrogen as affected by long-term land use within taxonomically similar soils in the Appalachian Plateau and Coastal Plain regions of AL.

		Microbial biomass C		SOC[§]		TN[¶]	
		Depth (in)					
Site[†]	Land Use[‡]	0-2	0-8	0-2	0-8	0-2	0-8
		----µg g^{-1}----		-----%-----		-----%-----	
SMRC	Pastureland	170.9	70.3	1.9	1.1	0.05	0.03
	Woodland	252.3	83.9	nd[#]	2.6	0.13	0.04
	Rotational cropping- no tillage	135.4	79.2	2.0	1.4	0.05	0.03
	Continuous cropping- no tillage	163.1	77.2	2.4	1.3	0.06	0.03
	Rotational cropping- conv. tillage	101.4	53.9	1.2	0.9	0.03	0.02
	Continuous cropping- conv. tillage	62.3	44.6	1.2	1.0	0.03	0.02
LSD$_{0.05}$		39.7	19.0	0.68	0.18	0.09	0.07
EVS	Pastureland	186.4	75.6	2.3	1.2	0.08	0.04
	Woodland	157.3	74	1.4	1.1	0.04	0.03
	No tillage row crop	135.4	90	1.5	1.0	0.05	0.03
	Conventional tillage row crop	79.3	88.6	1.1	0.9	0.03	0.02
LSD$_{0.05}$		24	17.9	0.39	0.25	0.016	0.01

[†] SMRC= Sand Mountain Research Center located near Crossville, AL; E.V. Smith Research Unit located near Shorter, AL.

[‡] Land use= SMRC: pastureland consisted of bahiagrass, woodland consisted of mixed forest, no-till and conventional tillage systems possessed both continuous corn-wheat and corn-wheat-soybean-wheat in rotation. EVS: pastureland consisted of bermudagrass, woodland consisted of managed loblolly pine plantation, no-till and conventional tillage systems consisted of continuous corn, corn-soybean rotation and cotton cover crops consisted of sorghum-sudangrass during summer 1999, ryegrass during winter of 1999-2000, sorghum-sudangrass during summer 2000 and black oat cover during winter of 2000-2001.

[§] SOC= soil organic carbon for June 2001.

[¶] TN= total nitrogen for June 2001.

[#] nd= indicates no data.

CONCLUSIONS

Lower values of SOC and microbial biomass C in our conventional tillage systems compared to the less cultivated soils suggest decreasing quality that may ultimately lead to a decline in productivity. At EVS, our data suggested that loblolly pine (*Pinus teada* L.) plantation management did not improve soil quality relative to cropland. Our data suggests some ability for no-tillage management to mitigate degradation in agricultural systems, but quality remains below woodland (for SMRC) and pastureland. This may suggest pasture rotations within agricultural cropping systems in no-tillage management to be a sound strategy with regard to soil quality. Our data showed that significant differences in near-surface properties existed for identical soil taxa. These differences were related to the land use system. Variation in near-surface properties that change as a result of land use suggests further work is necessary for developing criteria to enhance soil map unit interpretations.

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PROMOTION OF PLANT GROWTH OF MAIZE BY PLANT GROWTH PROMOTING BACTERIA IN DIFFERENT TEMPERATURES AND SOILS

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ABSTRACT

Plant-growth-promoting bacteria isolated from the plants grown in different climatic regions of Germany and Uzbekistan were analyzed for plant-growth-promoting effects and nutrient uptake in maize on different soils and under different temperature regimes. The investigations were carried out in pot and field experiments using loamy sand soil from Müncheberg, Germany and Calcisol soil from Tashkent, Uzbekistan. The temperature and soil types were found to influence growth-promoting effects. Inoculation with bacterial strains, *Pseudomonas fluorescens* PsIA12, *Pantoea agglomerans* strain 370320, strain 020315 and strain 050309 isolated from a temperate-climate location (Müncheberg, Germany) was found to significantly increase the root and shoot growth of maize (*Zea mays* L.) grown in loamy sand at 16°C compared to 26°C . Bacterial inoculation also resulted in significantly higher values for plant growth and N, P, and K content of plant components in field experiments. Bacteria isolate *Bacillus amyloliguefaciens* BcA12, isolated from Tashkent in a semi-arid climate, was found to significantly increase the root, shoot growth and nutrient uptake of maize in nutrient-poor Calcisol at 38°C than in nutrient-rich loamy sand at 16°C.

KEY WORDS

Plant growth promoting bacteria, maize, nutrient uptake, soil type, temperature

INTRODUCTION

Beneficial effects of rhizosphere bacteria are most often based on increased plant growth and called plant-growth-promoting rhizobacteria (PGPR) (Kloepper *et al*., 1980). Rhizosphere bacteria *Pseudomonas* spp., *Azospirillium* spp., *Pantoea* spp., *Agrobacterium* spp., increased plant growth and the nutrient uptake of maize, wheat and legumes (Ruppel, 1987; Höflich and Kuhn, 1996; Höflich *et al*., 1994; 1997; Boddey and Döbereiner, 1995; Okon, 1991).

The mechanisms of PGPR are mobilization of nutrients, production of phytohormones, and nonsymbiotic nitrogen fixation (Bothe *et al*., 1992; Sarwar, 1992; Höflich *et al*., 1994). Increased uptake of nutrients such as N, P, and K was suggested as one of the mechanisms by which PGPR increased crop yield (Kapulnik *et al*., 1985).

Many factors could contribute to the inconsistent performance of PGPR, including complex interactions among host, rhizobacteria and the soil environment. Two of the most important factors are soil type and temperature. Therefore, studies on the effect of different temperatures and soils on plant-growth-promoting bacteria efficiency would be very important. The major objective of our research was to study the effect of the plant-growth-promoting bacteria isolated from the different climatic regions on the growth of maize at different temperatures and soils.

Table 1. Soil chemical properties, and soil particle distribution at 0-30 cm soil layer

Site	Type	C_{tot}	$N_{tot.}$	$P_{tot.}$	K	Mg	pH	soil particle size, mm		
		---------mg $(100\ g)^{-1}$----------						2 – 0.2 %	0.2 – 0.02 %	< 0.02 %
Müncheberg	Loamy sand	700	60	6.2	7.4	3.7	6.9	7.6	79.8	12.6
Tashkent	Calcisol	200	6	3.0	12.0	6.0	8.5	2.2	54.5	43.3

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MATERIALS AND METHODS

Plant and Soil

The experiments were carried out on loamy sand soil from Müncheberg and a Calcisol soil from Tashkent, Uzbekistan. The soil chemical and physical properties are presented in Table1. The total carbon content, C_{tot}, was identified by elementary analysis while total nitrogen, N_{tot}, content was determined by the Kjeldahl method. The molybdenum blue method determined the total phosphorus content, P_{tot}, in the soil. Potassium, K, was determined using the Flame Photometric Method (Riehm, 1985). The Atomic Absorption Spectrophotometer (AAS) was employed to measure calcium chloride ($CaCl_2$) and extractable magnesium (Schachtschnabel and Heinemann, 1974). Soil pH-value was measured by means of electrometer. Soil particle distribution was determined using sodium phosphate. Maize cvs. Felix, Larix (Germany) and cv. Wir-200 (Uzbekistan) were employed as the inoculation experiments. Seeds of these plants were obtained from the Center for Agricultural Landscape and Land Use Research in Müncheberg, Northeastern Germany and from the University of Agriculture, Uzbekista.

Microorganisms

Rahnella aguatilis 6, *Pseudomonas fluorescens* PsIA12, *Pantoea agglomerans* strain 050309, strain 370320, strain 370308, strain 020315 and *Bacillus amyloliguefacines* BcA12 were used as the test microorganisms. The bacterial strains were isolated from the following plants: *R. aguatilis* 6, *P. fluorescens* PsIA12 from the rhizosphere of wheat, *P. agglomerans* strain 050309, strain 370320, strain 370308, and strain 020315 from the phyllosphere of triticale grown in loamy sand (Müncheberg) and *B. amyloliguefaciens BcA12* from soil of the root zone of wheat grown in Calcisol soil (Tashkent). For isolation of bacteria from the rhizosphere, 10 g of washed roots and bacteria from the phyllosphere and 10 g of leaves were macerated and shaken with 10 ml sterile water. For isolation of bacteria from the soil of the root zone, 10 g of soil from the root surface were shaken with 10 ml sterile water. The resulting suspensions were spread over the surface of a glycerol-peptone agar. After an incubation time of seven days at 28 °C, the bacterial strains were isolated from the plates and identified.

Identification of strains

The identification of strains relied on standard biochemical and physiological tests according to the classification of Bergey (1984) and using the Biological System (Behrendt, 1997). Gram stain, morphology, spore formation, motility, nitrate reduction, and gas production from glucose were determined according to methods by Gerhardt (1981). The auxin production was tested using Salkowsky's reagent (Sarwar *et al*., 1992). The strains were tested for properties such as nitrogenase activity (Ruppel, 1987), and antagonistic activity. *Fusarium culmorum,* were used as indicator strains for antagonistic bacteria. Bacteria isolates were tested on growth-plates on Hirte agar (Hirte, 1961). A small block of peptone dextrose agar with fungus was placed on the test plate. Bacteria isolates were streaked on the test plates perpendicular to the fungus. Plates were incubated at $28^{o}C$ until the fungi had grown over the control plates without bacteria. Antifungal activity was recorded as the width of the zone of growth inhibition between the fungus and the organism tested. Salt tolerance was determined in Hirte agar medium containing NaCl at 5-7%.

Plant growth and inoculation in pots

The study of the effect of isolated strains on plant growth and nutrient uptake was carried out in pot experiments using a nutrient-rich loamy sand soil originating from a moderate climate (Germany) and a nutrient-poor calcareous, Calcisol, soil from a semi-arid climate (Uzbekistan). Plants were grown in pots for four weeks under open natural conditions with a temperature of 36 °C to 38 °C during the day and 20 °C to 24 °C at night in summer (Uzbekistan). Also, the study of the effect of bacteria on plant growth was tested in plastic containers (5 cm diameter and 18 cm deep) with 350 g of soil placed in a temperature regulated growth chamber at a light intensity of 20 kLux for 16 h. at a temperature of 16 °C during the day, 12 °C at night, and 24kLux with 26 °C day and 16 °C night (Germany). The soil was moistened with water and maintained at 60% of its moisture holding capacity (MHC). The inoculation treatments were set-up in a randomized design with eight replicates. The day before sowing, pots (10 cm diameter and 13 cm deep) were filled with 500 g soil. Three seeds of maize were sown per pot. After the emergence of the seeds, plants were thinned to two per pot. The bacteria were grown in a glycerol-peptone-medium. Tubes were secured on a rotary shaker (120 rpm; 23 °C) and agitated for three days. Seedlings of these plants were inoculated with 1 ml of the bacterial suspension that resulted, with an inoculum density of ca. 10^6 cfu/ml. Control seeds received 1 ml glycerol-peptone-medium. Four weeks after germination, shoots and roots were separated and dried overnight at 105 °C before determining the root and shoot dry weight. The criteria for growth promotion were studied as root and shoot dry matter in a 6-leaf-stage and N, P, and K content of plants.

FIELD EXPERIMENT

In Germany, another experimental field site on Salmtieflehm-Fahlerde (Arbeitsgruppe Boden, 1994) was established in a randomized block design with six replications (plot size: 15 m2, harvest was performed at the 12-leave stadium). Preceding crops were yellow lupin (*Lupinus luteus* L.) with under-sown cocksfoot (*Dactylis glomerata* L.). Farmyard manure (300 dt ha-1 fresh weight) was mixed into the soil by a milling machine before the sowing of corn. The seeds of plants were inoculated with the bacterial preparation (10^8 cfu / g preparation) (Höflich, 1987). The criteria for growth promotion were studied as root and shoot dry matter and the N, P, K and Mg content of plants.

STATISTICAL ANALYSIS

The data were analyzed with a two-way ANOVA and Student-Newman-Keuls test for testing the significant differences ($\alpha = 0.05$) of main effects.

RESULTS

GROWTH PROMOTION OF MAIZE BY BACTERIAL INOCULANTS AT DIFFERENT TEMPERATURES AND SOILS.

Bacterial inoculation affected the early plant growth and the nutrient content of maize grown at different soils and temperatures.

Inoculation experiments at different temperatures showed that plant growth promoting bacteria

P. fluorescens Ps1A12, *P. agglomerans* strain 050309, strain 370320, and strain 020315 isolated from moderate climate were more effective at 16 °C than at 26 °C. The strain significantly increased shoot and root dry matter from 21 to 27% at 16 °C (Fig. 1).

B. amyloliguefaciens BcA12 isolated from a semi arid climate was more effective for maize in nutrient poor Calcisol soil at 38 °C than in nutrient-rich loamy sand at 16 °C (Fig.2). The strain significantly ($P = 0.05$) increased the root and shoot dry matter of maize in Calcisol soil at 38 °C from 16 to 37 % as compared to the control. This increase in biomass translated into significantly higher total N, P, and K contents. Bacterial inoculants had no significant effects on the percentage N and P of shoot material in loamy sand.

Increases in plant growth and nutrient uptake were recorded for treated plants (12 leaves stage) in field experiments (Fig.3). Strain *Rahnella aguatilis* 6 gave the best performance and resulted in a 27% increase in plant growth over the control. The various bacterial inoculants differentially influenced the N, P, K, and Mg contents of plant components. K content was increased in all treatments significantly. Only strain *Rahnella aguatilis* 6 resulted in the significant increase of N uptake.

DISCUSSION

This work demonstrated that independent of the origin, selected growth stimulating bacteria isolates (Rhizosphere, Phyllopshere, and Soil of the root zone) are able to increase the growth and nutrient uptake of maize in loamy sand and Calcisol soil at different temperatures and soils.

Increased nutrient uptake by plants inoculated with effective bacteria was attributed to the production of plant growth regulators by the bacteria at the root interface, which stimulated root development and resulted in better absorption of water and nutrients from the soil (Höflich *et al*., 1996). The positive effects of bacterial strains in these experiments indicated that bacterial production of plant-growth-promoting substances might be responsible for the observed effects. Several workers demonstrated the production of phytohormones by rhizosphere bacteria (Haahtela, 1990; Zimmer *et al*., 1995; Turjanista *et al*., 1995). In the present work, Auxin was detected in all bacterial suspensions.

The importance of physiological plant promotion characteristics may vary with

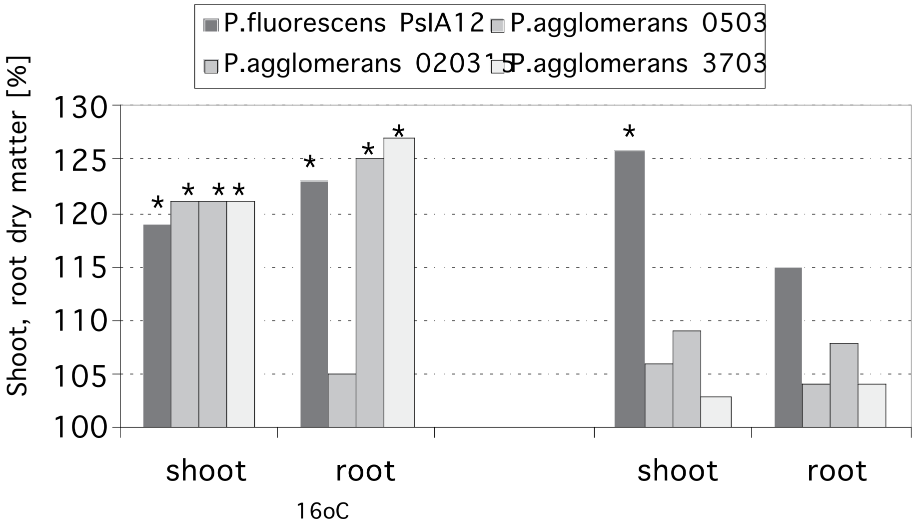

Fig. 1. The Influence of *Pseudomonas fluorescens* Ps1A12, *Pantoea agglomerans* 37/03/20, *P. agglomerans* 03/05/09 and *P. agglomerans* 02/03/15 on plant growth of maize at different temperatures (pot experiment, control=100)

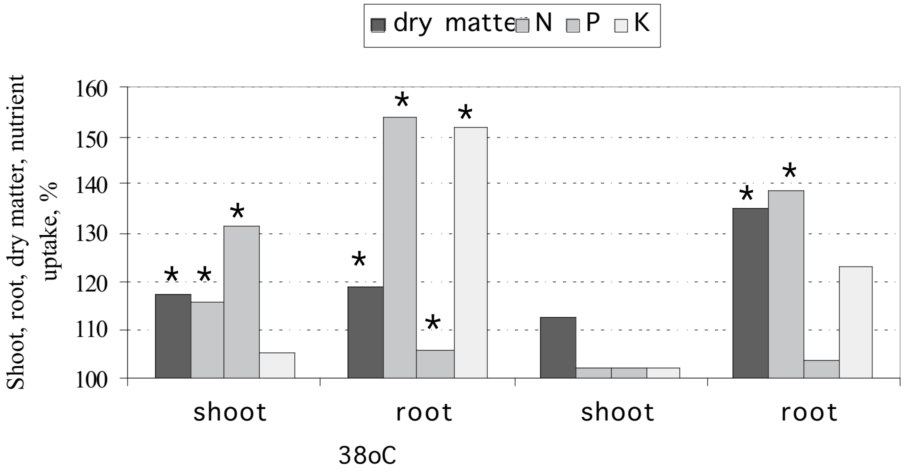

Fig. 2. Inoculation effect of *Bacillus amyloliguefaciens BcA12* on dry matter and nutrient uptake of maize at different soils and temperatures (pot experiment, control=100).

soil and weather parameters (Höflich *et al*., 1994). This is partly affected by different growth stimulation effects after inoculation. In our study, a statistical enhancement in maize growth promotion by bacterial strains isolated from moderate climates was observed at a moderate temperature of 16 °C, rather than 26 °C. According to Höflich *et al*., (1994, 1996, 1997) *Pseudomonas* sp., *Rhizobium* sp. and *Agrobacterium* sp. isolated from the temperate climate promoted the growth of young plants and increased the yields of Gramineae, Legume, and Maize in temperate climates under field conditions. Also in our field experiments, bacterial strains *Rahnella aguatilis* 6, *P. agglomerans* 050309, and *P. agglomerans* 370308 increased the growth and nutrient uptake of maize.

Our bacteria *B. amyloliguefaciens* BcA12, isolated from a semi arid climate, significantly increased the plant growth and nutrient uptake of maize at 38°C compared to 16 °C.

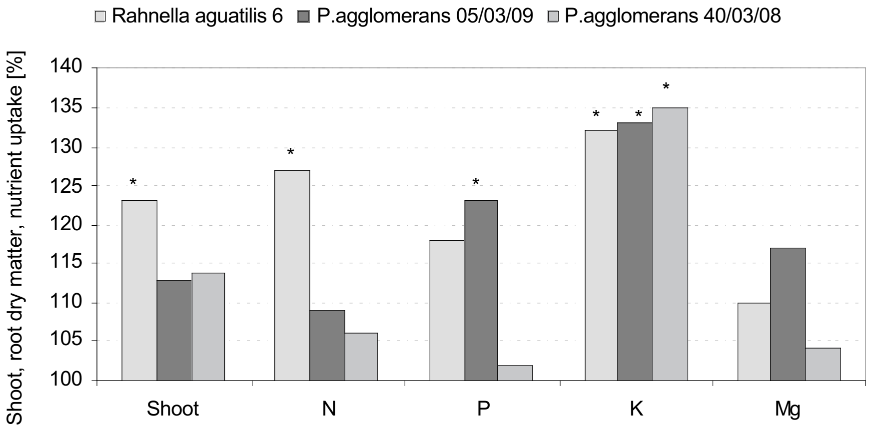

Figure 3. Inoculation effect of *Rahnella aguatilis* 6, *Pantoea agglmerans* 05/03/09 and *P. agglomerans* 37/03/08 on shoot dry matter and nutrient uptake of maize in field experiments with loamy sand (control=100).

Also in our previous experiments, the same strain was effective at 38 °C rather than 16 °C for winter wheat and cotton (Egamberdiyeva and Höflich, 2001). From our results we suggest that plant growth promoting bacteria are effective in such conditions, which supposedly are adapted to the particular climatic conditions of an area. Waldon (1989) also demonstrated that rhizobial bacteria, isolated from nodules of the desert woody legumes *Prosopis glandulosa,* grew better at 36 °C than at 26 °C. They are physiologically distinct, suggesting adaptation to their respective environmental conditions.

Our bacteria *B. amyloliguefaciens* BcA12 from a semi-arid climate was more effective for maize in nutrient-poor Calcisol soil than in nutrient-rich loamy sand. Defreitas (1992 a,b) also demonstrated that in low fertility, Asquith soil, pseudomonas bacteria strains significantly enhanced early plant growth. Also, Paula *et al*. (1992) suggested that the magnitude of the plant response to any microbial inoculation is greatly affected by the nutrient content of soil. Bacterization only marginally increased yields when tested under ideal climatic situations. The greatest benefits occurred when crops encountered stressful conditions for prolonged periods (Lazarovits, 1997). Non-treated plants by comparison performed poorly under such conditions.

In summary, the final results of plant growth promotion in our experiments showed that plant-growth-promoting bacteria can play an essential role in helping the plant establish and grow. Effective bacteria-plant partners must be selected through vegetation trials with consideration to the specific ecological conditions (crop, soil, temperature). However, the extent of stimulation of plants by effective bacteria from Uzbekistan and their persistence in plant-growth-promotion activity under actual field conditions remains unclear. The experiments concerning stimulation of maize by effective strains from Uzbekistan must be followed by investigations under field conditions.

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POTASSIUM OXALATE AS A NITRIFICATION INHIBITOR AND ITS EFFECT ON MICROBIAL POPULATIONS AND ACTIVITIES IN A CALCAREOUS UZBEKISTANIAN SOIL UNDER COTTON CULTIVATION

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ABSTRACT

Application of fertilizers combined with nitrification inhibitors affects soil microbial biomass and activity. The objective of this research was to determine the effects of fertilizer application combined with the nitrification inhibitor potassium oxalate (PO) on soil microbial population and activities in a nitrogen poor soil in Uzbekistan under cotton cultivation. Fertilizer treatments were N as urea, P as monoammonium phosphate (MAP) , and K as potassium chloride. The nitrification inhibitor, (PO) was added to urea and MAP at the rate of 2%. Two treatments: $N_{150}P_{140}K_{60}$ (T1) and $N_{150\ PO}P_{140}K_{60}$ (T2) (subscripts are concentrations in mg kg^{-1} soil) were applied. The control (C) was without fertilizer and PO. Populations of oligotrophic bacteria, ammonifying bacteria, nitrifying bacteria, denitrifying bacteria, mineral assimilating bacteria, oligonitrophilic bacteria, and *Azotobacter* were determined by the most probable number method. Treatment T2 increased the number of oligonitrophilic bacteria, utilization of mineral forms of nitrogen by ammonifying bacteria, decreased the number of nitrifying bacteria, denitrifying bacteria and net nitrification, and increased the cellulose degradation activity of soil. In conclusion, our experiment showed that PO combined with mineral fertilizer is a most promising compound for inhibiting nitrification, which increased N fertilizer availability and efficiency to the cotton plants.

KEYWORDS

Urea, MAP, nitrification inhibitor, cellulose decomposition, microorganisms

INTRODUCTION

Nitrogen fertilizers in the form of urea are commonly applied in Uzbekistan in order to increase cotton yield in low fertile soils. The NO_3 formed through nitrification of urea is susceptible to loss by leaching and may contribute to NO_3 pollution of ground- and surface waters. Treatments of fertilizers with nitrification inhibitors have been suggested as a technique to reduce the nitrification rate and NH_3 volatilization (Malzer, 1979; Malhi and Nylorg, 1982; McCarty and Bremner, 1990; Freney *et al.,* 1992). Nitrification inhibitors may potentially reduce NO_3^- losses by leaching from NH_4-N, liberating fertilizer materials, including organic N sources, by maintaining N as NH_4^+, which is less susceptible to loss from the soil by this route, and NH_3 volatilization (Bremner and Krogmeier, 1989; Smith and Hadley, 1992; Poberejskaya *et al.,* 1993; Kholdebarin *et al.,* 1998). The soil microorganisms are thus of great importance to the nitrogen nutrition of the crop vegetation. They are sensitive to changes in the surrounding soil (Hodges, 1990; Schinner and Sonnletner, 1996). It has been shown that the microbial population changes after fertilization (Hyman *et al.,* 1990; Dobbs, 1992; Anonymous, 1992). Fertilizer can directly stimulate the growth of microbial populations as a whole by supplying nutrients and may affect the composition of individual microbial communities in the soil (Khonje *et al.,* 1989; Sarathchandra *et al.,* 1989; Khamis *et al.,* 1990).

The effects of the nitrification inhibitor, Potassium oxalate, with a combination of fertilizers (200kg ha^{-1}) on the soil microbial population has been studied in our previous work experiments. In this study we reduced the amount of fertilizer combined with Potassium oxalate. The purpose of this study was to investigate the influence of mineral fertilizer (150 kg ha^{-1}) combined with potassium oxalate on the soil microbial population and the activities and nitrification rate in nitrogen deficient calcareous soil Uzbekistan under cotton cultivation.

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MATERIALS AND METHODS

Study Site and Soil Sampling

Sites used in this study represent continuously cultivated (more than 50 years) cotton fields located in Kalinin province, the northeastern part of Uzbekistan. The soil type is calcareous Calcisol having a calcic horizon within 80 cm of the surface. The orchic horizon is low in organic matter. The climate is semi arid with mean annual air temperatures of 16°C and 18°C, and mean annual rainfalls of 200 mm. Soil samples were taken from the top 10 cm of soil from an existing cotton field. The cores were pooled and field-moist soils were sieved (<2mm) directly after collection. The soil samples were kept in black polyethylene bags and stored at 4∞C. These “fresh” field-moist, sieved samples were used for the incubation study.

Pot experiments

Soil microbial activity and N transformation in soils amended with the mineral fertilizers and combined with potassium oxalate were studied in small pots in laboratory experiments with three replicates. Field-moist sub samples (1kg) of each treatment replicate were placed in pots and treated with N as Urea at a rate of 150 mg kg^{-1} soil. P was supplied as MAP at a rate of 140 mg P kg^{-1} soil and Potassium chloride at a rate of 60 mg K kg^{-1} soil. PO was added to urea and MAP at a rate of 2%. The control pots ($N_0P_0K_0$) received neither PO nor fertilizer. Two treatments: $N_{150}P_{140}K_{60}$ (T1) and $N_{150PO}P_{140}K_{60}$ (T2) were applied for this study. The tested pots were then placed in incubators maintained at 27°C for 45 days.

Soil chemical and physical analysis

Air-dried samples were analyzed for the total C, N, P, K and Mg contents. Soil particle distribution was determined using sodium phosphate. The soil chemical and physical properties are presented in Table 1. The total carbon content, C_{tot}, was identified by elementary analysis while total nitrogen, N_{tot}, content was determined by the Kjeldahl method. The molybdenum blue method determined the total phosphorus content, P_{tot}, in soil. Potassium, K, was determined using the Flame Photometric Method (Riehm, 1985). The Atomic Absorption Spectrophotometer (AAS) was employed to measure calcium chlorite ($CaCl_2$) and extractable magnesium (Schachtachnabel and Heinemann, 1974). Soil pH-value was measured by means of electrometer.

Soil microbiological analyses

After 45 days pots were removed from the incubation and were analysed for microbiologic tests. A plate dilution method was used for the determination of numerous microorganisms using agar medium. In order to count the number of microorganisms, 10 g of soil was shaken with 90 ml of ster.-distilled water. From this suspension the serial dilution (1:10) was prepared and plate counts were performed in triplate and incubated until growth occurred (usually 3-7 days). CFU of ammonifying bacteria were enumerated on glycerine peptone agar. Mediums containing 10 g of starch, 2 g of $(NH_4)_2SO_4$, 1 g of K_2HPO_4, 1 g of $MgSO_4$ and 3 g $CaCO_3$, 1 g of NaCI and 15 g of agar l^{-1} were used for mineral assimilating bacteria. Nitrifying bacteria were determined on plates containing 2 g of $(NH_4)_{2SO4}$, 1 g of K_2HPO_4, 0.5 g of $MgSO_4$, 0.1 g $FeSO_4$, 5 g $CaCO_3$, and 0.4 g NaCl l^{-1} of liquid medium. Denitrifying bacteria on Giltay medium containing 1 g KNO_3, 1g KH_2PO_4, 1g K_2HPO_4, 2 g $MgSO_4$, 0.2 g $CaCI_2$, 0.1 mg $FeCI_3$, 0.1% solution of brom thimolblue, oligotrophic bacteria on soil agar containing 900 ml water, 100g soil, 18g agar L^{-1}, oligonitrophilic bacteria and *Azotobacter* were determined on Eshbi agar containing 0.2 g K_2HPO_4, 0.2 g $MgSO_4$, 0.2 g of NaCl, 0.1 g K_2SO_4, 5 g $CaCl_2$, 20 g sacharosa, and agar 15 gl^{-1}.

Soil biochemical measurements

Cellulose degrading activity of soil was measured according to Swyaginzew (1987). Cellulose material was placed into soil for an incubation period of 45 days. After 45 days the material was removed and the cellulose degradation percentage was analyzed. Net nitrifications were measured by incubating the soil samples with the soil moisture content adjusted to 60% of the WHC at 28°C for 45 days. The method used is described in detail in Aristowskaya (1962). The data were analyzed using the statistical analysis of variance by Tepper (1974).

RESULTS AND DISCUSSION

Changes in soil microbial populations

T1 and T2 decreased the number of oligotrophic bacteria compared to the control (Table 2). A decreasing of coloniza-

Table 1. Chemical and physical parameters for the 0-30cm depth.

Chemical						Physical		
C_{tot}	N_{tot}	P	K	Mg	pH	Sand	Silt	Clay
----------- mg $100g^{-1}$ ---------						----------- % -----------		
200	.6	3	12	6	8.5	2.2	54.5	9.4

tion frequency of oligotrophic bacteria after inhibitor nitrification in cotton plants has been also reported (Poberejskaya *et al.,* 1993). Oligotrophic microorganisms are able to survive in low nutrient content soil. An input of a high concentration of nutrients inhibited their activity. The T1 and T2 decreased the number of mineral assimilating bacteria (Table 2). In particular, decreasing soil water potential following mineral N application and declining pH resulting from nitrification of NH_4^+sources are known to reduce the activity of mineral assimilating microorganisms (Soderstrˆm *et al.,* 1983).

Table 2. Effect of mineral fertilizer combined with potassium oxalate (PO) on the number of oligotrophic. ammonifying and mineral assimilating bacteria (10^6cfu g^{-1} soil)

Treatment	Oligo-trophic	Ammoni-fying	Mineral assimilating
$N_0P_0K_0$	184.0 ± 0.62	7.7 ± 0.25	94.7 ± 0.59
$N_{150}P_{140}K_{60}$	10.6 ± 0.51	8.9 ± 0.55	27.4 ± 0.62
$N_{150\,PO}P_{140}K_{60}$	50.0 ± 0.77	4.5 ± 0.47	17.2 ± 0.83

The number of ammonifying bacteria were reduced by T2 (Table 2). That shows the utilization of mineral forms of nitrogen in soil on the background of reducing the quantity of ammonifying bacteria. A decreased number of ammonifying bacteria after the application of the nitrification inhibitor in Calcisol soil has been reported early (Poberejskaya *et al.,* 1993). The decrease in microbial indices in the fertilizer treatments could indicate a change in the quality of organic matter to a less available substrate for ammonifying bacteria than in the no fertilized soil (Nohrsedt *et al.,* 1989). An increased population of oligonitrophilic bacteria 3-6 times compared to that of controlled was found after T1 and T2 (Table 3). All treatments had no negative effect on nitrogen fixing bacteria *Azotobacter* (data not shown). According to (Miyan *et al.,* 1986; Kucharski, 1991; Govedarica *et al.,* 1999), the treatments of nitrification inhibitors also increased the number of oligonitrophilic bacteria and had no negative effects on *Azotobacter.*

Treatments T1 and T2 decreased the number of nitrifying bacteria compared to the control (Table 3). The results showed that PO inhibited nitrifies, which was reflected in the reduced NO_3^+ losses by leaching from fertilizer material. Other authors also reported that Thiourea inhibited the nitrifying activity of nitrifies, which reflected in the increased availability and efficiency of fertilizer nitrogen to the rice plants and indicated a potential as a nitrification inhibitor (Fog, 1988; Witthaya and Thongpan, 1987).

Table 3. Effect of mineral fertilizer combined with potassium oxalate (PO) on the number of oligonitrophilic denitrifying and nitrifying bacteria (10^6cfu g^{-1} soil)

Treatment	Oligonitro-philic	Denitrifying	Nitrifying
$N_0P_0K_0$	2.6 ± 0.90	700.0 ± 0.59	0.110 ± 0.79
$N_{150}P_{140}K_{60}$	12.7 ± 0.67	70.0 ± 0.65	0.25 ± 0.49
$N_{150\,PO}P_{140}K_{60}$	7.3 ± 0.59	60.0 ± 0.38	0.13 ± 0.55

The number of denitrifying bacteria with T2 significantly decreased 12 times in comparison with the control (Table 3). Denitrifying activity is an indicator of the carbon mineralization of soil. Nitrogen fertilization may result in an unbalanced nutrient composition in the soil, which can reduce the denitrifying activity of bacteria. Nitrification inhibitors have a very marked effect on production of N_2 and N_2O through the reduction of NO_3 by denitrifying microorganisms because it blocks the reduction of N_2O to N_2 by these microorganisms (Yoshinari and Knowles, 1976). It also has been found that urea fertilization increases the pH value and results in decreased microbial biomass and activity (Nˆmmik and Wiklander, 1983).

Changes in biochemical properties

The application of fertilizer increased net nitrification 7 times compared to the control (Table 4). T2 decreased the net nitrification compared with fertilizer alone. Nitrification inhibitors reduced the rate of nitrification and so increased the thermal-time required for NH_4-N depletion and NO_3-N accumulation in soil amended with NH_4-N forming materials compared with fertilizer alone. Some authors suggested the reduction of nitrification after application of nitrification inhibitors Malhi and Nylorg, 1982; Hyman *et al.,* 1990; Smith and Hadley, 1992). Our results indicate that PO slows the rate of nitrification and may effectively reduce potential NO_3^- leaching losses.

To assess the potential value of a PO in soil, it is important to have information concerning other trials' formations of N in soil. The study of the effect of PO on cellulose degradation activity in soil showed that T1 and T2 increased the cellulose degradation activity of soil, which shows the increasing number of cellulose degrading microorganisms (Table 4). Other authors also found that after application of mineral fertilizers, the number of cellulolytic microorganisms became higher (Govedarica *et al.,* 1999).

Table 4. Effect of mineral fertilizer combined with Potassium oxalate (PO) on the net nitrification and cellulose degradation activity of soil.

Treatment	Net nitrification	Cellulose degradation
	mg N-NO_3 100g^{-1} soil	----- % -----
$N_0P_0K_0$	2.15 ± 0.72	0.8 ± 0.85
$N_{150}P_{140}K_{60}$	12.15 ± 1.14	12.3 ± 1.04
$N_{150\,PO}P_{140}K_{60}$	6.98 ± 1.00	3.75 ± 1.98

CONCLUSIONS

It was clearly demonstrated that fertilization supplied with nitrification inhibitors influenced soil microorganisms. All combinations of mineral fertilizers combined with PO during the incubation had an inhibitory effect on the activity of oligotrophic bacteria, ammonifying bacteria, and denitrifying bacteria. The marked stimulus effect on the number of bacteria during the incubation was achieved with T2 and the lowest with T1. To summarize, the work reported in this paper suggests that PO combined with mineral fertilizers had no adverse effects on the biological nitrogen fixing bacteria *Azotobacter* and increased the activity of oligonitrophilic bacteria and increased the cellulose degrading activity in soil. PO indicated potential as nitrification inhibitors for the soil of urea used in this study. The treatment T2 decreased the net nitrification compared with fertilizer alone. In conclusion PO is one of the promising nitrification inhibitor compounds for reducing potential NO_3^- leaching losses by nitrifying microorganisms from materials during cotton plant establishment.

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EFFECTS OF COVER CROP RESIDUE MANAGEMENT ON THE SOIL SURFACE INVERTEBRATE COMMUNITY

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ABSTRACT

Effects of different methods for managing residues from a rye (*Secale cereale* L.) cover crop on insects and other arthropods active on the soil surface were determined in a field experiment in north central Florida. Treatments consisted of five methods for managing the cover crop: 1) rye combined and remaining residues left on the untilled soil surface; 2) rye mowed, residues removed, plots not tilled; 3) rye mowed, residue left on surface, plots not tilled; 4) rye mowed, residues removed, plots conventionally tilled; 5) rye mowed, residues left on surface, plots conventionally tilled. Arthropod populations were monitored using pitfall traps in a subsequent peanut (*Arachis hypogaea* L.) crop. Most arthropods showed distinct seasonal population trends, becoming more abundant as the growing season progressed. An exception occurred with the *Hypogastrurid Collembola*, which reached unusually high levels (>10,000 per sample) shortly after planting. Most arthropod groups were not consistently affected by the cover crop residue management treatments, although at the end of the peanut crop, total numbers of arthropods were most abundant in the untilled plots in which mowed residues had been left on the plots. Possibly the surface residues offered cover and a habitat favorable to the soil surface invertebrate community.

KEYWORDS

Arthropods, conservation tillage, insects, peanut, rye

INTRODUCTION

Interest in agronomic systems conserving N and soil fertility has been increasing steadily, and the use of cover crops has become more prevalent in such systems (Powers and McSorley, 2000). It is of interest that until inexpensive synthetic N fertilizers became available, cover crops were often used (Bugg and Dutcher, 1989). The use of cover crops is an appealing option since they can both improve the soil fertility and contribute to insect pest management (Bugg and Dutcher, 1989; Bugg *et al*., 1990).

Many insects inhabit the soil surface and the litter layer, using debris for cover (Coleman and Crossley, 1996), and the cover crop used will affect the quality and amount of litter present. The influence that the tillage system and the cover crop will have on pest problems related to future cash crops is contingent on the cover crop, the insect, and the tillage environment (All and Musick, 1986). Both indirect and direct impacts have been noted on habitat suitability for soil invertebrates as a result of different tillage operations in which the intensity of mechanical disturbance varies (Neave and Fox, 1998). Due to the variable nature of these many factors affecting the soil and litter environment, predicting the sorts of changes that may occur or how they might influence existing invertebrate communities is often uncertain.

Effects on the invertebrate community at the soil surface depend on the available cover crops and management practices at our disposal. Research has been completed in parts of California (Altieri and Schmidt, 1985), Massachusetts (Bugg and Ellis, 1990), and Georgia (Bugg and Dutcher, 1989; Bugg *et al*., 1990) illustrating the differences in soil surface invertebrate populations due to choices of various cover crops or to usage of conventional versus conservation tillage practices.

The management of residues from cover crops may also effect soil invertebrate populations in conservation tillage systems. Nematodes in soil were not affected whether cover crop residues were removed as forage or retained on plots as green manure (McSorley and Gallaher, 1994). However, the presence of crop residues on the surface may be more critical for insects and other arthropods that typically reside on the soil surface in debris or litter. The objective of our study was to determine the effect of tillage and cover crop residue management on the "soil" surface invertebrate community (i.e., those invertebrates active at the soil surface and litter layers).

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MATERIALS AND METHODS

The study was located at the former University of Florida Green Acres agronomy farm in Alachua County (29E40'N, 92E30'W), about 5 mi northwest of Gainesville, Florida. The soil type was Arredondo fine sand, a loamy, siliceous, hyperthermic, Grossarenic Paleudults, with 90-92% sand, 4-5% silt, and 4-6% clay, with <2.0% organic matter and pH 5.6-5.9. The study site was planted with a cover crop of 'Wrens Abruzzi' rye at 90 lbs acre^{-1} 20 Nov. 1999. On 8 May 2000, the rye cover crop was terminated, and the following five treatments were applied: 1) rye was combined and residues remaining after combining were left on the untilled soil surface; 2) rye was mowed (stubble <2-3 in tall), residues removed, and plots not tilled; 3) rye was mowed, residues left on the soil surface, and plots not tilled; 4) rye was mowed, residues removed, and plot was conventionally tilled; 5) rye was mowed, residues left on the surface, and plot was conventionally tilled. Conventional tillage consisted of three passes of a rototiller tilling to a depth of 6 to 8 in. The five residue management treatments were arranged in a randomized complete block design with five replications. Individual plots were 25 ft x 20 ft in size. Plots were planted with''Georgia Green' peanut on 11 May 2000 at a density of 380 seeds per 25-ft-long row. At planting, 50 lbs acre^{-1} of muriate of potash was applied as fertilizer. Plots were irrigated as needed using overhead sprinkler irrigation. Plots were sprayed 28 days after planting for weed control using a mixture of Starfire at 11 oz acre^{-1} + Storm at 1.5 pt acre^{-1} + Activate Plus (25%).

Samples of insects were collected on 28 May, 20 July, and 26 Sept. 2000. A plastic sandwich container (5.5 in x 5.5 in x 1.5 in) was used as a pitfall trap (Borror *et al.*, 1989). Pitfall traps typically recover a wide range of soil-surface-dwelling insects, including pest and beneficial species (Duelli *et al.*, 1999). Each pitfall trap was centrally placed in a plot between two rows of Georgia Green peanuts, buried so that the upper edge was flush with the soil surface. The traps were filled three quarters of the way with water

Table 1. Arthropod numbers in pitfall traps from cover crop residue management experiment conducted in 2000. Data are means of 25 traps, pooled across crop management treatments and replicates.

Residue treatment	28-May	20-Jul	26 Sept.
	------------------- count per trap ------------------		
Acari (mites	0.4 b†	0.8 b	4.4 a
Araneae (spiders)	0.3 b	0.7 b	5.9 a
Coleoptera:Carabidae (ground beetles)	0.4 b	0.2 b	2.8 a
Coleoptera:Cicindelidae (tiger beetles)	0.1 b	1.9 a	0.2 b
Coleoptera:Elateridae (wireworms)	1.0 a	0.6 a	0.2 a
Total Coleoptera (beetles)	3.6 a	4.0 a	3.8 a
Collembola:Entomobryidae	0.1 a	7.4 b	16.9 a
Collembola:Hypogastruridae	11447.7 a	30.2 b	4.6 b
Total Collembola (springtails)	11447.8 a	37.8 b	21.6 b
Dermaptera (earwigs)	0.1 b	0.5 ab	1.0 a
Diptera (flies)	0.1 b	8.0 a	7.8 a
Hemiptera (true bugs)	0 c	2.6 b	5.1 a
Homoptera (leafhoppers)	0 b	3.0 b	9.3 a
Hymenoptera:Formicidae (ants)	1.7 b	23.2 ab	41.2 a
Hymenoptera (wasps)	0 b	2.2 a	3.1 a
Total Hymenoptera	1.7 b	25.4 ab	44.3 a
Orthoptera (crickets)	0.1 b	0.1 b	4.0 a
Orthoptera (grasshoppers)	0 b	0.4 ab	0.9 a
Total Orthoptera	0.2 b	0.9 b	5.8 a
Thysanoptera (thrips)	0 a	0.6 a	0.2 a
Total Arthropoda	11453.9 a	76.8 b	87.2 b

†Means within rows followed by the same letter are not significantly different (P = 0.01), according to Duncan's multiple-range test.

Table 2. The effect of rye cover crop residue management on the number of mites, spiders, and beetles in pitfall traps during the 2000 season. Data are means of five replicates.

Residue treatment	28-May	20-Jul	26 Sept.
	---------- count per trap	--------------	
Acari (mites)			
Combined, residue left on plot	0.2 a[†]	2 a[†]	2.4 a[‡]
Mowed, residue removed	1.4 a	0.6 a	0.6 a
Mowed, residue left on plot	0.2 a	0 a	0.6 a
Mowed, residue removed, cultivated	0 a	1.2 a	2.6 a
Mowed, residue left, cultivated	0.2 a	0 a	15.8 b
Araneae (spiders)			
Combined, residue left on plot	0 a[†]	0.6 a[†]	3.6 a[†]
Mowed, residue removed	0.2 b	0.6 a	6.6 a
Mowed, residue left on plot	0.4 ab	0.6 a	6.8 a
Mowed, residue removed, cultivated	0.8 a	1.0 a	3.6 a
Mowed, residue left, cultivated	0.2 b	0.8 a	7.8 a
Carabidae (ground beetles)			
Combined, residue left on plot	0 a[†]	0.8 a[†]	2.2 a[†]
Mowed, residue removed	1.00 a	0.2 a	3.0 a
Mowed, residue left on plot	0.80 a	0.2 a	3.4 a
Mowed, residue removed, cultivated	0 a	0 a	1.6 a
Mowed, residue left, cultivated	0 a	0 a	3.6 a
Total Coleoptera (beetles)			
Combined, residue left on plot	1.4 a[†]	4.8 a[†]	3.2 b[‡]
Mowed, residue removed	6.0 a	3.6 a	3.2 b
Mowed, residue left on plot	3.0 a	3.8 a	6.0 a
Mowed, residue removed, cultivated	5.6 a	5.2 a	2.0 b
Mowed, residue left, cultivated	2.8 a	2.6 a	4.4 ab

[†] For each arthropod group, means within columns followed by the same letter are not different ($P = 0.10$), according to Duncan's multiple-range test.

[‡] Means within these groups were separated at $P = 0.05$ according to Duncan's multiple-range test

along with 3 to 4 drops of dish detergent (Ultra Joy®, Procter & Gamble, Cincinnati, OH), which was added to break the surface tension, ensuring the insects would remain in the trap. Pitfall traps were set out in the morning before noon (Eastern Daylight Savings Time) and collected the next day (recorded as sampling date) before noon. The traps were transported to the lab, placed in a cold room at 50°F, and then contents were transferred to vials and stored in 70% alcohol. Sample counts were completed using a dissecting microscope and specimens were identified to order or family where possible. All data were subjected to analysis of variance using MSTAT-C software (Freed *et al.*, 1991). Where significant ($P = 0.10$) F-tests occurred, differences among means were determined using Duncan's multiple-range test (Freed *et al.*, 1991).

RESULTS AND DISCUSSION

A variety of different arthropod groups (mostly insects but some mites and spiders) were collected at this site. The abundance of most arthropods was greatly affected ($P = 0.01$) by sampling date. Significant effects (even at $P = 0.10$) from crop residue management treatment and interactions (date x crop residue treatment) were observed much less frequently. The seasonal effects are summarized for the most common arthropod groups (Table 1). Most arthropods became more abundant later in the season, as the growth of the peanut plants progressed. An important exception occurred with the *Hypogastrurid* springtails, which reached unusually high numbers in all plots on 28 May but declined rapidly thereafter (Table 1). These minute fungivorous insects are abundant in litter, and their ability to rapidly increase

Table 3. The effect of rye cover crop residue management on the number entomobryid springtails, flies, and total arthropods in pitfall traps during the 2000 season. Data are means of five replicates.

Residue treatment	28-May	20-Jul	26 Sept.
	----------------- count per trap -----------------		
Entomobryidae (springtails)			
Combined, residue left on plot	0 a†	20 a‡	10.8 b†
Mowed, residue removed	0 a	6.8 b	12.4 b
Mowed, residue left on plot	0 a	2.8 b	26.6 a
Mowed, residue removed, cultivated	0.2 a	4.8 b	15.2 b
Mowed, residue left, cultivated	0.2 a	2.8 b	19.6 ab
Diptera (flies)			
Combined, residue left on plot	0 b†	4.6 b†	7 a†
Mowed, residue removed	0 b	9.4 ab	5.4 a
Mowed, residue left on plot	0 b	5.2 b	9 a
Mowed, residue removed, cultivated	0 b	14.8 a	6.6 a
Mowed, residue left, cultivated	0.4 b	6.2 b	10.8 a
Total Arthropods			
Combined, residue left on plot	10,141.8 a†	73.8 a†	65.8 b†
Mowed, residue removed	9,578.4 a	130.2 a	83 b
Mowed, residue left on plot	10,616.8 a	57.2 a	133.8 a
Mowed, residue removed, cultivated	14,539.0 a	57.8 a	59.4 b
Mowed, residue left, cultivated	12,393.4 a	64.8 a	93.8 ab

†For each arthropod group, means within columns followed by the same letter are not different (*P* = 0.10), according to Duncan's multiple-range test.

‡Means within these groups were separated at *P* = 0.05 according to Duncan's multiple-range test

population size and form large aggregations is well known (Coleman and Crossley, 1996). The reason for the large population peak in this experiment is not known. Numbers of these springtails were unaffected (*P* = 0.10) by the cover crop management treatments that resulted in very different amounts of residue on the plots.

Arthropod groups for which significant (*P* = 0.10) residue treatment effects or interactions were observed are summarized (Tables 2, 3). Interactions (date x treatment) resulted from the fact that treatment effects were significant (*P* = 0.10) on some sampling dates but not on others (Tables 2, 3). At the end of the season, total arthropods were most abundant (*P* = 0.10) in uncultivated, mowed plots in which residues were left on the plots (Table 3). This trend was also observed on the same date with *Entomobryid* springtails and total numbers of beetles (Tables 2, 3). Presumably, the greater amount of residue remaining on these plots offered cover and habitat for these surface-dwelling insects. Other effects from the residue management treatments were less consistent.

Typically, conventional tillage is disruptive to soil invertebrates, especially larger organisms such as earthworms, spiders, and ground beetles (Coleman and Crossley, 1996; Wilson-Rummenie *et al.*, 1999). In a recent study, population levels of several soil invertebrate groups were inversely proportional to the amount of tillage that had occurred (Wilson-Rummenie *et al*., 1999). Perhaps the differences observed in the current study were not as great as those expected based on previous work. For example, ground beetles, which comprised the largest group of beetles collected on the final sampling date, were unaffected by treatment at that time (Table 2). It is possible, however, that the plot size used (500 ft^2) was too small to effectively assess these wide-ranging, active predators that could run easily from plot to plot. Use of larger plots may address this problem, and in a subsequent study in spring 2001, much larger plots (3600 ft^2) were used (Tremelling *et al*., unpublished).

Much remains to be learned about the influence of tillage and residue cover on specific groups of soil arthropods. These practices can affect both predators and pests (Wilson-Rummenie *et al*., 1999), and so data from each location must be carefully evaluated to determine potential benefits or risks that may result.

CONCLUSIONS

Population levels of most groups of arthropods inhabiting the soil surface increased over time during the course of a peanut crop. At the end of the peanut crop, greatest total numbers of arthropods occurred in untilled plots on which the residues of the previous cover crop were retained. The effects of cover crop residue management on specific groups of arthropods were generally inconsistent and inconclusive. Such effects likely vary with specific locations and crops, and in some cases, relatively large plot sizes may be needed to assay active, wide-ranging insects.

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SOIL MICROARTHROPODS: BIOINDICATORS OF CONSERVATION MANAGEMENT PRACTICES

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INTERPRETIVE SUMMARY

Microarthropods are important components of the soil decomposer food web. Organic matter is a major influence on microarthropod abundance and diversity. Conservation practices that increase soil organic matter improve soil quality by supporting the development of the soil biotic community. The microarthropod community is a positive feed back for improved soil quality. Microarthropods use organic matter, regulate other decomposers in the soil food web, and aid in the release of nutrients bound up in residues and microbial biomass (bacteria and fungi). Microarthropods also contribute to soil aggregation with the production of fecal materials. Our objective is to compare the impact of two cover crops (legume blend, rye-legume blend) and examine changes with successive years under conservation strip tillage on microarthropod abundance and diversity.

Four fields in Tift County, Georgia were selected for this study. At each of the four fields two cover crops were grown, a legume blend and a rye plus legume blend. All fields are planted to cotton for the summer growing season. Each cover crop field was divided into four quadrats. We began sampling microarthropods in the four fields at the initiation of conservation practices. Sampling occurred at the end of the first winter cover crop season and at the mid and end of season for summer crop and the successive winter cover crop. Five subsamples for microarthropods were taken within each quadrat, within a 3-meter radius of each other at successive sample dates. We will sample twice during each growing season of cotton and winter cover for two consecutive years.

Microarthropods were extracted by a 5-watt heat source from intact soil cores (5 cm by 5 cm) inverted over a funnel and collection jar filled with 70% ethanol. Organisms were identified to major groups of Insecta (I) and Acari (A): Collembola (I), Insect larvae/nymph (Coleoptera, Diptera, Hemiptera/Homoptera), Prostigmata (A), Astigmata (A), Mesostigmata (A), and Oribatida (A).

We have completed sampling for the first year of cover crop and cotton seasons. Seasonal changes in abundance of mites for the first year were driven by soil moisture content. Prostigmata were the most abundant across all fields and seasons. Astigmata were extremely rare. The diversity of microarthropods increased in mid season cotton samples. Abundances and diversity across cover crops and seasons remain to be calculated for the second year. Statistical comparisons between seasons and cover crops will be made after the second year of sampling.

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IMPACT OF DEEP RIPPING OF PREVIOUS NO-TILLAGE CROPLAND ON RUNOFF AND WATERQUALITY

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ABSTRACT

Long-term conservation tillage practices might lead to soil compaction in some soils, altering water and chemical movement and resulting in environmental problems. The problem gets exacerbated where restrictive soil horizons are near or close to the surface. Farming practices are needed that allow a loosening of such natural or human-induced restrictive layers so as to reduce water runoff and associated off-site chemical losses. We have been monitoring surface runoff volume and associated nutrient concentrations since 1998 from four catchments that have been under a no-till cropping system for at least ten years. We paratilled two of the catchments every fall during this experiment to a depth of 12-16 in. We have found that runoff volume is significantly reduced from the catchments that have been paratilled. While the effect of paratilling on nitrate-nitrogen (NO_3-N) and soluble orthophosphate (PO_4-P) loss is not yet clear, losses of iron (Fe) and aluminum (Al) have been higher from the paratilled catchments, suggesting that any surface soil disturbance to a long standing no-till system could lead to immediate disruption of an established equilibrium. An ongoing severe drought reduced the potential data set from the experiment.

KEYWORDS

Conservation tillage, no-till, paraplow, paratill

INTRODUCTION

Large areas of eroded, degraded soils exist in the Southeast because of poor row crop production practices. Trimble (1974), Langdale *et al.* (1992), and others attribute this to intensive tillage practices that decrease soil organic matter content and leave soils vulnerable to the erosive action of intense rainfall. The challenge to restore degraded land to improve productivity, curtail environmental degradation of water and land resources, and develop a favorable and sustainable ecological balance has been met through improved farming systems. Such systems include, among others, converting cropland to pastures and forests and minimizing tillage. Adoption of conservation tillage for major crops such as cotton and soybeans has risen in the Southeast in recent times. According to CTIC (2000), about 20% of the cotton and 58% of the soybeans in the Southeast are now under no-till. Agricultural sustainability is a dynamic concept, however. As new farming systems are put in place to alleviate past problems, their short and long-term impacts need to be understood. This is true in particular due to regional variations in soil type, climate and landscape ecology.

The national drive for increased adoption of conservation tillage practices in US agriculture indicates general acceptance of its economic and environmental benefits. The scientific literature is mixed, however, on the effect of conservation tillage on the hydraulic and physical properties of various soils. Restricted plant rooting due to increased soil density is sometimes reported with no-till planting (West *et al.*, 1996; Griffith *et al.*, 1992). The Cecil soil series has a restrictive sub-surface horizon, which often times lies close to or at the surface due to past erosion. A restrictive horizon coupled with potential compaction from no-till farming could exacerbate environmental problems associated with water and chemical movement.

Pidgeon (1983) described the Paraplow, an implement that can be used to loosen soil without inversion to a depth of 14-16 in. with minimal disturbance of residue on the soil surface. The implement loosens soil by lifting it and dropping it back down with legs or shanks, angled at the side at 45 degrees from the horizontal. The soil fractures along zones of weakness as it is lifted and stays loose with increased storage and conductivity after it is dropped back. A disc coulter is used ahead of the each leg to reduce soil surface disturbance and cut previous crop residue. West *et al.* (1996) made distinctions between the "Paraplow", where the legs are attached to a moldboard frame at 20" spacing, and the "Paratill", where the legs are mounted on a square toolbar frame with variable spacing. The Paraplow and Paratill are available in four, six, and eight-leg models (West *et al.*, 1996). Pidgeon (1983) found that the Paraplow increased water infiltration while preserving residue cover.

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The objective of this study was to evaluate surface water runoff volume and associated nutrient and mineral concentrations from a long-standing no-till cropping system on a Cecil soil with or without paratilling.

MATERIALS AND METHODS

BACKGROUND, SITE AND SOIL

The study site is located at the USDA-ARS, J. Phil Campbell Sr. Natural Resource Conservation Center near Watkinsville, GA (83°24' W and 33°54' N). The Center has a rich history of research into abating soil erosion problems in the Southern Piedmont land resource area (Hendrickson and Barnett, 1963; Adams and Dawson, 1964; Carreker *et al*., 1977; Langdale and Moldenhauer 1995; Endale *et al*., 2000). As part of this effort, the four catchments used in this research were established in 1972. The research has produced a wealth of information into infiltration and runoff, soil and chemical loss, and residue management and dynamics in response to management of such summer crops as soybeans, grain sorghum, millet, corn and cotton under conventional and conservation tillage, with fallow and such cover crops as barley, wheat, rye, and crimson clover.

The four catchments designated as P1, P2, P3, and P4 have areas of 6.69, 3.19, 3.11 and 3.46 acres, respectively. P3 and P4 are immediately adjacent to each other and are separated by 1.8 and 2.3 miles from P2 and P1, respectively. The catchments represent common land forms of the Southern Piedmont. Cecil sandy loam soil (fine, kaolinitic, thermic, Typic Kanhapludults) dominates the catchments. Typic Kanhapludults cover approximately two-thirds of the 34.8 million acres available for cropping in the Southern Piedmont (Langdale *et al*., 1992). The Cecil soil series generally consists of deep well-drained and moderately permeable soils. Saturated hydraulic conductivity of the Bt horizon is < 0.4 in. hr^{-1}, while for horizons above it can reach 6-8 in. hr^{-1}. Mean annual precipitation is 49 in. and temperature is 62°F. The spring-summer cropping season coincides with the season of high rainfall energy.

Slopes on P3 and P4 range from 1.5 to 3% and both have had a grass waterway bisecting them to channel runoff towards measuring flumes. Slopes on P1 and P2 range from 2 to 7% and P1 also has had a grass waterway. There has not been a grass waterway on P2. All grass waterways were incorporated into the catchments at the start of this research. The top of the Bt horizon generally lies within 20 in. of the surface in all catchments.

P1 has been under a continuous doubled cropping conservation cropping system since 1975. The other three had been managed under both conventional and conservation tillage prior to 1990 but only conservation tillage since.

ARRANGEMENT

We began this study in 1998. P1 and P3 were left in continuous no-till while P2 and P4, which have also been under no-till, were paratilled in mid to late October or November of each year to 12-16 in. depth. Summer crops were Maize (*Zea mays*) in 1999, pearl millet (*Pennisetum glaucum*) in 2000, and grain sorghum (*Sorghum bicolor*) in 2001. Winter cover crops were crimson clover (*Trifolium incarnatum*) on P2 and P3 and rye (*Secale cereale*) on P1 and P4 in 1998/1999, barley (*Hordeum vulgare*) in 1999/2000, and rye in 2000/2001. Crops were fertilized according to soil tests with inorganic N-P-K, as well as broiler litter in July 2000, July 2001, and December 2001 at 1.1 ton $acre^{-1}$. We will refer to P2 and P4 as PT (paratilled) and P1 and P3 as N-PT (non-paratilled) catchments.

Each catchment is instrumented with an automated system that measures rain and runoff and collects discrete water samples over the runoff event. Samples were kept refrigerated on site until collected for analysis. Composite samples were sent to the University of Georgia in Athens, GA for analysis of minerals, and nitrate and phosphate. Rain and runoff data were downloaded form data loggers after the events and processed for statistical analysis with the General Linear Models Procedure of SAS (SAS Inst., 1989).

PRELIMINARY RESULTS

RUNOFF PRIOR TO PARATILLAGE

Runoff from seven storms immediately prior to the start of paratilling is presented in Table 1. Runoff is expressed in cubic feet per acre for direct comparison between catchments, since the areas of P2 to P3 differ slightly and P1 has about twice the area of the others. Considering runoff events above 5 ft^3 $acre^{-1}$, P3 and P4 had runoff from six of the seven storms while P2 had four, and P1 three. Volumetric accuracy of runoff below 5 ft^3 $acre^{-1}$ is not certain. We were unable to measure one of the three events for P1 because of equipment malfunction. The two catchments that were later paratilled (P2, P4) had higher runoff compared to the other two. Runoff from P4 was 1.4 to 3.6 times that from P3 except for the event of 04/05/98, where it was about 28 times. P2 had higher runoff than P3 for three of the events. A linear regression of runoff in response to rainfall showed an R^2 value of 0.84 for P3 and 0.87 for P4. Although runoff between P1 and P2 appear similar, recall that P1 has twice the area.

Over the whole period, total rainfall producing the runoff events was 17.2 in. Runoff in cubic feet per acre per inch of rain amounted to 239 for P1, 274 for P2, 244 for P3, and 379 for P4. P2 had 15% more runoff than P1, and P4 had 38% more runoff than P3.

Table 1. Total runoff for plots 1-4 from seven storms in 1998 before paratillage started. P1 and P2 had barley, P3 had clover, and P4 had rye during this period

Date	Rainfall	P1	P2	P3	P4
	inches	----------- ft^3 acre^{-1} -----------			
01/07/1998	2.10	431	542	90	187
01/22/1998	0.87	<5	<5	<5	129
02/03/1998	4.67	†	2059	1716	2759
03/08/1998	4.81	3670	2085	1995	2744
04/05/1998	2.48	<5	<5	6	176
05/03/1998	1.24	<5	<5	143	509
05/08/1998	1.02	<5	13	246	<5

†Not determined due to equipment malfunction

Runoff after paratillage

Runoff from nine storm events after paratilling started is presented in Table 2. The effect of paratilling in reducing runoff is clear. Since P3 and P4 are adjacent to each other and about the same size, the comparison between them is more meaningful. Whereas before paratilling P4 had more runoff than P3 from storms of about 1 to 5 inches, runoff was less for all events of similar magnitude after paratilling. P3 had runoff of 178-1077 ft^3 acre^{-1} from four of the storms, whereas P4 had minimal runoff from these same storm events. The high correlation between rainfall and runoff before paratilling for P4 disappeared after paratilling. The 6.5 in. storm of July 24, 2001 represents a 1 in 50 to 100 year storm and is considered an extreme event. Rainfall that produced the nine, runoff events amounted to 23.6 in. Runoff in cubic feet per acre per inch of rain was 345 for P1, 350 for P2, 442 for P3, and 241 for P4. P2 had just 2% more runoff than P1, down from 15% of the earlier period. But this time P4 had 55% less runoff than P3.

Variance between runoff amounts was high, and the data were, therefore, log-transformed for statistical analysis. Log-means of runoff from P2 and P4 were not statistically significant from those P1 and P3 before paratillage (P = 0.79), but were significantly lower after paratillage (P = 0.06).

Water quality

We do not have a 'before and after' comparative water quality data as that for the runoff, but results of analysis for NO_3-N, PO_4-P, Fe, and Al from seven of the nine post-paratill sampling are presented in Fig. 1 as box plots. We did not run analysis of varience as a statistical test on these. We had samples from the very low flows that showed high concentration of especially Fe and Al. These might bias statistical tests, but nevertheless are included in Fig. 1. Mean concentration for each parameter is indicated by dotted lines inside each box in Fig. 1.

Mean soluble orthophosphate (PO_4-P) concentration from the PT catchments was about half that of N-PT catchments. Variance was higher from N-PT (9.5 for P1 and 34 for P3) than the PT catchments (2.3 for P2 and 0.28 for P4). One of our hypotheses in this experiment, namely that paratilling will induce/encourage less offsite transport of phosphorus, appeared to be correct.

The effect of paratillage is not apparent on the distribution for NO_3-N concentration in Fig. 1. Almost all concentrations were below 10 ppm (mg liter^{-1}), an index often used as an indicator for possible environmental problems. The largest concentration occurred during the extreme event of July 24, 2001 (5.6 to 10.5 ppm).

Concentrations shown in Fig. 1 for Fe and Al are interesting and telling. The Cecil soil series is high in Fe (red color) and Al oxides in subsurface horizons, which had been exposed in many landscapes in the Southern Piedmont due to past erosion. The graph clearly shows that disturbance of the soil surface even in long standing conservation systems can lead to a disruption of the established equilib-

Table 2. Total runoff for plots 1-4 from nine storms after paratillage started. The Cropping system was rye except for: 02/01/1999 clover on P2 and P3, 01/10/2000 all barley, and 07/24/2001 all sorghum.

Date	Rainfall	P1	P2	P3	P4
	inches	----------- ft^3 acre^{-1} -----------			
02/01/1999	3.64	110	98	874	11
01/10/2000	2.15	5	2	279	<5
12/06/2000	2.91	114	109	1077	<5
03/03/2001	1.75	<5	5	242	<5
03/12/2001	1.68	<5	7	179	<5
03/15/2001	1.83	477	125	1106	238
03/20/2001	1.73	15	58	469	85
03/29/2001	1.41	<5	<5	6	<5
07/24/2001	6.56	7436	7885	6213	5356

rium. Although the figures include samples from the very low flows, all runoff from P4 was visually higher in sediment and brown to red in color. P1 has been under continuous double cropped conservation system since 1975 with no surface disturbance other than during no-till planting. Mean Fe loss from P1 was only 0.7 ppm compared to 10.3 from P2 and 21.6 from P4. The variance was only 0.25 for P1 but was high to very high for P3 and P4. Mean Fe concentration from P3 was 5.2 ppm with a variance of 9.7. The history of P3 includes cultivation through the 1980s and before.

The pattern for concentration of Al in runoff water was similar to that of Fe. The highest mean concentration was from P4 (45.3 ppm) followed by P2 (17.4 ppm). Variance was highest from these two catchments. Mean Al concentration from P1 was 1.5 ppm and the variance was 0.96. P3 had a mean Al concentration of 9.7 ppm and a variance of 43.3.

DISCUSSION

We consider these results preliminary not only because of the short period of the study so far, but also because the period has coincided with the drought that had gripped the Southeast since mid-1998. Analysis of monthly rainfall data from 1937 to 2001 showed that annual rainfall varied from 33.7 to 72.3 in. with a mean of 49.1 and a median of 50.2 in. Year 2000 was the 6th driest on record with annual rainfall of 36.1 in., followed by year 2001, which was the 19th driest with 42 inches. Year 1999 was the 21st driest with 43.1 in. annual rainfall. The pattern was similar for the fall,

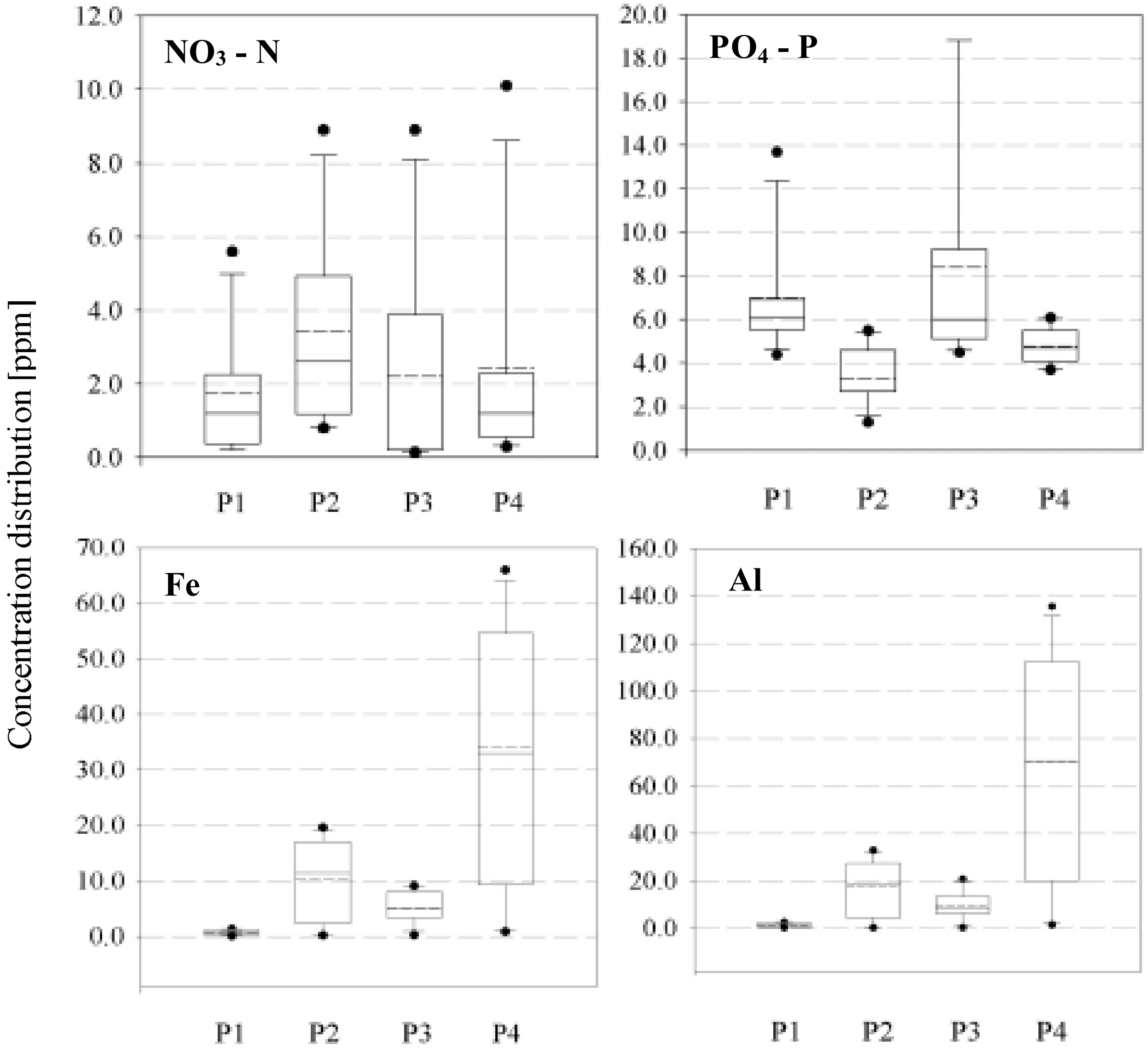

Fig. 1. Distribution of concentrations of NO_3-N, PO_4-P, Fe and Al in ppm (mg liter^{-1}) from seven runoff events, following start of paratillage. Each box shows the 25th percentile, median, and 75th percentile. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots. Means are shown as dotted lines inside boxes.

winter, and spring seasons for periods when the summer crop is harvested and the cover crop has not developed full canopy. Optimum soil moisture is important during paratilling to minimize unnecessary and unintended disturbance of the soil surface. Drier conditions will result in production of larger clods, while wetter conditions could cause plant residue to cling to the cutting edge of the plow and force soil to collect on the surfaces. This problem may have caused rougher surface conditions in P4 that might have lead partly to some of the high Fe and AL losses indicated in Fig. 1. Franzluebbers *et al*. (2002) discuss the effect of paratilling no-till fields on surface-soil distribution of bulk density and organic C and N from this experiment.

CONCLUSIONS

Mean runoff from two small-sized Southern Piedmont catchments with at least ten years of conservation tillage cropping history became less ($P = 0.06$) after paratillage to 12-16 in depth started. The runoff before paratillage started was higher and similar to catchments with similar cropping history that were not paratilled ($P = 0.79$). Loss of the minerals iron and aluminum through runoff was higher from the two paratilled catchments compared to the two others that continued no-till with no paratillage. Paratillage may also have reduced the off-site loss of phosphorus to some degree. The experiment coincided with a period of drought that reduced the expected seasonal rainfall and runoff events, and these results are, therefore, considered preliminary.

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IMPACT OF DEEP RIPPING OF PREVIOUS NO-TILLAGE CROPLAND ON SURFACE SOIL PROPERTIES

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ABSTRACT

The use of continuous no-tillage cropping raises concern about water and nutrient movement into subsoil due to high soil bulk density. Deep ripping (i.e., paraplowing) might be a conservation strategy to loosen surface and subsoil without excessive incorporation of surface crop residues. We initiated a multi-year study comprised of four water catchments (3.1-6.7 acres each) that had previously been under continuous no-tillage cropping for at least 10 years. Two of the water catchments were paraplowed each autumn, but managed otherwise with conservation tillage, similar to the two remaining water catchments. Soil-surface properties were evaluated during the first and second year of the study. Soil bulk density of the surface (20 cm) was significantly lower under paraplowing (1.37 Mg m^{-3}) than under no tillage (1.51 Mg m^{-3}). Soil organic C was significantly greater under paraplowing (10.4 mg g^{-1}) than under no tillage (8.7 mg g^{-1}). Surface residue C was not different between tillage systems in either year. There was no difference in the standing stock of total organic C in residue and soil to a depth of 20 cm between tillage systems in either year. We conclude from these early years of the study that annual paraplowing in combination with conservation tillage management had few negative impacts on soil-surface chemical properties and may have improved soil physical conditions to possibly allow greater water utilization.

KEYWORDS

Bulk density, poultry litter, paraplow, soil organic carbon, total soil nitrogen

INTRODUCTION

Crop management systems can vary greatly in their production potential and impacts on the environment. Tillage is an important management variable that influences long-term sustainability. Restoration of eroded cropland in the southeastern USA has been demonstrated with the development of conservation tillage systems, which limit soil disturbance and allow surface residue accumulation (Langdale *et al*., 1992). Long-term no-tillage management can increase infiltration by increasing soil macroporosity (Edwards *et al*., 1988). Many of the management options for achieving sustainability, however, are regionally specific with variations due to soil type, climatic conditions, and landscape ecology.

Land application of manure provides essential nutrients to crops and helps alleviate waste disposal. Poultry production in the Southern Piedmont is extensive (Census of Agriculture, 1992). Manure is often mixed with bedding material at the end of the production cycle, cleared from confinement housing, and applied as litter (manure plus bedding) to nearby land as a source of nutrients. Depending upon management, however, repeated application of poultry litter could become a source of excessive nutrients (Vervoot *et al*., 1999). Surface application of poultry manure without soil incorporation may potentially cause unwanted nutrient enrichment in surface water runoff, which can be high in the high-rainfall region of the southeastern USA. Of increasing concern is the unbalanced load of P in poultry manure compared with N. Crop production in the southeastern USA benefits greatly from P application, because these soils have a great capacity to fix P, especially in the subsurface clayey horizons. However, little information is available to predict the impact on surface water concentration of P and soil profile distribution of P from poultry manure application to conservation-tilled cropland. Increased density of soil under continuous no-tillage cropping could limit water and nutrient movement into subsoil. Deep ripping, i.e., paraplowing, might be a conservation strategy to loosen surface and subsoil without excessive incorporation of surface crop residues. This loosening of the soil could also enhance water and nutrient storage at lower depths than possible with continuous no tillage.

We evaluated the effect of no tillage compared with paraplowing on surface-soil distribution of bulk density and

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organic C and N during the first two years of an intended long-term study. Surface water runoff volume and nutrient concentration will be reported in these proceedings by Endale *et al*. (2002). Other aspects of this study that will eventually be reported are agronomics, N cycling of broiler litter, soil-profile distribution of inorganic N and P, ammonia volatilization, water-use efficiency, and fecal-borne pathogen survival and transport.

MATERIALS AND METHODS

This study consisted of four small water catchments [3.1-6.7 acres each (1.3-2.7 ha)] located near Watkinsville, Georgia (33˚ 52' N, 83˚ 25' W). Soils are Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult). These soils are classified as well drained with moderate permeability. Mean annual precipitation is 49" (1250 mm) and temperature is 62 ˚F (16.5 ˚C).

The four water catchments were managed separately under various forms of cropping and forage production since 1972. Two water catchments (P1 and P2) were separated by 0.5 mile. The other two water catchments (P3 and P4) were immediately adjacent to each other and separated from P1 by 2.3 miles and from P2 by 1.8 miles. Prior to this experiment, all water catchments were managed with no tillage for at least 10 years. Since the autumn of 1998, the four water catchments were managed together as described in the following. Two water catchments (P1 and P3) were allowed to continue under continuous no tillage and the other two water catchments (P2 and P4) were converted to no tillage planting of all crops with autumn paraplowing following harvest of the summer crop. Paraplowing depth was *ca.* 12-16" (30-40 cm). Summer crops were maize (*Zea mays*) in 1999, pearl millet (*Pennisetum glaucum*) in 2000, and grain sorghum (*Sorghum bicolor*) in 2001. Winter crops were crimson clover (*Trifolium incarnatum*) on P2 and P3 and rye (*Secale cereale*) on P1 and P4 in 1998/1999, barley (*Hordeum vulgare*) in 1999/2000, and rye in 2000/2001. Crops were fertilized according to soil testing with inorganic N-P-K, as well as with broiler litter in July 2000, July 2001, and December 2001 at 1.1 ton acre^{-1} (2.48 ± 0.25 Mg ha^{-1} application^{-1}).

Soils were collected from each water catchment in five zones, which served as pseudoreplicates for analyses. The five zones represented a central waterway and the four corner sections of each water catchment. Within each zone, eight sites separated by 50' (15 m) were sampled and composited. At each site, surface residue was collected from 64 sq. in. (20 x 20 cm) areas by first removing green plant material above 1.5"-height (4 cm) and then collecting all surface residue to ground level by cutting with a battery-powered hand shears. Following surface residue removal, a soil core [1.6" diam (4.1-cm diam)] was sectioned into depths of 0-1.2, 1.2-2.4, 2.4-4.7, and 4.7-7.9" (0-3, 3-6, 6-12, and 12-20 cm). Surface residue was dried at 158˚F (70 ˚C) for several days, ground to <1/32" (1 mm), and analyzed for total C and N with dry combustion. Soil was dried at 131˚F (55 ˚C) for 3 days, initially passed through a sieve with openings of 3/16" (4.75 mm) to remove stones, a subsample ground in a ball mill for 5 minutes, and analyzed for total C and N with dry combustion. Soil bulk density was calculated from the total dry weight of soil and volume of coring device.

Standing stock values of soil organic C and total soil N to a depth of 7.9" (0-20-cm depth) were calculated based on the density and volume of each soil depth section. Stratification ratios of soil properties were calculated based on the weighted concentration of a soil property at a depth of 0-6 cm divided by the concentration of that property at a depth of 12-20 cm.

Data were analyzed for variance due to tillage systems within each depth using the general linear models procedure of SAS (SAS Institute Inc., 1990). Differences among tillage systems were considered significant at $P = 0.1$.

RESULTS AND DISCUSSION

Soil bulk density was significantly lower under paraplowing (PP) than under no tillage (NT) at all soil depths to 20 cm in February 1999 (Table 1). Soil samples from February 1999 were collected *ca.* 4 months following the first paraplowing operation in this experiment. The vertical breaking action of the paraplow tool had a strong loosening effect on soil density. Except for no difference between tillage systems at a depth of 0-3 cm, soil bulk density in February 2000 responded similarly to tillage management as during the sampling in February 2000. Although paraplowing reduced soil bulk density, compaction of soil under NT was not excessive. Soil bulk density >1.7 Mg m^{-3} might be expected to hinder root growth of many plants. The protective layer of surface residue and accumulation of surface soil organic matter were very likely important long-term attributes that helped to alleviate excessive surface-soil compaction with continuous NT.

Soil organic C and total soil N concentrations were greater under PP than under NT at depths of 3-6 and 6-12 cm during sampling in 1999 and 2000 (Table 1). Some surface residue incorporation with paraplowing likely contributed to this tillage effect. Soil organic C and total soil N at a depth of 0-3 cm were also greater under PP than under NT in 1999, but not significantly different between tillage systems in 2000. Perhaps the more frequently that paraplowing is employed, the more disturbed the plow layer will become, which could eventually result in a decline in soil organic matter pools. This temporal effect

Table 1. Surface-soil properties as affected by tillage system during the first and second year. Paraplowing was in November 1998 and 1999. NT is continuous no tillage and PP is conservation tillage with autumn paraplowing.

Soil depth		Feb 1999			Feb 2000		
Inches	cm	NT		PP	NT		PP
Soil bulk density, Mg m^{-3}							
0-1.2	0-3	1.18	***	0.98	1.03		1.01
1.2-2.4	3-6	1.46	***	1.27	1.44	***	1.26
2.4-4.7	6-12	1.63	***	1.46	1.58	***	1.42
4.7-7.9	12-20	1.61	**	1.50	1.61	***	1.49
0-7.9	0-20	1.53	***	1.38	1.49	***	1.36
Soil organic C, mg g^{-1}							
0-1.2	0-3	21.6	**	26.9	24.7		23.3
1.2-2.4	3-6	11.3	**	14.9	13.1	*	16.5
2.4-4.7	6-12	6.6	*	8.7	7.6	*	9.4
4.7-7.9	12-20	4.8	†	6.1	5.3		6.2
0-7.9	0-20	8.2	*	10.3	9.2	†	10.5
Total soil N, mg g^{-}							
0-1.2	0-3	2.33	*	2.69	2.72		2.38
1.2-2.4	3-6	1.21	**	1.52	1.37	†	1.64
2.4-4.7	6-12	0.64	*	0.81	0.73	*	0.88
4.7-7.9	12-20	0.43		0.50	0.49		0.53
0-7.9	0-20	0.82	*	0.97	0.92		1.00
C:N ratio of soil organic matter, g g^{-1}							
0-1.2	0-3	9.5	**	10.2	9.3	*	10.1
1.2-2.4	3-6	9.6	†	9.9	9.9		10.2
2.4-4.7	6-12	10.5		10.8	10.7		10.7
4.7-7.9	12-20	11.2		12.5	11.0		11.8
0-7.9	0-20	10.1	†	10.7	10.1		10.6

†, *, **, *** indicate significant differences between tillage systems within a year at $P = 0.1$, $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

will be evaluated in years to come. Taken to a depth of 0-20 cm, soil organic C and total soil N were significantly greater under PP than under NT in February 1999 (Table 1). This analysis on a gravimetric basis was counteracted by the significantly lower soil bulk density with PP than with NT resulting in no significant difference in the stock of soil organic C and total soil N on a volumetric basis between tillage systems in either 1999 or 2000 (Table 2). The position within a water catchment had a significant effect on the stock of soil organic C (Fig. 1) and total soil N. Waterways were in a central position within the catchment, such that historical water and sediment movement would have been preferentially flowing through this zone, thereby depositing organically enriched surface soil and residues.

Surface residue C, although numerically lower under PP than under NT in both years, was not significantly different between tillage systems in either 1999 or 2000 (Table 2). However, surface residue N was significantly lower under PP than under NT in 1999, but not different in 2000. Surface residue C averaged 12 ± 1% of the total standing stock of C to a depth of 20 cm. Surface residue N averaged 6 ± 2% of the total standing stock of N to a depth of 20 cm. Surface residues C and N in either of these conservation tillage management systems were a significant portion of the total C and N of the near surface budget. This differs considerably with conventional tillage systems, in which surface residue C and N are often <1% (Franzluebbers *et al.*, 1999).

The C:N ratio of soil organic matter increased gradually with depth in both tillage management systems during both years (Table 1). The C:N ratio of soil organic matter at a depth of 0-3 cm was significantly greater under PP than under NT in 1999 and 2000. Differences in the C:N ratio of soil organic matter between tillage systems were often not significant at lower depths. The C:N ratio of surface residue was 25 ± 7 among tillage systems and sampling dates. This ratio is similar to that reported for 13 crop and pasture management systems from the same geographic region on similar soils (27 ± 8) (Franzluebbers *et al.*, 2000).

Stratification of soil bulk density during the sampling in February 1999 was the only property measured with a significant difference between tillage systems (Table 3). The lower stratification ratio under PP than under NT suggested that total soil porosity (i.e., the inverse of bulk density) was improved more under PP than under NT. Stratification ratios of soil organic C and total soil N were 3.7 ± 0.4 among tillage systems and sampling dates. These ratios are intermediately

Table 2. Surface residue and soil organic C and N stocks as affected by tillage system during the first and second year. Paraplowing was done in November 1998 and 1999. NT is continuous no tillage and PP is conservation tillage with autumn paraplowing.

	Feb 1999			Feb 2000	
Component	NT		PP	NT	PP
C stocks, g m^{-2}					
Surface residue	382		337	377	336
Soil (0-6 cm)	1228	*	1340	1319	1323
Soil (6-20 cm)	1259		1485	1396	1521
Soil (0-20 cm)	2487		2825	2715	2844
Total (residue + soil)	2869		3162	3092	3180
N stocks, g m^{-2}					
Surface residue	23	*	15	11	13
Soil (0-6 cm)	131		135	141	133
Soil (6-20 cm)	118		131	131	138
Soil (0-20 cm)	249		266	272	271
Total (residue + soil)	271		281	283	284

* indicates significant difference between tillage systems within a year at $P = 0.05$.

Table 3. Stratification ratio (0-6 cm / 12-20 cm) of soil properties as affected by tillage system during the first and second year. Paraplowing was done in November 1998 and 1999. NT is continuous no tillage and PP is conservation tillage with autumn paraplowing

	Feb 1999			Feb 2000	
Component	NT		PP	NT	PP
Soil bulk density, Mg m^{-3}	0.82	*	0.75	0.77	0.76
Soil organic C, mg g^{-1}	3.3		3.4	3.4	3.3
Total soil N, mg g^{-1}	3.9		4.2	3.9	3.9
C:N ratio, mg g^{-1}	0.9		0.8	0.9	0.9

* indicates significant difference between tillage systems within a year at P=0.05.

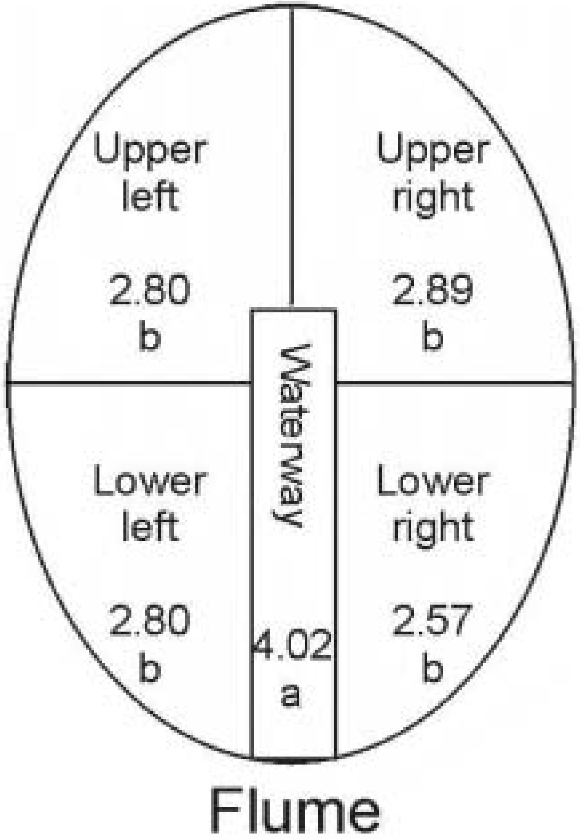

Fig. 1. Stock of organic C (kg m^{-2}) in surface residues and soil to a depth of 20 cm in February 1999 as affected by position within a water catchment. The diagram schematically represents the relative positions of each zone, as each watershed was shaped differently. Values followed by a different letter are significantly different at $P = 0.05$.

high on a theoretical scale that has been proposed to assess soil ecosystem functioning (Franzluebbers, 2002). The fact that paraplowing did not reduce the stratification ratio of soil organic C and total soil N suggests that this operation may not be detrimental to soil quality or ecosystem functioning. The energy requirements of paraplowing are not minor. Yet the benefit of paraplowing on increasing total soil porosity without destroying surface soil organic matter should be considered as a possible option to improve soil water-plant relations and possibly reduce water runoff concentration of nutrients.

CONCLUSIONS

This early evaluation of annual deep ripping (i.e., paraplowing) with conservation tillage compared with continuous no-tillage cropping suggests that soil physical conditions could be improved with deep ripping and that surface residue and soil organic C and total soil N could be maintained without significant degradation. We intend to evaluate these treatments in this experimental setup for at least five years.

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SURFACE-SOIL PROPERTIES IN RESPONSE TO SILAGE INTENSITY UNDER NO-TILLAGE MANAGEMENT IN THE PIEDMONT OF NORTH CAROLINA

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ABSTRACT

Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues that is returned to the soil will likely alter the success of a particular conservation tillage system within a particular farm operation. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil properties in different environments. We investigated the impact of three cropping systems (gradient in residue returned to soil) on soil bulk density, aggregation, organic C and N, and microbial biomass and activity in a Piedmont soil in North Carolina. Most soil properties were not significantly affected by silage cropping intensity during this early stage in the study. There was a tendency for soil bulk density to be lower and soil organic C and N to be higher with lower silage cropping intensity as a result of greater crop residue returned to soil. Potential soil microbial activity was significantly greater in surface depths with lower silage cropping intensity. These early results suggest that greater quantities of crop residue returned to soil can have beneficial effects on soil quality, even in continuous no-tillage crop production systems.

KEYWORDS

Bulk density, maize silage, soil microbial biomass carbon, soil organic carbon, total soil nitrogen

INTRODUCTION

Soil quality is a concept based on the premise that management can deteriorate, stabilize, or improve soil ecosystem functions. Soil provides a medium for plant growth, regulates and partitions water flow in the environment, and buffers the fluxes of natural and xenobiotic compounds through decomposition and fixation processes (Larson and Pierce, 1991). The organic components of soil are important in providing energy, substrates, and the biological diversity necessary to sustain many soil functions.

Conservation tillage systems are now widely adopted by many producers, because they

- reduce fuel, time, and labor needed to make multiple tillage operations,
- reduce machinery wear,
- allow for more timely planting of crops even under wetter soil conditions,
- improve soil and water quality,
- reduce runoff and make more effective use of precipitation,
- improve wildlife habitat, and
- meet Farm Bill requirements.

Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues that is returned to the soil will likely alter the success of a particular conservation tillage system within a particular farm operation. Crop residues left at the soil surface as a surface mulch are important for feeding the soil biology, suppressing weed seed germination, and suppressing wide fluctuations in temperature and moisture that can limit plant development. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil properties in different environments.

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Dairy producers in North Carolina rely on maize (*Zea mays* L.) and barley (*Hordeum vulgare* L.) silage as sources of high quality feedstuffs in their rations. High-intensity silage cropping is typically practiced to maximize the amount of feedstuffs produced per unit of land area. High-intensity silage cropping, however, leaves little residue at the soil surface, offering little buffer against equipment traffic. The lack of residue returned to the soil under high-intensity silage cropping brings into question issues of long-term compaction, water-use efficiency, nutrient cycling, and soil erosion when conservation tillage is used.

In this portion of the research endeavor, we investigated the impact of alternative cropping systems that returned more crop residues to the soil than the traditional maize-barley silage cropping system on surface-soil properties. Other portions of the research endeavor are concerned with agronomics, economics, water infiltration, and soil biological diversity.

MATERIALS AND METHODS

The site is located in Iredell County in the Southern Piedmont Major Land Resource Area of North Carolina (36 ˚N, 81 ˚W). Soils are mostly Fairview sandy clay loam (fine, kaolinitic, mesic Typic Kanhapludult) in Replication 1 and Braddock loam (fine, mixed, semiactive, mesic Typic Kanhapludult) in Replication 2. These soils are classified as well drained with moderate permeability. Mean annual precipitation is 48" (1220 mm) and temperature is 58 ˚F (14.4 ˚C).

Three cropping systems replicated twice were evaluated in 1000'long strips that were 50-75' wide (0.4-0.6 ha each). Plots were managed by the owner with his field equipment. Replication 1 was established in 1998 and Replication 2 was established in 2000. All plots were managed with no tillage for several years prior to, as well as during experimentation. Previous management of the field with no tillage was without high residue input. Prior to no tillage, this field was managed with a 2-4-year rotational strip cropping system of perennial forage with maize silage. Fertilizer as liquid dairy manure was applied in spring at a rate of 12,000 to 14,000 gallons acre^{-1} yr^{-1}, which was equivalent to 40-30-100-7 lbs acre^{-1} of N-P_2O_5-K_2O-S (45-15-93-8 kg N-P-K-S ha^{-1}).

The three cropping systems were designed as a gradient in silage intensity and inversely related to the amount of crop residues returned to the soil. The traditional cropping system (high silage intensity) was maize silage planted in May and harvested in September followed by barley silage planted in November and harvested in April. This was a one-year rotation and had the least above-ground residue returned to the soil. A medium silage intensity system was maize silage planted in May and harvested in September followed by a winter cover crop [rye (*Secale cereale* L.) alone or rye plus crimson clover (*Trifolium incarnatum* L.)] killed by an herbicide in April. This was a one-year rotation and had a moderate level of crop residue returned. A low silage intensity system was maize silage planted in May and harvested in September followed by barley planted in November and harvested for grain in June. Barley straw was left in the field and a summer cover crop [sudangrass (*Sorghum sudanense* Hitchc.) or sunnhemp (*Crotalaria juncea* L.)] planted in June and killed by frost in October. The summer cover crop was left in the field and followed by planting of rye as a winter cover crop in November, which was killed by an herbicide in April and left in the field. This was a two-year rotation and had the highest level of crop residue returned. Expressed as silage cropping intensity, treatments had 0.5 (low silage intensity), 1 (medium silage intensity), and 2 (high silage intensity) silage crops harvested per year.

Surface residue and soil were sampled in December 2000 and February 2002. In December 2000, plots were sampled in duplicate by splitting the plot in half to assess within-plot variability. For each sample collected, eight sites located 70' (20 m) apart were composited. Surface residue was collected from 64 sq. in. (20 x 20 cm) areas by first removing green plant material above 1.5"height (4 cm) and then collecting all surface residue to ground level by cutting with a battery-powered hand shears. Following surface residue removal, a soil core [1.6" diam (4 cm diam)] was sectioned into depths of 0-1.2, 1.2-2.4, 2.4-4.7, and 4.7-7.9" (0-3, 3-6, 6-12, and 12-20 cm). Surface residue was dried at 158˚F (70 ˚C) for several days, ground to <1/32" (1 mm), and analyzed for total C and N with dry combustion. Soil was dried at 131 ˚F (55 ˚C) for 3 days, initially passed through a sieve with openings of 3/16" (4.75 mm) to remove stones, a subsample ground in a ball mill for 5 minutes, and analyzed for total C and N with dry combustion. Soil bulk density was calculated from the total dry weight of soil and volume of coring device. Clay content was determined with a hydrometer at the end of a 5-h settling period following dispersion in 0.01 M $Na_4P_2O_7$.

Aggregate distribution and stability analyses followed a procedure outlined in Franzluebbers *et al*. (2000b). Dry aggregate distribution was determined by placing a 3.5 oz. portion (100 g) of soil on top of a nest of sieves [7.9" (20 cm) diam with openings of 1/24, 1/100, and 2/1000" (1.0, 0.25, and 0.05 mm)], shaking for 1 min at level 6 on a CSC Scientific Sieve Shaker (Catalogue No. 18480), and weighing soil retained on the 1.0, 0.25, and 0.05 mm screens and that passing the 0.05 mm screen. Water-stable aggregate distribution was determined from the same soil sample used for dry aggregate distribution placed on top of a nest of sieves [6.9" (17.5 cm) diam with openings of 1.0 and 0.25

mm), immersed directly in water, and oscillated for 10 min [3/4" (20 mm) stroke length, 31 cycles min^{-1}]. After removing the two sieves and placing them in an oven to dry, water containing soil passing the 0.25 mm sieve was poured over a 0.05 mm sieve, soil washed with a gentle stream of water, and the soil retained transferred into a drying bottle with a small stream of water. The <0.05 mm fraction was calculated as the difference between initial soil weight and summation of the other fractions. All fractions were oven-dried at 131 ˚F (55 ˚C) for 3 d.

Mean-weight diameter of both dry- and water-stable aggregates was calculated by summing the products of aggregate fractions and mean diameter of aggregate classes. Macroaggregates were defined as soil retained on 1.0 and 0.25 mm sieves. Large macroaggregates were defined as soil retained on the 1.0 mm sieve. Stability of macroaggregates was calculated as the weight of water-stable macroaggregates divided by the weight of dry-stable macroaggregates. Stability of mean-weight diameter was calculated as water-stable mean-weight diameter divided by dry-stable mean-weight diameter.

Carbon mineralization was determined by placing two 1 to 2 oz. (20 to 55g, inversely related to soil organic C concentration) soil subsamples in 1/4-cup (60 mL) glass jars, wetting to 50% water-filled pore space, and placing them in a 1-qt. canning jar along with 2 tsp. (10 mL) of 1 M NaOH to trap CO_2 and a vial of water to maintain humidity. Samples were incubated at 77 ˚F (25±1 ˚C) for up to 24 d. Alkali traps were replaced at 3 and 10 d of incubation and CO_2-C determined by titration with 1 M HCl in the presence of excess $BaCl_2$ to a phenolphthalein endpoint. Basal soil respiration was calculated as the linear rate of C mineralization between 10 and 24 d. At 10 d, one of the subsamples was removed from the incubation jar, fumigated with $CHCl_3$ under vacuum, vapors removed at 24 hr, placed into a separate canning jar along with vials of alkali and water, and incubated at 25 ˚C for 10 d. Soil microbial biomass C was calculated as the quantity of CO_2-C evolved following fumigation divided by an efficiency factor of 0.41 (Franzluebbers *et al.*, 1999).

Data were analyzed for variance due to silage cropping intensity within each depth using the general linear models procedure of SAS (SAS Institute Inc., 1990). Differences among silage cropping intensity treatments were considered significant at $P = 0.1$.

RESULTS AND DISCUSSION

SOIL BULK DENSITY

We note here up-front that the differential implementation of the two replications in this experimental design does not allow a strict temporal evaluation of the treatments. Sampling in December 2000 was after 3 years of treatment in Replication 1 and after 1 year of treatment in Replication 2. Sampling in February 2002 was after 4 years of treatment in Replication 1 and after 2 years of treatment in Replication 2. The value of this experiment will be enhanced with time. Despite this, the changes in soil-surface properties during the first few years of evaluation should be revealing towards possible future effects.

Soil bulk density increased with depth under all management systems (Table 1). This change in bulk density with depth is a common observance in natural ecosystems, in managed grasslands, and under conservation tillage (Franzluebbers *et al.*, 2000). The depth distribution of soil bulk density highlights the need to assess potential compaction problems under conservation tillage systems at a finer spatial scale than simply the traditional plow layer.

Soil bulk density in December 2000 was greater under high than under low silage cropping intensity at depths of 0-3, 3-6, and 6-12 cm, but not at 12-20 cm (Table 1). Soil bulk density under medium silage intensity was not different from that under high silage intensity at any depth interval, but was greater than under low silage intensity at 3-6 and 6-12 cm depths. Taken to a depth of 20 cm, soil bulk density was significantly greater under medium and high silage intensity than under low silage intensity.

Soil bulk density in February 2002 was not affected by silage cropping intensity (Table 2). The least significant difference among silage cropping intensity treatments was higher in the February 2002 sampling than in the December 2000 sampling. This was because experimental units were not split into duplicate strips during the February 2002 sampling as during the December 2000 sampling.

When mean values were plotted for each treatment and year since establishment, a significant temporal change in soil bulk density occurred between low and high silage cropping intensity (Fig. 1). These results suggest that compaction was occurring at a slow rate with high silage cropping intensity, but that compaction could be alleviated by low silage cropping intensity with high surface residue return. The slow conversion of organic matter from crop residues into soil organic C, especially at the soil surface, can lead to a large reduction in soil bulk density (Franzluebbers et al., 2001). Organic matter has a much lower specific density than mineral soil and the incorporation of organic matter with soil often leads to a more porous soil matrix as a result of soil faunal and microbial activity, which fabricate stable aggregates with large voids in between them.

SOIL TEXTURE AND AGGREGATION

Clay, silt, and sand proportions in soil were unaffected by management (Table 1). Clay-sized particles (<2 µm) averaged 25% of the soil, while silt-sized particles (2-50

Table 1. Soil physical properties within depth sections as affected by silage cropping intensity in December 2000.

Soil depth		Silage cropping intensity				
Inches	cm	Low	Medium	High	LSD$_{0.1}$	
Soil bulk density, Mg m^{-3}						
0-1.2	0-3	0.93	0.95	1.02	0.08	†
1.2-2.4	3-6	1.25	1.36	1.35	0.09	†
2.4-4.7	6-12	1.36	1.47	1.46	0.08	*
4.7-7.9	12-20	1.47	1.53	1.52	0.10	
0-7.9	0-20	1.32	1.40	1.40	0.07	†
Clay content, g g^{-1}						
0-1.2	0-3	0.22	0.23	0.24	0.06	
1.2-2.4	3-6	0.20	0.21	0.23	0.05	
2.4-4.7	6-12	0.22	0.24	0.24	0.08	
4.7-7.9	12-20	0.24	0.31	0.29	0.08	
0-7.9	0-20	0.22	0.27	0.26	0.06	
Water-stable macroaggregates, g g^{-1}						
0-1.2	0-3	0.77	0.76	0.73	0.08	
1.2-2.4	3-6	0.76	0.79	0.78	0.05	
2.4-4.7	6-12	0.70	0.72	0.75	0.04	*
4.7-7.9	12-20	0.66	0.62	0.61	0.03	*
0-7.9	0-20	0.70	0.69	0.69	0.03	
Stability of macroaggregates, g wet g^{-1} dry						
0-1.2	0-3	0.86	0.88	0.81	0.05	*
1.2-2.4	3-6	0.85	0.87	0.85	0.03	
2.4-4.7	6-12	0.79	0.83	0.82	0.05	
4.7-7.9	12-20	0.75	0.72	0.71	0.04	†
0-7.9	0-20	0.79	0.79	0.78	0.03	
Water-stable mean-weight diameter of aggregates, mm						
0-1.2	0-3	1.22	1.26	1.20	0.19	
1.2-2.4	3-6	1.28	1.36	1.32	0.14	
2.4-4.7	6-12	1.12	1.27	1.27	0.15	†
4.7-7.9	12-20	1.04	0.96	0.92	0.11	†
0-7.9	0-20	1.12	1.15	1.12	0.10	
Stability of mean-weight diameter, mm wet mm^{-1} dry						
0-1.2	0-3	0.69	0.77	0.66	0.09	*
1.2-2.4	3-6	0.69	0.74	0.70	0.07	
2.4-4.7	6-12	0.64	0.71	0.67	0.07	†
4.7-7.9	12-20	0.58	0.55	0.53	0.05	
0-7.9	0-20	0.62	0.65	0.61	0.05	

† and * indicate significance at $P = 0.1$ and $P = 0.05$, respectively.

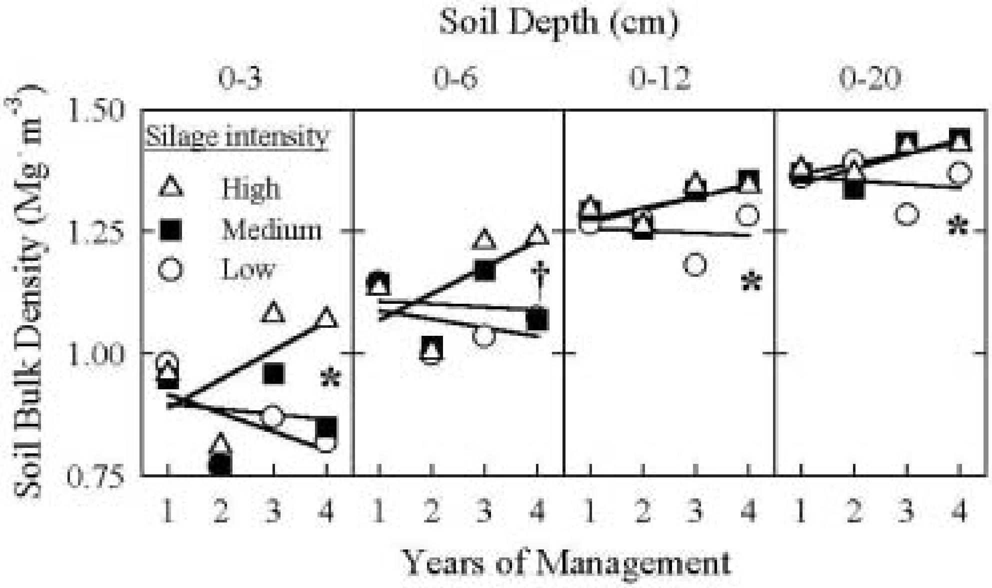

Fig. 1. Soil bulk density within the surface 7.9" (20 cm) of soil as affected by number of years under a particular silage intensity. Significant differences among regression slopes are indicated by † and * for the $P = 0.1$ and $P = 0.05$ level of significance, respectively.

μm) averaged 21%, and sand-sized (>50 μm) particles averaged 54%.

At a depth of 0-20 cm, aggregate distribution and stability sampled in December 2000 were not significantly different among silage cropping intensity treatments (Table 1). At a depth of 0-3 cm, stability of macroaggregates was greater under low and medium silage intensity than under high silage intensity. At this depth, stability of mean-weight diameter of aggregates was also greater under medium than under high silage intensity. Overall, few significant changes in aggregate distribution and stability occurred. Aggregate distribution and stability can be viewed as secondary response variables that are dependent upon surface residue retention, soil organic C, soil microbial activity, and compaction. We expect that aggregate distribution and stability will improve slowly with higher residue-retention management systems.

SOIL BIOCHEMICAL PROPERTIES

Soil organic C and N were highly stratified with depth under all management systems (Table 3). This stratification with depth is common in many undisturbed ecosystems, including native forests and grasslands, managed grasslands, and cropping systems with conservation tillage. Soil organic C and N were highly stratified with depth on this farm as a result of long-term management with conservation tillage. Although not significant, soil organic C and N tended to be higher with lower silage cropping intensity, especially nearest the soil surface. Greater quantities of crop residue are returned to the soil with lower silage cropping intensity. With time, we expect that soil organic C and N will become significantly greater with low than with high silage cropping intensity. The C:N ratio of soil organic matter was little affected by depth of sampling or by management (Table 3).

Soil microbial biomass C was highly stratified with depth, similar to that of soil organic C and N (Table 3). The only significant management effect occurred at a depth of 12-20 cm, where soil microbial biomass was greater under low than under medium and high silage cropping intensity. The portion of soil organic C as microbial biomass C was relatively uniformly distributed with depth and was little affected by management. Although soil microbial biomass represented only 4.7% of the soil organic C pool, it plays a major role in organic matter decomposition and nutrient

Table 2. Soil bulk density within depth sections as affected by silage cropping intensity in February 2002

Soil depth		Silage cropping intensity			
Inches	cm	Low	Medium	High	LSD $_{0.1}$
Soil bulk density, Mg m^{-3}					
0-1.2	0-3	0.80	0.81	0.94	0.24
1.2-2.4	3-6	1.28	1.27	1.31	0.18
2.4-4.7	6-12	1.52	1.56	1.48	0.25
4.7-7.9	12-20	1.53	1.51	1.54	0.19
0-7.9	0-20	1.38	1.38	1.40	

Table 3. Soil biochemical properties within depth sections as affected by silage cropping intensity in December 2000.

Soil depth		Silage cropping intensity				
Inches	cm	Low	Medium	High	LSD$_{0.1}$	
Soil organic C, mg g^{-1}						
0-1.2	0-3	38.2	33.3	30.0	12.7	
1.2-2.4	3-6	16.6	14.6	15.9	2.2	
2.4-4.7	6-12	10.3	10.4	10.8	2.6	
4.7-7.9	12-20	7.6	6.4	6.8	1.6	
0-7.9	0-20	12.9	11.6	11.8	2.4	
Total soil N, mg g^{-1}						
0-1.2	0-3	4.19	3.47	3.21	1.52	
1.2-2.4	3-6	1.75	1.52	1.74	0.30	
2.4-4.7	6-12	1.05	1.07	1.10	0.30	
4.7-7.9	12-20	0.77	0.63	0.63	0.16	
0-7.9	0-20	1.35	1.18	1.21	0.28	
C:N of soil organic matter, g g^{-1}						
0-1.2	0-3	9.2	9.6	9.4	0.5	
1.2-2.4	3-6	9.5	9.7	9.2	0.5	
2.4-4.7	6-12	10.2	9.8	9.9	0.9	
4.7-7.9	12-20	9.9	10.3	10.8	0.9	†
0-7.9	0-20	9.6	9.8	9.8	0.4	
Soil microbial biomass C, µg g^{-1}						
0-1.2	0-3	1711	1515	1340	479	
1.2-2.4	3-6	877	836	781	168	
2.4-4.7	6-12	422	471	532	126	
4.7-7.9	12-20	373	288	305	59	*
0-7.9	0-20	599	550	556	82	
Portion of soil organic C as microbial biomass C, mg g^{-1}						
0-1.2	0-3	45.4	45.7	45.4	6.1	
1.2-2.4	3-6	53.2	58.2	49.6	14.2	
2.4-4.7	6-12	40.7	45.7	49.5	7.9	†
4.7-7.9	12-20	49.8	45.0	45.4	7.3	
0-7.9	0-20	46.7	47.5	47.3	3.8	
Flush of CO$_2$-C following rewetting of dried soil, µg g^{-1} 3 d^{-1}						
0-1.2	0-3	544	643	402	153	*
1.2-2.4	3-6	291	293	220	45	*
2.4-4.7	6-12	148	173	150	41	
4.7-7.9	12-20	99	81	88	33	
0-7.9	0-20	188	198	160	29	*

† and * indicate significance at *P* = 0.1 and *P* = 0.05, respectively.

cycling as the agent that mediates elemental transformations. Changes in soil microbial biomass may be an early indicator of long-term changes in soil organic matter due to a particular management system (Powlson *et al*., 1987).

The flush of CO_2 following rewetting of dried soil was highly stratified with depth, similar to that of soil microbial biomass and total organic C (Table 3). The flush of CO_2 is an indicator of both potential soil microbial activity and soil microbial biomass (Franzluebbers *et al.*, 2000a). Even at an early stage in this study, the flush of CO_2 was greater under lower than higher silage cropping intensity at depths of 0-3 and 3-6 cm. These surface changes led to significant changes even when considering the 0-20 cm depth. Potential C mineralization has been found to be a sensitive indicator of tillage management in other studies as well (Franzluebbers and Arshad, 1996; Franzluebbers *et al.*, 1999).

CONCLUSIONS

Sampling of surface-soil properties at the end of the first few years of implementation of a study to evaluate the effects of alternative silage crop management systems suggested that soil physical properties such as bulk density and aggregation and soil biochemical properties such as organic C, microbial biomass C, and mineralizable C would respond positively and lead to an improvement in soil quality. Sufficient quantities of residues returned to the soil are necessary for organic matter transformations to facilitate the development of an improved soil condition. This study will continue to be able to more conclusively identify the impacts of silage cropping intensity on soil and water conservation and farm economics.

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NO-TILLAGE PERFORMANCE ON A PIEDMONT SOIL

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ABSTRACT

Many Piedmont soils in southeast USA are crust-prone and develop low infiltration rates. Maintaining residue cover may reduce surface sealing and decrease surface water runoff, soil loss and the loss of agricultural chemicals. The effectiveness of no-tillage (NT) to reduce runoff, erosion, and the loss of chemicals from row crops relative to the conventional plow/disk practice (CT) was investigated. Over a 5-year period, reductions in runoff in NT relative to CT were 22% during cropping periods and 35% during non-cropping periods. The reduction in runoff also fostered a decrease in the loss of soil, nutrients, and herbicides. Soil loss reductions were predominant during cropping periods, especially during erosive rainstorms following tillage and seedbed preparation. On average, CT had 59 times more soil loss than NT during cropping periods (23.4 *vs.* 0.4 ton acre^{-1}) and 4 times more soil loss during non-cropping periods (1.7 *vs.* 0.4 ton acre^{-1}). Crop growth and grain yield were generally greater in NT; this was attributed to greater soil water content. The formation of a seal soon following planting in CT explained the greater runoff and lower soil water content in this system. Tillage practices leaving crop residues on the soil surface, such as NT, can reduce surface runoff, soil loss, and loss of nutrients and herbicides while increasing crop growth and yield.

KEYWORDS

Runoff, soil erosion, nutrient loss, herbicide loss, corn, soybean

INTRODUCTION

Enhanced crop yields with conservation tillage systems are commonly obtained in southeastern USA, particularly on the sloping lands of the Piedmont and Appalachian Plateau. In most cases, yield increases due to conservation tillage are attributed to greater infiltration of soil water (Hargrove, 1985; Wager and Denton, 1989; 1992; Cassel *et al.*, 1995). Increased infiltration rates in conservation tillage systems have been attributed to the presence of surface residue. Residues protect the soil surface from raindrop impact, prevent seal formation, and reduce the transport capacity of surface flow (Laflen *et al.*, 1978; Foster *et al.*, 1985).

In the Piedmont and Appalachian Plateau, plowing plus disking is the conventional method of land preparation. This management system leaves the soil bare for several months, promotes surface sealing and, on drying, promotes crust formation (Radcliffe *et al.*, 1988). Surface seals substantially reduce infiltration because of their low hydraulic conductivity. Chiang *et al.* (1993) found the hydraulic conductivity for a Cecil soil crust to be one to two orders less than that of the underlying unsealed soil. Steady state infiltration rate on this sealed soil was 0.07 in hour^{-1} or less.

Other factors that promote soil erosion with conventional tillage are the lack of appreciable canopy cover in early crop vegetative stages, the likelihood of intense, erosive storms during seedbed preparation, and the sloping topography of fields. Thus, the need to evaluate the effects that conservation tillage systems have on soil erosion in the Piedmont and Appalachian Plateau is well warranted.

The main objective of this study was to investigate the effectiveness of no tillage to reduce runoff and erosion from row crops relative to the conventional plow/disk practice. Additional evaluations included crop response and losses of herbicide and nutrients.

MATERIALS AND METHODS

The study was conducted at the North Carolina A&T Farm, Greensboro, North Carolina. The site had soil types Enon clay loam and Mecklenburg sandy clay loam (fine, mixed, thermic Ultic Hapludalfs). Treatments were first

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implemented on May of 1994, but the collection of runoff and soil loss did not begin until May of 1995. The experiment was designed as a randomized complete block, replicated four times. Treatments were conventional tillage (CT) and no-tillage (NT). Conventional tillage consisted of chisel plowing to the 8-inch depth in mid spring followed by disking prior to planting. No tillage consisted of opening a small slit by means of a coulter running ahead of a planter unit with openers. Tractor traffic was confined to alternate interrow areas. Plot dimensions were 40 feet long by 24 feet wide designed for eight rows of corn or soybeans spaced 3 feet apart. Corn and soybeans were planted in the following order: soybeans in 1994, corn in 1995 and 1996, soybeans in 1997 and 1998, and corn in 1999.

Permanent soil erosion subplots were installed within each experimental plot and were similar in design to the unit plots used for runoff and soil loss data collection for development of the universal soil loss equation (USLE). Subplots isolated an area 33 feet long by 12 feet wide encompassing four crop rows. To achieve this, 48-inch long by 8-inch wide galvanized metal borders were forced into the ground to a depth of 4 inches. A trough made of PVC material was installed in the lower side for runoff and sediment interception. Troughs were designed to deliver runoff and sediment to a multislot divisor that delivered 0.9 of the flow to adjacent collection tanks. The system was designed to handle 8 inches of runoff. Runoff volume and sediment concentration was measured from each tank immediately after each rainfall event.

Herbicides measured in runoff and sediment included metalochlor in 1996 and atrazine in 1999. Nutrients measured in the runoff were nitrogen and phosphorous. Both herbicides were applied a day prior to planting, metalochlor at a rate of 3.1 lbs acre^{-1} and atrazine at a rate of 2.7 lbs acre^{-1}. A total of 107 lbs N acre^{-1} as NH_4NO_3, 53 lbs P acre^{-1} as P_2O_5, and 53 lbs K acre^{-1} as K_2O were applied. One third of each fertilizer source was surface banded along the planted row and the remainder was row-banded six weeks after planting.

Inorganic–N, PO_4 and total P (perchloric acid digestion) were measured with a Technicon Auto Analyzer. Total-N was measured using a CHNS analyzer. Atrazine and metolachlor were extracted using C-18 columns (solid phase extraction method). Concentrations were measured using a Hewlett Packard (HP) 5890-II gas chromatography and using a J&WD13-1 column for atrazine and a DB-17 capillary column for metalochlor. An HP 5973 auto-sampler was used.

Residue cover was measured at planting with the method of Sloneker and Moldenhauer (1977) using a 35 ft transect with 35 points. Transect end points were in diagonally opposed corners. Crop canopy height and cover were measured at the tasseling stage for corn and at the flowering stage for soybeans. Canopy cover measurements were based on three sets of ten readings per plot and using a PAR SF-80 Sunflex Ceptometer. Canopy height was based on five measurements per plot and performed by measuring the height from the soil surface to the upper most part of the canopy.

Statistical analyses were conducted using analysis of variance procedures (SAS Institute Inc., 1985). The statistical model was based upon a randomized block design. Comparisons between treatments means were done using Fishers Protected LSD test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Crop residue cover was measured at planting on both trafficked and non-trafficked interrows. The ANOVA showed no treatment x position interaction and no position effect. On average, conventional tillage had the least cover (18%) and no-tillage had the most cover (85%) (Table 1).

Averaged over the five-year period, total runoff was 22% less in NT than in CT in cropping periods. A similar response was observed in non-cropping periods (35% reduction), despite the full surface cover remaining after harvest in both treatments. In general, the sealed condition of the CT surface during this period eliminated any beneficial residue effects on infiltration. For example, surface residue is known to retard surface runoff and increase infiltration.

Soil losses were highly reduced in no-tillage. The reduc-

Table 1. Percent surface residue cover, runoff, and soil loss in each treatment. Cropping periods were from planting in May or April through harvest in late October.

	Tillage	
Parameter	CT	NT
Residue Cover, %	18a[†]	85 b
Runoff, inches		
Cropping Periods	6.2 a	3.5 b
Non-Cropping Periods	8.0 a	5.4 b
Soil Loss, ton acre^{-1}		
Cropping Periods	23.6 a	0.4 b
Non-Cropping Periods	1.7 a	0.4 b
Rainfall, inches		
Cropping Periods	21.3	
Non-Cropping Periods	21.4	

[†] For each parameter, means followed by the same letter are not significantly different at P = 0.05 based on Fisher's protected LSD test.

tion was more pronounced during the cropping period and was related to rainstorm characteristics during this period. In the North Carolina Piedmont, frequent rainstorms occur during the months of April, May, and June. These storms are of short duration, but their high intensity favors particle detachment and leads to the formation of surface seals. On average, there was 59 times more soil loss in CT during cropping periods (23.4 *vs*. 0.4 ton acre^{-1}) and 4 times more soil loss during non-cropping periods (1.7 *vs*. 0.4 ton acre^{-1}).

The nutrient and herbicide data shows a significant reduction in loss of inorganic-N, sediment-N, and metolachlor in NT (Table 2). Most of the inorganic-N loss was in the form of NO_3-N. However, concentrations were much less than the 10 ppm EPA standard. Significant losses of N occurred in CT because of the high loss of soil. A total of 20.3 lbs N acre^{-1} was found to be tied-up with sediment in CT, whereas only 7.8 lbs N acre^{-1} were found in NT. Overall, losses of herbicide were low except for metolachlor in CT (0.7 lbs acre^{-1}). Approximately 60% of this loss occurred in the month of May following the application of herbicide. No metolachlor was found in runoff or sediment after harvest in October.

As indicated by the canopy cover and canopy height data, crop growth was generally greater in NT compared with CT (Table 3). Generally, plants in NT were taller and heavier (dry weight data not shown) than CT plants. Over the five-year period, NT grain yield was equal to or better than that in CT. The greater plant growth and grain yield in NT is attributed to greater soil water content (not shown). Each year, we visually observed the formation of a seal soon following planting in CT, which explains the greater runoff and lower soil water content in this system.

The higher soil water content and lack of surface sealing found in NT are attributed to the presence of surface residue, which reduces the effect of raindrop impact on particle detachment and therefore maintains better conditions for infiltration.

Table 2. Losses of nutrients and herbicides in runoff and sediment. Nutrient losses are the losses averaged over 1995 and 1996 crop periods. Metolachlor loss was measured in the 1996 crop period and atrazine loss in the 1997 crop period.

	Tillage	
Parameter	CT	NT
Nutrients		
Inorganic N, lbs acre^{-1}	7.6a	10.2b
PO_4, lbs acre^{-1}	2.2 a	3.7 a
Sediment N, lbs acre^{-1}	20.3 a	7.8 b
Sediment P, lbs acre^{-1}	0.3 a	0.1 a
Herbicides		
Metolachlor, lbs acre^{-1}	0.7 a	0.1 b
Atrazine, lbs acre^{-1}	0.05 a	0.01 a

[†] For each parameter, means followed by the same letter are not significantly different at $P = 0.05$ based on Fisher's protected LSD test.

Table 3. Measurements of crop growth (canopy cover and height) and grain yield for corn and soybeans. Data for corn is the average of results in 1995, 1996, and 1999. Data for soybeans beans is the average of results in 1997 and 1998.

	Tillage	
Parameter	CT	NT
Canopy cover, %		
Corn	79.6 a	88.6 b
Beans	92.0 a	97.0 a
Canopy height, inches		
Corn	71.3 a	83.5 b
Beans	37.0 a	45.8 b
Grain yield, bu acre-1		
Corn	88.7 a	98.9 b
Beans	40.9 a	43.2 a

[†] Means within each **row** followed by the same letter are not significantly different at $P = 0.05$ based on Fisher's protected LSD test.

CONCLUSION

Many Piedmont soils are crust-prone because of kaolinite predominance in the clay fraction and low soil organic matter content. Surface crop residue provides protection against raindrop impact and seal formation increasing rainfall capture and infiltration. Tillage practices that leave crop residues on the soil surface, such as NT, can reduce surface runoff, soil loss, and loss of nutrients and herbicides while increasing crop growth and yield.

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IMPACT OF CONSERVATION TILLAGE ON SOIL CARBON IN THE 'OLD ROTATION'

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ABSTRACT

Soil organic carbon (SOC) changes in long-term experiments can provide valuable information regarding management impacts on carbon sequestration and sustainability. The 'Old Rotation', the oldest continuous cotton (*Gossypium hirsutum* L.) experiment in the world, provides a valuable and unique resource for researching sustainable agricultural production. The objective of this paper is to quantify the impact of conservation tillage adoption after 42 months (May 1996, last conventional tillage) on SOC in the 'Old Rotation', after 100 years of conventional tillage (1896-1996). Although the 13 plots have undergone modifications since 1925, six basic cropping systems have been maintained: 3-yr cotton-corn (*Zea Mays* L.)-small grain/soybean [*Glycine max* (L) Merr.] + legume + nitrogen; continuous cotton without legume; continuous cotton + legume; continuous cotton without legume + nitrogen; 2-yr cotton-corn + legume; and 2-yr cotton-corn + legume + nitrogen. Soil organic carbon was determined by dry combustion from samples taken in 1994 (0-8 in depth) and again in 1999, 42 months after the last tillage event, (0-2 and 2-6 in depths). Soil organic carbon stratification ratios (SOC 0-2 in/SOC 2-6 in depths) were determined from samples taken in 1999. After 42 months, conservation tillage increased SOC concentrations 39% averaged across all plots. These changes are linked to increases in yield during this period. The SOC stratification ratio in the 'Old Rotation' in 1999 suggests that changes in soil quality from adoption of conservation tillage are in the initial stages. However, the study confirms that conservation tillage had a dramatic impact on SOC and these changes occurred sooner than other research suggests.

KEYWORDS

Carbon sequestration, cropping systems, soil quality, sustainable production

INTRODUCTION

Conventional tillage practices can result in significant losses of soil organic matter (SOM), inducing an increase in soil erosion and loss of soil structure (Dalal and Mayer, 1987). Soil organic carbon is a decisive component in maintaining the quality of agricultural soils (Doran *et al.*, 1994; Reeves, 1997). Soil organic carbon - SOM conversion factors for surface soils range from 1.724 to 2.000 (Nelson and Sommers, 1982). Soil organic carbon or SOM is linked to many soil quality indicators and is perhaps the most significant single gauge of soil quality and productivity (Reeves, 1997).

Normally, cultivated sandy Coastal Plain soils of the southern United States have very low SOC (< 1%) (Hunt *et al.*, 1995; Motta *et al.*, 2002). Studies have shown the way to increase SOC has been with the inclusion of no-till systems with increasing cropping intensity (Bruce *et al.*, 1990, Motta *et al.*, 2002). Hunt *et al.* (1995) evaluated rotations and tillage systems on sandy soils in the Coastal Plain. After 9 years of conservation tillage, the SOC in the surface layers (0-2 in) was nearly double that of conventional tillage.

The 'Old Rotation', a long-term continuous cotton experiment, provides valuable and unique information for researching sustainable agricultural production (Mitchell *et al.*, 1998). It is a cotton rotation study that includes corn, soybean and small grain. Winter legumes are included as a source of nitrogen in some treatments and to evaluate the best management practice for sustainable cotton production. Since 1997, all crops have been planted using conservation tillage and crop residues are left as surface mulch (Mitchell *et al.*, 2002). Our objectives were to quantify the effect of 42 months of conservation tillage on SOC levels. This may help to explain variations in productivity in the

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'Old Rotation' Experiment at Auburn University as well as provide information on soil quality as a result of conservation tillage adoption.

MATERIALS AND METHODS

Site Description

The 'Old Rotation' experiment at Auburn University, Alabama, (ca. 1896) is the oldest continuous cotton experiment in the world, and the third longest-running continuous field crop experiment in the USA (Mitchell and Entry, 1998). It is located on the campus of Auburn University at the merger of Coastal Plain sediments and the southern Piedmont Plateau in east-central Alabama (32° 36'N, 85° 36'W). The area receives an average of 56.7 in of annual precipitation and the mean temperature is 65° F. The soil is mostly Pacolet fine sandy loam (fine, kaolinitic, thermic Typic Kanhapludults).

Site Management

A total of 13 plots, each 21.6 ft x 136.1 ft, with a 3-ft alley were established in 1896. The treatments have undergone modifications since 1925 in terms of legumes used, fertilizer applications, and varieties (Mitchell and Entry, 1998). Winter legumes used have been hairy vetch (*Vicia villosa* Roth), common vetch (*Vicia sativa* L.), and, since 1956, crimson clover (*Trifolium incarnatum* L.). Oat (*Avena sativa* L.) was used prior to the 1950s; since then, cereal rye (*Secale cereale* L.) or wheat (*Triticum aestivumi* L.) are included as small grain rotation crops. Despite these changes, six basic cropping systems have been maintained within the 13 original plots (Table 1).

Conventional tillage vs. Conservation tillage

Traditionally, all treatments were conventionally tilled using a moldboard plow and disking until 1990; chisel plowing and disking were used up to spring 1996. In-row subsoiling to a depth of 14-in has become a common practice since 1985 in all treatments. In spring of 1997, conservation tillage was implemented. This consists of planting into killed cover crop or winter weed residue. Deep tillage (non-inversion) was applied without surface soil disruption with a Paratill® (AgEquipment Group, Lockney, TX 79241) to a depth of 16-in before planting in 1997, 1998 and 1999. In 1999, corn plots were subsoiled under-the-row to a depth of 15-in with a KMC® subsoiler equipped with pneumatic-tire closing wheels (Kelley Manufacturing Co., Tifton, Ga 31793). Both deep tillage (Paratill® and KMC® subsoiler) implements result in minimal residue disturbance in a 4 to 6-in zone. Since 1996, Roundup Ready® varieties of cotton and soybean and Liberty-Link® corn have been planted (Mitchell *et al.*, 2002).

Soil Data Collection

In 1994, a composite sample from 30 cores was taken from each plot in two seasons (winter and spring) at the 0-8 in depth. Since conventional tillage had been used for 98 yr, SOC would likely have been evenly distributed through the plow layer. Samples were lightly crushed and sieved through a 2-mm screen and dried at 140° F for 12 hours. All samples were ground in a roller mill grinding apparatus (Kelley, 1994). For analysis of SOC, the average of these two measurements was used. For particle size analysis, 40 g sub-samples from a composite of these 30 cores per plot were taken. Soil texture was determined by sieving (>2 mm) and determining % clay, silt and sand content using a hydrometer (Gee and Bauder, 1986).

Table 1. Treatments used in the 'Old Rotation' Experiment in Auburn, AL. (ca. 1896) (Mitchell et al., 1996). Soil texture (0-8 in depth) sampled in 1994.

Cropping systems	Plot	Sand	Silt	Clay
		------------	%	------------
Continuous cotton – legume†	1, 6	70.0	17.5	12.5
Continuous cotton + legume†	2, 3, 8	69.6	17.9	12.5
Continuous cotton + N‡	13	57.5	17.5	25.0
2-yr cotton-corn + legume†	4, 7	67.5	21.3	11.2
2-yr cotton-corn + legume† + N‡	5, 9	60.0	22.5	17.5
3-yr cotton-corn-small grain/soybean + legume† + N§	10, 11,12	61.2	21.3	17.5

† Legume = winter cover crop; crimson clover since 1956.

‡ Nitrogen applied to cotton or corn (120 lbs acre^{-1} yr^{--1})

§ Nitrogen applied to small grain (60 lbs acre^{-1} yr^{-1})

In November 1999, 42 months after the last surface tillage event (May 1996); 26 locations were chosen at random from each plot and sampled at two depths (0-2 in and 2-6 in). The two depths were sampled as conservation tillage results in stratification of SOC and soil chemical properties (Franzluebbers, 2002). Each location was a composite sample from three cores centered around a 1-ft diameter area. A total of 338 locations at two depths were analyzed in 1999. Samples were prepared for analysis as in 1994. Samples were analyzed for SOC by dry combustion (Yeomans and Bremner, 1991). In addition, samples collected in 1994 were analyzed for SOM colorimetrically by the Walkey-Black technique (Walkley and Black, 1934). Soil organic carbon stratification ratios (Franzluebbers, 2002) were calculated from samples collected in 1999 (SOC 0-2 in/ SOC 2-6 in depths).

There is considerable variation in soil texture on the site, as a thin cap of unconsolidated Coastal Plain sediment overlies residual Piedmont soil (Table 1). Because of the variation in soil texture, data were analyzed using an analysis of covariance model (SAS Institute, 1996). Clay content was taken as a covariant for all analyses. Statistical analyses, including analyses of variance, and separation of least square means by least significant differences (LSD$_{0.10}$), was performed using the General Linear Models (GLM) procedure in the SAS system (SAS Institute, 1999). In addition, preplanned single degree of freedom contrasts (Table 2) were used for means comparisons. Like most nineteenth century experiments, treatments were not always replicated. The continuous cotton without legume + nitrogen (plot 13) was not replicated; therefore, it was not included in the single degree of freedom comparisons analysis.

Table 2. Single degree of freedom contrasts analyzed among principal cropping systems in the 'Old Rotation' Experiment, Auburn, AL.

Contrasts	Plot
Continuous cotton + legume[†] vs. 2-yr cotton-corn + legume[†]	2, 3, 8 vs. 4, 7
2-yr cotton-corn + legume[†] vs. 2-yr cotton-corn + legume[†] + N[‡]	4,7 vs. 5,9
2-yr cotton-corn + legume[†] vs. 3-yr cotton-corn-small grain/ soybean + legume[†] + N[§]	4,7 vs. 10,11,12
Continuous cotton + legume[†] vs. 3-yr cotton-corn-small grain/ soybean + legume[†] + N[§]	2, 3, 8 vs. 10,11,12
Continuous cotton – legume[†] vs. Continuous cotton + legume[†]	1, 6 vs. 2, 3, 8

[†] Legume = winter cover crop; crimson clover since 1956.

[‡] N applied to cotton or corn (120 lbs acre^{-1} yr^{-1})

[§] N applied to small grain (60 lbs acre^{-1} yr^{-1})

RESULTS AND DISCUSION

SOIL ORGANIC CARBON AND TEXTURE ANALYSIS

Differences between soil textures (Table 1) may have affected carbon dynamics and storage in the experiment. Bajracharya *et al.* (1998) suggested that a strong association between micro-aggregates and clay keeps SOC more stable, resistant, and protected from decomposition. The potential for a soil to sequester carbon appears to be linked to formation of organo-mineral complexes leading to the stabilization of aggregates, thus increasing SOC resistance to breakdown by physical and chemical agents (Bajracharya *et al.*, 1998).

RELATIONSHIP BETWEEN SOC AND SOM IN 1994

As expected, a highly significant linear relationship was observed between SOC determined by dry combustion and SOM determined by Walkley and Black in 1994 (Fig. 1). Soil organic matter is frequently estimated from SOC determinations and the conversion factor is soil specific, ranging from 1.724 to 2.00 (Nelson and Sommers, 1982; Tabatabai, 1996). The 1.724 value is most frequently used to convert SOC determinations to SOM. An average multiplier of 2.01 best estimated SOM using SOC values determined by dry combustion on samples from the 'Old Rotation' collected in 1994. Due to inaccuracies associated with determination of SOM, either directly through wet chemistry procedures, or indirectly through SOC determination/conversion from various methodologies, it is recommended that researchers determine and report SOC directly, rather than report values for SOM (Nelson and Sommers, 1982; Tabatabai, 1996). Dry combustion techniques, coupled with improved soil processing (Kelley, 1994) offer a rapid and convenient method for determining SOC. However, many producers, technical advisors, and consultants are more comfortable with values for SOM being reported, rather than reporting SOC. For acid, weathered soils like those in the 'Old Rotation', our results suggest a conversion factor of 2.02 is more accurate than the commonly quoted factor of 1.724.

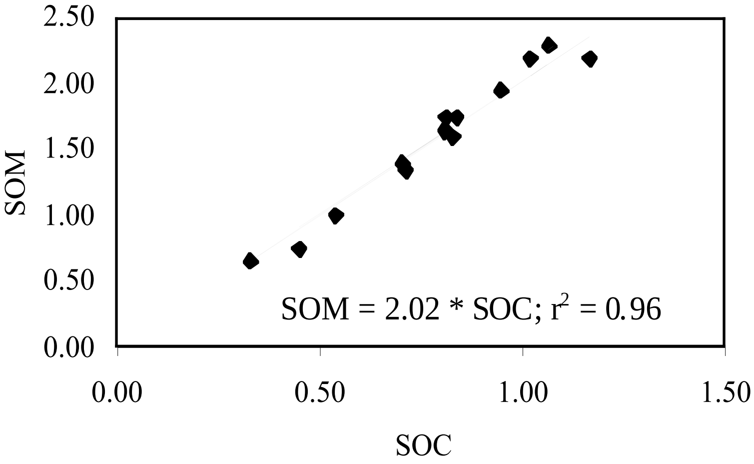

Fig.1. Comparison of SOC determined by dry combustion technique and SOM determined by Walkey-Black procedure from soil samples in the 'Old Rotation' Experiment, Auburn, AL., 1994.

SOC IN 1994

In 1994, after 98 years of conventional tillage, the 3-yr rotation of cotton-corn-small grain/soybean with winter legume, and the 2-yr rotation of cotton-corn with winter legume and 120 lbs N acre^{-1} year^{-1} had the highest SOC in the plow layer (0-8 inches) (Fig. 2). The continuous cotton with winter fallow and no N had the lowest SOC. Continuous cotton is detrimental to soil quality because cotton is a low residue crop. Without significant inputs of carbon from residues and with conventional tillage, the loss of SOC was dramatic.

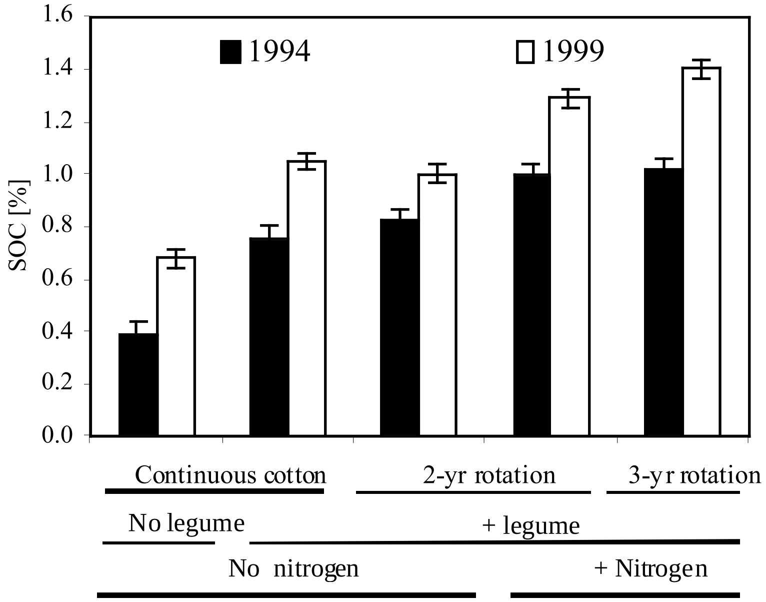

Fig. 2. Soil organic carbon in 1994 (0-8 in depth) and 1999 (0-6 in depth) among principal cropping systems in the 'Old Rotation' Experiment, Auburn, AL. The last conventional tillage was performed in spring 1996.

The 3-yr rotation of cotton-corn-small grain/soybean with winter legume and the 2-yr rotations of cotton-corn with winter legume with or without N had historically higher seed cotton yields than other treatments (Mitchell and Entry, 1998). These authors indicated that winter legumes increased both C and N in the soil, which ultimately contributed to higher cotton yields.

CHANGES IN SOC BETWEEN 1994 AND 1999

From May 1996 until November 1999 (42 months after the last conventional tillage) plots were managed using conservation tillage, and the impact of these practices was exceptionally large. All cropping systems increased SOC values between 21 and 73% (Fig. 2).

Conservation tillage on Coastal Plain soils has been reported to increase both SOC and crop yields after 17 years (Motta et al., 2002), but the time necessary to demonstrate these effects depends on soil type and climate (Reeves, 1997). Karlen *et al.* (1989) concluded that 8 years were required for conservation tillage systems to increase SOC significantly in the Coastal Plain. After 42 months, conservation tillage increased SOC an average of 39% in the 'Old Rotation', indicating a dramatic change in a short time period in a thermic humid regime

The rate of SOC change between 1994 and 1999 varied significantly with cropping system (Table 3, Fig. 2). The greatest increase in SOC occurred with the most-degraded system (continuous cotton without a winter legume). Although this system had the lowest SOC value for all cropping systems in 1999, it had the highest ratio of change between 1999 and 1994. This was due to a very low SOC value in 1994 (0.39%). Reeves (1997) stated that without significant input of carbon from crop residues, conservation tillage alone could only slow the loss of SOC, not halt or reverse it. Across a wide range of climatic conditions, research has shown that SOC increases with increased cropping intensity in conservation tillage systems. The actual increase in SOC between 1994 and 1999 was actually higher in the 3-yr rotation of cotton-corn-small grain/soybean + legume + nitrogen (Δ 0.39%), supporting the premise that cropping inten-

Table 3. Percent soil organic carbon (SOC) in 1994 (0 – 8 inch depth) and 1999 (0 – 6 inch depth) and the change in SOC expressed as the ratio of 1999 data divided by 1994 data among principal cropping systems in the 'Old Rotation' Experiment, Auburn, AL.

Contrasts	1994	1999	Change
	---------- %	---------	
Continuous cotton + legume[†] vs. 2-yr cotton-corn + legume[†]	ns	ns	**
2-yr cotton-corn + legume[†] vs. 2-yr cotton-corn + legume[†] + N[‡]	ns	***	**
2-yr cotton-corn + legume[†] vs. 3-yr cotton-corn-small grain/ soybean + legume[†]+ N[§]	ns	***	***
Continuous cotton + legume[†] vs. 3-yr cotton-corn-small grain/ soybean + legume[†] + N[§]	ns	***	ns
Continuous cotton – legume[†] vs. Continuous cotton + legume[†]	***	***	**

*. **, *** significant at $P = 0.10$, 0.05 and 0.01, respectively

[†] Legume = winter cover crop; crimson clover since 1956.

[‡] Nitrogen applied to cotton or corn (120 lbs acre^{-1} yr^{--1})

[§] Nitrogen applied to small grain (60 lbs acre^{-1} yr^{--1})

sity is critical for increasing SOC in conservation systems. Studies by Varvel *et al.* (1994) concluded that positive affects of crop rotations on physical, chemical and biological soil properties are related to higher carbon inputs and diversity of plant residues returned to soils. Langdale *et al.* (1992) showed that no-till management of grain sorghum [*Sorghum bicolor* (L.) Moench], coupled with winter cover cropping increased SOC by an average of 2020 lbs acre^{-1} year^{-1} over conventional tillage in the Georgia Piedmont.

In 1994, only 1 of the 5 rotations subjected to analysis had significant differences in SOC. In 1999, 4 of 5 rotations resulted in a significant differences after only 42 months of conservation tillage. Thus, our data validate the conclusion by Bruce (1990) and Reeves (1997) that tillage practices negate cropping system affects. Our data suggests that simultaneous use of conservation tillage and crop rotations can rapidly improve soil quality and productivity.

SOC STRATIFICATION RATIO IN 1999

The stratification of SOC with soil depth is common in many ecosystems. Franzluebbers (2002) developed a concept of using a SOC stratification ratio as an indicator of dynamic soil quality. In our study, the SOC stratification ratio (SOC 0-2 in/SOC 2-6 in depths) for 1999 data showed that the smallest SOC stratification ratio was with continuous cotton without winter legume but values were statistically similar to any rotation that included corn (Table 4). Our data generally agrees with Franzluebbers (2002), who found larger SOC stratification ratios with increasing cropping intensity. Contrary to this, however, the 3-yr and 2-yr rotations that included corn had lower SOC stratification ratios than continuous cotton with winter legume. The overall average SOC stratification ratio in 1999 was 1.31; closer to values found with conventional tillage than for conservation tillage as reported by Franzluebbers (2002). This indicates that the 'Old Rotation' is only in the beginning stages of change regarding SOC and associated properties. Franzluebbers (2002) concluded that a good SOC stratification ratio is between 2 to 3, depending on soil type and climatic conditions.

CONCLUSION

Soil organic carbon in the 'Old Rotation' was dramatically affected by use of conservation tillage for three years. The rapid change in SOC among cropping systems with conservation tillage mirrors yield increases reported by Mitchell *et al.*, 2002a,b). The study confirms that conservation tillage systems with crop rotation and winter legume cover crops had the largest impact on SOC. Changes in SOC occurred more quickly than other research suggests. Conservation tillage has induced changes in the distribution of SOC and these changes depended on the cropping system implemented. The SOC stratification ratios in the 'Old Rotation' are low, indicating a severely degraded soil. The full impact of conservation tillage on soil quality may take years to reverse this degradation.

Table 4. Soil organic carbon stratification ratio among principal cropping systems (0-2 / 2-6 in depth) in the 'Old Rotation' Experiment, Auburn, AL

Cropping Systems	SOC Stratification Ratio
Continuous cotton - legume[†]	1.17
Continuous cotton + legume [†]	1.52
2-yr cotton-corn + legume [†]	1.21
2-yr cotton-corn + legume[†] + N[‡]	1.28
3-yr cotton-corn-small grain /soybean + legume[†] + N[§]	1.26
LSD$_{0.10}$	0.32

[†] Legume = winter cover crop; crimson clover since 1956.

[‡] Nitrogen applied to cotton or corn (120 lbs acre^{-1} yr^{--1})

[§] Nitrogen applied to small grain (60 lbs acre^{-1} yr^{--1})

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SOIL CARBON AND NITROGEN AS INFLUENCED BY TILLAGE AND POULTRY LITTER IN NORTH ALABAMA

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ABSTRACT

Conservation tillage and waste management are manipulative strategies for sequestering carbon (C) in the soil in the Cotton Belt, where a large amount of poultry waste is being produced every year. A study was initiated in 1996 at the Tennessee Valley Research and Extension Center, Belle, Mina, AL, to study the effects of no-till and mulch-till systems, surface application of poultry litter, and winter rye (*Secale cereale* L.) cover cropping on soil pH, C and N concentrations and growth and yield of cotton (*Gossypium hirsutum* L.). There were no significant differences in soil pH among the treatments prior to cotton planting in 2001. In April 2001, soil C in the upper 5 cm under mulch-till was 12% greater than that under conventional till, and 46% higher than that in bare fallow (BF) plots. In a cotton-winter rye cropping system, soil C in the upper 5 cm was 25% and 42%, greater than under cotton-winter fallow and BF plots, respectively, while in plots which received 100 kg N ha^{-1} and 200 kg N ha^{-1} in the form of poultry litter (PL), it was 7% and 20%, greater than in plots which received 100 kg N ha^{-1} in the form of ammonium nitrate (AN), respectively. Total soil N in the 0-5 cm soil depth at the start of the season in April 2001 under no-till was not significantly different from that in the conventional till. However, mulch-till plots contained 10% and 25% greater total soil N, compared to conventional till and no-till, respectively. The results from this study show that four years of conservation tillage system with winter rye cover cropping and poultry litter as a source of N did not have adverse effects on soil pH and that winter-rye cover cropping and PL use in conservation tillage increased total soil C in the top 5 cm of soil.

KEYWORDS

Conservation tillage, cover crop, cotton, rye, soil pH.

INTRODUCTION

Implementation of conservation tillage systems such as no-till and mulch-till with winter rye cover cropping and the application of poultry litter in cotton production may lead to significant changes in soil physical, chemical, and biological properties in the plow layer. These changes can have a significant impact on the environment and hence the sustainability of cotton production systems (Nyakatawa *et al.*, 2001a). Despite being one of the most profitable crops available to growers in the Southern and Mid-southeastern region, cotton is considered to create a greater soil erosion hazard than other annual crops such as corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] (Nyakatawa, *et al.*, 2001b). The adoption of mulch-till and no-till practices and leaving crop residue on the soil surface can increase the amount of carbon in agricultural systems. In addition, no-till can reduce soil erosion while maintaining or increasing soil productivity (Steven *et al.*, 1992; Triplett *et al.*, 1996). The main reason for this is that the soil is less exposed to air, thus less soil carbon is oxidized and released into the atmosphere as CO_2.

Agricultural soils play an integral part in C sequestration and storage that can help mitigate global warming (Lal *et al.*, 1998). The moldboard plow has been the symbol of U.S. agriculture over the last 150 years and through its intensive usage, agricultural soils have been mineralized or oxidized of its soil C and soil organic matter (Reicosky, 2001). Until recently, cotton in north Alabama was mainly grown under conventional tillage systems. This includes the moldboard plow or chisel plow primarily in the fall, spring disking or harrowing, and inter-row cultivation for weed control during the cotton-growing season. These tillage operations make the soil more susceptible to erosion that leads to the depletion of soil C and nitrate leaching.

Poultry litter accumulation in several southeastern states is becoming an increasing problem to farmers. Poultry litter is a by-product that needs to be disposed of safely to avoid environmental issues, primarily due to soil NO_3 and phosphorous enrichment from the litter. The application of

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poultry litter to crop lands serves both as an important means of waste disposal and a valuable source of plant nutrients, such as N and P. When applied in no-till conservation tillage systems, this waste acts as a mulch which reduces soil erosion while at the same time improving soil organic matter, conserving soil moisture, and providing nutrients for crops (Reddy *et al.*, 2000; Nyakatawa *et al.*, 2001a; 2001b; 2001c;). In north Alabama, the poultry industry produces an abundant supply of poultry litter whose application to croplands as a fertilizer provides an environmental friendly way of disposing large quantities of poultry litter.

Plant residue management that combines no-till with cover crops offers soil coverage with protective residue and therefore, maximal benefit for reduced erosion and preserved soil quality (Reeves, 1997). The attributes that make winter rye a superior cover crop over legumes include vigorous growth, winter hardiness, early spring growth, herbicide sensitivity, and mulch persistence (Brown *et al.*, 1985; Bauer and Reeves, 1999). Winter rye cover crops may also reduce leaching losses of residual N fertilizer (Kelley *et al.*, 1992). The objectives of this study were to evaluate the effects of no-till and mulch-till with winter cover cropping and poultry litter on soil pH, C and N in cotton plots on a Decatur silt loam soil in North Alabama.

MATERIALS AND METHODS

The study has been conducted since 1996 at the Tennessee Valley Research and Extension Center,, Belle Mina, AL (34°41‘N, 86°52‘W) on a Decatur silt loam soil (clayey, kaolinitic thermic, Typic Paleudults) and the results reported here are from the 2001 cropping season. The cropping history of the plots is presented in Table1. Treatments included three tillage systems (conventional till, mulch-till, and no-till), two cropping systems (cotton plus winter fallow and cotton plus winter rye (*Secale cereale* L.) sequential cropping), three N rates (0, 100 and 200 kg N ha^{-1}), and two N sources (ammonium nitrate and fresh poultry litter). Ammonium nitrate was used at one N rate (100 kg N ha^{-1}) only. In addition a continuous bare fallow treatment was included. The experimental design was a randomized complete block design with four replications. Plots were 8 m wide and 9 m long, which resulted in eight rows of cotton, 1 m apart. Conventional tillage included moldboard plowing in November and disking in April before cotton seeding. A field cultivator was used to prepare a smooth seedbed after disking. A field cultivator and spot applications of herbicides were used for controlling weeds during the season. Mulch-till included tillage with a field cultivator to partially incorporate crop residues before cotton seeding. No-till involved seeding without any tillage operation. The crop residues were left lying on the surface. Weeds were controlled by spot applications of herbicides in the no-till and mulch till systems.

Ammonium nitrate and poultry litter were applied immediately before cotton seeding. The poultry litter was broadcasted by hand and incorporated to a depth of 5 to 8 cm by pre-plant cultivation in the conventional and mulch-till systems. In no-till system, the poultry litter was surface applied. The N content for the poultry litter was determined by digesting 0.5g samples using the Kjeldhal wet digestion method (Bremner and Mulvaney, 1982), followed by N analysis using the Kjeltec 1026 N analyzer (Kjeltec, Sweden). The amounts of poultry litter to supply 100 and 200 kg N ha^{-1} were calculated each year based on the N content of the poultry litter. A 60% adjustment factor was used to compensate for the N availability from poultry litter during the first year of application. At the beginning of the experiment in 1996, all plots received a blanket application of 336 kg ha^{-1} of 0-20-20 fertilizer to nullify the effects of P and K applied through poultry litter.

The winter rye cover crop cv. Oklon, was planted in fall and killed by Roundup herbicide (glyphosate) about 7 days after flowering in spring. A no-till planter was used to seed the rye cover crop at a rate of at 60 kg ha^{-1} into the previous cotton stubble immediately after cotton harvest. Cotton cv. Deltapine NuCotton 33B was planted in all plots at 16 kg ha^{-1}, using a no-till planter. A herbicide mixture of Prowl (pendimethalin) at 2.3 L ha^{-1}, Cotoran (fluometuron) at 3.5 L ha^{-1}, Gramoxone Extra (paraquat) at 1.7 L ha^{-1} was applied to all plots before planting in May for weed control. In addition, all plots received 5.6 kg ha^{-1} of Temik (aldicarb)

Table1. Cropping history of plots used in the study, Belle Mina, AL 1996 to 2002.

Season	Year	Crop
Summer	1996	Cotton
Winter/Spring	1996/1997	Rye
Summer	1997	Cotton
Winter/Spring	1997/1998	Rye
Summer	1998	Cotton
Winter/Spring	1998/1999	Fallow
Summer	1999	Corn
Winter/Spring	1999/2000	Rye
Summer	2000	Cotton
Winter/Spring	2000/2001	Rye
Summer	2001	Cotton
Winter/Spring	2001/2002	Fallow

for the control of thrips. During the season, a cultivator was used for controlling weed in conventional till system while spot applications of Roundup using a knapsack sprayer were used to control weeds in the no-till and mulch-till systems. Aphids were controlled with Karate (cypermethrine). The growth regulator, Pix at 0.8 kg ha^{-1} was applied to cotton to reduce vegetative growth at 2.5 months after planting. The cotton was defoliated with a mixture of Finish at 2.3 L ha^{-1} and Def at 0.6 kg ha^{-1} two weeks before the first harvest. Seed cotton yield was determined by mechanically harvesting open cotton bolls in the central four rows of each plot.

Four soil cores, each 5 cm in diameter, were randomly collected from the central four rows of each plot in April 2001 using a tractor powered hydraulic probe. The soils were composited within each plot at depths of 0-5, 5-15, 15-30, 30-60, and 60-90 cm. The soil was air-dried and ground to pass through a 2 mm sieve before analysis. Soil pH was measured using a glass electrode connected to the Orion A290 pH meter (Orion Research Inc., Boston, MA) in 1:1 soil: water suspension at Alabama A&M University. Total soil N and C were measured using the LECO Carbon analyzer at the USDA/ARS Soil Dynamics Research Laboratory, Auburn, AL.

RESULTS AND DISCUSSION

There were no significant differences among treatments for soil pH (Table 2). Average soil pH in the top 15 cm was about 6.0, which is within the optimum range for cotton (5.8 to 6.5) (Burmester, 1993). Soil carbon in averaged over all treatments the top 0-5 cm was about three times that in the bottom 30-90 cm soil profile (Table 3). This can be explained by the accumulation of organic residues from crops and poultry litter manure in the upper soil layer.

Table 2. Soil pH in cotton plots under conventional till (CT), mulch-till (MT), and no-till (NT) tillage systems; cotton-winter fallow (CF), cotton-rye sequential (CR), and bare fallow (BF) cropping systems, and ammonium nitrate (AN) and poultry (PL) sources of N prior to cotton planting in April 2001 at the Tennessee Valley Research and Extension Center, Belle Mina, AL.

Depths	Tillage system			
-- cm --	CT	MT	NT	BF
0 - 5	5.84a[†]	5.73a	5.78a	5.37a
5 - 15	5.91a	5.98a	5.96a	5.72a
15 - 30	5.82a	5.79a	5.91a	5.68a
30 - 60	5.50a	5.46a	5.51a	5.32a
60 - 90	5.12a	5.01a	5.05a	4.97a
	Cropping system			
	CF	CR	BF	
0 - 5	5.74a	5.82b	5.37a	
5 - 15	5.93a	5.95a	5.72a	
15 - 30	5.86a	5.86a	5.68a	
30 - 60	5.46a	5.51a	5.32a	
60 - 90	5.01a	5.09a	4.97a	
	N-treatment, lbs N acre^{-1}			
	0N	100AN	100PL	200PL
0 - 5	5.80b	5.63a	5.97b	5.68a
5 - 15	5.93a	5.92a	5.95a	5.94a
15 - 30	5.85a	5.82a	5.88a	5.86a
30 - 60	5.47ab	5.56b	5.45ab	5.24a
60 - 90	5.08a	5.12a	4.99a	4.89a

[†] Means within a row followed by the same letter are not significantly different at $P = 0.05$.

Table 3. Soil carbon [%] in cotton plots under conventional till (CT), mulch-till (MT), and no-till (NT) tillage systems; cotton-winter fallow (CF), cotton-rye sequential (CR), and bare fallow (BF) cropping systems, and ammonium nitrate (AN) and poultry (PL) sources of N prior to cotton planting in April 2001 at the Tennessee Valley Research and Extension Center, Belle Mina, AL.

Depths	Tillage system			
-- cm --	CT	MT	NT	BF
0 - 5	1.37bc[†]	1.49c	1.30b	1.02a
5 - 15	1.12b	1.10b	1.00b	0.98a
15 - 30	0.92a	0.88a	0.87a	0.81a
30 - 60	0.40a	0.46b	0.41ab	0.37a
60 - 90	0.32ab	0.36b	0.30a	0.31a
	Cropping system			
	CF	CR	BF	
0 - 5	1.01a	1.09b	0.98a	
5 - 15	0.83a	0.91b	0.81a	
15 - 30	0.39a	0.43a	0.37a	
30 - 60	0.30a	0.33a	0.31a	
60 - 90	1.16a	1.45b	1.02a	
	N-treatment, lbs N acre^{-1}			
	0N	100AN	100PL	200PL
0 - 5	1.18a	1.32a	1.42ab	1.59b
5 - 15	0.99a	1.09a	1.08a	1.00a
15 - 30	0.84a	0.88a	0.90a	0.92a
30 - 60	0.40a	0.41a	0.40a	0.42a
60 - 90	0.31a	0.31a	0.32a	0.33a

[†] Means within a row followed by the same letter are not significantly different at $P = 0.05$.

Differences in soil C among the tillage treatments were significant in the top 0-5 and 5-15 cm soil profile. In the top 0-5 cm, soil C under mulch till was 12% greater than that under conventional till and no-till and 46% higher than that in BF plots (Table 3). There was no significant difference in soil C between no-till and conventional till systems.

Soil C in the 0-5 cm soil profile under cotton-winter rye cropping system was 25% and 42% greater than that under cotton-winter fallow and bare fallow plots respectively (Table 3). Soil C in the 0-5 cm soil profile in plots, which received 100AN, 100PL, and 200PL, were 13%, 20% and 36%, greater than in the 0N plots respectively (Table 3). Plots receiving 100PL and 200PL had 7% and 20% greater soil C than 100AN plots, respectively. This shows the advantage of using PL as a N source in increasing soil C.

Differences in total soil N among the treatments were significant in the top 0-5 and 5-15 cm soil profile. Total soil N under no-till in the 0-5 cm soil depth was not significantly different from that in conventional till (Table 4). However mulch-till plots contained 10% and 25% greater total soil N, compared to conventional till and no-till respectively. The difference between mulch till and no-till can be attributed to the higher mineralization of crop residues in mulch till compared to no-till, while that between mulch till and conventional till may be attributed to greater amount of crop residues in mulch till (Nyakatawa *et al.*, 2001a). As was expected, bare fallow plots contained the least amount of residual total soil N, since these plots did not receive any N fertilizer and also, had no residues which supply N after mineralization. Similar results were found in the 5-15 soil depth.

Table 4. Soil nitrogen [%] in cotton plots under conventional till (CT), mulch-till (MT), and no-till (NT) tillage systems; cotton-winter fallow (CF), cotton-rye sequential (CR), and bare fallow (BF) cropping systems, and ammonium nitrate (AN) and poultry (PL) sources of N prior to cotton planting in April 2001 at the Tennessee Valley Research and Extension Center, Belle Mina, AL.

Depths		**Tillage system**		
-- cm --	CT	MT	NT	BF
0 - 5	0.09a†	0.10a	0.08a	0.07a
5 - 15	0.08b	0.08b	0.07a	0.07a
15 - 30	0.07a	0.07a	0.06a	0.06a
30 - 60	0.05ab	0.06b	0.04a	0.04a
60 - 90	0.05a	0.06a	0.05a	0.05a
		Cropping system		
	CF	CR	BF	
0 - 5	0.07a	0.08a	0.07a	
5 - 15	0.06a	0.07a	0.06a	
15 - 30	0.04a	0.05b	0.04a	
30 - 60	0.05a	0.05a	0.05a	
60 - 90	0.08a	0.09b	0.07a	
		N-treatment, lbs N acre^{-1}		
	0N	100AN	100PL	200PL
0 - 5	0.08a	0.09a	0.09a	0.09a
5 - 15	0.07a	0.08a	0.07a	0.06a
15 - 30	0.07a	0.07a	0.06a	0.06a
30 - 60	0.05a	0.05a	0.05a	0.04a
60 - 90	0.05a	0.05a	0.05a	0.05a

†Means within a row followed by the same letter are not significantly different at $P = 0.05$.

Total soil N in the 0-5 cm soil profile under cotton-winter rye cropping system was 13% and 29%, greater than that under cotton-winter fallow and bare fallow plots respectively (Table 4). The great amount of residual soil N in cotton-winter rye cropping system was from the residues from the winter rye cover crop. Total soil N in the 0-5 cm soil profile in plots which received poultry litter at 200 kg N ha^{-1} PL (200PL) was 10% greater than that in plots which received 100AN and 100PL N treatments (Table 4). Plots receiving 100AN and 100PL N treatments had the same amount of total soil N.

CONCLUSION

Results from this study show that the use of no-till and mulch till conservation tillage systems with winter cover cropping and poultry litter as a source of N generally have had no significant effect on soil pH in cotton plots on the Decatur silt loam soil at Belle Mina Alabama over the five year duration of the experiment. This is a good result in the sustainability of the soil. The other positive result from this study is that there is no significant accumulation of residual total soil N among the treatments, especially in the deeper soil profile, which could otherwise pose a leaching problem. In the top 5 cm of the soil, the residual soil N is easily accessible and available for use by the following summer crop. Finally, this study demonstrates that winter rye cover cropping and poultry litter use in conservation tillage can increase total soil C in the top soil which improves soil moisture conservation, soil structure, and nutrient holding capacity of the soil.

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SOIL MANAGEMENT EFFECTS ON INTERRILL ERODIBILITY OF TWO ALABAMA SOILS

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ABSTRACT

Many Southeastern soils have been managed with conventional tillage practices in past, and most are considered highly erodible. Conservation tillage is effective in reducing soil loss. The objective of this study was to quantify soil loss and calculate interrill erodibilities (K_i) for a loamy sand (Typic Hapludult, E.V. Smith Research Center) and a silt loam soil (Rhodic Paleudult, TN Valley Substation) in the Coastal Plain and Limestone Valley, respectively, managed under conventional- (CT) and no-till (NT) systems. We also evaluated NT with and without fall paratilling (+P, -P), as well as with and without surface cover from a small grain winter cover crop (C, NC). Therefore, four tillage/residue treatments evaluated were: 1) conventional tillage without paratilling and without a winter cover crop (CT-PT, NC), 2) no-tillage without paratilling and without a cover crop (NT-P, NC), 3) no-tillage without paratilling but with a winter cover crop (NT-P, C), and 4) no-tillage with paratilling and a cover crop (NT+P, C). Tillage treatments were replicated four times. Duplicate 10 ft^2 (1 m^2) plots established on each tillage treatment were exposed to simulated rainfall (2 in h^{-1} or 50 mm h^{-1} for 2 h). Runoff and soil loss were continuously measured from each flat, level-sloping plot. Slopes for rainfall simulation plots on each soil were about 1%. At E.V. Smith, runoff and soil loss were controlled by residue cover. Interrill erodibilities ranged from 0.14-4.34. Runoff, soil loss, and interrill erodibility (0.29-5.12) values at TN Valley were controlled by fall paratilling. At both sites, runoff, soil loss, and erodibility values were greatest and infiltration was lowest for CT-P, NC plots (worst-case scenario). Runoff, soil loss, and erodibility values were lowest and infiltration was highest for NT+P, C plots (best-case scenario). Interrill erodibility values for CT-P, NC plots were 18-20 times and 10-14 times greater than corresponding values for NT+P, C plots at E.V. Smith and TN Valley, respectively. The CT-P, NC treatment in the Coastal Plain and Tennessee Valley regions of Alabama represents the greatest potential for runoff and soil loss. Surface residue management through conservation tillage coupled with non-inversion deep tillage like paratilling is the best system to promote infiltration and reduced runoff, soil loss, and interrill erodibility for soils in the Coastal Plain and Tennessee Valley regions of Alabama.

KEYWORDS

Coventional till, no-till, non-inversion deep tillage, paratill

INTRODUCTION

Alabama soils are traditionally managed under conventional tillage, tend to be drought-prone, and are susceptible to erosion. Conservation tillage is effective in reducing soil loss, yet some farmers are still reluctant to adopt these practices, despite potential benefits.

Conservation tillage reduces runoff and soil loss by increasing residue, organic matter, aggregate stability, and decreasing water dispersible clay (Shaw *et al*., 2002; Truman *et al*., 2002 a,b). In the Southeast, equipment traffic, implement action, and consolidation compact weakly-structured surface soils, and deep tillage is needed to disrupt compacted zones (Raper *et al*., 1994; Reeves and Mullins, 1995). Paratilling, a noninversion deep tillage technique, reduces bulk density and soil strength in the soil profile (Pierce and Burpee, 1995; Schwab *et al*., 2002; Truman *et al*., 2002 a), which affects infiltration and erosion (Rawitz *et al*., 1994; Truman *et al*., 2002 a,b). We quantified soil loss and calculated interrill erodibilities for two Alabama soils managed under conventional- (CT) and no-till (NT) systems.

MATERIALS AND METHODS

Site 1 was at the Alabama Agricultural Experiment Station's (AAES) E.V. Smith Research center near Shorter, AL. The soil was a loamy sand (Typic Hapludult). The surface horizon (0-9.5 in, 0-24 cm) had a sand content of

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81% and a clay content of 5%. Historical details regarding this site are given in Reeves *et al*. (2000) and Truman *et al*. (2002a). The site was managed under conventional- (CT) and no-till (NT) systems since 1989. Each tillage treatment (four reps) was established on field plots 10 ft wide and 70 ft long. Conventional tillage consisted of disking, chisel plowing, in-row subsoiling, disking, and field cultivating. Paratilling was conducted in the spring with a four-shank Paratill· (Bigham Brothers, Inc., Lubbock, TX), equipped with a smooth roller that disrupted soil to about 16 in (40 cm).

Site 2 was at the AAES Research & Extension Center at Belle Mina, AL. The soil was a silt loam (Rhodic Paleudult). The surface horizon (0-7.5 in, 0-19 cm) had a sand content of 15% and a clay content of 31%. Historical details regarding this site are given in Schwab *et al*. (2002) and Truman *et al*. (2002b). The silt loam was managed under CT and NT systems. Each tillage treatment (four reps) was established on field plots 26 ft wide and 50 ft long. Conventional tillage consisted of fall chisel plowing followed by spring disking and cultivator leveling. Paratilling was done in fall following cotton (*Gossypium hirsutum* L.) harvest each year since 1994.

At both sites, tillage/residue treatments included: 1) conventional tillage without paratilling (P) and without residue cover (CT-P, NC), 2) no-tillage without paratilling and without cover (NT-P, NC), 3) no-tillage without paratilling and with cover (NT-P, C), and 4) no-tillage with paratill and cover (NT+P, C). Winter cover crops in residue cover treatments were planted each fall since 1994 at Belle Mina and since 1989 at E.V. Smith. The fall prior to rainfall simulations, cover crops used were black oat (*Avena strigosa* Schreb.) and rye (*Secale cereale* L.) at E.V. Smith and Belle Mina, respectively.

Soil samples were taken from within each tillage treatment at each site. When possible, samples were collected in the immediate vicinity of areas designated for simulated rainfall. Soil properties were determined with the following methods: particle size distributions (PSDs) by the pipette method (Kilmer and Alexander, 1949), soil organic carbon (SOC) by the combustion method (Yeomans and Bremmer, 1991), aggregate stability by the water stable aggregate method (Kemper and Rosenau, 1986), and bulk density by the core method (Blake and Hartge, 1986).

For PSDs, samples were air-dried, crushed, and coarse fragments removed. PSDs were measured by the pipette method, with sands separated into size fractions by sieving.

SOC was determined from samples taken from 10 composite core samples (1 in diameter) taken adjacent to rainfall simulation plots. Samples were divided into five depth increment from 0-7 in. (0-1, 1-3, 3-6, 6-12, and 12-18 cm) depths. Recognizable debris was removed from the samples, and subsamples were finely ground in a roller mill (Kelly, 1994). Subsamples were analyzed for carbon by automated combustion using an NA 1500 NCS analyzer (Fisons Instruments Inc., Beverly, MA 01915). Each ground subsample was subjected to four carbon analyses.

Percent water-stable aggregates (WSA) from the 0-1.2 in (0-3 cm) soil depth were determined from composite samples taken from five locations adjacent to areas designated for rainfall simulations. Mean WSAs (%) were determined from eight lab determinations from each composite sample per plot.

Bulk density was determined from core samples (2 in diameter) taken from three locations and three depths ranging from 0-17 in for both sites (0-6, 6-12, 12-18 cm for E.V. Smith; 0-15, 15-30, 30-45 cm depths for TN Valley) adjacent to areas designated for rainfall simulation.

Duplicate 10 ft^2 (1 m^2) plots were established on one replicate of each tillage treatment (13-17 July, 1999 for site 1; 8-10 Nov., 1999 and 26-27 Jun., 2000 for site 2), and were considered replicates. Simulated rainfall was applied to each 10 ft^2 (1 m^2) plot at an intensity of 2 in h^{-1} (50 mm h^{-1}) for 1 h. One hour after the end of the first simulated rainfall event, each plot received an additional simulated rainfall event (2 in h^{-1} for 1 h). Rainfall was applied with an oscillating nozzle rainfall simulator (Foster *et al*., 1982) that used 80100 VeejetÆ nozzles. The simulator was placed 10 ft (3 m) above each subplot. Well water was used in all simulations at all sites.

Runoff (R) and soil loss (E) from each plot were measured continuously at 5-min intervals during each simulated rainfall event. Runoff and E were determined gravimetrically, and infiltration (INF) was calculated by difference (rainfall–runoff).

At the conclusion of each simulated rainfall event, all identifiable non-decomposed residue cover from each plot was collected, dried at 80^{o}C for 72 h, cleared of soil particles, and weighed.

Interrill erodibility was first calculated from the equation: $E=K_{ii} \times I^2$, where E is the interrill erosion rate, K_{ii} is the interrill erodibility parameter, and I is the rainfall intensity (Truman and Bradford, 1995). Interrill soil erodibility was then calculated from the equation $E=K_{ii}I \times q$, where K_{ii} is the interrill erodibility parameter and q is the flow discharge (Truman and Bradford, 1995).

Regression analysis was used to determine relationships between dependent and independent variables. Means and coefficients of variation (cv, %) are given for measured data.

RESULTS AND DISCUSSION

Bulk density (BD), soil organic carbon (SOC), and residue cover for each tillage treatment are given in Table 1.

Table 1. Mean values and coefficient of variation (CV) for elected soil properties for tillage treatments studied.

Tillage		Residue	Bulk density†		S0C-1‡		SOC-3§		Residue¶	
Surface	Paratill	Cover	Mean	CV	Mean	CV	Mean	CV	Mean	CV
			g cm^{-3}		-- % --		-- % --		lbs acre^{-1}	
E.V. Smith										
NT	Yes	Yes	1.52	14	0.82	9	0.52	3	7591	5
NT	No	Yes	1.71	5	1.46	3	1.09	2	9630	9
NT	No	No	1.71	14	1.09	1	0.69	1	2910	25
CT	No	No	1.54	8	0.62	9	0.53	10	110	13
Tennessee Valley										
NT	Yes	Yes	1.31	10	1.37	3	1.25	1	3999	25
NT	No	Yes	1.44	4	2.58	3	1.25	6	4438	14
NT	No	No	1.43	8	1.71	1	1.05	1	2393	16
CT	No	No	1.54	5	0.94	3	0.9	1	927	5

† Bulk density for 0-6 inch depth

‡ SOC-1 soil organic carbon values for the 0 - 0.4 inch depth

§ SOC-3 soil organic carbon for the 0.4 - 1.2 in depths. Residue

¶ Amount of residue cover from a 10 ft2 area after rainfall simulation.

At E.V. Smith, BD values were 6% greater for no-till plots compared to those of conventional-till plots for this sandy soil. Conversely, for the silt loam at the TN Valley, BD values were 10% greater for conventional-till plots compared to those of no-till plots. In no-till plots, paratilling reduced BD values by 10-12% at both sites compared to non-paratilled no-till plots.

At both sites, no-till plots had about 65% more SOC than conventional-till plots, and SOC values for the 0-0.4 in (0-1 cm) soil layer of no-till plots were 80-100% greater than those for conventional-till plots (Table 1). Also, SOC values decreased with depth with no differences occurring below 1.2 in (3 cm). At both sites, no-till plots had at least 4 times more surface residue than conventional-till plots. Also, no-till plots with cover had 1.8-2.9 times more surface cover than no-till plots without cover.

At E.V. Smith, runoff and infiltration were controlled by surface cover (Table 2). No-till plots with cover had the lowest runoff (highest infiltration), whereas conventional-till plots with no cover had the highest runoff (lowest infiltration). Among no-till plots, those without cover had 5 times more runoff than those with cover.

At TN Valley, runoff and infiltration were controlled by fall paratilling (Table 2). The no-tillage paratilled plots with cover (NT+P, C) had the lowest runoff (highest infiltration), whereas CT-P, NC plots had the highest runoff (lowest infiltration). Runoff losses differed slightly for NT-P, C and NT-P, NC plots.

For both sites, runoff rates increased through the first simulated rainfall event (0-60 min), then reached steady-state rates during the second (60-120 min) simulated rainfall event. Removing residue caused runoff rates to increase at a faster rate than those from plots where residue remained in place, and increased steady-state runoff rates for all plots. Conventional tillage plots had the highest runoff rates, while NT+P plots had the lowest runoff rates.

At E.V. Smith, soil loss, like runoff and infiltration, was controlled by residue cover (Table 3, Fig. 1), despite this site having a well-developed hardpan. Soil loss values were greatest for conventional-till plots, and lowest for NT-P, C and NT+P, C plots. Removing residue from no-till plots increased soil loss by at least 6 times. Overall, no-till plots had at least 5 times less soil loss than conventional-till plots. Soil loss rates during both simulated rainfall events increased rapidly during the first 20 min of simulated rainfall, then reached steady-state values. Conventional tillage plots had the greatest steady-state soil loss rates, whereas NT+P, C plots had the lowest steady-state rates (20-fold differ-

Table 2. Runoff and infiltration values for the first (0-60 min) and second (60-120 min) simulated rainfall events. Target rainfall intensities were 2 in h^{-1}.

			0 - 60 minutes				60 - 120 minutes			
Tillage		Residue	Runoff		Infiltration		Runoff		Infiltration	
Surface	Paratill	Cover	Mean	CV	Mean	CV	Mean	CV	Mean	CV
			%							
E.V. Smith										
NT	Yes	Yes	3.5	8	96.5	0	3.3	8	95.7	1
NT	No	Yes	3.3	19	96.7	1	6.7	33	92.8	3
NT	No	No	19.1	16	80.9	4	44.6	6	55.2	5
CT	No	No	60.8	8	39.1	12	72.1	4	27.7	10
Tennessee Valley										
NT	Yes	Yes	5.2	39	94.8	4	7.1	36	92.8	4
NT	No	Yes	18.6	19	81.4	17	65.7	1	34.3	30
NT	No	No	16.8	41	83.2	9	54.1	15	45.9	17
CT	No	No	36.5	3	63.5	9	74.1	0	25.9	0

ence). Surface residue protects the soil surface from raindrop impact, thus limiting surface seal development and maintaining infiltration and reducing runoff and soil loss. As a result, removing residue from no-till plots increased runoff and soil loss, and decreased infiltration. Soil loss was correlated with surface residue cover ($R^2 = 0.77$). The R^2 value for soil loss vs. surface residue cover for no-till plots was 0.97.

Interrill erodibility (K_i) is a calculated parameter that represents the combined processes of soil detachment and sediment transport. Equations for calculating K_i (Table 3; Fig. 1) use measured values of soil loss, rainfall intensity, and/or runoff. The equation, $E=K_{ii}*I^2$, has been used to calculate K_i values because soil loss from interrill areas is generally thought to be detachment-limiting, and soil detachment has been related to rainfall parameters (I). However, soil loss and K_i values at E.V. Smith were dependent upon the transportability of soil particles, which are dominated by cohesionless sand-sized particles and thus were transport-limiting. Soil loss was related to runoff (transport capacity) for all plots (R^2=0.76), with CT-P, NC plots having a R^2 value of 0.98. Therefore, the equation, $E=K_{iq}*I*q$, was used to calculate erodibilities. Conventional tillage nonparatilled plots without cover (CT-P, NC) had the highest K_{ii} value and NT+P, C plots had the lowest K_{ii} value (18-fold difference). Again, surface residue controlled soil loss and K_{iq} values as no-till plots with cover were at least 5 and 12 times less erodible (based on K_{iq}) than no-till plots without cover and conventional-till plots.

At Belle Mina (TN Valley), soil loss, like runoff and infiltration, was controlled by fall paratilling (Table 3; Fig. 1). Soil loss values were greatest for conventional-till plots, and lowest for NT+P, C plots. Paratilling no-till plots decreased soil loss by 2.3 times. Overall, no-till plots had 4.7 times less soil loss than conventional-till plots. Soil loss rates during both simulated rainfall events increased rapidly during the first part of simulated rainfall, then reached steady-state values. Conventional tillage plots had the greatest steady-state soil loss rates, whereas NT+P, C plots had the lowest steady-state rates (14-fold difference). Paratilling reduces compaction, breaks up dense subsurface layers, thus maintains infiltration and reduces runoff.

Soil loss and K_i values at TN Valley were dependent on both the detachment of soil particles and the transport of sediment. This silt loam soil is more cohesive than the loamy sand soil at E.V. Smith, therefore, calculated K_i values need to represent detachment and transport processes. For our experimental conditions, both equations, $E=K_{ii}*I^2$ and $E=K_{iq}*I*q$, were adequate in quantifying K_i, including differences in K_{ii} (0.29-4.03) and K_{iq} (0.48-5.12) values between no-till paratilled and non-paratilled plots, which had a 14-fold difference in runoff. CT-P, NC plots had the greatest K_{ii} and K_{iq} values and NT+P, C plots had the lowest K_{ii} and K_{iq} values (13-fold difference for K_{ii} and

Table 3. Total soil loss for the first (0-60 min = E_{60}) and second (60-120 min = E_{120}) simulated rainfall events, steady-state soil loss ($E_{s/s}$), and interrill erodibility (K_i) values for each tillage.

			Soil loss					Interill Erodibility	
Tillage		Residue	0 - 60 min.		60 - 120 min.		Steady	without	with
Surface	Paratill	Cover	Mean	CV	Mean	CV	state	flow	flow
			------------- g m^{-2} ------------				kg m^{-2} h^{-1}	----- kg s m^{-4} -------	
E.V. Smith									
NT	Yes	Yes	11	32	13	1	0.01	0.14	0.24
NT	No	Yes	8	6	14	56	0.02	0.29	0.47
NT	No	No	78	17	70	43	0.07	1.00	1.87
CT	No	No	193	20	180	9	0.20	2.87	4.34
Tennessee Valley									
NT	Yes	Yes	24	26	21	15	0.02	0.29	0.48
NT	No	Yes	38	67	58	49	0.07	1.00	1.18
NT	No	No	45	34	65	10	0.07	1.00	1.59
CT	No	No	136	40	261	0	0.28	4.03	5.12

10-fold difference for K_{iq}). Among no-till plots, paratilled plots (NT+P, C) were 3 times less erodible than non-paratilled (NT-P, C and NT-P, NC) plots.

At both sites, runoff, soil loss, and K_i values were greatest and infiltration was lowest for CT-P, NC plots, while runoff, soil loss, and K_i values were lowest and infiltration was highest for NT+P, C plots. The CT-P, NC treatment has historically been the "standard practice" for farmers in the Coastal Plain region and Tennessee Valley region of Alabama, yet represents the greatest potential for runoff and soil loss. Therefore, from our data, we concluded that NT+P, C plots represented the best-case scenario and CT-P, NC plots represented the worst-case scenario.

CONCLUSIONS

We evaluated soil loss and interrill erodibilities (K_i) from two Alabama soils managed under conventional- (CT) and no-till (NT) systems. Four tillage/residue treatments evaluated were conventional tillage without paratilling and without a small grain cover crop (CT-PT, NC), no-tillage without paratilling and without cover (NT-P, NC), no-tillage without paratilling but with a cover crop (NT-P, C), and no-tillage with fall paratilling and a cover crop (NT+P, C). Each 10 ft^2 (1 m^2) plot was exposed to 2 h of simulated rainfall (I=2 in h^{-1}, 50 mm h^{-1}), and runoff and soil loss were measured continuously. The following conclusions can be made:

1. At both sites, no-till plots had 65% more SOC than conventional-till plots, and SOC values for the 0-0.4 in (0-1 cm) soil layer of no-till plots were 80-100% greater than those for conventional-till plots. Soil C values decreased with depth with no differences occurring below 1.2 in (3 cm). No-tillage resulted in at least 4 times more surface residue than conventional-till plots, and no-till plots with a winter cover crop had 1.8-2.9 times more surface cover than no-till plots without cover.

2. At E.V. Smith, runoff, infiltration, soil loss, and K_i values were controlled by surface cover. No-tillage plots with a winter cover crop had the lowest runoff (highest infiltration), whereas conventional-till plots (without cover) had the highest runoff (lowest infiltration). No-tillage plots without cover had 5 times more runoff than no-till plots with cover. Soil loss and K_i values depended on the transportability of soil particles. Removing residue from no-till plots increased soil loss by at least 6 times. Conventional tillage resulted in the greatest soil loss and K_{ii} values, whereas NT+P, C plots had the lowest corresponding values (18-20 fold difference). Surface residue protects the soil surface from raindrop impact, thus limiting surface sealing, maintaining

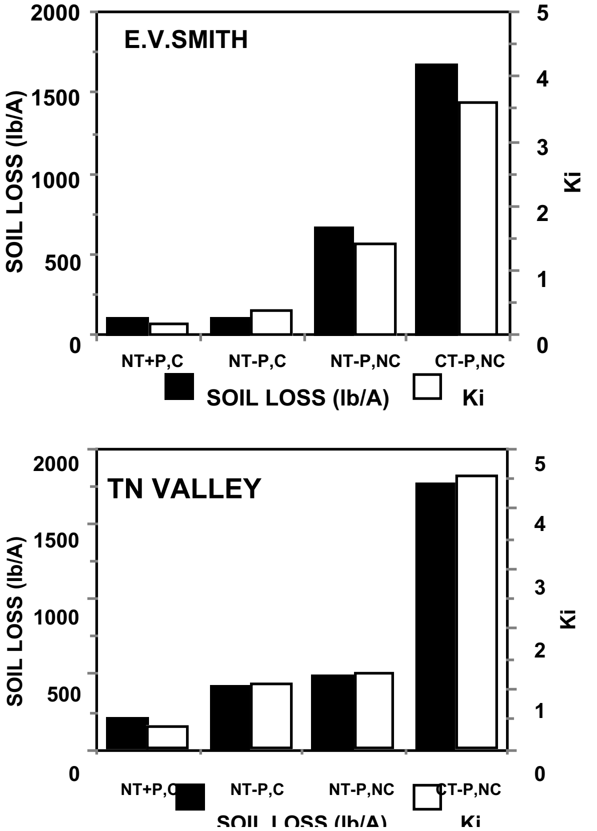

Fig. 1. Soil loss and interrill erodibility (K_i) at E.V. Smith and TN Valley for the four tillage treat-ments studied (NT=no-till; CT=conventional-till; P=paratill; C=residue cover; NC=no residue cover).

infiltration and reducing runoff and soil loss. As a result, no-till plots with cover were at least 5 and 12 times less erodible than no-till plots without cover and conventional-till plots.

3. For the silt loam soil in the TN Valley; runoff, infiltration, soil loss and K_i values were controlled by fall paratilling. No-tillage with fall paratilling and a rye cover crop resulted in the lowest runoff (highest infiltration), whereas CT-P, NC plots had the highest runoff (lowest infiltration). Soil loss and K_i values depended on both detachment of soil particles and transport of sediment. For this heavier soil, fall paratilling prevents compaction, breaks up dense subsurface layers, and thus increases infiltration and reduces runoff and erosion. As a result, NT+P, C plots were 3 times less erodible than NT-P, C and NT-P, NC plots. Conventional tillage plots had the greatest soil loss, K_{ii}, and K_{iq} values, whereas NT+P, C plots had the lowest corresponding values (10-14 fold difference).

4. At both sites, runoff, soil loss, and K_i values were greatest and infiltration was lowest for CT-P, NC plots (worst-case scenario), while runoff, soil loss, and K_i values were lowest and infiltration was highest for NT+P, C plots (best-case scenario). The CT-P, NC treatment has historically been the "standard practice" for farmers in the Coastal Plain and Tennessee Valley regions of Alabama, yet represents the greatest potential for runoff and soil loss. We conclude that surface residue management through conservation tillage systems coupled with noninversion deep tillage like in-row subsoiling or paratilling is the best system to promote infiltration and reduce runoff, soil loss, and K_i for soils in the Coastal Plain and Tennessee Valley regions of Alabama. Our findings support the rapid rate of adoption of these soil management systems in recent years by Alabama farmers.

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Cover Crops
and
High Residue Systems

INFLUENCE OF COVER CROPS AND TILLAGE ON BARNYARDGRASS CONTROL AND RICE YIELD

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ABSTRACT

Cover crops can improve weed control and soil tilth when used in reduced tillage systems. However, weed and crop response can vary. Reduced tillage rice (*Oryza sativa* L) production has gained considerable popularity in the mid-South production region of the United States. However, the role of cover crops in rice production systems has not been clearly established. Three experiments were conducted in Louisiana during 1995 and 1996 to compare barnyardgrass (*Echinochloa crus-galli* L.) control and rice grain yield when rice was drill seeded into desiccated wheat (*Triticum aestivum* L), oats (*Avena sativa* L.), cereal rye (*Secale cereale* L.), Italian ryegrass (*Lolium multiflorum* Lam.), Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Schreb.), crimson clover (*Trifolium incarnatum* L.), and hairy vetch (*Vicia villosa* L.). Conventional tillage and stale seedbed (native vegetation) systems were also included. Barnyardgrass control at harvest was less than 50% when in-season herbicides (herbicides applied after weed and rice emergence) were not applied regardless of the cover crop or tillage system. Italian ryegrass and tall fescue were the most suppressive cover crops, controlling barnyardgrass 45 to 49%. Suppression of barnyardgrass ranged from 6 to 21% for the cover crops wheat, oats, cereal rye, annual bluegrass, crimson clover, and hairy vetch. Conventional tillage and native vegetation (stale seedbed) controlled barnyardgrass 42 and 33%, respectively. In-season herbicides controlled barnyardgrass at least 86% regardless of the cover crop or tillage system, and increased yields for all systems except for the cover crops Italian ryegrass and tall fescue. When herbicides were not applied in-season, rice grain yield ranged from 560 lbs acre^{-1} to 2380 lbs acre^{-1} regardless of cover crop, with the only difference among cover crop or tillage systems existing between crimson clover (560 lbs acre^{-1}) and tall fescue (2380 lbs acre^{-1}). Rice yield ranged from 4100 to 4550 lbs acre^{-1} for conventional and stale seedbed systems and the cover crop cereal rye; 3670 to 3760 lbs acre^{-1} for wheat, oat, and annual bluegrass cover crops; and 1680 to 3170 lbs acre^{-1} for Italian ryegrass and tall fescue cover crops when in-season herbicides were applied.

KEYWORDS

Allelopathy, conventional tillage, cover crops, *Echinochloa crus-galli* (L.) Beauv., herbicide, stale seed bed, weed control

INTRODUCTION

Although rice in the United States is typically grown in conventionally tilled systems, reduced tillage systems can be a successful alternative to this energy-intense approach (Bollich and Feagley, 1994). Cover crops can suppress weed populations, and in some instances they can reduce reliance on in-season herbicides (Worsham, 1991; Yenish *et al*., 1996; Jordan *et al*., 1999). Success depends on a number of factors including the cover crop, weed spectrum and density, herbicide, and response of the crop (Burgos and Talbert, 1996; Yenish *et al*., 1996; Zadasa *et al*., 1997; Jordan *et al*., 1999). Determining weed and rice response to cover crops is important in determining if cover crops can be an effective management tool for rice production. Therefore, research was conducted during 1995 and 1996 in Louisiana to determine which cover crops were most effective in suppressing barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] populations and if specific cover crops affect rice growth and grain yield.

MATERIALS AND METHODS

Experiments were conducted at the Northeast Research Station located near St. Joseph, LA in 1995 and 1996 and near the Macon Ridge Branch of the Northeast Research Station located at Winnsboro, LA in 1995.

Soils at St. Joseph and Winnsboro were a Sharkey clay (very fine, montmorrilonitic, nonacid, Vertic Haplaquepts) and a Gigger silt loam (fine-silt, mixed, thermic, Typic Fragiudalfs), respectively. During the fall prior to planting rice in the spring, test areas were disked twice, field cultivated, and precision leveled. Wheat, oats, cereal rye, Italian ryegrass, Kentucky bluegrass, tall fescue, crimson clover, and hairy vetch cover crops were established in

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October of 1994 and 1995. Grass cover crops were seeded at 100 lbs acre^{-1}. Crimson clover and hairy vetch were seeded at 35 lbs acre^{-1}. Additional treatments included conventional tillage and stale seedbed (native emerged winter and summer vegetation) systems.

Glyphosate (Roundup Ultra) at 0.75 lbs ae acre^{-1} was applied two weeks prior to seeding rice to control grass cover crops and emerged weeds in the stale seedbed system. Paraquat (Gramoxone Extra) at 0.125 lbs ai acre^{-1} was applied at this timing to control crimson clover and hairy vetch. A nonionic surfactant at 0.25% (v/v) was included with herbicides. The entire test area, other than the conventional tillage system, was treated with paraquat at 0.125 lbs acre^{-1} within two days prior to seeding rice. Conventional seedbeds were prepared with two passes of a vertical-action tiller set to a depth of four inches. The cultivar 'Cypress' was seeded at a rate of 100 lbs acre^{-1} using a drill with rows spaced eight inches apart with a single coulter establishing a narrow tilled zone prior to seed placement. In-season herbicide treatments for each cover crop and tillage system consisted of a no-herbicide control or a tank mixture of propanil plus molinate plus quinclorac (Arrosolo plus Facet) at 3.0 + 3.0 + 0.38 lbs ai acre^{-1}, respectively, applied one week prior to permanent flood establishment (approximately four weeks after rice emergence). Nitrogen at 150 lbs acre^{-1} (as urea) was broadcast two days prior to permanent flood establishment with the flood maintained until rice grain reached physiological maturity. Plot size was 6 by 25 feet.

Visual estimates of percent barnyardgrass control were recorded two days prior to permanent flood establishment and again two weeks prior to rice harvest using a scale of 0 to 100% where 0 = no control and 100% = complete control. The cover crop or tillage system with the poorest level of barnyardgrass control was assigned a value of 0, with all other treatments within that replication evaluated relative to that treatment. Chlorosis, necrosis, plant stunting, and stand reduction were used when making the visual estimates. Barnyardgrass density ranged from 50 to 200 plants per square yard. Native vegetation in the stale seedbed system consisted of annual bluegrass (*Poa annua* L.), little barley (*Hordeum pusillum* Nutt.), and buttercup (*Ranunculas* spp.). Rice grain was harvested when grain moisture was approximately 18%. Final grain moisture was adjusted to 12%.

The experimental design was a randomized complete block with a split plot arrangement of treatments. Tillage and cover crop systems served as main plots with in-season herbicide treatments serving as sub-plots. Data were subjected to analyses of variance for a ten (cover crop or tillage system) by two (in-season herbicide treatments) factorial treatment arrangement. Means for the interaction of tillage and the cover crop system by the in-season herbicide program for barnyardgrass control at a permanent flood establishment, prior to harvest and for rice grain yield were separated using Fisher's Protected LSD Test at P = 0.05.

RESULTS AND DISCUSSION

Barnyardgrass control and rice yield varied among cover crops, tillage systems, and between in-season herbicide programs. Therefore, the interaction of these treatment factors is presented for barnyardgrass control and rice grain yield (Table 1). In-season herbicides were generally needed to obtain satisfactory control of barnyardgrass and utlimately to optimize grain yield. The exception was barnyardgrass control at flood establishment when rice was seeded into desiccated Italian ryegrass. Control without in-season herbicides using this cover crop was 76%, and applying propanil plus molinate plus quinclorac prior to permanent flood establishment did not increase control. Although tall fescue controlled barnyardgrass similar to the control by Italian ryegrass (58% versus 76%) when in-season herbicides were not applied, control was improved by herbicides. Control by these cover crops exceeded that by stale seedbed systems and by wheat, crimson clover, and hairy vetch cover crops when herbicides were not applied. Control in conventional tillage, stale seedbeds, and wheat, oats, cereal rye, Kentucky bluegrass, tall fescue, and hairy vetch cover crops was similar. Control with crimson clover was the lowest (20%). Applying in-season herbicides increased control at permanent flood establishment to at least 96% regardless of cover crop or tillage system.

Barnyardgrass control at harvest was less than 50% regardless of the cover crop or tillage system when herbicides were not applied after rice planting (Table 1). Italian ryegrass and tall fescue were the most suppressive cover crops, controlling barnyardgrass 45 to 49%. Suppression of barnyardgrass ranged from 6 to 21% for the cover crops wheat, oats, cereal rye, Kentucky bluegrass, crimson clover, and hairy vetch. Conventional tillage and stale seedbed (native vegetation) systems controlled barnyardgrass 42 and 33%, respectively. Propanil plus molinate plus quinclorac controlled barnyardgrass at least 86% regardless of the cover crop or tillage system.

In-season herbicides increased yields for all systems except when rice was seeded into desiccated Italian ryegrass and tall fescue cover crops. When herbicides were not applied in-season, rice grain yield ranged from 560 lbs acre^{-1} to 2380 lbs acre^{-1} regardless of cover crop, with the only difference among cover crops or tillage systems existing between crimson clover (560 lbs acre^{-1}) and tall fescue (2380 lbs acre^{-1}). When in-season herbicides were applied, rice yield ranged from 4100 to 4550 lbs acre^{-1} for

Table 1. Barnyardgrass control and rice grain yield following planting in drill-seeded systems either with or without in-season herbicides depending upon cover crop selection and tillage system.†

Tillage system or cover crop	In-season herbicides‡	Barnyardgrass control§		Rice yield
		Flood establishment	Harvest	
		%		lbs acre^{-1}
Conventional tillage	No	38 cde	42 bcd	1740 de
Conventional tillage	Yes	97 a	99 a	4980 a
Stale seedbed	No	30 de	33 be	1650 de
Stale seedbed	Yes	98 a	95 a	4780 a
Wheat	No	34 de	21 be	990 de
Wheat	Yes	98 a	89 a	3670 abc
Oats	No	39 cde	15 de	860 e
Oats	Yes	97 a	91 a	3760 abc
Cereal rye	No	39 cde	15 de	1390 de
Cereal rye	Yes	98 a	94 a	4720 a
Italian ryegrass	No	76 ab	45 bc	620 e
Italian ryegrass	Yes	98 a	97 a	1680 de
Kentucky bluegrass	No	45 cd	20 cde	1200 de
Kentucky bluegrass	Yes	97 a	94 a	3670 abc
Tall fescue	No	58 bc	49 b	2380 cd
Tall fescue	Yes	97 a	99 a	3170 bc
Crimson clover	No	20 e	20 cde	1350 de
Crimson clover	Yes	96 a	94 a	4100 ab
Hairy vetch	No	31 de	6 e	560 e
Hairy vetch	Yes	99 a	86 a	4550 ab
CV (%)	-	18	25	29

†Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD Test at *P* = 0.05. Data are pooled over three experiments.

‡In-season herbicides were a tank mixture of propanil plus molinate plus quinclorac (Arrosolo plus Facet) at 3.0 + 3.0 + 0.38 lbs acre^{-1}, respectively, applied postemergence approximately one week prior to permanent flood establishment.

§Early-season evaluations were recorded when the permanent flood was established approximately four weeks after rice emergence and one week after in-season herbicide applications. Late-season evaluations were recorded two weeks prior to harvest.

conventional and stale seedbed systems and the cover crop cereal rye, 3670 to 3760 lbs acre^{-1} for wheat, oat, and Kentucky bluegrass cover crops, and 1680 to 3170 lbs acre^{-1} for Italian ryegrass and tall fescue cover crops.

These data suggest that cover crops will not suppress barnyardgrass sufficiently to prevent reductions in rice yield when populations of barnyardgrass are relatively high in drill-seeded production systems. In-season herbicides were needed to control barnyardgrass adequately. Previous research (Jordan *et al*., 1999) suggested that establishing a wheat cover crop often resulted in a lower infestation of barnyardgrass after planting when compared with conventional tillage systems. Additionally, less barnyardgrass was noted in stale seedbed systems when compared with that of conventional tillage systems. However, in-season herbicides were still needed to optimize rice grain yield.

Italian ryegrass and tall fescue were among the cover crops that suppressed barnyardgrass the most; however, these cover crops reduced yields when barnyardgrass was controlled with in-season herbicides. While these cover crops most likely were reducing either nitrogen availability or suppressing rice growth through allelopathy, additional research is needed to define the exact mechanism. Previous research (Jordan *et al*., 1999) suggested that a desiccated wheat cover crop suppressed weed and rice growth in both water-seeded and dry-seeded rice production. Increasing the nitrogen rate did not sufficiently overcome poor rice growth that was associated with seeding rice into a desiccated wheat cover crop (Jordan *et al*., 2000).

These data also indicate that conventional tillage and stale seedbed systems were among the highest yielding systems when herbicides were applied in-season. Although cover crops are often promoted in reduced tillage systems, results from these experiments suggest that growers should carefully consider strengths and weaknesses of cover crops in rice production systems.

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ROOT GROWTH AND SOIL STRENGTH IN CONSERVATION AND CONVENTIONAL TILL COTTON

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ABSTRACT

Corn (*Zea mays* L.), soybean (*Glycine max* L. Merr.), and wheat (*Triticum aestivum* L.) have shown inverse linear relationships between average soil strength within the top 2 feet of the profile and yield in Coastal Plain soils that have subsurface hard layers. We tested this relationship for cotton (*Gossypium hirsutum* L.) hypothesizing that root growth and lint yield of cotton would be greater with annual deep tillage. Effects of surface tillage, deep tillage, and rye (*Secale cereale* L.) cover crop were evaluated. Reduction of root growth was correlated ($r^2 = 0.66$) with mean soil strength or with the 95th percentile of soil strength distribution, which acted as a stabilized, surrogate measurement of maximum strength that cotton roots would encounter. Cotton lint yield was not reduced by the treatments, even though root growth decreased with increasing soil strength. Lack of tillage treatment effects on yield may have been the result of management practices that employed a small disk in conventionally treated plots and maintained traffic lanes in all plots. Both of these practices would help prevent re-compaction. These management practices may help reduce the frequency of subsoiling while maintaining viable production practices for cotton grown in traditionally wide (38-in) rows.

KEYWORDS

Subsoiling, Hardpan, Cotton, Root growth, Deep tillage

INTRODUCTION

Recent studies have shown inverse linear relationships between soil strength and yield of corn, soybean, and wheat grown on southeastern Coastal Plain soils that have hard subsurface layers (Frederick *et al.*, 1998; Busscher *et al.*, 2000). Yield increases were attributed to the use of a paratill® to disrupt the hard layer and planting in narrow rows. These results agreed with earlier, more general recommendations that Coastal Plain soils be deep tilled annually (Threadgill, 1982) and went a step further by showing that deep tillage twice a year increased yield even more for double-cropped wheat and soybean production. Compaction, characterized by the high soil strength, reduced crop yields but was alleviated by deep tillage. These recent studies were conducted to quantify the amount of yield reduction that compaction would cause and to develop a relationship between yield and strength.

Cover crops, such as rye, have been reported to prevent or reduce the severity of compaction. They appeared to reduce compaction or re-compaction by minimizing the effects of machinery traffic or by perforating hard layers with deep root growth when water contents within the hard layer were favorable for growth (Ess *et al.*, 1998; Raper *et al.*, 2000; Rosolem *et al.*, 2002).

The relationship between soil strength and cotton yield in controlled traffic systems with traditional wide (38-in) row management is unknown, but we hypothesized that root growth and lint yield would increase as soil strength decreased. We tested this hypothesis in a two-year study using surface tillage with a disk, deep tillage with an in-row subsoiler, and rye cover crop treatments to provide a range of soil strengths.

MATERIALS AND METHODS

This project was first reported at the Southern Conservation Tillage Conference in 1998 when we presented information on cover crop vs soil strength characteristics (Busscher and Bauer, 1998). This presentation focuses on the relationships among tillage, root growth, and yield. The methods as reported earlier are reviewed and extended for the additional aspects discussed. In 1990, rye cover crop plots for cotton production were established at the Clemson Pee Dee Research Center near Florence, SC. Between then and 1992, half of the plots were converted from conventional to conservation tillage (Bauer and Busscher, 1996). In 1993, all plots were subsoiled and planted to cotton which was not harvested because of drought. In 1994 and 1995, the plots were split to accommodate deep tillage treatments (in-row subsoiling and not subsoiling). Treatments included fallow or rye winter cover, disked or non-disked surface tillage, and deep tillage or no deep tillage.

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The experimental design was split-split plot, randomized complete block design with three replicates. Main plot treatments were winter cover, subplot treatments were surface tillage, and subsubplot treatments were deep tillage. Subsubplots contained four 38-inch wide rows that were 50-feet long. The plots were located on a Norfolk loamy sand (fine, loamy, siliceous, thermic, Typic Kandiudult).

In October 1993 and 1994, after cotton stalks were shredded, half of the plots were seeded to rye at 110 pounds of seed acre^{-1} in 7.5-inch rows using a John Deere 750 grain drill. In early May of the following year, plots that were to be surface tilled were disked with a 10-foot wide disk harrow (Tufline Mfg. Co., Columbus, GA); plots that did not receive surface tillage were desiccated with paraquat (1,1'_dimethyl_4,4'_bipyridinium).

In a separate operation prior to planting, half the subsubplots were subsoiled within 6 inches of the previous year's rows with a KMC four-row subsoiler. In mid-May, plots were seeded to cotton ('DES 119') over the subsoiled areas with a four-row Case-IH 900 series planter equipped with Yetter wavy coulters. Wheel tracks and row positions were maintained by centering equipment within plots guided by range poles.

Nitrogen (80 lbs N acre^{-1} as ammonium nitrate) was applied in a split application - half at planting and half one month later. Nitrogen was banded approximately 2 inches deep and 6 inches from the rows. Lime, P, K, S, B, and Mn were applied as needed based on soil test results and Clemson University Extension recommendations. Weeds were controlled with a combination of herbicides, cultivation in only the disked plots, and hand-weeding. Insects were controlled by applying aldicarb (0.75 lbs ai acre-1) in furrow for thrips [*Frankliniella occidentalis* (Pergande)]; other insecticides were applied as needed.

Soil cone index was measured in each subsubplot in early June with a 0.5-inch diameter, 30° solid angle cone tip attached to a hand-operated, recording penetrometer (Carter, 1967). Soil cone index was measured to a depth of 22 inches at nine positions across a mid-plot row (from non-traffic midrow to traffic midrow). Each measurement was the mean of three probings within each subsubplot. Cone indices in the form of analog data were recorded on index cards and subsequently digitized (Busscher *et al.*, 1986b). Data were normalized using a log transformation before making any statistical analyses (Cassel and Nelson, 1979).

When cone index data were collected, soil water contents were measured gravimetrically in 4-in depth increments within non-wheel-track mid row and in-row positions. These measurements were considered representative of water contents for each subsubplot.

In early August, in-row root growth was measured by collecting two one-inch diameter core samples from each plot to a depth of three feet. The two cores from each plot were combined and subjected to hydropneumatic elutriation which used flowing water and compressed air to separate roots from soil and to deposit them on a fine screen (Smucker *et al.*, 1982). Roots were then stained methyl violet blue, floated on water in a transparent tray, and counted with an automated digitizer (Delta-T Devices, Ltd., Burwell, Cambridge, England). All roots, primary and laterals, were counted together. Root data were not lengths but associated counts based on digitization of the root image (Harris and Campbell, 1989; Busscher *et al.*, 2001).

Table 1. Cone indices, water contents, and cone indices corrected for water content differences listed by depth for the top 22 in of the horizon.

	Cone index (CI)		Water content		Corrected CI[‡]	
Depth	1994	1995	1994	1995	1994	1995
inches	-------- Atm --------		- lbs (100 lbs soil)$^{-1}$ -		---- Atm ----	
2	10.3 f[†]	8.9 e	5.8 e	10.6 c	8.7	10.8
6	21.7 e	18.6 d	6.0 de	10.0 d	18.6	21.6
10	36.1 d	24.5 c	6.8 c	10.0 d	33.0	28.5
14	57.1 a	38.5 a	6.6 cd	10.2 cd	51.3	45.5
18	46.0 b	30.3 b	8.3 b	11.6 b	47.1	39.8
22	41.6 c	31.3 b	10.3 a	12.9 a	49.5	45.4

[†] Means by year with the same letter are not different based on LSD$_{0.05}$.

[‡] Cone indices corrected to a water content of 10 lbs (100 lbs soil)$^{-1}$

In mid to late October, cotton was chemically defoliated. In early November, seed cotton yield was harvested from the two interior rows using a two-row spindle picker and bagged. Each harvest bag was subsampled and the subsample was saw-ginned to measure lint percent. Lint percentage was multiplied by seed cotton yield to estimate lint yield.

Statistical differences among the data were determined using ANOVA and the LSD mean separation procedure (SAS Institute Inc., 2000). Differences were considered statistically significant at the 5% level unless otherwise specified.

RESULTS AND DISCUSSION

Soil Water Contents

For both years, water contents differed only for depth and for depth by cover by surface tillage interaction. Water contents generally increased with depth (Table 1). The depth by cover by surface tillage interaction showed differences in the lower foot of the profile. There, fallow by disked and rye by non-disked interactions had greater water contents than rye by disked and fallow by non-disked interactions.

Water contents in the upper half (top foot) of the profile differed by depth only in 1994. All other effects for the top foot were not significant. To avoid complications with water content, some tillage and root growth analyses with cone index were limited to the top foot of the profile.

Though water content data did not generally vary with treatment, when all depths were averaged together, water content and soil strength were correlated (Fig. 1). This relationship provided a way to compare cone indices measured at different water contents by permitting adjustment of cone indices to values they would have had if measured at a single water content.

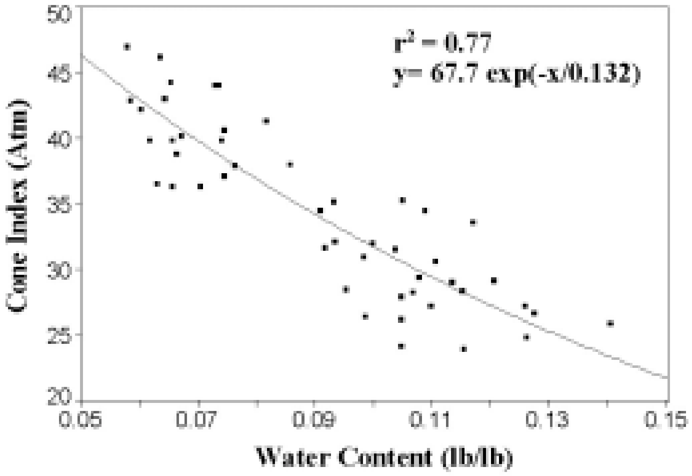

Fig 1. Regression of soil cone index as a function of water content used to correct cone indices to a common water content.

Depth

For both years, cone index increased with depth to the hard layer at about 14-in below the surface. Below the hard layer, cone index decreased with depth (Table 1 and Fig. 2). Increases in cone index readings above the hard layer (above 14 in) were actual increases in soil strength because they were accompanied by increases in water content. Decreases in cone index reading below the hard layer were also accompanied by increases in water content and may have been due to the increasing water content. However, after correction of the cone indices to a common water content (Table 1), cone indices still decreased below the hard layer showing that the highest strength was still at the 14-in depth which was the hard pan.

Position

Cone indices within the top foot varied with position across the row. Cone indices were lower under the non-wheel-track mid row (Fig. 2, position = 0 in) than under the wheel-track mid row (position = 38 in). Differences between non-wheel-track and wheel-track mid rows were greater for tilled treatments than for non-tilled treatments (Fig. 2) presumably because the tilled-treatment compaction was loosened and recompacted annually while the non-tilled-treatment compacted continuously from year to year (Busscher *et al.*, 2001). As expected, the lowest cone indices were found at mid rows (position = 19 in) because of soil loosening associated with deep tillage or residual loosening from tillage of previous years.

Tillage

Within the top foot, cone indices were lower for treatments that were disked or deep tilled than for those that were not tilled (Table 2). Cone indices decreased from treatment to treatment as more tillage was practiced. Deep-tilled treatments had lower cone indices than non-deep-

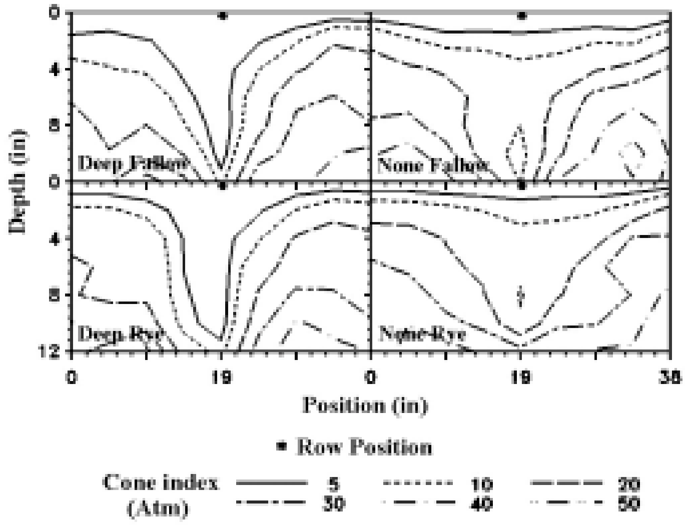

Fig. 2. Contours of cone index as a function of depth into the profile and position across the row averaged over disked and non-disked treatments in 1995. Labels are for deep tillage or none and fallow or rye winter cover.

Table 2. Mean cone index by tillage treatment for the top foot of the soil.

	Surface Tillage		
Deep Tillage	Disked	Non disked	Mean
	-------------- Atm --------------		
1994			
Subsoiled	20.8	21.8	21.3b
None	22.9	30.6	26.5a†
Mean	21.8b†	25.8a	
1995			
Subsoiled	14.1	16.2	15.1b
None	20.8	25.2	22.9a†
Mean	17.2b‡	20.2a	

† Means with the same letter are not significantly different at 5% using the LSD mean separation procedure.

‡ Means with the same letter are not significantly different at 10% using the LSD mean separation procedure.

tilled treatments; disked treatments had lower cone indices than non-disked treatments. Disked and deep tilled treatments had the lowest cone indices. Soil cone indices in the top foot were not different for the cover crop vs. fallow treatments.

More tillage and lower cone indices did not lead to differences in yield (Busscher and Bauer, 1998). One reason for this could be the residual effect of the previous year's tillage. Perhaps, it was sufficient to maintain a suitable soil environment for cotton growth. The residual loosening can be seen in the center of the zone of measurement of Fig. 2, even in the treatments that had not been deep tilled for two years. In most cases, residual loosening would not be enough to maintain proper growth as seen by standard recommendations for annual tillage in these soils (Threadgill, 1982). However, in this study, there appeared to be less reconsolidation than in other studies (Busscher *et al.*, 1986a). This may have occurred because we used the same wheel tracks to prevent re-compaction by wheel traffic and because we used a relatively small disk that did not produce a disk pan (Fig. 2).

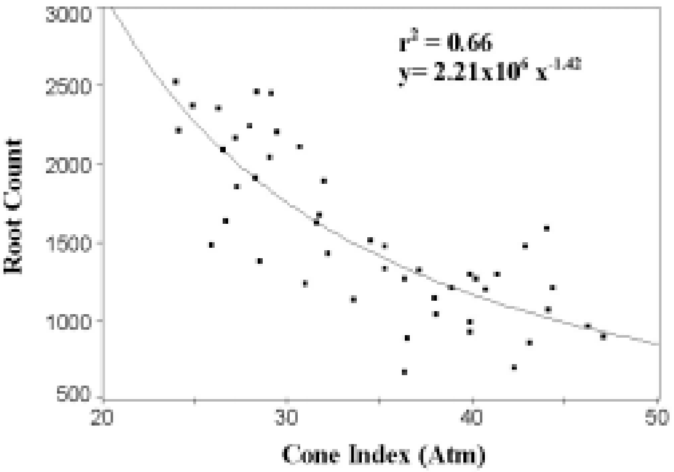

Fig. 3. Root count as a function of mean profile soil strength. Mean strength was taken over the top 2 feet of the profile and across a row.

ROOT GROWTH

Root growth was correlated with soil strength. Though root growth was measured only under the row, it correlated better with mean cone index across the whole profile ($r^2 = 0.66$, Fig. 3) than with the cone index measured only under the row ($r^2 = 0.51$). Correlation with cone index across the profile was consistent with recent findings where roots encountering high soil strength slowed shoot growth (Mulholland *et al.*, 1999; Roberts *et al.*, 2002). It is not surprising that root growth might be slowed as well.

We found similar results when correlating root growth with the maximum cone index that the roots would encounter. We used the 95th percentile of cone index rather than the maximum measured data point to represent the maximum cone index that the root might encounter because it was a more stable number. The maximum measured data point was the result of only one measurement while the 95th percentile was the result of all the data, calculated by adding the mean and two standard deviations. Root growth was marginally better correlated to the 95th percentile of cone index ($r^2 = 0.68$) than to mean profile cone index. Root growth was not correlated to yield.

COVER

The rye cover crop treatment resulted in lower cotton lint yield in 1994, but that was expected because of difficulty planting into it. The cover crop also did not have a significant effect on soil water content, presumably because of high seasonal rainfall for 1994 and 1995 (51 in and 57 in compared to the 120 year average of 45 in). When rainfall is limiting, cover crops can increase soil water content by increasing infiltration and decreasing evaporation or decrease it by using soil water for transpiration. The cover crop in this study also did not show any consistently significant differences with cone index data.

CONCLUSIONS

The rye winter cover crop had no effect on soil strength or yield under conditions of this study. This response differed from previous studies where rye cover increased yield within conservation tillage on these same soils when rainfall was lower (Bauer and Busscher, 1996).

Cone index continued to increase if soils were not deep tilled each year. Root growth decreased as soil strength increased. The reduction in root growth had the best statistical relationship with either the mean soil strength across the whole profile or the 95th percentile of soil strength. The latter acted as a stabilized, surrogate measure of the maximum strength that the cotton roots would encounter.

Yield was not related to soil strength in this study suggesting that not subsoiling for at least two years may be a viable production practice for cotton grown in traditionally wide rows using controlled traffic. Yield limiting soil strengths may have been partially prevented by our use of a small disk harrow; use of heavier equipment may not produce the same effect. Additional research on the frequency of deep tillage and degree of re-compaction that reduces cotton lint yield are needed to insure that this can be a reliable production practice.

ACKNOWLEDGMENT AND DISCLAIMER

We thank E.E. Strickland and B.J. Fisher for technical support. Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agric. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

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LEGUME COVER CROP DEVELOPMENT BY NRCS AND AUBURN UNIVERSITY

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ABSTRACT

Winter-season legume cover crops are an essential component of crop management practices such as conservation tillage and organic farming systems. Hairy vetch *(Vicia villosa* L.) and crimson clover (*Trifolium incarnatum* L.) are among the best known species used as cover crops. Caley pea (*Lathyrus hirsutus* L.) is a cool-season annual legume that can be successfully grown in areas too wet or too calcareous for most annual clovers, but is also tolerant of mildly acid soils. The objective of this work was to develop and release new cultivars from early flowering selections of hairy vetch and crimson clover and a caley pea adapted to the lower South. Plant material selected was originally collected by NRCS in the southeastern USA. The hairy vetch cultivar AU EarlyCover was released in 1994. It flowers 23 to 36 days earlier than common hairy vetch. The crimson clover cultivar AU Sunrise was released in 1997. It is a cultivar that flowers 5 to 18 d earlier than AU Robin, the earliest crimson clover cultivar available in the market, and 12 to 28 d earlier than Tibbee. The caley pea cultivar AU GroundCover was released in 1994. AU GroundCover yielded as much forage as common hairy vetch.

KEYWORDS

Cover crops, early maturity, dry matter yield, crop rotation

INTRODUCTION

For many decades farmers in the Southeastern United States have utilized legumes in crop rotations to increase organic carbon and nitrogen content in the soil, thus improving soil fertility and water-holding capacity. However, beginning in the 1960's, the availability of relatively inexpensive chemical fertilizers contributed to the decline in the use of forage legumes as a nitrogen source. More recently, there has been renewed interest in these plants due to use as mulches for organic farming (Teasdale and Abdul-Baki, 1997), economic pressure to improve animal performance and lower nitrogen costs in forage/livestock production, and because of the soil and water conservation benefits observed in systems that use conservation tillage for grain production.

Winter-season legume cover crops are an essential component of crop management practices such as conservation tillage and organic farming systems. Hairy vetch and crimson clover are among the best known species used as cover crops. Hairy vetch is a winter annual legume which is extensively used as a cover crop because of the soil and water conservation benefits it provides, and because it is an inexpensive source of nitrogen in conservation tillage systems. However, a major limitation in its use in the lower South (South of the Tennessee border with Alabama, Mississippi, and Georgia) was that the types commercially available mature (bloom) in late spring. Hence, a substantial portion of its potential is not realized because row crop land must be sprayed with a herbicide or turned well before maximum vetch dry matter yields have been attained. Crimson clover is also a winter annual particularly well adapted to the lower South. There has been a growing interest in planting early flowering types because of their reseeding potential and subsequent reduction in seeding costs (Reeves, 1994).

Caley pea, also called wild winter pea, singletary pea, or roughpea, is a cool-season annual legume introduced from the Mediterranean region. For many years this plant has been used in the southeastern U.S.A. as a livestock forage as well as a cover crop despite the fact that no cultivars have been commercially available. When farmers have been able to locate a commercial source of seed, it has most commonly been a mixture of vetch and caley pea.

Caley pea is mostly grown on heavy clays of the lower Mississippi Delta and on calcareous clays of the Alabama and Mississippi Black Belt areas, where it is superbly well adapted and has readily reseeded. Research has shown that when caley pea is seeded into johnsongrass in the autumn, the following season's growth of johnsongrass greatly benefits from the nitrogen fixed by the legume. Forage

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yield of johnsongrass is much higher when grown with caley pea than with other cool-season legumes, and the forage production season is lengthened by the legume (Scarsbrook *et al*., 1963). Also, caley pea has been successfully grown for silage.

Caley pea can be successfully grown in areas too wet or too calcareous for most annual clovers, but is also tolerant of mildly acid soils. It is useful as a temporary ground cover and green manure crop on land, which is to be replanted to another crop in mid to late spring as a source of nitrogen and spring forage in johnsongrass and dallisgrass hayfields or pastures and as a wildlife plant. The objective of this work was to develop and release new cultivars from early flowering selections of hairy vetch and crimson clover and a caley pea adapted to the lower South.

MATERIAL AND METHODS

Hairy vetch

Accession 9053961 collected in Henry County Alabama was used as the base population from which 33 plants were initially selected because they were earlier blooming and had higher vigor and uniformity. Recurrent restricted phenotypic selection was utilized to improve the population. The main selection criterion during the three cycles of selection was early flowering date. Additional traits considered during the selection process were vigor, pest resistance, and uniform morphological traits. Three populations, selected after progeny testing, were used to create this composite.

Extensive testing for forage yield, maturity, canopy height, composition, and diseases of selected hairy vetch populations was conducted throughout Alabama (Winfield, Belle Mina, Marion Junction, Monroeville and Tallassee) and in Americus, Georgia.

Crimson clover

The crimson clover cultivar was developed using recurrent restricted phenotypic selection from a population consisting of 11 crimson clover accessions collected in Alabama, Florida, Georgia, and South Carolina. The population was subjected to three cycles of selection but cycle 2 was eventually released. The main selection criterion during the selection cycles was early flowering date. Additional traits considered during the selection process included vigor (plant size and overall health) and uniformity of morphological traits.

Starting in 1994, extensive testing for maturity, forage yield, canopy height, protein content, and disease susceptibility of AU Sunrise was conducted throughout Alabama (Winfield, Belle Mina, Marion Junction, Prattville, Brewton and Tallassee) and at Americus, Georgia.

Caley pea

The new cultivar had its beginning in 1983 when a collection of caley pea and other legume cover crops was assembled at the Americus Plant Material Center for initial screening. Starting in 1989, extensive testing for forage yield, maturity, canopy height, composition, and diseases of selected caley pea ecotypes was conducted throughout Alabama (Winfield, Belle Mina, Marion Junction, Monroeville and Tallassee) and in Americus, Georgia.

A randomized complete block design with four replications was used in all field experiments. Data were subjected to ANOVA.

RESULTS AND DISCUSSION

Hairy vetch

The three populations performed quite well in clipping trials at each location. Thus, they were pooled to create the cultivar AU EarlyCover, which was released in 1994. This cultivar is an excellent cover crop because of its early growth (Table 1). When AU EarlyCover is harvested or incorporated into the soil as a green manure on or around April 1 (about the time when many lower South farmers get ready to plant corn), it has a dry matter yield comparable or superior to the common type hairy vetch (Table 2). By mid-February, when common hairy vetch has little accumulated growth, AU EarlyCover can have 150 to 200 lb. per acre of dry matter; therefore, it can be turned earlier than common hairy vetch.

AU EarlyCover could also be a better choice in many cases when hairy vetch is used for forage purposes. It is a common practice for hairy vetch to be used as a legume companion with small grain, which is to be cut for silage or hay. AU EarlyCover will work better in such a situation

Table 1. Canopy height and forage dry matter yield of vetches grown at Tallassee and Americus and harvested February 15, 1993.

	Tallassee		Americus	
Cultivar	Canopy Height	Dry matterYield	Canopy Height	Dry matterYield
	-- inch --	-- lbs acre^{-1} --	-- inch --	-- lbs acre^{-1} --
AU EarlyCover	10.6	206.3	13.3	153.6
Common	5.5	11.6	3.9	48.2
MSD$_{0.05}$	3.0	82.2	1.6	55.4

Table 2. Forage dry matter yield of AU EarlyCover and common type hairy vetch at six locations around April 1 in 1992 (mean of 3 lines) and 1993.

Location	1992		1993	
	AU EarlyCover	Common	AU EarlyCover	Common
	------------------------- lbs DM acre^{-1}		--------------------------	
Tallassee	808	763	910	605
Americus	1288	1090	1118	722
Winfield	582	431	†	†
Belle Mina	1560	2571	2706	2653
Marion Junction	1339	806	1234	834
Monroeville	3071	1965	2084	2740
Average	1456	1271	1611	1446

† Plants were killed by frost, except for the common type that was not killed but was damaged.

because its maturity (and thus the optimum harvest date) better matches that of the small grains. If hairy vetch is to be used in a pasture, AU EarlyCover would be a better choice when early grazing is desired.

AU EarlyCover flowers 23 to 36 days earlier than common hairy vetch (Table 3). Nitrogen content of AU EarlyCover is about 270 g kg^{-1} (dry matter basis) on or near April 1. AU EarlyCover has longer leaflets than common hairy vetch. Its stems are pubescent (covered with short soft hair) at the seedling stage, whereas common hairy vetch has glabrous (no hair) stems. AU EarlyCover is well adapted to the Central and Southern part of Alabama and Georgia.

CRIMSON CLOVER

Cycle 2 was found to be better than AU Robin and was released as AU Sunrise in 1997. Results from two years of testing showed that AU Sunrise is a cultivar that flowers 5 to 18 d earlier than AU Robin, the earliest crimson clover cultivar available in the market, and 12 to 28 d earlier than Tibbee (Tables 4 and 5). AU Sunrise would be an excellent cover crop because of its early growth. It is well-adapted to Alabama and Georgia. Forage yields across all locations of AU Sunrise compared to AU Robin were 151%, 81%, and about the same in 1994, 1995, and 1996, respectively. Crude protein content measured in late March of 1996 was the same in both cultivars (about 200 g kg^{-1}). This cultivar did not show any particular resistance to diseases beyond those typical of the species.

AU Sunrise plants are erect and the canopy is open. Leaflets have serrate margins and are obovate in shape, with the narrower end at the base. Stems are completely covered by white, short, fine hairs. Approximately half of the plants have green stems, whereas the remaining plants have stems that are green with some red. The population has ovate, yellow seeds.

CALEY PEA

Several accessions performed very well in clipping trials at each location. Thus, the cultivar AU GroundCover was released in 1994. AU GroundCover yielded as much forage as common hairy vetch (Table 6) (differences were not significant). This new cultivar has a crude protein content of about 20% at flowering time. AU GroundCover and common hairy vetch flower at about the same time. AU GroundCover plants have purplish flowers, light green foliage and develop a canopy nearly 30 inches tall at flowering time. Hard seed coats allow natural reseeding when stands are not heavily grazed during the seed production period. Initial stand establishment should be done with scarified seed.

Table 3. Number of days to 75% bloom (counted from March 1) at Tallassee and Americus in 1992 (mean of 3 lines) and 1993.

Cultivar	Tallassee	Americus	Average
	----------- days	after March 1	------------
1992			
AU EarlyCover	46.4	32.3	39.0
Common	69.5	68.8	69.1
1993			
AU EarlyCover	42.3	32.5	36.7
Common	74.0	†	74.1

† Plots were lost

Table 4. Days to 50% flowering of eight crimson clover entries in 1994 (counted from Feb. 1)
.

Entries	Tallassee	Americus	Prattville	Marion Junction	Belle Mina	Brewton	Average
	------------------------------	days	after February 1	------------------------------			
AU Sunrise	58.0	42.0	55.5	60.7	†	37.0	50.6
AU Robin	63.0	51.0	59.7	68.2	†	49.5	58.2
Cycle 1	58.0	42.0	56.7	63.0	†	42.0	52.3
Cycle 3	58.0	42.0	54.7	61.5	†	37.0	50.6
Tibbee	70.0	61.5	70.5	74.0	†	56.5	66.5
Flame	70.0	59.0	70.5	71.5	†	54.0	65.0
Chief	70.0	61.5	70.5	72.0	†	55.5	65.9
Dixie	70.0	62.7	70.2	72.5	†	55.7	66.2
MSD $_{(0.05)}$	0.1	2.1	1.0	1.7		0.7	
Difference between AU Sunrise and AU Robin							
	5	9	4.2	7.5		12.5	7.6

† Lost Data.

Table 5. Days to 50% flowering of eight crimson clover entries in 1995 (counted from Feb. 1) .

Entries	Tallassee	Americus	Prattville	Marion Junction	Belle Mina[1]	Brewton	Average
	------------------------------	days	after February 1	------------------------------			
AU Sunrise	51.0	49.5	55.0	45.0	55.0	33.7	48.2
AU Robin	58.0	55.0	66.0	53.5	64.0	52.0	58.0
Cycle 1	51.0	50.5	55.0	45.5	55.0	34.2	48.5
Cycle 3	51.0	50.0	55.0	43.0	55.0	31.0	47.5
Tibbee	76.0	65.0	69.0	65.5	69.0	61.7	67.7
Flame	76.0	63.2	68.5	66.2	69.0	62.2	67.5
Chief	76.0	66.0	69.0	64.5	69.0	64.0	68.0
Dixie	76.0	65.0	69.0	66.0	69.0	63.7	68.1
MSD $_{(0.05)}$	0.1	1.9	0.3	2.6	0.1	0.8	
Difference between AU Sunrise and AU Robin							
	7	5.5	11	8.5	9	18.3	9.8

Table 6. Mean forage dry matter yield of the five accessions that make up AU GroundCover and of common hairy vetch at six locations in 1992 and 1993.

Entry	1992	1993
	----- lbs $acre^{-1}$ ------	
AU GroundCover	3169	3159
Common hairy vetch	3748	2837
$MSD_{0.05}$	NS	NS

CONCLUSIONS

Plant material selected was collected in the Southeast has potential for producing superior cultivars. The hairy vetch cultivar AU EarlyCover released in 1994 flowers 23 to 36 days earlier than common hairy vetch. The crimson clover cultivar AU Sunrise released in 1997 is a cultivar that flowers 5 to 18 d earlier than AU Robin, the earliest crimson clover cultivar available in the market, and 12 to 28 d earlier than Tibbee. The caley pea cultivar AU GroundCover released in 1994 yielded as much forage as common hairy vetch.

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PARTITIONING OF DRY MATTER AND MINERALS IN SUNN HEMP

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ABSTRACT

Sunn hemp (*Crotalaria juncea* L.) is a tropical legume commonly used as a cover crop or green manure, because of its soil improvement benefits. It has recently been introduced to the U.S. as a potentially valuable N source and nematode suppressor. The objective of this study was to determine the partitioning of dry matter, N, and other minerals in sunn hemp to better understand its efficiency as an organic N source. Ten replications of 'Tropic Sun' sunn hemp were grown in fall 2001 and harvested at the mid-flowering stage from 32 ft^2 plots, four inches above the soil surface. Some plants were separated into flower heads, leaves, and stems, and others were left as whole plants for comparison. Plant material from each plant part and whole plant were dried and mixed prior to sub-sampling. Two sub-samples were taken from each plant part and whole plant for N and mineral analysis. One set of sub-samples was re-dried prior to analysis to determine true mineral concentration, and the other set was analyzed "as is," such that some moisture would be present from natural accumulation after the first drying. Nitrogen and mineral concentrations were higher in dried whole plant and plant parts than those analyzed "as is." Stems had the greatest percent dry matter at 27.4%, and flower heads had the least at 21.8%. Stems had the largest accumulation of micronutrients. Leaves and flower heads combined contained 66.5% of the total P in the plant and 80.6 % of the total N.

KEYWORDS

Crotalaria juncea L., nitrogen content, plant parts, macronutrients, micronutrients

INTRODUCTION

Tropical Sunn hemp (*Crotalaria juncea* L.) is a relatively new leguminous crop to the United States. In recent studies it has proven to be a potentially valuable crop to U.S. organic farmers and to sustainable farmers in developing nations. Sunn hemp has the ability to suppress some plant-parasitic nematodes, mostly sedentary endoparasites, but is not effective against migratory nematodes (Wang *et al*., 2002). A study in Tanzania included 'Tropic Sun' sunn hemp in rotation with vegetables, ornamentals, and other crops to suppress weeds, control erosion, reduce root-knot nematodes, and to add N and organic matter to the soil. It was found that in 60 days after planting, at a broadcast-seeding rate of 40 to 60 lbs. acre^{-1}, sunn hemp produced 145 pounds of N and three tons of dry matter acre^{-1}. High plant densities were recommended to cause the stems to be more succulent and easier to be incorporated into the soil (Rupper, 2001). Another study found that sunn hemp could produce 98 to 125 lbs N acre^{-1} (Marshall *et al*., 2001).

Sunn hemp has been planted in the southern U.S. immediately after corn (*Zea mays* L.) harvest as a winter cover crop and as a speedy alternative to traditional covers like hairy vetch (*Vicia villosa* Roth) and crimson clover (*Trifolium incornatum* L.) (Comis,1997). In Alabama, a sunn hemp residue study found that approximately 66.8 lbs N acre^{-1} was released from the residue to the soil during the winter (Reeves *et al*., 1996). Sunn hemp bares large showy flowers that occur in inflorescence, each flower having 10 stamens: five with short filaments and long narrow anthers and five with long filaments and small round anthers (Howard *et al*., 1919). Sunn hemp stems are comprised of two fibers, the bast and woody core, that have similar fiber widths (Cunningham *et al*., 1978).

A recent study in north Florida found that sunn hemp has an impressive growth rate and accumulation of plant nutrients, making it potentially useful in cropping systems in the tropics and sub-tropics (Gallaher *et al*., 2001). Sunn hemp can be used as a mulch, green manure, or organic fertilizer. Therefore, it is important to know the partitioning of dry matter and nutrients within a plant to better understand how the plant functions and which parts contain the bulk of the nutrients. The objective of this study was to determine the partitioning of dry matter, N, and other minerals in sunn hemp.

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MATERIALS AND METHODS

Sunn hemp, c.v. 'Tropic Sun,' was planted in August of 2001 and harvested in November at the mid-flowering stage by cutting the stalks four inches above the soil surface. The entire planting was uniform and 10 replications of 180 plants per 32 ft^2 plots were harvested. Plants were separated into reproductive tissue (flower heads), leaves, and stems, and other plants were left whole and analyzed separately for comparison. All parts were weighed fresh, and then the parts and whole plant samples were dried for 48 hours in a 70 °C forced air oven. After drying, samples were re-weighed to determine dry matter. Then the individual parts and whole plant sample were chopped and thoroughly mixed in a small forage mixer for 60 minutes to ensure homogeneity. Two sub-samples were taken from each mixed plant part and whole plant for N and mineral analysis.

The reason for the two sub-samples was to run an analysis on the plant material in an "as is" state, where some moisture would be present from natural accumulation after the first drying. The other set of sub-samples were re-dried for 24 hours in a 70 °C convection oven prior to N and mineral analysis to determine true N and mineral concentrations. By allowing half of the sub-samples to contain moisture we would know the mineral content of the sunn hemp as it would most likely be applied as fertilizer in a practical situation. The plant material was analyzed for N using a modified micro-Kjeldahl procedure. A mixture of 0.100 g of each tissue sample, 3.2 g salt-catalyst (9:1 K_2SO_4:$CuSO_4$), 2 to 3 Pyrex beads, and 10 ml of H_2SO_4 were vortexed in a 100 ml Pyrex test tube under a hood. To reduce frothing, 2 ml 30% H_2O_2 was added in one-ml increments, and tubes were digested in an aluminum block digester at 370 °C for 3.5 hours (Gallaher *et al.*, 1975). Tubes were capped with small Pyrex funnels that allowed for evolving gases to escape while preserving refluxing action. Cool digested solutions were vortexed with approximately 30 ml of de-ionized water, allowed to cool to room temperature, brought to 75 ml volume, transferred to square Nalgene storage bottles (glass beads were filtered out), sealed, mixed, and stored.

Nitrogen trapped as $(NH_4)_2SO_4$ was analyzed on an automatic Technicon Sampler IV (solution sampler) and an Alpkem Corporation Proportioning Pump III. A plant standard with a long history of recorded N concentration values was subjected to the same procedure and used as a check (Agronomy Lab, University of Florida).

For mineral analysis, 1.0 g from each of the 75 samples of sunn hemp tissue was weighed into 50-ml Pyrex beakers and ashed in a muffle furnace at 480 ∫C for 6 hours. The samples were then cooled to room temperature and moistened with de-ionized water. Under a hood, 20 ml de-ionized water and 2 ml concentrated HCl were added to the beakers, which were then placed on a hot plate, slowly boiled to dryness, and then removed.

Another 20 ml de-ionized water and 2 ml concentrated HCl were added and small Pyrex watch glasses were used to cover the beakers for reflux. They were brought to a vigorous boil and removed from the hot plate to cool to room temperature. The samples were then brought to volume in 100-ml flasks and mixed. They were set aside for a few hours to let the Si settle out. Twenty ml of solution was decanted into 20-ml scintillation vials for analysis. Phosphorous was analyzed by colorimetry; K and Na by flame emission, and Ca, Mg, Cu, Fe, Mn, and Zn by atomic adsorption spectrometry (AA).

Data was recorded in Quattro-Pro (1987) spreadsheets, transformed accordingly, made into ASCII files, and transferred to MSTAT 4.0 (1985) for analysis of variance for a completely randomized experiment design. Standard deviations are reported for mean separation.

RESULTS

Sunn hemp stems had the greatest fresh and dry weights and percent dry matter among the plant parts tested (Table 1). This was expected because of the large amount of fibrous material found in the stems. The majority of biomass is composed of stem material, comprising about 50% of whole plant weight. Leaf percent dry matter was very similar to that of whole plant. Leaf weights were 1682 lbs. and 588 lbs. greater than flower head fresh and dry weights, respectively (Table 1).

Mineral analysis was also determined by averaging plant mineral contents over 10 replicates (Table 2). All N and mineral concentrations were higher in the dried whole plant and plant parts than those analyzed "as is" (Table 3).

Table 1. Average values (n = 10) ± standard deviation for fresh weight, dry weight, and percent dry matter of tropical sunn hemp of plant parts and whole plants

Plant Part	Fresh Weight	Dry Weight	Dry Matter
	---------------- lbs acre^{-1}	-------------	----- % -----
Leaves	5954 ± 792.1	1522 ± 133	25.97 ± 4.31
Flower Head	4272 ± 703.1	934 ± 169	21.84 ± 2.15
Stem	8971 ± 827.7	2456 ± 365	27.37 ± 3.55
Whole Plant	19,197 ± 1975.8	4913 ± 596	25.67 ± 3.16
CV	12.5%	15.0%	13.4%

Table 2. Average mineral contents ± standard deviation (n = 10) of sunn hemp.

Minerals	Leaves	Flower Head	Stem	Whole Plant	CV
	---------------------------- lbs acre^{-1} --------------------------------				%
Ca	45.0 ± 4.01	8.9 ± 1.60	9.2 ± 1.34	57.8 ± 7.12	13.91
Mg	6.8 ± 0.62	3.0 ± 0.53	5.2 ± 0.80	15.8 ± 1.96	14.61
K	18.7 ± 1.69	18.6 ± 3.38	32.4 ± 4.81	66.0 ± 8.10	14.94
P	7.4 ± 0.62	4.6 ± 0.80	5.9 ± 0.89	18.1 ± 2.23	14.56
N	60.3 ± 5.34	38.5 ± 7.03	21.5 ± 3.20	122.6 ± 15.04	14.59
Na	0.4 ± 0.09	0.8 ± 0.09	1.8 ± 0.27	8.6 ± 1.07	18.48
Cu	.0008 ± .0008	.0005 ± .0001	.0010 ± .0002	.0025 ± .0003	15.00
Fe	.0308 ± .0028	.0102 ± .0019	.0515 ± .0076	.0628 ± .0077	14.61
Mn	.0093 ± .0008	.0027 ± .0005	.0022 ± .0004	.0117 ± .0014	13.46
Zn	.0062 ± .0005	.0041 ± .0007	.0049 ± .0007	.0250 ± .0031	16.39

There was about a 3% increase in N concentration for dried leaves and whole plant, and a 13% increase in N concentration for dried flower heads and stems compared to the N concentrations of the samples that were analyzed with a higher moisture content (Table 3).

The highest N concentration was found in dry flowers and lowest in "as is" stems (Table 3). Leaves and flower heads contained comparable amounts of N, but flower heads had slightly higher dry N concentration. Leaves had the greatest N content for the whole plant, followed by flowers (Table 2).

A much smaller amount of flower head and leaf tissue is required to provide the same amount of N from stems alone or whole plant (Table 4).

For the other minerals examined, stems contained the highest amount of K among the plant parts, and leaves had the largest contents of Ca, Mg, P, N, Mn, and Zn. Stems had the largest accumulation of Cu and Fe. Leaves and flower heads combined contained 66.5% of the total P in the plant and 80.6 % of the total N (Table 2).

Table 3. Average N concentration (n = 10) in plant parts and whole plant.

Plant Part	Tissue N concentration "As Is"	Tissue N concentration Dry
	-------------%	-----------
Leaves	3.83	3.96
Flower heads	3.67	4.14
Stems	0.78	0.88
Whole Plant	2.42	2.50

Table 4. Amount of plant material required to be equivalent to one lb. of N.

Plant Part	Amount
	----- lbs -----
Leaves	57.44
Flower heads	59.95
Stems	282.06
Whole Plant	90.90

DISCUSSION AND CONCLUSIONS

The whole plant sunn hemp from our experiment contained N-P_2O_5-K_2O in amounts of 123-42-80 lb acre^{-1}, which gives a ratio of 3:1:2. According to this ratio, we can assume that sunn hemp could be an adequate fertilizer to meet most of the nutritional requirements of vegetable crops such as summer yellow squash (*Cucurbita pepo* L.), bush bean (*Phaseolus vulgaris* L.), and sweet corn (*Zea mays* L.) (Hochmut, *et al.*, 1998) (Table 5).

Since most of the N and macro-nutrients are found in leaves and flower heads, use of sunn hemp as a mulch or green manure would be most beneficial at the early to mid-flowering stage when the C:N ratio is presumed to be low and the nutrients are most available. Sunn hemp is a short day crop, which results in a restriction on its growth in the sub-tropics and its soil improvement abilities. In northern Florida and other parts of the sub-tropics, it can be grown in the fall when day length shortens. However, sunn hemp is

Table 5. Macronutrient requirements of vegetables (Hochmuth *et. al.*, 1998)

Species	N	P_2O_5	K_2O
	----------- lbs acre^{-1}	------------	
Summer Yellow Squash	120	80 – 120	80 – 120
Bush Bean	90	80 – 120	80 – 120
Sweet Corn	150	80 – 120	80 – 120

very susceptible to frost kill, so there is only about a 3 to 4 month window of opportunity during the fall to grow sunn hemp for its full benefits as a green manure in north Florida. Therefore, a winter crop would have to be grown to benefit from or preserve the nutrients released by the decaying sunn hemp. However, in our study we harvested sunn hemp as an organic fertilizer for spring vegetables. Since the hemp was harvested and dried, we were able to preserve nutrients at the early to mid-flowering stage for use as an organic fertilizer throughout the year, rather than risk losing them over the winter.

The greatest amount of dry matter was in the fibrous stems, which makes sunn hemp a good annually renewable fiber source, but not as good of a forage or immediate source of N. However, stems contain 17.6% of the total plant N, so they may still be incorporated as a useful and beneficial part of the fertilizer. Stems may prove to be a beneficial contributor to the organic fertilizer if they are shown to have a much slower rate of decay and release of N than leaves or flowers. If this is the case then the stems may allow for a better distribution of N over the growing season. However, if the stems have a very high C:N ratio, the leaves, flower heads, and soil may actually be robbed of N for the stems to be able to decay.

Net N mineralization can occur when C:N ratios are <20:1 (Foth et. al., 1988). Mansoer et al. (1997) conducted a decay rate study of sunn hemp residue for use as an alternative cover crop. They reported that sunn hemp leaf C:N ratios were <20:1, while stem C:N ratios were >20:1 after three weeks from the planting date. They also reported that stem tissue had high lignin concentration. A combination of high C:N ratio and high lignin concentration would reduce N mineralization. Further research on C:N ratio and decay rates of each plant part would help to better understand the potential of sunn hemp as an organic fertilizer, rather than a cover crop.

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AGRONOMIC AND GENETIC ATTRIBUTES OF VELVETBEAN (*MUCUNA* SP.): AN EXCELLENT LEGUME COVER CROP FOR USE IN SUSTAINABLE AGRICULTURE

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ABSTRACT

Conservation tillage is one of the most important changes that have taken place in the development of sustainable agriculture. Cover and green manure crops as a conservation practice can improve soil health. In the Southern USA, velvetbean (*Mucuna* sp.), a tropical legume cover crop, was once widely grown as a rotational crop in the early 1900's and offers tremendous potential for use in today's sustainable agriculture. Our objective was to evaluate 24 velvetbean accessions originating from different sources for fresh biomass (FB) and dry matter (DM) production, total N and C accumulation, and C: N ratio in two environments. Days to first flower were also recorded. The experimental design was a randomized complete block with four replications and treatments, considered as random, were accessions. Exotic lines had higher DM than the U.S. landraces. Within the U.S. landraces, DM ranged from 7.3 tons acre^{-1} (for the genotype 25.S5) to 8.0 tons acre^{-1} (for the genotype 24.S) averaging 7.6 tons acre^{-1}, while in the exotic lines DM ranged from 7.8 (for the genotype PI365415) to 9.2 tons acre^{-1} (for the genotype PI365411), averaging 8.5 tons acre^{-1}. Thus, the largest variability occurred in the exotic lines. N and C accumulations averaged 484.9 lbs acre^{-1} and 7037.8 lbs acre^{-1}, respectively, in the U.S. landraces, while in the exotic lines N and C accumulations averaged 517.6 lbs acre^{-1} and 7747.2 lbs acre^{-1}, respectively. For all accessions, the C:N ratio was less than 20 to allow early mineralization of N. These characteristics make velvetbean an excellent legume cover crop for use in a conservation tillage system. The range in relative maturity, as indicated by the days to first flowering shown among velvetbean accessions, may be potentially advantageous depending on the precise objective in specific farming systems.

KEYWORDS

Velvetbean, *Mucuna sp.*, dry matter, nitrogen, C:N ratio.

INTRODUCTION

Conservation tillage is one of the most important changes that have taken place in the development of sustainable agriculture. In the subtropical south, crop production is limited by a variety of economic factors and pest problems, which have resulted in high rates of pesticide use for some crops. Velvetbean (*Mucuna* sp.) has become one of the key groups of species promoted for use as a legume cover crop, weed control and green manure crop (Buckles, 1995). In the Southern USA, velvetbean was once widely grown as a rotational crop in the early 1900's and offers extensive potential for use in sustainable agriculture. Growing velvetbean as a cover crop is mainly the result of economic and environmental concerns, not just among chemical-conscious consumers, but among farmers too. A simple measure of success with a legume cover crop is the amount of nitrogen the producer does not have to purchase to produce cash-crop yields equal to those receiving a normal rate of fertilizer nitrogen. In general, dry matter yield, amount of nitrogen available for the next crop, availability of seed, and appropriate Rhizobium inoculant are among the factors to consider in the choice of a legume cover crop. Reports show that velvetbean is one of the most effective rotational crops for reducing nematode problems in cotton (*Gossypium hirsutum* L.), peanut (*Arachis hypogea*), and soybean (*Glycine max* L.).

Several factors affect biomass and dry matter production of crops. Velvetbean exhibits reasonable tolerance to a number of abiotic stress factors, including drought, low soil fertility, and high soil acidity, although it is sensitive to frost and produces poorly in cold, wet soils (Duke, 1981; Hairiah, 1992; Lobo *et al*., 1992). Velvetbean thrives best under warm, moist conditions, and in areas with plentiful rainfall. In such environments, velvetbean vines can grow up to 32.0 ft and the canopy may stand as high as 3.3 ft

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above the soil surface (Duke, 1981). However, specific growth characteristics depend on the genotype. Various studies have confirmed *Mucuna*'s high biomass and dry matter production and its ability to both fix and recycle large amounts of nitrogen. In the TROPSOILS program trials in Brazil, velvetbean produced up to 3.8 tons acre^{-1} of aboveground dry matter, containing 555.7 lbs of nitrogen (Lathwell, 1990; Lobo *et al.*, 1992). Triomphe (1996) reported an average dry matter biomass production of 5.2 tons acre^{-1}, containing 659 lbs acre^{-1} of N. Sanginga *et al.* (1996) measured an average nitrogen content of 279.5 lbs acre^{-1} in sole-cropped and 148.2 lbs acre^{-1} in intercropped conditions. Levels of aboveground biomass range from 2.2 to more than 5.4 tons of dry matter acre^{-1}; below ground, more than 893 lbs of dried roots acre^{-1} may be produced (Duggar, 1899; Ferris, 1917; Camas, 1991; Chávez, 1993). Buckles (1998) reported an average level of total above ground biomass falling within a relatively narrow range of 4.8 to 5.5 tons acre^{-1} on a dry matter basis. Dry matter accumulation may vary with growth stage and environment. Buckles (1998) reported that total dry matter increased from 4.5 tons acre^{-1} (early flowering) to 5.3 tons acre^{-1} a month later and to 6.2 tons acre-1 after another 3 to 4 weeks.

The velvetbean's N2 fixing and recycling abilities prevent significant nutrient losses to the environment and practically eliminate the need for costly and impractical use of external fertilizer without compromising yield levels (Buckles *et al.*, 1998). Thus, the crop acts alternatively as a major collector (when growing) or supplier (when decomposing) of nutrients, so its natural seasonal dynamics dictate the major features of the velvetbean system. In fact, because of the large dry matter accumulation and the amount of time it has to accomplish this task, velvetbean appears to be a prime candidate for removing any available N (Buckles *et al.*, 1998). The amounts of N fixed by *Mucuna* are variable, ranging from 0 to about 159.5 lbs acre^{-1} in a season (Carsky *et al.*, 1998). Sanginga *et al.*

Table 1 Accessions of velvetbean (*Mucuna* sp.) used for agronomic attributes. The full accession names are listed in this table. In the text these are abbreviated by replacing the code given by the authors.

Plant name	Code	Donor †	Origin
None	PI364362	USDA, ARS	Mozambique
Branco	PI365411	USDA, ARS	Mozambique
Oscola	PI365414	USDA, ARS	Mozambique
Verde Radio	PI365415	USDA, ARS	Mozambique
Mucuna pruriens var cochinchinensis	Cochinchinensis	CIEPCA	Singapore
Mucuna pruriens var rajada	Rajada	CIEPCA	Brazil
Mucuna pruriens var japeada	Jaspeada	CIEPCA	Brazil
Mucuna pruriens var preta	Preta	CIEPCA	Brazil
USA (AL)-black	22.B	AU	USA
USA (AL)-speckled	22.S	AU	USA
USA (AL)-white	22.W	AU	USA
Edgar farm (AL)-black	23.B	AU	USA
Edgar farm (AL)-speckled	23.S	AU	USA
Edgar farm (AL)-white	23.W	AU	USA
90 day runner-black	24.B	AU	USA
90 day runner-speckled	24.S	AU	USA
90 day runner-white	24.W	AU	USA
Belle Mina speckled-2	25.S2	AU	USA
Belle Mina speckled-3	25.S3	AU	USA
Belle Mina speckled-4	25.S4	AU	USA
Belle Mina speckled-5	25.S5	AU	USA
Belle Mina speckled-6	25.S6	AU	USA
Belle Mina light speckled	25.LS	AU	USA
Belle Mina light black	25.LB	AU	USA

† USDA, ARS: United States Department of Agriculture, Agriculture Research Service
CIEPCA: Centre d'Information et d'Echange sur les Plantes de Couverture en Afrique
AU: Auburn University

(1996) reported an amount of 200.0 lbs acre^{-1} of N fixed in three months after planting. The objective of this study was to evaluate velvetbean accessions for fresh biomass and dry matter production, total N and C accumulation, and C:N ratio. The evaluation of these traits will be useful for the integration of velvetbean as a legume cover crop in the development of sustainable southern agriculture.

MATERIALS AND METHODS

CULTURE

Twenty four velvetbean (*Mucuna* sp.) accessions were used as experimental materials. Sixteen of the accessions were U.S landraces and 8 were exotic lines from a tropical region (Table 1). Accessions differed for maturity, seedcoat color, pod color, pod pubescence, and leaf shape. These traits are among the main parameters observed in a process of genetic diversity estimate (Capo-chichi *et al.*, 2001). Seeds were planted on May 12, 2000 and May 16, 2001 at the Plant Breeding Unit (PBU), Tallassee, AL. The soil at PBU is a Cahaba fine sandy loam (fine-loamy, siliceous, thermic Typic Hapludults). The Latitude was 32°42'N. Plots were four rows wide with 2.5 ft between rows. All plots were 13.9 ft long. *Mucuna* sp. were sown 0.06 to 0.1 ft deep and 2 viable seeds per 1 ft of row, so that the seeding rate was approximately 36450 seeds acre^{-1}. No fertilizer was applied. Average air and soil temperatures and rainfall are shown in Fig. 1.

The number of days from planting to first flower was recorded. At that stage, plots were harvested for biomass. Fresh leaf and vine mixture was harvested and weighed on site. Samples were air dried over night. Sample dry matters were weighed to determine the total dry matter production. Subsamples were taken in bag. Contents of each bag were ground to pass a 1 mm sieve, and total C and N were determined by combustion method using LECON CHN-600 analyzer (Leco Corp., St. Joseph, MI).

The experimental design was a randomized complete block with four replications and treatments were accessions. Data were analyzed by analysis of variance using the general linear models procedure of SAS. Combined analysis of variance across environments was also computed. All factors were considered random. F-test was used to test all main effects and their interactions. Single-degree-of-freedom contrasts were used to test the difference among the means among all genotypes. Unless indicated otherwise, all tests were made at $P = 0.05$.

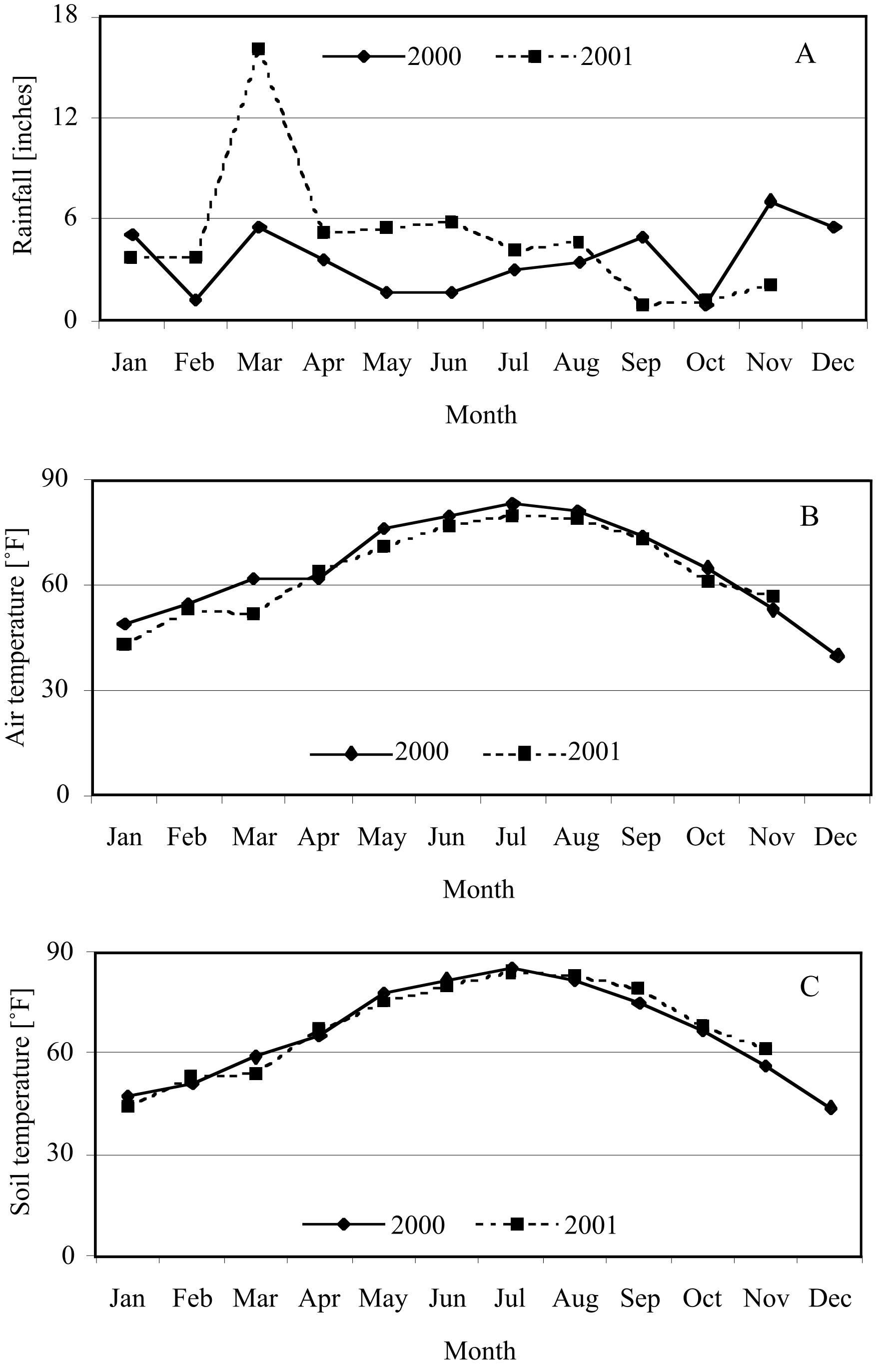

Fig.1 Rainfall (A), air (B) and soil (C) temperatures recorded at the Plant Breeding Unit, Tallassee, AL in 2000 and 2001

Table 2 Significance from the combined analysis of variance for fresh biomass, dry matter, nitrogen(N), carbon (C) and carbon to nitrogen ratio (C:N) of velvetbean grown in two environments.

Source	df	Fresh biomass	Dry matter	1st flower	N	C	C:N
Environment (E)	1	NS	*	***	-	-	-
Rep (R)	3	NS	NS	NS	NS	NS	NS
Error (a)	3	NS	NS	NS	-	-	-
Genotype (G)	23	***	***	***	***	***	***
US landrace vs Exotic	1	NS	***	***	***	*	NS
G x E	23	***	***	***	-	-	-
Error (b)	895†						

*,**,*** significant at $P = 0.05$, 0.01 and 0.001, respectively

†df = 464 for N, C and C:N

RESULTS AND DISCUSSION

In the combined analysis of variance, effects of genotype were highly significant for fresh biomass (FB) (Table 2). The genotype x environment interaction was significant for fresh biomass, indicating that genotype performance was dependent upon environment. Across environments, fresh biomass yields varied from 22.9 tons acre^{-1} for PI364362 to 17.2 tons acre^{-1} for Cochinchinensis (Table 3). Effects of the origin (the U.S. landraces vs. exotic lines) were not significant for fresh biomass (Table 2). The U.S. landraces and exotic lines averaged 19.4 and 19.6 tons acre^{-1}, respectively (Table 4). Effects of genotypes and environments were significant for dry matter (DM) (Table 2). This may be explained by the difference in rainfall observed between environments. When comparing the U.S. landraces and the exotic lines for DM, the exotic lines yielded slightly more than the U.S. landraces (8.5 and 7.6 tons acre^{-1}, respectively) (Table 4). This may be explained by the difference in time of harvesting, which was done at the first flowering. The U.S landraces flowered 91 days after planting (DAP) and the exotic lines flowered 120 DAP. A slight variability was observed within the U.S. landraces for DM. The average levels of total aboveground DM fell within a relatively narrow range of 7.3 tons acre^{-1} for the genotype 25.S5 to 8.0 tons acre^{-1} for the genotype 24.S (Table 4). Within the exotic lines, DM ranged from 7.8 tons acre^{-1} (for the genotype PI365415) to 9.2 tons acre^{-1} (for the genotype PI365411), averaging 8.5 tons acre^{-1} (Table 4). The largest variability for DM production occurred within the exotic lines and may be explained by their geographical origins. This may imply that the U.S landraces constitute a more homogenous population for DM compared to the exotic lines. Genotype x environment interaction was significant for DM, indicating that genotype

Table 3 Means of fresh biomass, dry matter, nitrogen and carbon of 24 velvetbean accessions grown in two environments.

Genotype	Origin	Fresh biomass	Dry matter	Nitrogen (N)	Carbon (C)	C:N ratio	1st flower
		----t acre^{-1}-----	----t acre^{-1}-----	---lb acre^{-1}--	----lb acre^{-1}-----		----days----
PI364362	Exotic line	22.9 a †	8.4 bc	490.5 bcd	7558.0 bcdef	15.6 bc	95.9 h
25.S2	Landrace	20.4 b	7.8 def	485.2 bcd	8002.1 ab	16.4 ab	89.6 i
24.S	Landrace	20.2 bc	8.0 cde	468.8 cd	7849.5 bc	16.8 a	90.1 i
PI365414	Exotic line	20.2 bcd	8.0 cd	504.1 bcd	7992.4 ab	16.4 ab	78.5 i
23.B	Landrace	20.2 bcd	7.7 def	500.5 bcd	7809.4 bcd	15.5 bc	87.9 i
23.S	Landrace	19.9 bcde	7.5 def	456.3 d	7347.8 bcdef	16.2 abc	90.0 i
24.B	Landrace	19.9 bcde	7.7 def	495.3 bcd	7727.4 bcde	15.6 bc	90.0 i
Rajada	Exotic line	19.9 bcde	8.9 ab	618.7 a	8727.7 a	14.2 de	102.9 g
22.W	Landrace	19.8 bcde	7.8 def	534.5 b	7524.2 bcdef	14.3 de	89.0 i
22.S	Landrace	19.6 bcdef	7.4 ef	484.5 bcd	6856.2 ef	14.2 de	86.9 i
23.W	Landrace	19.5 bcdef	7.5 def	495.5 bcd	7665.1 bcdef	15.4 bc	109.0 f
PI365411	Exotic line	19.5 bcdef	9.2 a	514.3 bcd	7919.1 ab	15.4 bc	117.1 e
25.S6	Landrace	19.4 cdef	7.6 def	497.9 bcd	7913.6 ab	15.9 abc	89.4 i
Preta	Exotic line	19.3 def	8.8 ab	500.8 bcd	6975.6 cdef	14.1 e	144.7 b
25.LB	Landrace	19.1 efg	7.4 def	476.4 bcd	6813.7 f	14.3 de	97.4 h
22.B	Landrace	19.0 efg	7.7 def	483.8 bcd	7503.9 bcdef	15.4 bc	89.5 i
24.W	Landrace	19.0 efg	7.4 def	454.6 d	7250.9 bcdef	15.9 abc	88.2 i
Jaspeada	Exotic line	18.9 fg	8.9 ab	502.0 bcd	7970.5 ab	15.9 abc	134.6 c
25.S4	Landrace	18.7 fg	7.6 def	483.6 bcd	7311.4 bcdef	15.1 dc	87.4 i
25.S3	Landrace	18.7 fg	7.4 ef	475.8 bcd	7262.8 bcdef	15.3 c	89.5 i
25.LS	Landrace	18.7 fg	7.5 def	473.9 bcd	7483.4 bcdef	15.9 abc	88.9 i
PI365415	Exotic line	18.7 fg	7.8 def	520.6 bc	7901.4 ab	15.1 dc	127.7 d
25.S5	Landrace	18.4 g	7.3 f	492.5 bcd	7547.6 bcdef	15.5 bc	90.0 i
Cochinchinensis	Exotic line	17.2 h	8.4 bc	490.2 bcd	6932.8 def	14.2 de	159.1 a

† Means followed by the same letter are not significantly different at 0.05 probability level with a Duncan's Multiple Range Test

Table 4. Ranges and means of FB, DM, N, C, C:N ratio of exotic lines and U.S. landraces grown in two environments

Accession	Range	Mean	Range	Mean
	Fresh biomass, tons acre^{-1}		**Dry matter, tons acre^{-1}**	
Exotic lines	17.2 - 22.9	19.6 a†	7.8 - 9.2	8.5 a
U.S. landraces	18.4 - 20.4	19.4 a	7.3 - 8.0	7.6 b
	Nitrogen (N), lbs acre^{-1}		**Carbon (C), lbs acre^{-1}**	
Exotic lines	490 - 619	509.9 a	6933 - 8728	7675.4 a
U.S. landraces	455 - 535	485.9 b	6813 - 8002	7497.6 a
	C : N ratio			
Exotic lines	14.1 - 16.4	15.2 a		
U.S. landraces	14.2 - 16.8	15.5 a		

† Means followed by the same letter are not significantly different at 0.05 probability level according to Least Significant Difference

performance was dependent upon environments. The two main phases of the velvetbean life cycle are the vegetative and the reproductive stages. Because DM accumulation does not stop at flowering (Buckles, 1998), it is possible that higher DM production could have been observed for the genotypes studied if plots had been sampled later. Buckles (1998) reported that DM increased from 4.5 tons acre^{-1} in early flowering to 5.4 tons acre^{-1} a month later and 6.2 tons acre^{-1} after another 3 to 4 weeks. The differences in DM production may be attributed to the growth characteristics of the genotype. Reports showed that seedling survival, which is an important component of DM yield, ranged from 15 to 95 % of the target seeding rate, depending on the environments (Chikoye and Ekeleme, 2001). Failure of Mucuna seedlings to emerge may be attributed to rotting or the inability of seed to imbibe water, and higher seedling survival may be related to the large seed size of some genotypes (Qi *et al*., 1999), which has been shown to improve germination percentages of *Mucuna* (Barbedo *et al*., 1988).

Effects of genotype and environment were highly significant for days from planting to first flower (Table 2). The genotype x environment interaction was significant for days to first flower, indicating that genotype performance depends upon environment. This agrees with early work by Aiming *et al*. (1999) who observed a significant response of *Mucuna* to photothermal and photoperiod. The photothermal regimes in which flowering did not occur within 200 days were generally the coolest and/or the warmest temperature combined with longer photoperiods (Aiming *et al*., 1999). Averaged across environments, the exotic lines were later flowering than the U.S. landraces (Table 3). Within the exotic lines, days from planting to first flowering varied from 159 for Cochinchinensis to 78 for PI365414, while in the U.S. landraces the genotype 23.W flowered in 109 days and genotype 22S flowered 86 days after planting.

Effects of genotype were highly significant for N, C, and C:N ratio (Table 2). Within the exotic lines, N accumulation ranged from 490.2 to 618.7 lbs acre^{-1}, averaging 509.9 lbs acre^{-1} (Table 4). In the U.S. landraces, N accumulation ranged from 454.6 to 534.5 lbs acre^{-1}, averaging 485.5 lbs acre^{-1} (Table 4). Reports showed that total N accumulation is greater at the beginning of flowering or during the flowering than other growth stages (Gataulina, 1992). Since N was determined at the beginning of flowering, the estimates may represent potential total N velvetbean should accumulate. The amount of N accumulated in velvetbean may have a great contribution in sustainable agriculture. Amado *et al.* (1999) showed that conservation tillage plus legume cover crop increased total N at soil surface.

Although N is the nutrient of interest in this study, the accumulation of other key nutrients in velvetbean biomass was significant. Carbon accumulation ranged from 3.4 tons acre^{-1} (for the genotype 25LB) to 4.4 tons acre^{-1} (for the genotype Rajada). Considerable variability was observed within the U.S. landraces and the exotic lines for total C. Within the U.S. landraces C accumulation ranged from 6813.0 to 8002.1 lbs acre^{-1}, averaging 7497.6 lbs acre^{-1}. In the exotic lines, C accumulation ranged from 6932.8 to 8727.7 lbs acre^{-1}, averaging 7675.4 lbs acre^{-1}. The C: N ratio ranged from 14.2 (for Cochinchinensis) to 16.4 (for the genotype 24.S). The C:N ratio has important implications for decomposition processes and nutrient availability. Fox *et al.* (1990) observed that N concentration in plant materials should be greater than 2% (or C: N ratio less than 20) before mineralization can occur. Nitrogen concentrations less than 2% or C: N > 25 lead generally to N immobilization (Fox *et al*., 1990; Myers *et al*., 1994). Thus, C: N ratios were low enough for the biomass of all genotypes used in the present study to allow early mineralization of N (Table 3). The velvetbean rotation may allow at least the conservation of the initial stocks of C and N despite continuous annual tillage or increase the level of C and N in any no-tillage cropping system. Gliessman *et al.* (1981) reported how the velvetbean system shows a working example of how to sustainably exploit the properties and dynamics of a natural ecosystem for the benefit of commercial crops.

CONCLUSIONS

In conclusion, the selected characteristics of the aboveground biomass in velvetbean such as dry matter yield, amount of nitrogen accumulated, and the C:N ratio evaluated in the present study make *Mucuna* a legume of excellent choice to use in rotation or inter-cropping systems. The range in relative maturity periods displayed among *Mucuna* accessions has potential advantages, depending on the precise objective in a specific farming system. If there is only a narrow window of opportunity for growing *Mucuna*, such as between the cropping of subsistence cereals, then an early-maturing genotype could guarantee the satisfactory completion of the crop's growth within the cropping cycle. However, if the objective was weed suppression for the longest possible period, such as under plantation crops or to maximize biological productivity for green manuring, an exceptionally late-flowering genotype might be preferable.

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CONSERVATION MANAGEMENT PRACTICES IN MISSISSIPPI DELTA AGRICULTURE: IMPLICATIONS FOR CROP PRODUCTION AND ENVIRONMENTAL QUALITY

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ABSTRACT

For wider acceptance of conservation management systems, e.g., reduced tillage and cover crops, experimental information is needed to guide growers in implementing these systems and also to critically evaluate environmental impacts. This paper summarizes a series of laboratory and field experiments assessing the effects of conservation management on soil properties, herbicide fate, weed control and yield. Adoption of conservation management practices alters organic matter distribution, especially in the soil surface. Enhanced organic matter typically increases microbial activity and often increases the capacity of the soil to sorb herbicides. Increased herbicide retention and microbial activity affect the degradation of herbicides and bioavailability for weed control. Results from an on-farm study showed that balansa clover (*Trifolium balansae*) was successfully established in a cotton (*Gossypium hirsutum L.*) production field, altered certain indices of soil quality (e.g., microbiological indicators, N availability), and provided some weed control and slight yield benefit. However, the economics of using legume cover crops such as balansa clover in cotton is in question and needs more critical evaluation over several additional years of study and multiple sites.

KEYWORDS

Soil organic matter, *Trifolium balansae*, herbicide sorption, and herbicide degradation

INTRODUCTION

Conservation systems such as reduced tillage have gained increased acceptability in the Mississippi Delta Region, especially with the use of transgenic herbicide resistant crops such as cotton and soybean (*Glycine max.*) (Locke *et al.*, 2002). Some growers are also integrating fall cover crops into their crop management programs. Both reduced tillage and cover crops have applicability for growers in attaining water quality standards that are being sought under the U.S. Environmental Protection Agency Total Maximum Daily Load (TMDL) regulations. To achieve wider grower acceptance, more information is needed to guide them in the management of conservation systems or to determine the potential impacts that these systems have on receiving waters and soil quality.

Adoption of practices such as reduced tillage and cover crops usually results in changes in soil characteristics (Locke and Bryson, 1997; Reeves, 1997). Associated with enhanced levels of organic carbon in the surface of conservation management soils are increased microbial populations and microbial activity (Wagner *et al.*, 1995; Zablotowicz *et al.*, 1998; Zablotowicz *et al.*, 2000). Increasing plant residue cover on soil reduces the loss of soil and nutrients in runoff, thus improving the quality of receiving waters and preserving valuable soil resources (Zablotowicz *et al.*, 2001; Knight *et al.*, 2001). Long-term accumulation of organic residues gradually improves soil quality in terms of tilth, nutrient availability, and structure, especially in the soil surface.

Some aspects of plant residue management improve the potential to influence management of weeds (Locke *et al.*, 2002). For example, cover crops may shade the soil, thus reducing germination and growth of weeds. Leaving the soil undisturbed by tillage prevents exposure of weed seeds to conditions suitable for germination. The use of cover crops, however, may not always be economical and, depending on the management system, may not contribute significantly to reducing other weed management inputs (e.g., herbicides). Also, increased soil organic carbon can increase the binding of herbicides in soil (e.g., Locke *et al.*, 1996; Reddy *et al.*, 1997), possibly rendering the herbicide less bioactive for weed control (Gaston *et al.*, 2001). Longer retention of herbicides in a conservation managed soil surface may result in negative carryover effects to the next crop, especially in crop rotations.

This paper summarizes results from some conservation management studies that evaluated trends in soil character-

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istics, herbicide dissipation, and potential effects on weed management and crop production.

METHODS AND MATERIALS

TILLAGE EFFECTS ON HERBICIDE SORPTION

Surface soil (0 to 5 cm) was sampled from a long-term (12 y) study under no-tillage and conventional tillage soybean production near Stoneville, MS. The soil was a Dundee silt loam. Soil was air-dried and ground to pass through a 2-mm sieve. Sorption of several herbicides, 2,4-D (2,4-dichlorophenoxy acetic acid), acifluorfen (5-[2-chloro-4-(trifluoromethyl)phenoxy]- 2-nitrobenzoic acid), alachlor (2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl)acetamide), bentazon (3-(1-methylethyl)-(1H)- 2,1,3 benzothia diazin-4(3H)-one 2,2-dioxide), and chlorimuron (2-[[[[4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl] benzoic acid) to Dundee soil were evaluated using batch methods similar to those described in Locke *et al.* (1997). Briefly, for each herbicide a solution was prepared in 0.01 M $CaCl_2$ using technical grade and ^{14}C-labelled herbicide stocks. Sorption was evaluated at one concentration for each herbicide, and concentrations ranged from one to two µg mL^{-1}. Air-dried soil was weighed into 25-mL centrifuge tubes, and herbicide solution was added at a ratio of 1:2 (w:v). The samples were shaken for 24 h, centrifuged, and decanted. Radioactivity (i.e., herbicide concentration) in the supernatant was measured using a liquid scintillation counter (Packard TriCarb 4000 Series, Packard Instruments, Meriden, CT). Herbicide sorption was calculated by difference between concentration added and concentration in solution after equilibration.

Technical grade 2,4-D (98% purity), acifluorfen (98% purity), alachlor (97% purity), and bentazon (98% purity) were obtained from Chem Service (West Chester, PA), and chlorimuron (98.7% purity) was obtained from DuPont Agricultural Products (Wilmington, DE). The

^{14}C-labelled herbicides were obtained as follows: acifluorfen (CF_3-ring-UL-label, 99% purity, specific activity [s.a.] 18.03 mCi $mmol^{-1}$) and bentazon (ring label, 98% purity, s.a. 10.54 mCi $mmol^{-1}$) from BASF (Research Triangle Park, NC), 2,4-D (carboxyl label, 98% purity, s.a., 9.0 mCi $mmol^{-1}$) and alachlor ([UL]-ring label, 99%, s.a. 27.0 mCi $mmol^{-1}$) from Sigma Chemical (St. Louis, MO), and chlorimuron ([UL]-phenyl label, 99% purity, s.a. 24.25 mCi $mmol^{-1}$) from DuPont Agricultural Products.

HERBICIDE PERSISTENCE IN A COTTON TILLAGE AND COVER CROP FIELD STUDY

A split plot (four replications) experiment was established in Stoneville, MS in 1990 to evaluate tillage (conventional *vs*. no-tillage) as a main effect and ryegrass (*Lolium multiforum* Lam.) cover crop (cover *vs*. no-cover) as a split effect on herbicide dissipation. The soil was a Dundee (fine-silty, mixed, thermic Aeric Ochraqualf), ranging from silt loam to silty clay loam. Norflurazon (4-chloro-5-(methyl amino)-2-(3-(trifluoromethyl)phenyl)-3(2H)-pyridazinone) was applied as a pre-emergence herbicide at a rate of 0.8 kg ha^{-1}.

Surface soil (0 to 2 cm) was sampled periodically during the 1994 season beginning at planting. Soil samples were frozen until processing. For determination of norflurazon concentrations in soil, samples were extracted in 90% methanol (1:1 w:v) for 24 h, centrifuged, and filtered through Whatman 42 (Whatman Paper, Clifton, NJ) and Gelman Acrodisc PVDF 25 µm (Gelman Laboratory, Ann Arbor, MI) filters. Extracts were analyzed with a 2690 Waters, Inc. HPLC System (Waters, Inc., Milford, MA). HPLC analytical conditions included Waters, Inc., Photo Diode Array UV Detector at 235 nm wavelength, Waters, Inc., Scanning Fluorescence Detector 470 at Ex. 294 nm and Em. 398 nm wavelengths, Alltech C18 Econosil column, 250 mm x 4.6 mm, 5 µm (Alltech, Deerfield, IL), Gradient with initial 55% HPLC grade water / 45% ACN to 70% ACN at one mL min^{-1} flow rate, 50-µL injection volume, and a retention time of 11 min.

ON-FARM NO-TILLAGE COTTON COVER CROP STUDY

In fall, 1999, balansa clover was seeded (6.5 kg ha^{-1}) on a 24-ha no-tillage field near Swiftown, MS. The field was a mixture of soil series including Forrestdale (fine, smectitic, thermic Typic Endoaqualfs) silt loam and silty clay loam with some areas of Dowling (very-fine, smectitic, thermic Vertic Epiaquepts) clay, Alligator (very-fine, smectitic, thermic Alic Dystraquerts) silty clay, and Dundee silt loam, and very fine sandy loam. In March of 2000, six 0.37-ha areas (each 60 m x 60 m) located throughout the field were desiccated with paraquat to maintain no-cover crop plots. Clover in the remainder of the field was allowed to mature to produce seed before desiccation in mid-May, 2000. Sorghum was planted May 25, 2000.

On May 12, 2000, two 16-m^2 sub-plots (4 m x 4 m) were selected from within each of the six no-cover crop areas, and locations were geo-referenced. Two 16 m^2 sub-plots were also selected in the cover crop areas adjacent to each of the six no-cover crop areas. Two composite soil samples (0 to 5 cm) were collected from each no-cover and cover crop sub-plot. Clover was also removed from the cover crop sub-plots for biomass determination. The only weed evaluations in no-cover crop and cover crop areas were made at the same time as the soil sampling.

In fall 2000, the clover reseeded naturally and was allowed to develop until desiccation on April 10, 2001. On

April 6, 2001, sub-plots (16 m^2) were selected near (within 30 m) to the location of the sub-plots sampled in 2000. Soil was collected from these sub-plots at depths of 0 to 2 cm and 2 to 10 cm. Clover biomass was determined in the sub-plots, and weeds were evaluated (April 6, 2001) just prior to desiccation with Roundup™ (N-(phosphonomethyl) glycine). Roundup Ready™ cotton was planted on May 7 and was managed as a dryland crop. Roundup was applied three times during the season, once over-the-top before the four-leaf stage of cotton and twice post-directed. Weeds were evaluated again later in the season (June 14 and August 23). All cotton received N fertilizer (70 kg ha^{-1}), regardless of cover crop. At maturity, cotton bolls were hand picked from a 4 m^2 no-cover crop or cover crop areas near the sub-plots and ginned to measure lint yield.

Soils from both 2000 and 2001 were characterized for microbial activity, enzyme activity, and chemistry. Total bacterial and fungal populations in soil samples were determined by serial dilution and spiral plating as described elsewhere (Wagner *et al.*, 1995). Tetrazolium chloride (TTC)-dehydrogenase activity in presence of yeast extract and fluorescein diacetate activity (FDA) was determined using techniques described elsewhere (Staddon *et al.*, 2001). Organic matter and soil nutrients were determined on air-dried soil samples from both years (Soil Testing Laboratory, University of Arkansas). Exchangeable nutrients were extracted from soil using Mehlich 3 (1:7, w:v), whereas pH and electrical conductivity (EC) were measured in water (1:2, soil:water).

RESULTS AND DISCUSSION

Tillage Effects on Soil Characteristics and Herbicide Sorption

Several reports from our research program have demonstrated how organic matter is increased in the surface of no-tillage soils as compared to conventional tillage (e.g., Locke *et al.*, 1997; Reddy and Locke, 1998). In one study, after 11 years of continuous no-tillage practices on a Dundee silt loam at Stoneville, MS, the organic carbon content of the surface 0 to 2 cm of no-tilled (NT) soil was 47% greater than that of the conventionally tilled (CT) soil, while no significant differences were observed at lower soil depths (Zablotowicz *et al.*, 2000). In the upper 2 cm of soil, both microbial biomass and FDA hydrolytic activity were 106 and 127% greater, respectively, than that of conventionally tilled soil. Mixing of soil due to tillage, however, resulted in greater microbial biomass and FDA hydrolytic activity in CT compared to NT at the 2 to 10 cm soil depth.

Similar increases in soil organic carbon were measured for the Dundee NT surface (0 to 5 cm) soil used in the present study evaluating sorption of five herbicides to soil (NT 22.4 and CT 11.9 g organic carbon kg^{-1}, Locke *et al.*, 1997). Sorption was higher in no-tillage than in conventional tillage for all herbicides except bentazon (Table 1). Chemical characteristics of the individual herbicides play a role in their sorption to soil. Nonpolar molecules have a strong hydrophobic attraction for organic components in soil. Different functional groups on the herbicide molecules, such as carboxyls and amines have varying affinities for sorption sites in the organic matter. Bentazon has a negative charge that reduces its attraction to soil. The other herbicides possess both hydrophobic and hydrophilic characteristics, and as the ratio of hydrophilicity and hydrophobicity varies from herbicide to herbicide, so does their attraction to organic matter. From top to bottom in Table 1, the herbicides tend to become more polar, or more hydrophilic. This is reflected in the size of the K_d value; the larger the K_d, the higher the sorption to soil.

Table 1. Effect of tillage on sorption (K_d) of herbicides in the soil surface (0 to 5 cm).

Herbicide	NT	CT
	---------Sorption K_d---------	
Alachlor	5.62	3.61
Acifluorfen	5.22	2.04
2,4-D	3.24	2.16
Chlorimuron	2.15	1.64
Bentazon	0.13	0.13

Norflurazon Persistence in the Field as Affected by Tillage and Cover Crop

Norflurazon dissipation in the surface soil from no-tillage with no-cover crop plots was more rapid than in conventional tillage surface soils with either no-cover crop or ryegrass cover (Fig 1). In the no-tillage, no-cover crop treatment, extractable norflurazon was about 1 mg kg^{-1} seven days after application, while similar soil concentrations were found in the conventional tillage treatments 14 days after application. For the remainder of the season, norflurazon in the surface soil did not differ among tillage or cover crop treatments.

The dissipation of norflurazon in the surface soil of the no-tillage cover crop treatment was a distinctly different pattern from the other treatments. Only low concentrations of norflurazon (~ 1 mg kg^{-1}) were measured in the no-tillage cover crop surface soil throughout the season. Lack of norflurazon in surface soil indicates that the norflurazon was intercepted by the cover crop, retained and released slowly into the soil during the course of the season as a result of wash-off from the cover crop residue and as the cover crop decomposed. In a laboratory study with another

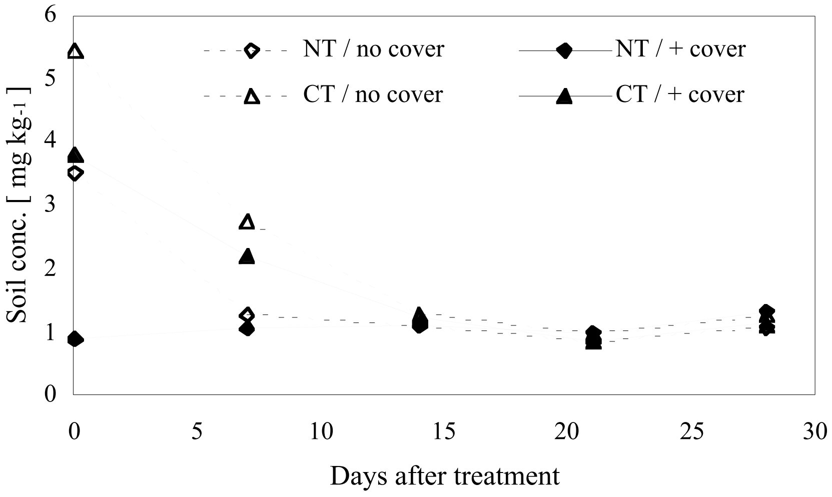

Fig. 1. Effect of ryegrass cover crop on norflurazon persistence in conventional tillage and no-tillage surface (0 to 2 cm) soils.

herbicide, fluometuron (N,N-dimethyl-N'-[3-(trifluoro methyl)phenyl]urea), sorption to soil was compared with sorption to rye (*Secale cereale*) cover crop material (Locke *et al.*, 1995). The Freundlich sorption parameter K_f for fluometuron sorption to rye was 21.8 ($n^{-1} = 0.96$) *vs.* 2.60 ($n^{-1} = 0.86$) for soil, indicating a much larger capacity for herbicide sorption in the cover crop material than in soil. Relating results from the fluometuron laboratory study may help explain the present field study where only low concentrations of norflurazon were observed in the soil surface of no-tillage cover crop throughout the season, indicating norflurazon movement to soil was impeded by retention to ryegrass material. The cover crop material also may have provided an environment conducive for more rapid biodegradation of norflurazon. For example, in laboratory studies with fluometuron (Locke *et al.*, 1995; Zablotowicz *et al.*, 1998), biodegradation was enhanced when soil was amended with cover crop material.

EFFECT OF COVER CROP IN A FARMER'S FIELD

Balansa clover may have potential as a cover crop for the Mississsippi Delta region because it flowers early enough to reseed itself and still permits a relatively late cotton planting. In the first year of establishment, balansa clover yielded a biomass of 2330 kg ha^{-1}, contributing 47 kg N ha^{-1}. The clover successfully reseeded in fall, 2000, following the first crop. By the time of cotton planting in May, 2001, the clover cover produced a biomass of 3360 kg ha^{-1} that contained about 97 kg N ha^{-1}.

Yield assessments in 2001 indicated a numerical 8% greater harvest of cotton lint in the cover crop area as compared to the no-cover crop area (Fig. 2). Yields across the field were variable, however, and standard deviations indicated no statistical difference. Although a detailed economic analysis was not done in this study, any slight yield effect likely did not translate into an economic advantage. In this study, both areas received nitrogen fertilizer, thus we were unable to ascertain the contribution of nitrogen from the clover. The cost of desiccating the cover crop also may offset any yield advantage and nitrogen contributed by the cover crop. In other studies on Mississippi Delta soybean production, the cost of using annual cover crops, especially annual legumes such as subterranean clover and crimson clover, was not justified (Reddy, 2001).

Table 2. Effect of cover crop on weed population in May, 2000.

Treatment	Broad leaf	Grass	Sedge	Total Weeds (SE)	Vines
	------------- % of	total area covered	--------------		
Cover	4.2	0.1	0.4	4.6 (3.9)	1.4
No-cover	37.8	29.3	0.0	67.2 (8.5)	27.1

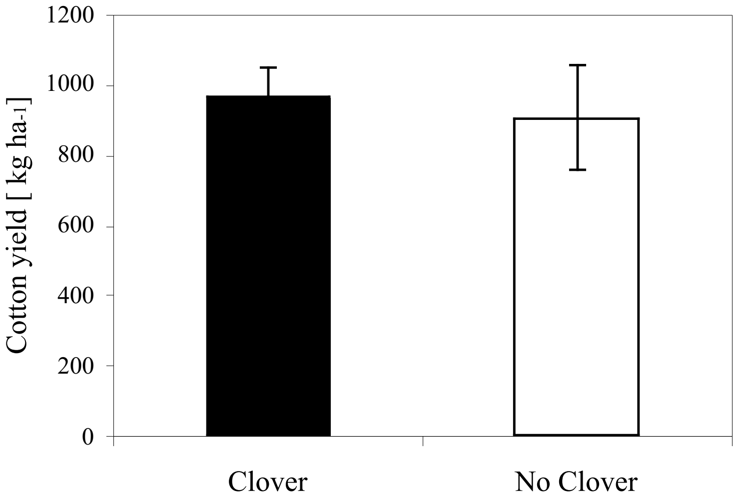

Fig. 2. Effect of balansa clover cover crop on cotton lint yield under no-tillage management.

Table 3. Effect of cover crop on weed population in 2001.

Treatment	Broad leaf	Grass	Sedge	Total Weeds (SE)	Vines
	------------- % of	total area covered	--------------		
April 6, 2001					
Cover	0.5	0.4	0	0.9 (0.8)	0.1
No-cover	19.6	35.0	0	54.6 (14.6)	14.5
June 14, 2001					
Cover	15.6	0.4	0.3	16.3 (5.8)	13.1
No-cover	24.6	0.3	0.1	25.0 (11.7)	24.3
August 23, 2001					
Cover	7.1	0.1	0.4	7.5 (7.1)	4.5
No-cover	17.5	0.1	0.1	17.7 (15.6)	17.2

Successful establishment of the balansa clover provided sufficient cover to augment weed control from herbicide both years (Tables 2 and 3). In the spring of 2000 and 2001 just prior to planting, clover cover crop residues occupied 95 to 99% of the surface in the cover crop areas, effectively shading most existing weeds and inhibiting germination and sprouting of summer weeds. Evening primrose (*Oenothera* spp.), horseweed (*Conyza canadensis*), redvine (*Brunnichia ovata*), and annual bluegrass (*Poa annua*) were the predominant early season weeds in no-cover crop areas both years. By mid-June, 2001, much of the clover had decomposed and weed pressure increased in the cover crop areas to a level comparable with no-cover crop areas (Table 3). By this time, vine-like species such as morningglories (*Ipomoea* spp.), redvine, and trumpetcreeper (*Campsis radicans*) were the major weeds present in both cover crop treatments. Overall weed pressure decreased by August with slightly more in the no-cover crop areas (Table 3). Although overall weed pressure was lower in the cover crop areas, suppression attributed to cover crops was variable, especially with regard to the troublesome perennial, vine-like weed species. This study suggests that residues of cover crops alone may not be a sufficient weed management tool, as postemergence herbicides were needed to control weeds, especially for perennial species.

In both years of the study, total bacterial propagules were significantly greater in the surface soil under clover compared to soil from the no-cover crop areas (Table 4). Fungal propagules also were significantly greater in the surface soil (0 to 5 cm) under clover compared to soil from the no-cover plots in 2000, but in 2001 differences between clover and non cover plots were significant at a lower probability level (P = 0.10). In the lower 2 to 10 cm soil depth in 2001, there was no effect of the clover on either bacterial or fungal propagules. The effects of balansa clover cover crop on enhancing bacterial and fungal populations in surface soils are similar in magnitude to effects reported for other cover crops (Wagner *et al.*, 1995; Zablotowicz *et al.,* 1998).

In 2000, TTC-dehydrogenase activity was significantly higher in soils under clover compared to soils from no-cover crop areas (Table 4). In 2001, however, the opposite effect was observed, where TTC-dehydrogenase activity was significantly greater (P = 0.05) in the surface (0 to 2 cm) soils from the no-cover compared to clover areas. In the TTC-dehydrogenase assay, yeast extract was added as an exogenous substrate, and the lower TTC-dehydrogenase in the clover soils the second year may be due to a repression of dehydrogenase activity as was reported in soils from vegetative filter strips by Staddon *et al.* (2001). In 2001,

Table 4. Microbial populations and soil enzyme activity (Tetrazolium chloride dehydrogenase and fluorescein diacetate hydrolysis) associated with soil under balansa clover or no-cover soils. Means within rows followed by the same letter are not significantly different at P = 0.05.

Year	Depth (cm)	Clover	None
Total bacteria , log$_{10}$ CFU g^{-1} soil			
2000	0 - 5	8.65 a	7.89 b
2001	0 - 2	8.56 a	8.02 b
2001	2- 10	8.07 a	7.81 a
Total fungi , log$_{10}$ CFU g^{-1} soil			
2000	0 - 5	5.73 a	5.14 b
2001	0 - 2	6.32 a	6.02 b
2001	2- 10	5.74 a	5.71 a
TTC, nmol product formed g soil^{-1} h^{-1}			
2000	0 - 5	50 a	38 b
2001	0 - 2	18 b	34 a
2001	2- 10	11 a	14 a
FDA, nmol product formed g soil^{-1} h^{-1}			
2000	0 - 5	ND	ND
2001	0 - 2	2979 a	2190 b
2001	2- 10	2134 a	1903 a

Table 5. Soil chemical changes associated with soil under balansa clover or no-cover soils.

Year	Depth	Clover	(SE)	No cover	(SE)
	--- cm ---				
Organic matter, %					
2000	0 - 5	1.98	(0.45)	1.9	(0.80)
2001	0 - 2	3.83	(1.08)	3.22	(0.93)
2001	2 -10	3.31	(1.00)	3.43	(0.97)
Nitrate-N (kg ha^{-1})					
2000	0 - 5	10	(6)	17	(10)
2001	0 - 2	97	(23)	40	(8)
2001	2 -10	38	(11)	21	(3)
P (kg ha^{-1})					
2000	0 - 5	86	(20)	95	(22)
2001	0 - 2	101	(24)	142	(26)
2001	2 -10	65	(16)	79	(20)
K (kg ha^{-1})					
2000	0 - 5	571	(164)	614	(197)
2001	0 - 2	554	(87)	680	(137)
2001	2 -10	384	(90)	453	(142)
pH, (1:2 Soil:Water)					
2000	0 - 5	6.3	(0.5)	6.2	(0.5)
2001	0 - 2	6.2	(0.5)	6.8	(0.5)
2001	2 -10	6	(0.6)	6.6	(0.5)
EC, 1:2 Water, µmhos cm^{-1}					
2000	0 - 5	81	(34)	86	(37)
2001	0 - 2	143	(52)	81	(22)
2001	2 -10	69	(30)	55	(9)

FDA-hydrolytic activity was higher in the surface 0 to 2 cm soils under clover compared to no-cover plots (Table 4). No effect of cover crop on either FDA-hydrolytic activity or TTC-dehydrogenase was observed at the lower 2 to 10 cm soil depth sampled in 2001 (Table 4). These results indicate that surface soils under balansa clover were showing improved microbiological productivity and may reflect improved potential for carbon and nitrogen cycling as biological indicators of soil quality.

Chemical analysis of soils collected in 2000 and 2001 are summarized in Table 5. In the first year of establishment there was no effect of the clover cover crop on any of the six parameters measured. It also should be noted that in the first year of the study there was some establishment of clover in the no-cover crop areas before killing with paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) in early spring, 2000. However, in May, 2000, when soil samples were collected, live clover present in the no-cover crop plots was only about 3 percent of the total area. In no-cover areas, soil samples were not collected where clover was present.

In 2001, there was approximately a two-fold increase in extractable nitrate in both soil depths under balansa clover compared to the no-cover crop areas, indicating a benefit from nitrogen fixation via rhizobial symbiosis (Table 5). Annual pasture legumes can contribute 30 to 160 kg ha^{-1} N in a season (Puckridge and French, 1983). As this study covered a large area and several soil types, a rather high variance was observed. Organic matter in 2001 was about 19% higher in the clover 0 to 2 cm soil depth as compared with no-cover. Under clover, soil pH was lower than no-cover, as might be expected with a higher rate of nitrification and organic matter decomposition. Electrical conductivity has been considered a useful index in soil quality assessment, having value as a practical estimator of soil nitrate and leachable salts (Doran and Parkin, 1996). Electrical conductivity was greater in soil under balansa clover compared to no-cover soil, although key nutrients such as potassium and phosphate were lower. A decrease in potassium and phosphate might be expected as they were assimilated by the clover and still associated with the clover biomass at time of sampling.

CONCLUSIONS

The following general observations can be made from these studies assessing reduced tillage and cover crop management:

1. Organic matter and microbial activity are greater in the surface of no-tillage and cover crop soils as compared to conventional tillage and no-cover crop.
2. Herbicide sorption capacity is higher in no-tillage and cover crop surface soils due to the increases in organic matter.

3. Norflurazon dissipation was slightly faster in the surface of no-tillage soil, perhaps due to higher microbial activity and associated degradation.
4. Cover crop residues intercepted norflurazon in the no-tillage treatment and did not release it in great quantity. The herbicide may have degraded as the cover crop decomposed, or been retained by the cover crop and released slowly.
5. Balansa clover residues repressed some weed growth throughout the crop season. The most difficult type of weeds observed in this no-tillage were the perennial vine-like species.
6. Balansa clover cover crop enhanced microbial activity and nitrate in the surface soil.
7. Balansa clover had only a marginal effect on yield, and economic benefit is questionable.

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HIGH-RESIDUE CONSERVATION SYSTEM FOR CORN AND COTTON IN GEORGIA

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ABSTRACT

Two limiting factors to economical crop yields in Georgia are short-term drought and root-restricting hard pans. Deep tillage eliminates the effects of the hard pan and improves water infiltration, increasing the volume of soil water accessible by crop roots. The objectives of this study were to develop a practical high-residue conservation tillage system that reduces risk of short-term drought and improves soil quality for corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.). A strip-split plot design was used to test the following treatment combinations at the Coastal Plains Experiment Station, Tifton and the Southwest Branch Experiment Station in Plains on a Tifton sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) and Greenville sandy clay loam (fine, kaolinitic, thermic Rhodic Kandiudults), respectively, during 1999-2001: 1) surface tillage (disk and field cultivate vs. no-till), 2) deep tillage (in-row subsoil, zonal paratill, and no-till), and 3) cover crops (black oat [*Avena strigosa* Schreb.) , wheat (*Triticum aestivum* L.) and natural winter weed infestations. Corn was grown in 1999 and 2000. Cotton was planted in 2001. Grain yield differences were obtained only at the Tifton location. Corn grain yields were significantly higher ($P = 0.10$) in the deep tillage plots compared to no deep tillage in both years and with surface tillage of residue in 2000. There was a strong trend for corn following a black oat cover crop to have the highest yields both years at Tifton, especially with in-row subsoiling. Cotton yields in 2001 were significantly higher with deep tillage (either in-row subsoiling or paratilling) at both locations ($P = 0.10$) There was a strong trend at both locations for higher cotton yields when the residue was incorporated. There was also an interaction of surface tillage and cover crops in cotton at Tifton. Cotton yields were highest with surface tillage with no cover but lowest in the no-till without a cover crop. These data suggest that without deep tillage, surface tillage regardless of cover is needed for best yields in both corn and cotton on Tifton soils. This effect may be due to improved water infiltration and mineralization of residue. However, this was not observed in corn at Plains.

KEYWORDS

Soil compaction, hardpans, in-row subsoiling, *Avena strigosa* Schreb, *Triticum aestivum* L.,

INTRODUCTION

Short term drought stress and root-restricting hard pans are the two most yield limiting factors in crop production in Georgia. Soils are highly weathered and eroded, inherently infertile and low in organic matter that results in poor soil structure, limited rainfall infiltration and water storage. Conservation tillage has been shown to increase soil organic matter and improve water infiltration and storage (Reeves, 1997). Unfortunately, only 25% of Georgia's corn and cotton are grown with conservation tillage. A majority of this acreage does not have sufficient residue or cover mulch to effectively increase moisture conservation and organic matter. Production practices are needed that improve both moisture conservation and reduce limitations on root growth in order to sustain corn and cotton production in Georgia; where available water resources fast are becoming more limited. The objectives of this research were to: 1) develop a practical high-residue conservation tillage system that reduces risk of short term drought and improves soil quality and 2) demonstrate the practicality and benefits of the system as compared to conventional practices.

MATERIALS AND METHODS

The study was conducted in 1999, 2000 and 2001 at the Coastal Plains Experiment Station, Tifton and the South-

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west Branch Experiment Station in Plains on a Tifton sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) and Greenville sandy clay loam (fine, kaolinitic, thermic Rhodic Kandiudults), respectively. Four replications of a strip-split plot design were used to test the following treatment combinations: 1.) surface tillage (disk and field cultivate vs. no-till), 2.) deep tillage (in-row subsoil, zonal paratill, and no-till), and 3.) cover crops black oat, wheat and natural winter weed infestation). Individual plots were 45 feet long and 12 feet wide. Cover crops were planted on Dec. 3, 1998, Oct. 13, 1999, and Oct.17, 2000 in seven-inch rows. Cover crops were fertilized with 40 lbs N acre^{-1} after planting. Winter cover was chemically killed with glyphosate two weeks prior to planting corn and cotton with a four row no-till planter equipped with residue managers. Pioneer® brand hybrid 3163 was planted in 30 inch rows on March 18, 1999 and March 23, 2000 at 28,000 plants per acre and 30, 000 plants per acre, respectively. Corn was fertilized according to soil test recommendations by the University of Georgia Cooperative Extension Service. Nitrogen for corn was applied in a split application: 40 lbs acre^{-1} at planting and 100 lbs acre^{-1} at 3 and 6 leaf stage. Irrigation was applied as needed or available. Corn plots were harvested approximately August 18, 1999 and August 23, 2000.

Table 1. Mean residue dry matter biomass (lbs acre^{-1}) as affected by cover crop.

	1999		2000		2001	
Cover Crop	Plains	Tifton	Plains	Tifton	Plains	Tifton
Black oats	1778	2586	2207	4225	6967	6469
Wheat	1837	2520	2514	3739	12,089	9966
None	155	329	2764	2789	717	1675
LSD$_{0.10}$	260	287	382	236		

The cotton variety, DeltaPine 655 B/RR was planted on May 11, 2001 following fertilization of P and K according to soil test recommendations. Nitrogen was applied in a split application: 42 lbs acre^{-1} at planting and 70 lbs acre^{-1} in mid-June. At-plant insecticides were used each year for both corn and cotton. The growth regulator, mepiquat chloride was applied to cotton at the rate of 8 oz acre^{-1} at both locations. Cotton was harvested mechanically on October 22-24, 2001.

Data were subjected to analysis of variance. Means were separated using Fishers protected LSD ($P = 0.10$ *a priori*).

RESULTS AND DISCUSSION

The late planting date for the cover crop in 1998 limited biomass/residue production but was greatly improved with earlier plantings in 1999 and 2000. Mean residue increased as expected in year two and three of the test at both locations (Table 1) due to previous corn residue and a more timely planting date for the cover crop. Residue was much higher at Tifton than Plains due to better moisture conditions and soil type. Winter weed population was much greater in the second and third year due to the early corn harvest of 1999 and 2000, which allowed more time for weed emergence and growth. In 2000, black oat and wheat were equal in biomass/residue accumulation except under no-till production (Table 2). Black oat produced significantly more biomass than wheat or winter weeds in no-till production in 2000. In Brazil, where black oat are commonly used in no-till production, studies have indicated black oat tolerates denser soil conditions than other small grains (Calegari *et al.*, 1993; Derpsch *et al.*, 1985).

Table 2. Mean corn grain yields and residue as affected by cover crops and deep tillage.

		Grain yield		
Tillage	Cover	1999	2000	Residue
		----- bu acre^{-1}---		lbs acre^{-1}
Subsoil	black oat	170	182	3925
Paraplow	black oat	160	169	4148
No-till	black oat	154	150	4558
Subsoil	wheat	165	174	4112
Paraplow	wheat	164	170	4103
No-till	wheat	137	123	2988
Subsoil	none	167	167	2676
Paraplow	none	162	163	2899
No-till	none	143	142	2569
LSD$_{0.10}$		NS	NS	401

CORN (1999 AND 2000)

No differences in yield were obtained in either year at Plains. Mean yields at the Plains location were lower than at the Tifton location (128 bu acre^{-1} vs. 158 bu acre^{-1} in 1999; 108 bu acre^{-1} vs. 159 bu acre^{-1} in 2000, respectively).

At Tifton, corn grain yields were much higher following deep tillage than no deep tillage (Table 3) both years, although, there was no difference between either deep tillage treatment (zonal paratilling or subsoiling in-the-row). Corn following surface tillage of residue yielded significantly greater than corn planted without incorporation of the residue (187 bu acre^{-1} vs. 169 bu acre^{-1}, respectively). While plant population was slightly lower in the no surface tillage treatments as compared to the surface tillage treatment (28,200 vs. 29,480 plants per acre), it was only significantly reduced in the no surface tillage, no-till treatment plots (25,780 plants per acre). The higher grain yields may be due to better water infiltration from a less compacted surface area and greater mineralization of the incorporated residue. At Tifton, corn behind the subsoil and black oat treatment tended to be higher in yield than any other combination treatment (Table 2) in both 1999 and 2000 ($P = 0.13$ and $P = 0.17$). This trend for higher crop yields with black oat has been noted in other studies (Calegari, *et al.*, 1993; Derpsch, *et al.*, 1985, Bauer and Reeves, 1999).

COTTON (2001)

Lint yields were significantly higher following deep tillage than no-deep tillage (averaged over surface tillage treatments) at both locations (Table 4) . As with corn, there was no difference between either deep tillage treatment. There was a trend at Tifton and Plains for higher lint yields following surface incorporation of the residue prior to planting ($P = 0.19$ and $P = 0.11$, respectively). At Tifton, cotton yields were affected by a surface tillage X cover crop interaction (Table 5). Yields with surface tillage and no cover were greater than those in the no-till, no cover plots. Reasons why are inconclusive, plant populations were lower in the no-till plots (data not shown). The surface of the no- till, no cover plots was much denser and may have reduced water infiltration and also had less N mineralization.

Table 3. Mean grain yield (bu acre^{-1}) as affected by tillage, Tifton.

Treatment	1999	2000
Subsoil	167	175
Paratill	162	167
No deep tillage	145	137
LSD$_{0.10}$	14	14

Table 4. Effects of tillage on cotton lint yield, 2001.

Treatment	Tifton	Plains
	------ lbs lint acre^{-1} ------	
Paratill	1562	1207
Subsoil	1557	1254
Notill	1468	1135
LSD$_{0.10}$	56.7	85.0

Table 5. Cotton yields and cover crop residue as affected by surface tillage and cover crops at Tifton.

Surface tillage	Cover crop	Lint yield	Residue yield
		---- lbs acre^{-1} ----	
Conventional	black oat	1552	6551
No-till	black oat	1510	6431
Conventional	wheat	1488	10362
No-till	wheat	1542	9570
Conventional	none	1621	908
No-till	none	1460	2442
LSD$_{0.10}$		81	

CONCLUSIONS

Corn yields were increased 14% in 1999 and to 25% in 2000 by deep tillage at Tifton. There was a trend for corn following a black oat cover crop to have the highest yields both years at Tifton, especially with in-row subsoiling. This trend was not observed in cotton in the one year it was grown. Also, there was a strong trend for the lowest corn yields to be obtained with no-surface tillage, no-deep tillage, and a wheat cover crop. The poorest cotton yields were also in the no surface tillage and no-deep tillage plots. No differences in corn yields were obtained with any combination treatment at the Plains location which was unexpected. Moisture conditions were poorer at the Plains location during both years due to limited irrigation capabilities, however, crop response to tillage and cover was not evident. Most likely greater amounts of residue are needed to maximize moisture conservation for subsequent crop production. The trend towards higher grain yields with black oat suggest that more studies are needed to understand this relationship and develop use of this cover crop into a practical conservation tillage system. Cover crops did not affect cotton yields at either location, the one year tested. Given that both locations were irrigated, the incidence of short term drought stress observed in strict no-till plots may not have been significant enough to demonstrate any benefits from the cover crop residue. There was a trend across both crops for higher yields in plots where the surface was disked prior to planting. This may have aided in water infiltration and aeration during the early season.

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Development of Management Systems

TILLAGE TECHNIQUES FOR GARDENS AND SMALL-SCALE VEGETABLE PRODUCTION

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ABSTRACT

Sandy soils of the Coastal Plain and Applachian Plateau can develop traffic pans or hardpans as a results of some conventional tillage practices. Techniques for disrupting these traffic pans are well documented for field crop production. However, gardeners and small-scale vegetable producers can experience the same problems when using garden tillers. Slit tillage using a modified, 5-hp, garden tiller in a sandy, Coastal Plain soil significantly increased yields of sweet corn, okra, and southern peas over more conventional tillage practices such as using a standard, front-tined or rear-tined garden tiller. Slit tillage disrupted traffic pans, reduced in-row soil compaction, and resulted in yields as high or higher than traditional subsoiling. Slit tillage may offer the home gardener and small farmer a low-cost solution to a soil compaction problem created by conventional tillage practices. Additional techniques such as double digging and manual slits using a spade are being evaluated for use by the home gardener in reducing the damaging effects of subsoil compaction.

KEYWORDS

Darden tillage, slit tillage, vegetable, garden, traffic pan, soil compaction, hardpans

INTRODUCTION

Traffic pans or plow pans in Coastal Plain soils of the southeastern U.S. are a common problem in non-irrigated field crops. Traffic pans are a thin layer (2 to 4 inches) of compacted soil resulting from the downward force of tillage equipment on the soil just beneath the plow layer. The problem is particularly serious on soils with a sandy topsoil (Ap horizon) just above a finer textured subsoil. This situation is common on soils of the Coastal Plain and Appalachian Plateau (e.g. Sand Mountain).

Many large-scale producers routinely subsoil their fields prior to or at planting to create a deeper rooting zone for non-irrigated crops. In order to reduce the energy needed for this operation, innovative techniques such as "slit tillage" have been proposed. Slit tillage uses a blade to cut a narrow slit through the traffic pan, which roots can follow into the subsoil. Root channels through this slit persist from year to year if the soil is not drastically disturbed. Unfortunately, coarse textured, sandy soils tend to rapidly wear away a blade. Therefore, slit tillage has not become a practice for large-scale farmers.

Traffic pans or tillage pans may also be a problem for gardeners and small-scale vegetable producers. These growers probably don't have access to large equipment necessary for deep tillage and subsoiling. Often they depend on small tractors with disks and/or garden tillers, which may create traffic pans as serious or worse than those created by field cropping practices. In fact, estimates of soil compaction by common activities rank tillers among the most serious.

Source of Compaction	Estimated compaction
	lbs inch^{-2}
Man walking	6
Crawler-type tractor	12
Wheel-type tractor	20
Cattle	23
Horse	40
Garden rototiller	107-750

The faster the tines of a tiller rotate, the more energy is transferred into the soil just beneath the tines. This rapid rotation of a rear-tined tiller has the potential to create traffic pans more severe than a large tractor and disk.

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OBJECTIVE

The objectives of this study and demonstrations are to apply what we have learned about tillage and soil compaction in field crops for small gardens and small-scale vegetable producers and to demonstrate the effects of soil compaction and techniques to overcome its negative effects on root growth..

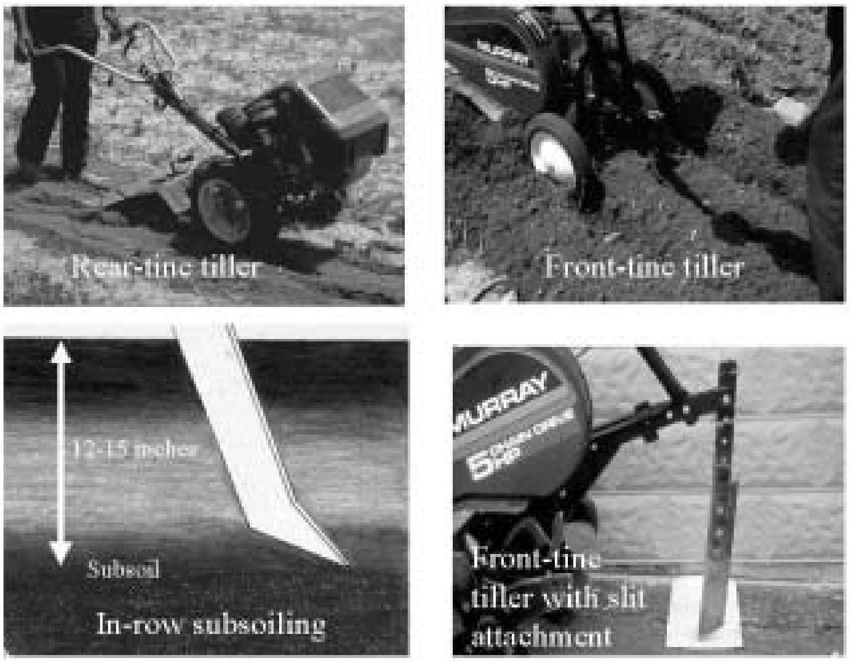
METHODS

Since the early 1990s, experiments and demonstrations with Master Gardeners have demonstrated the effect of soil compaction on selected vegetable crops using common and modified mechanical garden tillage techniques. These tests and demonstrations have enabled us to explain soil compaction to Alabama gardeners and small-scale vegetable producers.

AUBURN EXPERIMENT

One of the first experiments was located on the campus of Auburn University on a Marvyn loamy sand (fine-loamy, siliceous, thermic Typic Kanhapludults), a typically sandy, Coastal Plain soil with a sandy clay loam subsoil (Bt horizon) approximately 10-12 inches deep. These soils are known to develop traffic pans about 8 inches deep. Soil was limed as needed to†maintain soil pH between 5.8 and 6.5. Phosphorus, potassium, and sulfur were applied annually at a rate of 100, 100, and 20 pounds per acre P_2O_5, K_2O, and sulfate-S, respectively. Nitrogen was applied to sweet corn at 150 pounds N per acre in split applications and to okra at 80 pounds N per acre in split applications.

Fig.1. Treatments used in the Auburn experiment.



Soil was prepared just prior to spring planting using four tillage treatments (Fig. 1):

(1) Rear-tine garden tiller Using a 10-hp rear-tine, BCS garden tiller; soil was prepared to a depth of 6 inches with multiple passes of tiller just prior to planting.

(2) Front-tine garden tiller Using a 5 hp front tine garden tiller; soil was prepared with multiple passes of tiller just prior to planting; tillage depth was approximately 6 inches.

(3) In-row subsoiled Using a small tractor and a conventional subsoil shank to a depth of 14 inches directly beneath the row. Final seedbed preparation was made with the rear-tined tiller as in treatment 3 to a depth of 4 inches.

(4) Slit tillage Using the same 5 hp, front-tined, garden tiller adapted with a modified drag bar to cut a slit 12 inches beneath the row; soil was prepared as in the above treatment as the slit was being cut directly beneath the row.

Crops planted during the 3-year experiment were:

- Sweet corn (*Zea mays L.* var. silver queen) — every year
- Okra (*Abelmoschus esculentus (L.) Moench* var. Clemson spineless) — 2 of 3 years
- Southern peas (*Vigna unguiculata (L.) Walp* var. Pinkeye Purplehull) — 1 of 3 years

Each crop was planted in a separate, randomized block with four replications. During the third year of the experiment, seedling disease resulted in such a poor stand of okra that the plots were replanted in southern peas. All plots consisted of three, 36-inch rows 15 to 20 feet long. Marketable yield was measured by harvesting the center row in each plot. Sweet corn was picked twice. Okra was picked twice weekly for a total of 15 to 20 harvests. Southern peas were harvested twice as mature, green pods.

Soil penetrometer measurements were taken in early fall of year 1 and year 3 to determine relative compaction of the soil.

CULLMAN EXPERIMENT

The Cullman County Master Gardeners have assisted in conducting a similar experiment with additional tillage variables at the North Alabama

Fig. 2. Additional treatments used in the Cullman experiment and in the Central Alabama demonstration.

Horticulture Substation at Cullman, Alabama, in 2001 and 2002. The soil at this site is mapped as a Hartsells fine sandy loam (fine-loamy, siliceous, thermic Typic Hapludults). Eight treatments were used with the first four treatments being the same as described in the previous experiment (Fig. 1, 2):

1. Front-tine garden tiller.
2. Slit tillage.
3. Rear-tine garden tiller. (8-hp Troy Bilt was used).
4. In-row subsoiled.
5. Hand tilled using the "double-digging" technique under the row.
6. No tillage using a spade or blade to cut a slit into subsoil.
7. Conventional disking with a small tractor
8. Rototilling using tractor-mounted rototiller.

Sweet corn was planted on this site in mid April and harvested in late July. Plot size was 12 feet by 20 feet (4, 36-inch rows 20 feet long) and treatments were replicated four times in randomized blocks. The two center rows were harvested for yield. Following sweet corn harvest, the stalks were cut and cabbage and broccoli were hand planted as a fall crop with no additional tillage. This experiment will be repeated at Cullman.

Central Alabama demonstration

The same experiment conducted at Cullman is also being repeated as a non-replicated demonstration at E.V. Smith Research Center in Central Alabama on a Norfolk fine sandy loam (fine-loamy, siliceous, thermic Typic Kandiudults) in 2002. Alabama Master Gardeners are helping to conduct this demonstration.

RESULTS

Experiment 1

In some years, crops under moisture stress showed dramatic, visual, growth responses to the 4 tillage practices. The degree of stress, of course was dependent on soil moisture. Total marketable yields reflect rainfall distribution as well as tillage practice. None of the crops were irrigated. †There were significant and fairly consistent yield differences due to tillage for every crop and every year of the test. Slit tillage increased total marketable yield of sweet corn, okra, and southern peas (Fig. 3, 4, 5). The rear-

Fig. 3. Three-year average marketable yields of sweet corn as affected by the type of tillage system used in the Auburn experiment. Yields followed by the same letter are not significantly different ($P = 0.05$).

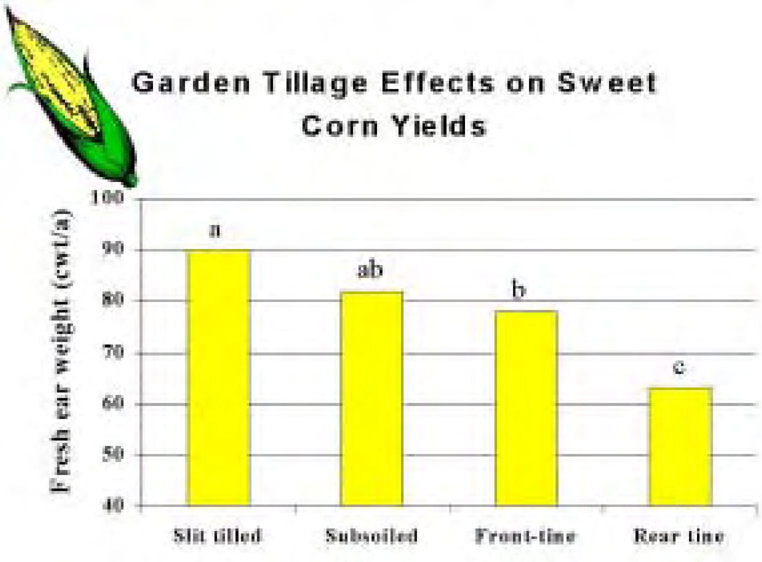


Fig. 4. Two-yr average marketable yields of okra as affected by the type of tillage system used in the Auburn experiment. Yields followed by the same letter are not significantly different (*P* = 0.05).

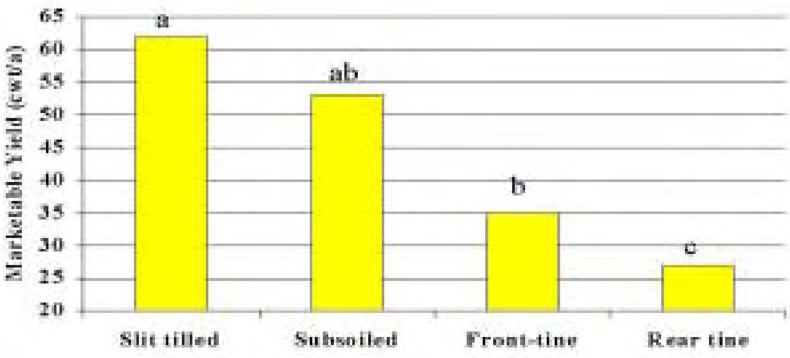


Fig. 5. Average marketable yields of southern peas as affected by the type of tillage system used in the Auburn experiment. Yields followed by the same letter are not significantly different (P<0.05) from others.

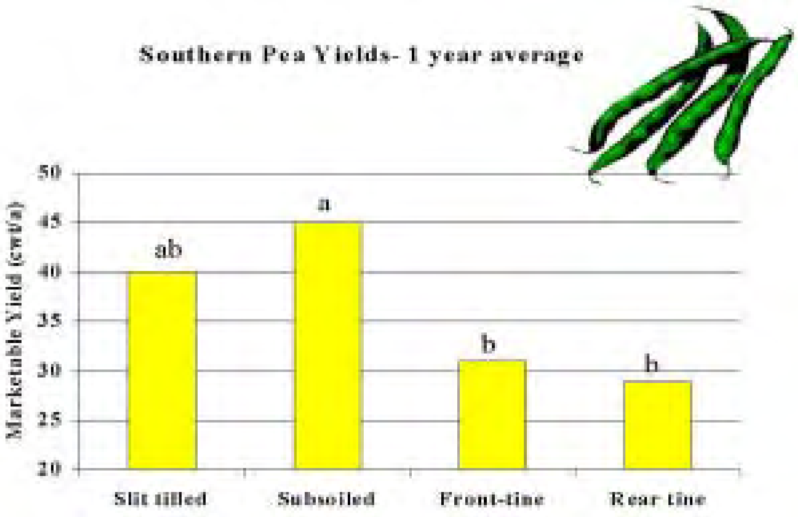
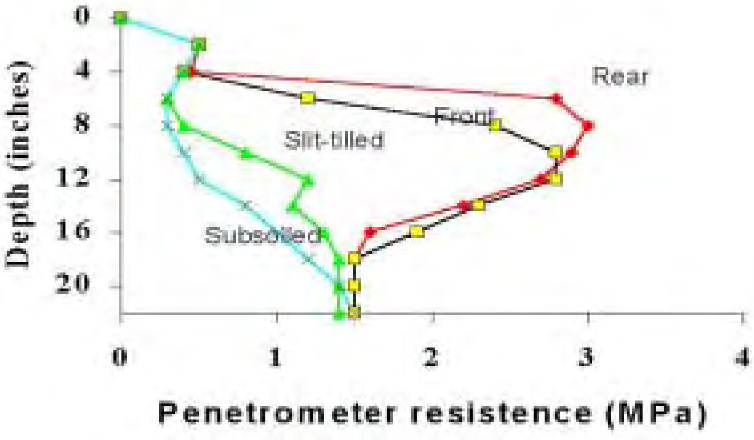


Fig. 6. Average penetrometer resistance (relative soil compaction) taken under the row after the first and third growing seasons following sweet corn and southern peas.



tined tiller resulted in lowest yield, presumably due to soil compaction resulting in moisture stress during short-term droughts. In general, yields were of the order:

Subsoiled = Slit tilled > Front-tine tiller > Rear-tine tiller

Soil penetrometer measurements made in the row at the end of the cropping. Season identified pronounced soil compaction following the rear-tine. Tiller and the front-tine tiller (Fig. 6). Subsoiling and slit tillage effectively disrupted the plow sole at 20-30 cm.

Experiment 2

An extremely wet summer and severe summer thunderstorms damaged the corn crop. We also believe that the very wet season reduced the expected responses to the tillage variables. Problems with weeds and cutworms masked any tillage variables we may have had in the fall crop. No data are presented.

SUMMARY

Slit tillage using a modified 5-hp garden tiller in a sandy Coastal Plain soil significantly increased yields of sweet corn, okra, and southern peas over more conventional tillage practices such as using a standard, front-tined or rear-tined garden tiller. Slit tillage disrupted traffic pans, reduced in-row soil compaction, and resulted in yields as high or higher than traditional subsoiling. Slit tillage may offer the home gardener and small farmer a low-cost solution to a soil compaction problem created by conventional tillage practices. Additional techniques such as double digging and manual slits using a spade are being evaluated for use by the home gardener in reducing the damaging effects of subsoil compaction.

RESEARCH IN NORTH CAROLINA WITH REDUCED TILLAGE SYSTEMS FOR PEANUT (1997-2001)

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ABSTRACT

Reduced tillage peanut (*Arachis hypogaea* L.) production has gained considerable interest in North Carolina over the past few years. Determining if peanut yield is maintained in reduced tillage compared with conventional tillage is important in determining the utility of this approach to peanut production. Thirty experiments were conduced from 1997 through 2001 in North Carolina to compare peanut yield in conventional tillage systems to yield when peanut was strip tilled into stubble from the previous crop or a small grain cover crop. When pooled over experiments, pod yield in conventional tillage was 164 lb acre^{-1} or 5.0% higher than pod yield in strip tillage. Differences in yield between systems were as high as 29.9%, with greater yield differences noted on finer-textured soils. Yield in conventional tillage exceeded that of strip tillage when major differences in yield were noted. In eleven of these experiments, pod yield of peanut in conventional tillage, strip tillage into stubble, and strip tillage into stale seedbeds (beds established the previous fall or winter) was compared. When peanut was strip tilled into stale seedbeds and crop stubble, pod yield was 6.0% and 11.4% lower than yield in conventional tillage, respectively. Results from these experiments suggest that while peanut yield can equal and occasionally exceed that of conventional tillage when strip tilled into crop stubble or stale seedbeds, yield generally remained higher in conventional tillage. These experiments were conducted in situations that would be considered a transition from conventional tillage to strip tillage. Results from long-term strip tillage production may be more positive due to improvements in soil tilth in strip tillage.

KEYWORDS

Conventional tillage, stale seedbed, wheat cover crop.

INTRODUCTION

Peanut in the United States is typically grown in conventionally tilled systems (Sholar *et al*., 1995). Peanut response to reduced tillage has been inconsistent. Research suggests that yields in reduced tillage can be lower than (Brandenburg *et al*., 1998; Cox and Sholar, 1995; Grichar, 1998; Sholar *et al*., 1993; Wright and Porter, 1995) or similar to (Baldwin and Hook, 1998; Hartzog *et al*., 1998; Williams *et al*., 1998) yields in conventional tillage systems. Higher yields in reduced tillage systems have been associated with lower incidence of tomato spotted wilt *tospovirus* (Baldwin and Hook, 1998).

Between 10 and 18% of growers planted peanut in reduced tillage systems in North Carolina from 1998 through 2000 (Jordan, 2002). Although reduced tillage systems offer several potential benefits, consistency of yield is a concern of growers and their advisors. Therefore, experiments were conducted in North Carolina to compare pod yield of peanut grown in conventional tillage and strip tillage systems in an attempt to define factors influencing peanut response to tillage.

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MATERIALS AND METHODS

Experiments were conducted in North Carolina from 1997 through 2001 at a variety of locations, on several soils, with various Virginia market type cultivars, and with several different seedbeds prepared for strip tillage (Table 1). In eleven of these experiments, beds were established in separate plots during the previous fall or winter prior to spring planting (referred to as stale seedbeds). With the exception of tillage systems, all other production and pest management practices were held constant over the entire test area. Plot size ranged from four rows to eight rows (36-inch spacing) by 30 to 75 feet long. With the exception of experiments at Edenton, strip tillage implements consisted of in-row subsoiler followed by two sets of coulters and two basket attachments to smooth the tilled zone. The tilled zone was approximately 20 inches wide. At Edenton, a vertical-action tiller, either with or without in-row subsoiler, was used to establish the tilled zone. Peanut was planted within one week following strip tillage. Peanut was harvested using standard equipment designed for small-plot harvesting. The experimental design was a randomized complete block with four replications in each experiment. The average pod yield of conventional tillage and strip tillage into crop stubble or stale seedbeds from each experiment was combined into one data set to determine the overall average. The percent difference in yield was calculated for each experiment based on the higher yield among systems.

RESULTS AND DISCUSSION

When averaged over the 30 experiments, peanut pod yield was 164 lb/acre higher in conventional tillage compared with strip tillage into stubble (Table 1). This correlated into strip tillage yields being 5.0% lower than yields for conventional tillage. Considerable variation in yield was noted among experiments, soil series, and other treatment factors. Differences in pod yield ranged from 1069 lb acre^{-1} lower (29.9%) to 463 lb acre^{-1} higher (10.6%) for strip tillage compared with conventional tillage. When comparing the ranges of percent yield difference between tillage systems, yield was within 5% in 12 of 30 experiments (40% of experiments)(Table 2). The difference in pod yield in 8 of 30 experiments ranged from 5.1 to 10%. The distribution between the highest and lowest yielding systems, either as conventional tillage or strip tillage, was equal. Four experiments fell into the 10.1 to 15% range of percent difference, with half of the experiments within this group having higher yields for conventional tillage compared with yield from strip tillage. Pod yield in six of 30 experiments was higher in conventional tillage compared with yield in strip tillage when the yield difference exceeded 15%.

Peanut yield potential appeared to be maintained at a higher level in conventional tillage rather than strip tillage. This was especially the case when major differences in yield were noted among tillage systems. Soil series, specific tillage practices for conventional tillage systems, the seedbed in which strip tillage was performed, and cultivar selection did not conclusively explain the variation in response. For example, yield on Norfolk sandy loam (NSL) soils for strip tillage yielded 14.7% lower to as much as 10.7% higher than yield in conventional tillage (Table 1). When peanut was planted on a Conetoe loamy sand (CLS) soil, yield in strip tillage was 8.3% higher in one experiment and 3.1% lower in another experiment when compared with conventional tillage. Peanut yield on Craven (CrSL), Perquimans (PSL), and Roanoke (RSL) soils, which are not considered ideal soils for peanut production, were higher for conventional tillage than strip tillage in all eight experiments where these soils were present (Table 1).

In all but one experiment (Tyner in 1999), conventional tillage included bedding or ripping and bedding operations (Table 1). Very little bed remained when peanut was strip tilled into a killed small grain cover crop or stubble from the previous crop. Although peanuts are planted on flat ground with success in North Carolina, most practitioners indicate that peanuts are more efficiently dug when grown on elevated beds compared with digging peanut planted on flat ground or where minimal beds are present. This may be especially true for large-seeded Virginia market type peanut which can experience high digging loss when soil conditions are not optimal for digging. Although not documented in these experiments, lack of beds in strip tillage systems and potential pod loss in the digging process may explain inconsistent yields in strip tillage, especially on finer-textured soils such as the Roanoke and Craven series. Although response differed on more appropriate soils for peanut production (Goldsboro, Norfolk, and Conetoe soils), inconsistent response also may have been influenced by the ability to effectively dig peanut on essentially flat ground. These soils are easier to dig than Roanoke or Craven soils and digging losses are generally lower. This explanation may be only partially complete as the reason for inconsistent response to strip tillage, and additional research is needed to refine these systems in an attempt to improve wide-scale success.

One approach to maintaining yields, if in fact elevated beds improve digging efficiency, would be to prepare beds

Table 1. Year, location, soil series, conventional tillage system, seedbed present during strip-till operation, cultivar, absolute yield difference, and percent yield difference from 30 trials comparing conventional tillage and strip tillage in North Carolina during 1997-2001. A positive value for actual and percent yield indicates that peanut yield was higher in conventional tillage systems compared with strip tillage systems.

Year	Location	Soil Series[†]	Conventional tillage	Strip-till seedbed	Cultivar	Yield difference	
						Abs.	Rel.
						lb acre^{-1}	%
1997	Tyner	CLS	Disk/Rip/Bed	Wheat	Multiple[‡]	-327	-8.3
1997	Edenton	RSL	Disk/Chisel/Bed	Cotton stubble	Multiple[§]	905	21.7
1997	Lewiston	NSL	Disk/Rip/Bed	Corn stubble	NC 10C	-458	-9.7
1997	Rock Mount	GLS	Disk/Rip/Bed	Corn stubble	NC 10C	-463	-10.6
1997	Lewiston	NSL	Disk/Rip/Bed	Cereal rye	NC 7	-438	-10.7
1998	Lewiston	NSL	Disk/Chisel/Rip/Bed	Corn stubble	NC 9	-116	-2.9
1998	Edenton	RSL	Disk/Chisel/Bed	Cotton stubble	NC 7	938	27.1
1998	Edenton	RSL	Disk/Chisel/Bed	Corn stubble	NC 7	148	4.8
1998	Halifax	NSL	Disk/Chisel/Rip/Bed	Wheat	NC-V 11	277	7.2
1998	Lewiston	NSL	Disk/Rip/Bed	Wheat	NC 7	317	11.0
1998	Woodland	CrSL	Disk/Chisel/Rip/Bed	Cotton stubble	NC-V 11	274	9.4
1999	Woodland	CrSL	Disk/Chisel/Rip/Bed	Cotton stubble	NC-V 11	1069	29.9
1999	Scotland Neck	NSL	Disk/Rip/Bed	Wheat	NC-V 11	729	14.9
1999	Halifax	NSL	Disk/Chisel/Rip/Bed	Wheat	NC 12C	-192	-4.2
1999	Rocky Mount	GSL	Disk/Rip/Bed	Cotton stubble	VA 98R	258	9.5
1999	Edenton	PSL	Disk/Chisel/Rip/Bed	Cotton stubble	NC-V 11	115	3.4
1999	Edenton	PSL	Disk/Chisel/Bed	Cotton stubble	NC-V 11	981	24.3
1999	Lewiston	NSL	Disk/Chisel/Rip/Bed	Corn stubble	NC 9	614	17.2
1999	Lewiston	NSL	Disk/Rip/Bed	Cereal rye	NC 7	-258	-6.3
1999	Gatesville	CLS	Disk/Rip/Bed	Cotton stubble	Multiple[¶]	146	3.1
1999	Williamston	GLS	Disk/Rip/Bed	Corn stubble	Multiple[¶]	4	0.2
1999	Tyner	CSL	Disk	Cotton stubble	Multiple[¶]	-162	-4.5
1999	Whitakers	GSL	Disk/Rip/Bed	Cotton stubble	Multiple[¶]	-149	-4.1
2000	Woodland	CrSL	Disk/Rip/Bed	Wheat	NC-V 11	546	23.2
2000	Lewiston	NSL	Disk/Rip/Bed	Corn stubble	NC 12C	202	4.5
2000	Lewiston	NSL	Disk/Rip/Bed	Corn stubble	Multiple[#]	-258	-6.3
2000	Lewiston	NSL	Disk/Chisel/Rip/Bed	Wheat	NC 12C	17	0.5
2000	Rocky Mount	GSL	Disk/Rip/Bed	Cotton stubble	NC-V 11	273	7.2
2001	Lewiston	NSL	Disk/Rip/Bed	Corn stubble	Multiple[#]	53	2.0
2001	Lewiston	NSL	Disk/Rip/Bed	Corn stubble	NC 12C	-120	-4.3
Average						164	5.0

[†] Abbreviation: CLS, Conetoe loamy sand; CrSL, Craven silt loam; GSL Goldsboro sandy loam; NSL, Norfolk sandy loam; PSL, Perquimans silt loam; RSL, Roanoke silt loam.

[‡] Averaged over the cultivars NC 7, Gregory, and NC-V 11.

[§] Averaged over the cultivars NC 7, VA 93B, and VA-C 92R.

[¶] Averaged over the cultivars Georgia Green, NC 10C, NC-V 11, NC 12C, Perry, and VA 98R.

[#] Averaged over the cultivars NC-V 11, NC 12C, Perry, and VA98R.

Table 2. Comparison of percent differences in yield between conventional tillage (CT) and strip tillage (ST) into stubble from the previous crop from 30 experiments conducted from 1997-2001 in North Carolina.

% difference in yield		Total #	CT > ST	
from	to	of expts	# expts	% expts.
0.0	5.0	12	6	50
5.1	10.0	8	4	50
10.1	15.0	4	2	50
15.1	20.0	1	1	100
20.1	25.0	3	3	100
25.1	30.0	2	2	100
	>30.0	0	0	
Total		30	18	60

during the previous fall or winter and strip till into these beds prior to seeding peanut. In the eleven experiments where this tillage system was included, pod yield was 11.4% and 6.0 % lower than conventional tillage when peanut was strip tilled into stubble from the previous crop or stale seedbeds, respectively (Table 3). These data suggest that stale seedbed production, a compromise between strip tillage into fields without prior primary tillage versus intensively tilled conventional systems, can be relatively successful. The stale seedbed approach allows establishment of beds, and this may be advantageous from a digging standpoint. In most instances where considerable difference in yield was noted between conventional tillage and reduced tillage, yield in stale seedbeds approached that of conventional tillage (Table 4). However, seeding peanut into conventionally tilled seedbeds yielded consistently higher than reduced tillage systems in 18 of 30 experiments.

When comparing data sets with 30 experiments (strip tillage into previous crop stubble versus conventional tillage) or with 11 experiments (stale seedbed system included), the difference in yield between conventional and strip tillage into stubble was 5.0% and 11.4%, respectively (Tables 1 and 3). This difference in yield between the two data sets may have been a result of the percentage of finer-textured soils within the two data sets. In the stale seedbed experiments, 5 of 11 experiments (46% of experiments) were on Craven, Perquimans, or Roanoke soils. In contrast, only 8 of 30 experiments (26% of experiments) were conducted on these soils in the data set containing all 30 experiments. These data suggest that pea-

Table 3. Year, location, soil series, actual yield difference, and percent yield difference from 11 trials comparing conventional tillage with strip tillage into crop stubble or stale seedbeds in North Carolina during 1997-2001. A positive value for actual and percent yield indicates that peanut yield was higher in conventional tillage systems compared with strip tillage into stale seedbeds or stubble from the pervious crop.

		Soil	Actual difference		% difference	
Year	Location	series[†]	Stale bed	Stubble	Stale bed	Stubble
			------ lbs acre^{-1} ------		---------- % ---------	
1997	Tyner[‡]	CLS	-391	-327	-10.7	-8.3
1998	Lewiston	NSL	15	-116	3.9	-2.9
1998	Edenton	RSL	480	938	13.9	27.1
1998	Edenton	RSL	492	148	16.0	4.8
1999	Woodland	CrSL	616	1069	17.2	29.9
1999	Rocky Mount	GSL	39	258	1.4	9.5
1999	Edenton	PSL	684	981	16.9	24.3
1999	Lewiston	NSL	247	614	6.9	17.2
2000	Woodland	CrSL	-162	546	-6.4	23.2
2000	Lewiston	NSL	362	202	8.0	4.5
2001	Lewiston	NSL	-30	-120	-1.1	-4.3
Average			214	381	6.0	11.4

[†] Abbreviations: CLS, Conetoe loamy sand; CrSL, Craven silt loam; GSL, Goldsboro sandy loam; NSL, Norfolk sandy loam; PSL, Perquimans silt loam; RSL, Roanoke silt loam.

[‡] Averaged over cultivars NC 7, Gregory, and NC-V 11.

Table 4. Comparison of percent differences in yield between conventional tillage (CT) and strip tillage (ST) into stale seedbeds or crop stubble from 11 experiments conducted from 1997-2001 in North Carolina.

% difference in yield		Total # of expts.		CT > ST	
from	to	Stale bed	Crop stubble	Stale bed	Crop stubble
0.0	5.0	3	4	2	2
5.1	10.0	3	2	2	1
10.1	15.0	2	0	1	0
15.1	20.0	3	1	3	1
20.1	25.0	0	2	0	2
25.1	30.0	0	2	0	2
	>30.0	0	0	0	0
Total		11	11	8	8

nut response to strip tillage into the previous crop stubble may be more favorable on coarser-textured soils rather than finer-textured soils. These data also suggest that the gap in yield potential in reduced tillage compared with conventional tillage is narrowed when peanut is strip tilled into stale seedbeds.

Although these data suggest that peanut yields in conventional tillage may be consistently higher than yields in strip tillage, these experiments represented a short-term transition into reduced tillage production from conventional tillage. Positive benefits of reduced tillage often require several years of reduced tillage production before being realized.

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SOYBEAN VARIETIES RESPONSE TO TILLAGE SYSTEMS

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INTERPRETIVE SUMMARY

Preliminary research on clay soils had indicated that some soybean varieties showed a yield increase to tillage, while others showed no yield differences. Therefore, a two-year (2000-2001) study was conducted to evaluate 16 soybean varieties' yield response to conventional and no-tillage systems on a Catalpa silty clay loam soil, which had been in no-till production for three years.

The study was conducted as a split split plot with years as main plot, tillage (no-tillage and conventional) as subplot, and varieties as sub-subplot with four replications. The conventional tillage system consisted of two field cultivations (2-3 inch depth) applied in late March or mid April followed by a harrow prior to planting in early May. The seeding rate was 8 seed/ft of row in 30-inch rows. The same weed management was applied across the whole study, except for the burn-down herbicide applied to the no-tillage plots. Appropriate preemergence and postemergence herbicides were applied to all plots to maintain a high level of weed control. No cultivation was applied to the conventional tillage system during the growing season.

Fifty percent bloom dates (50% of the plants with at least one bloom/plant) and maturity dates (95% of the pods dry) were recorded. The two-row x 30 ft long plots were harvested with a plot combine to determine grain yield. Yield data was analyzed using the mixed procedure program in the Statistical Analysis Systems (SAS) software. Means were separated using Fishers Protected least significant differences (LSD) at the 5% probability level.

Bloom dates ranged from June 19 for the late maturity group IV varieties to July 13 for the late maturity group V varieties. Maturity ranged from early to mid September for late maturity group IV varieties and from early October to mid October for the late maturity group V varieties. Analysis indicated that tillage and varieties had no effect on yield and there was no tillage by variety interactions. These results indicated variety yield was not affected by tillage, which was contrary to preliminary research that showed varieties' yield response interacted with tillage.

However, analysis indicated a year by variety interaction. The varieties differed in yield stability across years, as influenced by different environmental growing conditions. Rainfall was 3.18 inches for July 16 to 31 in 2000 compared to 0.28 inches in 2001. Delta and Pineland DP 4748S, however, had the highest yield of 38 and 28.5 bu/ac in 2000 and 2001, respectively. In 2000, both Delta and Pineland DP 3478 and DP 4748S had similar but higher yields than all other varieties. However, in 2001, DP 4748S had a greater yield than DP 3478 and all other varieties, except Delta and Pineland DP 5655, DP 5915R, and DP 3588. The results suggest that to maximize yield potential, varieties should be selected which have a consistently high yield performance across diverse growing environments or more than one year of evaluation.

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SEQUENCE AND ROTATION EFFECTS ON PEST INCIDENCE AND YIELD OF WINTER WHEAT AND CANOLA DOUBLE-CROPPED WITH PEARL MILLET AND SOYBEAN

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INTERPRETIVE SUMMARY

Double-cropping is an important practice in areas of the southern U. S., where length of growing season and adequate rainfall or irrigation permit timely stand emergence, development, and maturity of a summer crop. The predominant double-crop sequence is winter wheat (*Triticum aestivum* L.) and soybean [*Glycine max* (L.) Merr.], although grain sorghum and cotton are sometimes grown as a double-crop with wheat. Double-cropping has advantages of increased cash flow for producers and reduced soil erosion and water loss by having ground cover most of the year and cost savings from more intensive use of the land and better utilization of crop inputs, labor and capital investments. However, double-cropping essentially can result in a continuous production of crops in the same field each year, which can cause a build up of damaging levels of disease, insect, and weed populations. Indeed, in the 1970s and 1980s continuous double-crop production of winter wheat resulted in serious damage in many fields by take-all root and crown rot caused by the fungus *Gaeumannamyces graminis* var. *tritici* (Ggt), and by devastating outbreaks of the Hessian fly, *Mayetiola destructor* (Say). Incorporating alternative crops that are culturally and biologically compatible with a soybean/wheat double-crop system could help reduce pest incidence and severity and also provide farmers with commodity marketing alternatives. Canola (*Brassica napus* L.) is an alternative winter grain crop that provides high quality edible oil for various uses and defatted meal for livestock, particularly poultry. Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a new alternative summer crop that produces high-quality feed grain for poultry. Grain millet is an attractive alternative to other summer crops in non-irrigated systems because of its short growing season and inherent tolerance to hot and droughty conditions.

We established a five-year study in the Coastal Plain region of GA to examine the effects of incorporating canola and pearl millet in multiple-year rotational sequences on the agronomic performance and pest incidence and severity in a wheat-soybean double-crop system. The experiment was conducted on a Greenville sandy loam at the Southwest Branch Experiment Station near Plains, GA. A twelve crop sequence and rotational treatments were established in a randomized complete block design with four replications. Plots measured 40 ft by 40 ft (1600 ft^2). Rotations included winter wheat, winter canola, winter rye or fallow, and summer crops were soybean or pearl millet for grain production.

Winter wheat productivity was affected by previous crop sequences and rotation history. A single year of canola production greatly reduced the severity of infection take-all root and crown rot in wheat. Wheat rotation with canola every few years was very effective in suppressing take-all stem and root rot. Canola as the previous winter crop reduced winter infestations and, to some extent, spring infestations of Hessian fly. Furthermore, the wheat-soybean rotation had lower winter infestations levels of the Hessian fly than a wheat-millet rotation. Reduced Hessian fly infestation in rotations with canola is understandable because of the lack of a host plant. The reason for increased infestation levels following millet compared with soybean is not clear. Possibly the herbicide regime in millet did not control volunteer wheat in late summer as well as in soybean, thereby providing a bridging host for the first fall generation of Hessian fly which develops in volunteer wheat before the planting of the winter wheat crop.

Canola grain yields were not affected by previous summer and winter crops and cropping sequences in any year. However, continuous canola production tended to yield

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about 200 lbs per acre less than first time and rotated canola in the last three years of the study. Planting canola after canola also enhanced Sclerotinia infection levels in both years where the disease was present. Current canola production guidelines recommend planting canola only one in four years to help avoid infection by blackleg, caused by the fungus *Leptospharia maculans*. More frequent rotations of every one or two years may be feasible if highly blackleg-resistant varieties are grown.

Pearl millet stands were lower following canola than wheat in two of the four years. Stand loss was mainly the result of seedling feeding damage caused by the false chinch bug, (*Nysius raphanus* Howard) following canola. Soybean stands also were consistently reduced by 18 - 25% following canola as compared with small grains in all years except 1998. As with millet, false chinch bugs were more numerous on soybean seedlings following canola than winter wheat in some years, but the level of injury from chinch bugs does not explain the reductions in soybean stands. Although the cause of soybean stand reductions was not determined, losses most likely were caused by physical interference of the canola stubble with planter performance or possibly by undetermined chemical or biological factors associated with canola stubble.

Except for seedling damage by false chinch bugs, the sequence of previous winter crops had little consistent effect on insect populations on soybean or grain millet or on soybean diseases. In millet, the incidence of stalk and neck rot (caused by *Fusarium graminearum*) infection was greater following canola than wheat, and the severity of smut (caused by *Moesziomyces penicillariae*) was enhanced after three continuous years of millet cultivation (Wilson *et al*., 1999). Despite these effects on stand and disease incidence, previous winter or summer crops or the number of sequential years of cultivation had no detrimental, limiting impacts on grain yields of either pearl millet or soybean (Wilson *et al*., 1999).

These results show that the continuous planting of a crop can enhance host-specific pests such as Hessian fly and take-all disease in wheat. Stands of soybean and grain millet usually were reduced when planted into canola stubble as compared to winter wheat, rye, or fallow. However, the previous cropping sequence did not reduce grain yields of pearl millet or soybean. Both soybean and millet tolerate a considerable range of plant populations without affecting grain yield. Therefore, rotating canola with wheat to disrupt pest cycles in wheat can be done without detrimental, limiting effects on subsequent soybean or millet crops as long as plant populations are not near or below the minimum for a full stand.

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CONSERVATION ROTATIONS FOR COTTON PRODUCTION AND CARBON STORAGE

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ABSTRACT

Intensive cropping and conservation tillage can increase soil organic C (SOC) and improve soil quality, however, economic reality often dictates cotton (*Gossypium hirsutum* L.) monoculture. We conducted a study on a Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) from 1998-2001 to compare an intensive conservation cropping system to standard cotton production systems used in the southeastern USA. The system uses sunn hemp (*Crotalaria juncea* L.) and ultra-narrow row (UNR; 8-inch drill) cotton in a rotation with wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.). The standard systems used continuous cotton (both standard 40-inch rows and ultra-narrow row) and a corn - cotton rotation with standard row widths. A cover crop mixture of black oat (*Avena strigosa* Schreb.)/rye (*Secale cereale* L.) was used in all systems preceding cotton and a white lupin (*Lupinus albus* L.)/crimson clover (*Trifolium incarnatum* L.) mix was used before corn in the corn-cotton and intensive system. All systems were tested under conservation and conventional tillage in a split plot design of four replications; main plots were cropping systems and subplots were tillage. We used extension budgets to calculate net returns over variable costs and determined C balance of all residues returned to the soil. At the end of the experiment, soil C was determined by dry combustion (0-0.4, 0.4-2, 2-4, 4-8, and 8-12 in depths). Cropping system had a more consistent effect on cotton yield than tillage system. Four-yr average lint yields were 872, 814, 711 and 663 lbs acre^{-1} for continuous UNR, intensive, corn-cotton, and continuous 40-in cotton systems, respectively. The UNR systems with conservation tillage had the highest net returns [\$105 acre^{-1} yr^{-1} (continuous) and \$97 acre^{-1} yr^{-1} (intensive)] while the conventional tillage continuous 40-in system had the lowest returns (\$36 acre^{-1} yr^{-1}). Conservation tillage increased SOC concentration in the top 2-in of soil 46% compared to conventional tillage. Cropping system affected SOC levels to the 4-in depth and the corn-cotton rotation resulted in the lowest SOC levels of all systems. Results suggest that small grain cover crops and wheat for grain in the intensive system were the dominate factor in SOC changes. For these drought-sensitive soils, UNR cotton production systems with conservation tillage and small grain cover or cash crops have the potential to rapidly increase soil organic matter; improving soil productivity and enhancing economic sustainability of cotton production in the southeastern USA.

KEYWORDS

Soil C, cropping intensification, cover crop, conservation tillage, economics, C sequestration

INTRODUCTION

Carbon sequestration has become a popular term among scientists, environmental advocates, agricultural producers, energy policy makers and government agencies in recent years. Within the agricultural arena, the term describes the process of photosynthetic fixation of atmospheric CO_2 into plant tissue and/or soil organic matter. There is debate regarding the potential to mitigate global climate change through C sequestration, however, there is ample research to show that increasing soil C improves soil quality and agronomic productivity (Reeves, 1997; Machado and Silva, 2001; Dìaz-Zorita *et al.*, 2002).

Research from Brazil and other countries in subtropical and tropical regions has shown that warm humid climates have great potential to increase soil C (Sá *et al.*, 2001). For example, calculated values for C sequestration potential in southern Brazil range from 9.37 to 12.54 Tg C yr^{-1} (10.3 to 13.8 million tons yr^{-1}; Bayer *et al.*, 2000b; Sá *et al.*, 2001). Although warm humid climates like those in the southeastern USA favor rapid decomposition of soil organic matter, the capacity for C fixation in subtropical and humid tropical regions can be greater than in temperate regions. Compared to cooler temperate regions, the Southeast has longer

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growing seasons, a greater capacity for cropping intensification and biomass production, and fewer agroecological constraints to adoption of conservation tillage; which more than compensates for this region's higher rate of organic matter decomposition.

Soil management strategies for increasing C sequestration and improving soil quality on existing arable land include conservation tillage, cropping intensification, application of animal manures, and inclusion of sod-based or pasture rotations. Crop rotation is critical to cropping intensification and has long been recognized as being agronomically beneficial (Reeves, 1994; Bayer *et al.*, 2000b). In addition, the need for sound rotation practices is even greater for conservation tillage systems than for conventional tillage systems (Reeves, 1997). Intensive cropping systems, using high-residue crops in rotations coupled with conservation tillage, can dramatically improve soil quality and productivity. Unfortunately, government farm policies, agricultural mechanization and specialization, and economic reality often discourages cropping diversity and intensification.

Brazilian scientists are world leaders in crop rotation and conservation tillage research (e.g., Sá *et al.*, 2001; Bayer *et al.*, 2000a; Bayer *et al.*, 2000b; Machado and Silva, 2001). Transposing their principles and techniques to the subtropical region of the southeastern USA, we established a study to compare an intensive cropping system, maximizing the production of crop residues and legume N inputs, to standard cotton (*Gossypium hirsutum* L.) production systems used in the southeastern USA. The specific objectives of the research were to: 1) develop a cotton production system that maximizes soil carbon inputs; 2) determine the impact of the system on soil quality and productivity; and 3) determine the most economically favorable cropping system compared to standard cotton production systems.

MATERIALS AND METHODS

The system used sunn hemp and ultra-narrow row (UNR) cotton (drilled in 8-in rows) in an intensive rotation with wheat and corn. Soybean [*Glycine max* (L.) Merr.] could be substituted for cotton in this rotation, following wheat, but cotton currently enjoys a comparative economic advantage in the southeastern USA compared to soybean because of the risk from short-term drought and favorable government commodity support programs for cotton. Control systems used continuous cotton (both standard 40-in rows and ultra-narrow row) and a corn - cotton rotation (row widths of 30-in and 40-in, respectively). All systems were tested under conservation and conventional tillage.

We began the experiment in August of 1997 with the planting of sunn hemp on a Compass sandy loam in east-central AL. Cropping systems were imposed through 2001. The site had previously been a tillage study with a corn-soybean rotation and a winter cover crop of crimson clover for the past 10 years. The previous study had conservation (no-tillage; with and without in-row subsoiling to 16-in depth) and conventional (disk-chisel-disk-field cultivate; with and without in-row subsoiling) tillage variables. Prior to starting this cropping system study, the entire area was non-inversion deep-tilled with a Paratill® bent-leg subsoiler (AgEquipment Group, Lockney, TX 79241) to 16-in. Research has shown that some form of in-row subsoiling is needed for this soil to disrupt an inherent root-restricting hardpan (Reeves and Mullins, 1995; Reeves and Touchton, 1986). Consequently, non-inversion subsurface tillage (in-row subsoiling or paratilling) was done for all plots each year, regardless of surface tillage practices. Specially designed equipment enable this to be done in high residue with very little disturbance of crop residue and soil; and for practical purposes emulates no-tillage.

Tillage treatments in the cotton systems study were arranged to maintain the integrity of the previous 10-years conservation and conventional tillage treatments. The experiment design was a split plot arrangement of treatments in a randomized complete block of four replications. Main plots were cropping systems and subplots were tillage, i.e., the previous conventional and conservation tillage treatments maintained. Cropping systems were: 1) intensive system; 2) cotton-corn rotation with standard row widths (40-in for cotton and 30-in for corn); 3) continuous cotton with standard rows; and 4) continuous ultra-narrow row cotton (8-in drill width).

The intensive system maintained actively growing cash or cover crops about 330 days of the year. Corn was planted in early April and harvested in August; followed immediately by sunn hemp, which was terminated in early November when wheat was drilled. Ultra-narrow row cotton was drilled following wheat harvest in early to mid-June. Following cotton harvest in October, a white lupin - crimson clover mixed cover crop was drilled prior to the following corn crop that started another rotation cycle. In the continuous cotton (both 40-in and 8-in row widths) and corn-cotton rotation treatments, a black oat - rye cover crop mix was used prior to cotton and the white lupin-crimson clover cover crop was used prior to corn. All phases of each rotation were present each year in all cropping systems, to eliminate confounding year effects with system effects.

All cover crops were killed 14-21 days prior to planting using glyphosate and a mechanical roller (Ashford *et al.*, 2000). Weeds were controlled with glyphosate over-the-top at 4 true leaves; in 1999 preemergence applications of fluometuron and pendimethalin were also applied. Nitrogen was broadcast applied to the black oat/rye cover crop, wheat and ultra-narrow row cotton, and banded beside the row for standard row width cotton and corn. Rates were 30 lbs N acre^{-1} for black oat/rye, 150 lbs N acre^{-1} for corn, and 120 lbs N acre^{-1} for cotton and wheat. Standard row cotton was harvested with a spindle picker and ultra-narrow row cotton was harvested with a stripper fitted with a finger harvester.

The critical factor in agricultural sustainability is economic viability. We used Auburn University Extension Budgets, adjusted for differences in actual practices that varied from inputs in the standard budgets, to calculate four year average (1998-2001) net returns over variable costs for the cropping/tillage systems. We allowed a deduction for UNR cotton lint (fiber) of US$0.04 lbs^{-1} in calculations.

In addition to harvested yield determinations, we also measured biomass returned to the soil from all cash crops and cover crops in the various tillage/cropping system treatments. Total C was determined in biomass samples by dry combustion (Yeomans and Bremner, 1991). In March 2002, soil C was determined by dry combustion from samples taken at depths of 0-0.4, 0.4-2, 2-4, 4-8, and 8-12 inches, following grinding in a roller mill (Kelly, 1994). For these soils, total C is equivalent to soil organic C (SOC), as they contain no appreciable carbonate-C.

RESULTS AND DISCUSSION

As expected cotton yields varied with year (Table 1); with the exception of 2000, summer crops grown were subjected to extreme drought stress every season. Tillage system effect was not consistent; no-tillage (with subsoiling or paratilling) resulted in greater yields in 1998, while conventional tillage (chisel/disk + subsoiling) resulted in higher yields in 1999. In 2000 and 2001, cotton lint yields were similar with either tillage system.

Cropping system or rotation had a more consistent effect on cotton lint yield than tillage system (Table 1). Ultra-narrow row systems (continuous cotton and the intensive system) resulted in the highest lint yields and continuous cotton in 40-in rows resulted in the lowest yields. The corn-cotton rotation with 40-in rows consistently resulted in slightly higher lint yields than the continuous cotton grown with 40-in rows, however, the increase was significant only in 2001, the one season without severe drought stress on the cotton. The ultra-narrow row cotton in the intensive system was double-cropped behind wheat, and was planted later than the continuous ultra-narrow row cotton in most years. Ultra-narrow row cotton has a compressed flowering and boll set period compared to standard row width cotton, and our data suggest that this narrower window for reproductive growth may increase risk from short-term droughts compared to standard row width cotton, which can compensate for short-term drought with a longer boll set window. This is illustrated by the lower yield of the UNR cotton in the intensive system in 1999, which was planted later than the other systems and was impacted by severe drought at flowering and boll set.

Table 1. Cotton lint yields (1998-2001) as affected by cropping-tillage systems imposed on a sandy coastal plain soil with a hardpan in east-central Alabama. Within cropping systems, regular denotes the common 40-in row spacing, whereas UNR denotes an ultra narrow 8-in row spacing.

	Cropping system				
	Intensive	Corn-Cotton	Continuous cotton		
Year	Regular	Regular	Regular	UNR	$LSD_{0.10}$
	------------------------- lbs lint acre^{-1}	--------------------------			
1998	712	505	491	729	36.2
1999	395	577	566	613	120.1
2000	953	765	716	858	70.9
2001	1194	996	880	1286	88.8
Mean	814	711	663	872	-

	Tillage system		
Year	Chisel/disk	No-tillage	$LSD_{0.10}$
	--------- lbs lint acre^{-1}	------------	
1998	596	623	20.2
1999	563	513	49.1
2000	810	837	62.1 ns
2001	1085	1093	78.2 ns
Mean	764	767	-

A major benefit of cropping diversification and in-

Table 2. Four year (1998-2001) mean economic return over variable costs of cropping-tillage systems imposed on a sandy coastal plain soil with a hardpan in east-central Alabama. Within cropping systems, regular denotes the common 40-in row spacing, whereas UNR denotes an ultra narrow 8-in row spacing.

	Cropping system			
	Intensive	Corn-Cotton	Continuous cotton	
Tillage system	Regular	Regular	Regular	UNR
	--------------------$ acre^{-1} year^{-1}	---------------------		
No-tillage	97.20	40.17	44.30	104.57
Chisel/disk	76.46	40.80	36.00	95.12

tensification is reduction in economic risks. All UNR or high-density cotton systems exhibited higher net returns than standard 40-in row spacing cotton systems (Table 2). The highest net return over variable costs was obtained with continuous no-tillage UNR cotton (\$104.57 acre^{-1} yr^{-1}). This was a function of higher cotton yields with this monoculture system coupled with the comparative advantage for cotton due to favorable commodity support programs. Lowest net return (\$36.0 acre^{-1} yr^{-1}) was obtained with the conventional grower practice of monocropped cotton in 40-in rows using a chisel plow/disking conventional tillage system. The no-tillage intensive cropping system had the second highest net return (\$97.20 acre^{-1} yr^{-1}) of any of the tillage/cropping system combinations.

Economics dictates short-term sustainability, but maintenance or improvements in soil C impact productivity and sustainability in the long-term. As expected, conservation tillage resulted in increased SOC concentrations in the top 2-in of soil (Table 3). Tillage systems were imposed on this site since 1988, but all plots were subjected to the same cropping systems until 1998, when this study was begun. Cropping systems imposed for only 4 yr (1998-2001) also affected SOC to the 4-in depth (Table 3). Surprisingly, the corn-cotton rotation resulted in the lowest SOC concentrations among the cropping systems. This despite the fact that the amount of C returned to the soil averaged 1.65 tons C acre^{-1} yr^{-1} with the corn-cotton system, compared to 1.36 tons C acre^{-1} yr^{-1} with the 40-in row continuous cotton system. The intensive system averaged 2.3 tons C acre^{-1} yr^{-1} and ultra-narrow row cotton averaged 1.15 tons C acre^{-1} yr^{-1}. All systems used in this experiment incorporated the use of a winter cover crop; a small grain (black oat/rye mix) before cotton and a winter legume (crimson clover/white lupin mix) before corn. The winter legume biomass and C were

Table 3. Soil organic C (SOC) concentrations by depth as affected by cropping-tillage systems imposed on a sandy coastal plain soil with a hardpan in east-central Alabama. Within cropping systems, regular denotes the common 40-in row spacing, whereas UNR denotes an ultra narrow 8-in row spacing.

	Cropping system				
	Intensive	Corn-Cotton	Continuous cotton		
Depth	Regular	Regular	Regular	UNR	LSD$_{0.10}$
-- inches--	------------------------------	%	---------------------------------		
0 - 0.4	1.14	0.95	1.21	1.02	0.187
0.4 - 2	0.84	0.73	0.87	0.86	0.112
2 - 4	0.65	0.57	0.62	0.65	0.035
4 - 8	0.42	0.42	0.49	0.38	0.084 ns
8 - 12	0.28	0.29	0.35	0.28	0.084 ns

	Tillage system		
Depth	Chisel/disk	No-tillage	LSD$_{0.10}$
-- inches--	------------- %	-------------------	
0 - 0.4	0.690	1.440	0.094
0.4 - 2	0.700	0.920	0.067
2 - 4	0.640	0.590	0.053 ns
4 - 8	0.450	0.400	0.047
8 - 12	0.290	0.300	0.057 ns

greatly reduced compared to the black oat/rye that preceded cotton. We speculate that the reduced biomass from the winter legume used with corn (compared to small grain cover or cash crop) diminished the benefit of increased biomass production from corn, and more importantly, provided a more favorable C:N ratio to mineralize C in residues. Further laboratory C and N analyses underway may confirm this theory. Potter *et al.* (1997) and Torbert *et al.* (1998) reported that grain sorghum [*Sorghum bicolor* (L.) Moench.] and corn resulted in greater biomass inputs than wheat (*Triticum aestivum* L.) in tillage/rotation studies conducted in Texas but wheat resulted in greater SOC storage. The small grain covers in this study used before cotton likely would have a similar effect. We wish to emphasize that conventionally tilled cotton without a cover crop would have returned only 0.36 tons C acre^{-1} yr^{-1} to the soil (data not shown). The data suggest that the inclusion of wheat in the intensive rotation mitigated the negative effect of the winter legume-corn phase used in this rotation on SOC, as opposed to the alternating winter legume/corn - small grain/cotton rotation.

CONCLUSIONS

Cropping system had a more consistent effect on cotton yield than tillage system. The UNR systems with conservation tillage had the highest yields and net returns, $105 acre^{-1} yr^{-1} for continuous UNR cotton and $97 acre^{-1} yr^{-1} for UNR double-cropped with wheat in rotation with corn in the intensive system. The conventional tillage continuous cotton 40-in system had the lowest returns ($36 acre^{-1} yr^{-1}). Conservation tillage increased SOC concentration in the top 2-in of soil 46% compared to conventional tillage. Cropping system affected SOC levels to the 4-in depth and the corn-cotton rotation resulted in the lowest SOC levels of all systems. Results suggest that small grain cover crops and wheat for grain in the intensive system were the dominate factor in SOC changes. For these drought-sensitive soils, UNR cotton production systems with conservation tillage and small grain cover or cash crops have the potential to rapidly increase soil organic matter; improving soil productivity and enhancing economic sustainability of cotton production in the southeastern USA.

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EFFECTS OF CONVENTIONAL TILLAGE AND NO-TILLAGE ON COTTON GAS EXCHANGE IN STANDARD AND ULTRA-NARROW ROW SYSTEMS

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ABSTRACT

The availability of soil water to crops is a major limitation to crop production. Use of conservation tillage systems enhances soil residue cover, water infiltration and reduces evaporative soil water loss. Our objective was to measure cotton (*Gossypium hirsutum* L.) leaf level photosynthesis, stomatal conductance, and transpiration during reproductive growth under different row spacing and tillage conditions on a Norfolk loamy sand (Typic Kandiudults; FAO classification Luxic Ferralsols) in east-central AL. Gas exchange measurements occurred in the summer of 1999, 2000, and 2001. The study used a split-plot design replicated four times with row spacing (standard 40 inch row and ultra-narrow row) as main plots and tillage systems (conventional and no-tillage) as subplots. In 1999, standard row cotton under conventional tillage maintained higher photosynthetic rates during early reproductive growth when soil water was not limiting; the opposite pattern occurred latter during drought cycles. During drought periods, photosynthetic rates were higher in no-tillage systems especially under standard row conditions. In 2000 and 2001, the benefits of no-tillage were sporadic due to frequent rainfall events occurring throughout reproductive growth. In 2000, ultra-narrow row cotton consistently had lower photosynthesis rates compared to standard row cotton; lesser degrees of this occurred in 1999 and 2001. In all years, stomatal conductance and transpiration measurements generally mirrored those of photosynthesis. These results suggest that during periods of infrequent rainfall, high rates of photosynthesis can be maintained in no-tillage systems that conserved soil water needed during critical reproductive stages such as boll filling.

KEYWORDS

Residue management, soil water loss, photosynthesis, transpiration, stomatal conductance

INTRODUCTION

Plant growth is often reduced under soil water deficits owing to decreases in photosynthesis, stomatal aperture, and water potential (Boyer, 1982). In particular, cotton grown on loamy sand soils is highly susceptible to periods of soil water deficits due to low soil water holding capacity. Furthermore, periods of soil water deficits often occur during critical reproductive stages when demand for water is high. Adoption of conservation tillage systems that maintain high levels of residue cover can help mitigate such problems by enhancing soil C storage and soil water holding capacity, reducing evaporative soil water loss, and improving soil water infiltration (thereby reducing water and nutrient runoff). Recent work at the National Soil Dynamics Laboratory has shown that planting cotton with a grain drill in ultra-narrow rows (UNRC) to be a very promising cotton production system (Reeves *et al*., 2000); however, little information exists on the physiological response of cotton in this production system. The objective of this study was to quantify the impact of row spacing (standard *vs*. ultra-narrow row) and tillage systems (conventional *vs*. conservation tillage) on gas exchange of cotton during reproductive growth.

MATERIALS AND METHODS

This study is a component of a larger farming systems experiment (Reeves *et al*., 2000), which was established on a site that had been in conventional and conservation tillage for over 10 years (Reeves *et al*., 1992; Torbert *et al*., 1996). The cotton systems evaluated (summer of 1999, 2000, and 2001) were standard row (40 inch) and ultra-narrow row (8 inch) under conventional and no-tillage using a black oat (*Avena strigosa* Schreb.) - rye (*Secale cereale* L.) cover crop mix on a Norfolk loamy sand at the E.V. Smith

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Research Center of the Alabama Agricultural Experiment Station in east central Alabama, U.S.A. (N 32˚ 25.467', W 85˚ 53.403'). The cover crop was killed 2-3 weeks prior to planting using a mechanical roller and glyphosate; weeds were also controlled with glyphosate. Cotton seeds (PayMaster 1220) were sown in early May of each year. The study used a split-plot design replicated four times with row spacing as main plots and tillage systems as subplots. Extension recommendations were used in managing both the soil and crop. Fertilizer application rates were based on standard soil test.

During reproductive growth, leaf level measurements (i.e., photosynthesis, stomatal conductance, and transpiration) were made twice a week using a LI-6400 Portable Photosynthesis System (LI-COR, Inc., Lincoln, NE). Measurements were taken at midday on six different randomly chosen leaves (fully expanded, sun exposed leaves at the canopy top) per plot and were initiated near first flower (mid July, ~DOY 197) and terminated towards the end of August (~DOY 232), approximately ten days before defoliant application. Also during this period, soil water status was monitored at two depths (20 and 40 cm) using time domain reflectometry (data not shown). The study site had a total of 1.96, 0.05, and 1.74 inches of rainfall during the two weeks prior to study initiation in each respective year. During the 1999 study period, one irrigation and six rainfall events occurred (total of 2.5 inches). During the 2000 study period, one irrigation and ten rainfall events occurred (total of 4.07 inches). During the 2001 study period, fourteen rainfall events occurred (total of 4.77 inches).

Statistical analyses of data were performed using the Mixed procedure of the Statistical Analysis System (Littell *et al*., 1996). A significance level of $P < 0.10$ was established *a priori*.

RESULTS AND DISCUSSION

SUMMER OF 1999

At the beginning of the study (DOY 197, 201, 222) the main effects of row spacing and tillage were often significant. Gas exchange measurements were generally high since soil moisture conditions were optimum due to rainfall events two weeks prior to (total of 1.96 inches) and during this period (Fig. 1A). Photosynthesis, stomatal conductance, and transpiration were higher for cotton grown in standard rows and were lower under no-tillage conditions (Figs. 1B - D). The lower values noted in the ultra-narrow systems was not surprising since higher plant density (due to closer row spacing) promotes more plant to plant competition for belowground resources (i.e., water and nutrients) which results in a smaller or shorter crop when compared to standard row cotton. These results also suggest no advantage of no-tillage for standard row cotton under conditions of adequate soil moisture. However, it is important to note that although standard row cotton under conventional tillage initially exhibited higher rates of photosynthesis, this competitive advantage rapidly diminished during a water stress period due to larger plants being more susceptible to lack of available soil water.

Following DOY 203, soil water depletion was rapid due to extensive boll development and lack of rainfall (Fig. 1A).

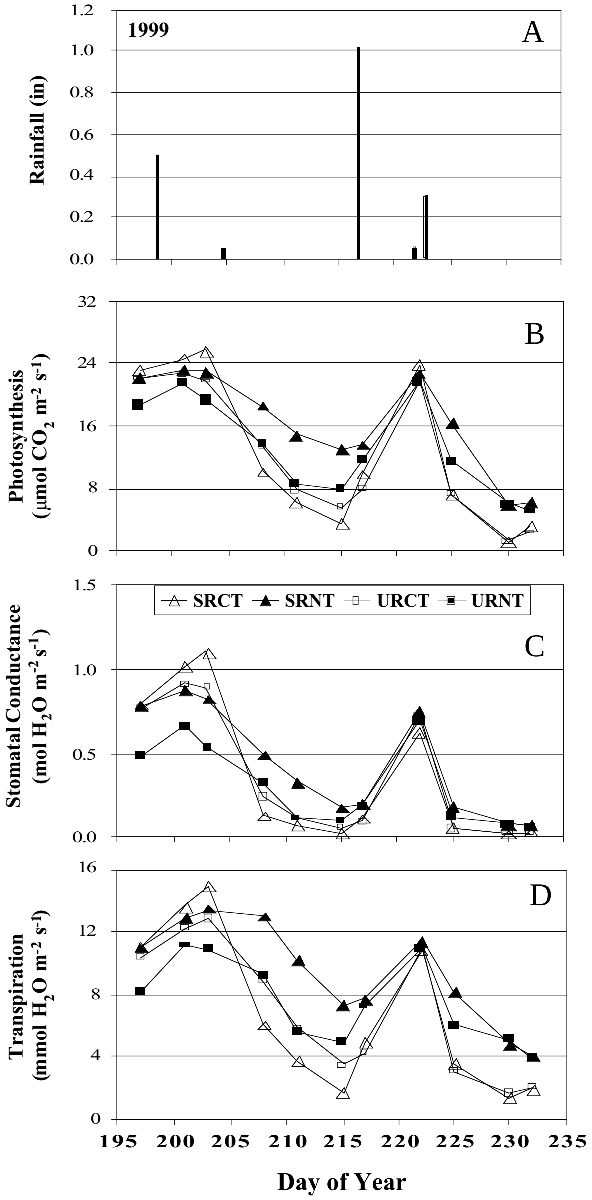

Fig. 1. Rainfall (A) and leaf level photosynthesis (B), stomatal conductance (C), and transpiration (D) for cotton during repro-ductive growth in 1999 as affected by row spacing (SR = standard row; UR = ultra-narrow row) and tillage (CT = conventional tillage; NT = no-tillage).

During this time (DOY 208, 211, 215), the main effects of tillage and row spacing by tillage interactions were significant for photosynthesis, stomatal conductance, and transpiration. In general, these measures were highest in the standard row system under no-tillage, lowest in the standard row system under conventional tillage, and somewhat intermediate for the ultra-narrow system regardless of tillage system. Dry, hot conditions during this period contributed to the shedding of late-developing bolls, especially under conventional tillage in the standard row system.

Measurements taken on DOY 217 and 222 followed irrigation/rainfall events. On DOY 217, the main effects of tillage were significant for all variables. Under no-tillage conditions, photosynthesis, stomatal conductance, and transpiration were increased; no differences were noted on DOY 222. Measurements taken on DOY 225, 230, and 232 show similar patterns as observed on DOY 217. At all dates, photosynthesis, stomatal conductance, and transpiration were increased due to optimum soil moisture conditions found under no-tillage conditions.

SUMMER OF 2000

Gas exchange measurements were initially very low (Figs. 2B - D) due to inadequate soil moisture conditions caused by lack of rainfall (Fig. 2A). The total amount of rainfall in the two weeks preceding the start of gas exchange measurements was 0.05 inches. On DOY 200 and 202, a significant interaction indicated that photosynthesis, stomatal conductance, and transpiration were highest in no-tillage cotton grown in standard rows and were lower in the ultra-narrow system especially under no-tillage conditions.

On DOY 206, gas exchange measurements increased to a high level due to irrigation and rainfall events (total of 1.8 inches) and remained high for an extended period (i.e., DOY 206 to 224) due to eight rainfall events (total of 2.12 inches; Fig. 2A). During this period, the main effects of row spacing were often significant for photosynthesis (DOY 206, 208, 213, 221, and 224), stomatal conductance (DOY 206, 208, 213, and 221), and transpiration (DOY 206, 208, and 221). In general, these measures were typically higher for the standard row system compared to the ultra-row system.

After DOY 224, gas exchange measurements dropped rapidly due to minimal rainfall (Fig. 2A) and remained low until study termination (DOY 235). As seen previously, the main effects of row spacing were significant; the standard row system exhibited higher values of photosynthesis (DOY 224, 228, and 231), stomatal conductance (DOY 228 and 231), and transpiration (DOY 228 and 231) compared to the ultra-row system. Under no-tillage conditions, photosynthesis and stomatal conductance were increased on DOY 224; similar trends were noted on DOY 228. No treatment effects were observed on the final study day.

SUMMER OF 2001

Initial gas exchange measurements in 2001 were generally high (Fig. 3B - D) since soil moisture conditions were optimum due to rainfall/irrigation events (total of 1.74 inches) two weeks prior to this period. In comparison, the amount of rainfall two weeks before measurement initiation was 0.05 and 1.96 inches for years 1999 and 2000, respectively. Due to adequate soil moisture conditions,

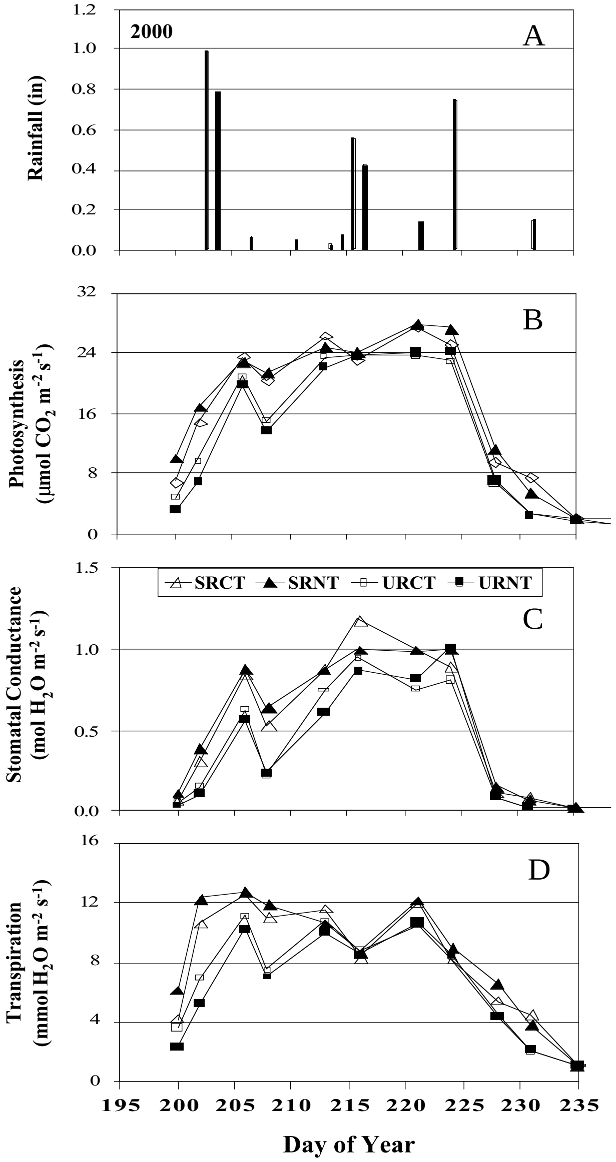

Fig. 2. Rainfall (A) and leaf level photosynthesis (B), stomatal conductance (C), and transpiration (D) for cotton during repro-ductive growth in 2000 as affected by row spacing (SR = standard row; UR = ultra-narrow row) and tillage (CT = conventional tillage; NT = no-tillage).

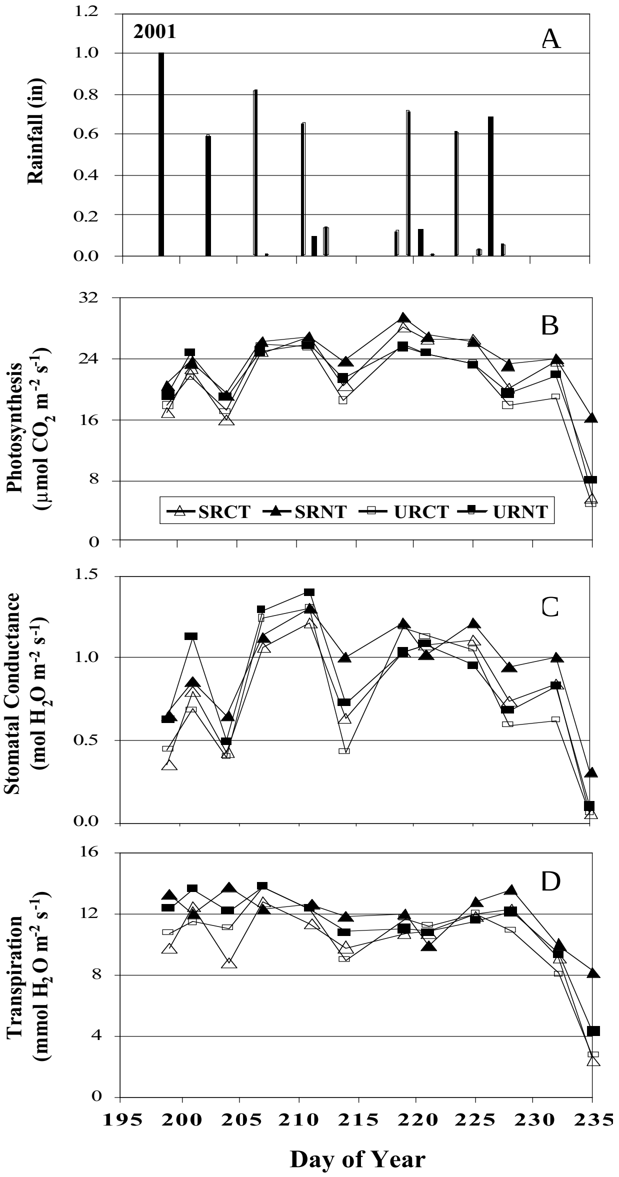

Fig. 3. Rainfall (A) and leaf level photosynthesis (B), stomatal conductance (C), and transpiration (D) for cotton during repro-ductive growth in 2001 as affected by row spacing (SR = standard row; UR = ultra-narrow row) and tillage (CT = conventional tillage; NT = no-tillage).

initial gas exchange measurement for years 1999 (Figs. 1B - D) and 2001 (Figs. 3B - D) were similar to each other, but much higher than year 2000 (Figs. 2B - D). However, it is important to note that most of the measurements in year 2000 and 2001 were consistently high, and similar to each other, due to the frequent rainfall events that occurred over most of the sampling period in both years (i.e., between DOY 204 to 225; Figs. 2A and 3A); this was in stark contrast to the sporadic rainfall patterns observed in 1999 (Fig. 1A).

During the first week of sampling in 2000 (DOY 199 to 204), photosynthesis tended to be slightly higher under no-tillage conditions. Stomatal conductance and transpiration exhibited similar patterns, but were more variable. For example, on DOY 201 a significant interaction was noted indicating that these measurements were higher for cotton grown in ultra-narrow rows under no-tillage conditions.

On DOY 207 and 211, treatment effects were negligible, except for stomatal conductance on DOY 207, which was higher in the ultra-narrow row treatments. On DOY 214, photosynthesis, stomatal conductance, and transpiration tended to be higher under no-tillage conditions. On this same day, the main effects of row spacing were significant for stomatal conductance, which was lower in the ultra-narrow row systems.

During the period covering DOY 219 to 232, photosynthesis exhibited the most consistent treatment effects relative to the other measures, which were more variable. During this period, the main effect of row spacing was often significant; photosynthesis was lower in the ultra-row system compared to standard row cotton. On DOY 228, the main effect of tillage was significant for photosynthesis and stomatal conductance; these measures were higher under no-tillage. On the final sample date (DOY 235), gas exchange measures dropped due to declining soil moisture. A significant row spacing by tillage interaction was noted for all variables. Photosynthesis, stomatal conductance, and transpiration were highest in the standard row system under no-tillage, while the other treatment combinations were similar to each other.

CONCLUSIONS

Our findings suggest that management schemes favoring surface residue accumulation could help conserve soil water. The benefits of no-tillage are most probable in years experiencing sporadic precipitation patterns throughout reproductive growth as seen in the first year of study (1999). Reflective of optimum soil water status, no-tillage cotton exhibits high stomatal conductance that contributes to a higher transpirational loss of water while allowing for good CO_2 uptake required to maintain high rates of photosynthesis. In years exhibiting frequent rainfall during reproductive growth (e.g., years 2000 and 2001), the benefits of no-tillage can occur, but are less frequent. Compared to standard row cotton, ultra-narrow cotton tends to exhibit lower rates of photosynthesis and the benefits of no-tillage are less pronounced in this system. Faster canopy closure and greater plant-to-plant competition for soil resources are contributing factors that may explain these differential responses. Adoption of no-tillage practices can help minimize detrimental impacts of water stress on cotton grown in coarse textured soils.

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EFFECT OF CROP ROTATION/TILLAGE SYSTEMS ON COTTON YIELD IN THE TENNESSEE VALLEY AREA OF ALABAMA, 1980-2001

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ABSTRACT

A replicated cotton (*Gossypium hirsutum* L.) rotation experiment has been conducted for 22 years on a Decatur silt loam (fine, kaolinitic, thermic, Rhodic Paleudults) in the Tennessee Valley of northern Alabama. The highly productive soil with little disease and nematode problems resulted in cotton yield increases from rotations of generally less than 10% during the first 15 years of the study. A switch to no-tillage in all rotations except continuous cotton in 1995 greatly improved cotton yield response to rotations. From 1995 to 2001 cotton yield increases to rotation have averaged between 5% and 18%. In this study, yield increases due to rotations seem linked to increases in soil organic matter and consequent improvements in soil quality. From 1979 to 1994 using conventional tillage, the only rotation that produced a greater than 10% yield increase was cotton rotated with wheat (*Triticum aestivum* L.) and double-cropped soybean [*Glycine max* (L.) Merr.]. This rotation was also the only rotation that significantly increased organic matter levels under conventional tillage. From 1995 to 2001 all rotations were no-tilled and the greater yield increases to rotations can also be associated with higher soil organic matter levels. Wheat as a grain rotation or cover crop often produced the greatest yield increases to the following cotton crop. Under conventional tillage the wheat residue provided increased organic matter residue. With no-tillage the wheat cover crop reduced surface soil compaction. No-tillage and rotations that increased residue production were linked to increased cotton yields on this soil.

KEYWORDS

Double-cropping, soil organic matter, soil compaction, wheat, soybean

INTRODUCTION

In 1979, a cotton rotation experiment was established at the Tennessee Valley Substation in northern Alabama. At that time continuous cotton production was one practice being investigated for declining cotton yields across the US Cotton Belt. This long-term test has provided valuable information about the benefits of crop rotation to cotton producers in Alabama and across the United States. Many changes have been made to the test during the last 22 years as farming practices have changed. The research results have provided needed information as farmers switched to conservation tillage and searched for alternative crops.

MATERIALS AND METHODS

An area with a history of continuous cotton production was selected as the test site on the Tennessee Valley Substation in northern Alabama. Plot size was 26.7 feet (8, 40 inch rows x 50 feet). Yields were determined by mechanically harvesting the middle four rows. Treatments were replicated four times in a randomized complete block design. Initial treatments established in 1979 included:

1) continuous cotton,
2) continuous soybean,
3) two year rotation, cotton-soybean,
4) two year rotation, cotton-corn,
5) two year rotation, cotton-wheat/soybean,
6) three years alfalfa (*Medicago sativa* L.) followed by cotton, and
7) skip row (2 x 1) cotton.

In 1988 the alfalfa and skip row treatments were eliminated. A cotton-wheat rotation was established as well as two continuous no-tillage areas. The two no-tillage treatments consisted of planting into old cotton stubble or into a wheat cover crop.

In 1994 all plots except continuous cotton were changed to no-tillage. Row spacing was changed from 40 inches to 30 inches. Three treatments added in 1994 were:

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1) cotton ridge-tilled into old cotton stubble,
2) cotton ridge-tilled with a wheat cover crop, and
3) fall tillage (disk-chisel) with a wheat cover crop.

With all the changes four treatments have remained continuous since 1980. They include:

1) continuous cotton,
2) cotton/soybean,
3) cotton/corn, and
4) cotton/wheat-soybean.

The two continuous no-tillage plots have also been maintained since 1988.

RESULTS AND DISCUSSION

Results from the first eight years of the experiment indicated only small cotton yield increases due to rotations (Burmester *et al.*, 1988). Yield increases due to rotations were generally about 2% to 7%. The smaller than expected yield increases with rotations may have been due to limited disease and nematode pressure at the test location. Soil organic matter samples taken from the rotation plots in 1987 also revealed very little organic matter increase due to rotations (Table 1). All plots used conventional fall chiseling with spring leveling that limited organic matter building.

From 1988 through 1994 cotton yield responses to rotations were still small except for one treatment (Table 2).

Table 1. Soil organic matter (%) from 0-2.5 inch depth in long-term rotation/tillage experiment at the Tennessee Valley Substation, Belle Mina, Alabama, 1980-2001.

Rotation/Tillage System	1987	1994	2001
Continuous Cotton[†]	1.34	1.48	1.41
Cotton/Soybean[‡]	1.38	1.58	1.65
Cotton/Corn[‡]	1.35	1.50	1.70
Cotton/Wheat-Soybean[‡]	1.46	1.85	1.98
Cotton – No till stubble[§]	¶	1.75	2.23
Cotton – No till wheat[§]	¶	1.68	2.26
LSD $_{(0.05)}$	0.27	0.19	0.18

[†] continuous conventional tillage cotton since 1979.
[‡] rotations established in 1979, converted from conventional to no-tillage in 1994.
[§] no-tillage into wheat cover crop or previous cotton stubble established in 1988.
[¶] treatment not established until 1988.

A rotation with wheat and double-crop soybean increased cotton yields 13% compared to continuous cotton during this period. All other rotation increased yield by 9% or less. The yield increase with the wheat and double-soybean can be traced to an increase in soil organic matter levels (Table

Table 2. Seed cotton yield response to long-term crop rotation/tillage systems at the Tennessee Valley Substation, Belle Mina, Alabama, 1988-1994.

Rotation/Tillage System	1988	1989	1990	1991	1992	1993	1994	Avg.	(%)[#]
	------------	------------	------------	------------	lbs acre^{-1}	------------	------------	------------	
Continuous Cotton[†]	1400	2780	1700	1090	2990	1900	2660	2070	100
Cotton/Soybean[‡]	1270	2620	1760	1020	3340	2030	3190	2180	105
Cotton/Corn[‡]	1280	3040	1910	1110	3260	2200	2800	2230	108
Cotton/Wheat-Soybean[‡]	1310	2860	1940	1240	3290	2160	3490	2330	113
Cotton- No till stubble[§]	1140	2430	1510	920	3160	1760	3250	2020	98
Cotton- No till wheat[§]	1380	2490	1920	970	3150	1790	3410	2160	104
Cotton/Wheat[¶]	1500	2800	1940	1040	3270	2350	2930	2260	109
LSD $_{(0.05)}$	234	456	258	112	239	329	762	-	-

[†] continuous conventional tillage cotton since 1979.
[‡] rotations established in 1979, converted from conventional to no-tillage in 1994.
[§] no-tillage into wheat cover crop or previous cotton stubble established in 1988.
[¶] established in 1988.
[#] mean yield increase compared to continuous conventional tillage cotton.

Table 3. Seed cotton yield response to long-term crop rotation/tillage systems at the Tennessee Valley Substation, Belle Mina, Alabama, 1995 – 2001.

Rotation/Tillage System	1995	1996	1997	1998	1999	2000	2001	Avg.	(%) [#]
	----------	----------	----------	----------	lbs $acre^{-1}$	----------	----------	----------	
Continuous Cotton[†]	1500	3170	1490	1830	1890	1770	2400	2007	100
Cotton/Soybean[‡]	1550	3030	2210	2120	2100	1730	2300	2149	107
Cotton/Corn[‡]	1680	3040	2270	2110	2020	1930	2450	2214	110
Cotton/Wheat-Soybean[‡]	1560	3420	2230	2240	2200	2000	2320	2281	114
Cotton-No till stubble[§]	1580	3430	2120	2260	1820	1800	2550	2223	111
Cotton-No till wheat[§]	1580	3550	2310	2400	1890	1795	2810	2334	116
Ridge-till wheat[¶]	1590	3070	2100	2020	1800	1920	2640	2163	108
Ridge-till stubble[¶]	1570	3130	1990	2050	1780	1800	2410	2104	105
Fall chisel-wheat[¶]	1650	3480	1990	2340	2280	1950	2820	2359	118
LSD $_{(0.05)}$	178	303	287	263	260	305	265	-	-

[†] continuous conventional tillage cotton since 1979.

[‡] rotations established in 1979, converted from conventional to no-tillage in 1994.

[§] no-tillage into wheat cover crop or previous cotton stubble established in 1988.

[¶] established in 1994, cotton planted no-tillage in wheat cover crop or cotton stubble.

[#] mean yield increase compared to continuous conventional tillage cotton.

1). Soil samples taken in 1994 found continuous cotton with organic matter levels of 1.48% compared to 1.85% with the wheat/double-cropped soybean. Even with fall and spring tillage this rotation was building organic matter. Rotations with soybean and corn increased organic matter only slightly to 1.58% and 1.50%, respectively. The two no-tillage treatments also increased soil organic matter levels compared to conventional cotton (Table 1). Cotton yield, however, was actually slightly lower (98%) when cotton was no tilled into old stubble compared to conventional tillage. When cotton was no tilled into a wheat cover crop, average yields during this period were 4% greater than for conventional tillage continuous cotton. Yield decreases with no-tillage seemed greatest in the drought seasons of 1988, 1990, 1991 and 1993. Much of this difference may have resulted from surface soil compaction on these no-tillage sites as reported by Burmester *et al.*, 1995. Burmester reported that these soil types often develop surface soil compaction with no-tillage, limiting cotton root growth and water uptake. Growing a wheat cover crop reduced this surface compaction which corresponds with yield trends seen in this rotation test. The wheat cover crops were terminated three to four weeks prior to planting in early-April and resulting surface residue quickly dissipated by mid-summer.

Cotton yield response to rotations increased greatly during the period 1995 to 2001 (Table 3). Yield increases due to rotations averaged between 7% and 18% during this period. This increased cotton yield response to rotations compared to the earlier periods may be due in part to the switch to no-tillage in 1995. Research has shown that tillage can negate the benefits of crop rotation (Bruce *et al.*, 1990; Reeves, 1997). Soil samples taken in 2001 revealed a more rapid building of soil organic matter with rotations compared to conventional continuous cotton (Table 1). This was particularly evident in the two plots that have been in no-tillage since 1988 and the wheat and double-cropped soybean rotation. The largest increases in yields seem to be with rotations that include wheat as a cover crop (Table 3) or for grain, and coordinating research showed dramatic improvements in soil quality with these systems (Motta, 2002). The wheat/soybean double cropping, no tillage with wheat cover, ridge-till with wheat cover and fall chiseling with wheat cover increase cotton yields 14%, 16%, 8% and 18%, respectively, compared to conventional tillage continuous cotton. The yield increases resulting from the combination of fall tillage with a wheat cover crop are corroborated by similar findings using non-inversion deep tillage and a rye (*Secale cereale* L.) cover crop for this soil (Raper *et al.*, 2000; Schwab *et al.*, 2002). Cotton no-tilled into old stubble or ridge-tilled into old cotton stubble averaged 3% to 5% lower yields during this period compared to corresponding treatments using a wheat cover crop. This could be due to wheat reducing soil compaction as mentioned earlier or other unknown factors. Nematodes are still not a problem in this test area as indicated by sampling in 2001. During 1995 to 2001 soybean and corn rotations increased cotton yields 7% and 10%, respectively, compared to continuous cotton.

CONCLUSIONS

This experimental area was a highly productive and well-drained soil with little disease problems and no detectable levels of nematodes to affect cotton yields. Because of this, and/or due to conventional tillage negating rotation effects, cotton yield response to various rotations was generally lower than expected during the first 15 years of this study. Only the rotation of wheat and double-cropped soybean produced a cotton yield increase greater than 10% during this period compared to continuous cotton. This treatment was also the only rotation that significantly increased soil organic matter when conventional tillage was used in all rotations.

Cotton yield response to rotations were generally much higher during 1995 to 2001 when all rotations except continuous cotton were converted to no-tillage. Highest yielding rotations during this period contained wheat as a cover crop or grown for grain. Previous research on these soils found that small grains might reduce surface soil compaction under a no-tillage system. This may explain part of the increase in cotton yield when wheat was used in the rotations. Increases in soil organic matter levels and consequent improved soil quality (Motta, 2002) with the rotations under no-tillage was also a factor in the higher yield increases seen after 1994.

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COMPARISON OF TILLAGE TYPE AND FREQUENCY FOR COTTON ON PIEDMONT SOIL

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ABSTRACT

In-row chisel (IC) and paratill (PT) tillages disrupt root restricting consolidated soil zones and improve rooting capacity. Compaction-disrupting tillages increase costs of farm operations because of the need for more powerful tractors and greater fuel use. We evaluated the need for continuous or less frequent disrupting tillages for cotton (*Gossypium hirsutum* L.) production in a typic Kanhapludult soil. Lint yields of IC treatments were 15 to 20% greater than conventional disk tillage (DT) each year. In 1994, yields ranged from 480 to 750 lbs acre^{-1} (0.53 to 0.84 Mg ha^{-1}) with continuous IC having better yields than continuous secondary tillage (ST) or PT. In 1995, cotton yields ranged from 830 to 1150 lbs acre^{-1} (0.92 to 1.29 Mg ha^{-1}) with the top yield associated with current year IC application. In 1996, the fifth year of the study, no significant differences in yields were observed among tillages; however, two of the top five yields were IC treatments. For the three cotton years, continuous IC plots out yielded DT and had numerically greater yields than continuous PT and (ST). Yields for PT and ST were no better than those of DT. Average annual net returns from continuous IC were 179, 154, and 113 \$ acre^{-1} greater than those from continuous DT, PT, and ST, respectively. In-row chisel appears to be a more economically viable production practice for heavy Piedmont soils with consolidated zones because of its lower energy requirement and greater cotton yield response compared to PT.

KEYWORDS

Conservation tillage, paratill, in-row chisel, economic return, Cecil soil

INTRODUCTION

Nearly two thirds of the Southern Piedmont region is covered by Cecil series and related soils (clayey, kaolinitic, thermic typic Kanhapludults) (Hendrickson *et al.*, 1963). These soils have a zone of high strength at 6 to 10 in (0.15 to 0.25 m) below the surface usually near the top of the Bt horizon (NeSmith *et al.*, 1987; Radcliffe *et al.*, 1988; Tollner *et al.*, 1984). Hardpan development in these soils has been associated with fall disk tillage (NeSmith *et al.*, 1987) wheel traffic (Radcliffe *et al.*, 1989) and disturbance of the low organic matter-weakly structured horizons by deep tillage (Radcliffe *et al.*, 1989). Annual use of an in-row chisel can disrupt the hardpan in these soils (Radcliffe, *et al.*, 1989) and improve infiltration (Mills *et al.*, 1988).

Several studies have compared deep tillage implements, and deep tillage with conventional and no-tillage (Busscher *et al.*, 1988; Reeder *et al.*, 1993; Kanwar *et al.*, 1997; Raper *et al.*, 2000a & b). Few studies have compared tillage type and frequency especially for soils of the Southern Piedmont and cotton production systems. Raper *et al.* (2000a) showed that shallow in-row chisel in the fall was as effective or more effective than deeper tillage to disrupt an impeding clay layer and increase cotton yield on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult) in Alabama. Subsoiling in the autumn was equally effective as spring subsoiling and was more beneficial to time management.

Limited data are available on response of cotton to annual or less frequently applied shallow or deep tillage (in-row chisel or paratill) in Southern Piedmont soils. We evaluated combining no-tillage with shallow or deep tillage to improve water penetration or with secondary tillage (to control weeds) and residual effects of these tillages on cotton yield. Economic evaluations were conducted to determine net return and profitability of the various tillage-management systems.

MATERIALS AND METHODS

Tillage and residual tillage effects were evaluated on a slightly eroded Cecil sandy loam soil (clayey, kaolinitic, thermic Typic Kanhapludult) near Watkinsville, GA begin-

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Table 1. Mean depth of the soil profile horizons, bulk density and soil texture (Radcliffe *et al.*, 1989)

Horizon	Depth		Bulk Density		Sand	Silt	Clay
	in	m	lbs in^{-3}	g cm^{-3}	---------------	%	---------------
Ap1	1 to 5	0.03 to 0.13	0.046	1.28	73	20	7
Ap2	5 to 10	0.13 to 0.24	0.055	1.53	67	23	10
Bt1	10 to 14	0.24 to 0.36	0.055	1.53	43	20	37
Bt2	14 +	0.36 +	0.051	1.41	30	20	50

ning in the fall of 1991. The study was located on a site between terraces in a summit position on uniform slopes of 3%. Soil characteristics are given in Table 1.

The experimental design was a randomized complete block with three replications and 16 treatments (tillage-by-year of tillage combinations). Four tillage systems were evaluated: (IC) coulter planting with in-row chisel to a depth of 9 in (230 mm) with 1.5 in (38 mm)-wide points; (PT) paratill with a Tye Paratill plow (Bigham Brothers, Lubbock, TX) equipped with six legs (three right and three left) spaced 24 in (0.61 m) apart and angled at 45° to the side and outfitted with a 0.25 in (6.4 mm) serrated coulter ahead of each leg; (ST) coulter planting with trash wipers followed by secondary tillage using 24 in (0.6 m) sweeps to control weeds during the summer crop season, and (DT) conventional tillage using a 12 ft (3.05 m)-wide offset disk harrow to a depth of 4 to 5 in (0.1 to 0.13 m) followed by coulter planting. Years of tillage application and treatment designations are given in Table 2.

Each plot consisted of eight rows on 30 in (0.76 m) spacing (20 ft wide by 75 ft long, 6.10 m by 22.86 m) with wheel traffic confined to areas between alternating rows. Rows were re-established so that tillage, planting, and traffic occurred in the same location each year. The study began with disking the entire area to a depth of 4 to 5 in (0.1 to 0.13 m) with a 160 hp (120 kW) Hesston 180-90 tractor and offset disk harrow. The same tractor was used each fall to paratill PT plots approximately 12 to 14 in (30 to 36 cm) deep following summer crop harvest (except in the fall of 1992 when soils were too wet and PT was delayed until May 1993). The tillage depth was approximately the top of the Bt horizon. The 160 hp tractor was used in the spring to disk harrow DT plots and plant designated IC plots. A 75 hp (56 kW) John Deere 3020 tractor was used in the spring to plant remaining plots with a four-row no-till planter and in the fall on all plots to plant cover crops with a conservation tillage grain drill. Field operation dates are presented in Table 3. Management followed standard recommended practices from the University of Georgia Extension Service.

Hybrid pearl millet (*Pennisetum glaucum*) (4 lbs acre^{-1}, 4.5 kg ha^{-1}) was planted following crimson clover *(Trifolium incarnatum*) (15 lbs acre^{-1}, 17 kg ha^{-1}) in 1992 and 1993. Poor yields and bird damage caused the cropping system to be switched to cotton (15 lbs acre^{-1}, 17 kg ha^{-1}) following winter rye (*Secale cereale*) (70 lbs acre^{-1}, 78 kg ha^{-1}) for 1994, 1995 and 1996. Cover crops were planted on all plots in the fall and were killed with a burn-down herbicide (paraquat or glyphosate) following emergence on DT1 plots and in the spring 2 to 3 weeks prior to planting summer crops on remaining plots (Table 3). In 1994, 1995,

Table 2. Primary tillage treatments and years of application.

	Year of tillage application				
Treatments[†]	1992	1993	1994	1995	1996
IC1, PT1, ST1, DT1	X	X	X	X	X
IC2, PT2, ST2	X		X		
IC3, PT3, ST3	X			X	
IC4, PT4, ST4	X				X
IC5, PT5, ST5	X				

[†] IC in-row chisel, PT paratill, ST secondary tillage, DT disk tillage

Table 3. Field operation dates (dd/mm/yy).

Field	Summer Crop Year				
Operation	1992	1993	1994	1995	1996
Plant Cover Crop	25/09/91	23/11/92	07/10/93	09/11/94	20/10/95
Fertilize	20/09/91	02/12/92	07/10/93	09/11/94	18/10/95
Paratill	28/09/91	17/05/93†	07/10/93	09/11/94	18/10/95
Kill Cover Crop	22/05/92	06/05/92	01/04/94	04/04/95	13/04/96
Plant Summer Crop	01/06/92	21/05/93	09/05/94	04/05/95	10/05/96
Harvest	17/11/92	27/09/93	07/11/94	12/10/95	22/10/96

† Due to a wet fall the paratill operation was delayed until the spring.

and 1996 cotton was harvested with a two-row cotton picker (John Deere, Model 299, John Deere and Company, Moline, IN) and yield was determined on 60 ft (18.3 m) of the middle two plot rows.

Crop enterprise budgets were developed that focused on the three years of cotton production using the Farm Suite whole farm planning system (Lamb *et al.*, 1992). Application rates for variable inputs were those used in the study. Operating costs, overhead, and returns on investments were computed for 1994, 1995, and 1996 using data from various published sources (Givan, 1994, 1995, and 1996; Ga. Ag. Stat. Service, 2001) and records collected for actual costs. Gross returns were calculated annually as the product of treatment yields and Georgia market-year average prices. Variable costs were actual prices paid by farmers each year and include costs of herbicides, seed, labor, fuel, repair and maintenance of equipment, and interest on operating capital. Fixed costs include costs of tractors, self-propelled equipment, and implements. Total specified costs included both variable and fixed costs. Appropriate tillage expenses were charged annually for DT1, IC1, PT1, and ST1. For other tillage treatments, costs were prorated on an annual basis to allocate a cost incurred during one year over all years that received benefit from tillage. No charges were included for land, management, or general farm overhead. Net returns were calculated as the difference between gross income and total specified costs. Average net returns were calculated from the annual net returns over the study period.

Statistical analysis of year and treatment effects on cotton yields and net returns were evaluated using the MIXED model procedure in the Statistical Analysis System (SAS Inst, 1990; Littell *et al.*, 1996). Year, replication, year-by-replication, and year-by-treatment were considered random effects. Covariance structures were modeled with the repeated option. Degrees of freedom were determined using Satterthwaite's procedure. Specific single degree of freedom contrasts were used to compare treatments across and within years. All means were estimated as Best Linear Unbiased Predictors (Littell *et al.*, 1996). Differences were considered significant at alpha = 0.10 unless otherwise stated. Treatment effects on plant populations for each year were determined using the GLM procedure of SAS (SAS Inst, 1990).

RESULTS

CLIMATE

The three growing seasons were different in terms of heat unit (growing degree days base 60 F, 15.6 C, GDD) accumulation, rainfall amount, and rainfall distribution (data not shown). In 1994, rainfall from planting to 01 September was 23.8 in (695 mm) and only five rainfall events exceeded 3 in (75 mm) per 24 hours. A period of water stress occurred from mid-August to mid-September. Above average fall rainfall combined with early cool temperatures delayed and impeded boll development in1994. Heat unit accumulation was insufficient (1596 by 01 September) to complete crop maturation (2100 to 2200 GDD needed for crop maturation). Significant numbers of unopened bolls were present at the time of harvest.

Temperatures were more favorable for boll development in 1995 and 1996; however, rainfall from planting to 01 September was limited in 1995 (16.7 in, 426 mm) and 1996 (12 in, 303 mm) with very poor distribution particularly in 1995. During 1995, there was a long dry period from mid-June to mid-August that made it necessary to irrigate to avoid crop loss. Water (approximately 1 in, 0.025

m) was applied using a traveling gun over a three-day period (one day per replication) during July 18 to 20 and again July 26 to 28. In 1996, the limited growing season rainfall was more evenly distributed and along with early spring rain that resulted in significant stored water, helped eliminate the need for irrigation. A period of water stress was experienced during late July that almost certainly depressed cotton yields.

PLANT STANDS

Stand establishment was influenced by tillage treatments all three years ($p < 0.02$). Cotton populations (plants acre^{-1}, plants m^{-2}) ranged from 17,800 to 64,300 (4.4 to 15.9) in 1994, 16,500 to 52,000 (4.1 to 12.9) in 1995, and 28,000 to 54,600 (7.0 to 13.5) in 1996. Populations below 28,300 to 36,400 (7 to 9) can result in decreasing yields with decreasing populations but above these values are considered adequate for cotton production with little change in yield as populations increase (Bednarz *et al.*, 2001). Populations tended to be greatest for IC treatments during the year of application. Although planting equipment was nearly identical, the chisel may have created better seedbed conditions compared to that of other treatments.

COTTON YIELDS

Significant year ($P = 0.012$), treatment ($P = 0.134$), and year-by-treatment ($P = 0.093$) effects were present in the yield analysis. The significant year-by-treatment interaction resulted from greater yields in 1995 than in 1994 and 1996, and a greater yield response to in-row chisel in 1994 and 1995 than for the other tillages (Table 4). Comparison of yields among reduced tillage treatments each year indicated that continuous IC had the greatest positive effect on cotton yield while continuous PT and ST did not respond as favorably (Tables 4 and 5). Averaged across years, yields of IC1 were 274, 239, and 197 lbs acre^{-1} (306, 268 and 221 kg ha^{-1}) greater than DT1, PT1, and ST1, respectively. Response to in-row chisel tended to be greatest during the year of application as indicated by the absence of a significant difference between IC1 and IC2 in 1994 or IC1 and IC 3 in

Table 4. Cotton lint yield, annualized net return, and tillage cost for tillage treatments.

Tillage [‡]	Lint cotton[†]				Annual	
	1994	1995	1996	Avg	Net return	Tillage cost
	----------------- lbs acre^{-1} -----------------				------------ \$ acre^{-1} ----------	
DT1	486	838	666	663	122	20.12
IC1	754	1150	909	937	302	20.62
IC2	715	996	808	840	249	14.88
IC3	636	1077	822	845	243	14.88
IC4	532	845	644	674	140	14.88
IC5	592	997	764	784	207	12.97
PT 1	538	865	694	699	147	20.51
PT 2	523	881	763	723	162	14.84
PT 3	547	964	719	743	178	14.84
PT 4	630	920	766	772	202	14.84
PT 5	628	978	805	803	220	12.95
ST1	586	909	727	741	188	18.38
ST2	593	881	721	732	178	13.57
ST3	570	845	653	689	155	13.57
ST4	615	928	802	782	211	13.57
ST5	483	847	677	669	132	12.10

[†] Yields are best linear unbiased predictor means.

[‡] Tillage treatments are listed in Table 2.

1995 but IC1 was better than IC4 in 1996 due to poor stand establishment in IC4. Yield of IC1 was greater than that of plots that had not received a second IC by 29% in 1994 (IC3, IC4, and IC5), 27% in 1995 (IC4 and IC5) and 17% in 1996 (IC5). Yield of IC1 was greater than that of plots in-row chiseled the previous year in 1995(IC2) but not greater than that of plots in-row chiseled the previous year in 1996 (IC3). The in-row chisel treatment appeared to provide an improved soil condition that enhanced cotton stand establishment, growth and yield predominantly in the year of application.

Yields of cotton were not differentially influenced by continuous or alternative year paratill treatments (Table 4). In each year, yields for PT1 were similar to plots paratilled for that season and to plots paratilled in previous seasons. Response to paratilling may have been reduced due to insufficient fracturing of the soil profile in the fall (moist soils) and subsequent re-consolidation of the soil profile between paratilling and cotton establishment. Three tractor operations (planting the rye cover crop, herbicide application to kill the cover crop, and cotton planting) occurred following paratilling, which probably enhanced re-consolidation of the disturbed subsoil (Reeder *et al.*, 1993). Although tractor traffic was confined to the same area in the plots each year some drift across plots during field operations was possible.

Similar to the yields with PT, few differences in yields were apparent among ST plots that received continuous ST and those that received less frequent ST (Table 4). The ST treatment caused some disturbance of the soil surface but minimal burial of crop residues. Keeping residues on the soil surface is important in these soils to reduce soil crusting, runoff, and decreased infiltration associated with depletion of organic matter in the top 1 inch (0.025 m) (Bruce *et al.*, 1995). One advantage of the ST treatment is that it could be used for weed control in a sustainable

Table 5. Average annual lint yield and net return comparisons between treatments.

Contrast[†]	Lint Cotton	P > |t|	Net return	P > |t|
	lbs acre^{-1}		\$ acre^{-1}	
DT1[‡] - IC1	-274	0.0023	-179	0.0010
DT1 - PT1	-35	0.6879	-25	0.6339
DT1 - ST1	-77	0.3814	-66	0.2127
IC1 - PT1	239	0.0078	154	0.0044
IC1 - ST1	197	0.0275	113	0.0339
PT1 - ST1	-42	0.6349	-41	0.4384
IC1 - IC2	97	0.2706	53	0.3165
IC1 - IC3	92	0.2981	58	0.2689
IC1 - IC4	263	0.0034	161	0.0030
IC1 - IC5	153	0.0854	95	0.0754
PT1 - PT2	-24	0.7866	-15	0.7827
PT1 - PT3	-44	0.6144	-31	0.5599
PT1 - PT4	-73	0.4061	-54	0.3054
PT1 - PT5	-105	0.2369	-72	0.1737
ST1 - ST2	9	0.9217	10	0.8437
ST1 - ST3	51	0.5624	33	0.5298
ST1 - ST4	-41	0.6395	-22	0.6705
ST1 - ST5	72	0.4174	56	0.2895

[†] Contrasts are between best linear unbiased predictor means for each treatment.

[‡] Tillage treatments are listed in Table 2.

agriculture or organic system where reductions in yield would be offset by greater premiums paid for organic cotton (usually 3 to 1).

Plant populations were significantly correlated to yields all three years. The correlation (r value) was 32 % in 1994, 54% in 1995, and 29% in 1996. Although significant correlation between yield and population existed each year, reduced yields due to stand density were probably present only for treatments with very low populations. Bednarz *et al.* (2001) found that plant populations had little effect on final cotton yields because of changes in boll retention and position as populations changed. Although low populations may have influenced yield for some treatments, the greater yield response to in-row chisel is attributed to additional effects like water availability or hardpan disruption because populations of several other treatments were similar to those of IC1 but yields were consistently lower for these treatments.

ECONOMIC ANALYSIS

Net returns were significantly influenced by year (P = 0.047) and treatment (P = 0.078) but there was no significant year-by-treatment interaction. Net returns averaged across the three years of cotton ranged from $122 to $300 acre^{-1} ($300 to $745 ha^{-1}) annually depending primarily on cotton yield (Table 4). Costs for tillage, planting, and weed control ranged from $13 to $21 acre^{-1} ($30 to $51 ha^{-1}). Operational costs of IC1 were greatest but net returns were also greatest (Table 4). Surprisingly, operational costs of DT1 were nearly the same as for IC1 (Table 5). The yield advantage with reduced tillage treatments increased profits over DT1. Net return for paratill plots increased from PT1 to PT5, which was unexpected. The PT1 plots were paratilled each year while those of PT2, PT3, and PT4 were paratilled 2 times with the second paratill operation occurring in succeeding years. Net returns indicate that a paratill operation once every five years is the most economical approach to deep tillage on these soils. This is in contrast to the results of Clark *et al.* (1993) and Radcliffe *et al.* (1989) who concluded that annual paratilling was needed in these soils due to reconsolidation and increases in soil strength following paratillage. Our results may have been affected by poor stands in the PT plots and because including the winter rye cover crop on infrequently paratilled plots may have helped establish more permanent root networks and channels of less resistance due to the absence of disturbance in these plots.

DISCUSSION

Variable growing conditions experienced during the three years of this study illustrate why many producers have adopted cotton as a crop of choice in the Southeast. Even with poor growing conditions yields were generally better than 500 lbs acre^{-1} (0.56 Mg ha^{-1}) for most treatments (Table 4). In two out of the three years, the reduced tillage plots that received annual tillage treatments significantly out yielded the conventional tillage plots. Previous work on soils at the same location has demonstrated the beneficial effects of conservation tillage on soil physical, biological and chemical properties (Bruce *et al.*, 1995; Langdale *et al.*, 1990; Franzluebbers *et al.*, 1999). Bruce *et al.* (1995) showed that for Cecil soils in the Southern Piedmont, reduced tillage and increased crop residue inputs increase soil organic matter and water stable aggregates at the soil surface. Infiltration rates were 51 % greater in no-till plots compared to conventional tillage plots, and that removal of residues from the soil surface during the infiltration measurements was detrimental to conventional tillage plots but had little effect on NT plots. Franzluebbers *et al.* (1999) found that at a depth of 0 to 150 mm, mean-weight diameter averaged 0.041 in (1.03 mm) with conventional tillage, 0.044 in (1.12 mm) with paratill, 0.046 (1.17 mm) with secondary tillage, and 0.048 in (1.23 mm) with in-row chisel for plots in the current study. Biophysical improvement of surface soil structure would lead to greater water infiltration and presumably improved water use efficiency.

The benefit of current year IC was apparent in all three. In each year, the annual IC (IC1) and current year IC, had similar yields. It was somewhat surprising that IC was superior to PT since PT results in a deeper disturbance of the soil profile, which should allow greater soil exploration by the cotton roots. Two possible effects may have negated the impact of the PT treatment. First, PT was executed during the fall and therefore some reconsolidation of the profile may have occurred before the following cotton growing season. Reeder *et al.* (1993) found that soil strength following paraplowing returned to pre-subsoiling strength during the first growing season and reconsolidation occurred more rapidly than with other subsoiling equipment. Clark *et al.* (1993) and Radcliffe *et al.* (1989) indicate that in Cecil soil, wheel traffic contributes to hardpan formation at 6 to 10 in (0.15 to 0.25 m) below the surface. One to two tractor operations following PT may be enough to re-compact the soil profile to the same state as prior to the PT operation (Reeder *et al.*, 1993). Radcliffe *et al.* (1989) concluded that compaction is a problem without deep tillage in this region and that the depth of compaction caused by traffic exceeds the depth of secondary tillage. Since IC was performed at planting any negative effects of wheel traffic would be minimized compared to fall PT, which was followed by killing of the cover crop and planting the summer crop. This subsequent wheel traffic may be one reason that IC effects were consistently present in the year IC was performed. A second reason for the less significant response to PT may have been due to poor germination and stand establishment. Plant stands were reduced in some PT plots but cotton can compensate for lower stand density and this was not considered to be the major cause of yield reduction. In situations where PT is not performed at the proper depth, the soil surface can remain rough, which may adversely affect seed to soil contact and reduce stand density.

Our results indicate that paratilling Cecil and similar soils may not provide a positive economic return to producers. Costs associated with PT were similar to IC but required an additional tractor operation (time and labor) and a large tractor. Additional savings for IC could be accrued with use of a smaller tractor and its associated reduced maintenance costs. Therefore, IC appears to be a superior choice on these Southern Piedmont soils. West *et al.* (1996) concluded that PT in no-till systems was beneficial only on dark, poorly drained soils and provided little benefit on other silty loam soils in Indiana. Wesley *et al.* (2000) found that fall deep tillage had 9% greater net returns for nonirrigated soybean than fall paratillage on Tunica clay (clayey over loamy, smectitic, nonacid, thermic Vertic Haplaquept) in Mississippi. When deep tillage was performed every second or third year, yields and returns were within 5% of continuous deep tillage. They concluded fall deep tillage should be performed at least once every 3 yr to maximize and sustain higher yields and net returns. Clark *et al.* (1993) concluded from cone index and water infiltration data that moderately and severely eroded soils of the Southern Piedmont require annual chiseling to ensure minimizing the effect of soil compaction on crop growth. Our results along with other studies demonstrating variable response to PT indicate that in-row chisel is probably a better option. Development of tools to measure soil strength on the go to help determine the need for in-row chisel or paratilling would be beneficial to producers.

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DISCLAIMER

ENHANCING SUSTAINABILITY IN COTTON WITH REDUCED CHEMICAL INPUTS, COVER CROPS, AND CONSERVATION TILLAGE

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ABSTRACT

In the fall of 2000, an on-farm sustainable agricultural research project was established for cotton at two locations in Georgia. The objectives were to (1) develop cover crop systems for conservation tillage cotton that enhance habitat for aboveground beneficial insects, reduce risks of belowground plant parasitism by nematodes, improve nutrient cycling and water availability, and reduce costs of cotton production, and (2) enhance producer understanding of sustainable principles and practices. Cover crop treatments included: (1) no cover crop, (2) cereal rye, (3) legume blend - balansa clover, crimson clover, and hairy vetch mixture, (4) combination of legume blends plus rye, and (5) crimson clover. This paper is a preliminary report on some of the results on insects for the first year of the project. In the cover crops, mean number of pest insects from highest to lowest occurred in the following order: blend < crimson clover < rye < blend+rye. Mean number of predators followed a similar pattern suggesting that more predators occurred when insect pest density was higher. In cotton, mean number of pest insects from highest to lowest occurred in the following order: blend < blend+rye < crimson clover < rye < no cover. Except for the blend and blend+rye treatments, higher numbers of predators occurred where insect pest numbers were highest. Predator numbers were higher in all cover crop treatments compared to the no cover treatment. No differences in cotton yields were detected among treatments. Number of insecticide applications was significantly lower for the crimson clover and rye treatments than for the no cover, blend+rye, and blend treatments. The data suggests that higher predator density resulted in fewer insecticide applications. So, even though differences in yields statistically were not detected among the treatments, the cover crops benefited the growers by reducing insecticide inputs and thus increasing profit.

KEYWORDS

Cover crops, natural enemies, forage legumes, rye

INTRODUCTION

Eradication of the boll weevil in the early 1990's has re-established cotton as a significant component of farm enterprises in Georgia where cotton expanded from 0.3 million acres in 1990 to 1.5 million acres in 1998 (CTIC, 1998). However, during this time, world yield out paced demand with prices falling from near \$1.15 lb^{-1} in 1995 to between 52 and 55 cents currently (Shurley, 1999). Prices more than 75 cents lb^{-1} are needed to provide a profit with current practices, but sustained price increases are not projected for the future; therefore, to remain competitive in a global market production costs must decline.

Benefits of conservation tillage and cover crops have largely been overlooked in cotton production systems, even though these practices can reduce expensive inputs through improved soil water relationships and long-term soil productivity, increased habitat for beneficial insects and greater agroecosystem stability (Altieri, 1994; Reeves, 1994). Today, nearly 75% of US cotton is grown using conventional tillage without cover crops or rotation (Reeves, 1994), and farm expenditures under these practices have increased 14 percent from 1993 to 1998.

A significant amount of research has been conducted on cover crops in conservation tillage systems in the south (Reeves, 1994). Limited research has focused use of cover crops with conservation tillage to enhance beneficial insects (Ruberson *et al*., 1997; Lewis *et al*., 1997) or for adoption in cotton production (Touchton *et al*., 1984; Hargrove, 1986; Daniel *et al*., 1999a & b). Most studies have focused on comparisons among single species of legumes and non-legumes (Reeves, 1994). Only a few studies have addressed mixtures even though they can provide a more

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diverse biological habitat through an extension of availability of nectar and other food sources (Altieri, 1995).

In the fall of 2000, an on-farm sustainable agricultural research project funded by SARE was established for cotton at two locations in Georgia. The objectives were to

1. develop cover crop systems for conservation tillage cotton that enhance habitat for aboveground beneficial insects, reduce risks of belowground plant parasitism by nematodes, improve nutrient cycling and water availability, and reduce costs of cotton production, and
2. enhance producer understanding of sustainable principles and practices through research and outreach components that educate about environmental and economic benefits of sustainable agriculture systems and expand the network of producers who can provide leadership for further adoption and dissemination of information on sustainable production practices. This paper is a preliminary report on some of the results on insects for the first year of the project.

MATERIALS AND METHODS

Cover Crop Treatments

In 2001, studies were conducted on farms near Louisville, GA and Tifton, GA. Only the results of the studies in Tifton will be reported in this paper. The primary on-farm study compared traditional cover crop practices to two diverse cover crop mixtures designed to extend availability of food sources to beneficial insects and increase biomass inputs to improve soil organic matter content. Cover crops in the mixture were chosen based on early, midseason, and late blooming characteristics and their adaptation to the area. Cover crop treatments included: (1) no cover crop-conventional practice where farmers allow weeds to grow during the winter, (2) cereal rye - standard grass cover crop, (3) legume blend - balansa clover, crimson clover, and hairy vetch mixture chosen to extend flowering (early, mid, and late flowering, respectively), (4) combination of legume blend plus rye - combines benefits of legume nectar production and N fixation with enhanced biomass production of rye, and (5) crimson clover – standard legume cover crop. Ten-acre fields were used for each treatment. Fields were chosen to ensure homogenous soil types for all fields within a location.

Cover Crop Management

Cover crops were drill planted in the fall directly into mowed cotton stubble. Cover crops were killed 3 weeks prior to cotton planting by applying glyphosate in 24 inch wide bands leaving 12 inch wide strips of cover crop that grew to maturity providing an insect habitat for a relay of insects from the cover crop to cotton.

Cotton Production

Cotton was planted at 7 to 10 lbs acre^{-1} on all fields using either 4 or 6 row strip-till planters. No nematicide was applied to the fields. In the rye-legume mixture, cotton was planted in killed rye strips. Aboveground insect control relied on beneficial insects, and insecticides were applied only as a last resort for pest control. The number of insecticide applications was recorded. Cotton yield was determined using a mechanical picker. Cotton yield and insecticide application data were analyzed by PROC MIXED COVTEST followed by LSD separation of means (SAS Institute 2000).

Above Ground Insect Dynamics

Insect population density was determined for insect pests and natural enemies. Cover crops and cotton were sampled from the seedling stage until senescence or harvest. Sampling method depended on plant growth stage and species, and biology and behavior of pest and natural enemy species. Techniques included shake cloth samples, sweep net samples, and whole plant samples. This paper reports some of the results from sweep samples. Twenty-one 20-ft sweep samples were obtained each week for each replicate of each treatment. Insect pest and natural enemy density data were analyzed by PROC MIXED COVTEST followed by LSD separation of means (SAS Institute 2000).

Results and Discussion

In the cover crops, mean number of pest insects from highest to lowest occurred in the following order: blend < crimson clover < rye < blend+rye (Table 1). Mean number of predators followed a similar pattern suggesting that more predators occurred when insect pest density was higher.

Table 1. Mean pest insects and predators in cover crops for 20-foot sweeps in the legume blend, crimson clover, legume blend + rye treatments.

	Insect Pests			Predators		
Treatment	Mean		SE	Mean		SE
	-------- count per 20-foot sweep ---------					
Blend	12.25	a[†]	0.68	7.06	a	0.22
Crimson Clover	7.51	b	0.68	3.85	b	0.22
Rye	6.45	b,c	0.77	1.38	c	0.25
Blend + Rye	4.33	c	0.80	0.87	c	0.24

[†] Means within a column followed by the same letter do not differ statistically based on $LSD_{0.05}$.

Table 2. Mean pest insects, predators, cotton yields, and insecticide applications in cotton for 20-foot sweeps in legume blend, crimson clover, legume blend + rye, rye, and no cover treatments. The last columns refer to the number of insecticide applications needed as a last resort for pest control.

	Pest insects			Predators			Cotton Yield			No. of applica.		
Treatment	Mean		SE	Mean		SE	Mean		SE	Mean		SE
	-------- count per 20-foot sweep --------						Bales acre^{-1}					
No cover	2.1	c[†]	0.8	1.1	d	0.4	1.9	a	0.2	1.8	a	0.4
Blend + Rye	2.3	c	1.1	3.4	a,b	0.4	2.4	a	0.2	1.7	a	0.4
Blend	1.9	c	1.0	3.1	c	0.4	2.1	a	0.2	1.3	a,b	0.4
Rye	10.4	a	1.1	4.6	a	0.4	2.1	a	0.2	0.3	b,c	0.4
Crimson Clover	6.4	b	1.1	4.4	bc	0.4	2.4	a	0.2	0.0	c	0.4

[†] Means within a column followed by the same letter do not differ statistically based on LSD$_{0.05}$.

In cotton, mean number of pest insects from highest to lowest occurred in the following order: blend < blend+rye < crimson clover < rye < no cover (Table 2). Except for the blend and blend+rye treatments, higher numbers of predators occurred where insect pest numbers were highest. Predator numbers were higher in all cover crop treatments compared to the no cover treatment. Interestingly, predator numbers were higher in the blend and blend+rye treatments than in the no cover treatment even though pest numbers were about the same for all three treatments. No differences in cotton yields were detected among treatments. The number of insecticide applications was similar for the no cover, blend+rye, and blend treatments. The number of insecticide applications was significantly lower for the crimson clover and rye treatments than for the no cover, blend+rye, and blend treatments. Except for the blend+rye treatment, the data suggests that higher predator density resulted in fewer insecticide applications. So, even though differences in yields statistically were not detected among the treatments, the cover crops benefited the growers by reducing insecticide inputs and thus increasing profit.

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COVER CROPS AND TILLAGE COMBINATIONS FOR WIDE AND ULTRA NARROW ROW COTTON

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ABSTRACT

Ultra Narrow Row (UNR) cotton (*Gossypium hirsutum* L.) has potential to lower machinery costs and increase yields on poorer quality soils, but research with this system is lacking. Alternative crops and management methods are needed for drought prone soils in southeast Alabama. Lint yields from cotton planted in traditional wide (36 inch) rows with conventional tillage are often severely depressed by drought. High plant populations and close row spacing used in UNR systems may assist in drought avoidance, particularly when combined with conservation tillage techniques. Legume cover crops including white lupin (*Lupinus alba* L.) have been shown to increase lint yields of UNR cotton in Alabama, compared to traditional grain cover crops such as rye (*Secale cereale* L.). An experiment was conducted on a Lucy loamy sand (loamy, kaolinitic thermic Arenic Kandiudults) in southeast Alabama to determine the optimum combination of winter cover crops (rye or legumes), tillage (conventional or no-till), and row spacing (36-inch or 8-inch) on a drought prone soil from 1998 through 2001. In this experiment, UNR lint yields in 1998 were 50% greater than with 36-inch rows and 15% greater in 2001 with no difference in 1999. Conventionally tilled rye cover treatments yielded 35% more lint than no-tilled rye cover treatments in 1999. In 2000, conventional tillage yielded 19% more than no-till treatments. Leaf Area Index taken at early bloom and plant population counts usually followed the same trends as lint yields. These results indicate that UNR cotton may be a more productive system for cotton on marginal soils than traditional wide rows.

KEYWORDS

Ultra Narrow Row, cotton, lupin, rye, no-till

INTRODUCTION

Ultra Narrow Row (UNR) cotton, or cotton grown in row spacings of 10 inches or less, acreage has rapidly increased in in the last several years in the southeast US. The close rows and high plant populations used in this system have the capability to more rapidly shade the soil surface, conserving moisture and shading weeds, and to capture more sunlight at earlier growth stages. With these high populations, cotton plants may set only 3 to 4 bolls per plant, with most of these at the first or second position from the stalk. The small number of fruit per plant may allow cotton to rapidly set fruit and avoid drought effects with limited water.

Alternative crops and production methods are needed for marginal soils in southeast Alabama, where sandy soils with low moisture holding capacity often produce sub-economic cotton lint yields. Previous research has shown increased yields with the use of conservation tillage and lupin/legumes as winter cover crops for cotton. Producers have become interested in UNR cotton as a way to use lower cost harvest machinery and to possibly increase yields on marginal cropland.

MATERIALS AND METHODS

A study was conducted from the fall of 1997 through the fall of 2001 at the Wiregrass Regional Research and Extension Center, Headland, Alabama to investigate the optimum combinations of row spacing, cover crops, and tillage for cotton on a marginal soil. Soil type was a Lucy loamy sand (loamy, kaolinitic thermic Arenic Kandiudults). Wide row (36-inch) cotton lint yields in this area have typically ranged from 500 to 600 lbs acre^{-1} or less, due to drought stress (B. Gamble, pers. comm.).

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The Experiment Design was a strip-split plot design with four replications. Cover crops (rye *vs*. legumes) were horizontal strips, tillage treatments (no-till *vs*. conventional) were in vertical strips, and row spacings (Wide *vs*. UNR) were split-plots.

Cover crops were planted in October or November in the test area, as soil moisture allowed. Rye (*Secale cereale* L.) and white lupin (*Lupinus albus* L.) were drilled in their respective plots and cultipacked. The lupin cultivar "Lunoble" was planted in 1997-98 in legume cover plots. Due to winterkill of the "Lunoble" in 1997-98, "AU Homer" white lupin was used in following years, and crimson clover (*Trifolium incarnatum* L. cv. AU Robin) was also broadcast in legume plots immediately before cultipacking.

All cover crops were killed with herbicides in the spring at the early bloom stage at least one month before planting cotton. No-till plots were then rolled flat with a crimping roller. Conventional tillage treatments were also begun at this time, including disk harrowing, chisel plowing, and leveling with a harrow before planting. All plots were subsoiled with a paraplow annually.

Paymaster PM 1220 BG/RR (1998, 1999) or PM 1218 BG/RR (2000, 2001) cotton was planted in May of each year. Plots were replanted in June of 1998 and abandoned in 2000 due to poor stands from extremely dry weather. Seeding rates were 84,000 seed per acre for Wide (36-inch) Rows planted with unit planters, and 180,000 to 200,000 seed per care for UNR (8-inch) planted with a no-till drill. Best known management practices, including optimum fertility and growth regulators, were used. Wide rows were harvested with a spindle picker, while UNR plots were harvested with a stripper equipped with a finger harvester head.

Yearly rainfall patterns varied considerably with 1998 having a relatively dry spring and wet late summer. 1999 was wet early in the summer and dry later, and 2000 was extremely dry from early spring to mid-summer, while 2001 was dry in early spring and wet in mid-summer. No irrigation was applied.

All data was analyzed using SAS 8.2 (SAS Institute, Cary, NC) at P = 0.10, *a priori,* and LSD's calculated, where significant differences were obtained.

RESULTS AND DISCUSSION

Plant population counts showed that UNR had a higher population in 1998 than Wide Row (148,000 *vs*. 38,000 plants acre^{-1}, LSD = 22,000). In 1999, there was an interaction between Tillage and Row Width, with Wide Row treatments having a population of 37,000 plants acre^{-1}, while conventional UNR had a higher population of139,000 plants acre^{-1} and was higher than no-till UNR (98,000 plants acre^{-1}) with the LSD = 21,000 plants acre^{-1}. All cotton plots were abandoned due to drought in 2000. In 2001, there was a significant interaction of Legume and Tillage effects, as well as a significant Row Spacing effect. UNR plots had higher plant populations in each combination, except for those planted with No-till into rye (see Table 1).

Lint yields of UNR were over 50% higher (911 lbs acre^{-1}) than Wide Rows (596 lbs acre^{-1}) in 1998 (LSD = 50 lbs acre^{-1}). There was an interaction of Cover Crops and Row Width for yield in 1999, with Conventional tillage yielding higher with Legume and with Rye covers (see Table 2), while there was no difference in yield between UNR and Wide Rows. No lint yields were available in 2000, due to drought.

In 2001, there were main effects only for lint yield, with UNR (1387 lbs acre^{-1}) greater than Wide Rows (1203lb acre^{-1}; LSD = 68 lbs acre^{-1}), and Conventional Tillage plots yielding (1417 lbs acre^{-1}) greater than with No-till (1173 lbs acre^{-1}, LSD = 149 lbs acre^{-1}).

Table 1. Cotton plant populations for 2001.

Cover / Tillage	36 inch	UNR	LSD $_{0.10}$
	----- 1000 plants acre^{-}1 -----		
Legume / Conventional	31	132	47
Rye / Conventional	33	184	47
Legume / No-till	28	112	47
Rye / No-till	55	85	47

Table 2. Cotton lint yield for 1999.

Cover	Conventional	No-till	LSD $_{0.10}$
	------------- lbs lint acre^{-}1 ---------------		
Legume	949	865	49
Rye	923	669	49

CONCLUSIONS

These results show that Ultra Narrow Row cotton was a more productive system than traditional wide rows on this marginal soil for cotton lint yield in two of the three crop years studied. In a year with limited early season rainfall (1998), it yielded over 50% more than the Wide Row system. In a year with more evenly distributed rainfall (1999), there was no difference between UNR and Wide Row lint yields, while in the third crop year (2001), again with limited early season rainfall, UNR yielded 15% more lint than Wide Rows.

FORAGE YIELD OF TEN NO-TILLAGE TRIPLE CROP SYSTEMS IN FLORIDA

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ABSTRACT

Growing crops in conservation tillage and multiple cropping systems is efficient, cost productive, and environmentally beneficial. This experiment was designed to evaluate the potential of ten triple-cropping systems to produce forage. A split-plot design was used with main effects as two winter crops and sub-effects as five fall-planted crops. The winter crops were rye (*Secale cereale* L.) and lupin (*Lupinus angustifolius* L.), and the fall crops consisted of soybean (*Glycine max* [L.] Merr.), cowpea (*Vigna unguiculata* [L.] Walp.), sorghum x sudangrass (*Sorghum bicolor* [L.] Moench), sunn hemp (*Crotalaria juncea* L.), and corn (*Zea mays* L.). A summer crop of corn was planted in all plots between the winter and fall crops. Rye plots yielded higher than lupin plots in the winter. There were no differences in the summer corn yields. A highly significant interaction was observed among fall crop yields, with sorghum x sudangrass plots yielding highest and soybean plots yielding lowest across main treatments. Total dry matter production for all three crops combined was significant among sub-plot means. Systems with sorghum x sudangrass produced the most biomass. As much as 11.5 – 14.5 tons dry matter acre^{-1} can be produced using these triple-cropping systems. Even the results of the lowest yielding systems (soybean and cowpea as fall crops) are considered positive results because of the additional forage production and potential for animal waste utilization in a non-polluting manner during the fall, a non-traditional growing season for the proposed crops.

KEYWORDS

Multiple-cropping, rye, lupin, corn, soybean, cowpea, sudax, sunn hemp.

INTRODUCTION

In Florida, there is a window of opportunity to grow forages in the fall because many dairy farmers use a double-cropping system that includes a small grain in the winter followed by corn (*Zea mays* L.) in the summer. After corn harvest in late summer, their land will often lay unused until planting of the winter crop several months later. Our sub-tropical climate keeps temperatures warm enough to support growth of a crop in the fall. There are multiple advantages to such a system. Not only would it provide an additional crop for a supplementary feed for cattle, but it could also alleviate some of the waste disposal problems that a dairy farm faces. There would be a new opportunity to dispose of wastes by applying them to the land as a fertilizer to be taken up by the additional crop.

Incorporation of no-till planting methods into this triple cropping system also has numerous benefits. Timely planting is one of the most important because time that is used to prepare the land for planting, incorporation of residues, or weed control is time that could be saved in no-till systems. This saved time translates to savings in labor costs, equipment and fuel costs from fewer trips through the field, and maintenance and upkeep costs (Gallaher, 1980; Teare, 1989). Plus, earlier crop planting can allow more time for biomass production before cooler weather settles in, thereby limiting the production of the fall crop. Also, no-till has been widely documented for its potential to prevent soil erosion and for more efficient water use because of less evaporation and improved root channeling.

Florida has been a leader in no-tillage research for decades. Through the 1980s, many publications demonstrating the beneficial effects of conservation tillage have been documented (Brecke, 1984; Colvin, 1986; Colvin and Wehtje, 1984; Costello, 1984; Costello and Gallaher, 1984; Wright and Cobb, 1984; Wright and Teare, 1993). More recently, the positive trends have continued with conservation tillage in a variety of cropping systems (Barnett *et al.*, 1997; Edenfield *et al.*, 1999; Gallaher, 1999; Tubbs *et al.*, 2000; Tubbs *et al.*, 2001). With such positive results,

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adoption of conservation tillage practices should continue to increase, as they have for the past 20+ years.

Fall plantings of soybean (*Glycine max* [L.] Merr.) (Tubbs and Gallaher, 2001), cowpea (*Vigna unguiculata* [L.] Walp.) (Tubbs and Gallaher, 1998; Tubbs *et al.*, 1998), and sunn hemp (*Crotalaria juncea* L.) (Gallaher *et al.*, 2001; Marshall *et al.*, 2001) have proven successful in Florida. These legume crops also may be used as forages. Wheeler (1950) supplies an abundance of information on forage usage of cowpea, soybean, sorghum (*Sorghum bicolor* [L.] Moench), and sudangrass (*Sorghum sudanense* [Piper] Stapf). Sunn hemp has also been used as a forage for livestock (Comis, 1997). Because of the advantages of conservation tillage and multiple cropping in addition to the positive results seen with fall plantings of several crops that can be used as forages, research was conducted to evaluate the forage yield potential of ten triple-cropping systems using no-tillage management methods.

MATERIALS AND METHODS

This experiment took place at the Institute of Food and Agricultural Sciences (IFAS) Plant Science Research and Education Center in Citra, FL. A split-plot design was used with main plots of two winter crops and sub-plots of five fall crops. Rye (*Secale cereale* L.) and lupin (*Lupinus angustifolius* L.) were each planted in two blocks within each rep to allow for a crop rotation effect in future years. Thus, the study was analyzed as if there were 20 cropping systems, yet there were actually 10 systems with winter crops duplicated.

Two winter crops, ‘Wrens 96’ rye and ‘Tift Blue’ lupin were planted on 20 November 2000 using a Tye no-till drill (10-inch spacing) into a minimum tilled seedbed that consisted of using a tandem harrow two times. Rye seed was planted at 90 lbs acre^{-1} and lupin seed at 40 lbs acre^{-1}. All plots were fertilized with 500 lbs acre^{-1} of a fertilizer mix containing 17.6% N, 5.7% P_2O_5, 17.8% K_2O, 1.4% Mg, and 2.85% S and received a supplemental application of 100 lbs acre^{-1} of ammonium nitrate (34% N). No chemical pesticides were required for control of pests in the winter crops. The winter crops were harvested at ground level for above-ground forage yield on 13 March 2001.

All plots were planted to ‘Florida IRR’ corn on 21 March 2001 into the stubble of the previous crop. The Tye no-till drill was used and 50,000 seeds acre^{-1} were planted. A fertilizer containing 18.8% N, 4.6% P_2O_5, 17.2% K_2O, 1.12% Mg, and 2.28% S was applied in three applications of 375 lbs acre^{-1} at planting, at 12-inch crop height, and at 24-inch crop height. Corn was harvested for above ground forage yield on 28 June 2001. Labeled rates of Roundup Ultra and Atrazine + Dual Magnum were applied pre-emergence for weed control. A labeled rate of Furadan was applied pre-emergence and labeled rates of Lannate were applied post-emergence for insect control.

The five fall crops of ‘Hinson Long Juvenile’ soybean, ‘Iron Clay’ cowpea, ‘Cow Chow’ sorghum x sudangrass (*Sorghum bicolor* [L.] Moench) (henceforth sudax), ‘Tropic Sun’ sunn hemp, and ‘Florida IRR’ corn were planted on 19 July 2001 using the Tye no-till drill into the remaining corn stubble. Soybean, cowpea, and sudax were planted at 420,000 seeds acre^{-1}, sunn hemp at 260,000 seeds acre^{-1}, and corn at 50,000 seeds acre^{-1}. All plots were fertilized using the same fertilizer mix as mentioned above for the summer corn crop, again in three applications of 375 lbs acre^{-1} at planting, at 12-inch crop height, and at 24-inch crop height (based on height of sudax). A labeled rate of Roundup Ultra was used pre-emergence for weed control. Labeled rates of Lannate were applied for insect control. Overhead irrigation was used on all crops. The fall crops were harvested on 3 October 2001 for above ground forage yield. Data were analyzed using analysis of variance for a split-plot design, and where appropriate, means separated by LSD test at $P = 0.05$.

RESULTS AND DISCUSSION

The blocks planted to rye in the winter yielded higher than blocks planted to lupin (Table 1). In the summer corn crop, there were no significant differences in above-ground forage yields (Table 2). However, there was a highly significant interaction for the yields of the fall crops (Table 3). When all dry matter was added together for the three crops combined, the sub-plot effect was significant for total biomass produced (Table 4).

As seen in Table 3, sudax yielded highest in each of the winter crop main plots, and sunn hemp was equally as high in one of the main plot rye treatments. Soybean had lowest

Table 1. Forage yield for the 1st (winter) crop averaged over fall crops, Citra, FL 2001, R.S. Tubbs, R.N. Gallaher, K-H. Wang, and R. McSorley. Means followed by the same letter are not significantly different based on LSD$_{0.05}$.

Winter crop	Dry matter yield
	------ tons DM acre $^{-1}$ -------
Rye 1	2.47 A
Lupin 1	1.97 B
Rye 2	2.52 A
Lupin 2	2.07 B

Table 2. Forage yield for 2nd (summer) crop - corn in 10 triple-cropping systems and rotations with winter crops, Citra, FL 2001. The main effects for fall crops and winter crops as well as the fall crop x winter crop interaction were all non-significant ($P = 0.05$).

	Winter Crop				
Fall Crop	Rye 1	Lupin 1	Rye 2	Lupin 2	Average
	----------------------------- tons DM acre $^{-1}$ ---------------------				
Soybean	7.39	6.39	7.14	7.63	7.14
Cowpea	6.42	6.67	6.42	7.25	6.69
Sorghum X Sudangrass	7.99	7.12	7.21	7.31	7.41
Sunn Hemp	7.26	6.79	6.48	7.16	6.92
Corn	8.18	6.19	7.40	6.53	7.07
Average	7.45	6.63	6.93	7.18	

Table 3. Forage yield for 3rd (fall) crop in 10 triple-cropping systems and rotations with winter crops, Citra, FL 2001. The interaction was highly significant ($P < 0.001$). Therefore the weighted LSD $_{0.05}$ = 0.58 was used for comparison of interaction means. The LSD$_{0.05}$= 0.45 was calculated for comparison among sub-plot (fall crop) means within whole plots (winter cover).

	Winter Crop				
Fall Crop	Rye 1	Lupin 1	Rye 2	Lupin 2	Average
	-------------------------- tons DM acre $^{-1}$ ----------------------				
Soybean	1.98	2.13	1.90	2.09	2.03
Cowpea	2.16	2.69	2.84	2.17	2.47
Sorghum X Sudangrass	4.19	4.49	5.02	4.17	4.47
Sunn Hemp	3.84	3.05	3.00	3.57	3.37
Corn	3.08	3.25	2.65	2.89	2.97
Average	3.05	3.12	3.08	2.98	

yields in all of the winter main plots and cowpea was equally as low in one of the rye and one of the lupin treatments. The total forage yields show that systems with sudax planted as the fall crop yielded higher than any of the other triple-cropping systems (Table 4). The systems with sunn hemp and corn as the fall crop were statistically equal, and those with soybean, cowpea, and corn in the fall yielded similarly to each other as well, but lower than sunn hemp and sudax.

Although the winter production of rye was higher than for

Table 4. Total forage yield for 10 triple-cropping systems and rotations with winter crops, Citra, FL 2001. The main effect for winter crop was non-significant (*P* = 0.05). The sub-plot (fall crop) main effect was significant at *P* = 0.001. Fall crop means followed by the same letter are not significantly different based on $LSD_{0.05}$= 0.87.

	Winter Crop				
Fall Crop	Rye 1	Lupin 1	Rye 2	Lupin 2	Average
	----------------------tons DM acre $^{-1}$ ------------------				
Soybean	11.84	10.49	11.56	11.79	11.42
Cowpea	11.05	11.33	11.78	11.49	11.41
Sorghum X Sudangrass	14.65	13.58	14.75	13.55	14.13
Sunn Hemp	13.57	11.81	12.0	12.8	12.55
Corn	13.73	11.41	12.57	11.49	12.30
Average	12.97	11.72	12.53	12.22	

lupin, the same effect did not show up in total forage yields. Based on these results, growing either rye or lupin in the fall, followed by corn, followed by sudax would provide a farmer with the most feed for his or her cattle. This does not necessarily mean that this system would be the most beneficial for maximizing nutrient removal from application of waste materials, however. Different crops have different capacities for nutrient removal. In addition, farmers want high quality forages that are rich in nutrients so the cattle get more benefit from each bite. Quality is often more important than quantity when it comes to feeding lactating animals. More analyses on plant material for nutrient removal and digestibility would need to be done in order to give a more thorough recommendation of the optimal triple-cropping system for waste disposal and highest quality feed.

Growing three grasses in a row, as is the case in the rye-corn-sudax and rye-corn-corn systems, may not be the best option in the long run for sustainability because of potential pest problems. Alternating grasses and legumes are often wiser crop rotation strategies to break pest cycles. Legumes have greater concentrations of N than grasses in most cases (Morrison, 1947), making legumes important in crop rotations for nutrient removal and improving forage quality. Nitrogen is the element with the most potential for leaching and pollution so more research is needed to determine the best system for removal of this element to prevent losses to groundwater.

CONCLUSIONS

Regardless of which triple-cropping system is chosen, all could provide the grower with the opportunity to utilize nutrients in animal wastes while supplementing their feed stocks during a time of the year when feed supplies are low. Depending on the system, anywhere from 11.5 to 14.5 tons dry matter acre^{-1} can be produced using a triple cropping system of rye or lupin in the winter, corn in the summer, and soybean, cowpea, sudax, sunn hemp, or corn in the fall. Maximized biomass production came from the systems with sudax as the fall crop. Back to back corn crops in the summer and fall yielded fairly well, but only additional years of data from this area will tell if such a system is sustainable. Although sunn hemp systems did not yield quite as high as those with sudax, this fall-grown legume still performed very well. It may have promise for a number of purposes in Florida including cover crops, green manure, organic fertilizers, and possibly forages.

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TILLAGE, WEED CONTROL METHODS AND ROW SPACING AFFECT SOIL PROPERTIES AND YIELD OF GRAIN SORGHUM AND SOYBEAN

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ABSTRACT

In the southeast, soybean and grain sorghum are important crops, and there is a need to determine the effects of tillage, weed control methods, and row spacing on soil properties and yield of these crops. The objectives of this research were to determine the effects of three weed control methods (none, cultivation, and herbicides) and three row spacings (45, 60, and 90 cm) on no-till (NT), planted grain sorghum (after wheat and clover), conventionally planted soybeans and no-till in wheat stubble for two growing seasons. NT planted soybeans produced 3102 kg ha^{-1}, 2911 kg ha^{-1} and 2216 kg ha^{-1} seed with herbicide, mechanical, and no weed control system, respectively. In conventionally prepared seedbeds, use of herbicides and cultivation produced almost equal seed yield (3898 kg ha^{-1} and 3954 kg ha^{-1}), which was significantly higher than no weed control (3151 kg ha^{-1}) plots. Soybean in narrow (45 cm) rows (3997 kg ha^{-1}) consistently out-yielded the wider, 60 cm (3130 kg ha^{-1}) and 90 cm (2490 kg ha^{-1}), rows. Results averaged across years showed that conventionally planted soybean produced higher yields (3668 kg ha^{-1}) than NT planted soybeans (2743 kg ha^{-1}). The weed infestation was significantly less in narrow rows (45 cm) than in wider row (60 and 90 cm) plots. Similar results were observed in the case of grain sorghum. Soil moisture content, organic matter content, total soil nitrogen, and disease ratings of bacterial blight in soybeans were higher in NT than in conventional plots.

KEYWORDS

No-till, cover crops, double-cropping, herbicides.

INTRODUCTION

Pre-plant tillage has traditionally been performed to prepare the seed bed, incorporate the fertilizer, and control weeds. No-till (NT) planting systems have enhanced double cropping production systems of soybean (*Glycine max* (L.) Merr.) and grain sorghum (*Sorghum bicolor* (L.) Moench) following wheat (*Triticum aestivum* L.) or clover. However, NT planting has sometimes resulted in poor crop stands in comparison with conventional tillage (CT). The low germination rates in NT stands are due to excessive crop debris, which causes poor soil-seed contact, greater weed infestation, and higher disease incidence (Wright *et al.*, 1984; Vasilas *et al.*, 1988). Weed problems have been minimized by judicious use of pre- and post-emergent herbicides. Crabtree and Rupp (1980) reported lower soybean yields due to poor stands with NT in comparison with CT systems, whereas Edwards *et al.* (1988) observed that soybean yields under NT were higher than those from CT owing to the advantage conferred by the moisture-conserving mulch in a NT system.

While studying the influence of row spacing on cowpea, Herbert and Baggerman (1983) found that seed yield was higher in wide rows and it increased with increasing plant densities within rows. Witt (1984) studied the effects of herbicides on weeds in NT systems and concluded that weed problems can be reduced when either tillage or herbicides are used for weed control. Sufficient information is not available on grain sorghum, soybean, and soil property responses to integrated cultural practices such as row spacing and weed control methods in NT and CT systems. Therefore, this research was undertaken to determine the effects of tillage systems, row spacing, and weed control methods on grain sorghum and soybean yields and soil properties after soybeans.

MATERIALS AND METHODS

The experiments were conducted for two crop-growing seasons on a Decatur silty clay loam (Rhodic Paleudult) soil with a pH of 6.3. The two tillage systems used in the study were: (1) CT with fall plowing, spring disking, and harrowing and (2) NT after wheat and clover harvested as forage. The row spacings were 45, 60 and 90 cm, and the methods of post-plant weed control were the use of herbicide, hoeing, and no weed control. The experimental design was a split-split plot with five replications using tillage systems as main plots, which were randomly as-

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signed within each replication. Row spacings were randomly arranged within each main plot as subplots, and weed control methods were sub-subplots and were randomized within subplots. Each subplot was comprised of four rows 7.5 m long and 1.8 m, 2.4 m, and 3.6 m wide for the 45 cm, 60 cm and 90 cm row spacings, respectively.

Soybean cv. "Essex" and grain sorghum cv. Funk-G-1516 BR were planted in mid May at the recommended seeding rates with an Allis-Chambers™ NT planter. Fifteen days before planting, glyphosate (N- (phosphonomethyl) glycerin) was sprayed in all NT plots at the rate of 0.6 kg a.i. ha^{-1} to kill existing weeds. Acifluorfen 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid was sprayed at 25 and 45 days after planting (DAP) on the chemical control plots in both CT and NT areas at the rate of 2.24 kg a.i. ha^{-1} using a Solo™ knapsack sprayer (Solo, Germany). A surfactant, Surf-Ac 820 (Drexel Chemical Co., Memphis, TN) was added to the glyphosate and acifluorfen spray solutions at the rate of 0.5%. Mechanical post-plant weed control was performed by hand hoeing on the same day that acifluorfen was applied. In sorghum, atrazine at 1.4 kg a.i. ha^{-1} was applied at the 6 leaf stage. Soybean plant population was determined 40 DAP by counting plants in a 2 m section of the row in each plot selected at random. The total number of weeds in an area of 1 m^2 selected at random in each plot was also counted at 40 DAP in soybeans, but at crop maturity in grain sorghum. In both planting systems, the incidence of bacterial blight of soybean (BBS) caused by *Pseudomonas syringae* pv *glycinea* (Coerper) was evaluated at full pod (R4) growth stage and recorded. To determine gravimetric soil moisture content, soil samples were collected from the 0-15 cm depth at growth stages V5, R2, R4, and R8 (Fehr and Caviness, 1977) from each plot. Soil samples were collected at harvest (R8) to determine organic matter (OM) and nitrogen (N) content using the techniques of Walkley and Black (1934) and Bremner and Mulvaney (1982), respectively. Soybeans were combine-harvested from each plot at harvestable maturity of the crops. The seeds were cleaned and the yields were recorded in kg ha^{-1} at 12% moisture. Data were subjected to an analysis of variance procedure appropriate for a split-split plot design using a data processing package of the Statistical Analysis Systems Institute (SAS, 1982). The differences between treatment means were separated by use of Tukey's test.

RESULTS AND DISCUSSION

TILLAGE SYSTEM

A lower plant population of soybeans (221,754 plants ha^{-1}) was observed in NT plots in comparison with the CT (335,439 plants ha^{-1}), as shown in Table 1. The greater plant population in conventional plots probably occurred because of better soil-seed contact. Wright *et al.* (1984) and Vasilas *et al.* (1988) observed a similar difference in plants' density owing to shallow planting of seeds and the presence of crop residues in NT plots which hindered good soil-seed contact. Use of glyphosate as a pre-plant herbicide was more effective in controlling weeds in NT than in CT, which showed that weeds could be effectively controlled in a NT system.

Disease rating (DR) and infestation (DI) of BBS were significantly higher in NT than in the CT system. Similarly, average soil moisture content, soil organic matter, and total nitrogen were higher in NT than in CT at the 0-15 cm depth (Table 1). The beneficial effects of NT on soil moisture can

Table 1. Tillage effects on plant population, weed population, bacterial blight rating, soil properties and soybean seed test weight.

Response variable	No-till following wheat (NTW)	Conventional tillage (CT)	$LSD_{0.04}$
Plant population, 1000 plants ha^{-1}	222	335	4
Weed population, weed m^{-2}	19.8	23.9	3.9
Bacterial blight rating†	8.8	6.8	0.8
Soil moisture content, %‡	16.8	15.6	0.4
Soil organic matter at harvest, %	2.31	1.46	0.84
Total soil nitrogen at harvest, %	0.14	0.12	0.01
Hundred seed weight, g	12.2	14.3	0.8

†Disease rating from 0 = no infection to 9 = 90% disease and defoliation.

‡Means averaged over three periods (during V5, R2, and R8)

Table 2. Weed population and soybean yields under different row spacings, weed control method and tillage systems

	No-till (NT)			Conventional till (CT)		
Treatments	Weed population	Seed yield		Weed population	Seed yield	
	1988	1987	1988	1988	1987	1988
	weeds m^{-2}	------kg ha^{-1}------		weeds m^{-2}	------kg ha^{-1}------	
Row spacing, cm						
45	17.6 b[†]	3463 a	3306 a	18.8 c	4736 a	4483 a
60	20.2 a	2593 b	2593 b	22.9 b	3216 b	3836 b
90	21.7 a	2379 c	1844 c	30.1 a	2645 c	3091 c
Weed control method						
Hoeing	15.4 b	2930 b	2913 b	10.3 b	3789 a	4159 a
Herbicide	13.1 b	3119 a	3086 a	8.8 b	3512 b	3512 b
No control	30.9 a	2406 c	2026 c	52.7 a	334 b	2967 b

[†] Means within a column followed by the same letter do not differ significantly at $P = 0.05$ according to Tukey's studentized range test.

be attributed to the mulching effect of wheat stubble and killed weeds, which reduced runoff and evaporation. Soil organic matter, even with CT, was higher than usual for the region because the experimental site had been under sod for many years before this experiment was conducted. Organic matter and soil N could be expected to be somewhat higher with NT, as reported by Culley *et al.* (1987), who found that organic C and soil moisture were both higher under NT than under CT. The relatively large difference in OM between NT and CT in this experiment may have been owing to poor mixing of the organic duff layer with the soil when the sampling was done.

Tillage systems significantly influenced soybean yields in both years (Table 2). A similar yield trend was also observed in grain sorghum (Table 3). The difference in yields probably occurred primarily because NT had a lower plant population than CT. The plant population of 221,754 plants ha^{-1} with NT was significantly less than that recommended as a base population for predicting yield losses due to stand reduction (308,600 plants ha^{-1}; National Crop Insurance Association, 1985). Torri *et al.* (1987) reported that no yield reduction occurs during vegetative growth stages if a plant population of at least 308,600 plants ha^{-1} is maintained. Second, the higher incidence of BBS and lower seed weight in NT likely had negative effects on yields. Results averaged across years showed that conventionally planted soybeans produced a significantly higher yield (3668 kg ha^{-1}) than no-till planted soybeans. In grain sorghum, the significant increase in yield from no-till after clover and after wheat over conventional tillage was probably due to higher soil moisture content in no-till plots as well as due to the soil nitrogen fixed by clover. With no-till after wheat and clover, no significant yield differences were observed between chemical and mechanical methods of weed control; however, the herbicide controlled weeds more effectively than hoeing.

Row spacing

Decreasing the row width significantly reduced weed populations in both tillage systems (Table 2 and 3) because of increased competition from a higher density of crop plants. Similar effects on weed population of increased crop resulting from better soybean root distribution and more rapid shading of the ground have been reported by Burnside and Moomaw (1977) and Murdock *et al.* (1986). Freed *et al.* (1987) also observed that if weeds are controlled for the first 4-5 weeks after planting in narrow rows, the soybean canopy suppresses late emerging weeds. The yield from the

Table 3. Effects of tillage, row spacing and method of weed control on weed population and yield of grain sorghum.

	Conventional till (CT)		No-till after wheat (NTW)		No-till after clover (NTC)	
Main effect	Weed infestation[†]	Grain yield	Weed infestation	Grain yield	Weed infestation	Grain yield
	----- % -----	-- lbs acre^{-1} --	----- % -----	-- lbs acre^{-1} --	----- % -----	-- lbs acre^{-1} --
Row spacing						
18 in	43.8 b[‡]	4375 a	47.7	5031 a	87.7 a	5713 a
24 in	66.2 a	3696 b	50 a	4619 b	51.1 b	4407 b
36 in	63.3 a	3301 c	54.5 a	3562 c	48.3 b	3635 c
$LSD_{0.05}$	5.5	164.5	9.8	259.6	31.1	126.4
CV%	11.3	17	18.9	19.3	19.3	12.5
Weed control methods						
None	100	3696 b	100 a	4267 b	100 a	4532 b
Mechanical	46.5 b	4090 a	44.6 b	3445 ab	5.8 b	4569 b
Chemical	26.9 c	4052 a	7.7 c	4506 a	2.3 c	4769 a
$LSD_{0.05}$	6	138.1	9.4	220.5	26.3	190.8
CV%	13.7	16.7	14.4	15.9	15.6	14.7

[†] Weed percentageare in comparison to check as 100%.

[‡] Means within a column and variables followed by the same letter are not significantly different ($P = 0.05$) by Duncan's multiple range test .

45 cm row spacing was significantly higher than those from the 60 and 90 cm rows for all planting systems (Table 2 and 3). In both crops, a significant increase in yields from the 45 cm row was probably owing to suppression of weeds and better utilization of light, water, and nutrients because of rapid shading of the soil with the dense canopy and the greater number of plants per unit area. Similar yield results in soybeans have been reported by Parker *et al.* (1981). Although a significant tillage system x row spacing interaction affected both the seed yield and weed population (Table 4 and 5), it accounted for 0.4% and 1%, respectively, of the total variance.

WEED CONTROL METHOD

The average weed population in plots treated with herbicide was markedly lower than that in plots with no control but was not significantly different from that in the hoeing treatment in both planting systems (Table 2 and 3). These results concur with those reported by Burnside and Moomaw (1977). Acifluorfen provided variable control of broadleaf and grass weeds, being very effective when applied at an early stage of growth. In NT, herbicide treatment consistently produced the highest grain sorghum as well as soybean yield. The lowest yields were obtained from the plots with no weed control, because of weed competition in both crops. A row spacing x weed control interaction was not significant for seed yield (Table 4 and 5). However, the tillage systems x weed control and tillage systems x row spacing x weed control interactions were found to be significant for the seed yields, but they only accounted for less than 3% of the total variance and were deemed to be unimportant for further testing.

Table 4. Analysis of variance mean squares for soybean seed yield and weed population.

Source	d.f.	Seed yield	Weed population
Tillage system (T)	1	22930929 **	304 *
Error A	3	28589	27
Row spacing (R)	2	12455060 **	359 **
T ´ R	2	131721 *	87 **
Error B	12	9762	3
Weed control (W)	2	10063362 **	7173 **
T ´ W	2	161626 *	1401 **
R ´ W	4	78195	47 **
T ´ R ´W	4	226448 **	35 **
Error C	36	37588	6

*, ** Effect significant at *P* = 0.05 and *P* = 0.01, respectively.

Table 5. Analysis of variance for each sorghum planting system for weed infestation, grain yield and protein percentage.

		Conventional (CT)			NT after wheat			NT after clover		
Source	d.f.	Weed pop.	Grain yield	% protein	Weed pop.	Grain yield	% protein	Weed pop.	Grain yield	% protein
Replicate	4	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row Spacing (S)	2	**	**	**	**	**	**	**	**	**
R x S	8	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed Control (W)	2	**	**	**	**	**	**	**	**	**
R x S x W	4	**	**	NS	**	**	NS	NS	**	NS

*, ** Effect significant at *P* = 0.05 and *P* = 0.01, respectively.

CONCLUSIONS

The results of this research indicate that with proper weed control and other management inputs, growers can improve soybean and grain sorghum yield and reduce the cost of weed control by planting in narrow rows. Although yields with NT were lower, the land preparation costs were less and soil moisture as well as total soil nitrogen levels were higher. The loss in soybean seed yield can be minimized with adequate plant stands, which can be achieved with planter modification to achieve good soil-seed contact. Grain sorghum planted no-till after clover and wheat produced more grain than in the conventional tillage

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OPTIMIZING CONSERVATION TILLAGE PRODUCTION: SOIL SPECIFIC EFFECTS OF MANAGEMENT PRACTICES ON COTTON, SOYBEAN, AND WHEAT

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ABSTRACT

Our objective was to determine if crops grown on different soil types differed in their yield response to residue management systems. Two large experiments were conducted near Florence, SC on a field where soil type was mapped on a 100-ft grid. In the first experiment, cotton (*Gossypium hirustum* L.) was grown with conventional and conservation tillage with residue covers of cotton stubble, rye (*Secale cereale* L.) winter cover crop stubble, or corn (*Zea mays* L.) stubble. In the second experiment, a wheat (*Triticum aestivum* L.) and soybean (*Glycine max* L.) double crop system was grown with different surface and deep tillage treatments, and these treatments were compared against a two-year wheat-soybean-corn rotation. Only data from two soil map units (Norfolk loamy sand and Bonneau loamy sand) were used in this analysis. Interactions occurred for yield between soil management factors and soils for cotton and wheat yield, but not for soybeans. Most soil-specific yield responses to these management factors occurred primarily within the conventional tillage regime. For all three crops, both soils had similar yield responses to the soil management factors when conservation tillage was used. Our data indicate that across soil map units, the yield response to residue management inputs is more predictable with conservation tillage than with conventional tillage.

KEYWORDS

Cotton, wheat, soybean, tillage, cover crops

INTRODUCTION

Soil management practices that optimize conservation tillage production are likely to be soil specific (Triplett, 1986), and profit margins will partially dictate the use of a specific management option. Two relatively expensive practices for conservation tillage crop production that are recommended for coastal plain soils are the use of cover crops to increase the amount of surface residues and the use of deep tillage to alleviate compaction. Both practices generally increase plant available water, or at least reduce the effects of water-deficit stress. We hypothesized that plant productivity in response to these management techniques would be soil specific and conducted two experiments to determine the effect of these soil management practices on crop yield. The objective of the first experiment was to determine if Norfolk and Bonneau soils differed in their response to residue management systems for cotton yield. The objective of the second experiment was to determine if these soils differed in their yield response to deep tillage and rotation with corn for double cropped wheat and soybean.

MATERIALS AND METHODS

These two experiments were initiated in the fall of 1996 at Clemson University's Pee Dee Research and Education Center near Florence SC. Both experiments were grown in the same field, and corn was grown in the summer of 1996 prior to the start of these trials. For both experiments, large plots were used ($\geq$400 feet long) and each plot contained several soil map units. Plots were subdivided into 50 ft long subplots. Soil type was determined for each subplot based on a soil map of the field that was generated by USDA-NRCS soil scientists who mapped the field on a 100-ft grid. For this paper, only data from the Norfolk loamy sand (Typic Kandiudult) and Bonneau loamy sand (Arenic Paleudult) are included. These are two common soil types in agricultural fields on the coastal plain of the southeast USA. The Norfolk loamy sand is a very deep, well-drained soil where the loamy sand texture changes to a sandy clay loam texture within 17 inches of the surface. This is a

IN E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

productive soil with no major agronomic management concerns. Dissimilar to the Norfolk is the Bonneau soil. The Bonneau soil is also a very deep, well-drained soil, but the loamy sand texture reaches to a depth of 38 inches. Major agronomic considerations for this soil are doughtiness, low nutrient holding capacity, and high wind erosion potential (Anonymous, 1992).

COTTON EXPERIMENT

This experiment was designed to provide a range in residue covers, with a large amount of residue with cotton following a corn crop, a medium amount of residue with continuous cotton with a rye winter cover crop, and a low amount of residue with continuous cotton with winter fallow. Treatments were tillage (conservation tillage and disking) and residue type (fallow, rye winter cover crop, and corn stubble). Experimental design was randomized complete block and there were three replicates. Plot size was twelve 38-inch wide cotton rows that ranged in length from 400 to 700 ft long. Treatment assignments to plots remained the same each year.

Rye (approximately 100 lbs seed per acre) was planted in designated plots during the fall of each year. In 1997, 1999, and 2001 corn was planted in early April in designated plot. Corn was grown in 30-inch wide rows in 1997 and in 15-inch wide rows in 1999 and 2001. Seeding rates were 24,000 seeds per acre in 1997 and 30,000 seeds per acre in 1999 and 2001. Cotton was planted in early May each year. Seeding rates were approximately 4 seeds per foot of row in 1997 through 2000. Because of a planting error, seeding rates were approximately 7 plants per foot in 2001.

The conservation tillage management consisted of killing existing vegetation with herbicides at least two weeks before planting cotton each year. Herbicides used were glyphosate only in 1997, 1998, and 1999 and glyphosate and 2, 4-D in 2000 and 2001. The conventional tillage plots were disked twice and smoothed with an S-tined harrow equipped with rolling baskets about two weeks before planting cotton. Just prior to cotton planting, plots were deep-tilled to approximately 14 inches with a six-legged paratill. Shanks on the paratill were spaced 26 inches apart to allow for nearly complete loosening of the surface layer. This same tillage and weed management procedure was used prior to planting the corn plots in 1997, 1999, and 2001.

Lime and fertilizer applications were made as recommended for rainfed cotton by Clemson University Extension. Plots were scouted regularly and insecticide applications were made as needed to control insect pests. Two interior rows of each plot were harvested with a spindle picker. Samples of seedcotton were collected from the harvest bags from each subplot. These samples were ginned and lint percent was calculated from the ginout data.

WHEAT-SOYBEAN EXPERIMENT

This experiment was designed to evaluate surface and deep tillage in a continuous wheat-soybean double crop rotation and to compare those treatment combinations to deep-tilled wheat and soybean grown in a two-year rotation with corn. Treatments for the continuous wheat-soybean rotation were surface tillage (disking and conservation tillage) and deep tillage (paratill and no deep tillage). Surface tillage (disking and conservation tillage) was the only variable investigated for the wheat and soybeans grown in rotation with corn. Because deep tillage was not evaluated in the corn rotation treatment, we did not have a true factorial experiment in regard to tillage and rotation. Therefore, the four combinations of surface and deep tillage and the two treatments that included rotation with corn were treated as six soil management levels in the analysis of variance. Experimental design was randomized complete block and there were three replicates. Plots were 30 feet

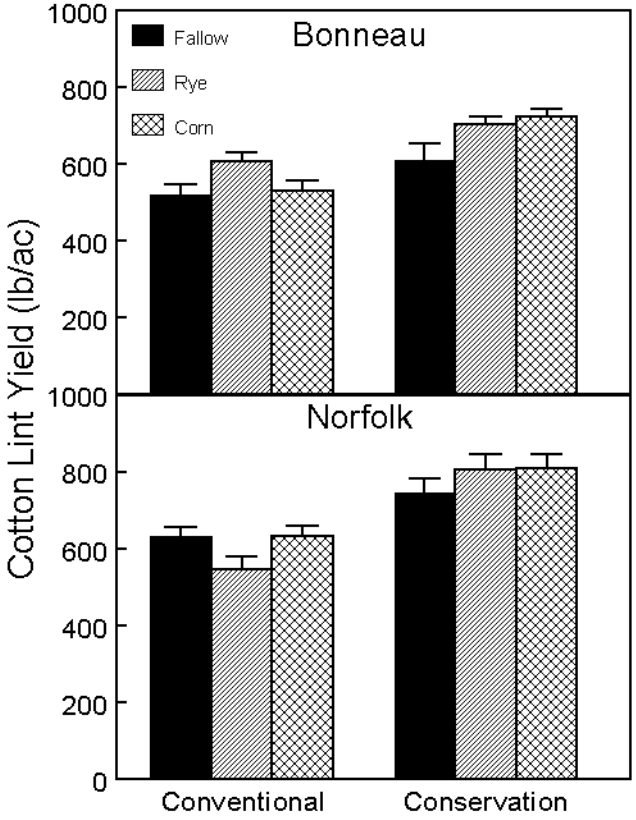

Fig. 1. Effect of residue cover and tillage on lint yield of cotton grown on two soil types near Florence, SC. Bars indicate continuous cotton (Fallow), continuous cotton grown with a rye winter cover crop (Rye), and cotton rotated with corn (Corn). Error bars are standard errors of means.

wide and 500 feet long, and treatment assignments to plots remained the same each year.

The soybeans and wheat were grown in 7.5-inch wide rows at recommended seeding rates (4 seeds per foot of row for soybean and 8 seeds per foot of row for wheat). Wheat was planted in November each year; soybeans were planted in June. In the plots rotated with corn, the corn was planted in April of 1998 and 2000. Row spacing for the corn was 30-inches wide in 1998 and 15-inches wide in 2000.

The conservation tillage management consisted of killing existing vegetation with herbicides and planting the crop. The conventional tillage plots were disked twice and smoothed with an S-tined harrow equipped with rolling baskets prior to planting. Just before planting, plots that received deep tillage were deep-tilled to approximately 14 inches with the same six-legged paratill that was used in the cotton experiment.

Lime and fertilizer applications were made as recommended for these crops by Clemson University Extension. Yields were determined by harvesting the plots with a combine equipped with an eight-foot wide cutting bar. Samples were collected from each harvest bag for seed moisture determinations.

RESULTS

COTTON EXPERIMENT

All treatments (including the cotton grown into corn stubble) were evaluated only in 1998 and 2000. Therefore, only data from those two years were included for this analysis.

Significant sources of variation for lint yield from the analysis of variance included soil, tillage, the tillage x year interaction (all $P \leq 0.01$), and the cover x tillage x soil interaction ($P = 0.1$). As expected, the Norfolk soil produced higher cotton lint yield than the Bonneau soil. Average yield of the cotton grown on the Norfolk soil was 700 lb/ac while lint yield of the cotton grown on the Bonneau soil averaged 629 lb/ac. Conservation tillage resulted in higher lint yield than conventional tillage both years, but the difference between the two tillage systems was 225 lb/ac in 1998 and only 83 lb/ac in 2000.

The nature of the cover x tillage x soil interaction indicates that residue management practices for the two tillage systems are soil specific. For cotton grown with conventional tillage, lint yield of the crop following a winter rye cover crop had higher yield than continuous cotton with winter fallow or cotton rotated with corn on the Bonneau soil (Fig. 1). On the Norfolk soil, however; cotton grown following the rye winter cover crop had lower yield than the other two residue types. There was no difference between continuous cotton grown with winter fallow and cotton grown in rotation with corn on either soil (Fig. 1). With conservation tillage, the yield response to the residue types was the same on both soils. Lint yield was lowest when the only residue cover was cotton stubble, and there was no difference between continuous cotton grown with a rye winter cover crop and cotton grown in rotation with corn.

WHEAT-SOYBEAN EXPERIMENT

Since all treatments, including the wheat and soybeans grown in rotation with corn, were only grown in 1999 and 2001, only data from those two years were included for this analysis. Both 1999 and 2001 had lower than average rainfall for both wheat and soybean growing seasons, and this resulted in low yields for this experiment (Figs. 2 and 3).

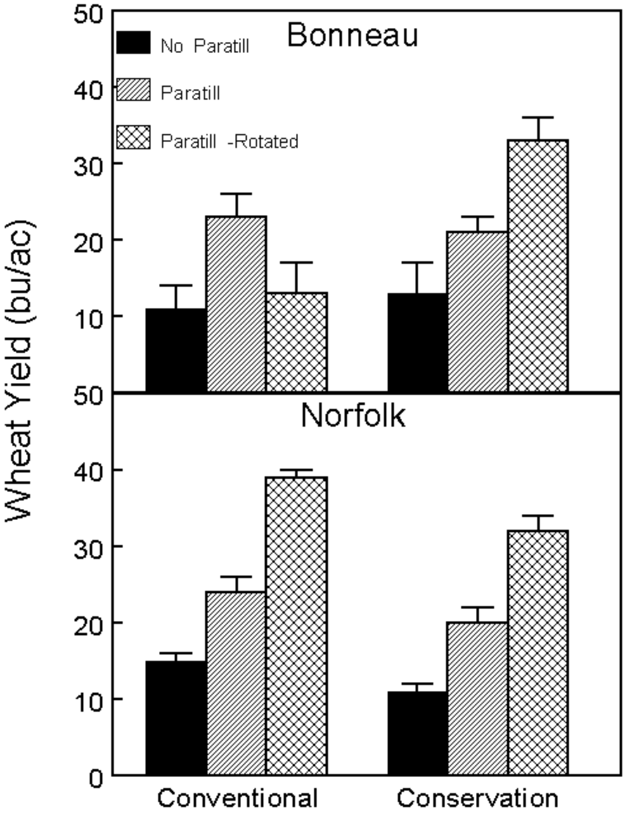

Fig. 2. Effect of surface and deep tillage and rotation with corn on yield of wheat grown in a wheat-soybean double crop system on two soil types near Florence, SC. Bars indicate continuous wheat-soybean with no deep tillage (No Paratill), continuous wheat-soybean with deep tillage (Paratill), and wheat-soybean rotated with corn with deep tillage (Paratill-Rotated). Error bars are standard errors of means.

For wheat yield, significant sources of variation from the analysis of variance were year, soil, soil management, and the soil x soil management interaction (all $P \leq 0.01$). Average wheat yields were 31 bu/ac in 1999 and 19 bu/ac in 2001. Similar to the results from the cotton experiment, average wheat yield was greater on the Norfolk soil (26 bu/ac) than on the Bonneau soil (23 bu/ac). Deep tillage with a paratill increased yield on both soils in both conventional and conservation tillage (Figure 2). The soil X soil management interaction was primarily the result of the wheat yield response to rotation with corn. For conventional tillage on the Norfolk soil and for conservation tillage systems on both soils, rotating with corn resulted in substantially higher yield than continuous wheat-soybean. On the Bonneau soil with conventional tillage, however, yield for the wheat rotated with corn was lower than wheat yield from the continuous wheat-soybean treatment that was paratilled (Fig. 2).

For soybean yield, significant sources of variation from the analysis of variance were year, soil, soil management, and the soil management X year interaction. Average soybean yields were 29 bu/ac in 1999 and 15 bu/ac in 2001. Soybean yield on the Norfolk soil average 23 bu/ac and yield on the Bonneau soil averaged 20 bu/ac. The soil management X year interaction was primarily due to magnitude differences between treatment combinations between years and not ranking. Lower yields in 2001 than in 1999 resulted in smaller differences between treatments in that year.

The Norfolk and the Bonneau soils had similar soybean yield response to the treatment combinations; the soil X soil management interaction was not significant ($P = 0.16$). For both conventional and conservation tillage on both soils, lowest yield was generally for soybean grown without deep tillage, and greatest yield was for soybeans rotated with corn (which was deep tilled) (Fig. 3).

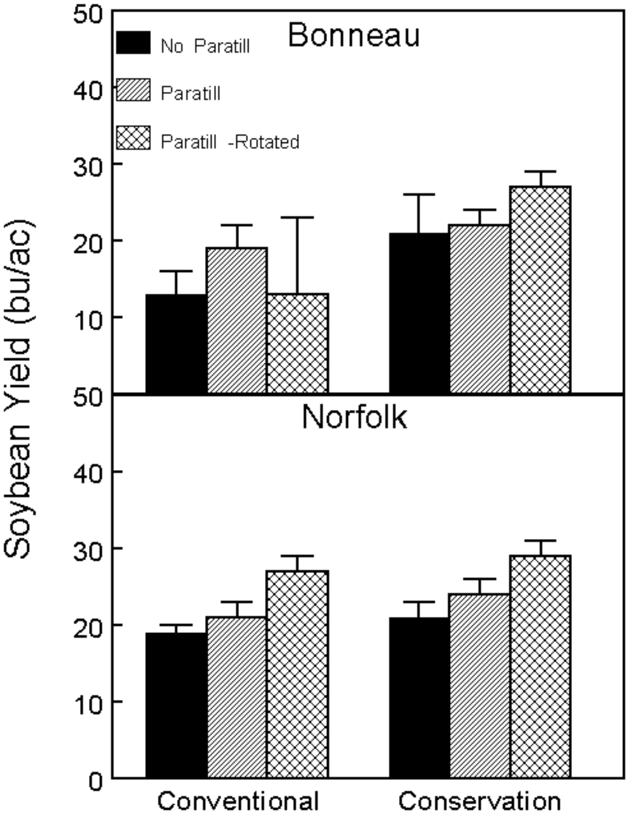

Fig. 3. Effect of surface and deep tillage and rotation with corn on yield of soybean grown in a wheat-soybean double crop system on two soil types near Florence, SC. Bars indicate continuous wheat-soybean with no deep tillage (No Paratill), continuous wheat-soybean with deep tillage (Paratill), and wheat-soybean rotated with corn with deep tillage (Paratill-Rotated). Error bars are standard errors of means.

SUMMARY

Some results of this experiment support and some results are contrary to our hypothesis that soil management systems are specific to these two soils. Interactions occurred between the management factors and the soils for cotton and wheat yield, but did not occur for soybeans. However, inspection of Figures 1, 2, and 3 indicate that the soil-specific yield responses to these management factors occurred primarily within the conventional tillage management regime. For all three crops, both soils had similar yield responses to the treatments we evaluated when conservation tillage was used. Although further research is needed to support these findings, they suggest that grower returns to management practices may be more predictable throughout and across fields when conservation tillage is used.

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EFFECTS OF TALLER WHEAT RESIDUE AFTER STRIPPER HEADER HARVEST ON WIND RUN, IRRADIANT ENERGY INTERCEPTION, AND EVAPORATION

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ABSTRACT

Storage of precipitation as soil water is critical to stable dryland crop production in the semiarid southern Great Plains. The region is characterized by high winds that promote evaporation and reduce precipitation storage efficiency. Evaporation may be reduced by residues that intercept irradiant energy and increase the aerodynamic resistance. Combine harvesters with stripper-type headers remove grain while leaving taller, erect straw that is not left by conventional platform headers; and thus, they potentially reduce evaporation. Our objectives were to characterize the effect of residue height after wheat (*Triticum aestivum* L.) harvest with stripper or conventional sicklebar platform headers on wind velocity, intercepted solar irradiance, and evaporation. We measured wind velocity, solar irradiance at the soil surface, and evaporation with Bowen ratio radiation and energy balance systems in two contiguous 16-acre wheat fields after stripper header harvest, SHH, or platform header harvest, PHH. Compared with PHH wheat residue, the taller residue after SHH reduced mean wind velocity and, consequently, the potential transport of water vapor (especially for evaporation from wet soil). Measured irradiant energy at the soil surface was 12% lower in the taller residue left by the SHH compared with short residue left by the PHH. Consequently, Bowen ratio estimated soil evaporation from SHH plots was reduced 26% compared to PHH plots during a 4-day evaluation interval. However, the differences in evaporation between the tall and short residue were very small because of the dry soil conditions during our experiment. We conclude that water conservation will be increased when using stripper type combine headers to harvest wheat because taller residue reduced wind velocity and increased interception of irradiant energy.

KEYWORDS

Stripper header, wind profile, intercepted irradiance, Bowen ratio, latent heat transport

INTRODUCTION:

The semiarid climate of the southern Great Plains is characterized by high winds that promote evaporation and precipitation that is erratic in amount (ranging from 15.7 to 23.6 inches annually) and in frequency, resulting in drought periods. Although sixty-five percent of the precipitation at Bushland falls as rain during the May-August (summer) growing season, the mean annual pan evaporation at Bushland is 90 inches or more than 4 times the 19 in. annual precipitation. For each inch of precipitation stored as soil water during fallow after wheat, the subsequent grain sorghum [*Sorghum bicolor* (L.) Moench] yield increased from about 385 lbs acre-1 (Jones and Hauser, 1975) to 430 lbs acre-1 (Baumhardt *et al*., 1985). Therefore, most dryland cropping systems in the southern Great Plains rely on fallow periods between crops to store precipitation as soil water, which stabilizes and increases yields of subsequent crops.

A commonly used cropping sequence is the three-year wheat-sorghum-fallow (WSF) rotation that produces two crops (Jones and Popham, 1997). Wheat is established in October of the first year and then harvested 10 months later in July. The soil is fallowed for 11 months until June of the second year when grain sorghum is grown using the stored soil water to augment rainfall. After sorghum harvest in November of the third year the soil is again fallowed for 10 months when wheat is planted and the cycle repeated. During fallow, crop residue increases infiltration (Baumhardt *et al*., 1993) and reduces evaporation; thus, conserving precipitation for dryland crop production (Steiner, 1994). For example, a no-tillage residue management system significantly increased profile soil water contents compared to stubble mulch tillage (Jones *et al*., 1994) because of reduced evaporation. Water loss due to evaporation during fallow, however, was 48% of total precipitation with the WSF rotation (Stewart and Burnett,

IN E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

1987).

Other studies have shown that residue amount reduced evaporation either by intercepting irradiant energy or by increasing aerodynamic resistance to evaporative flux (Heilman *et al*., 1992). In comparisons of bare soil with wheat-stubble protected soil, Lascano and Baumhardt (1996) related significant reductions in evaporation, primarily due to reduced net irradiance at the soil surface (R_n). More or taller residue may further reduce net irradiance. McMaster *et al*. (2000) reported that recently developed stripper type headers used with combine harvesters increased residue height compared to conventional sicklebar-type platform headers and reduced wind velocity. In that study, they concluded that taller residue architecture retained when using a stripper header harvesters, SHH, compared to conventional platform header harvesters, PHH, reduced the near surface wind velocity and consequently decreased potential evaporation and soil erosion. The effects of residue retained when using a SHH compared to the residues after a PHH on R_n and evaporation has not been reported. Our objectives are to characterize the effect of residue height after wheat harvest with stripper or conventional headers on wind velocity, intercepted solar irradiance, and evaporation.

MATERIALS AND METHODS

We conducted an experiment to quantify residue height effects on the wind velocity, interception of solar irradiance, and evaporation of soil water during the fallow after wheat-harvest phase of the WSF rotation at the USDA-Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, TX (35° 11' N, 102° 5' W). A 33-acre (950 x 1500 ft) nearly level Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) was cropped to winter wheat (TAM 110) sown 1 November 2000 at a 35 lbs acre-1 rate on a 12" row spacing and north-south orientation using a high-clearance grain drill with hoe openers and press wheels. At wheat harvest (19 June 2001), the field was divided into two 950 x 750 ft plots that were harvested using either a conventional sicklebar platform header, PHH, or stripper header, SHH, (Shelbourne Reynolds Inc., Colby, KS). The resulting straw heights were 15.5 ± 0.8 inches with PHH and 23.4 ± 1.3 in. with SHH. The fallow after wheat was maintained under no-till conditions by applying 3.5 lbs a.i. acre-1 atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and 1 lbs a.i. acre-1 2,4-D [(2,4-dichlorophenoxy) acetic acid] resulting in no soil disturbance.

Inter-row near soil surface pyranometers and anemometer arrays were measured by a centrally located data logger (Model 23X, Campbell Scientific, Logan, UT) at a 0.1Hz scan frequency and averaged (recorded) on 3, 20, 60, and 1440 -minute intervals. Near soil-surface shortwave solar irradiance was measured between the north-south wheat rows using triplicate pyranometers (Model LI200X, Campbell Scientific) mounted on 2x6x8 inch wood blocks. Because of the north-south row orientation and the resulting symmetry in energy interception, measurements centered between rows reflect a spatially averaged treatment value (Lascano *et al*., 1994). Pyranometers were exchanged between the two straw height plots at 37 days and compared after 74 days to quantify any sensor bias. Treatment effects on solar irradiance were contrasted using unpaired t-tests and regression analyses.

Wind velocity was measured using cup anemometers (Met-One 014A, Campbell Scientific) arrayed on two masts positioned with > 200 ft. fetch for winds originating from 210° ± 10° as determined by a vane (R.M. Young 03001, Campbell Scientific). Anemometers were positioned at heights of 14, 26, 43, and 79 inches and connected to the data logger (100 ft away) via remote input modules (Model SDM-SW8A, Campbell Scientific). Anemometer orientation was necessarily inverted near the soil surface, but prior instrument calibrations established that sensor orientation had negligible effect on indicated wind velocity, P(T<=t) of 0.73, and that instrument measurements were not different, P(T<=t) of 0.35, between the two array-masts. Wheat residue effects on wind velocity, *U*, with height, *z*, was described by the logarithmic wind velocity equation:

where *U** is the friction velocity, *k* is the von Karman constant, z_0 is surface roughness length, and *d* is the displacement height. We assumed that the log wind profile extended below the height of the sparse (29 stems/ft^2) wheat stubble canopy (Jacobs and van Boxel, 1991) and that z_0 and *d* could be estimated using nonlinear regression from a

$$U(z) = \frac{U^*}{k} \ln\left[\frac{(z-d)}{z_0}\right]$$

subset of wind data taken from day of year, DOY, 217 for tall (SHH) and short (PHH) stubble.

Soil water evaporation was estimated using the Bowen ratio-energy balance (BREB) method for day of year (DOY) 242-248. The BREB method uses measurements of the total available energy (net radiation), the energy absorbed in soil (soil heat flux), and air temperature and humidity at two heights to calculate the energy used to evaporate water as described by Todd *et al.* (2000b). Temperature and humidity sensors are influenced by an upwind "fetch" distance, which, if sufficient, results in evaporation estimates that are uninfluenced by the field edges. We used two BREB systems (Radiation and Energy Balance Systems, Seattle, WA) installed in the northeast corner of each treated field, 65 ft. from the north and 330 ft.

from the east boundary, to maximize fetch in the direction of the prevailing winds, i.e., fetch to the south and southwest varied from 900 ft to greater than 1000 ft. Each BREB system consisted of aspirated temperature and humidity sensors, a net radiometer, two soil heat flux transducers, and two soil temperature sensors. Measurements were averaged over 30 minutes, stored on automatic dataloggers, and, subsequently, screened for validity using the methods of Ohmura (1982). Calculations of the temperature and vapor pressure gradients, Bowen ratio, and BREB latent heat flux followed Bausch and Bernard (1992) using valid common measurement periods between the two BREB systems.

RESULTS AND DISCUSSION

Solar irradiance measured at the soil surface in the taller residue is plotted as a function of the corresponding value of solar irradiance measured in the short residue (Fig. 1) for the period from DOY 178-253. The resulting slope of a least squares regression line forced through the origin (i.e., measured solar irradiance at night would be zero regardless of straw height) shows that the taller stubble left by the stripper header had approximately 12% less irradiance at the soil surface than with the shorter straw. The intercepted irradiance during the first 37 days (plotted as open circles) was 11.4 % compared to 12.4 % for the 37 days following instrument exchange between treatments (plotted as closed circles) These data varied less than the limits ($P<0.95$) around the 11.8% calculated for the combined data; thus, indicating that there was no instrument bias. The effect of taller SHH residue was to lower irradiance at the soil surface compared to PHH residue and, consequently, reduce more of the energy that drives evaporation in the SHH plots.

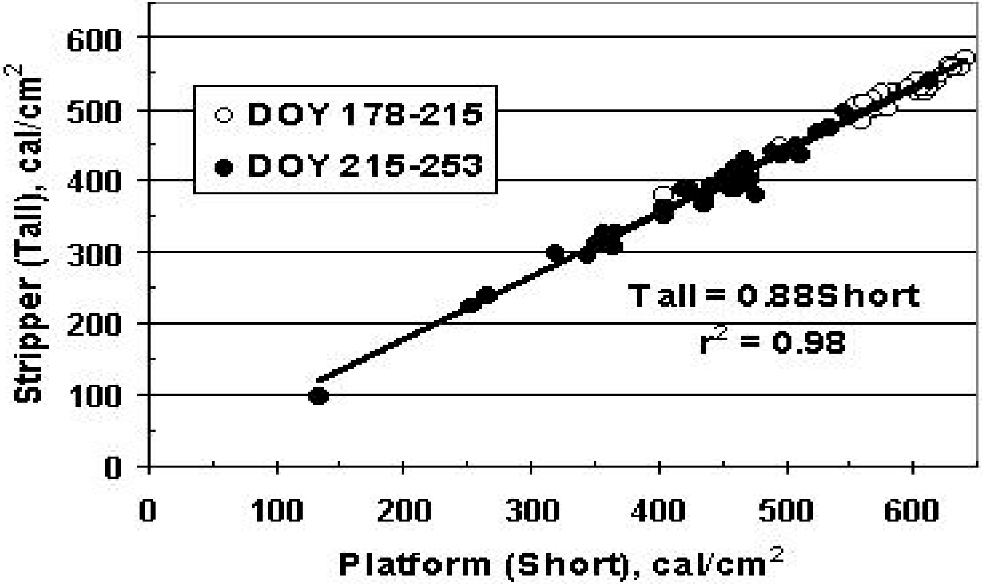

Fig. 1. Mean daily solar irradiance measured at the soil surface after stripper header harvest, SHH, plotted relative to the corresponding solar irradiance after platform header harvest, PHH, for day of year, DOY, 178-253. Sensors were exchanged after 37 days, but the values from DOY 178-215 (open circles) and 216-253 (closed) indicated no sensor bias and that 12% more interception of radiation with tall SHH residue than with short PHH residue.

Examples of mean solar irradiance at the soil surface for platform or stripper header residue treatments are plotted with time (Fig. 2) for DOY 217-218. The primary difference in the amount of shortwave solar irradiance at the soil surface occurs in the morning and evening periods. Compared to the PHH residue, the taller SHH residue shaded the soil in the morning and evening; thus, shortening the time when soil was exposed to the sun. Peak solar irradiance occurred near solar noon and tended to be greater with tall residue, probably because of in-canopy reflectance. The mean daily solar irradiance for the tall residue left by the stripper header was 540 cal cm^{-2} compared to 614 cal cm^{-2} measured in the shorter residue, about 77 and 88 % of the 700 cal cm^{-2} reference irradiance measured at 80 inches above the soil surface. The energy needed to drive evaporation is reduced by the taller residue architecture retained after stripper header harvest.

Daily wind velocity averaged using anemometers at all heights during the same period, DOY 178-253, was 5.0 ± 1.2 mph in taller SHH wheat residue compared with 5.4 ± 1.3 mph measured in the short PHH residue. The pair-wise t-test comparisons of mean daily wind velocity in the taller SHH wheat residue was significantly ($P>0.99$) lower than for the corresponding short PHH residue. An example 15-minute wind profile plot (Fig. 3.) for DOY 217 when the wind originated from approximately 210°, i.e., from the prevail-
rection (R. Nolan Clark,
n.), conforms to a log-
e resulting displacement
the short PHH residue
compared to the 8.8 in.
for the taller SHH
ue. We expected that the
residue would vertically
pwardly) the wind ve-
le compared with PHH
ich is similar to results
McMaster *et al*. (2000).
Master *et al.* (2000) dif-
mean wind velocity due
height effects on mo-
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heights of at least 80 inches.

Increased aerodynamic resistance will reduce vapor transport, i.e, evaporation and was calculated for DOY 217 from surface roughness, z_0, values of 1.1 in. for the taller

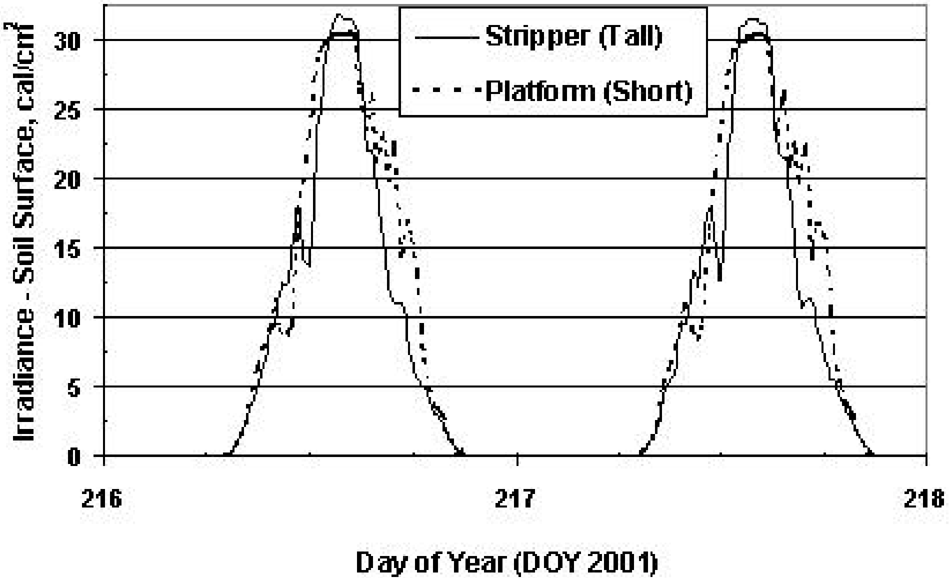

Fig. 2. Mean solar irradiance measured at the soil surface after platform header harvest, PHH, (dashed line) and after stripper header harvest, SHH, (solid line) plotted with time. Taller SHH residue intercepted morning and evening irradiance, resulting in a shorter (narrower) period when irradiance reached the soil.

SHH residue compared to 1.7 in. for the shorter PHH residue and the corresponding friction velocities, *U**, of 0.6 and 0.7 mph (Shuttleworth and Gurney, 1990). The resulting total aerodynamic resistance in the tall SHH residue (20.4 s/ft) was 15 % greater than for shorter residue of conventional PHH (18 s/ft). Our data show that the greater aerodynamic resistance to evaporation with the tall SHH residue has the potential to reduce soil evaporation compared with the PHH wheat residue. The potential impact of aerodynamic resistance on evaporation, however, will be most important immediately after a rainfall because the initial soil water evaporation is often limited by vapor transport and energy.

Bowen ratio measurements of daily soil water evaporation (E) from the SHH field varied from 18 - 36 % less E than from the PHH field (Fig 4.) during the period DOY 242-245 and 248. Measurements of evaporation on DOY 246 and 247 could not be used because a net radiometer malfunctioned. Todd *et al*. (2000b) calculated a root mean square difference of 8% between these two BREB systems, which was less than the range of differences we observed between the two harvest treatments in this study. Total E from the SHH field was 0.13 in. compared with 0.18 in. from the PHH field, resulting in an overall mean evaporation reduction with SHH of 26 % compared with PHH. The surface soil was dry during these measurements; however, our reported evaporation rates were consistent with the range of soil-limited E rates measured for a bare Pullman soil using small lysimeters (Todd *et al*., 2000a). We attributed the reduced evaporation in the SHH plots compared with PHH plots to (i) a reduction in net radiation (R_n) in the stripper header field that averaged 9% less than that measured in the shorter residues of the platform header field, and (ii) greater (more negative) soil heat flux (G) in the PHH field, averaging about 5% more. The calculated daily Bowen ratios were always positive, ranging from 1.3 to 4.0 in the PHH field and from 1.5 to 6.1 in the SHH field.

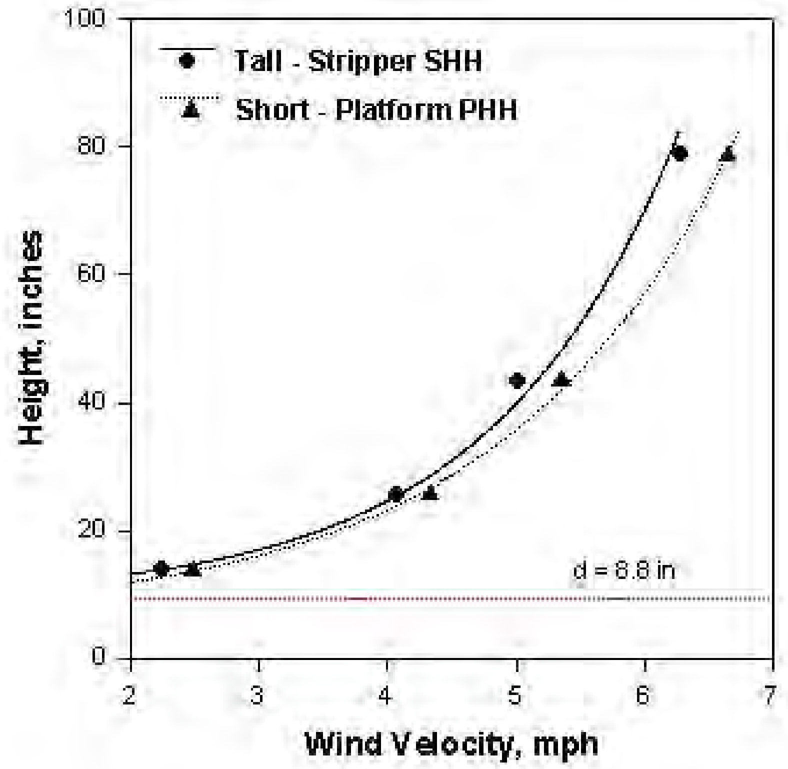

Fig. 3. Wind profiles over wheat residues harvest with platform headers, PHH, or stripper headers, SHH. The displacement height (*d*) of the taller SHH wheat residue is 8.8 inches above the surface compared with the shorter PHH residue displacement height (not shown) of 6.5 inches.

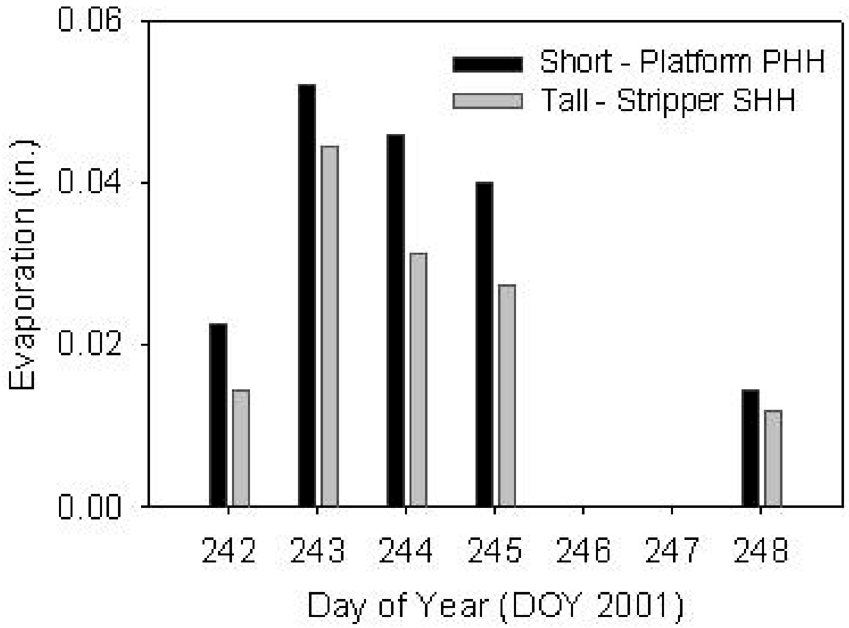

Fig. 4. Soil water evaporation estimated by Bowen ratio-energy balance from two wheat fields harvested by platform header, PHH, (short residue) or by stripper header, SHH, (tall residue).

Under the conditions of our experiment, the measured differences in E between SHH plots, tall residue, and PHH plots, short residue, was significant.

SUMMARY AND CONCLUSIONS

We compared shortwave solar irradiance, wind velocity, and evaporation in fields with 23.4 in. residue after stripper header harvest or with 15.5 in. residue after platform header harvest. Measured irradiant energy at the soil surface was reduced approximately 12 % by the taller residue SHH plots compared with short residue in PHH plots. Compared to PHH residue, the taller SHH residue architecture reduced the wind velocity and, consequently, reduced potential transport of water vapor (especially for evaporation from wet soil). Evaporation measured during a 4-day evaluation interval using the Bowen ratio method was 26% less in residue after stripper harvest compared with the short residue after platform header harvest. The differences, however, were very small because of the dry soil conditions during our experiment. Nevertheless, we conclude that water conservation will be increased when using stripper type combine headers to harvest wheat, because of reduced wind velocity profiles and increased interception of irradiant energy compared with platform header harvested wheat.

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DISCLAIMER

THE POTENTIAL OF NO-TILL RICE PRODUCTION IN ARKANSAS

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ABSTRACT

Increasing production costs combined with recent and pending environmental legislation are forcing Arkansas' rice producers to find new ways to maintain their productivity without degrading the natural resource base on which they depend. The objective of this work was to evaluate the potential for shifting to no-till rice production using current and novel crop rotations. A series of plots were established in 1999 that contain two and three phase rotations using rice, soybeans, corn, and wheat. All rotations have a conventional and no-till comparison along with fertility and variety comparisons. On average, no-till grain yields in 2000 from the conventional rotations were 957 kg ha^{-1} lower than those from conventional tillage plots. This yield difference was more than cost savings from no-till production, thus there was an average reduction in net income of \$166.57 ha^{-1} in the no-till treatments when compared to the conventional till treatments. In 2001 grain yields were similar for both tillage treatments. This resulted in a \$146.45 ha^{-1} increase in net returns from the no-till treatment when compared to the conventional till treatment. Rice grain yields in plots grown after wheat were low in 2000 with all treatments resulting in negative net returns. Improved management in the wheat rotations in 2001 resulted in an average net return of \$82.60 ha^{-1} for the no-till treatments. This was lower than net returns for the conventional tillage treatment. No-till rice has potential in the crop rotations currently used in the rice production areas of Arkansas

KEYWORDS

Crop rotation, wheat, economic analysis, crop budgets, returns

INTRODUCTION

Rice, as it is grown in the Mississippi Delta area of Arkansas, ranks as one of the most tillage intensive row crops in the United States. In order to maintain a 'flood' through much of the growing season, farmers have cut or leveled their fields to slopes between 0 and 0.15%. To move water smoothly across a field it has been the tradition to 'smooth' a field numerous times with a land plane prior to planting. To effectively use the land plane, it is necessary to disc and harrow the field numerous times. Oftentimes these field operations are carried out in the autumn and spring. Rice is harvested when grain moisture is between 18 and 20%, a time when the soil is wet from the flood. Field operations at this time can result in extensive rutting which leads to a need for more tillage. Years of intensive cultivation have resulted in an appreciable decline in soil organic matter (Scott and Wood 1989; Scott *et al*. 1994). Government regulation and support payments that as a percentage of profits, were as high as 120% have not provided farmers with incentives to reduce production costs, a scenario that might stimulate interest in no-till rice production (Cramer *et al*., 1990; Greenwalt 1997). The Federal Agriculture Improvement Act of 1996 removed controls on the amount of rice produced but did not guarantee high payments if market prices were low. There is speculation that the farm bill under negotiation may place more emphasis on conservation and restrictions on supplemental payments. This, along with growing pressures to improve air and water quality, makes the introduction of conservation tillage a key feature to future rice production in the Arkansas delta area. More recently there has been a move by some farmers to what is termed a "stale seedbed" approach to rice production. In this system the ground is tilled and floated in the fall. In spring a burn-down herbicide is applied and the rice is planted. While reducing the amount of tillage, this system leaves the soil bare at the beginning of the winter when rainfall increases. This greatly increases the potential for water erosion. This system is attractive to growers in that it can decrease production costs. However, it is unlikely to pass the land stewardship test. With no guidelines on how rice might fit

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into the conservation tillage framework, it is unlikely farmers will make a change to conservation tillage. It is one goal of this project to provide rice farmers with information that will allow them to move to conservation tillage without compromising their profitability.

MATERIALS AND METHODS

The following two and three phase rotations were selected for use in this study: 1) continuous rice, 2) rice-soybean, 3) soybean-rice, 4) rice-corn, 5) corn-rice, 6) rice (wheat) rice (wheat), 7) rice (wheat)-soybeans (wheat), 8) soybeans (wheat)-rice (wheat), 9) rice-corn-soybeans, and 10) rice-corn (wheat)-soybeans. The two-phase rotations are commonly used in Arkansas rice producing areas, while the rotations containing wheat are not currently used. Wheat is grown as a winter crop. In all the rotations where rice is grown after wheat, it was necessary to begin the study with experimental varieties because commercial varieties available at that time were of too long a duration to allow harvest in time to plant the following rice crop. In February 1999 a site was selected for this study at the University of Arkansas Rice Research and Extension Center and the field cut to a 0.15% slope. The soil at this site is a fine, montmorillonitic, thermic Typic Albaqualf of the DeWitt soil series. Main or rotation plots measuring 76 m x 12 m were laid out in a north-south direction. Each of the four replications was then divided in half with each side randomized as conventional or no-till tillage treatments. Each tillage treatment was then split into a standard and high fertility treatment. Two varieties of each crop species were planted in a continuous strip across the conventional-and no-till treatments. As a result of field leveling all plots were tilled in 1999 and the no-till treatments started in 2000. Fertility treatments consisted of a 'standard' recommendation that a farmer would receive from the analysis of soil samples collected from the field. The 'enhanced' fertility level consisted of elevated levels of nitrogen, phosphorus, and potassium. Care was taken to select popular commercial varieties that would be available for a number of years. All rice and wheat plots were sown with an Almaco no-till drill at a 190mm row width. At harvest a 1 m boarder was removed from the outside of each fertility plot with the remainder of the plot harvested. Grain yields were calculated at 13% moisture. Plot levees were replaced on all plots not planted into wheat by November in order to impound winter rainfall. In March of the following year the levees were removed and the plots either tilled or sprayed with Roundup to control the winter weeds.

Detailed notes were kept on all field operations and inputs for each treatment. These data were used to estimate net returns for each treatment using the procedure outlined in the Mississippi State Budget Generator User Guide, version 3.0 (Spurlocka and Laughlin, 1992). All economic returns were estimated using a rice price of $153.74 t^{1}, a land cost of 25%, and input costs comparable to those on a 405 ha rice farm. Yield and economic returns have been collected and calculated for all crops and phases. Only those results for rice will be presented in this paper.

RESULTS

FULL SEASON RICE

Rice grain yields pooled over all treatments were 10,080 kg ha^{-1} in 1999 (Table 1). These are considered high yields and are attributed to the field being fallowed for a number of years prior to initiating the study. Analysis of soil samples from the site support this conclusion along with differences observed when comparing fertility treatments (Table 1). Variety differences were significant in 1999 with the newer variety Wells higher than LaGrue.

Overall dry grain yield dropped by 1,109 kg ha^{-1} in 2000 when compared to the previous year (Table 1). Grain yields for the no-till plots were on average 957 kg ha^{-1} lower than for the conventional till plots. Plant stands were lower in the no-till plots (data not presented), while these plots were slower emerging. Problems in achieving acceptable plant stands in the no-till plots was attributed to difficulties in adjusting the seed drill to not 'hairpin' when there was litter on the soil surface. The biggest impact on grain yield came from rotation, where dry grain yield in the continuous rice rotation was 1,764 kg ha^{-1} less than from the rice following either soybeans or corn. As in the previous year, dry grain yield from the 'standard' fertility treatment was higher than that from the enhanced fertility treatment. However, that difference was only 353 kg ha^{-1}. There was little difference between the two varieties in dry grain yield with Wells dry grain yield 555 kg ha^{-1} higher than LaGrue.

Mean dry grain yield over all treatments was 7,963 kg ha^{-1} for the 2001 season, a decrease of 1,008 kg ha^{-1} from the previous year. Dry grain yields for rice have declined each year since this study was initiated. We have no specific data that identifies the cause of this decline but feel that it might be attributed to fertilizer rates that are less than is needed and/or a decline in soil quality that is the result of cropping an area that was previously fallowed for a long period of time. Unlike the previous year, dry grain yields for the no-till treatments averaged 202 kg ha^{-1} more than the conventional till treatments. Stand counts indicated there were no differences in plant stand between the two tillage treatments. We attribute this to modifications we made on the grain drill, in particular changing coulters and adding 'close till' closing wheels. As in the previous year, dry grain yields for the continuous rice rotation were lower than rice following either soybeans or corn. Unlike the two previous years, there was a 302 kg ha^{-1} increase in dry grain yield

Table 1. Summary of 1999, 2000 and 2001 full-season rice grain yields for the long-term cropping systems study at Stuttgart, Arkansas.

Effect	Treatment	1999 yield Kg ha^{-1}	2000 yield kg ha^{-1}	2001 yield kg ha^{-1}
All	All	10,080	8,971	7,963
Tillage	Conventional	NA	9,475	7,862
	No-till	NA	8,518	8,064
Rotation	Continuous rice	NA	7,812	7,308
	Following soybeans	NA	9,576	8,266
	Following corn	NA	9,576	8,316
Fertility	Standard	10,282	9,173	7,812
	Enhanced	9,878	8,820	8,114
Variety	Wells	10,786	9,274	7,913
	LaGrue	9,374	8,719	8,014

with the enhanced fertility treatment when compared to the standard fertility treatment. This result suggests that we are probably equilibrating to the two fertility levels used. Declining grain yields was accompanied by a change in variety rankings with the variety LaGrue yielding 101 kg ha^{-1} more than Wells. Nutrient uptake data (not shown) indicate Wells consistently removed more nutrients than LaGrue to achieve the same yield. LaGrue consistently partitions a higher percentage of above-ground dry matter to grain than does Wells.

Overall high grain yields in 1999 resulted in an average net return for all treatments of $330.50 (Table 2). The cost of land leveling was not included in this budget. Increasing fertilizer rates resulted in lower yields and a $35.02 ha^{-1} drop in net profits. The biggest impact in net profit was variety with average net profits for Wells $73.28 ha^{-1} higher than for LaGrue.

Lower grain yields in the year 2000 did not result in lower net returns (Table 2). This result is attributed to the fact that the field was not disturbed once it was leveled in 1999; thus, there was not a need for extensive tillage, particularly with the conventional till plots. Highest net returns ($620.61 ha^{-1}) were from the conventional till plots. Lowest net returns ($349.48) were from the continuous rice rotation. Net returns for rice following corn were lower than for rice following soybeans because of the field operations required to deal with corn stalks and stubble remaining after harvest. Lower grain yields from the enhanced fertility treatment compared to the 'standard' fertility treatment resulted in a $104.13 decrease in net returns from the enhanced fertility plots. Higher overall yields from the variety Wells resulted in a $73.41 ha^{-1} advantage over LaGrue.

Mean net return over all treatments in 2001 decreased from the year 2000 but was higher than in 1999 (Table 2). With nearly equal grain yields in the two tillage treatments, the advantage of no-till in reducing production costs was evident in its $146.45 ha^{-1} higher net returns. Net returns for the continuous rice rotation were $88.68 and $100.34 ha^{-1} less than rice following soybeans or corn, respectively. Despite these lower net returns continuous rice had higher returns than either corn or soybeans, the other two crops tested in these rotations (data not presented). The increase in grain yield resulting from higher fertility levels (Table 1) was not sufficiently high to offset the cost of fertilizer and thus resulted in a $8.11 ha^{-1} decrease in net returns (Table 2). This was the third consecutive year that there was a net loss from the enhanced fertility treatment. Unlike the previous two years, the variety LaGrue had the highest net returns when averaged across all treatments.

Table 2. Net returns ($ ha^{-1}) for each main effect from rotations containing full-season rice varieties. Rice was priced at $153.74 t^{-1} and a 25% land cost included.

Effect	Treatment	1999 net Returns $ ha^{-1}	2000 net Returns $ ha^{-1}	2001 net Returns $ ha^{-1}
All	All	$330.50	$499.38	$410.46
Tillage	Conventional	NA	$620.61	$337.23
	No-till	NA	$454.04	$483.68
Rotation	Continuous rice	NA	$349.48	$347.45
	Following soybeans	NA	$579.81	$436.13
	Following corn	NA	$568.89	$447.79
Fertility	Standard	$348.00	$551.35	$414.52
	Enhanced	$312.98	$447.22	$406.41
Variety	Wells	$367.14	$535.99	$404.02
	LaGrue	$293.86	$462.58	$416.89

Table 3. Summary of 1999, 2000 and 2001 short-season rice grain yields for the long-term cropping systems study at Stuttgart, Arkansas.

Effect	Treatment	1999 yield kg ha^{-1}	2000 yield kg ha^{-1}	2001 yield kg ha^{-1}
All	All	NA	6,250	6,300
Tillage	Conventional	NA	6,451	6,703
	No-till	NA	5,393	5,846
Rotation	Following wheat	NA	6,250	6,300
Fertility	Standard	NA	6,199	6,048
	Enhanced	NA	6,300	6,552
Variety	STG95L-28-045	NA	6,300	5,040
	Early LaGrue	NA	5,544	dropped
	XL-6	NA	7,963†	7,459

† Average value of standard and enhanced fertility only on conventional till plots

SHORT-SEASON RICE

Initial plantings of short-season rice were made in the year 2000 (Table 3). Overall grain yields (6,250 kg ha^{-1}) were much lower than those for the full season treatments (Table 1). Wheat harvest and subsequent sowing of these varieties was in July when the temperatures were high. A large number of 'blank heads' resulting from high temperatures were observed in all treatments. No-till grain yields were 1,058 kg ha^{-1} lower than those for conventional tillage. There were severe weed problems in all no-till plots, even though they were treated with the same herbicide program as the conventional till plots. There was a small (101 kg ha-1) advantage in grain yield from the enhanced fertility treatment. There was insufficient seed of the two experimental varieties, and the commercial variety XL-6 was used to complete the sowing of all plots. Grain yield for XL-6 was highest at 7,963 kg ha^{-1}.

Mean dry grain yield of all treatments in the year 2001 was 6,300 kg ha^{-1} (Table 3). As in the previous year, grain yields were lower in the no-till treatment. Weed control in the no-till treatment was good early in the season but became a problem later. There was a 504 kg ha^{-1} advantage for the enhanced fertility treatment compared to the standard fertility treatment. The variety STG95L-28-045 yielded very lowly and will be dropped in 2002.

None of the treatment combinations resulted in a positive net return in 2000 (Table 3). This is the result of very low yields and high input costs for weed and insect control. This situation improved in 2001 when the average net returns over all treatments was $190.54 ha^{-1}. Lower grain yields from the no-till plots when compared to the conventional till plots resulted in lower net returns. The increase in grain yields from increasing fertility was more than sufficient to result in increased net returns in the 'enhanced' fertility treatments when compared to the 'standard' fertility treatment. Averaged over all plots, the variety STG95L-28-045 had a negative net return. This is in contrast with the variety XL-6 that had an average net return over all plots of $294.37. Currently farmers plant soybeans after wheat. Net returns from plots

Table 4. Summary of net returns for short-duration rice varieties grown after wheat in a long-term cropping systems study conducted at the University of Arkansas Rice Research and Extension Center. Rice was priced at $153.74 t^{-1} and a 25% land cost included

Effect	Treatment	1999 net Returns $ ha^{-1}	2000 net returns $ ha^{-1}	2001 net returns $ ha^{-1}
All	All	NA	($217.41)	$190.54
Tillage	Conventional	NA	($115.40)	$189.52
	No-till	NA	($317.42)	$82.60
Rotation	Following wheat	NA	($217.41)	$190.54
Fertility	Standard	NA	($230.18	$125.18
	Enhanced	NA	($149.16)	$146.96
Variety	STG95L-28-045	NA	($224.50)	($22.25)
	Early LaGrue	NA	($227.43)	dropped
	XL-6	NA	($78.18)	$294.37

where soybeans were planted after wheat were all lower than those for the rice variety XL-6, indicating a good potential for planting rice after wheat.

DISCUSSION

Two years of comparing no-till to conventional till rice production indicate there is potential for no-till rice production in Arkansas. Results indicate that in the currently used two phase rotations it is possible to achieve the same yield levels using no-till as is possible with conventional tillage. When grain yield levels from no-till plots were equal to those of conventional tillage plots, there were significant reductions in production costs and subsequent gains in net return for the no-till treatments. Achieving equal levels of rice production in a no-till environment involves a number of changes in production practices. We were not able to obtain acceptable plant stands in the no-till plots without retrofitting the grain drill with appropriate disc openers and a “close till” packing system. Impounding water on the field during the winter months to facilitate straw decomposition was a useful way to manage the nearly 10 t ha^{-1} of stubble and straw remaining after a rice crop is harvested. This practice reduced problems of ‘hair pinning’ when planting into rice stubble. Data collected on nutrient uptake showed no differences between tillage treatments. This finding indicates that the practice of aerial fertilizer application will not need to be modified in a no-till setting. We have found that crusting does not occur in our no-till plots and thus eliminates the need to ‘flush’ fields after planting. Flushing is a standard practice of applying sufficient water to bring the soil to field capacity and then removing the excess water. Eliminating this step represents a water savings of 102.8 – 205.6 m^3. With a number of the rice producing areas of Arkansas having been declared critical water areas, this savings will be important for future rice production in the state.

The potential for no-till rice in rotations after wheat is currently not as high as it is for standard rotations. Temporal considerations dictate the planting of rice as soon as possible after wheat harvest and the subsequent wheat planting immediately after rice harvest. For both scenarios there is a large volume of plant material in the field, thus sowing is difficult. We have also encountered weed problems with no-till rice following wheat. Growing rice after wheat in our conventional tillage plots resulted in higher net returns than growing soybeans, the current practice. We believe there is potential for this system by need to identify better rice varieties and weed control practices.

Net returns for no-till rice were not always as high as they were for conventional till rice, but in all cases they were higher than the net returns for other crops used in rotations with rice. This was expected and highlights the need to keep rice as a component in the rotations. With water issues and possible environmental restrictions, interest in no-till rice is expected to increase. Our results indicate shifting to no-till rice in the current rotations will not result in decreased yields and potentially can increase profits.

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INFLUENCE OF IRRIGATION AND RYE COVER CROP ON CORN YIELD PERFORMANCE AND SOIL PROPERTIES

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ABSTRACT

Crops grown in the Macon Ridge region of northeast Louisiana are very responsive to irrigation. In dry years, it is extremely difficult to maintain adequate soil moisture on the Macon Ridge soils because of a shallow root zone. Additionally, when several irrigations are required, high salt accumulation occurs in the root zone because of poor quality irrigation water. An experiment was conducted in 2001 on a Gigger silt loam at the Macon Ridge Research Station near Winnsboro, LA to evaluate the influence of irrigation, cover crop, N rate, and plant population on corn grain yield, soil moisture, and total soil salts. Data suggest that a mulch-forming cover crop such as cereal rye that persists through most of the growing season can improve soil moisture conditions and enhance yield. Further findings suggest that potential salt problems may be alleviated somewhat by the use of a cover crop.

KEYWORDS

Loess, fragipan, pH, perched water table, natural vegetation

INTRODUCTION

Crops grown in the Macon Ridge region of northeast Louisiana are very responsive to irrigation. These loessial silt loam soils have fragipans at 15 to 25 inches deep and have low soil pH values below the Ap horizon. According to Reichman and Trooien (1993), a given site should not be irrigated if it has a barrier at a depth of 60 inches or less. Two potential effects of irrigation when a barrier is present are development of a perched water table and accumulation of excess salts in the root zone. If excessive, either possibility can impair crop root function and decrease yield.

In dry years, it is extremely difficult to maintain adequate soil moisture on the Macon Ridge soils because of the shallow root zone. A negative correlation between the number of furrow irrigations and yield often occurs with yields decreasing as the number of irrigations increase. When several irrigations are required, plants oftentimes have the appearance of dryland corn with a short plant stature and very small ears, suggesting that high salt accumulation in the root zone may be producing an “osmotic” effect. Salt analyses of both the irrigation water and soil have confirmed these suspicions (personal communication).

Winter cover crops can increase N availability and conserve soil moisture for subsequently planted crops in the southeastern U.S. (Munawar *et al*., 1990; Teasdale and Mohler, 1993; Wagger, 1989). Non-legume cover crop residue develops a persistent surface mulch for soil water conservation (Munawar *et al*., 1990; Teasdale and Mohler, 1993). Wilhelm *et al*. (1986) reported a positive linear relationship between grain and stover yield and amount of residue applied to the soil surface. Residue effects on crop yield were mainly through changes in soil water and temperature.

Rye has long been recommended as a winter cover crop because of its winter hardiness (Ditsch and Alley, 1991) and has been shown to provide additional mulch for no-till corn (Moschler *et al*., 1967) and soybean (Eckert, 1988). Gallaher (1977) found that corn planted into killed rye mulch conserved soil water, was more drought tolerant, and showed greater use and earlier depletion of water by roots deep in the soil profile. Corn grain and soybean yields were increased 46 and 30%, respectively, by the rye mulch treatment. Cover crop treatments may also affect the soil salt content. When more water is left in the soil profile to leach or dilute the salts, the electrical conductivity of the soil saturation extract is reduced (Reichman and Trooien, 1993). Other cultural practices that reduce water consumption such as plant population and hybrid may influence yield and soil salinity. The objective of this research was to evaluate the

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influence of irrigation, cover crop, N rate, and plant population on grain yield, soil moisture, and total soil salts.

MATERIALS AND METHODS

An experiment was conducted in 2001 on a Gigger silt loam (fine silty, mixed, thermic Typic Fragiudalf) at the Macon Ridge Research Station near Winnsboro, LA to evaluate the influence of irrigation, cover crop, nitrogen (N) rate, and plant population on yield, soil moisture, and soil salt content. Factors evaluated included irrigation at 1.5- and 2.5-inch soil moisture deficits (SMD), native and cereal rye cover crops, 100 and 200 lbs N acre^{-1}, and 25,000 and 30,000 plants acre^{-1}. Furrow irrigation treatments were scheduled using the 'Arkansas Irrigation Scheduler' (Cahoon *et al*., 1990). The 1.5-inch SMD treatment was considered well watered and the 2.5-inch SMD moderately well watered. 'Elbon' rye was planted November 2, 2001 at a seeding rate of 100 lbs acre^{-1}. Growth of cover crops was chemically terminated with Roundup-Ultra about three weeks prior to planting. Pioneer brand 3223 was over planted and thinned back to 25,000 and 30,000 plants acre^{-1}. Nitrogen as 32% N-solution was knifedin at about the four-leaf growth stage at rates of 100 and 200 lbs N acre^{-1}. The only tillage was bed rehippingin the fall of 2000. The previous crop was cotton.

The experiment design was a randomized complete block with a split-split plot arrangement of treatments. Irrigation was the main plot, cover crop the split-plot, and N rate and plant population treatments the split-split plots. Treatments were replicated four times. Measurements included grain yield, yield components (ears acre^{-1}, kernel weight, and kernels ear^{-1}), soil moisture, and total soil salt concentration. In one replication, three tensiometers/plot were placed in each treatment at the 10-inch depth. Within a plot, tensiometers were 6-inches apart. Tensiometer readings in cb were collected daily and plot data were determined from the average of three tensiometers. Soil samples (0-8 inch depth) were collected in one replication on June 26 and July 27. The LSU AgCenter's Soil Testing Lab determined total salts. All data were analyzed with the GLM procedure using the SAS package (SAS Inst., 1985). The LSD ($P = 0.05$) test was used to evaluate differences among treatments when the F-test indicated significance ($P = 0.05$).

RESULTS AND DISCUSSION

Cover crop was the only treatment that significantly affected grain yield or yield components (Table 1). The lack of response between irrigation treatments was probably due to several rainfall events in June during the critical pollination and early grain fill growth stages. There were seven irrigations for the 1.5-inch SMD, beginning May 29 and ending July 23, compared to four irrigations for the 2.5-inch SMD, beginning June 19 and ending July 25. Similar yields between irrigation treatments also may have been related to the minimal level of tillage utilized in this study. The only tillage performed was the rehipping of beds in the fall of 2000.

Corn yields following rye were significantly higher than following native vegetation for both irrigation treatments (Table 1). Averaged across irrigations, the rye cover crop increased corn yields 21%. The yield component that most affected the cover crop response was kernel weight. Following rye, 100 kernel weight was 12% higher than native vegetation for the 1.5-inch SMD and 14% higher than native vegetation for the 2.5-inch SMD. Although not significant, kernels per ear followed similar trends.

Tensiometer data indicated that the rye cover was providing a mulch which enhanced soil moisture (Fig. 1). This effect was most pronounced for the 1.5-inch SMD treatment, particularly early in the season. Samples taken prior to corn planting indicated that there was approximately 3100 lbs acre^{-1} of rye cover and 650 lbs acre^{-1} of native vegetation.

Influence of irrigation and cover crop on the total soil salts is presented in Table 2. Treatments from one replication were evaluated so data cannot be statistically analyzed. However, some interesting trends occurred among treatments for total soil salts. Averaged across irrigation and cover crop treatments, total soil salts increased from 544 ppm for the June 26

Table 1. Influence of irrigation and cover crop on grain yield and kernel weight at Winnsboro in 2001, averaged across N rate and plant population treatments. Irrigation means and irrigation x cover crop interaction means did not differ at $P = 0.05$.

Irrigation	Cover crop	Grain yield	Kernel weight	Kernels ear^{-1}
		bu acre^{-1}	g (100 kernels)$^{-1}$	No. ear^{-1}
1.5-in. SMD	Native	126.8	28.0	439
	Rye	154.1	31.6	460
2.5-in. SMD	Native	124.8	27.1	433
	Rye	151.1	30.9	461
$LSD_{0.05}$				
Irrigation (I)		NS[†]	NS	NS
Cover crop (C)		17.2	2.1	NS
I x C		NS	NS	NS

[†] NS-Not significant at $P = 0.05$

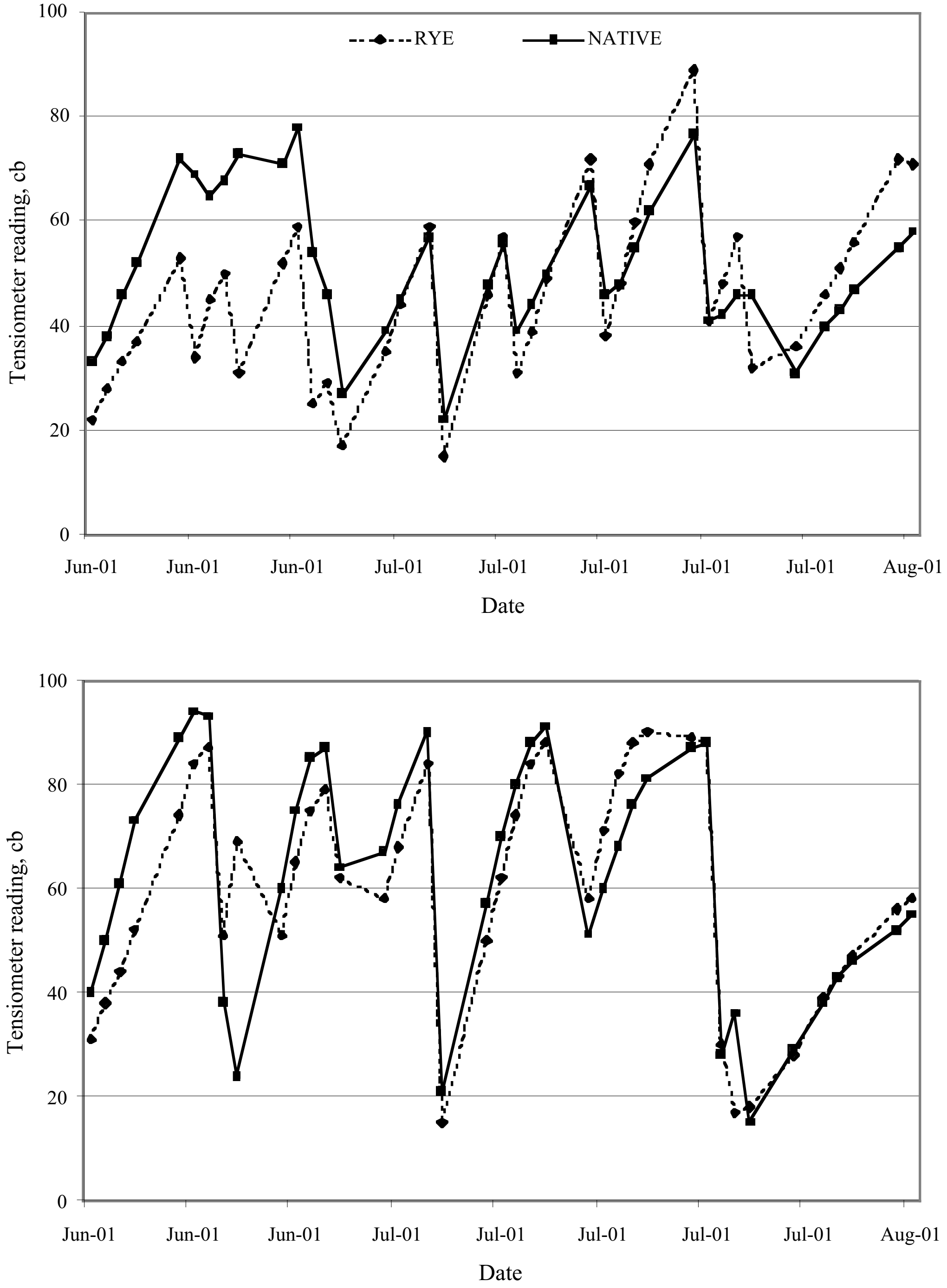

Fig. 1. Influence of cover crop on tensiometer readings at Winnsboro in 2001. The top panel depicts the response when irrigation was applied at 1.5-inch soil moisture deficit (SMD). The bottom panel is for 2.5-inch SMD.

sampling date to 1919 ppm for the July 27 sampling date. At each sampling date, the lowest salt levels occurred for the rye cover crop treatment. The highest salt level of 3266 ppm occurred at the July 27 sampling date for the 1.5-inch SMD and native vegetation treatments. Since most of the irrigations occurred between the two sampling dates, the increase in salts at the later sampling date was probably due to irrigation water. Indeed, the salt content of the irrigation water was greater than 1500 ppm. The Louisiana Cooperative Extension Service considers total soil salts > 1500 ppm as very high.

Table 2. Influence of irrigation and cover crop on total soil salts in the Ap horizon of Gigger silt loam at two sampling dates at Winnsboro in 2001.

Irrigation	Cover crop	Total salts
		ppm
June 26, 2001		
1.5-in. SMD	Native	719
	Rye	523
2.5-in. SMD	Native	503
	Rye	429
July 27, 2001		
1.5-in. SMD	Native	3266
	Rye	1498
2.5-in. SMD	Native	1614
	Rye	1296

CONCLUSIONS

The data from this one-year study suggest that a mulch-forming cover crop such as rye that persists through most of the growing season can improve soil moisture conditions and enhance yield. Further findings suggest that potential salt problems may be alleviated somewhat by the use of a cover crop. This study will be continued in 2002 with the addition of a non-irrigated control.

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COVER CROPS AND CONSERVATION TILLAGE IN SUSTAINABLE VEGETABLE PRODUCTION

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ABSTRACT

Cover crops have never been as popular as they are today, and the information on cover crops is readily available. There is a cover crop available for every need. However, cover crops in vegetable production are used mainly as green manuring crops. When used for green manuring cover crops are plowed under. Benefits derived from plowed under cover crops are temporary. However, when cover crops are used along with conservation tillage not only is the soil quality improved, but healthy crops are produced which resists insect pests, diseases, and nematodes better. Lewis *et al.* (1997) established why a total system approach is more sustainable for pest, disease, and nematode management and that the "treat-the-symptoms" mentality should be the last line of defense rather than the first. With the integration of cover crops and conservation tillage in vegetable production, it is possible to make pesticide intervention as a last line of defense. In most situations insecticides, fungicides, and nematicides are not needed or used. Weed control strategies are altered. No-till delays harvest of vegetables and thus, strip-tilling is essential to raise vegetables to match harvest with market window.

KEYWORDS

Vegetable, sutainable, total-system tillage, cover crops

INTRODUCTION

Conservation tillage acreage in agronomic crops has rapidly increased in recent years. However, vegetable growers are reluctant to introduce conservation tillage in production systems. Phatak and Reed (1999) outlined the reasons for the lack of increase in vegetable acreage in conservation tillage. Vegetable growers are not willing to take any risks just to save a few dollars by changing tillage alone. It is essential to introduce a total system, which in addition to reduced tillage also reduces use of fertilizers, insecticides, fungicides, nematocides, hebicides and other off-farm inputs. This will make a production system really sustainable. This article discusses some essential components of the total systems approach.

COVER CROPS

Popularity of cover crops has never been as high as it is today and the information on cover crops is readily available (SAN, 1998). There is a cover crop available for every need. However, cover crops in vegetable production are used mainly as green manuring crops. When used as green manuring crops cover crops are chopped by discing a number of times and then residue is buried deep with a moldboard plow. Discing and plowing accelerate oxidization and decomposition of cover crop residues and soil organic matter. Thus, benefits derived from plowed under cover crops are only temporary. This practice of plowing under cover crops fails to bring about a permanent change in soil organic matter or soil physical properties. To make vegetable production sustainable it is essential to make a permanent change in soil organic matter and soil physical properties. Changing tillage from conventional to conservation in combination with cover crops will achieve this objective. Integration of conservation tillage is important to make vegetable production truly sustainable.

TILLAGE

It is essential to have a thorough understanding of tillage for optimum vegetable crop production and to maintain soil productivity for the future. An important function of tillage in vegetable crop production is to provide proper conditions for optimum root and plant growth. Soil conditions that directly regulate plant activities are soil moisture, soil aeration, soil temperature, soil nutrients and soil strength or soil compaction (Blake and Aldrich, 1955; Flocker *et al*., 1959; 1960; Phatak *et al*., 1980a; 1980b). There are some variations in tillage practices used in vegetable production (Emmert, 1937).

Soil tillage in vegetable production can be classified into three forms: primary, secondary and tertiary. Primary and secondary tillage is used as a pre-plant preparation of the seed-bed, while tertiary tillage is performed after planting

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vegetable crops to control weeds and reduce compaction between rows. In vegetable production, primary tillage is performed with a moldboard plow. Secondary tillage is used to prepare a fine seed-bed just before planting. Rotary hoes, sweeps, and other equipment are used in vegetable production for tertiary tillage.

In conventional vegetable production all soil tillage operations described above are essential to maintain a high level of production. However, intensive soil tillage used eroded and degraded soils (Magdoff and van Es, 2000; Wolf, 1999).

SOIL ORGANIC MATTER

Importance and benefits of soil organic matter has been discussed in details by Magdoff and van Es (2000), Wolf (1999), and Snyder and Wolf (2002). Wolf (1999) stated that "no single constituent of the soil is as important as organic matter in changing a pile of decomposed rocks into vibrant, dynamic, living entity. In so doing it affects all three sides of the fertility triangle, affecting air, water, and nutrients in significant ways." These books also gave examples of permanent increases in soil organic matter by changing tillage from conventional to conservation tillage. Readers are advised to read these books to better understand the importance of organic matter in sustainable vegetable production.

CONSERVATION TILLAGE

Lal *et al*. (1990) summarized some of the research done during the seventies and eighties on comparisons of conventional and conservation tillage and suggested that "conservation tillage can be made an integral part of sustainable agricultural systems through practically oriented, multidisciplinary research". Hatfield and Karlen (1994) expressed concerns in the area of nutrient and pest management strategies with these systems with conservation tillage. However, substantial progress in promotion and adaptation of conservation tillage in sustainable agriculture has been made during the last ten to twelve years. In all reality, conservation tillage is an essential component of sustainable agriculture, as it helps to improve soil OM and productivity. Soil health and productivity is important in achieving sustainability in agriculture.

Sumner *et al*. (1986) stated that conservation tillage has not been researched in vegetable production as in agronomic crops. Phatak (1987) suggested that using conservation tillage for vegetables should only be implemented where it has been proven consistently successful. Most research on conservation tillage in vegetable crops has been on individual aspects of vegetable production for example, fertility, weeds, insect pests, diseases, nematodes etc. and not on total system (Abdul Baki *et al*., 1996; Brunson, 1991; Brunson *et al*., 1997; Bugg *et al*., 1990; 1991; Ghate *et al*., 1991; Hoyt *et al*., 1994; Phatak, 1987; 1992; 1998; Phatak *et al*., 1991; Putnam, 1990; Sumner *et al*., 1986; 1988; 1995). Some research has been done on comparisons of conventional and sustainable vegetable production (Brunson, 1991; Brunson 2002; Brunson *et al*., 1997). Phatak and Reed (1999) discussed the opportunities for conservation tillage in vegetable production and also outlined small plot research and on-farm research conducted since 1985. Overall, most research on conservation tillage on vegetables conducted in recent years has been very encouraging. However, more practically oriented research is needed to integrate conservation tillage in a sustainable vegetable production system.

INTEGRATIVE APPROACH

Phatak (1992) outlined a total systems approach to vegetable production. Lewis *et al*. (1997) further established why a total systems approach is more sustainable for crop production including insect pests, diseases, nematode and weed management, and that "treat-the-symptoms" strategies should be the last line of defense rather than the first line of defense used since the discovery and development of pesticides. Strategies for management of insect pests, diseases, nematodes and weeds in vegetable and agronomic crops by integrating cover crops with conservation tillage have been discussed by Phatak (1998). These strategies were based on research on small plots and on farm research with growers (Phatak and Reed 1999). Since 1985, major vegetables like tomatoes, eggplants, peppers, snap beans, southern peas, lima beans, cucumbers, cantaloupes, squash, and watermelons were produced without insecticides, fungicides, and nematicides. The main observation noted was that these pesticides were not needed to produce these crops. Use of herbicides and fertilizers were substantially reduced. Vegetable growers using these strategies were able to improve their bottom line and increased profits. However, more multi-disciplinary research with approach is needed to make sustainable vegetable production systems practical for all growers.

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USING SOIL MOISTURE TO DETERMINE WHEN TO SUBSOIL

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ABSTRACT

Determining the optimum time to subsoil depends upon several factors, including maximizing belowground soil disruption, minimizing aboveground soil disruption, and minimizing tillage energy requirements. An experiment was conducted to examine how soil moisture affects these factors and to determine the optimum moisture content to subsoil based on tillage forces and soil disruption. Two different shanks, a straight shank and a "minimum tillage" shank, were tested in a Coastal Plain soil in the soil bins of the National Soil Dynamics Laboratory in Auburn, AL. A three-dimensional dynamometer was used to measure tillage forces and a laser profilometer was used to measure soil disruption. Tillage forces and soil disruption from the soil with the lowest moisture content were found to be greater than results from all other moisture contents tested. The "minimum tillage" shank was found to require more energy and disrupt the soil a lesser amount than the straight shank.

KEYWORDS

Tillage, subsoil, soil compaction, disruption, soil moisture

INTRODUCTION

Compaction of agricultural soils can have devastating effects on crop growth and overall productivity. This has been particularly true in the southeastern USA, where soils have been proven to be highly compactable by natural forces and by vehicle traffic (Cooper *et al.*, 1969; McConnell *et al.*, 1989). Two techniques have been used to minimize the effect of soil compaction. The first method that has proven effective is prevention. Controlled traffic (Dumas et al., 1973), reduced tire inflation pressure (Raper *et al.*, 1995a; Raper *et al.*, 1995b), reduced vehicle size (Cooper et al., 1969), and use of cover crops (Reeves *et al.*, 1992) have reduced the negative effects of soil compaction.

Another technique that is commonly used to alleviate the effects of soil compaction is subsoiling(Campbell *et al.*, 1974; Reid, 1978; Garner *et al.*, 1987). This tillage practice disrupts compacted soil profiles to depths of 12 – 20 in. (0.3–0.5 m). However, it is not a permanent solution because of the aforementioned natural reconsolidation and vehicle traffic. It is common practice in this region to subsoil on an annual basis (Busscher *et al.*, 1986; Tupper *et al.*, 1989). Some research has indicated that subsoiling could be performed less frequently but this entails a greater risk of soil compaction (Colwick *et al.*, 1981; Smith, 1985; Reeder *et al.*, 1993).

Because of the significant draft forces that are required to subsoil compacted profiles, many different types of subsoilers have been designed and tested (Nichols and Reaves, 1958; Choa and Chancellor, 1973; Tupper, 1974; Upadhyaya *et al.*, 1984; Smith and Williford, 1988; Sakai *et al.*, 1993; Reeder *et al.*, 1993; Mielke *et al.*, 1994). However, subsoilers have also been designed to minimize soil inversion which maximizes residue cover after subsoiling (Pidgeon, 1982; Pidgeon, 1983). Many manufacturers now promote the ability of their subsoiler shank to disrupt compacted profiles as well as maintain sufficient residue coverage.

The scheduling of a subsoiling operation is usually ruled by the availability of the producer's time. Many subsoiling operations are performed in the fall of the year when time is usually more plentiful, but some soils reconsolidate so quickly that subsoiling must be performed in the spring for the full benefit to be realized by the summer crop (Touchton *et al.*, 1986; Vaughan *et al.*, 1992). Another consideration for reducing energy consumption of subsoilers has been to target tillage times when soil moisture reduces sliding friction between soil and metal. However, some soils adhere to metals when soil moisture is increased, thereby increasing draft force (Nichols, 1925; Nichols, 1931; Chancellor, 1994).

Another consideration concerning the timing of subsoiling that has not been extensively studied is how to maximize soil disruption, perhaps increasing the long-term

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benefits of the subsoiling event. Subsoiling is routinely recommended when the soil is driest to maximize disruption, but few data exist to support this recommendation (Schuler *et al.*, 2000). Therefore, the objectives of this study are to:

1. Determine the force required to subsoil a Coastal Plain soil at several levels of soil moisture,
2. Determine soil disruption caused by subsoiling at each moisture level,
3. Evaluate the differences in draft and disruption caused by a straight subsoiler and a subsoiler designed for “minimum tillage”.

MATERIALS AND METHODS

An experiment was conducted in the soil bins at the USDA-ARS National Soil Dynamics Laboratory in Auburn, AL to determine the force necessary to disrupt a hardpan profile in a bin of Norfolk sandy loam soil (fine-loamy, kaolinitic, thermic Typic Kandiudults) and to determine the amount of soil disruption caused by the subsoiling event. Norfolk soil is a Coastal Plain soil commonly found in the southeastern USA and along the Atlantic Coast, and was selected because it is indigenous in many locations where subsoiling is commonly used to disrupt compacted soil layers. The bin is located indoors, which facilitates the maintenance of constant moisture content for an extended period of time.

A hardpan condition was formed in the soil bins to simulate a condition commonly found in the southeastern USA. This naturally occurring and sometimes traffic-induced hardpan was found approximately 4-8 in. (0.1-0.3 m) below the soil surface and was quite impervious to root growth, particularly at low moisture levels. The hardpan condition was created in a soil bin using a moldboard plow to laterally move the soil and then using a rigid wheel to pack the soil left exposed in the plow furrow. A small amount of soil was packed at a time and the entire procedure repeated until the entire bin had been traversed. The surface soil was then bladed and leveled. Variations can occur between bin fittings, but within one bin fitting, the same depth of the hardpan can usually be achieved with little error.

The shanks used for the experiment were manufactured by Deere & Co. (Ankeny, IA; Fig. 1). The straight shank is 1.25 in. (31.8 mm) thick with a 5 in. (127 mm) LASERRIP™ Ripper Point and is currently used on the John Deere 955 Row Crop Ripper. The minimum tillage shank is 0.75 in. (19 mm) thick with a 7 in. (178 mm) Min-till point and is used on the John Deere 2100 Minimum till Ripper.

These shanks were mounted on the dynamometer car to a 3-dimensional dynamometer, which has an overall draft load capacity of 10,000 lbs (44 kN). Draft, vertical force, side force, speed, and depth of operation were recorded continuously for each shank test. The speed of tillage for all tests was held constant at 1 mi hr^{-1} (0.45 m s^{-1}). The depth of operation of 13 in (33 cm) was kept constant for all tests.

The soil bin was treated as a randomized complete block design with four moisture contents, two shank types, and four replications. Four subsoiling runs were conducted side-by-side across the width of the bin with eight separate lanes being constructed along the length of the bin. This arrangement allowed all 32 runs to be conducted accurately. The approximate size of each plot was therefore 4.9 ft (1.5 m) wide by 16.4 ft (5 m) long. The spacing across the bin was sufficient to ensure that disturbed soil resulting from a previous tillage operation would not affect a current test. Each set of force values obtained from each plot was averaged to create one specific value per plot of draft, vertical force, and side force. Preplanned single degree of freedom contrasts and Fisher’s protected least significant difference (LSD) were used for mean comparison. A probability level of 0.10 was assumed to test the null hypothesis that no differences in tillage forces or soil disruption existed between the soil moisture levels or between shanks.

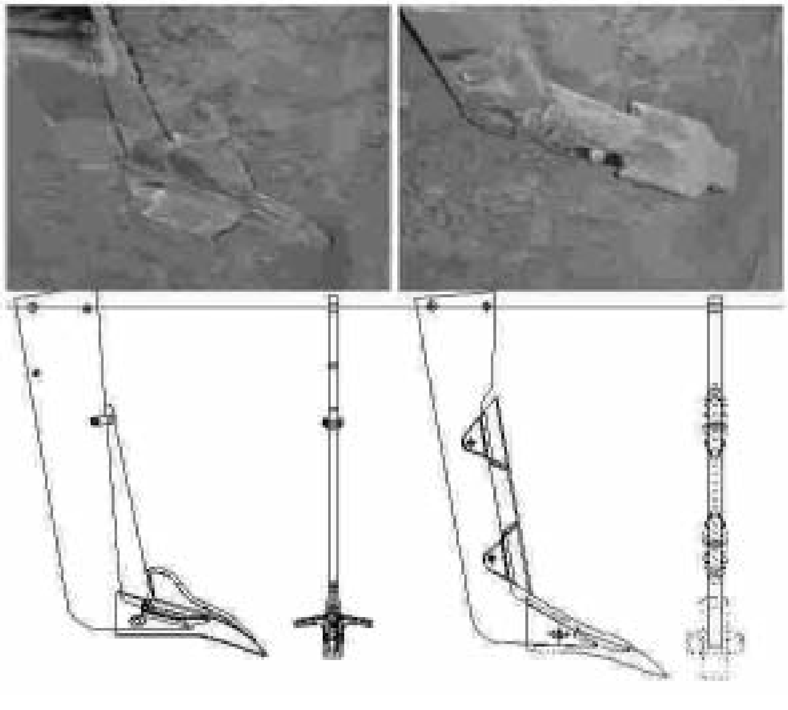

Fig. 1. “Minimum tillage” shank (left) and straight shank (right) used for experiment.

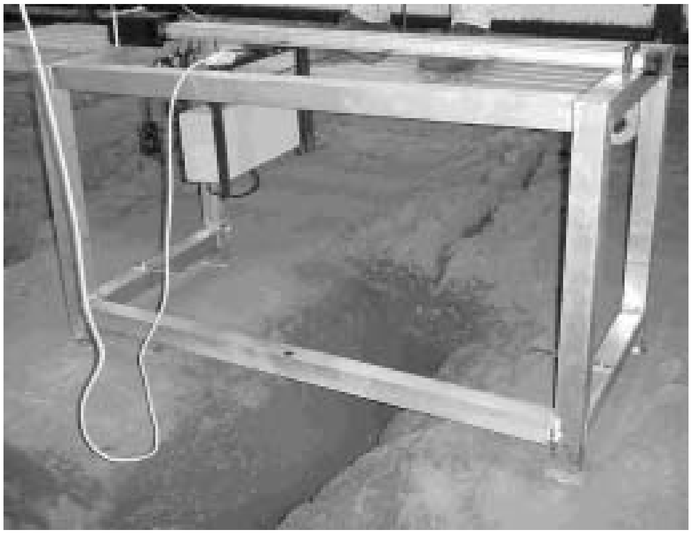

Fig. 2. Laser profilometer used to measure area of spoil and trench.

The soil bin was initially wet to a completely saturated soil condition prior to the first set of experiments. After this set of tests was conducted, the soil was left uncovered for several days to allow a different soil moisture condition to develop. Daily measurements of soil moisture using a time-domain reflectrometry (TDR) probe were conducted to achieve the targeted soil moisture level so that the next set of tests could be conducted. This procedure was repeated three times to allow four distinct levels of soil moisture to be tested.

Before the shank tests were conducted in each plot, a set of five-cone index measurements was acquired with a multiple-probe recording penetrometer. This set of measurements was taken with all five-cone index measurements being equally spaced at a 7.5 in. (20 cm) distance across the soil with the middle measurement being directly in the path of the shank. As soon as the shank had been tested in each plot, another set of five cone index measurements was also taken in the disturbed soil, close to the original cone index measurements.

Measurements of soil moisture were taken in undisturbed regions of each plot for analysis. Values of gravimetric moisture content were measured at depths of 0-6 in. (0-15 cm) immediately after the experiment was completed. Bulk density values were taken at depths of 2-4 in. (5-10 cm), 8-10 in. (20-25 cm), and 12-14 in. (30-35 cm) in each replication at the end of test.

After each set of tillage experiments was conducted, a laser profilometer (Fig. 2) was used to determine the width and volume of soil that was disturbed by the tillage event. The disturbed soil was then manually excavated from the trenched zone for approximately 3.3 ft (1 m) along the path of plowing to allow several independent measurements of the area of the subsoiled or trenched zone. Care was taken to ensure that only soil loosened by tillage was removed.

RESULTS AND DISCUSSION

Volumetric moisture contents as determined by TDR were 16.3% for wet soil, 13.3% for moist soil, 8.3% for dry soil, and 5.8% for very dry soil. The gravimetric moisture contents at the 0-6 in. (0-15 cm) depth were 11.2% for wet soil, 9.9% for moist soil, 6.5% for dry soil, and 6.1% for very dry soil.

Bulk density values showed the approximate location of the hard pan installed in the soil bin. Surface bulk density from a depth of 2-4 in. (5-10 cm) was found to be 1.58 Mg m^{-3} while the soil within the hard pan at a depth of 8-10 in. (20-25 cm) had a bulk

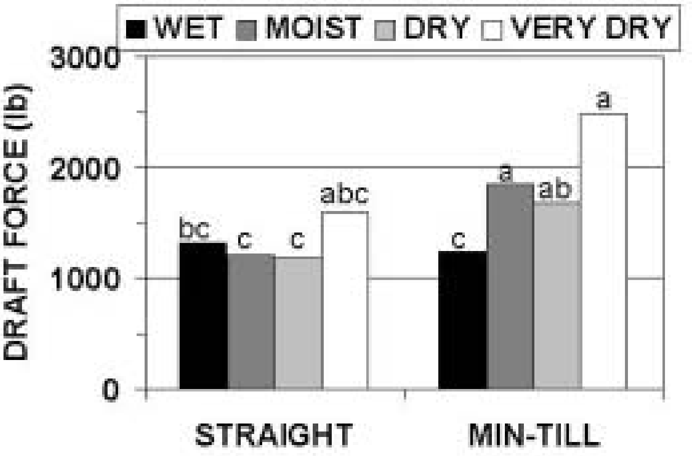

Fig. 3. Draft forces from shanks. Differences in letters indicate statistical differences at $P = 0.10$ across both shanks.

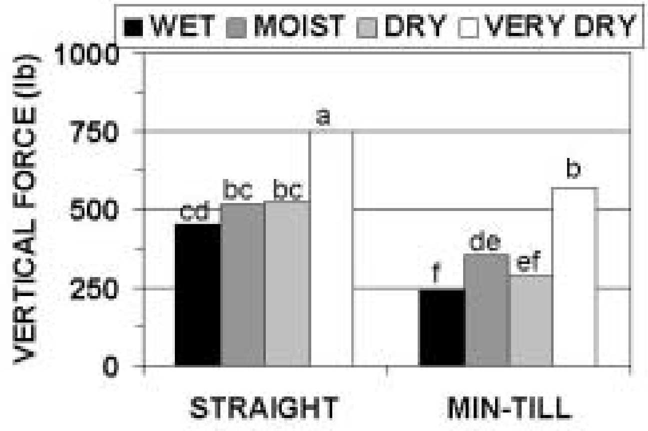

Fig. 4. Vertical forces from shanks. Differences in letters indicate statistical differences at the 0.10 significance level across both shanks.

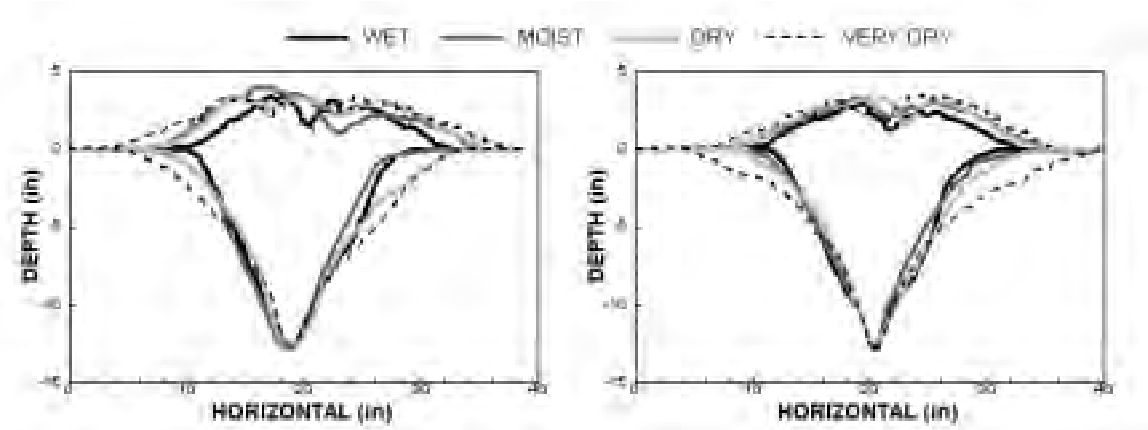

Fig. 5. Spoil and trench areas for straight shank (left) and "minimum tillage" (right) shank, as measured with the laser profilometer.

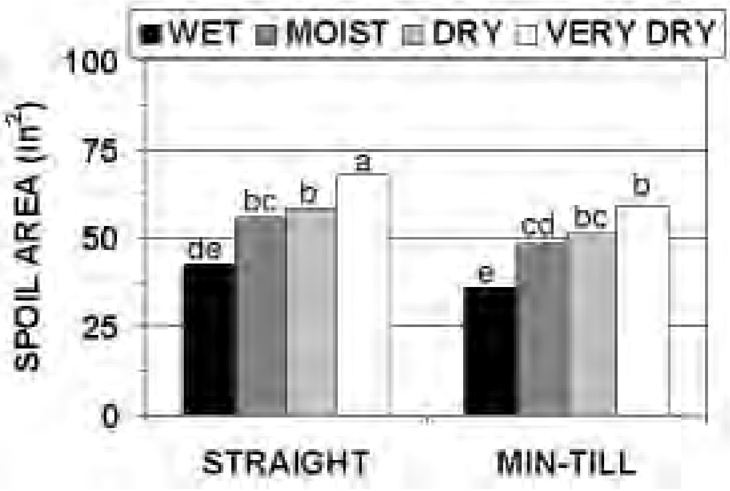

Fig. 6. Spoil area measured with profilometer. Differences in letters indicate statistical differences ($P = 0.10$) across both shanks.

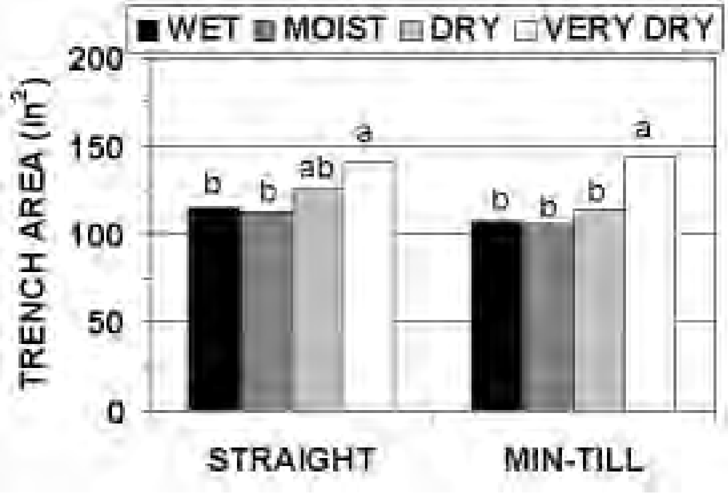

Fig. 7. Trench area measured with profilometer. Differences in letters indicate statistical differences ($P = 0.10$) across both shanks.

density of 1.93 Mg m^{-3} and the soil below the hardpan at a depth of 12-14 in (30-35 cm) had a density of 1.80 Mg m^{-3}.

Soil moisture had a statistically significant effect on draft force averaged across shank type. Draft force from the very dry soil condition was found to differ from all other soil moisture conditions: 1977 lbs (8794 N) vs. 1433 lbs (6374 N) ($P = 0.003$) for the dry soil condition, 1977 lbs (8794 N) vs. 1531 lbs (6810 N) ($P = 0.009$) for the moist soil condition, and 1977 lbs (8794 N) vs. 1283 lbs (5707 N) ($P = 0.004$) for the wet soil condition (Fig. 3). Draft measurements from all other soil conditions were not found to be statistically different from each other.

Draft force measurements were also found to differ based on the type of shank used ($P = 0.001$; Fig. 3). The straight shank was found to require 1330 lbs (5916 N) of draft force averaged over all moisture contents while the "minimum tillage" shank required an average of 1769 lbs (7868 N) of draft force. Only in wet soil did the "minimum tillage" shank have a lesser draft force (1242 lbs (5524 N) vs. 1323 lbs (5885 N)), but this difference was statistically insignificant. In all other soil moisture conditions, the draft force of the "minimum tillage" shank exceeded the draft force of the straight shank.

Soil moisture also had a significant effect on vertical force (Fig. 4). Vertical force from the very dry soil condition was found to differ from all other soil moisture conditions: 674 lbs (3001 N) vs. 406 lbs (1806 N) ($P = 0.0001$) for the dry soil condition, 675 lbs (3001 N) vs. 435 lbs (1935 N) ($P = 0.0001$) for the moist soil condition, and 675 lbs (3001 N) vs. 346 lbs (1543 N) ($P = 0.0001$) for the wet soil condition. The vertical force from the moist soil condition (435 lbs (1935 N)) was also found to be significantly greater than the draft force from the wet soil condition (347 lbs (1543 N)). The straight shank was also found to have greater average vertical force requirements than the "minimum tillage" shank, 562 lbs (2501 N) vs. 348 lbs (1547 N) ($P = 0.001$).

Several measurements of soil disruption were obtained with the laser profilometer. The above-surface area, or spoil area, provides a measurement of the amount of soil displaced above the original soil surface by the tillage process. Another measurement of a shank's effectiveness is the area of soil that is disrupted below the soil surface, or trenched area. Figs. 5 shows the averaged profiles of spoil and trenched areas for the two shanks tested at the various moisture contents. These figures show some enlargement of the trench area near the soil surface for the very dry soil condition as compared with other soil moisture conditions.

Decreased soil moisture was found to contribute greatly to increased soil disruption above ground (Fig. 6). The very dry soil moisture condition was found to have the greatest spoil area with a value of 63.4 in^2 (409 cm^2) as compared to all other treatments. The "minimum tillage" shank (48.6 in^2 (313.7 cm^2)) was also found to have a smaller spoil area than the straight shank (56.0 in^2 (361.2 cm^2); $P = 0.006$).

Decreased soil moisture also produced an enlarged trenched area. This value was found to be much greater for the very dry soil moisture condition (142 in^2 (916 cm^2)) as opposed to all other soil moisture conditions (Fig. 7). No statistical differences were found between the two shanks tested at 0.10 significance level.

CONCLUSIONS

1. Tillage forces obtained from the driest soil were found to be significantly greater than tillage forces obtained at all other soil moisture levels.
2. Measured values of soil disruption showed the driest soil to have significantly increased spoil and trenched areas compared to all other soil moisture levels.
3. Increased draft forces were measured for the "minimum tillage" shank as opposed to the straight shank. However, the "minimum tillage" shank reduced aboveground soil disruption (spoil) as compared to the straight shank.

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DISCLAIMER

The use of trade names or company names does not imply endorsement by USDA-ARS.

APPENDIX A

Past conferences, chairmen, and citations of proceedings

Year	Location	Program Chairman or Co-Chairmen	Proceedings
1978	Griffin, GA	J.T. Touchton Agronomy Department University of Georgia 1109 Experiment St. Griffin, GA 30223-1797	Touchton, J.T., and D.G. Cummins (eds.). 1978. Proc. First Annual Southeastern No-Till Systems Conference. Experiment Georgia 29 November 1978. Georgia Exp. Sta. Special Pub. No. 5 Univ. of Georgia, Agri. Exp. Stn., Experiment, GA.
1979	Lexington, KY	Shirley Phillips Agronomy Department University of Kentucky Lexington, KY. 40546	No Proceedings Published
1980	Gainesville, FL	R.N. Gallaher PO Box 110730 Agronomy Department University of Florida Gainesville, FL 32611	Gallaher, R.N. (ed.). 1980. Proc. 3rd Annual No-Tillage Systems Conference. Williston, Florida 19 June 1980. Inst. Food & Agri. Sci., Univ. of Florida, Gainesville, FL
1981	Raleigh, NC	A.D. Worshum, W.M. Lewis & G.C. Naderman Crop Science Department NC State Univ. Raleigh, NC 27650	Lewis, W.M. (ed.). 1981. No-Till Crop Production in North Carolina – Corn, Soybean, Sorghum, and Forages. North Carolina Agri. Extension Service AG-273, Raleigh, NC.
1982	Florence, SC	J.H. Palmer Agronomy Department Clemson University Clemson, SC 29634	Palmer, J.H., and E.C. Murdock (eds.). 1982. Proc. 5th Annual Southeastern No-Till Systems Conference. Florence, SC 15 July 1982. Agronomy and Soils Extension Series No. 4. Clemson Univ. Clemson, SC.
1983	Milan, TN	E.L. Ashburn & T. McCutchen Univ. of Tennessee West TN Agic. Exp. Stn. Jackson, TN	Jared, J., F. Tompkins, and R. Miles (eds.). 1983. Proc. 6th Annual Southeastern No-Till Systems Conference. Milan, TN 21 July 1983. Univ. of Tennessee Inst. of Agri., Knoxville, TN.
1984	Headland, AL	J.T. Touchton Agronomy Department Auburn University Auburn, AL 38301	Touchton, J.T., and R.E. Stevenson (eds.). 1984. Proc. 7th Annual Southeast No-Tillage Systems Conference. Headland, AL 10 July 1984. Alabama Agri. Exp. Stn., Auburn Univ., Auburn, AL.
1985	Griffin, GA	W.L. Hargrove Agronomy Department University of Georgia 1109 Experiment Station Griffin, GA 30223-1797	Hargrove, W.L., F.C. Boswell, and G.W. Langdale (eds.). 1985. Proc. 1985 Southern Region No-Till Conference. Griffin, GA. 16-17 July 1985. Georgia Agri. Exp. Sta., Univ. of Georgia, Athens, GA
1986	Lexington, KY	R.E. Phillips and K. L. Wells Agronomy Department Univ. of Kentucky Lexington, KY 40546	Phillips, R.E. (ed.). Proc. Southern Region No-Till Conference. Lexington, KY 18 June 1986. Kentucky Agri. Exp. Stn., Southern Region Series Bulletin 319. Univ. of Kentucky, Lexington, KY
1987	College Station, TX	T.J. Gerik and B.L. Harris Blackland Research Center Temple, TX 76501	Gerik, T.J., and B.L. Harris. (eds.). 1987. Proc. Southern Region No-Tillage Conference. College Station, TX 1-2 July 1987. Texas Agri. Exp Stn. MP-1634, Texas A & M Univ. System. College Station, TX
1988	Tupelo, MS	N.W. Buehring & J.E. Harrison Mississippi State Univ. NE Miss. Branch Stn. Verona, MS 38879	Hairston, J.E. (ed.). 1988. Proc. 1988 Southern Conservation Tillage Conference. Tupelo, MS 10-12 August 1988. Mississippi Agri. and Forestry Exp. Stn., Special Bulletin 88-1. Mississippi State Univ., Mississippi State, MS.

Year	Location	Program Chairman or Co-Chairmen	Proceedings
1989	Tallahassee, FL	D.L. Wright and I.D. Teare University of Florida N. Florida Res., & Educ. Ctr. Rt. 3 Box 4370 Quincy, FL 32351	Teare, I.D. (ed.). 1989. Proc. 1989 Southern Conservation Tillage Conference. Tallahassee, FL 12-13 July 1989. Inst. of Food and Agri. Sci. Special Bulletin 89-1. Univ. of Florida, Gainesville, FL.
1990	Raleigh, NC	M.G. Wagger NC State University Raleigh, NC 27650	Mueller, J.P., and M.G. Wagger (eds.). 1990. Proc. 1990 Southern Region Conservation Tillage Conference. Raleigh, NC 1990. NCSU Special Bulletin 90-1. North Carolina State Univ., Raleigh, NC.
1991	N. Little Rock, AR	S.L. Chapman & T.C. Keisling University of Arkansas Soil Testing & Res. Lab. P.O. Drawer 767 Marianna, AR 72360	Keisling, T.C. (ed.). 1991. Proc. 1991 Southern Conservation Tillage Conference. North Little Rock, AR 18-20 June 1991. Arkansas Agri. Exp. Sta. Special Report 148, Univ. of Arkansas, Fayetteville, AR
1992	Jackson, TN	J.F. Bradley & M.D. Mullen University of Tennessee P.O. Box 1071 Knoxville, TN 37901	Mullen, M.D., and B.N. Duck (eds.). 1992. Proc. 1992 Southern Conservation Tillage Conference. Jackson and Milan, TN 21-23 July 1992. Tennessee Agri. Exp. Sta. Special Publication 92-01. Univ. of Tennessee, Knoxville, TN.
1993	Monroe, LA	P.K. Bollich Louisiana State Univ. LA. Agric. Exp. Stn. P.O. Box 1429 Crowley, LA 70527-4129	Bollich, P.K. (ed.). 1993. Proc. 1993 Southern Conservation Tillage Conference for Sustainable Agriculture. Monroe, LA 15-17 June 1993. Louisiana Agri. Exp. Stn. Ms. No. 93-86-7122. Louisiana State Univ., Baton Rouge, LA.
1994	Columbia, SC	W.J. Busscher & P.J. Bauer USDA-ARS Coastal Plans Res. Ctr. Florence, SC 29501-1241	Bauer, P.J., and W.J. Busscher (eds.). 1994. Proc. 1994 Southern Conservation Tillage Conference for Sustainable Agriculture. Columbia, SC 7-9 June 1994. USDA-ARS Coastal Plains Soil, Water, and Plant Research, Florence, SC.
1995	Jackson, MS	N.W. Buehring & W.L. Kingery Mississippi State Univ. NE Miss. Branch Stn. Verona, MS 38879	Kingery, W.L., and N. Buehring (eds.). 1995. Proc. 1995 Southern Conservation Tillage Conference for Sustainable Agriculture. Jackson, MS 26-28 June 1995. Mississippi Agri. and Forestry Exp. Stn Special Bulletin 88-7., Mississippi State Univ., Mississippi State, MS
1996	Jackson, TN	P. Denton, J.H. Hodges, III, & D.Tyler Univ. of Tennessee Plant & Soil Sci. Dept. Knoxville, TN 37901	Denton, P., N. Eash, J. Hodges, III, and D. Tyler (eds.). 1996. Proc. 19th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Jackson and Milan, TN 23-25 July 1996. Univ. of Tennessee Agri. Exp. Stn. Special Public. 96-07. Univ. of Tennessee, Knoxville, TN.
1997	Gainesville, FL	R.N. Gallaher & D.L. Wright PO Box 110730 Agronomy Dept. Univ. of Florida Gainesville, FL 32611	Gallaher, R.N., and R. McSorley. 1997. Proc. 20th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Gainesville, FL 24-26 June 1997. IFAS Coop. Extn. Service, Special Series SS-AGR-60, Univ. of Florida, Gainesville, FL.
1998	North Little Rock, AR	S.L. Chapman & T.C. Keisling Univ. of Arkansas P.O. Box 391 Little Rock, AR 72203	Keisling, T.C. (ed.). 1998. Proc. 21st Annual Southern Conservation Tillage Conference for Sustainable Agriculture. North Little Rock, AR 15-17 July 1998. Arkansas Agri. Exp. Stn. Special Report 186, Univ. of Arkansas, Fayetteville, AR.

Year	Location	Program Chairman or Co-Chairmen	Proceedings
1999	Tifton, GA	J.E. Hook Univ. of Georgia-NESPAL Coastal Plain Exp. Sta. P.O. Box 748 Tifton, GA 31793-0748	Hook, J.E. (ed.). 1999. Proc. 22nd Annual Southern Conservation Tillage Conference for Sustainable Agriculture, Tifton, GA 6-8 July 1999. Georgia Agri. Exp. Sta. Special Pub. 95. Univ. of Georgia, Athens, GA.
2000	Monroe, LA	P.K. Bollich Rice Research Station, Louisiana Agric. Exp. Stn., LSU AgCenter, P.O. Box 1429, Crowley, LA 70527-1429	Bollich, P.K. (ed.). Proc. 23rd Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Monroe, LA 19-21 June 2000. Louisiana Agri. Exp. Sta., LSU Agri. Center Manuscript No 00-86-0205, Louisiana State Univ. Crowley, LA 70527-1429.
2001	Oklahoma City, OK	J.H. Stiegler Plant & Soil Sci. Dept. Oklahoma State Univ. Stillwater, OK 74078	Stiegler, J.H. 2001 (ed.). Proc. 24th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, Oklahoma City, OK 9-11 July. Oklahoma Agri. Exp. Sta. Misc. Pub. MP – 151. Oklahoma State Univ. Stillwater, OK.
2002	Auburn, AL	D.W. Reeves, R.L. Raper, and K. Iversen USDA-ARS NSDL 411 S. Donahue Dr. Auburn, AL 36832	E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

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APPENDIX B

Southern Conservation Tillage Conference for Sustainable Agriculture Award Recipients

Year	Recipient	Affiliation
1998	Dr. Raymond Gallaher	University of Florida, Gainesville, FL
1999	Dr. George Langdale	USDA-ARS, Watkinsville, GA
2000	Dr. Stan Chapman	University of Arkansas
2000	Dr. Don Howard	University of Arkansas
2001	Dr. Normie Buehring	Mississippi State University
	Dr. Terry Keisling	University of Arkansas

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