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PROCEEDINGS OF THE 26TH SOUTHERN CONSERVATION TILLAGE CONFERENCE FOR SUSTAINABLE AGRICULTURE

RALEIGH, NORTH CAROLINA, JUNE 8-9, 2004

INTRODUCTION

Conservation tillage systems have evolved considerably since the *First Annual Southeastern No-Till Systems Conference* held in 1978. A portion of the 2004 conference focuses on reduced tillage production in North Carolina Agriculture. North Carolina is a very diverse state not only agriculturally but geographically as well. The organizing committee has taken this opportunity to develop a program that explores changes in tillage practices in various cropping systems throughout the state that have distinctly different soils. For example, a wide range of row crops are grown in the Blackland or high organic soil region, and there are distinct challenges when comparing this region to the northern or southwestern Piedmont or the traditional sandy soils found in the Coastal Plain. Several papers will discuss recent findings associated with nutrient movement in reduced tillage systems. Our keynote speaker will address the larger issue of conservation incentives and how they have been successful in the state of North Carolina. These papers, along with the volunteered oral and poster presentations, should lead to a greater understanding of reduced tillage production systems and methods as research and extension efforts continue to define the benefits if conservation tillage production in the southern United States.

ORGANIZING COMMITTEE

David Jordan, Department of Crop Science, North Carolina State University
Michael Wagger, Department of Soil Science, North Carolina State University
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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/Research Activities – Information Exchange Group 20 (SERA-IEG –20). This Information Exchange Group is sponsored by the Southern Association of Agricultural Experiment Station Directors (SAAESD), the Association of Southern Region Extension Directors (ASRED), as well as Cooperative State Research, Education and Extension (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 among researchers, extension personnel, NRCS personnel, crop consultants, agribusiness, 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.

ASSOCIATION OF SOUTHERN REGION EXTENSION DIRECTORS (ASRED)

SOUTHERN ASSOCIATION OF AGRICULTURAL EXPERIMENT STATION DIRECTORS (SAAESD)

PREVIOUS CONFERENCES

Year	Location	Contact
1978	Griffin, Georgia	J.T. Touchton
1979	Lexington, Kentucky	S. Phillips
1980	Gainseville, Florida	R.N. Galaher
1981	Raleigh, North Carolina	A.D. Worsham
1982	Florence, South Carolina	J.H. Palmer
1983	Milan, Tennessee	E.L. Ashburn and T. McCutchen
1984	Headland, Alabama	J.T. Touchton
1985	Griffin, Georgia	W.L. Hargrove
1896	Lexington, Kentucky	R.E. Phillips and K.L. Wells
1987	College Station, Texas	T.J. Gerik and B.L. Harris
1988	Tupelo, Mississippi	N.W. Buehring and J.E. Harrison
1989	Tallahassee, Florida	D.L. Wright and I.D. Teare
1990	Raleigh, North Carolina	M.G. Wagger
1991	North Little Rock, Arkansas	S.L. Chapman and T.C. Keisling
1992	Jackson, Tennessee	J.F. Bradley and M.D. Mullen
1993	Monroe, Louisiana	P.K. Bollich
1994	Columbia, South Carolina	W.J. Busscher and P.J. Bauer
1995	Jackson, Mississippi	N.W. Buehring and W.L. Kingery
1996	Jackson, Tennessee	P. Denton, J.H. Hodges, III, and D. Tyler
1997	Gainseville, Florida	R.N. Gallaher and D.L. Wright
1998	North Little Rock, Arkansas	S.L. Chapman and T.C. Keisling
1999	Tifton, Georgia	J.E. Hook
2000	Monroe, Louisiana	P.K. Bollich
2001	Oklahoma City, Oklahoma	J.H. Steigler
2002	Auburn, Alabama	D.W. Reeves, R.L. Raper, and K. Iversen
2004	Raleigh, North Carolina	D.L. Jordan, B. Brock, and M.G. Wagger

Source: Gallaher, R.N. 2002. History and future challenges and opportunities in conservation tillage for sustainable agriculture: rsearch and extension perspective. Pages 2-11 IN E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of research. Proc. 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June. Special Reort No. 1. Alabama Agric. Exp. Stn. And Auburn University, AL 36849. USA

Contents

Keynote Speech

Nutrient Management Considerations in Conservation Tillage

Soil Properties and Conservation Tillage

Conservation Tillage Production Systems

Pest Management

Keynote Speaker

CONSERVATION TILLAGE:
INCENTIVES AND SUCCESSES IN NORTH CAROLINA

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ABSTRACT

Conservation tillage is the foundation for a large number of the cropland conservation systems planned and applied through NRCS technical assistance in North Carolina. According to our 2002 survey, 36% of our row cropped land is planted using no-till techniques. There is good reason for our reliance on conservation tillage technology. Conservation tillage saved the day for many of our state's farmers in meeting the Conservation Compliance provisions of the 1985 Farm Bill. Much of our highly erodible land is used for cotton or corn, and conservation tillage technology at that time provided a solution that could be economically incorporated into these operations and reduced soil erosion rates significantly. This was fortunate because our landscapes in North Carolina are not well suited to some of the other erosion control technologies, such as contour farming or structural practices to reduce slope length. Now, conservation tillage is emerging as a tool to help address a newer resource concern. Since 1999, phosphorus transport off-site has been a critical aspect of USDA's nutrient management policy and standards. This is particularly important in our State due to the large number of confined animal operations and the associated land application of organic sources. North Carolina's new phosphorus loss assessment tool estimates losses from each potential transport pathway. Based on available research and models, the tool incorporates the significant reduction in rainwater runoff from sites with heavy surface residue, and consequently identifies important reductions in soluble P losses. Similarly, conservation tillage reduces particulate phosphorus losses associated with soil erosion. There will be animal growers in this state who are able to stay in business because of the runoff and erosion reduction benefits of conservation tillage. North Carolina uses aggressive criteria in its federal and state cost-share programs to "raise the bar" on ground cover and residue management. We believe the research is demonstrating that we are missing significant potential benefits if we strive for only 30% ground cover. The impacts on soil quality and increased organic matter, nutrient loss reductions, pesticide loss reductions, and moisture conservation from a more aggressive use of residue is becoming apparent. Our federal and state cost share program guidelines have been revised over recent years to push us forward and utilize conservation tillage more effectively. We do grow a number of other crops, such as tobacco and vegetables, on land susceptible to erosion. And although we do have some growers using conservation tillage successfully to produce some of these crops, we still have a ways to go with both the technology and educational aspects of residue management in these operations. Again, we have designed some aggressive incentives for producers who are willing to be leaders in conservation tillage on these crops.

ROLE OF ADOPTING REDUCED TILLAGE PRACTICES TO SATISFY GOVERNMENT MANDATES IN THE NEUSE RIVER BASIN AND OTHER SENSITIVE WATERSHEDS IN NORTH CAROLINA

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ABSTRACT

Fish kills and the identification of *Pfiesteria piscicida* spurred environmental regulations of point and nonpoint source nitrogen (N) pollution in the Neuse River Basin. The majority of the producers selected to join a Local Area Plan to document best management practice (BMP) implementation and N reductions. Documentation required the development of a tracking tool, Nitrogen Loss Estimation Worksheet (NLEW). In determining N reduction coefficients for BMPs, the committee developing NLEW developed the following literature review on the efficacy of no-till. Since the majority of nitrogen lost from agricultural systems in the South is through the soil into the shallow groundwater, only soluble N was considered. The committee determined that cover crops could reduce N loading into shallow ground water but that research conducted on no-till showed no pattern of N reductions: sometimes nitrate loading to the shallow groundwater increased and sometimes it decreased.

INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) has estimated 70 to 80 % of all water pollution is caused by nonpoint sources (NPS) (USEPA, 1998). As a large part of the nonpoint source load, agriculture has been implicated in water quality deterioration of estuarian and ocean resources. Currently USEPA is under court order/consent decree to ensure that Total Maximum Daily Loads (TMDLs) are established in many states (USEPA, 2000a). The suits resulted in proposed revisions to existing regulations for administering the TMDL provisions of the Clean Water Act. On July 13, 2000, the final TMDL Rule was published in the Federal Register (USEPA, 2000b). Under the TMDL Rule, a TMDL will be established for each impaired water resource. Each TMDL specifies the pollutant and the amount by which a pollutant needs to be reduced from a particular source to meet water quality standards.

Specific water quality problems have already prompted passage of some TMDLs. Fish kills and the identification of *Pfiesteria piscicida* spurred environmental regulations of point and NPS nitrogen (N) pollution in the Neuse River (NC DENR, 1997). The intent of these regulations is aimed at improving the water quality of the Neuse River estuary by reducing N loading by 30% within five years. This 30% reduction in N has become the USEPA-approved TMDL (NC DENR, 1999).

Several rules were written to abate agriculturally derived NPS N in the Neuse River. One rule in particular, Rule .0238, requires that agricultural producers either implement mandatory best management practices (BMPs) or that they join a Local Area Plan. Under the mandatory BMP option, producers must utilize one of the following BMPs: 1) a 15-meter riparian buffer (9 meter tree, 6 meter other vegetation), 2) nutrient management and either a 9 meter vegetative buffer or a 6 meter tree buffer, 3) nutrient management and controlled drainage, and 4) controlled drainage and either grass (9 meter) or tree (6 meter) buffers. The local plan allows a local group to determine where the approved BMPs should be implemented to obtain the 30% N reduction. This precludes all producers from installing BMPs on all acres. In addition, the local option provided additional BMP options not specified in the rules.

In exchange for this flexibility, however, the rules mandated accountability in the form of an accounting tool rather than water quality monitoring. Water quality monitoring to demonstrate water quality attainment is expensive, long-term and technically difficult. An accounting tool - Nitrogen Loss Estimation Worksheet (NLEW) - was developed to track changes in N losses and BMPs (Osmond et al., 2000). Development of NLEW required decisions to be made on those BMPs that reduced N besides those mandated by the state. Since NLEW is based on soluble N losses primarily through the soil profile and into the shallow groundwater, we were only considering BMPS that reduce N through that pathway.

One BMP that is increasingly used in North Carolina is no-till. Since not all farmers who practice no-till also practice conservation tillage, we separated the effects of cover crops that received N reduction credit from the effects of tillage. Using research from Wagger (1996), nonfertilized cover crops received the following N reduction: wheat (*Triticum aestivum*) = 5%, oats (*Unicola paniculata*) and barley (*Hordecum vulgare*) = 10%, and rye (*Secale cereale*) and triticale (*Triticosecale spp.*) = 15%. Following is a summary of information about N loss effects resulting from no-tillage production practices. This was our basis for assessment of the N-reducing ability of no-till.

No-till Effects on N Loss Pathways

Agricultural fields lose N primarily through erosion, leaching, denitrification, and volatilization. The two loss pathways that degrade water quality are erosion and leaching. In humid regions, leaching losses of N are generally much greater than surface losses (Smith et al., 1990; Drury et al., 1993). Most mineralized N is in the soluble form and potentially moves through the soil into shallow groundwater, which subsequently moves to drainage ditches and streams (Mitsch et al., 1999; Gilliam et al., 1985). Jacobs and Gilliam (1985) found that in the Coastal Plain of North Carolina, only 6% of the soluble N was lost as surface runoff, whereas 94% of N loss was into shallow groundwater. Nitrate-N (NO_3^-) levels measured in streams and ditches have been found to increase from around 1 mg L^{-1} to 5 mg L^{-1} or more in well-drained agricultural watersheds (Mitsch et al., 1999; Goolsby et al., 1999). Several recent reports or review articles of tillage effects on subsurface N losses have concluded that there is no difference in N losses due to tillage systems (Mitsch et al., 1999; Smith et al., 1990).

A literature review to determine the effectiveness of no-till in reducing leaching losses of N revealed that differences in crop rotations, tillage systems, and other soil and crop management factors complicate the interpretation and comparison of research results. For example, the duration of no-till practices between relevant studies can vary from several years to several decades. In some studies, researchers separate the effects of cover crops from tillage type, whereas in other studies these effects are confounded. For this review, we will consider the cropping practice only by the type of tillage used in establishing a crop stand, exclusive of cover crop. In general, we will use the term "no-till" since many of the studies reviewed did not meet or recognize the conservation tillage standards defined by the Conservation Technology Information Center (CTIC, 2000).

No-till generally increases the macroporosity of the soil through increased aggregation. Changes in pore size generally allow for enhanced infiltration but can cause an increase in bulk density in high-traffic areas. Kamau et al. (1996) studied the effect of tillage and cropping practices on preferential flow through macropores and solute transport. Although these researchers were able to determine that macropore pathways played a major role in leaching losses, there was extreme variability in water and solute flow within plots, and they did not find any differences in solute movement due to tillage treatment. Rasse and Smucker (1999) and Ogden et al. (1999) found that no-till increased flow volume compared to conventional-till. The amount of solute lost in both studies, whether NO_3^- or bromide, was essentially similar even though flow was greater under no-till. Researchers in a recent study from Minnesota demonstrated that minimum tillage systems had higher soluble surface nitrogen losses as well as subsurface losses (Zhao et al, 2001).

Better soil structure and increased porosity that are associated with no-till systems may increase N leaching. Preferential flow of water through larger pores may permit more N and pesticides to move through the soil profile in no-till than in conventional tillage systems. Conversely, preferential flow actually can reduce the amount of NO_3^- lost if the water moves quickly through the pores without equilibrating with the N in the smaller pores. Total mass of N loss is a function of both NO_3^- concentration and volume of water flow. Nitrate-N concentration and water movement both must be considered in order to obtain the total mass of N lost below the root zone. There is often an increase in the amount of water moving through the soil in no-till systems. Although this increase may decrease the N concentration, the total mass of N lost from the no-till system will be similar to that of conventional-till systems.

Rasse and Smucker (1999), like many other researchers, have found that more total water was lost to subsurface drainage under no-till than conventional systems, but that the NO_3^- concentrations were greater under conventional tillage plots. Total NO_3^- leached in this study was similar to slightly lower for no-till. An 11-year study compared N leaching losses of no-till to conventional tillage corn (Randall and Iragavarapu, 1995). Total flow over the years was greater under no-till, but NO_3^- concentration was greater under conventional tillage. NO_3^- losses were greater for no-till in 6 out of the 11 years. Average flow-weighted NO_3^- concentration for the entire study period was 13.4 mg L^{-1} for the conventional system and 12.0 mg L^{-1} for the no-till system. Most of the difference in total N leaching between the two systems was due to large losses that occurred under conventional tillage in a single year. Grain yields and N removal were significantly higher 6 out of the 11 years for conventionally tilled corn.

Drury et al. (1993) found higher water losses under no-till and ridge-till but greater NO_3^- concentrations for the conventional-till treatments. Total subsurface NO_3^- losses were conventional-till (23.5 mg L^{-1}), no-till (17 mg L^{-1}), ridge-till (17 mg L^{-1}), and continuous bluegrass pasture (2 mg L^{-1}). Surface NO_3^- losses, however, were 1.6 kg N ha^{-1}, 3.3 kg N ha^{-1}, 2.9 kg N $ha^{-1}$and 0.14 kg N ha^{-1} for conventional-till, no-till, ridge-till, and continuous bluegrass pasture, respectively. Corn yields and N removal in plant biomass were greater for the no-till and ridge-till systems in this study than the conventional-tilled system.

Izaurralde et al. (1995) found greater N losses under no-till than conventional-till systems. Other researchers from Canada reported that NO_3^- leaching losses were greater under no-till than conventional systems, whereas another experiment showed that the reverse was true: conventional-tilled systems leached more N (Serem et al., 1997). Although research reports that present data with soil N concentration are useful, care must be taken in interpreting data that only provides soil N concentration information because of the possible differences in the amount of water movement.

Power et al. (2000) summarized research conducted on the Management Systems Evaluation Area Project. Losses of NO_3^- under conventional vs minimum till systems were dependent on the soil properties in differing location. Less NO_3^- was leached under no-till for a site with heavy clay soils in Missouri, whereas more NO_3^- was leached in deep loess soils of western Iowa. At two other locations there was no difference in NO_3^- leaching losses between the tillage systems.

Increased water infiltration can increase available soil moisture. If water is limiting, extra soil water can increase yields. Increased crop yields generally result in greater utilization of fertilizer N, which can reduce the amount of N available for leaching. However, these differences in plant N uptake are frequently so small that the effects on shallow groundwater NO_3^- concentrations are negligible. One reason may be that crops grown under no-till conditions often contain lower N concentrations in the above-ground biomass than conventionally produced crops, probably due to a dilution effect (Rasse and Smucker, 1999; Martens, 2000). In addition, identical rates of N may not have been applied to both systems. For instance, no-till burley tobacco (*Nicotiana tabacum*) generally requires an additional 30 kg N ha^{-1} over the N needs of a conventionally produced tobacco crop (Hoyt, 1991). In another example, agronomists recommend in a conservation tillage guide for cotton (*Gossypium hirsutum*) that an additional 34 kg ha^{-1} of N be applied to no-till cotton crops that are planted into a desiccated wheat cover crop (Reeves et al., 1993). This extra-recommended N is needed to offset the effects of immobilization.

Cropping systems tend to have a greater effect on NO_3^- leaching than tillage systems. Kanwar et al. (1997) examined the effects of tillage on tile drainage water quality in the Midwest (Table 1). Statistically, there were few differences between tillage treatments for subsurface drainage volume and NO_3^- loss in drainage water.

Table 1. Effects of various tillage practices and rotation on NO_3^- losses in drainage water (Kanwar et al., 1997).

	Tillage				
Rotation	CP	MBP	RT	NT	Average
	----------------------- NO_3^- losses, kg ha^{-1} ----------------------------				
Corn after corn	65	47	55	64	58
Corn after soybean	36	28	24	24	28
Soybean after Soybean	35	33	25	26	29
Average	45	36	34	38	

CP = chisel plow, MBP = moldboard plow, RT = ridge-till, NT = no-till

In this study, corn (*Zea mais*) in the rotation was more influential than tillage type in determining leaching losses of N. Typically, there were smaller differences between tillage treatments in the total amount of N leached and there was no statistical difference in the amount of NO_3^--N lost. The maximum difference in NO_3^--N losses between tillage treatments were less than 25%. In contrast, there were much larger differences between the amounts of NO_3^--N leached due to crop rotation, with a maximum 52% difference due to cropping system.

Southern Region No-till Studies

Staver and Brinsfield (1998) used a paired agricultural watershed design to study the effects of no-till, conventional-till, and a rye winter cover crop under both forms of tillage on N uptake and subsurface NO_3^- losses in the Coastal Plain of Maryland. They also examined the effect of planting date on the N-reducing effectiveness of a rye cover crop. Shallow groundwater NO_3^- concentrations were similar between tillage treatments when there was no cover crop (Staver and Brinsfield, 1998). Following inclusion of a rye cover crop, the following 5-year period depicted lower groundwater NO_3^- concentrations under no-till. After this period, NO_3^- concentrations were similar for both tillage treatments. Because of the changes that occur during the transition to no-till, it is important to monitor long-term experiments on no-till to separate the establishment phase from the semi-equilibrium phase. Based on their results, they concluded that a winter cover crop was much more effective in reducing soil NO_3^- leaching than no-till.

Sharpley and Smith (1994) compared conventional and no-till winter wheat systems in a paired-watershed experiment in Oklahoma. They used conventional tillage in two watersheds and found shallow groundwater concentrations of NO_3^- averaged 4 mg L^{-1} prior to converting one field to no-till. The NO_3^- concentration of the shallow groundwater under the conventional-tilled watershed varied between 2 and 4 mg L^{-1} of NO_3^- during the next 6 years of the experiment, whereas the NO_3^- concentration of the shallow groundwater under the no-till system increased immediately and rose as high as 25 mg L^{-1}. The increased NO_3^- concentration was attributed to poorer wheat yields from the inability to incorporate fall-applied fertilizer N into the no-till wheat.

Crop yields following a cover crop can be higher or lower than a non-cover crop system, depending on the environment. Yield has sometimes been used as an estimate of treatment affects on N leaching. When using yield as a surrogate, caution must be taken because higher yield does not always indicate lower leaching losses.

In a 3-year study conducted on a Norfolk sandy loam, Reeves and Touchton (1991) showed that corn yields were lower following a rye cover crop than following fallow (no cover crop) at N rates from 0 to 150 kg N ha^{-1}. At the highest N rate (150 kg N ha^{-1}), yields were similar. In the Georgia Coastal Plain, Neely et al. (1987) compared sorghum yields produced on a Greenville sandy clay loam over 2 years. Grain sorghum yields were greater after fallow than after a wheat cover crop at N rates ranging from 0 to160 kg N ha^{-1}. A long-term study of 10 years in Maryland (Poplar Hill) reported no statistical difference in yield between no-till and conventional-till plots (Coale, 1999) for corn and soybean (*Glycine max*). Early data from these same experiments demonstrated that conventional tillage had a slight (but not statistically significant) yield advantage at 0 and 80 kg N ha^{-1}. No-till had a slight, but not statistically significant, corn yield advantage at 120 and 160 kg N ha^{-1} (Bandel, 1986).

In Kentucky, Frye (1986) developed a N budget for a Maury silt loam by measuring N uptake and losses (Table 2). At lower N fertilizer rates, more N was translocated to the grain and less was immobilized in the soil in conventional tillage than no-till systems. Approximately the same proportion of N was lost under all tillage treatments and N rates.

Table 2. N Loss Budget

		Fertilizer N		
N Rate	Tillage	In grain	Immobilized	Lost
kg ha^{-1}			%	
84	No-tillage	23	42	29
84	Conventional	40	27	26
168	No-tillage	29	39	25
168	Conventional	28	37	27

Another long-term study was conducted in Tennessee, where researchers compared corn yields from different tillage systems for 11 years. Corn yields were higher in the conventional-tilled plots for 5 of the 11 years, with similar yields in the other 6 years (Howard, 2000). In spite of the yield differences, no-till remains an extremely important tool to reduce soil erosion on the highly erodible, sloping silt-loam soils in this area of Tennessee.

Researchers in Texas found that N applied to no-till wheat was more effective in improving grain yield than conventional treatments at all but the 100 kg N ha^{-1} rate (Hons et al., 1985). Conversely, grain sorghum yields were significantly higher for conventional tillage at all N rates, including the no N treatment. Cropping sequence had a more pronounced influence on yield, however, than tillage type.

Mullins and Mitchell (1989) examined wheat production on a Dothan loam fertilized at 120 and 180 kg N ha^{-1}. At both N rates, wheat yields were greater in conventional tillage than in reduced tillage. Camp et al. (1984) reported no difference in corn or soybean yields between conventional and minimum tillage with subsoiling in a 3-year study on Bonneau and Norfolk soil in the Coastal Plain of South Carolina. More recently, researchers in South Carolina found no consistent differences in yields of corn, wheat, and cotton, or in plant populations; or crop biomass between conventional tillage and no-tillage systems (Hunt et al., 1990; 1997). They did report differences among cultivars in seed cotton yield between the two tillage systems. Averaged over 3 years, three of the six cotton cultivars produced greater yields under conservation tillage management, compared to only one cultivar with higher yields under conventional tillage. In a related study, Bauer and Busscher (1996) reported slightly lower lint yield in conservation tillage compared to conventional tillage, but the difference was not significant. In another study, Torbert and Reeves (1994) evaluated cotton production under several tillage systems produced on three Hapludults: Wickham, Cahaba, and Bassfield. They found that strip-tillage increased lint yield by 14% over conventional tillage, but there was no difference in total N uptake.

The effects of tillage and cover crops at different fertilizer rates were studied for tomato (*Triticolsecale esculentum*) (Sainju et al., 1999). Nitrate-N losses were significantly greater for no-till (129 kg ha^{-1}) than either chisel-plow (54.8 kg ha^{-1}) or moldboard (55.6 kg ha^{-1}). As expected, nitrate losses increased with increasing fertilizer N rate.

Thomas (1992) found that cumulative NO_3^- losses between October and May were similar (100 kg ha^{-1}) for conventional and no-tilled corn. For no-till soybean, however, nitrate-N losses were twice as great as for this crop produced under conventional tillage.(30 kg ha^{-1} vs 15 kg ha^{-1}).

SUMMARY

During a national conference on no-till, it was concluded that no-till had little effect on increasing or decreasing N movement into shallow groundwater (Logan, 1987). Additional data since then continues to support this conclusion: the type of tillage, when considered alone and separately from cover crop practices, has little effect on N movement into the shallow groundwater, and may in fact increase N leaching.

From this review of the effectiveness of various BMPs in reducing N losses, we concluded that no-till, if considered separately from use of small grain cover crops, does not reduce soluble N losses in Coastal Plain cropping systems. We did, however, allow some reduction in N losses for no-till corn produced in the Piedmont since yields are immediately and significantly increased with no-till systems. Data from the Mountains do not support crediting N due to no-till. Cover crops in any physiographic region, however, will give some N-reducing credit.

Increasingly, as tools such as NLEW are developed to track NPS reduction in regulated watersheds or river basins, the scientific community will be asked to answer questions about BMPs such as "What pollutants do individual BMPs affect?" and "How effective are BMPs in reducing a particular pollutant?" Not all states will have the research data necessary to answer these questions and as a consequence, we must rely on the substantial body of scientific knowledge that already exists. Future research in conservation tillage will be most useful if experimental questions are carefully developed and research reports indicate the limitations of the data and results.

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CONTINUOUS CONSERVATION TILLAGE: EFFECTS ON SOIL DENSITY, SOIL C AND N IN THE PRIME ROOTING ZONE

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ABSTRACT

This study reports the results of sampling soil within a field experiment at CEFS, the Cherry Farm, Goldsboro, North Carolina. The experiment tested effects of six years of conservation tillage *with* cover crops, contrasted with chisel plow/disk tillage *without* cover crops, under three crop rotations. In April, 2003 two sets of undisturbed core samples were collected from six mapped soil areas, at depth increments of 0-2 and 2-5 inches, replicated four times. One set was used for soil bulk density; the other provided soil carbon and total nitrogen contents. The study found strong and consistent inverse correlations between soil carbon content and bulk density. Under conservation tillage the surface two inches generally sustained suitable density for root activities. However, at 2-5 inches density approached or exceeded 1.6 g cm-3. Given the textures involved, this density likely would affect root growth, especially under non-ideal, wet/cool or dry/hard conditions. This would be especially important for crop establishment within this prime rooting zone. This low carbon/high-density problem was less likely for soils containing the influences of more silt with less sand. It was greater when corn, peanut and cotton were grown compared to producing soybean or wheat/soybean with corn. This study revealed increased carbon sequestration from the conservation tillage systems used, along with increased total N content in the surface five inches of soil. Conservation tillage as practiced helped to reduce the "greenhouse effect" and lessened N leaching losses, holding more of these elements within the topsoil.

INTRODUCTION

The use of continuous conservation tillage has become an important practice for many farmers, and for some, an essential one. Through improved equipment and technology of recent years it has provided increased production efficiency, allowing them to use much less labor and fuel per acre. This has allowed them to expand acreage, thereby gaining economies of scale in the use of their labor, capital and management. Many farm operations have accepted and benefited from financial incentive programs in support of one or more components of conservation tillage concepts and technology offered by federal, state and local agencies, as well as by agricultural input suppliers having similar environmental interests. To these agencies and suppliers the use of continuous conservation tillage is a preferred approach toward their assigned missions and their business objectives. It promises proven benefits in the prevention of soil erosion and protection of the quality of our natural resources, including soil, water, air and wildlife habitat.

When weather conditions are reasonably good, most farmers are quite content with crop performance and yields under conservation tillage. However, slow early seedling growth is sometimes observed when the no-till planting method is used, particularly in some field conditions and in the first few years of its continued use. This may occur in certain fields or portions of fields, and it may be more obvious only in certain seasons. Not having a contrasting area under a differing tillage method to serve as reference, it often is very difficult for farmers to know the degree of yield limitation that may be present in such problem areas.

In a long-term experiment conducted at the Center for Environmental Farming Systems (CEFS) near Goldsboro, North Carolina, slow early crop growth under the conservation tillage treatments was often noted. The replicated study included contrasting conventional tillage treatments for each crop and rotation. In that study crop yields under conservation tillage were generally only equal, and often slightly inferior, compared to the conventional tillage treatments. This situation offered the opportunity to monitor soil impacts from six years of continuous conservation tillage. The results reported here are based on soil samples collected in the spring of 2003 from selected areas within that study.

MATERIALS AND METHODS

The above mentioned, large-scale field experiment was begun at CEFS in 1995, and was designed to compare the long-term effects of continuous conservation tillage in contrast to annual conventional tillage. This was a systems study in which specific crop rotations and tillage methods were tested using farm-scale field equipment. The study included 16 treatments, each considered a system composed of a crop rotation and tillage method. Individual plots were 2/3 acre in size, and each treatment was replicated four times. The total experimental area including access aisles covered approximately 50 acres.

The rotations included corn/full season soybean, corn-wheat/double cropped soybean, and corn/peanut/cotton. In the conservation tillage treatments a cover crop was planted each fall and killed with Roundup herbicide as late as possible pending planting of the spring crop. Throughout the study, commercial fertilizers and pesticides were carefully applied as needed, using labeled products, rates and timing as recommended by NC Cooperative Extension Service. An exception to this was that in later years no insecticide was applied in the corn/full season soybean rotation for insects attacking corn seedlings, this to facilitate a related study of beneficial nematodes in that rotation.

Where soybean, peanut or cotton was to be planted the cover crop was allowed to advance well into head formation before it was killed. No additional fertilizer nitrogen was applied to the cover crops. The cover crop in the first four years was wheat, until a problem developed with Hessian fly, which appeared to have over-wintered in the cover crop residue to then cause losses in the plots with wheat as grain. In the fifth and sixth years oat served as the cover crop in all conservation tillage plots.

In the first year of the study (1995) much attention was given to assurance throughout the experimental area of an optimum level of soil pH and available phosphorus. The area was divided via a grid into approximately five-acre areas, and each was sampled and treated separately, following the standard soil test recommendations. In the first year all crops were established in their assigned plots, although all were planted using conventional tillage. This involved use of a chisel plow, followed by tillage with a finishing disk and field cultivator. Conventional tillage was chosen the first season in order to assure proper incorporation of lime and phosphorus, and thus to facilitate continuous conservation tillage afterward. From that point onward all treatments and crop rotations were installed according to the plans specified in Table 1. It is important to realize that for practical purposes the crop sequence and cultural practices of any given plot within the experiment simulate a given field of a farmer's operation, where a standard rotation and tillage method is continually followed.

Following six complete years of the project (the 1996 through 2001 seasons), the study was modified. The individual plots locations were maintained, but much of the detailed original design aspects of the treatments were halted. The no till method was continued in planting the conservation tillage treatments. However, the differing rotations were dropped, and in 2002 the entire area was planted in soybean. The conventional tillage plots were planted following the standard chisel/disk preparation. A cover crop had been planted the preceding fall. The same procedures were used in 2003, except that corn was the sole crop throughout the study area, and there was no cover crop planted into the conservation tilled plots. Therefore the spring 2003 sampling that has provided the results reported herein is presented to document the results of six continuous years of the planned, contrasting tillage and rotations. However, the reader should note that the effects of six years of planned treatments probably had begun to diminish by the time sampling was done, because of the period of one summer and a winter in which the ongoing effects of the original plan for cover crops and differing crop rotations had been discontinued.

The entire area of this experiment lies near the Neuse River, and even closer to its tributary, the Little River. The soils throughout the area are subject to flooding, and belong within the taxonomic great group Hapludults. Typically these soils are quite spatially variable, which is the case throughout this experimental area. Commonly there are two or even three mapped soil areas within a plot area of 0.67 acre. Fortunately a detailed soil map has been developed and recorded in our GIS database.

Since the individual plots remained marked by corner posts, and these were easily located on the soil map, it was very feasible to choose sample areas of a given mapped soil within plots having chosen cultural system histories. In April 2003, just prior to any fertilization or preparatory tillage for the summer crop, 24 such study areas were chosen for soil sampling. Each of these areas represented a given mapped soil, along with its respective six-year history of the selected crop rotation and continuous tillage system. Within each area four replicate sites were sampled, each representing that combination of soil map unit and cultural system. In all cases sample areas were selected at about 8 inches beside the evident previous crop row, this to avoid the unusual local effects of recent root masses on soil bulk density, and the related contributions to soil carbon and nitrogen. Further, sites were chosen to avoid sampling the compacted areas of recent wheel tracks, especially those made by harvesting equipment.

In all cases the surface soil was sampled at depth increments of approximately the 0 to 2 inches and 2 to 5 inches. The thickness of these depth increments was accurate, because all samples were collected with a standard, undisturbed soil core sampler, using internal rings of 3 inches diameter. This core sampling procedure was modified by using a ring of 2-inch thickness for the upper sample, followed by the standard ring of 3-inch thickness for the second depth increment. However, the upper edge of these depth increments was approximate, judged to have been within a half-inch of the stated depths of 0 or 2 inches. This was necessary because in using the core sampler a small thickness of the surface soil must be removed in order to insure an exact and flat surface at the top of sample. Furthermore, the second depth increment cannot be taken directly beneath the surface sample because of the disturbance caused by a shovel, which is usually required to remove the upper sample. Therefore, an adjacent small excavation to approximately 2-inch depth was made with a small shovel, and the second depth sample was begun within that excavated area.

At each of these replicate sample sites two sets of samples at each depth increment were collected. The one set was used to determine soil bulk density, by standard oven drying of the samples. The second set of samples was used for determination of soil carbon and total soil nitrogen contents. These samples were kept at field moisture and cool temperature, stored inside sealed plastic bags for several weeks until the laboratory analyses were performed. These soil samples were then air-dried and crushed to pass through a 2 mm sieve. Total carbon and nitrogen contents were determined by dry combustion using a Perkin Elmer/Series II 2400 analyzer (Nelson and Sommers, 1982).

A portion of one of the replicate samples from each study area was used to determine the soil texture for that area of soil. Particle-size distribution was determined using the USDA classification system. Samples were pretreated with hydrogen peroxide for organic matter removal prior to sedimentation analysis. Clay and silt contents were determined using the hydrometer method. (Gee and Bauder, 1986)

Standard one-inch soil cores were also taken from the four replica sites, and these were combined as a composite to provide a single soil fertility sample representing each study area. The samples were analyzed by the Agronomic Division, North Carolina Department of Agriculture and Consumer Services (data not shown).

Statistical analyses were done, including analysis of variance and tests for correlations between soil bulk density and soil carbon content, and between soil carbon and soil nitrogen contents. (SAS) This permitted testing for differences between the tillage treatments at the same depth increment, and between depth increments for the same tillage system. For three of the soils it was also possible to test for differences between crop rotations.

RESULTS AND DISCUSSION

Mapped areas of six soils were chosen for study within the experiment. Although there were several more soils within the overall experimental area, the six were chosen because these were present in all versions of the tillage systems tested, and for three of those soils the areas were adequate to permit sampling and contrast for two or even three of the crop rotations in the study. Although time and analytical resources were limited, this selection of soils allowed the study of all forms of tested tillage, these giving ten differing combinations of soil and crop rotation, each at the depth increments of 0-2 and 2-5 inches. Table 2 presents the means of soil bulk density and the contents of soil C and N for the rotation or rotations tested, and for each of the six soils. The taxonomic classification of the soils is included. The soil “Newbegun” currently is in the status of “proposed,” because it is under formal review for use on soils currently being mapped in this state. Statistical significance of difference between the two sample depths for each variable, for each form of tillage and each soil is shown. Significance is indicated where there was 90% or greater certainty, although in most cases the certainty level was much higher.

Soil Density Concerns

Bulk density was significantly greater at the 2 to 5 inch depth for seven of the ten comparisons under conservation tillage, and for eight of those comparisons under chisel plow/disk tillage without cover crops. However, of more importance is the fact that under conventional tillage the density at both depths will be lessened before planting each spring, whereas with continuous no till planting there is no plan for loosening in the seedbed zone, because we assume the density and porosity to be suitable for plant growth. A recent agency soil quality publication (USDA-NRCS, 2003) lists ideal soil bulk densities of <1.4 for sandy loam, loam, sandy clay loam, and clay loam textures. It stated that root growth “may be affected” beginning at the density of 1.60 for sandy clay loam, loam and clay loam;

at 1.63 for sandy loam and at 1.69 for loamy sand and sand textures. (Note: All expressions of soil bulk density will refer to units of gram cm -3.) This indicates that for a given level of root restriction a slightly higher bulk density can be tolerated in the more coarse-textured soils.

In this study the average density within the surface 2-inch depth under conservation tillage was nearly ideal, given the textures of the soils included. The exceptions to this statement were for the State soil when corn/peanut/cotton rotation was grown and for the Dogue soil under all three rotations. Unfortunately however, under conservation tillage the density at the 2-5 inch depth approached or exceeded that which would affect root growth in all soils except the Newbegun and the Yeopim. Textural analyses of samples from this study revealed that the Newbegun and Yeopim soils have about 50% silt and 30% sand (making them of silt loam texture), whereas the other soils studied were approximately 50% sand and 30% silt (fitting the standard for loam or sandy loam textures).

With the assumption of a constant density for mineral soil particles of 2.65 gram cm –3, it is possible to determine useful estimates of total soil porosity for stated levels of soil bulk density. Using this approach, the above-stated benchmark densities for differing textures show that "ideal" total pore volume for sandy loam, sandy clay loam, loam, and clay loam would be a minimum of about 47 volume percent. For these same textures the loss of less than 1/5 of this porosity would "affect root growth," and loss of about a 1/3 of it would "restrict" root growth. For loamy sand and sand textures, the range is even more narrow; the loss of 1/12 total pore volume would "affect" and 1/5 would "restrict" root growth. It can be argued that porosity under conservation tillage culture may favor root growth and aeration because it may offer more continuous and more large-sized pore spaces.

However, based on the reality of constant density of mineral soil particles, these comparisons illustrate that quite small density changes may be quite detrimental to the soil porosity so necessary for healthy root systems. This is especially critical in the surface five inches as studied here, because this certainly is the prime zone of root development during early crop growth and establishment.

Similar bulk densities have been found by other workers studying tillage pans and how these limit root development and crop growth in soils of the southeastern states. Kashirad, et al, (1967) studied the tillage pan layers in the Norfolk, Red Bay, Orangeburg and Lakeland soils in many cropped fields in Florida. The pan layers in all of these soils were more sandy than in the soils studied here, (mostly sandy loam, loamy sand and sand textures) and the average densities within the pan layers were 1.63, 1.59, 1.65 and 1.63, respectively, for the soils named above. In those crop fields studied they reported that root growth "either did not penetrate the tillage pan or was constricted within the pan as shown by the lack of secondary roots, as compared to those in the soil above or below the pan a zone."

Kamprath, et al. (1978), in a study of the Norfolk and Wagram soils in North Carolina, a multi-year study that revealed significant soybean yield increases in response to deep tillage, in three seasons of the four tested, reported that in the zones of maximum mechanical impedance the bulk density of the dense, compacted pan layer was 1.65 to 1.67 for the Norfolk soil and 1.67 to 1.73 for the Wagram soil. In the Wagram soil the texture of the pan zone was more sandy than that of the Norfolk, probably loamy sand. Loosening the compacted zone by deep tillage significantly increased soybean root dry weight in the zone. Vepraskas, et al, studied soil physical properties and other factors affecting the root growth and yield response to subsoiling by tobacco in many fields in North Carolina. They found that the presence of a zone of soil bulk density of 1.63 or greater was one of two soil factors useful in predicting the responsiveness of soils to subsoiling for tobacco.

The Soil Carbon/Bulk Density Relationship

The correlation coefficients between these variables were consistent, strong and negative. The correlation coefficient for 80 samples from conservation-tilled plots was (-) 0.758; the same for the 80 samples from plots annually stirred by a chisel plow and disk was (-) 0.664. Note that this was found for 80 samples grouped across both sample depths, and for all soils and all rotations. These high correlations were found even though soil density usually differed greatly between sample depths for both tillage treatments. For both forms of tillage these correlation coefficients were statistically significant at >1:10,000. Correlation coefficients for the six individual soils, combining the values from both depths and the rotations sampled, were similarly strong and inverse, even though there many fewer samples per comparison. These were statistically significant at 90 percent or greater certainty for all six soils under conservation tillage and for three of the six soils under conventional tillage management. *Since the soil texture from the two sample depths was generally very similar, the strength and consistency of these inverse correlations strongly urge the conclusion that soil carbon content largely controlled soil bulk density, at the depths and under the conditions sampled in this study.* The soil carbon contents shown in Table 2 also often demonstrate significantly less carbon at 2-5 inches compared to the surface two-inch increment. *These statistical correlations suggest that if soil carbon content is adequately high, soil bulk density will be sustained at a desirable level for crop root growth and activity.*

Even with six years of strong conservation tillage emphasis in this study, that of producing a wheat or oat cover crop and conserving all crop residues, soil carbon content dropped to the range of 6/10 to 3/4 percent at this second depth, except for the more silty Newbegun and Yeopim soils, which sustained soil carbon at 8/10 to 1%, along with maintaining a satisfactory density at this depth. In fact, for conservation-tilled plots, soil carbon at the second sample depth was *statistically significantly less* than the chisel plow/disk plots in five of the ten combinations of soil and rotation compared. Also, for the more sandy soils studied the corn/peanut/cotton rotation resulted in lower soil carbon and higher bulk density, compared to rotations including soybean or wheat/soybean. Again, this was not apparent in the more silty Newbegun soil. Since soil carbon content appeared to control soil density, it is apparent that in the other four more sandy textured soils, it would be desirable either to mechanically loosen the soil in the prime root zone, or to successfully establish higher carbon content to at least 5 inches depth through some more effective choice of cover crops and management of cover and crop residues.

The Soil Carbon/Soil Nitrogen Relationship

As expected, total contents of soil nitrogen and carbon were closely related. Since the soil samples were collected prior to any spring fertilization and following wet conditions of the fall and winter, nearly all of the measured nitrogen was probably associated with the soil biota and organic matter. The correlation coefficients between soil C and N contents were very highly significant at 0.92 and 0.86 for all 80 samples from both the conservation tillage treatment and the chisel/disk treatment, respectively. This is also shown in Table 2, where N contents often were significantly less at the second sample depth, and there was always less N content where peanut and cotton were produced in the rotation instead of soybean or wheat/soybean. Again, the N content differences by depth and rotation were less apparent in the more silty Newbegun soil.

Measured Carbon Sequestration and Nitrogen Capture

Since the original field study was designed to include replicated plots of contrasting tillage systems, and the present research included equal sample numbers from these comparable treatments, it was possible to estimate the impact of the tillage treatments on carbon and nitrogen present in the soil.

For each sample depth and each soil and rotation tested, the average contents of these elements per acre-five inch depth were determined. These were compared for the conservation tillage and chisel/disk tillage systems. This was done by simple subtraction of mean computed values, based on the mean concentrations of C and N, which were multiplied by the respective mean bulk densities. As a result some variation can occur for a given comparison, since these values are subject to any unusual variability for either of the components being multiplied together.

Shown in Table 3 are the results of these estimates. In the case of carbon, when the value shown is positive, this can be referred to as "carbon sequestration" by six years of the conservation tillage system applied. (Further, some of this affect may have diminished because in the crop season preceding sampling, no cover crops nor planned rotations had been included.) This information is of much current interest because it confirms that the conservation tillage system used, through its consumption of substantially greater quantities of carbon dioxide in photosynthesis and the careful residue management applied, in most comparisons did in fact make a greater contribution to soil C, and has thereby reduced atmospheric "greenhouse gases" resulting largely from our societal use of fossil fuels.

The nitrogen values shown in Table 3, when positive, also indicate increased capture of nitrogen through the conservation tillage system used, in comparison to the chisel/disk tillage without cover crops. Since equal fertilization was applied to plots under both forms of tillage, this increased N held in the soil is primarily that from applied fertilizers and the symbiotic N fixed by the soybean and peanut crops grown. *This additional captured nitrogen is not readily susceptible to leaching loss and potential groundwater contamination--another contribution to the benefit of society. Although this additional soil N resulting from the use of conservation tillage is not immediately plant available, surely over time much of it will enter the plant-available pool. This suggests the need to plan future studies to test the opportunity for some reduction in plant fertilizer nitrogen requirement for comparable yields under long-term conservation tillage management.*

CONCLUSIONS

After six years of continuous conservation tillage soil bulk density within the surface two inches was generally sustained at an adequate level for root activities. However, just below, at 2-5 inches, soil density approached or exceeded 1.6 gram cm –3, a level considered to unfavorably affect root growth and activity because of inadequate soil pore volume, given the soil textures involved. During wet periods this would slow air and water exchange, while during dry conditions it may present excessive soil hardness for ideal root growth and normal expansion of root systems.

Soil bulk density was strongly and inversely related to soil carbon content. Based on this fact, the above concern may be considered one of low soil C/high soil density just below the soil surface, this within the prime zone of root growth for crop establishment. The problem may require some form of row-zone loosening, and/or achievement of deeper soil C deposition via changes in cover crop choice and management. Further study is needed to predict or determine where this is needed and the preferred solutions to it.

Soil textures with more silt (48-58%) and less sand (25-40%) influence maintained soil carbon at about 1 percent or greater, as well as bulk density suitable for crop growth. These soils were loam approaching silt loam in texture. The soils presenting the problem had less silt influence with more sand (25-45% silt, with an average of 52% sand). These soils were loam approaching sandy loam in texture. After six years of conservation tillage culture these soils maintained soil C content at the 2-5 inch depth at only about 0.8 percent or less.

The corn/peanut/cotton rotation was less soil carbon-friendly and more prone to high soil density than rotations including soybean or wheat and soybean. It is apparent that aggressive use of winter cover crops is especially important in such rotations.

Soil C and N contents were closely correlated. Because conservation tillage generally did increase soil C it also generally captured more N in the soil. Compared with chisel plow/disk culture without use of cover crops, conservation tillage generally did sequester more C from the atmosphere, where via residue conservation it was measured in the surface soil sampled. Also, generally more N was measured within the surface 5 inches of soil studied, indicating that there was reduced N loss and the associated probable groundwater contamination, provided by the six years of conservation tillage used. These are both benefits of importance our current society.

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SAS. The data analysis for this paper was generated using the GLM procedure in the SAS/STAT software, Version 8.2 of the SAS System for Windows. Copyright © 1999-2001. SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

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Information cited herein on soil bulk density in relation to soil texture was taken from Table 1, and that was provided by Pierce, F. J., W. E. Larson, R. H. Dowdy, and W. A. P. Graham. 1983. Productivity of Soils: Assessing the long-term changes due to soil erosion.

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Table 1. Details of the Tillage Systems Experiment, Center for Environmental Farming Systems (CEFS).

System	Crop Rotation	Tillage/Cover Crop	1995	1996	1997	1998	1999	2000	2001
A1	Corn/F. Season SB	No-Till--Yes	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn
A2	Corn/F. Season SB	No-Till--Yes	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean
A3	Corn/F. Season SB	Chisel Pl./Disk--No	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn
A4	Corn/F. Season SB	Chisel Pl./Disk--No	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean
A5	Corn/F. Season SB	Fall Chisel/Levl--Yes	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn
A6	Corn/F. Season SB	Fall Chisel/Levl--Yes	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean
B1	Corn-Wh/D. Cr. SB	No-Till--Wh. as Cvr/Grn.	Corn	Wh/SB	Corn	Wh/SB	Corn	Wh/SB	Corn
B2	Corn-Wh/D. Cr. SB	No-Till--Wh. as Cvr/Grn.	Wh/SB	Corn	Wh/SB	Corn	Wh/SB	Corn	Wh/SB
B3	Corn-Wh/D. Cr. SB	Ch.Pl./Disk--Wh. grain	Corn	Wh/SB	Corn	Wh/SB	Corn	Wh/SB	Corn
B4	Corn-Wh/D. Cr. SB	Ch.Pl./Disk--Wh. grain	Wh/SB	Corn	Wh/SB	Corn	Wh/SB	Corn	Wh/SB
C1	Corn/P'Nut/Cotton	No-Till--Yes	Corn	Peanut	Cotton	Corn	Peanut	Cotton	Corn
C2	Corn/P'Nut/Cotton	No-Till--Yes	Peanut	Cotton	Corn	Peanut	Cotton	Corn	Peanut
C3	Corn/P'Nut/Cotton	No-Till--Yes	Cotton	Corn	Peanut	Cotton	Corn	Peanut	Cotton
C4	Corn/P'Nut/Cotton	Chisel Pl./Disk--No	Corn	Peanut	Cotton	Corn	Peanut	Cotton	Corn
C5	Corn/P'Nut/Cotton	Chisel Pl./Disk--No	Peanut	Cotton	Corn	Peanut	Cotton	Corn	Peanut
C6	Corn/P'Nut/Cotton	Chisel Pl./Disk--No	Cotton	Corn	Peanut	Cotton	Corn	Peanut	Cotton

Shading indicates a Conservation Tillage Treatment-------- ▨

Table 2. Mean soil bulk density, carbon and total N contents, by soil, crop rotation, tillage system and sample depth, resulting from six years duration of the experiment at the Center for Environmental Farming Systems (CEFS).

	--Soil Bulk Density ($g.cm^{-3}$)--				**-------Soil Carbon (%)--------**				**--------Total Soil N (%)-------**			
	Cons.Till		Ch. P/Disk		Cons.Till		Ch. P/Disk		Cons.Till		Ch. P/Disk	
Crop Rotation	0-2 in.	2-5 in.	0-2 in.	2-5 in.	0-2 in.	2-5 in.	0-2 in.	2-5 in.	0-2 in.	2-5 in.	0-2 in.	2-5 in.
	--------State Soil (fine-loamy, mixed Typic Hapludults)--------											
Corn/FS Soybean	1.444	1.583*	1.601	1.641	1.370	0.730*	0.945	0.723*	0.160	0.103*	0.115	0.095*
Corn/Peanut/Cotton	1.602	1.651	1.564	1.597*	1.025	0.585*	0.773	0.690	0.128	0.095	0.115	0.100*
	--------Altavista Soil (fine-loamy, mixed Aquic Hapludults)--------											
Corn/Wheat/DC SB	1.464	1.623*	1.379	1.533*	1.188	0.758*	1.245	0.900*	0.158	0.110*	0.158	0.128*
	--------Newbegun Soil (fine-silty, mixed Typic Hapludults) --------											
Corn/Wheat/DC SB	1.396	1.540*	1.320	1.501*	1.388	1.110	1.290	1.025*	0.173	0.153	0.163	0.140*
Corn/Peanut/Cotton	1.439	1.536	1.439	1.539*	1.353	1.003	1.090	1.113	0.163	0.138	0.143	0.143
	--------Yeopim Soil (fine-silty, mixed Aquic Hapludults)--------											
Corn/F S Soybean	1.412	1.552*	1.305	1.530*	1.600	0.830*	1.110	0.943	0.188	0.118*	0.153	0.133*
	--------McQueen Soil (clayey, mixed Typic Hapludults)--------											
Corn/F S Soybean	1.456	1.596*	1.415	1.508*	1.573	0.780*	1.018	0.918*	0.170	0.103*	0.115	0.105
	--------Dogue Soil (clayey, mixed, Aquic Hapludults)--------											
Corn/F S Soybean	1.587	1.622	1.527	1.608	1.073	0.610*	0.963	0.785*	0.143	0.108*	0.125	0.110*
Corn/Wheat/DC SB	1.498	1.649*	1.438	1.617*	1.278	0.753*	1.068	0.773*	0.180	0.128*	0.130	0.100
Corn/Peanut/Cotton	1.530	1.653*	1.450	1.634*	1.010	0.653*	0.870	0.800	0.120	0.088*	0.125	0.118

*Indicates a difference at 90 percent or greater certainty between values for same variable (soil bulk density; soil C or Soil N) and for the same form of tillage (NT or CP/Disk) at differing soil sample depths.

Table 3. Differences in soil C and total soil N contents per acre-five inch resulting from six years of continuous conservation tillage with cover crops versus conventional tillage (chisel plow/disk) without cover crops for six soils and differing crop rotations in CEFS experiment.

Soil Name (Drn. Cl.)	Av. Sand	Av. Silt	Crop Rot'n	Diff. Soil C	Diff. Soil N
	%	%		------(Lbs/A-5 in.)------	
State (Well)	51.9	33.6	Corn/FS SB	+ 2,116	+ 201
State (Well)	"	"	Corn/Pnut/Cot	+ 1,093	+ 92
Altavista (Mod. Well)	44.8	38.4	Corn/FS SB	(-) 880	(-) 54
Newbegun (Well)	30.6	52.6	Corn/Wh-DC SB	+ 2,206	+ 287
Newbegun (Well)	"	"	Corn/Pnut/Cot	+ 637	+ 76
Yeopim (Mod. Well)	30.9	49.5	Corn/FS SB	+ 2,819	+ 123
McQueen (Well)	52.3	40.5	Corn/FS SB	+ 3,185	+ 421
Dogue (Mod. Well)	47.7	40.4	Corn/FS SB	(-) 800	+ 143
Dogue (Mod. Well)	"	"	Corn/Wh-DC SB	+ 1,730	+ 704
Dogue (Mod. Well)	"	"	Corn/Pnut/Cot	+ 185	(-) 311

THE EFFECT OF ROTATION, TILLAGE, AND FERTILITY ON RICE GRAIN YIELDS AND NUTRIENT FLOWS

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ABSTRACT

Rice is one of the most intensively cultivated row crops in America. In order to move away from current tillage practices it will be necessary to maintain current yield levels. A key to successful no-till rice production will be to maintain plant fertilizer efficiency in a system that is flooded much of the growing season and not increase nutrient runoff. A study was established in 2000 that compares fertility, variety, and conventional-and no-till rice rotations. Rice grain yields, across all treatments, were between 140 and 195 bu a^{-1}. Yields were most affected by rotation and tillage. Continuous rice grain yields averaged 34 bu a^{-1} lower than a rice-soybean rotation. Plant P and K uptake varied significantly between rotation treatments but not between tillage, fertility, or variety treatments. Phosphorus concentrations in run off liquid were significantly higher in the no-till plots. Total P in runoff was lower in the no-till plots because of reduced P being carried in solids. Total nitrogen uptake was lower in the continuous rice rotation compared to the rice-soybean rotation with soil N uptake higher for the no-till compared to conventional-till in both rotations.

MATERIALS AND METHODS

Field #8 at the University of Arkansas Rice Research and Extension Center was selected for this study and cut to a 0.15% slope in February, 1999. This site had not been previously used for rice research because irrigation water was not available. Soil at the site is referred to as a Stuttgart silt loam and classified as a fine, smectitic, thermic Albaqultic Hapludolf. Initial soil samples showed a pH range of 5.6 to 6.2 with carbon content averaging 0.84% and nitrogen 0.08%. Plots measuring 250' x 40' were laid out in a north-south direction. These plots were then divided in half east-west with each side randomized as conventional or no-till treatments. Each tillage treatment was then split into a standard and high fertility treatment. For rice, 'standard' fertility consisted of a single pre-flood N application of 100 lbs urea a^{-1} plus 40 lbs a^{-1} P_2O_5, and 60 lbs a^{-1} K_2O applied prior to planting. Rates increased to 150 lbs a^{-1} N, 60 lbs a^{-1} P_2O_5, and 90 lbs a^{-1} K_2O for the 'enhanced' treatment with application times remaining the same. Two varieties of each crop species were planted in a continuous strip across the conventional-and no-till treatments. In March, soil samples were collected for fertility evaluations. Soil samples were ground and dried. Phosphorus and potassium determinations were made using a Melich III extraction at a 1:10 extraction ratio. Plant samples were collected following physiological maturity but before leaf senescence for nutrient determinations in 1999, 2000, and 2001. Plants were divided into grain, leaf, and stem portions for analysis. Plant analysis was completed using a HNO_3 digest and read with a ICP (Spectro Model D). The following rotations were started in 1999: 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, 10) rice-corn (wheat)-soybeans. Yield data and nutrient uptake will be presented for the continuous rice and rice-soybean rotations.

Rice was sown into 7.5 in rows using an Almaco no-till drill. The seeding rate was 90 lbs a^{-1} with Icon used as a seed treatment. P and K were applied prior to sowing with a single pre-flood nitrogen application made prior to flooding. P and K were incorporated in the conventional till treatment and not in the no-till treatment. An ANOVA analysis for each year was completed using SAS PROC MIXED (Littell et al., 1996) and a Duncan means test used to group treatments. Comparisons were made using all rotations with data presented only for the three rotations included in nutrient uptake measurements.

Runoff data were collected in May, 2003 after the rice had been sown but had not emerged. A rainfall simulator representing a plot size of 5' x 7' was used. Rainfall was applied at a rate of 2in/hr for 30min. Runoff was collected and analyzed for turbidity, total solids, and phosphorus content.

Nitrogen uptake comparisons were made using ^{15}N enriched urea (5 atomic percent ^{15}N) fertilizer in 'enhanced' fertility plots planted into the variety Wells in the continuous rice and rice-soybean rotations. Four metal rings 2' in diameter were inserted into the appropriate larger plots. When the rice plants had reached the 4-5 leaf growth stage, labeled N was applied inside each ring at a rate of 150 lbs N a^{-1} (same rate that was used in the larger plots) at the same time the larger plots were fertilized. Each ring was flooded to a depth of 2-3 inches and water maintained at this depth for a period of two weeks. At that time, rubber stoppers were removed from the ring and water from the larger plot allowed to maintain water depth inside the ring. No additional fertilizer was applied to the larger plots after they were flooded. Plant and soil samples for ^{15}N determination were collected from rings at 2 weeks following N application, green ring, flowering, and harvest times during plant growth. Soil bulk density samples were collected at the two weeks and flowering sample times. The ^{15}N atomic enrichment of the soil was determined by continuous flow isotope ratio mass spectrometry, using a Fisons NA 1500 NC elemental analyzer coupled to a Finnigan Delta S mass spectrometer. Rainfall runoff was measured in 2003 on plots that had been planted into rice and before the rice had emerged.

RESULTS AND DISCUSSION

Mean rice grain yields were highest (195 bu a^{-1}) the first year of the study and declined the next two years (Table 1). In the years 2002 and 2003 grain yields reflected seasonal trends. Grain yields for three of four years tillage comparisons were made were higher in the conventional-till treatments when compared to the no-till treatments. This difference ranged between 11 and 18 bu a^{-1} with yields similar in 2003. This difference will represent a significant impediment to adopting conservation tillage in rice production. Government payments are closely tied to grain yield while farmers are not responsive to small changes in production costs. Obtaining equal grain yields in conservation-tilled fields, as was the case in 2003, will enhance adoption. Grain yield differences were most evident in the rotation comparisons with the continuous rice rotation grain yields significantly lower than the rice-soybean rotation (Table 1). For the continuous rice rotation, grain yields declined 27 bu a^{-1} from 2000 to 2002 and recovered only 6 bu a^{-1} in 2003. Trends of lower yields in continuous rice rotations when compared to rice-soybean rotations have been known for a number of years and there are fertilizer recommendations that compensate for this difference by adding additional N (Slaton, 2000). Significant differences in fertility comparisons were present only in 1999 when the 'standard' fertility treatment grain yield was 7 bu a^{-1} higher than the 'enhanced' treatment. This same trend continued until 2003 when the 'enhanced' fertility treatment resulted in higher, non-significant, grain yields. Lack of a clear response to higher fertility (N, P, K) levels supports current fertilizer recommendations. There were no significant differences between varieties for any year comparison.

Potassium fertilizer was applied pre-plant to the soil surface in the no-till plots while it was incorporated into the top 4in of soil in conventional-till plots. Plant K uptake and soil K levels were measured to determine if the two fertilizer application methods resulted in similar K uptake and soil K values. There were no treatment differences in the percent of total above-ground dry matter contained in grain, leaf, and stem for any given variety over the three years data were collected. For the variety Wells, percentages of 45% grain, 21% leaf, and 34% stem were used to determine nutrient uptake. Differences in K concentration in grain, leaf, or stem were present only in the rotation treatment comparison and not in tillage or fertility comparisons. Leaf K concentration increased from 1.10% in the continuous-rice rotation to 1.21% in the rice-soybean rotation. Plant stem K concentration increased from 2.08 to 257% for the same comparison while grain remained constant at 0.30% K. Annual total K uptake for tillage treatments averaged over 4 years was 189 lbs a^{-1} for the no-till treatments as compared to 195 lbs a^{-1} for conventional-till.

Phosphorus plant uptake trends closely followed those for potassium. Average yearly P uptake for Wells in the continuous rice rotation was 26 lbs a^{-1} as compared to 37 lbs a^{-1} for the rice-soybean rotation. This result came as a result of P concentration increases in all plant parts measured. P uptake for tillage treatments measured over the same time period averaged 32 lbs a^{-1}. Increasing P fertilizer levels resulted in an average increase in P uptake of 2 lbs a^{-1} annually.

Restricting the amount of P moving off agricultural fields is a focus of current environmental legislation. If applying P to the soil surface as it was in our no-till treatment results in increased P loss from the field a different approach to applying P fertilizer will be necessary. Rice soils are characterized as 'high runoff' (Figure 1). Runoff consists of liquid and solid material that is carried in the water. P concentrations in runoff water from no-till plots were significantly higher than in runoff form conventional till plots (Figure 2). These results illustrate problems encountered when P is added to the soil surface. When P contained in the solid runoff is included in total P lost in runoff no-till resulted in less P loss (Figure 3). These results indicate there is an expected reduction in P lost in runoff when no-till is compared to conventional-till but there needs to be concern on the high P concentrations found in water moving off no-till fields.

Nitrogen is the most important element in rice growth (Norman et al. 2003). Nitrogen concentration for the variety Wells averaged 1.34%, 1.80%, and 0.49% N in the grain, leaves, and stem respectively. Mean annual plant N uptake ranged between 120 and 151 lbs a^{-1} from 1999 to 2003. As with K and P uptake, there were no differences in tillage or variety treatments. Fertilizer N uptake measured using ^{15}N indicated a significant reduction in uptake by the continual rice rotation when compared to the rice-soybean rotation (Figure 3). These results follow yield trends. There was an additional significant reduction in N uptake by the no-till treatment when compared to the conventional-till treatment in the continuous rice rotation. This was not the case for the rice-soybean rotation where there was no difference in fertilizer N uptake between tillage treatments. Plant soil N uptake results indicate a benefit from no-till when compared to conventional-till regardless of rotation (Figure 5). There was a significant reduction in soil N uptake in the conventional-till treatment when compared to the no-till treatment in the continuous rice rotation; a trend that was not significant in the rice-soybean rotation. Total plant N uptake reflected both rotation and tillage effects (Figure 6). There were no tillage differences within each rotation but a significant reduction in total plant N uptake in the continuous rice rotation when compared to the rice soybean rotation. These results are similar to those found in California studies where it was reported that no-till continuous rice had approximately 10 lbs a^{-1} more plant N uptake when compared to a conventional-till treatment (Eagle et al. 2000). There was a clear advantage in N uptake in no-till when compared to conventional-till but no clear answer as to why we had lower uptake and grain yields from the continuous rice rotation.

CONCLUSIONS

Changing from conventional-till to no-till is not expected to result in significant reductions in rice grain yields for producers using a rice-soybean rotation. Producers who grow continuous rice should anticipate lower grain yields than they would get from a rice-soybean rotation. Applying potassium and phosphorus to the soil surface in no-till systems did not result in decreased plant K and P uptake. Phosphorus concentrations in runoff water increased significantly in no-till management; a result attributed to P being applied to the soil surface. Total P (liquid + solids) concentration in runoff was lower in the no-till managed field because of reduced soil (solids) loss. No-till reduces P loss via erosion but does not eliminate the loss of P that is dissolved in runoff water. No-till resulted in reduced fertilizer uptake in continuous rice while it had no effect on rice in a rice-soybean rotation. Soil N uptake was increased with no-till in both continuous rice and rice-soybean rotations. Total N uptake increased with no-till indicating a possibility of maintaining grain yields at slightly lower N fertilizer rates.

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Table 1: Summary of rice mean grain yield (bu a^{-1}) for treatment main effects in 1999, 2000, 2001, 2002, and 2003 in the long-term cropping systems study at the University of Arkansas Rice Research and Extension Center, Stuttgart, Arkansas.

		Year				
Effect	Treatment	1999	2000	2001	2002	2003
All	All	195	140	137	159	166
Tillage	Conventional	NA	149 a[z]	143 a	168 a	153 a
	No-till	NA	131 b	131 b	151 b	153 a
Rotation	Continuous rice	NA	159 b	145 b	132 c	138 b
	Rice-soybeans	NA	198 a	164 a	174 a	173 a
Fertility	Standard	198 a	138 a	135 a	156 a	159 a
	Enhanced	191 b	142 a	138 a	163 a	147 a
Variety	Wells	198 a	187 a	159 a	168 a	153 a
	LaGrue	191 a	178 a	157 a	164 a	157 a

[z] Means within a column followed by different letters are significantly different at the P=0.05 level of confidence.

Figure 1: Percent of total water collected as runoff following a single simulated rainfall event from continuous rice (RR), rice-soybean (R/S), and rice-corn (R/C) rotations that were either conventional-till (CT) or no-till (NT) from 2000 to 2003 when the samples were taken.

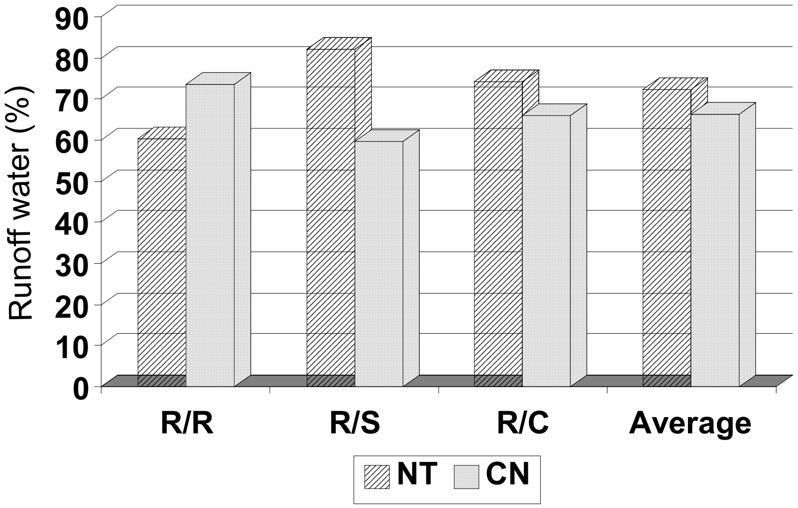


Figure 2: Phosphorus (P) concentration (mg/L) in runoff water following a single simulated rainfall event from continuous rice (RR), rice-soybean (R/S), and rice-corn (R/C) rotations that were either conventional-till (CT) or no-till (NT) from 2000 to 2003 when the samples were taken.

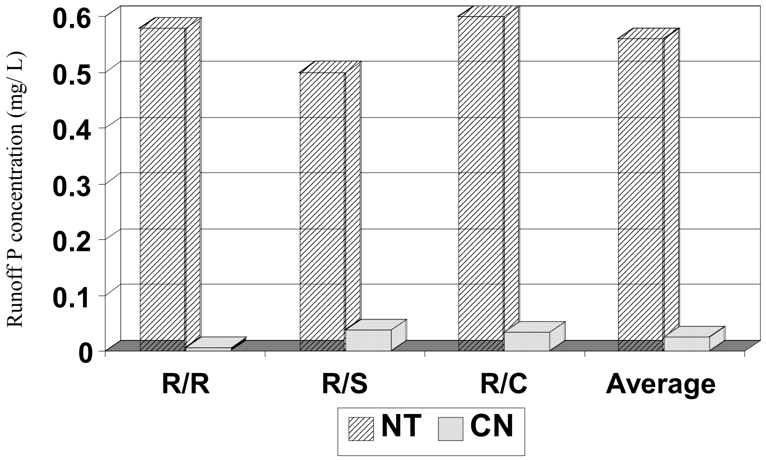


Figure 3: Total phosphorus (P) concentration in runoff (water+solids) following a single simulated rainfall event from continuous rice (RR), rice-soybean (R/S), and rice-corn (R/C) rotations that were either conventional-till (CT) or no-till (NT) from 2000 to 2003 when the samples were taken.

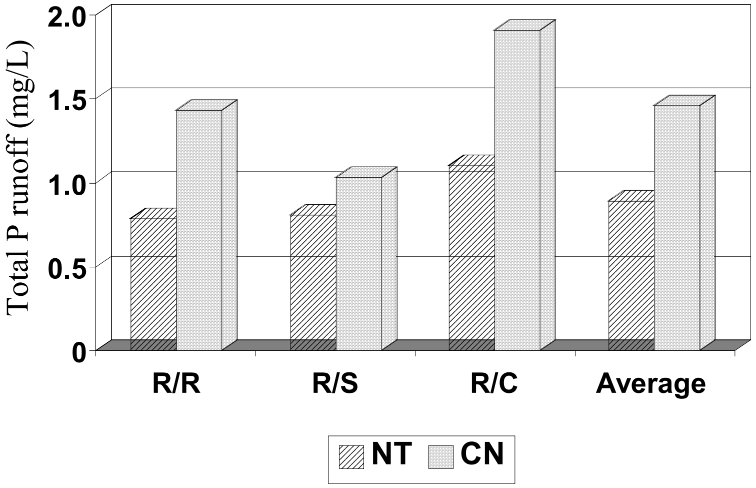


Figure 4: Plant fertilizer nitrogen (N) uptake measured using ^{15}N for conventional-and no-till rice grown in a continuous rice (RR) or rice-soybean (R-Soy) rotation at the University of Arkansas Rice Research and Extension Center in 2002 (bars indicate standard error).

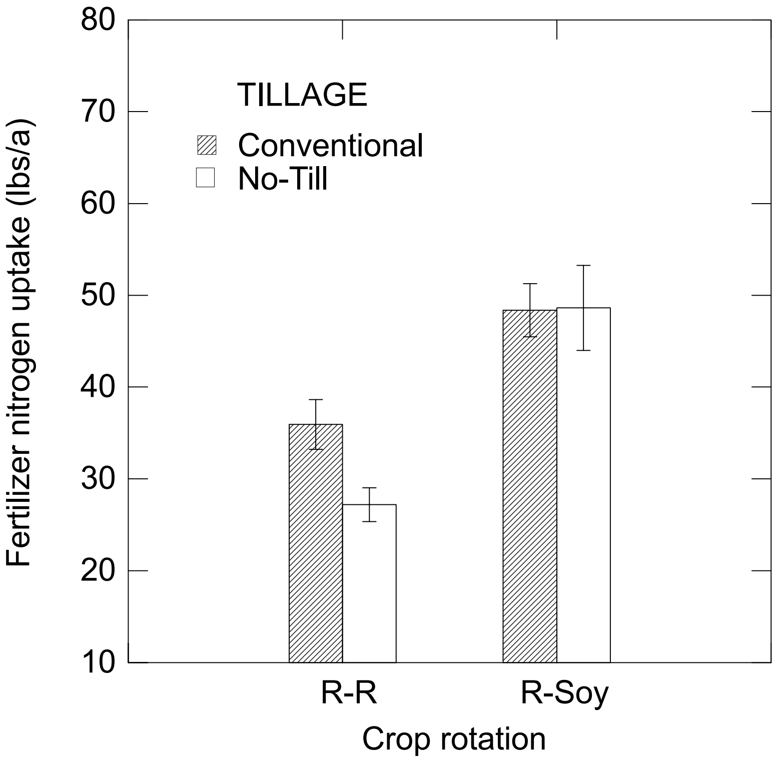


Figure 5: Plant soil nitrogen uptake measured using ^{15}N for conventional-and no-till rice grown in a continuous rice (RR) or rice-soybean (R-Soy) rotation at the University of Arkansas Rice Research and Extension Center in 2002 (bars indicate standard error).

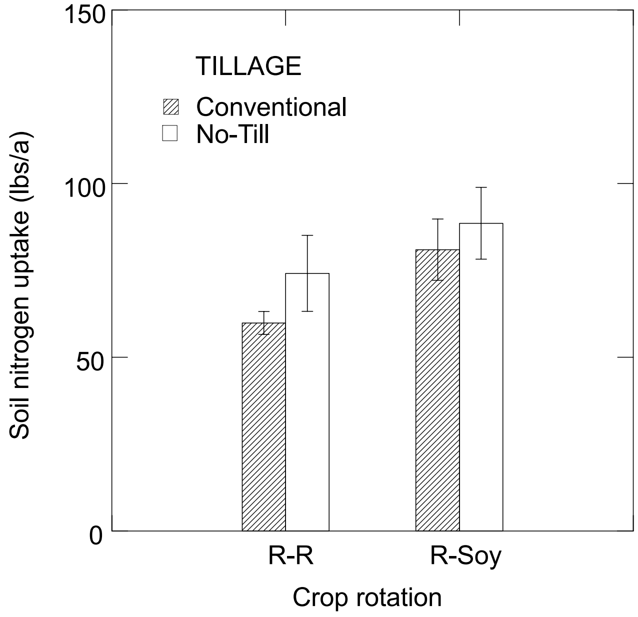
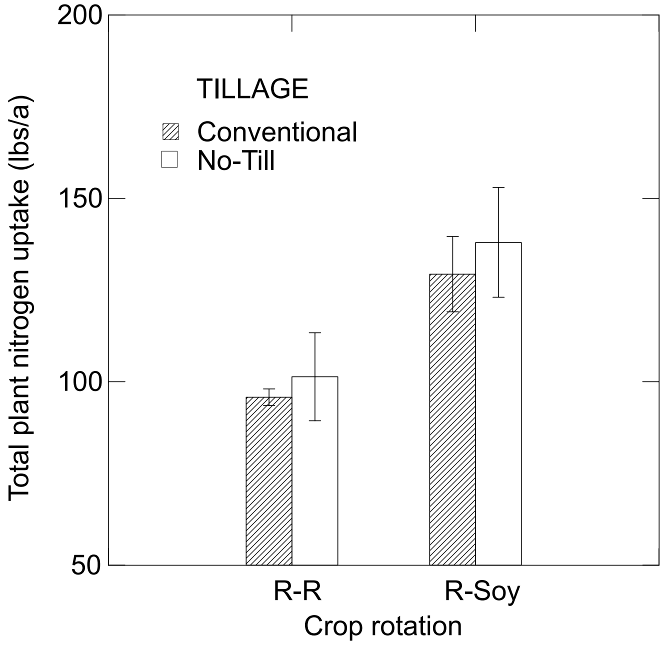


Figure 6: Total plant nitrogen (N) uptake measured using ^{15}N for conventional-and no-till rice grown in a continuous rice (RR) or rice-soybean (R-Soy) rotation at the University of Arkansas Rice Research and Extension Center in 2002 (bars indicate standard error).



FARMER INSPIRED DEMONSTRATION WORK IN CONTINUOUS NO-TILL IN THE NORTH CAROLINA WESTERN PIEDMONT

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ABSTRACT

In addition to regular programming, County Agricultural Extension agents are asked many times to respond to questions, suggestions and concerns by their farmer clientele. In North Carolina as in other states an advisory leadership system is in place and farmers can formally and informally make suggestions and requests for on-farm demonstrational work. In many cases what the farmers are observing in their fields and/or things they have read "spark" the interactions with agents. Such has been the case in Cleveland County, NC. For example in the early continuous no-till era many area farmers were concerned about soil compaction. Measurements and simple demonstrations conducted by the Cleveland and Lincoln County agents and supported by the NCSU Soil Science Department and Cleveland County Government helped alleviate these concerns. Later as fields were in continuous no-till for 5 or more years, farmers began to notice a greater than expected development of their crops prior to major applications of fertilizer nitrogen. These observations led to a replicated test in wheat conducted by the Cleveland County Agricultural Extension agent comparing a field in a 2 year no-till wheat soybean rotation verses a nearby field in a 5 year continuous no-till wheat soybean rotation. Also a 6 year replicated test was initiated on Cleveland County owned land that had been in continuous no-till for 10 years. The test was set up as a continuous soybean corn rotation and in addition to the standard dryland portion, irrigation was used in part of the study to simulate a "good" corn year. Five nitrogen rates were used. The economics of the cost of fertilizer nitrogen was used to demonstrate that the Realistic Yield Expectation (RYE) method for determining nitrogen rates was very much applicable in continuous no-till. Both the wheat and corn tests indicated that residual soil nitrogen was indeed becoming a major factor in continuous no-till for these field crops and when farmers considered the realities of the weather very likely nitrogen rates can be reduced with confidence.

SUMMARY

In 1993 a soil penetrometer was purchased but found to not be a reliable indication of measuring soil compaction. The NCSU Soil Science Department supplied a more scientific device that was used to make two comparisons of fields in continuous no-till verses some nearby fields in which tillage had disrupted continuous no-till. Six locations were sampled at random in each of the four fields in the study. In all cases the top 2 centimeters in the continuous no-till fields had lower bulk densities than the top 2 centimeters in the fields in which tillage had been used. The average bulk density for the balance of the soil to a depth of 6 inches in one of the comparisons was slightly less in the field that had had some tillage (1.44 vs. 1.54) however the average bulk density was slightly less in the 6 to 9 inch depth in the continuous no-till field (1.52 vs. 1.55). This comparison was from an area with a clay loam soil. The other comparison was in an area with some unusually sandy soil for our region of the state. In this comparison the average bulk densities for the 2 cm to the 6 inch depth was the same for the continuous no-till and the conventionally planted field (1.48). However the 6 to 9 inch depth for the field with recent tillage had a much lower average bulk density than the field in continuous no-till (1.50 vs. 1.65).

In 1992 a John Deere 71 demonstrational planter was fitted with an in row shank and closure wheels thanks to the expertise of a local farmer. The rig was used in 4 comparisons (2 in cotton, one in corn and another in soybeans). A significant yield response was achieved at one of the cotton locations to the shank (319 lb. lint vs. 272 lb.). The yields were low due to a very early October freeze. At the other location for cotton the study was not even harvested because the in row shank treatment resulted in such a cloddy seedbed that an adequate stand was not obtained. This likewise was the case with the soybeans. For both of these sites adequate stands were obtained with coulter only no-till planting. It was concluded that the use of in row tillage for our soils would very likely cause more problems than were solved. For corn the coulter only treatment slightly outyielded the in row shank treatment (69.5 bu. vs. 68.4 bu.). Upon presenting the results of the bulk density sampling and in row tillage work during subsequent winter meetings farmers were satisfied that in row tillage simply is not practicle for our area.

Beginning in 1995 some of our farmers began to notice that the crops in fields in 5 or more years of continuous no-till seemingly were developing faster than normal despite the lack of significant application of fertilizer nitrogen. One farmer noted this prior to wheat topdressing time and another noted the same in a remote field that he had forgotten to apply any fertilizer nitrogen to.

The farmer who had observed the situation in wheat offered two of his fields for a test, one had been in continuous no-till for 5 years and the other for only 2. The wheat received 20 pounds N per acre in the fertilizer used at planting in late November of 1996. Among the additional treatments in the replicated test were 62 and 96 pounds of topdressed N as ammonium nitrate for 82 pounds and 116 pounds total N. The test was replicated 4 times in each field. For the 2-year no-till field the 20 pound N treatment yielded only 34.6 bu. per acre. In contrast the field that had been in continuous no-till for 5 years yielded 58.2 bu. per acre. The 82 and 116 pounds total treatments were closer to the same in the 2 year and 5 year no-till fields (74.6 and 85.4 bu. vs. 79.7 and 89.7 bu.).

Sparked by the farmer who had forgotten to fertilize the remote field of corn, a replicated long-term test was initiated in 1996 in a Cleveland County owned field that had been in continuous no-till for 10 years. The test was set up as a continuous corn and soybean rotation and such that half of the study was planted in soybeans, the other half in corn and the following year the crops rotated. In addition half was irrigated to simulate a "good" corn year, not for maximum yields by any means. A stress tolerant variety of corn was used and for all of the fertilizer nitrogen ammonium nitrate was used to reduce the possible variability from N losses from urea forms of N. The nitrogen treatments were 30 pounds at planting only, 30 pounds topdressed N for a total of 60, 60 pounds topdressed N for a total of 90, 90 pounds topdressed N for a total of 120 and 120 pounds topdressed N for a total of 150. Individual plots were periodically soil sampled and limed separately to decrease variability from the different acidifying effects of the different amounts of N used. Each year the cost per pound of N as ammonium nitrate was recorded as was the price per bushel of corn.

For the dryland portion average yields for the 30, 60, 90, 120 and 150 pound N treatments were 72, 84, 89, 88 and 92 bus. per acre respectively. The value of the corn less the cost of the applied fertilizer N was $187, $213, $216, $208 and $208. For the irrigated portion average yields were 91, 114, 133, 136 and 144 bushels per acre. The value of the corn less the cost of the fertilizer N was $241, $296, $341, $341 and $355.

These data indicate that the Realistic Yield Expectation method for determining nitrogen rates is indeed a valid approach when considering the realities of the weather. It is interesting to note that even at the lowest nitrogen rate of 30 pounds per acre that 72 bushels were produced in the dryland portion and 91 in the irrigated portion. These levels exceed the bushel expected yield per pound of applied fertilizer N (RYE) indicating that in continuous no-till residual soil nitrogen may indeed be becoming a major factor.

As farmers continue to practice continuous no-till no doubt additional benefits and unfortunately problems will be observed. For land grant universities to remain on the cutting edge, Agricultural Extension agents must react. Many times the appropriate reaction will be either conducting local tests and demonstrations or passing on the ideas to specialists at the university level.

TILLAGE AND N-FERTILIZER SOURCE EFFECTS ON YIELD AND WATER QUALITY IN A CORN-RYE CROPPING SYSTEM

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ABSTRACT

Tillage and nutrient source choices have important agronomic and environmental consequences in cropping system management, which need to be quantified in the Southeast. In three years of research at the USDA-ARS J. Phil Campbell Sr. Natural Resource Conservation Center, Watkinsville-GA, we compared agronomic benefits and water quality impacts of no-till and poultry litter versus conventional-till and conventional fertilizer in a corn-rye cropping system. No-till and poultry litter each enhanced corn yield by 15 to 23% over three years. When combined, they enhanced yield by 27%. Off-site effects in terms of nitrate-nitrogen and ammonium-nitrogen losses through runoff or drainage were similar among treatments. Concentrations were dependant on N application rates. Below a 3 ton acre^{-1} application rate of poultry litter (90 lbs N acre^{-1}), nitrate levels are expected to be below 10 ppm, especially if the first precipitation or irrigation event is delayed after N application. Application of poultry litter increased loss of ortho-phosphate in runoff by 5 to 6 times compared to conventional fertilizer. The sex hormones estradiol and testosterone coming off poultry litter plots were not above levels observed for conventional fertilizer plots. Managing corn with no-till and/or poultry litter at normal N application rates has agronomic advantages, and does not appear to present large additional risks of nitrate or hormone contamination of water resources. However, offsite effect of ortho-phosphate is a concern.

INTRODUCTION

Tillage and nutrient source choices are important management variables that have agronomic and environmental consequences. Many soils in the Southeast have low water holding capacity and/or root restrictive layers. Crusting is a problem in soils with low organic matter, which encourages runoff from fields. Conventional-till methods, such as disking and harrowing, encourage development of these adverse soil conditions. No-till systems reduce runoff and soil loss, and increase infiltration as compared to conventional-till (Bradley, 1995; Endale et al., 2002; Fawcett et al., 1994; Golabi et al., 1995; Radcliffe et al., 1988). No-till systems increase soil water availability, which can offset water stress arising due to frequent summer droughts.

Poultry production is a significant source of income for many row crop and cattle producers. In 2002, 8.6 billion broilers were raised in the U.S. with a value of $13.3 billion (NAAS, 2003). Four southeastern states (AL, AR, GA and NC) produced 50% of these broilers. In the process, almost 14 million tons (2000 lb units) of poultry litter was produced. Poultry litter can be a valuable resource, which provides a wide range of nutrients and organic matter (Moore et al., 1995). It is often an economical alternative to inorganic fertilizer.

Repeated application of poultry litter can lead to potential negative environmental impacts. In particular, the water quality ramifications of repeated application of poultry litter in cropping systems are of interest to many citizens. Poultry litter can be a source of nitrate and phosphate, but the hormones estradiol and testosterone (shown to affect reproductive development in animals) are also present in it, which is a concern. Research is required that would address agronomic and environmental impacts of combinations of tillage and nutrient sources specific to the environmental conditions of the Southeast. The objective of this research was to quantify the agronomic benefits and water quality impacts of no-till and poultry litter in a corn-rye cropping system in comparison to conventional-till and conventional fertilizer.

MATERIALS AND METHODS

The research was conducted from fall 2000 to fall 2003 at the USDA-ARS J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville, GA (83°24' W and 33°54' N) on 12 large (30 x 100 ft) plots instrumented for automatic monitoring and sampling of runoff and drainage for water quality assessment. The site is located on nearly level (<2% slope) Cecil sandy loam (fine, kaolinitic thermic Typic Kanhapludult). Cecil and closely related soil occupy over half the area of the Southern Piedmont (Langdale et al., 1992). These soils are deep, well drained and moderately permeable. The pH decreases with depth. According to Bruce et al. (1983), the soil at the research site has about 8 inches thick Ap-horizon of brown sandy loam, underlain by 2 to 4 inches thick BA-horizon of red sandy clay loam to clay loam texture. The Bt-horizon consists of red clay about 40 inches thick followed by about 12 inches thick red loam to clay loam BC-horizon. The C-horizon is a loamy saprolite. Total available water in the top 40 inches of soil is approximately 4 inches, not taking changes due to long-term tillage manipulations into account. Long-term average daily air temperature in summer ranges from 75 to 80 °F at the site. Frost-free days in the growing season average 200 to 250. Mean annual rainfall is 48.8 inches. Mean monthly rainfall varies from 3.8 in May to 5.4 inches in March during fall, and from 3.8 in August to 4.8 inches in July during summer. Short-term summer droughts are frequent with serious consequences on crop yield.

The experiment was laid out as a randomized complete block split plot design with three replications. Conventional-till (CT) and no-till (NT) were main plots. Fertilizer subplots consisted of ammonium sulfate as, conventional fertilizer (CF), or poultry litter (PL). The CT consisted of a 12 inches deep chisel plowing followed by one to two diskings to a depth 8 inches and a subsequent disking to 3 inches 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.

The cropping system consisted of cereal rye (*Secale cereale* L., cv. Hy-Gainer) grown in the late-fall to early spring followed by corn (*Zea Mays*, cv. Pioneer 3223) from mid-spring to mid fall. Nitrogen fertilization for corn for the first two years was at a rate of 150 lbs N acre^{-1}. This meant an application of 5 tons acre^{-1} (30% moisture) for PL. The PL source was from local growers, who usually generate three flocks per cleaning on concrete floors covered with sawdust and shavings. Each flock takes 6-8 weeks to mature. Mineralization of N in PL was assumed to be 50% (Vest et al., 1994) during the corn season. Conventional fertilizer was put out in split applications, one-third a day or two before planting, and two-thirds about 33 days later. The N application rate was doubled to 300 lbs N acre^{-1} in the third year in order to increase potential levels of the hormones estradiol and testosterone, which remained at background levels at the application rates of the first two years. The rye cover crop was fertilized with ammonium nitrate at 100 to120 lbs N acre^{-1}. Soil analysis was used to determine P and K needs. All N, P and K fertilizers were applied to the surface of plots one to two days before planting, and incorporated in CT plots only. In addition, a mix of atrazine (1.5

qts acre-1), and dual (1 qt acre-1) was applied before planting and incorporated into soil in CT but not NT plots.

Corn yield was determined by hand harvesting and weighing all whole corn ears from each plot. Twenty to thirty ears were randomly picked from each plot to determine shelled corn weight. The kernel yield was determined in proportion to the whole ear yield of each plot and expressed at 15% moisture equivalent. Statistical analysis was carried out using the MIXED procedure of SAS (Littell et al., 1996; SAS Inst. 1990) including analysis as repeated measures for years. Unless otherwise indicated, all significant differences are given at $P \leq 0.05$.

RESULTS AND DISCUSSION

Annual Corn Kernel Yield

There were substantial differences in yield between years (Fig. 1; $P < 0.0001$ for year). Average kernel yield in 2001 varied from 6265 with CTCF to 8352 lbs acre^{-1} with NTPL. Yield plummeted across all treatments due to severe drought in 2002, and varied from 1586 with CTPL to 2083 lbs acre^{-1} with NTPL. Yield increased somewhat in 2003 and varied from 4103 with NTCF to 5958 lbs acre^{-1} of kernel with CTPL. The average yield over three years varied from 4195 with CTCF to 5253 lbs acre^{-1} of kernel with NTPL.

Several reasons contributed to the yield differential among years, besides treatments, the most prominent of which was reduced precipitation in 2002. Figure 2 shows the amount and distribution of precipitation during the 3 years of corn growth period. During the two weeks prior to planting, natural precipitation was 1.2, 0.7 and 3.6 inches in 2001, 2002 and 2003, respectively. Conditions for seed germination were unfavorable in 2002. The plots had to be irrigated. Since we also needed to induce runoff to measure hormone levels, we applied 2.2 and 2.6 inches of irrigation on days 13 and 14, respectively, after planting. Total natural precipitation between planting and start of flowering, approximately 42 days into the corn season, was 9.3, 3.6, and 12.3 inches in 2001, 2002 and 2003, respectively. But, because of the 4.8 inches of irrigation, the 2002 corn crop had received 8.4 inches of water supply by the start of flowering. During flowering, between days 42 and 70 after planting approximately, total natural precipitation amounted to 7.3, 2.0 and 6.9 inches in 2001, 2002 and 2003, respectively. The corn crop was, therefore, severely stressed in 2002 at a time of its most critical period of water need. Average daily temperature was 2 ^{o}F higher in 2002, during the flowering period, compared to 2001 and 2003 (78 ^{o}F) also, which would have increased potential evapotranspiartion during this period further exacerbating the water stress.

Precipitation was not an issue for the 2003 crop (Fig. 2) and yet corn kernel yield was 74, 81, 50 and 64 percent of the 2001 kernel yield for CTCF, CTPL, NTCF and NTPL, respectively. Four of the six NT plots had severe damage to the young shoots in several rows soon after germination, possibly by corn rootworm attack. Replanting became necessary in these rows, some of which did not recover as expected. In addition, growth in the downstream third of one NT plot in the 2nd replication and both NT plots in the 3rd replication was visibly less vigorous than in the remaining part of these plots, which resulted in reduced yield. The reasons are not clear, but there was an infestation of corn borer early in 2003 and we had to spray all the plots with sevin (carbaryl).

Soil water measurements in 2003 showed that precipitation events (Fig. 2) during the flowering period quickly replenished soil water and soil water levels remained steady, and averaged about 21 to 25%, but three CT plots averaged less than 20% and one NT plot averaged above 25%. In contrast, in 2002, soil water steadily decreased from about 20 to 25% at the start of flowering to about 10 to 15% at the end of flowering with the exception of a 5 to 8% replenishment in response to the 2 inches of precipitation a week and half into the flowering period. Average soil water content was 15 to 19% in half the CT plots, less than 10% in the remaining half, and 15 to 17% in the 5 of 6 NT plots, with the last NT plot averaging 22%. We do not have soil water measurement data during flowering in 2001. We can surmise from Fig. 1, however, that there would have been steady withdrawal of soil water during the first two weeks of flowering, followed by a full saturation of the soil profile in the third week in response to a 6.7 inches of precipitation which occurred in one day and replenished water for crop growth.

Tillage Effect on Corn Yield

Tillage had significant effect on yield but this varied from year to year (P = 0.005 for tillage; P = 0.0001 for tillage*year; Fig. 1). In 2001, corn yield from NT plots exceeded that from CT plots by 29% in plots receiving CF and 14% in plots receiving PL. Although corn yield was 30 to 40% greater in 2002 in NT compared to CT plots, the differences were not statistically significant because of high variance. Then in 2003 CT plots, in a reversal, produced about 13% greater corn yield than NT plots but the differences were again not statistically significant. In 2003 NT plots experienced proportionately more insect damage to plants. Over the three years, average corn yield in NT plots exceeded that in CT plots by 23% in plots receiving CF and 18% in plots receiving PL. Generally, no-till had greater yield enhancing influence in plots receiving conventional fertilizer than those receiving poultry litter.

Fertilizer Effect on Corn Yield

The fertilizer effect on corn yield was also variable from year to year (P = 0.001 for fertilizer; P = 0.005 for fertilizer*year; Fig. 1). In 2001, in plots under CT, those receiving PL produced 16.7% significantly greater corn yield than those receiving CF (i.e. CTPL > CTCF). Also in 2001, NTPL plots had 3% greater yield than NTCF plots but the difference was not statistically significant. In 2002 plots under CF treatment did better by producing 4 to 12% greater yield than those under PL treatment but the differences were not statistically significant. Poultry litter showed strong positive influence on corn yield in 2003 when PL plots produced 28 and 30% greater yield in plots under CT and NT treatment, respectively, than the equivalent CF treatment plots. Over the three years, in poultry litter plots, corn yield was greater by 13% with CT and 8% with NT. However, only the PL effect in CT plots was statistically significant. Generally, poultry litter had greater yield enhancing influence in conventional-till than no-till plots.

Combined Tillage and Fertilizer Effect on Corn Yield

The combined no-till and poultry litter treatment effect enhanced corn yield by 33% in 2001, 26% in 2002 and 14% in 2003, compared to the combined conventional-till and conventional fertilizer treatment effect. The effect, however, was statistically significant only in 2001. Over three years average corn yield was significantly greater in NTPL than CTCF by 27%.

Water Quality - Nutrients

Distribution of nutrient concentrations [nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH_4-N) and ortho-phosphorus (PO_4-P)] in runoff and drainage based on 14 samplings between 6/1/2001 and 7/1/2003 are presented in Figures 3 to 5.

NO_3-N

Nitrate-nitrogen in runoff was generally below 4 ppm (mg L^{-1}) with half in the range 0.5 to 2 ppm (Fig. 3). Overall means and medians for CTCF, CTPL, NTCF and NTPL were, respectively: 1.74 & 0.96, 0.90 & 0.79, 1.54 & 1.33, and 0.97 & 0.70 ppm. On the other hand, the cropping systems had impact on NO3-N released through drainage. The over all means were similar between treatments:

13.81, 18.84, 15.5 and 17.49 ppm for CTCF, CTPL, NTCF, and NTPL, respectively. The medians (10.11, 13.46, 11.42, and 12.62 ppm, respectively) were similarly all above the maximum EPA standard of 10 ppm for safe human consumption (Fig. 3). But since the N application rates were variable over time, NO_3-N concentrations in drainage were also highly variable. The highest concentrations occurred after the 300 lbs N acre^{-1} application (10 tons acre^{-1} for PL) on 5/27/03. Overall mean NO_3-N concentrations for events prior to this high rate of application were in 9.61, 10.82, 11.95, and 12.05 ppm for CTCF, CTPL, NTCF, and NTPL, respectively. Concentrations were lowest following the lowest application of 100 lbs N acre^{-1}, with the means below 10 ppm and similar among treatments.

NH_4-N

Mean NH_4-N concentrations varied between 3 and 4 ppm for all treatments in runoff (Fig.4). Mean concentrations were much less in drainage: 1.12, 0.31, 0.43, and 0.18 ppm for CTCF, CTPL, NTCF, and NTPL, respectively. The higher concentrations again occurred following the 300 lbs N acre^{-1} application in 2003.

PO_4-P

Mean concentrations for PO_4-P in drainage were 0.13, 0.32, 0.05, and 0.23 ppm for CTCF, CTPL, NTCF, and NTPL, respectively (Fig.5). Similarly median concentrations were 0.04, 0.11, 0.04, and 0.09 ppm, respectively. Treatment effects were clearly apparent in PO4-P concentrations in runoff. Overall means were 0.64, 1.48, 3.97, and 6.83 ppm for CTCF, CTPL, NTCF, and NTPL, respectively. Poultry litter application, therefore, had great impact on soluble phosphorus loss through runoff. This was influenced greatly again by the 300 lb N acre^{-1} application (without it equivalent overall means were 0.63, 2.70, 1.02, 3.60 ppm). In CF treatments about 71% of samples had PO_4-P concentration less than 1 ppm, whereas in PL treatments 78% were above 1 ppm.

Hormones

Application of poultry litter to field plots did not increase the amount of estradiol and testosterone in runoff or drainage. Typical values from irrigation and rainfall events are presented in Table 1. No statistical differences emerged due to treatment effects from these values. Background levels of estradiol and testosterone were present in the conventional fertilizer plots. We hypothesized that these hormone levels occurred naturally due to the local bird populations that included Canadian geese. Both estradiol and testosterone were also found attached to soil but again no treatment effects were observed.

CONCLUSIONS

The following conclusions can be made based on results from three years of research to quantify the agronomic benefits and water quality impacts of no-till and poultry litter in a corn-rye cropping system in a Cecil soil, in comparison to conventional-till and conventional fertilizer.

1. Environmental and management factors can lead to substantial yield variability from year to year across all treatments.
2. No-till enhances corn yield by as much as 25% over several years. Generally, no-till has greater yield enhancing influence in plots receiving conventional fertilizer than those receiving poultry litter.
3. Poultry litter enhances corn yield by as much as 15% over several years. Generally, poultry litter had greater yield enhancing influence in conventional-till than no-till plots.
4. The combined yield enhancing effect of no-till and poultry litter is greater than that of no-till or poultry litter individually.

5. Water stress and pest pressure can eliminate these yield enhancing advantages of no-till and poultry litter
6. Concentrations of NO3-N in runoff appear to be low (<2 ppm) in all treatments. Loss of NO3-N in drainage depended on application rate of N fertilizer; the higher the N rate, the higher the NO3-N concentration. Overall differences among treatments were small. For poultry litter application of less than 3 tons acre^{-1} (90 lbs N acre^{-1}), concentration of NO3-N in drainage appears to be less than 10 ppm, the EPA safe limit for human consumption. Higher rates leach through the soil if precipitation occurs soon after application.
7. Off-site effects could be of concern in cropping systems using no-till and poultry litter in terms of high PO4-P concentration in runoff. But because runoff is usually less in no-till compared to conventional-till, the off-site effect in term of loads could be similar among treatments. This needs further investigation.
8. Application of poultry litter to cropland even at 2 to 3 times the normal rate does not appear to increase hormones levels above those found naturally in the environment. Movement of hormones from poultry litter is similar in conservation tillage and conventional-till systems.

ACKNOWLEDGMENTS

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Table 1. Typical mean values of flow-weighted concentration of estradiol and testosterone in drainage and runoff from an irrigation and a rainfall event.

	Drainage		Runoff	
Treatment	Estradiol	Testosterone	Estradiol	Testosterone
	------------------------------ ppb (ng/l)--------------------------------------			
Irrigation event				
CTCF	23.3	6.7	27.8	7.6
CTPL	36.6	7.9	26.9	8.4
NTCF	5.7	4.7	35.2	7.4
NTPL	9.7	8.6	20.5	5.6
Rainfall event				
CTCF	25.2	5.7	8.7	16.8
CTPL	10.0	32.2	24.2	17.6
NTCF	10.7	15.9	16.5	13.6
NTPL	8.2	99.5	43.7	18.9

Figure 1. Corn kernel yield from 2001 to 2003. Within each year, corn yields between any two treatments sharing similar letters above the error bars are not significantly different from each other at P = 0.05.

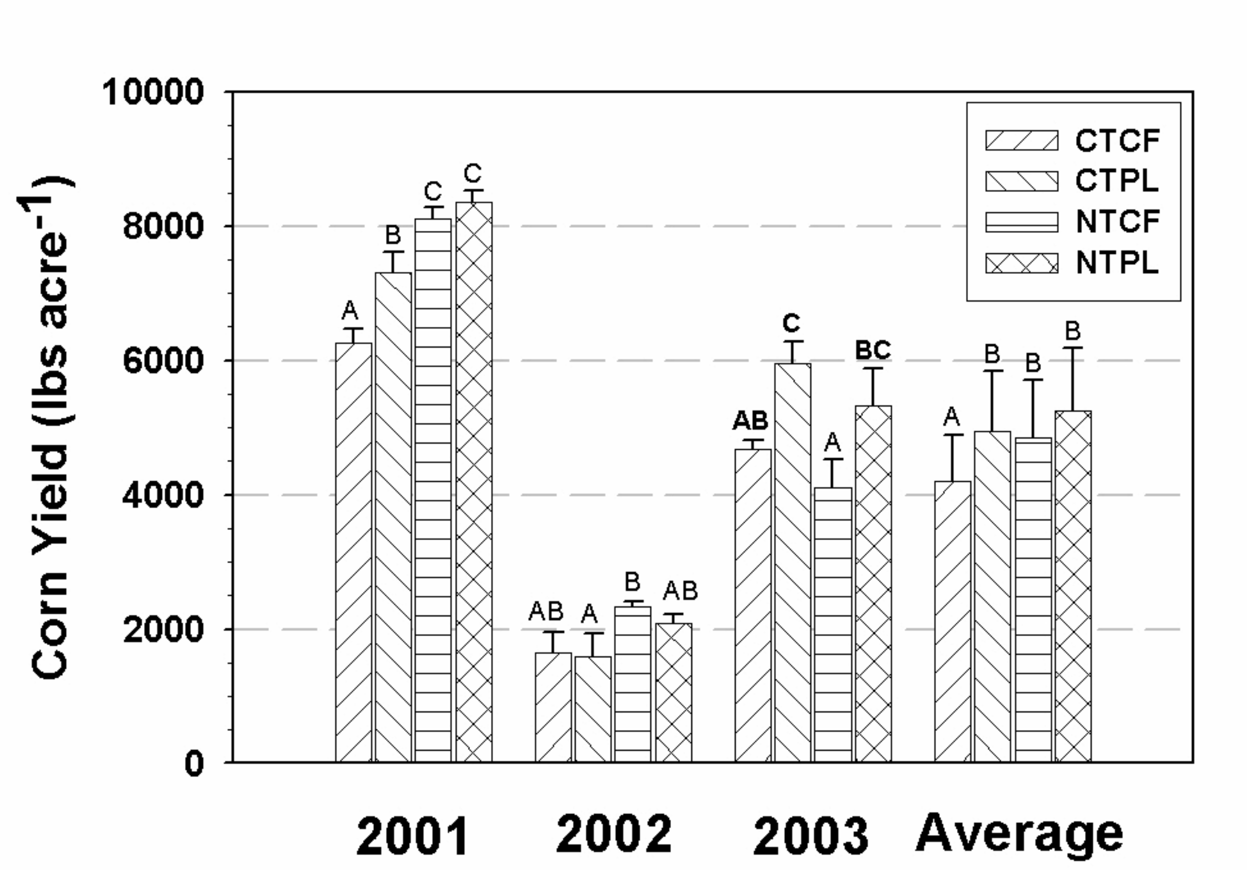


Figure 2. Cumulative precipitation during the 2001-2003 corn season.

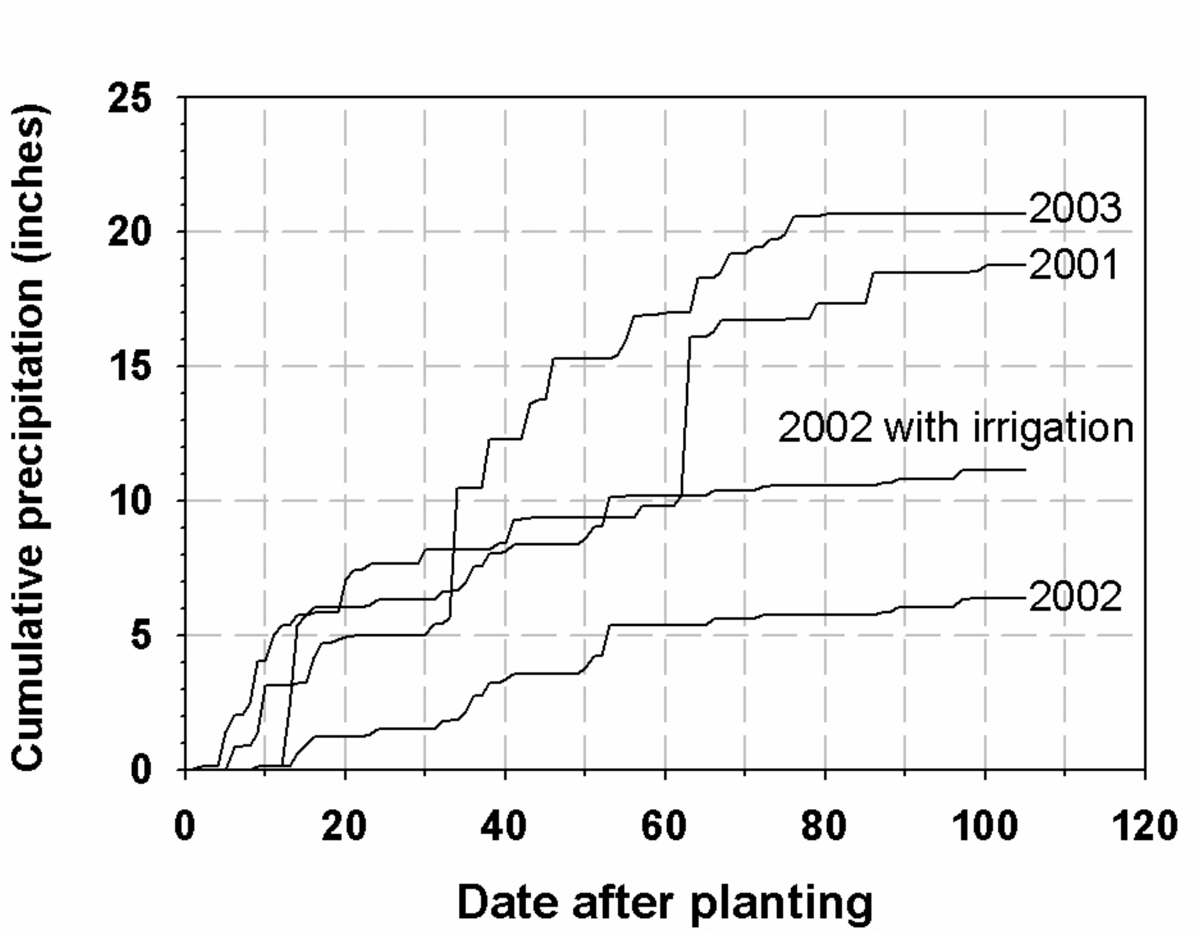


Figure 3. Box plots showing distribution of NO_3-N concentration in runoff and drainage based on 14 samplings between 06/01/2001 and 07/01/2003. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.

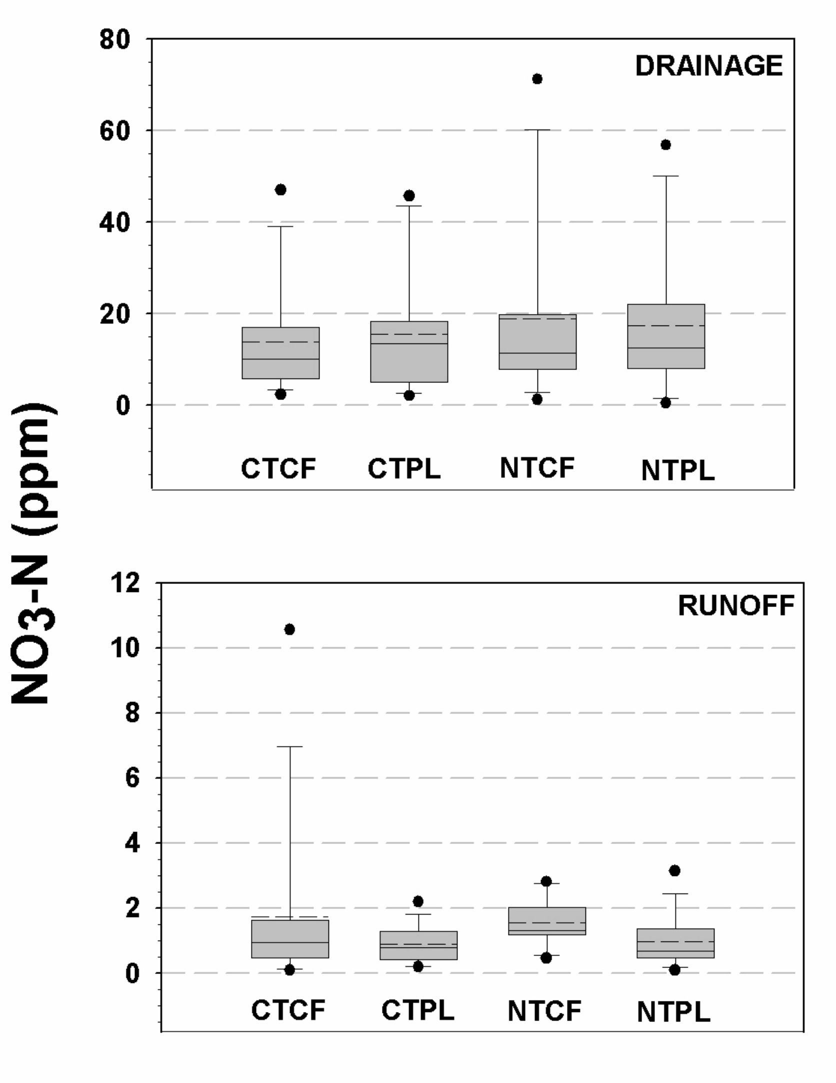


Figure 4. Box plots showing distribution of NH_4-N concentration in runoff and drainage based on 14 samplings between 06/01/2001 and 07/01/2003. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.

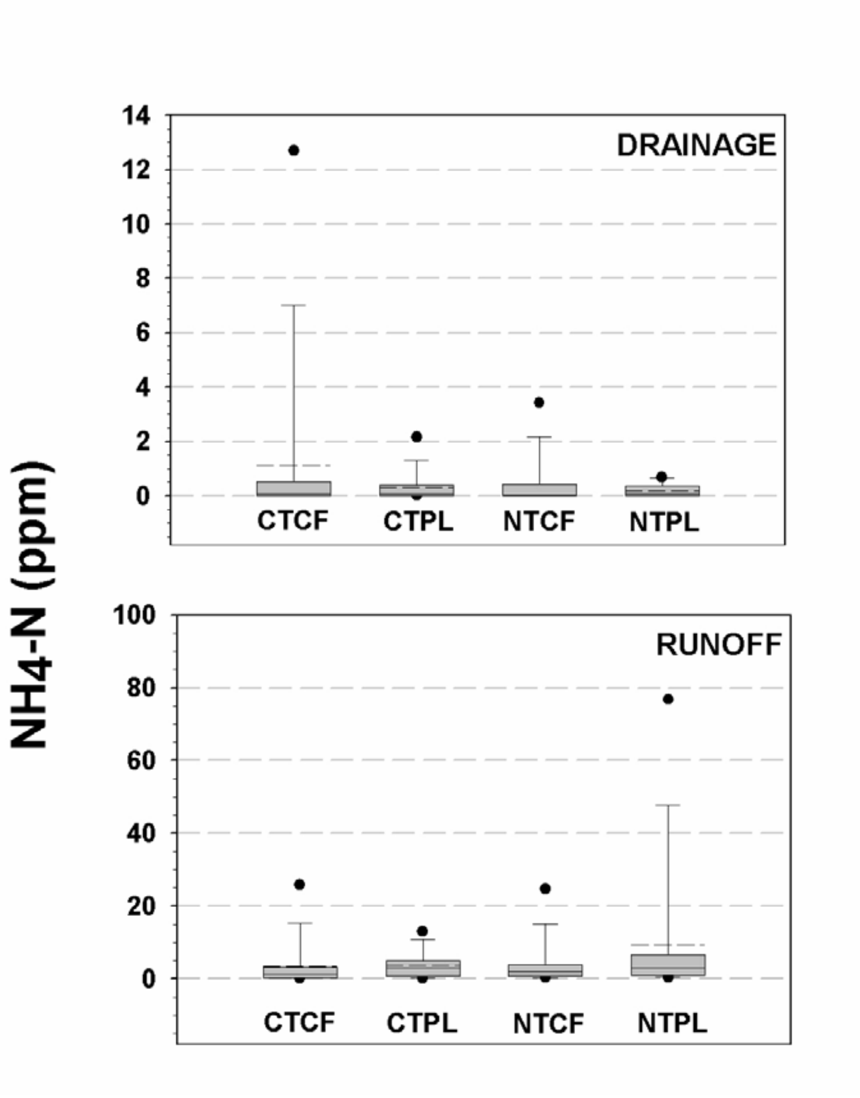
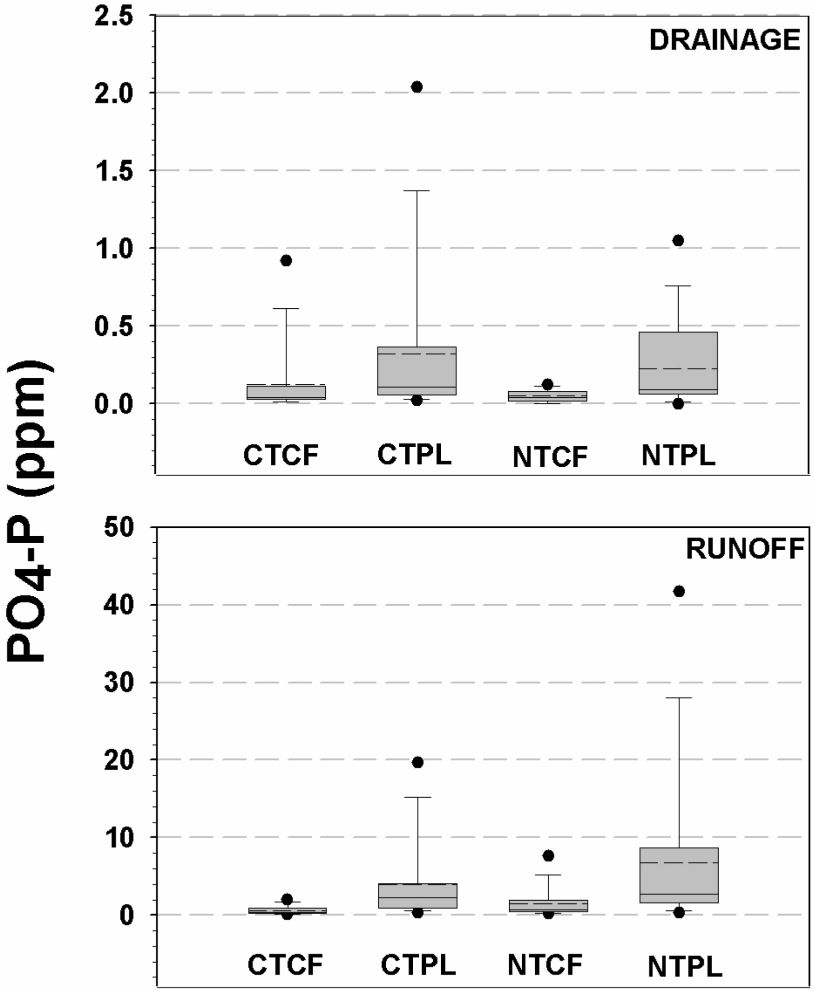


Figure 5. Box plots showing distribution of PO_4-P concentration in runoff and drainage based on 14 samplings between 06/01/2001 and 07/01/2003. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.



TILLAGE AND N-FERTILIZER SOURCE EFFECTS ON COTTON FIBER QUALITY

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ABSTRACT

Cotton lint yield along with fiber quality determines the value of the crop to growers since tests of fiber are a key consideration in sales of cotton to processing plants. Most cotton research has focused on impacts of genetic, environmental, and management factors on production and yield. More research is needed to describe the impact of these variables on cotton fiber quality. We analyzed two years of fiber quality data from a cotton-rye cropping system under a factorial set of tillage and fertilizer treatments (conventional till, no-till, conventional fertilizer, and poultry litter). Cotton fiber fineness, strength, length, uniformity index, and the 2.5% and 50% span lengths were measured partially using high volume instrumentation equipment. The data were classified and used in evaluating cotton quality according to industry standards. Categorical analysis showed that the production treatments impacted fiber quality. Fiber quality variation occurred over narrow ranges and differences were generally small. We found from our data that shifts had occurred from one class to another as a result of production treatments. These shifts may impact the economics of cotton production.

INTRODUCTION

Cotton fiber has a 60% share of the total retail market for apparel and home furnishings, excluding carpets, in the U.S. (Marek, 2001). Fiber quality determines the value of a bale of cotton to the processor. Most mills now use high-speed spinning equipment, which favors higher quality fiber. Short, inconsistent fibers do not run well through these spinners and can jam them, costing mills time and money (Haire, 2004). High volume instrument (HVI) testing gives managers of mills an efficient way to gage the processing quality of incoming bales of cotton. Low quality cotton fiber that cannot be processed successfully can be returned to growers with no compensation for production cost (Bradow and Davidonis, 2000). A differential pricing system is also in place that favors lint falling in a narrow optimum quality range, while penalizing fiber that falls outside this range through discount pricing. Hence the net value of a crop to a producer is determined not only by yield, but lint quality, cotton prices, and quality-based discounts.

There is concern about cotton quality across the Cotton Belt (Marek, 2001). Georgia's cotton crop quality has declined in recent years because of low scores in two important qualities, short fibers and inconsistent fibers, which might have deprived Georgia growers of $43 million in potential income in 2002 (Haire, 2004). At the same time, availability of higher quality cotton continues to increase from countries that compete against U.S. producers, particularly from those that use labor-intensive harvesting methods.

Fiber quality is expressed using a composite of both quantitative and qualitative parameters that include fiber length, length uniformity, fineness and maturity, strength, color, and trash content, partially determined using HVI (Bradow and Davidonis, 2000; USDA-AMS, 2001). Natural and environmental variations in fiber shape and maturity at bale, plant, boll, and seed level (Bradow et al., 1997) complicate this process.

Fiber length is reported in several ways: upper-half-mean (UHM) length, 2.5% span length, and 50% span length. It influences yarn strength and evenness, fineness, and the efficiency of the spinning process (Moore, 1996). Extreme temperatures, water stress, or nutrient deficiencies during cotton production may influence this quality (USDA-AMS, 2001). Length uniformity is the ratio between the mean length and the upper half mean length of test fibers expressed as a percentage. It influences yarn evenness and strength, and the efficiency of the spinning process (USDA-AMS, 2001). Fiber fineness and maturity, expressed in micronaire, an indirect measure of the airflow through a test specimen fiber, is also a very important determinant of yarn strength and uniformity. It can be influenced by environmental conditions during the growth period such as moisture, temperature, sunlight, plant nutrients and extremes in plant or boll population (USDA-AMS, 2001). Fiber strength determines yarn strength. It may be affected by plant nutrient deficiencies and weather (USDA-AMS, 2001). Color grade is determined by the degree of reflectance (bright or dull) and yellowness (the degree of color pigmentation). Color measurements appear to be correlated with overall fiber quality (USDA-AMS, 2001). Trash is a measure of the amount of non-lint material in the cotton.

Most cotton production research has focused on enhancing yield. Fiber quality has generally been considered a genetic trait. Faircloth et al. (2003) reported that cotton yield and quality are influenced by both genetics and environmental conditions. Bradow and Davidonis (2000) indicate that a broad range of fiber properties can occur at the crop and whole-plant levels, as a result of fluctuations of the macro- and micro-environment around the plants. Johnson and Bradow (2000) found correlation between soil properties and a number of fiber properties including micronaire, short fiber content, and fiber color. Coolman (2001) highlights the importance of adequate potassium levels in the soil as key to avoiding micronaire problems.

Cotton producers in the Southeast are increasingly using no-till and poultry litter fertilizer, which together have been shown to enhance lint yield (Endale et al., 2002a) and induce better infiltration (Endale et al., 2002b). These particular management practices may influence cotton fiber quality because of their impact on soil water and nutrient availability. Bauer et al. (1999) found that in the Coastal Plain of South Carolina, cotton grown with conservation tillage had fibers that were 0.02 inches longer than cotton grown with conventional tillage, regardless of soil type. And fiber properties were more uniform in conservation tillage than in conventional. Bauer and Busscher (1996) found that cotton lint quality was not affected by tillage system or winter cover, but a 0.1 decrease in micronaire was observed in cotton following rye compared with legumes. Daniel et al., (1999) found that cotton fiber quality (length, uniformity, strength and micronaire) was not affected by tillage system (no-till versus conventional till).

The Southern Piedmont has unique sets of environmental characteristics including, climate and soils. Research is needed on the impact of cropping systems and management on cotton fiber quality in this region. In this paper we compare two years of cotton fiber quality from a cotton-rye cropping system managed under either no-till or conventional tillage and fertilized with either poultry litter or conventional inorganic fertilizer near Watkinsville, GA. Endale et al. (2002a) have reported impact of this system on soil water and lint yield.

MATERIALS AND METHODS

Experimental details for the research from which the 1997 and 1998 fiber quality data were determined are given in Endale et al. (2002a). The field details are also described in these proceedings for a corn-rye cropping system (Endale et al., 2004). Briefly, the research was conducted in 1997 and 1998 at the USDA-ARS J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville, GA (83°24' W and 33°54' N) on 12 (30 x 100 ft) plots. The site is located on nearly level (<2% slope) Cecil sandy loam (fine, kaolinitic thermic Typic Kanhapludult). The experiment was laid out as a randomized complete block with a split plot feature with three replications. Conventional-till (CT) and no-till (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, followed by a one to two diskings to a depth 8 inches and a subsequent disking to 3 inches to smooth the seed bed. The only soil disturbance in NT was during planting with a four-row no-till planter equipped with fluted coulters to cut through surface residue, followed by double disk openers to make a narrow slit for the seed and press wheels to firmly cover the seed.

The cropping system consisted of winter cereal rye (*Secale cereale* L. cv. Hy-Gainer) as cover crop followed by summer cotton (*Gossypium hirsutem*). The cotton cultivar was 'Stoneville 474' and the cotton seasons lasted from May 14 to November 4, 1997, and May 14 to November 12, 1998. Nitrogen fertilizer rate for cotton was 60 lbs N acre^{-1} amounting to 2 tons acre^{-1} for the poultry litter. Other fertilizer rates were based on soil test recommendations. Pesticides and rates followed standard practice for the region. Fertilizers and pesticides were surface applied in no-till plots, but in conventional till systems were surface applied and then disked. Standard production management practices were followed for the rest of a season. In 1997 five random cotton lint samples were collected from each plot at harvest for fiber quality analysis. Sample numbers were tripled in 1998 by collecting five random samples from each third of a plot. Lint samples were sent to the Louisiana Agricultural Experiment Station, Cotton Fiber Testing Laboratory, in Baton Rouge, LA, for fiber quality determination using partially HVI equipment.

RESULTS AND DISCUSSION

Distributions of the fiber quality parameter values are presented in Figures 1 to 3. Fiber quality parameter frequency class in percent is presented in Table 1. Analysis of the proportions within each class indicated that micronaire and USDA UHM class were affected by production practice (Table 1). Analysis of variance also indicated that tillage impacted 50% span length ($P = 0.048$) but other analyses of variance did not detect significant effects on fiber quality ($0.208 < P < 0.856$). Figures 1 to 3 also show that the range of observations often were very small. For example, 80% of the data (10th to 90th percentiles) for upper half mean length (Fig 2, B) have a range of only 0.1 to 0.13 for treatments. This range is about 4 for the uniformity index (Fig. 2, A) and strength (Fig. 1, B). Only the fineness values of the CT treatments have relatively larger data ranges (Fig. 1, A). We found a strong correlation between the 2.5% span length (Fig. 3, A) and the upper half mean length (Fig. 2, B) ($R^2 = 0.93$).

In practical terms, HVI and other measurement values are used to create classes of fiber quality data, which are then used as quality evaluating guides (Table 1). The NT treatments shifted the fineness classes to higher micronaire values. This has implications for fiber processing and quality of yarns. In addition, micronaire values are used to set price differentials in bales of cotton, whereby values in the range 3.7 to 4.2 attract premium prices and those below 3.5 or greater than 4.9 evoke price deductions (USDA-AMS, 1991). The tillage treatments shifted micronaire values from the premium toward the base range (Table 1). No-till also shifted the upper half mean length into the USDA UHM code class of 36 and 37 (1.11 to 1.17 inches) (Table 1). The impact of the treatments on fiber strength was limited to no-till in CF plots, where fiber strength has shifted from the intermediate to the average class (Table 1), but this did not prove significant.

These demonstrated shifts impact the fiber processing and yarn quality arena, and ultimately have implication on the economics of the fiber processing plant, and the grower. Data were pooled for two years for these analyses. Year to year variations could impact fiber quality and treatment effects. Pending data from other years will be included in future analysis in due course.

CONCLUSIONS

The two years of fiber quality data showed that no-till and poultry litter affect the proportions of pooled mean fiber quality parameter values. However, the effects were relatively small and this is good news to growers since Endale et al. (2002a) reported that no-till and poultry litter individually and in combination significantly enhanced yield during the same years as these analyses at this site. Degraded fiber quality would have lessened the value of this yield enhancement.

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Table 1. Percents within frequency class for fiber quality parameters by treatment.

Fiber quality parameter, class and class range in parenthesis	**Parameter frequency class in percent**			
	CTCF	**CTPL**	**NTCF**	**NTPL**
Fiber fineness in Micronaire				
Very Fine (< 3.0)	**0.0**	**0.0**	**0.0**	**0.0**
Fine (3.0 to 3.9)	**21.7**	**16.7**	**0.0**	**0.0**
Medium (4.0 to 4.9)	**70.0**	**83.3**	**100.0**	**90.0**
Coarse (5.0 to 5.9)	**8.3**	**0.0**	**0.0**	**10.0**
Very Coarse (> 5.9)	**0.0**	**0.0**	**0.0**	**0.0**
Test of Mean Scores (*P*>Value)†		***P*<0.01**		
Micronaire Market Value				
Discount Range (< 3.5 or > 4.9)	**8.3**	**0.0**	**0.0**	**0.0**
Base Range (3.5 to 3.6)	**50.0**	**55.0**	**71.7**	**91.7**
Premium Range (3.7 to 4.2)	**41.7**	**45.0**	**28.3**	**8.3**
Test of Mean Scores (*P*>Value)†		***P*<0.01**		
Fiber Strength				
Weak (< 18)	**6.7**	**10.0**	**1.7**	**5.0**
Intermediate (18 to 21)	**40.0**	**35.0**	**20.0**	**35.0**
Average (22 to 25)	**50.0**	**50.0**	**75.0**	**51.7**
Strong (26 to 29)	**3.3**	**5.0**	**3.3**	**8.3**
Very Strong (> 30)	**0.0**	**0.0**	**0.0**	**0.0**
Test of Mean Scores (*P*>Value)†		***P*=0.14**		
Uniformity Index				
Very Low (< 77)	**0.0**	**0.0**	**0.0**	**0.0**
Low (77 to 79)	**1.7**	**5.0**	**1.7**	**5.0**
Average (80 to 82)	**56.7**	**65.0**	**50.0**	**56.7**
High (83 to 85)	**40.0**	**30.0**	**46.7**	**33.3**
Very High (> 85)	**1.7**	**0.0**	**1.7**	**5.0**
Test of Mean Scores (*P*>Value)†		***P*=0.26**		
USDA UHM Code				
31 (0.96 to 0.98)	**1.7**	**3.3**	**0.0**	**1.7**
32 (0.99 to 1.01)	**6.7**	**6.7**	**3.3**	**3.3**
33 (1.02 to 1.04)	**10.0**	**13.3**	**18.3**	**13.3**
34 (1.05 to 1.07)	**20.0**	**26.7**	**10.0**	**18.3**
35 (1.08 to 1.10)	**38.3**	**25.0**	**11.7**	**15.0**
36 (1.11 to 1.13)	**20.0**	**21.7**	**40.0**	**33.3**
37 (1.14 to 1.17)	**3.3**	**3.3**	**15.0**	**11.7**
38 (1.18 to 1.20)	**0.0**	**0.0**	**1.7**	**1.7**
39 (1.21 to 1.23)	**0.0**	**0.0**	**0.0**	**1.7**
Test of Mean Scores (*P*>Value)†		***P*<0.01**		

† Test based on Cochran-Mantel-Haenszel Statistic for row mean scores.

Figure 1. Lint fiber quality in terms of fineness expressed as micronaire (A) and strength (B), based on two years of pooled data. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.

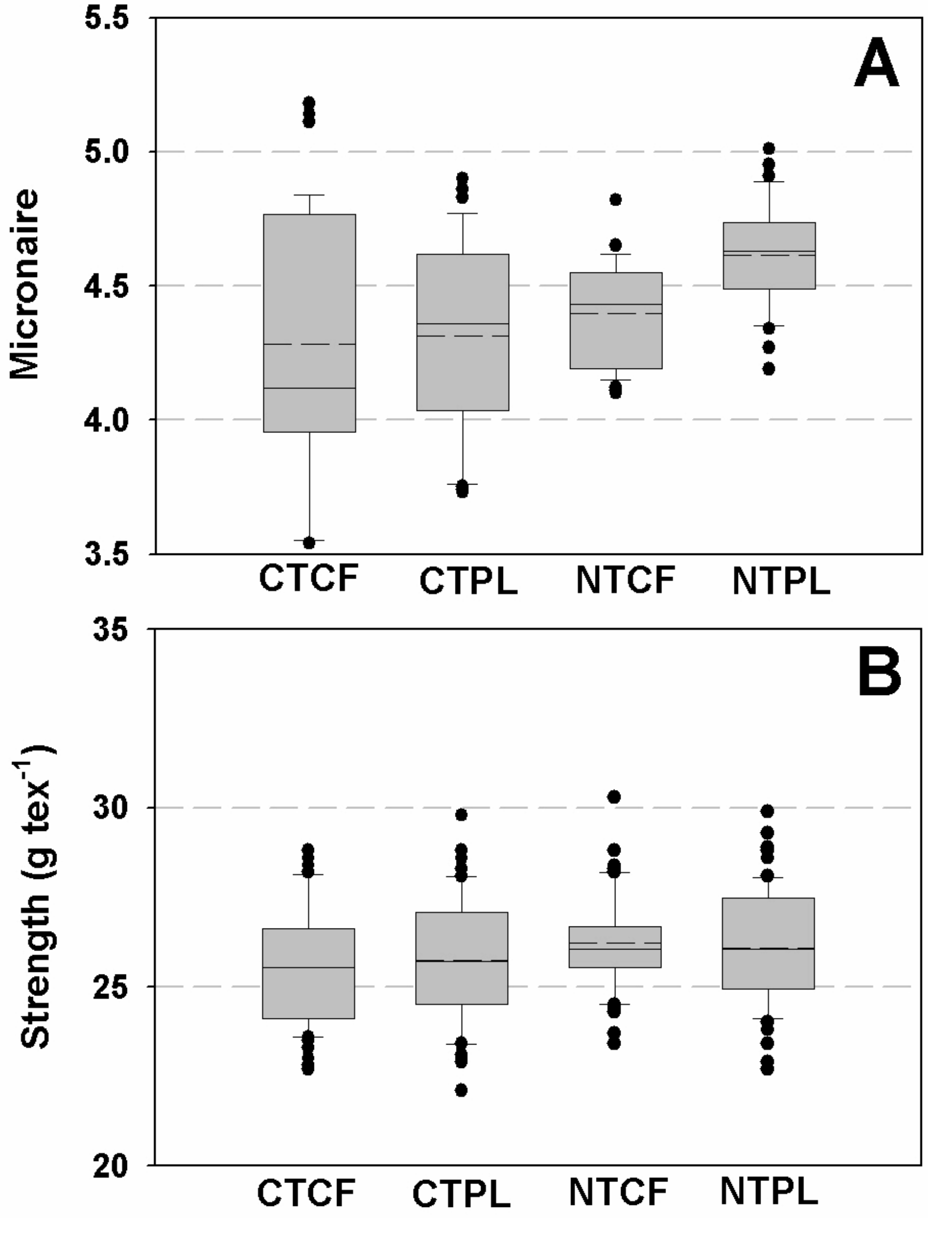


Figure 2. Lint fiber quality in terms of uniformity index (A) and length (B), based on two years of pooled data. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.

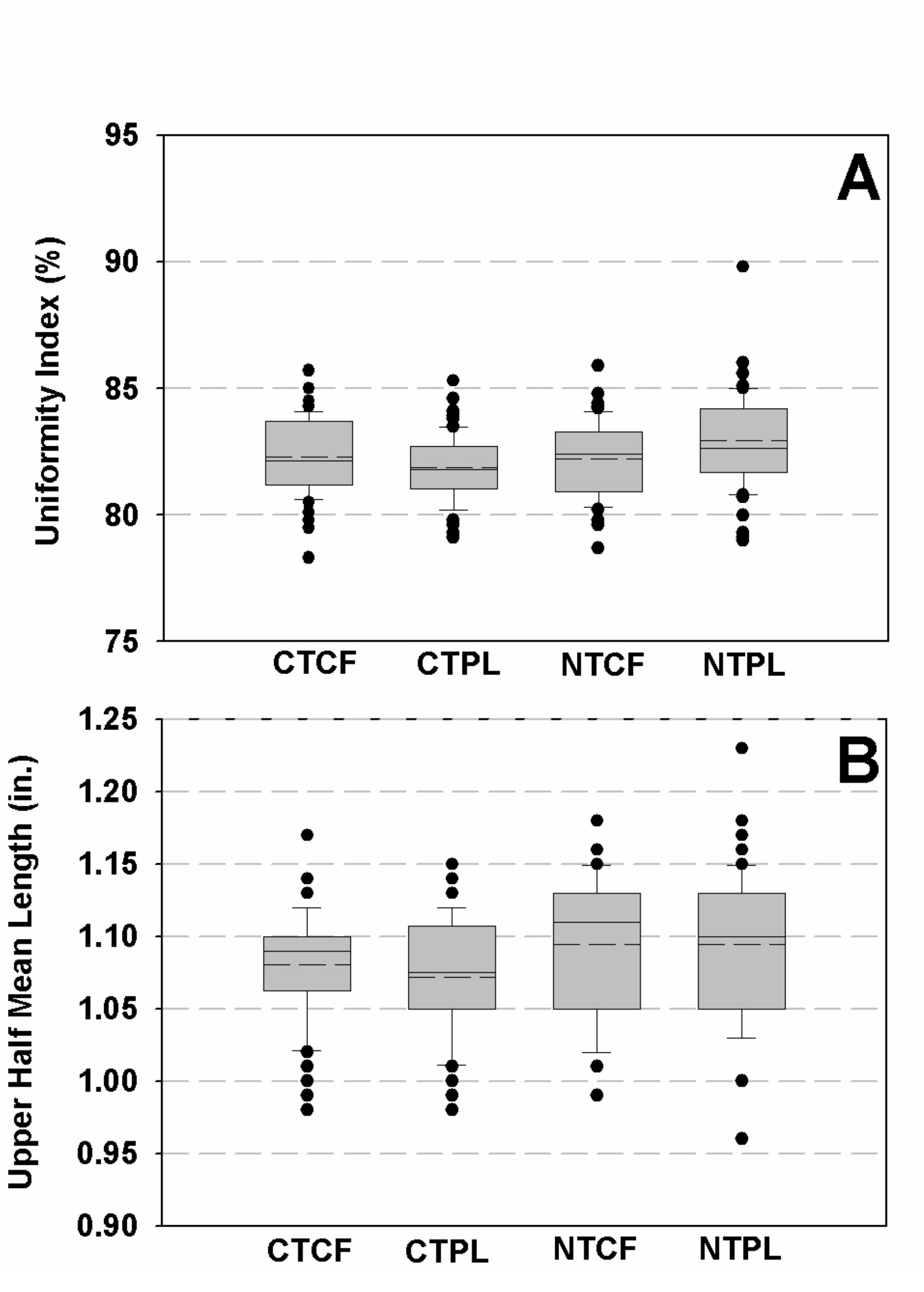
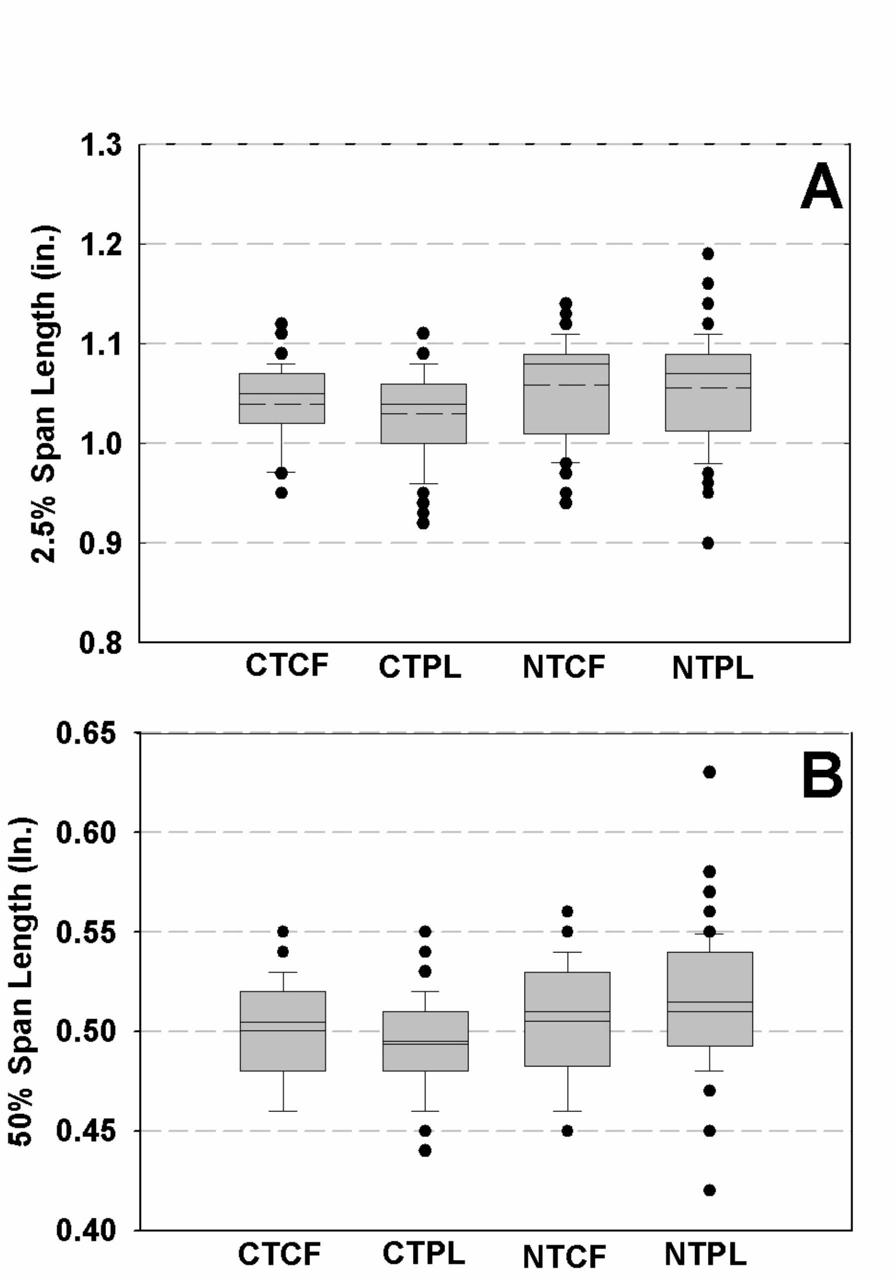


Figure 3. Lint fiber quality in terms of 2.5% span length (A) and 50% span length (B), based on two years of pooled data. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.



IMPROVEMENT OF WHEAT AND COTTON GROWTH AND NUTRIENT UPTAKE BY PHOSPHATE SOLUBILIZING BACTERIA

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ABSTRACT

Pot and field experiments were carried out on calcareous calcisol soil for evaluating the effects of phosphate solubilising bacterial inoculants combined with phosphorit on wheat, maize and cotton growth and yield. Stimulatory effects of bacterial species such *Pseudomonas, Bacillus, Arthrobacter* and *Rhizobium* on growth of wheat, maize and cotton growth, yield, N, P –uptake, soil P content were recorded. The results revealed that plant growth promoting bacteria combined with phosphorit significantly increased shoot, root length of wheat and maize. The phosphorus content was significantly increased in cotton plants inoculated with *Rhizobium meliloti* combined with phosphorit with respect to the uninoculated plants growing in the control soil. Standard treatment without bacterial inoculation has resulted very low P uptake in plants. This result suggests that phosphate solubilising bacteria are able to mobilise more P to the plants and improve plant growth.

INTRODUCTION

Phosphorus is a important element for growth development and yield of many crops. However many soils throughout the world are P-deficient because the free phosphorus concentration even in fertile soils is generally not higher than 10 μM even at 6.5 where it is most soluble (Arnou, 1953). Phosphorus deficiencies are common nutritional problems in crop production also in Uzbekistan.

Soil microorganisms have enormous potential in providing soil phosphates for plant growth. Phosphorus biofertilizers in the form of microorganisms can help in increasing the availability of accumulated phosphates for plant growth by solubilisation (Goldstein, 1986; Gyaneshwar et al., 2002). In addition, the microorganisms involved in P solubilisation as well as better scavenging of soluble P can enhance plant growth by increasing the efficiency of biological nitrogen fixation, enhancing the availability of other trace elements and by production of plant growth promoting substances (Gyaneshwar et al., 2002). Application of phosphorites along with phosphate solubilising bacteria (PSB) improved P uptake by plants and yields indicating that the PSB are able to solubilise phosphates and to mobilise phosphorus in crop plants (Rogers, 1993). In this respect, biofertilisation technology has taken a part to minimise production costs and at the same time, avoid the environmental hazards (Galal et al., 2001). Phosphorus application and bacterial inoculation affect yield of soybean through their effects on phosphorus use efficiency (Shah, 2001). Also they are successful applied in the cultivation of barley and chick pea plants (Rodriguez-Barraeco, 2002). A P-solubilizing *Rhizobium leguminosarum* has been shown to increase the growth of maize and lettuce (Chabot et al., 1996). The PSB- plant inoculations resulted in 10-15% increases in crop yields in 10 out of 37 experiments (Tandon, 1987). These studies also demonstrated an increase in P uptake by plants. There are only a few reports of P solubilization by Rhizobium (Chabot et al., 1993). In this study, the effect of new biopreparation based on PSB bacteria, *Rhizobium meliloti* on plant growth of wheat, maize and nutrient uptake and yield of cotton grown in P deficient soil were investigated.

MATERIAL AND METHODS

Soil and Plants

The soil for pot experiments was collected from a non-fertilized field site near Tashkent, located in the northeastern part of Uzbekistan. Soil is calcareous serozem soil (1 % organic matter, 0.6 mg N 100 g-1 soil; 3.0 mg P 100 g $^{-1}$; 12 mg K 100 g^{-1}; 6 mg Mg 100 g^{-1} soil; pH 7.4) having a calcic horizon within 50 cm of the surface. The orchic horizon is low in organic matter. The climate is continental with mean annual rainfall of 200 mm. For pot experiments the soil sampled from the surface orchic horison (0-30 cm). The total carbon content, C**,** was identified by elemental analysis, while total nitrogen content, N, was determined by the Kjeldahl method. The molybdenum blue method was used to determine the total phosphorus content, P, in 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 an electrometer. Soil particle distribution was determined using natrium phosphate**.** Wheat, maize, **c**otton were employed in the inoculation experiments. Plant seeds were obtained from the Tashkent University of Agriculture.

Microorganisms

Bacterial strains *Pseudomonas* sp. RM3M, *P. denitrificans* PsD6, *P. rathonis* PsR47, *Bacillus laevolacticus* BcL28, *B. amyloliquefaciens* BcA27, *Arthrobacter simplex* ArS43, and *Rhizobium meliloti* were used for the experiments. Glycerin-peptone-agar medium used for isolation of bacterial strains (Hirte, 1961). For isolation of rhizosphere bacteria 1 g washed roots of wheat, and maize was macerated and shacked with 10 ml sterile water. The resulting suspensions were evaluated for colony forming units (cfu) according to the dilution-plate method in glycerine-peptone-agar. With the addition of TMTD, the native fungal and bacterial flora was largely excluded from the plates. After an incubation time of 7 days at 28° C the reisolated, strains were identified. The identification of strains relied on standard biochemical and physiological tests according to the classification of Bergey (Holt et al., 1994). Gram stain, morphology, spore formation, motility, nitrate reduction, and gas production from glucose were determined according to methods for LAB described by Gerhardt (1981). Salt tolerance was determined in Hirte agar medium containing NaCl at 7%.

Plant Growth and Inoculation in Pots

The study of the effect of isolated strains on plant growth was carried out in pot experiments using a nutrient-poor calcareous Calcisol. The inoculation treatments were set-up in a randomised design with six replicates. The day before sowing, pots were filled with 350 g soil. Three seeds of wheat, and maize were sown per pot. After germination, plants were thinned to two per pot. The bacteria were grown in glycerine-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 which resulted in an inoculum's density of ca. 10^6 cfu/ml. Additionally bacterial strains applied to the plants with combination phosphorit. Plants were grown in pots for four weeks under greenhouse conditions with a temperature of 26°C to 28°C during the day and 17°C to 18°C at night.

The soil was moistened with water and maintained at 60% of its moisture holding capacity (MHC). Four weeks after germination, shoots and roots were separated and determined the root and shoot length.

Field Experiments

The field trials were conducted at the experimental farm of Institute of organic and inorganic chemistry, Uzbekistan. Recommended rates of phosphorus (140kg P h^{-1}, as phosphorit and superphosphate), nitrogen (200 kg N $ha^{-1,}$ as ammonium sulphate) and potassium (60 kg K $h^{-1,}$ as potassium sulphate) were applied. Treatments were: plants without treatments 1. (NoPoKo), 2. ($NP_{superphosphate}K$), ($NP_{phosphorit}K$), ($NP_{phosphorit+PSB}K$). These treatments were distributed in a randomised complete block design with four replications. The plot size was 5 m by 3 m. Cottonseeds were obtained from the University of Agriculture, Tashkent. *Rhizobium meliloti* URM1 used as phosphate soulubilisng bacterial inoculant, which combined with phosphorits (inoculum density 10^9 cells g^{-1}). Plants were harvested at tillering, flowering and maturity stages. Dry matter accumulation, N, P uptake efficiency in plants have been determined.

Statistical Analysis

The data were analysed with an ANOVA and Student-Newman-Keuls test for testing the significant differences ($p<0.05$) of main effects.

RESULTS AND DISCUSSION

Bacterial inoculation affected the early plant growth of wheat and maize. Many of our bacterial strains *Bacillus, Pseudomonas* and *Arthrobacter* had a significant effect on growth of wheat, maize in nutrient-poor Calcisol soil, while non-treated plants by comparison performed poorly under such conditions. Defreitas (1992) also demonstrated that in low fertility Asquith soil, *Pseudomonas* bacterial strains significantly enhanced early plant growth. According to Lazarovitz and Nowak (1997), the bacterisation only marginally increased yields when tested under ideal climatic situations. The greatest benefits occurred when crops encountered stressful conditions for prolonged periods.

After inoculation of bacterial strains combined with phosphorit the root and shoot length of maize, and wheat increased compared to the uninoculated plants. (Fig. 1, 2). Plant length of wheat after inoculation increased up to 22 %. The most effective shoot and root length promoting isolate was *Arthrobacter simplex* ArS43, which generated 22% increase in shoot length of plant and 17% root growth. over the control (Fig.1). Chaykovskaya 2001) reported, that PSB increased Phosphorus accumulation in plants, yield of pea and barley. The bacterial strains were able dissolve hard soluble organophosphates. Inoculation also lead to the increase of N content in the biomass of both plants. Jumaniyazova et al., (2002) reported that PSB *Bacillus* sp. mobilize phosphate from organic hard soluble phosphoric compounds and increased growth and yield of cotton in Calcisol soil.

Our experiments with maize showed that plant growth promoting bacterial strains effects on plant length positively. They increased shoot length up to 53%. (Fig.2). Most effective bacterial strains was *Ps. rathonis* PsR47 and *B. amyloliquefaciens* BcA27, which increased root growth up to 20% compare control plants. The combination of bacterial strains with phosphorit has lower effect on plant growth to compare single bacterial inoculation.(Fig. 2). According Asea et al., (1988) Bacillus megatherium is considered the most effective PSMs according to field experiments.

Field Experiments

The inoculation with phosphate solubilising bacteria also positively effected on shoot root growth of cotton in field experiments. The results of our experiments showed, that PSB combined with phosphorit have a significant effect on dry matter accumulation in leaves, shoot and root (Table 2). Compared to the control and fertiliser used along, the PSB combined with phosphorit was superior over the other treatments. Higher effect was found in maturity stage. In tillering stage of cotton, bacterial inoculation did not effect significantly. Co-inoculation of *Azospirillum*, *Rhizobium* and *Azotobacter* with PSMs showed synergistic effect on plant growth and crop yields (Barea et al., 1975).

In field experiments all treatments increased yield of cotton in comparison to control plants (Fig 1). Higher yield obtained after treatment with PSB *Rhizobium meliloti* URM1. The yield of cotton increased up to 77% (285.7 g^{-1} plant). PSMs can also increase the growth of plants by mechanisms other than P solubilisation, e.g. production of phytohormones such as Indole acetic acid (Arshad and Frankenberger, 1998). According to the results obtained, PSB was able to mobilise phosphorus efficiency in cotton. The phosphorus content was significantly increased in cotton plants with treatment PSB combined phosphorit (Table 3). The standard treatment with fertiliser along did not effect P uptake in plants. Shah et al., (2001) also reported phosphorus uptake efficiency and yield increased with phosphorus application and with inoculation.

A positive influence of treatments on soil P content is marked (Table 3). Soil P content in the variant with PSB reaches 6.0 mg $P_2O_5.100^{-1}$ soil. It has been found that application of phosphorit combined with PSB leads to the increase of P content in soil (tillering, flowering and maturity stages of Plants).

In summary, the final results of the bacterial plant growth-promotion in our experiments show that plant growth-promoting and phosphate solubilising bacteria can play an essential role in helping plants establish and grow in nutrient deficient conditions. PSB are able to mobilise more P into plants, where hard soluble phosphates are presented in soil and increased yield and growth.

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Table 1. The effect of Posphate solubilizing bacteria (PSB) *Rizobium meliloti* URM1 combined with phosphorite on dry matter of cotton (field experiments, g.plant $^{-1}$)

Treatments	Tillering		Flowering			Maturity		
	leaves	stem	leaves	stem	bud	leaves	Stem	bud case
NoPoKo	8.1	7.0	46.5	10.5	15.5	54.6	39.5	35.3
$NP_{superp}K$	9.5	6.3	47.0	18.7	17.1	53.0	42.1	36.0
$NP_{phosphorite}K$	8.9	6.0	46.9	18.0	18.4	57.4	51.0	38.3
$NP_{PSB}K$	14.6	8.7	47.0	18.9	23.4	89.1	64.8	49.5

Table 2. The effect PSB combined with phosphorite on N and P uptake of cotton (field experiments, N and P content in %)

Treatments	Leaves		Stem		Bud case		Cotton fibers	
	N	P	N	P	N	P	N	P
NoPoKo	1.45	0.51	0.68	0.21	0.78	0.19	1.78	0.81
$NP_{superp}K$	1.55	0.75	0.75	0.24	0.83	0.22	1.87	0.84
$NP_{phosphorite}K$	1.2	0.2	0.3	0.1	0.5	0.1	1.6	0.4
$NP_{PSB}K$	1.62	0.8	0.75	0.24	0.83	0.25	1.9	0.89

Table 3. Phosphorus content in soil as affected by PSB combined with phosphorite (before sowing 1.8 mg P_2O_5 . 100^{-1} soil)

Treatments	Tillering	Flowering	Maturity
NoPoKo	2.4	1.5	2.2
$NP_{superp}K$	2.8	6.0	4.7
$NP_{phosphorite}K$	2.0	1.8	1.9
$NP_{PSB}K$	5.4	6.0	4.0

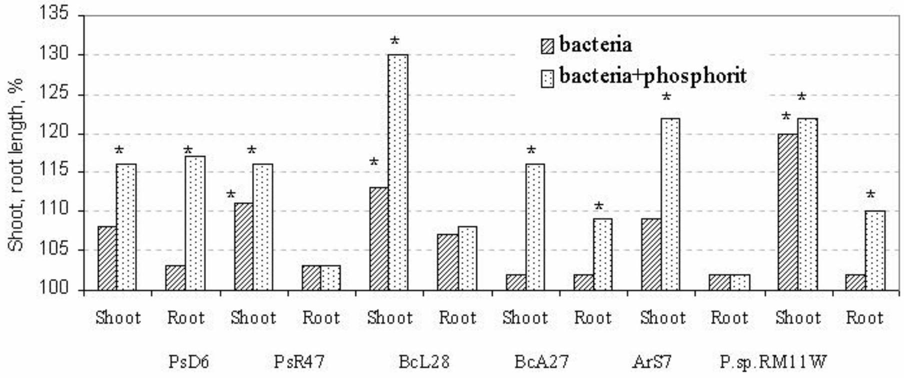

Fig. 1. The effect of plant growth promoting bacteria combined with phosphorit on shoot and root length of wheat in pot experiments (control=100%).

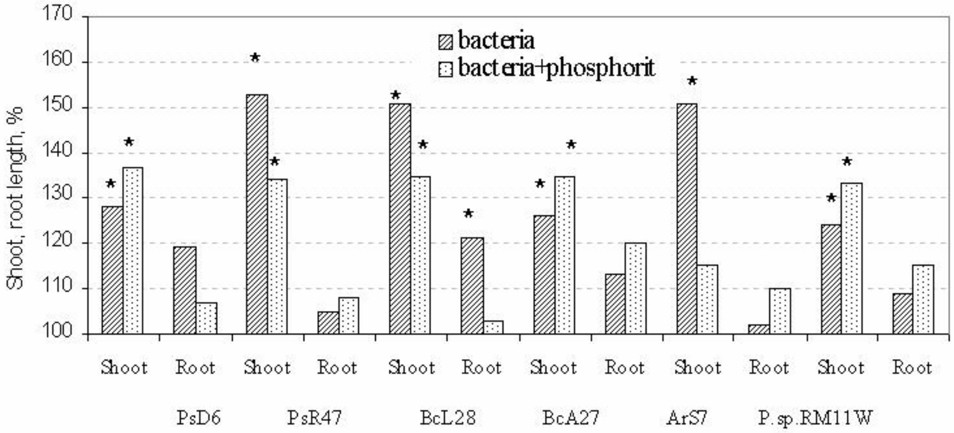

Fig. 2 The effect of plant growth promoting bacteria combined with phosphorit on shoot and root length of maize in pot experiments (control=100%).

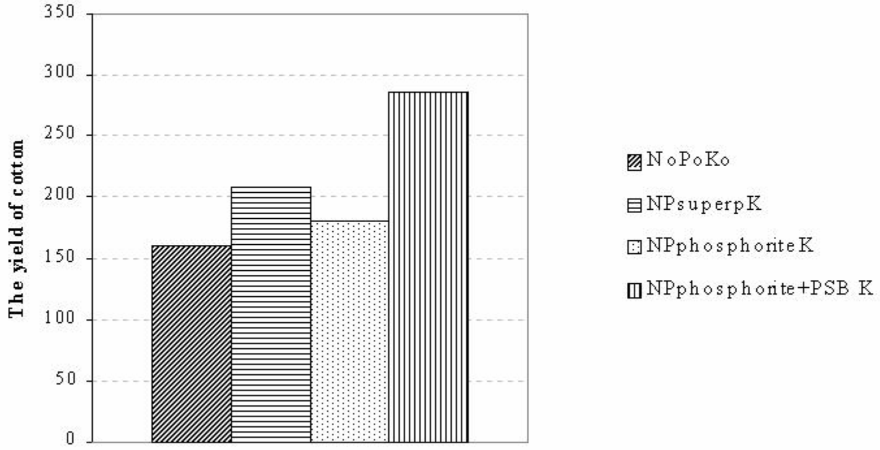

Fig.3 The effect of PSB combined with phosphorite on cotton yield in field experiments, g^{-1} plant, (Control plants, 160 g^{-1} plant =100%)

BIOMASS ACCUMULATION OF 'GA BUSH' VELVETBEAN ON THE PIEDMONT AND THE COASTAL PLAIN OF GEORGIA

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ABSTRACT

Cover crops are essential tools in a sustainable crop production system that utilizes conservation-tillage or no-till practices. Cover crops can produce large amounts of biomass that improve the texture and composition of a soil, resulting in better soil fertility. Velvetbean (*Mucuna pruriens*) is a tropical legume that has been used for many years in agricultural systems world-wide. The objective of this study was to determine the best harvesting and cutting (or tilling) dates for 'GA Bush' velvetbean grown on the Piedmont and Coastal Plain in Georgia based on the amount of biomass accumulated. Four planting dates including Apr. 15, May 15, Jun. 15, and Jul. 15 and four harvesting dates including 30, 60, 90, and 120 days after planting (DAP) were tested. The most successful growing/harvesting dates were considered those that accumulated the most biomass. Although, the best results were seen when velvetbean was allowed to grow for 120 days, significant biomass was accumulated at 60 DAP for some months and at 90 DAP, as well. This data suggests velvetbean may fit well as a short-rotation fallow in a sustainable vegetable production system in the Southeast.

INTRODUCTION

For centuries people have been growing cover crops as part of an agricultural system that improves the fertility and structural composition of their soil. Today, cover crops are still grown as part of a total agricultural system that promotes sustainability. Some of the long-term benefits obtained from the use of cover crops include weed suppression through competition or allelopathy, shorter fallow periods, possible insect control through rotation, and less monetary input through the decreased use of herbicides, pesticides, and water (Jordan, 1998; Phatak et al., 2002).

Sustainable crop production is achieved through the management of soil fertility and cover crops play a key role in soil fertility through a reduction in synthetic nutrients applied, particularly nitrogen. This reduces the cost of crop production and contamination of the environment (Phatak, 1992). Commonly used as cover crops, legumes are effective in the fixation of nitrogen and can accumulate large amounts of biomass that help to increase the nutrient availability and organic matter in a soil (Phatak, 1992). Organic matter in a soil is important because it improves the composition and texture of the soil. Phatak et al. (2002) note a system that utilizes cover crops, as one part of a whole system that utilizes sustainability will become more sustainable over time (Phatak et al., 2002). Many crops have been used for cover crops, but the choice ultimately depends on climate, cropping systems practiced, and the availability of seed (Pieters, 1927). Cover crops can be incorporated into a vegetable production system, however; the question is when is the optimal time to grow certain cover crops to best fit into rotation with vegetable crops based on accumulated biomass and nutrients.

Velvetbean (*Mucuna spp.)* is a tropical legume in the Fabaceae family that has been used for many years in agriculture and may fit well in a sustainable vegetable production system in the

Southeastern Region of the U.S. Traditionally used in agricultural systems in places such as Hawaii, the Philippines, and Meso-America, velvetbean was also once used in the early 1800s in the Southeastern United States. Here it was used as a green manure in orange orchards and in rotation with cotton and corn, because it helped lower external inputs and created a more sustainable system (Buckles et al., 1998; Taylor and Kabana, 1998, 1999).

The literature shows velvetbean can contribute significant amounts of N, as well as other important nutrients, to the soil when planted as a cover crop. Buckles et al (1998) report 336 lb N acre^{-1} in Northern Honduras. In West Africa, researchers note velvetbean can contain from 168-205 lb N acre^{-1} (Steinmaier and Ngoliya, 2000). Ibewiro et al. (2000) showed that velvetbean, in *in-situ* mulch systems, released 172 lb N acre^{-1} at 28 days. Velvetbean grown in Ghana accumulated 168 lb N acre^{-1} (Osei-Bonsu et al., 1996). When grown in Tifton, GA, velvetbean accumulated as much as 472 lb N acre^{-1} when planted in May and harvested in August (Martini, 2004). In Watkinsville, Georgia, velvetbean accumulated 243 lb N acre^{-1} when planted in April and harvested in August, and 226 lb N acre^{-1} when planted in May and harvested in August.

Velvetbean is also noted to accumulate large amounts of biomass. Buckles et al. (1998) note aboveground biomass production of velvetbean ranges from 2.2 to 5.4 T of dry matter acre^{-1} and in Ghana, Osei-Bonsu et al. (1996) report up to 4 T acre^{-1}. However, in recent years little research has been done on velvetbean as a cover crop in the United States. This results in a lack of information regarding when to grow and when to harvest velvetbean for the most biomass production as part of a sustainable vegetable production system in the United States.

The objective of this study was to determine the most ideal planting and harvesting (or cutting) dates for velvetbean as a green manure/cover crop in a sustainable vegetable production system in the Southeastern United States. The study took place at two locations in Georgia, the U.S.D.A. Phil Campbell, Senior, Natural Resource Conservation Center on the Piedmont in Watkinsville, Ga., and the University of Georgia Coastal Plain Experiment Station in Tifton, Ga. The two areas represent distinct physiographic regions, both with soils low in organic matter. The Piedmont soils are severely eroded due to a long history of conventional crop production, while the Coastal Plain soils are derived from marine sand deposits and are inherently low in organic matter.

MATERIALS AND METHODS

This study took place in Watkinsville, GA at the U.S.D.A. Agricultural Research Service Station on a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) and at the Coastal Plain Experiment Station on a Tifton sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) in Tifton, Georgia. One plot of velvetbean was planted on (within two days) four different dates, including 15 Apr., 15 May, 15 Jun., and 15 Jul. in the summer of 2002. Velvetbean seed was planted at 32 pounds/acre with an in-row spacing of 1.7 seed/foot in Watkinsville and 2 seed/foot in Tifton. In Tifton a 36-inch row spacing (between rows) was used and in Watkinsville 30 inch row spacing (between rows) was used due to the difference in planters available and used at each site. The velvetbean used in this study is ‘Georgia Bush,’ a newer variety of *Mucuna pruriens* released in 1999.

All plots were irrigated approximately .50 inch shortly after planting. No more than seven days after planting, 15 pounds/acre of Ammonium nitrate were applied to each plot. During the second week of May, Round up was sprayed on the April plot of velvetbean between rows due to an abundance of grassy weeds. Dual and Prowl were also sprayed in the middle of May on the plot to be planted at a later date (June and July plots) to control weeds. Round up was again sprayed in the April plot of velvetbean in late June for weed control. Dual and Prowl were sprayed again in July plots just prior to planting. In July all plots were irrigated approximately 2 inches. All plots were irrigated approximately two inches in August, as well.

Weed control was done by hand in Watkinsville throughout the month of July with about six hours of labor (for one person). Weeds were mostly a problem on the outer edges of the plots, in between the plots and in the bare spaces resulting from harvesting. The harvest dates included 30, 60, 90, and 120 days after planting (DAP). Four replicates of each treatment were collected as defined by areas previously randomly selected and mapped accordingly (see diagrams 1 and 2). In Watkinsville, biomass samples were collected by cutting the plants at the base in 3 linear feet per row, harvesting two rows per sample so each sample contained 6 linear feet. In Tifton 6 total linear feet were harvested, as well. The fresh weight of each sample was recorded shortly after harvesting and each sample was placed in an oven at 150 degrees F for at least 72 h to dry. Dry weights were then recorded for each biomass sample.

The data were analyzed using The GLM Procedure and Duncan's Multiple Range Test with an alpha value of 0.05. The mean weight of each (16) planting/harvest date was compared among each month of planting (April-July) using 64 observations except in Watkinsville for velvetbean, which is discussed later in this paper. A comparison of each planting/harvesting date was made among and within each month. A comparison of each planting and harvesting date, for example among the mean weights for all samples that were collected 30 DAP was also analyzed for differences in significance.

For the biomass accumulation based on heat units portion of this study, heat units were determined for each day using the following formula: [(Daily maximum temperature (T) + Daily minimum T) / 2] – 61 (OMAF, 2003; Ball, 2003; Nielson, 2001). Cotton's base temperature, or the temperature at which cotton will not grow, is 61°C (Ball, 2003). For this reason, 61°C has been chosen as the base temperature for velvetbean for the purpose of this section of the study. Heat units were summed between each planting and harvest date and these values were used similar to DAP to fit regressions for biomass and N accumulation for the Tifton and Watkinsville locations. All weather related data were taken from "The Georgia Automated Environmental Monitoring Network" website (www.GeorgiaWeather.net, 2003). Regression equations were developed for each location and cover crop using the REG procedure in SAS with no intercept in the model, for example no biomass at 0 DAP. The resulting regression equations were then combined for one model per cover crop. Equations were fit using all data points, except extreme outliers; which excluded the June planting in Tifton harvested 120 DAP.

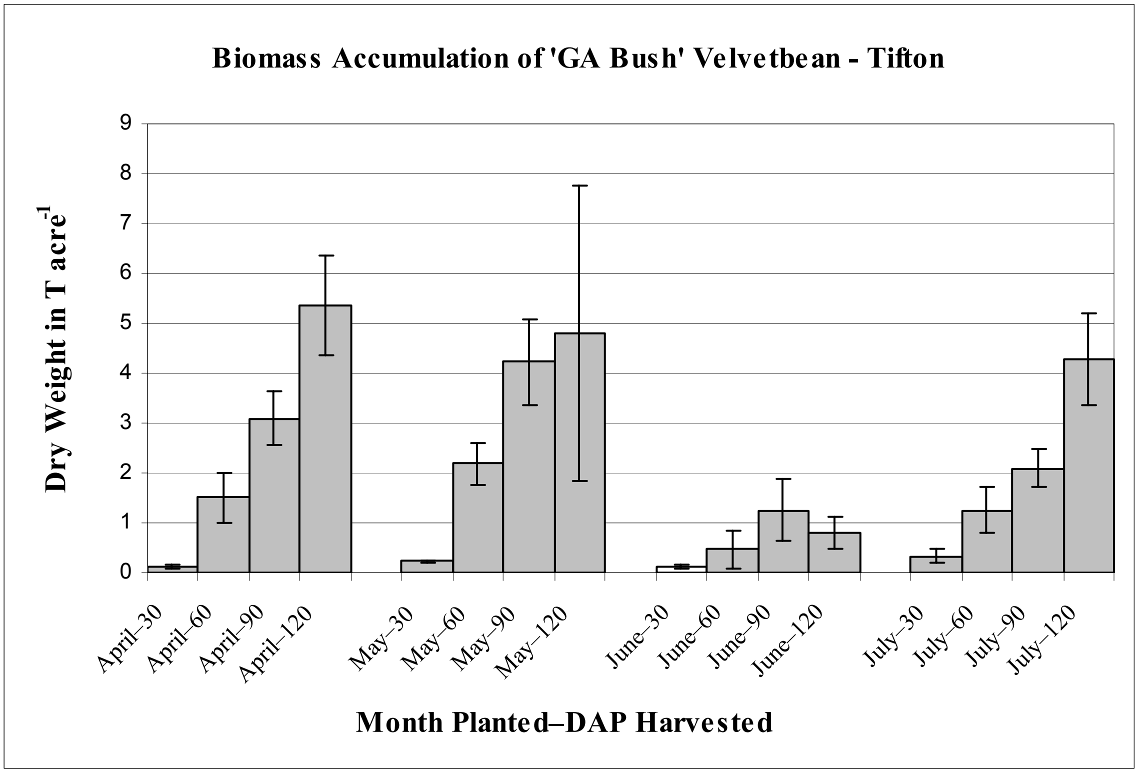
RESULTS AND DISCUSSION

In Tifton, velvetbean biomass harvested 120 DAP had the maximum mean DW of 3.8 t acre^{-1}, velvetbean harvested 90 DAP accumulated a mean DW of 2.7 t acre^{-1}, velvetbean harvested 60 DAP had a mean DW of 1.3 t acre^{-1} and velvetbean harvested 30 DAP accumulated a mean DW of 0.18 t acre^{-1}. The maximum biomass for velvetbean in Tifton was 29.2 t acre^{-1} (fresh weight) harvested 120 DAP from the May planting, however the standard error for this mean is 17.0 t acre^{-1}. The maximum DW was harvested 120 DAP from the April planting (5.4 t acre^{-1}), which was not significantly more than the May and July plantings with 4.8 t acre^{-1} and 4.3 t acre^{-1} DW accumulated respectively. The June planting harvested 120 DAP accumulated a significantly smaller amount of biomass with a DW of 0.80 t acre^{-1} probably as previously mentioned, due to a viral infection. The minimum fresh and DWs recorded for velvetbean in Tifton were 0.50 t acre^{-1} for the June and 0.1 t acre^{-1} for the April plantings, both harvested 30 DAP.

Velvetbean biomass harvested 60 DAP from each planting date accumulated from 0.4 t acre^{-1} for the June planting to 2.2 t acre^{-1} for the May planting. However, no significant difference occurred between the May planting (2.2 t acre^{-1}) and the April planting (1.5 t acre^{-1}). The biomass harvested 60 DAP from the July planting (1.2 t acre^{-1}) was not significantly less than the April planting harvested 60 DAP, which accumulated 1.5 t acre^{-1}.

Velvetbean biomass harvested 90 DAP accumulated DWs from 1.2 t acre^{-1} for the June planting to 4.2 t acre^{-1} for the May planting. At 90 DAP there was a significant difference between the April and May plantings with weights of 3.1 t acre^{-1} and 4.2 t acre^{-1} respectively. Biomass harvested 90 DAP from the July planting (2.1 t acre^{-1}) proved not to be significantly greater than the 1.2 t acre^{-1} of biomass harvested from the June planting (Figure 1).

Figure 1 DW (± SE) of 'Georgia Bush' velvetbean (*Mucuna pruriens*) planted in Tifton in April, May, June, and July, and harvested 30, 60, 90, and 120 days after planting (DAP).



In Watkinsville deer browsing was a problem for the velvetbean. For the first five months of the experiment deer were not a problem. They did go into the velvetbean plots during this time, however, they tended to only feed on the plants on the outer edge of the plots. The plot planted in July suffered slightly more damage from deer, probably because this planting had stunted growth due to a suspected virus, which kept the leaves small, tender, and more palatable to the deer. In early September, however, deer went into the velvetbean plots and completely defoliated all the plants.

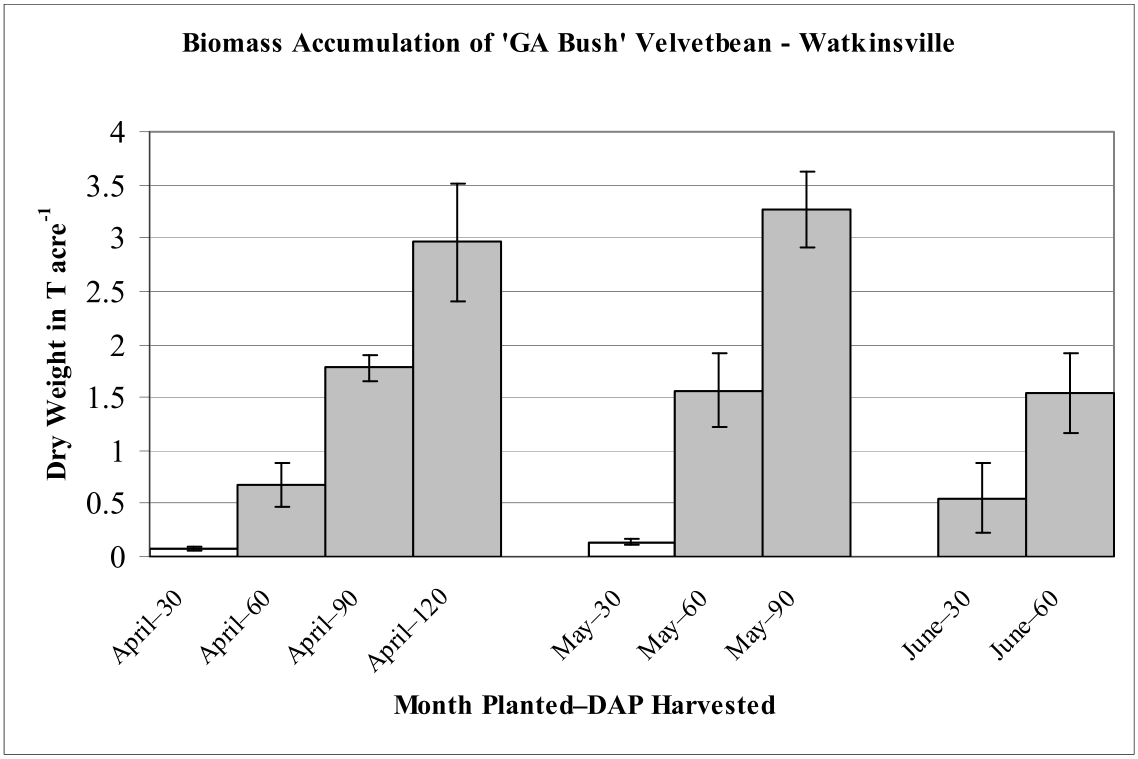
Unfortunately, due to the damage from the deer, collection of September samples of velvetbean plots was not possible. To determine the possibility of velvetbean recovering from the severe damage done by the deer, Milorganite™ nitrogen fertilizer containing human waste was put down on the perimeter of both the sunn hemp and velvetbean plots to deter the deer. The velvetbean began to put on new growth, however, in the middle of October either the fall army worm or the velvetbean caterpillar completely defoliated the foliage that remained or had grown back from the damage done by the deer.

In Watkinsville, a comparison among harvesting times (30, 60, 90, and 120 DAP) shows that velvetbean harvested 120 DAP accumulated the maximum DW of 2.9 t acre^{-1}, unfortunately only four samples were taken for this treatment of time due to damage to the velvetbean plantings as mentioned earlier. Velvetbean harvested 90 DAP accumulated a mean (of 8 samples) DW of 2.5 t acre^{-1}. The mean (of 12 samples) DW of velvetbean harvested 60 DAP accumulated 1.2 t acre^{-1} and the biomass collected 30 DAP accumulated a mean (of 12 samples) of 0.3 t acre^{-1}.

The DW of 16 samples from the April planting, 12 samples from the May planting and 8 samples from the June planting included four repetitions of each 30, 60, 90 and 120 DAP harvest time. At 30 DAP the June planting accumulated the most DW biomass with 0.5 t acre^{-1}, while the April and May plantings accumulated significantly less biomass (0.1 t acre^{-1} and 0.1 t acre^{-1} respectively) than the June planting.

Velvetbean biomass harvested 60 DAP from the May planting had the largest DW of biomass (1.6 t acre^{-1}) which is similar to the June planting (1.5 t acre^{-1}). The April planting accumulated the least amount after 60 DAP (0.7 t acre^{-1}). Biomass harvested 90 DAP was only recorded for the April and May plantings. The May planting accumulated significantly more biomass (3.2 t acre^{-1}) than the April planting (1.3 t acre^{-1}). No data were collected for the July plot (Figure 2).

Figure 2 DW (± SE) of 'Georgia Bush' velvetbean (*Mucuna pruriens*) planted in Watkinsville in April, May, June, and July, and harvested 30, 60, 90, and 120 DAP. Data are incomplete due to damage from a virus and damage from deer browsing and caterpillar feeding.



The model for velvetbean biomass accumulation versus DAP shows that as expected more biomass is accumulated the longer velvetbean is allowed to grow, however the variability increases later in time, such as at 120 DAP. The combined model for both locations is $\hat{Y}$= 0.025*DAP where $\hat{Y}$ is equal to the biomass accumulated in t acre^{-1} and r^2=0.88. The April, May, and June plantings in Tifton show a specific trend of more biomass accumulated 120 DAP. The June planting did not perform as might be expected based on the data from the other plantings, however, the suspected virus is probably the reason. Data are incomplete for velvetbean in Watkinsville due to pest damage (Figure 3).

When expressed on a cumulative heat units (CHU) basis, the combined model for velvetbean at both locations is $\hat{Y}$= 0.004*CHU where $\hat{Y}$ is equal to the biomass accumulated in t acre^{-1} and r^2=0.93. Cumulative heat units better described biomass accumulation than cumulative heat units plus cumulative rainfall. Variability among data points is small, except for the June plantings in Tifton; which are outliers due to viral damage to the planting. However, the linear pattern of the data points suggests an effective model at estimating potential biomass accumulation based on cumulative heat units (Figure 4).

Figure 3 Biomass accumulation of velvetbean in dry weight (DW) as a function of days after planting (DAP). Data points are mean of four observations. Data are incomplete for Watkinsville.

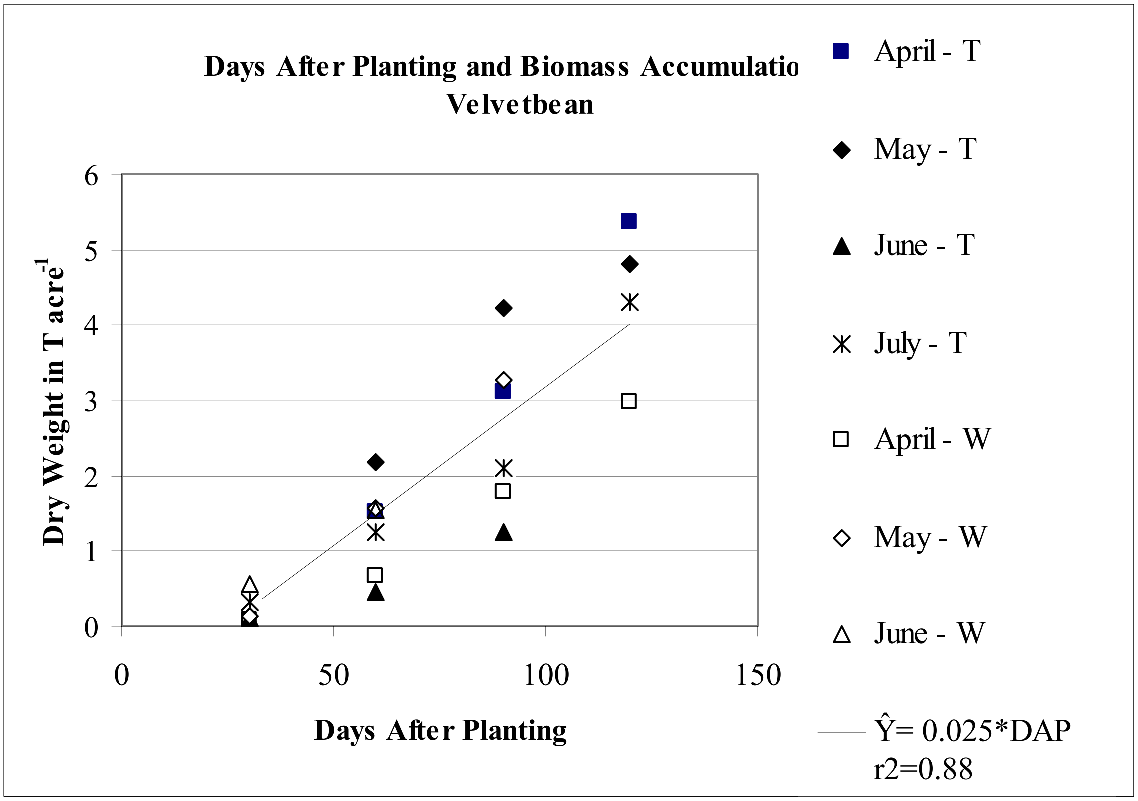
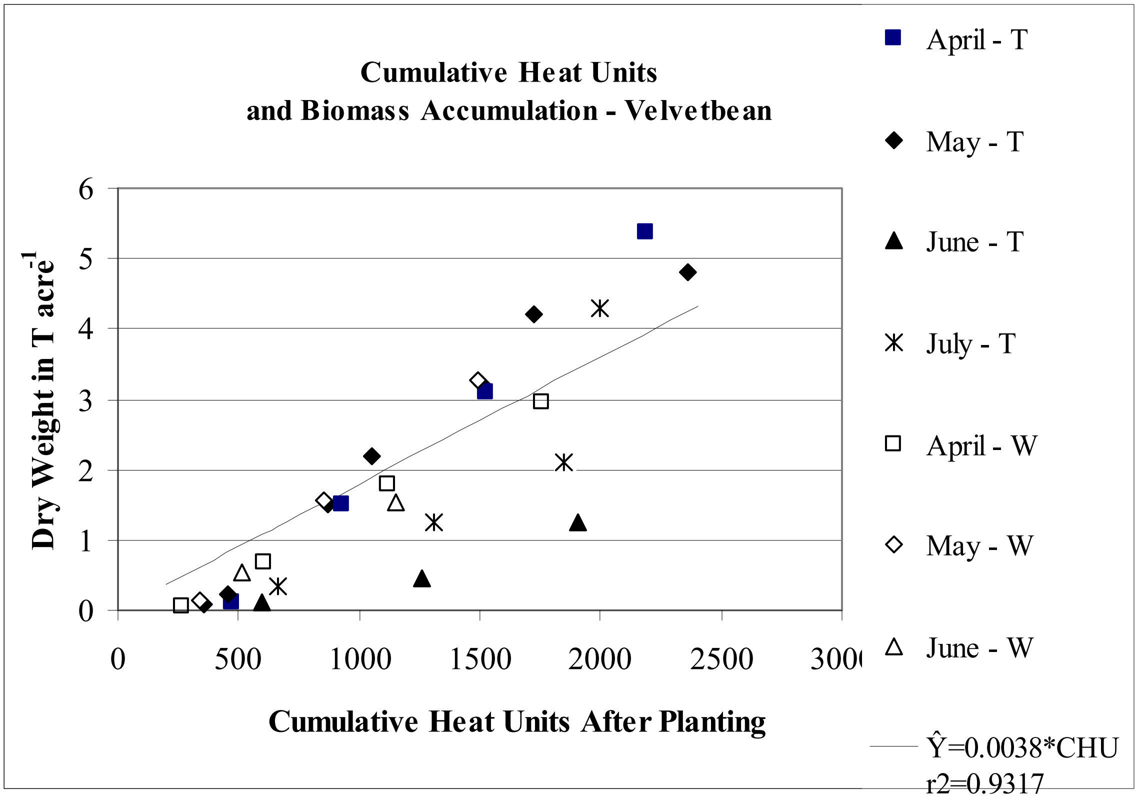


Figure 4 Biomass accumulation of velvetbean in dry weight (DW) as a function of cumulative heat units (CHU). Data points are mean of four observations. Data are incomplete for Watkinsville.



CONCLUSIONS

At 120 DAP velvetbean planted in Tifton accumulation in the April May and July plantings was similar, while the June planting accumulated significantly less DW biomass than the other plantings due to a suspected virus. The May planting harvested 90 DAP was similar to the April, May and July plantings harvested 120 DAP. It appears that to receive soil-improving benefits from velvetbean when grown in Tifton, allowing 120 days for the velvetbean to grow will provide the most benefit. If a grower needed a shorter growing period for velvetbean, planting in May and cutting 60-90 DAP or planting in July and cutting 90 DAP would also provide significant biomass. This provides two windows of opportunity for growing velvetbean in early or late summer as a short-fallow rotational crop in South Georgia.

At 90 DAP, the May planting of velvetbean grown in Watkinsville accumulated more biomass than the April planting. The April planting harvested 120 DAP accumulated less biomass than the May planting harvested 90 DAP. The data show a trend of increasing biomass accumulation with later planting dates. The May and June plantings were similar at 60 DAP, both producing average biomass. The biomass accumulated in the June planting at 30 DAP was similar to that produced in the April planting at 60 DAP. This data may suggest planting velvetbean after April is better for biomass accumulation in the Watkinsville, GA area.

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SURFACE SOIL ORGANIC POOLS IN RESPONSE TO SILAGE CROPPING INTENSITY UNDER NO TILLAGE

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ABSTRACT

Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues returned to soil will likely alter the success of a particular conservation tillage system within a farm operation. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil organic matter pools in different environments. We investigated the impact of three cropping systems (a gradient in residue returned to soil) on total organic C and N, particulate organic C and N, microbial biomass C, and mineralizable C and N in a Piedmont soil in North Carolina. There is an inverse relationship between silage intensity and residue returned to soil. With time, surface soil organic matter pools became higher with reduced silage cropping intensity as a result of greater crop residue returned to soil. These results suggest that greater quantities of crop residue returned to soil have positive effects on soil organic matter pools in continuous no-tillage crop production systems. These results can help to determine an optimum balance between short-term economic returns and longer term investments in improved soil quality for more sustainable production.

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
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 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 hinder 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.

Dairy producers in North Carolina rely on corn and barley 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 low soil biological activity, long-term compaction, inefficient water-use, poor nutrient cycling, and soil erosion even when conservation tillage is used.

We investigated the impact of alternative, reduced-silage-cropping-intensity systems that returned more crop residues to the soil than the traditional maize-barley silage cropping system on surface-soil properties. We consider the soil surface a critical component of agroecosystems, because it is the vital interface that initially determines the fate of fertilizers, pesticides, water, and gases into and out of the soil profile.

MATERIALS AND METHODS

The site is located in Iredell County in the Southern Piedmont Major Land Resource Area of North Carolina. 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" and mean annual temperature is 58 EF.

Three cropping systems replicated twice were evaluated in −1000-ft-long strips that were 40-67-ft wide 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- to 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 1930 to 2360 gal/acre/yr, which was equivalent to 40-31-100-7 lb N-P_2O_5-K_2O-S/acre.

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 alone or rye plus crimson clover) killed by a 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 or sunnhemp) 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 a 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 1 (low silage intensity), 2 (medium silage intensity), and 4 (high silage intensity) silage crops harvested during a 2-year period.

Surface residue and soil were sampled in December 2000, February 2002, and November 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 –67 ft apart were composited. Surface residue was collected from 8 x 8" areas by first removing green plant material above –2" height and then collecting all surface residue to ground level by cutting with a battery-powered hand shears. Following surface residue removal, a soil core (1-5/8" diam) was sectioned into depths of 0-1.2", 1.2-2.4", 2.4-4.7", and 4.7-8". Soil was dried at 131 EF for 3 days, initially passed through a sieve with openings of 3/16" 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.

Particulate organic matter was isolated from soil by shaking 0.7- to 2.3-oz subsamples of soil in 3.5 oz of 0.01 *M* $Na_4P_2O_7$ for 16 hr, passing the mixture over a sieve with 0.002" openings, and collecting the material >0.002". Samples were dried at 131 EF for 24 hr past visual dryness, weighed, ground to a fine powder in a ball mill, and analyzed for C and N concentration with dry combustion.

Potential C mineralization was determined by placing two 0.7- to 2.3-oz subsamples (inversely related to soil organic C concentration) in 2-oz glass jars, wetting to 50% water-filled pore space, and placing them in a 1-qt canning jar along with 0.35 oz of 1 *M* NaOH to trap CO_2 and a vial of water to maintain humidity. Samples were incubated at 77 EF 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. 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 77 EF 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.

Since the two replications in this experimental design were established two years apart, we chose to look at the temporal changes that occurred in soil properties through regression, rather than discrete sampling year effects. Sampling in December 2000 was after 3 years (Replication 1) and 1 year (Replication 2). Sampling in February 2002 was after 4 years (Replication 1) and 2 years (Replication 2). Sampling in November 2002 was after 5 years (Rep 1) and 3 years (Replication 2). Stratification ratio of soil properties was calculated from the concentration at a depth of 0-2.4" divided by the concentration at a depth of 4.7-8". Treatment means averaged across sampling events were evaluated for differences with a paired t-test. Differences among silage cropping intensity treatments were considered significant at *p*#0.1.

RESULTS AND DISCUSSION

Soil organic C averaged across all three sampling events was not significantly different among cropping systems (data not shown). Soil organic C of the surface 1.2" increased with time under low silage intensity, did not change with time under medium silage intensity, and decreased with time under high silage intensity (Fig. 1). These results are attributable to the expected return of crop residues to the soil surface in each of these three cropping systems.

Soil microbial biomass C of the surface 1.2" followed a pattern similar to that of soil organic C (Fig. 2), although there was a tendency for soil microbial biomass C to decline during the 5th year under low silage intensity. It is possible that the dry conditions of 2002 may have reduced soil microbial biomass C in the 5th year. Soil microbial biomass C as a percentage of total organic C was 4.8 ± 1.0%. It plays a major role in organic matter decomposition and nutrient cycling, and therefore, may be an early indicator of long-term changes in soil organic matter (Powlson et al., 1987). Soil microbial biomass is an important mediator in several nutrient cycles and biophysical manipulation of soil structure.

Potential C mineralization from the surface 1.2" of soil during 24 days of aerobic incubation did not change with time under low and medium silage intensity, but tended to increase with time under high silage intensity (Fig. 3). However when averaged across sampling times, potential C mineralization was 0.19 ± 0.06% under low silage intensity, 0.18 ± 0.03% under medium silage intensity, and 0.12 ± 0.02% under high silage intensity. Potential C mineralization reflects the quality and quantity of substrates available for utilization by soil heterotrophic microorganisms, which can affect short-term N and P mineralization/immobilization and long-term storage and subsequent slow release of nutrients. The results of this study suggest that surface soil is more enriched in mineralizable C with more crop residue returned.

Net N mineralization from the surface 1.2" of soil during 24 days of aerobic incubation declined during the first few years of management under low and medium silage intensity and tended to increase with time under high silage intensity (Fig. 4). The accumulation of surface residues with high C-to-N ratio probably contributed to the reduced net N mineralization with lower silage intensity, because soil microorganisms were active in processing the heavy load of organic C at the soil surface. Our analyses of surface residues are yet incomplete, but mass of surface residues was 2.46 ± 1.22 ton/acre with high silage intensity, 3.38 ± 1.02 ton/acre with medium silage intensity, and 3.26 ± 0.37 ton/acre with low silage intensity. The C-to-N ratio of the mineralizable fraction reflected this additional workload of surface soil micrchoorganisms, whereby C-to-N ratio increased greatly with time under low silage intensity, moderately with medium silage intensity, and remained at a low level with time under high silage intensity (Fig. 5).

Stratification of soil organic matter under conservation tillage systems is a natural consequence of crop residues left at the soil surface to decompose without alteration by tillage. The degree of stratification of various soil organic matter pools has been proposed as an indicator of soil quality or soil ecosystem functioning, because surface organic matter is essential to erosion control, water infiltration, and conservation of nutrients (Franzluebbers, 2002a). Increased stratification is likely to (1) improve water efficiency by reducing runoff and increasing retention in soil, (2) improve nutrient cycling by slowing mineralization and immobilizing nutrients in organic fractions rather than losing them in runoff and leachate, (3) resist degradative forces of wind and water erosion and mechanical compaction, (4) improve soil biological diversity, and (5) enhance long-term productivity of soils.

Stratification ratio of soil organic C did not change dramatically in any of the three cropping systems and was not different among cropping systems when averaged across sampling events (4.2 ± 1.3) (Fig. 6). There was a tendency for divergence in the stratification ratio of soil organic C between medium silage intensity and high silage intensity. Stratification ratio of soil microbial biomass C was greater (*p* = 0.09) under low silage intensity (4.6 ± 1.3) than under high silage intensity (3.5 ± 0.5) and intermediate with medium silage intensity (4.2 ± 0.9). In a similar manner, stratification ratio of the flush of CO_2-C during 3 days following rewetting of dried soil was greater (*p* = 0.03) under low silage intensity (6.0 ± 1.8) than under high silage intensity (4.3 ± 1.1) and intermediate under medium silage intensity (5.5 ± 1.2). Interestingly, however, there was no strong trend for changes in stratification ratios with time. It is possible that the relatively high stratification ratios in all systems at the beginning of this study, due to several previous years of no tillage silage production at this site, may have been near the upper level of values that are likely to occur within a decade of continuous management. The upper limits for this region have not been described, but ratios of various soil organic matter pools peaked at values of 4 to 10 in several evaluations of management systems in Alberta, Georgia, and Texas (Franzluebbers, 2002a). In a controlled experiment, infiltration of water into soil was maximized when a Typic Kanhapludult had a stratification ratio of soil organic C $\geq$5 (Franzluebbers, 2002b).

Previous results from this study suggested that surface compaction was occurring at a steady rate with high silage cropping intensity and that compaction could be alleviated by low silage cropping intensity with high surface residue return (Franzluebbers et al., 2003). 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, 2002b). 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 create water-stable aggregates.

CONCLUSIONS

Sampling of surface-soil properties within the first 5 years of implementation of alternative silage crop management systems suggested that soil biochemical properties such as organic C, microbial biomass C, and potential C mineralization responded positively and led to an improvement in soil quality. Soil organic C pools were highly stratified with depth under all management systems in this study as a result of long-term management with conservation tillage. Return of organic substrates to the soil surface were necessary to maintain high surface-soil biological activity, which would foster water and nutrient efficiency and prevent soil compaction. Sufficient quantities of residues returned to the soil are necessary for organic matter transformations to facilitate the development of an improved soil condition.

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LIST OF FIGURES

Fig. 1. Temporal changes in soil organic C at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

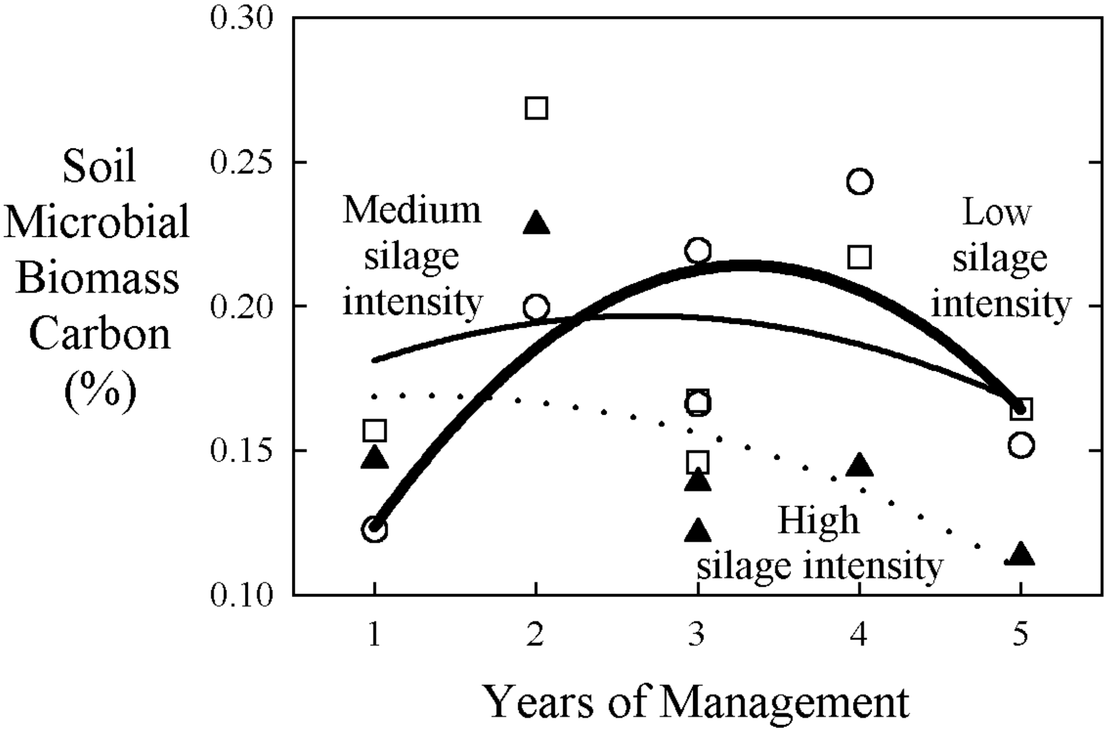
Fig. 2. Temporal changes in soil microbial biomass C at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

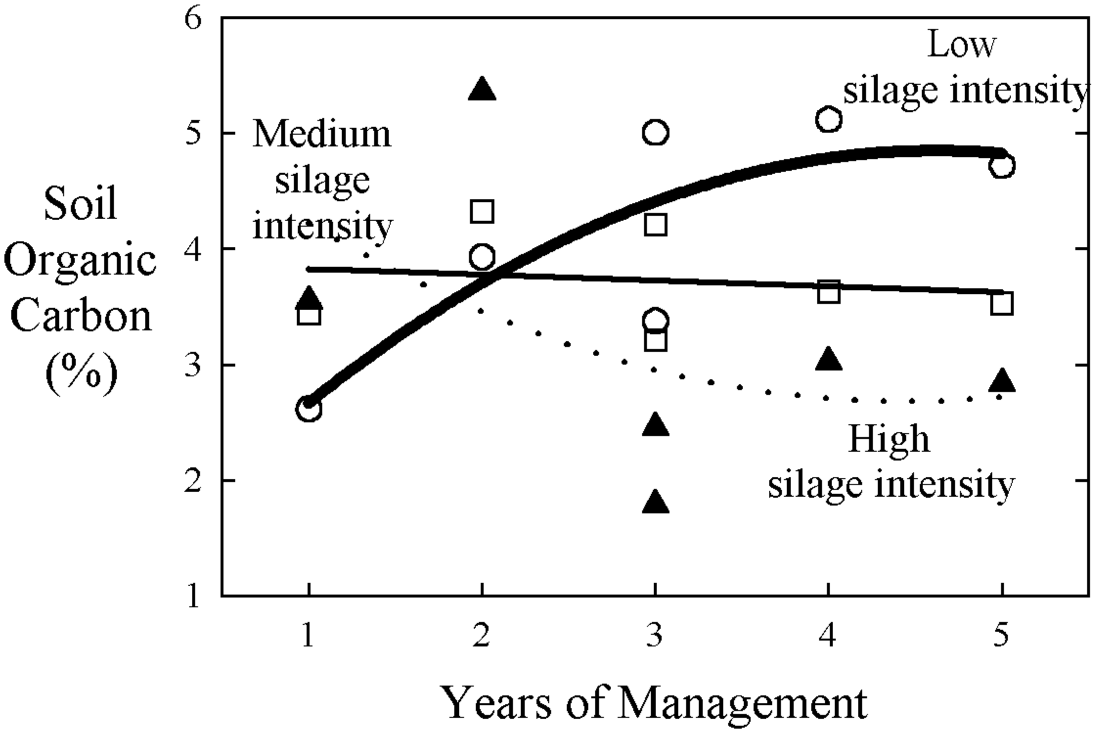
Fig. 3. Temporal changes in potential C mineralization at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

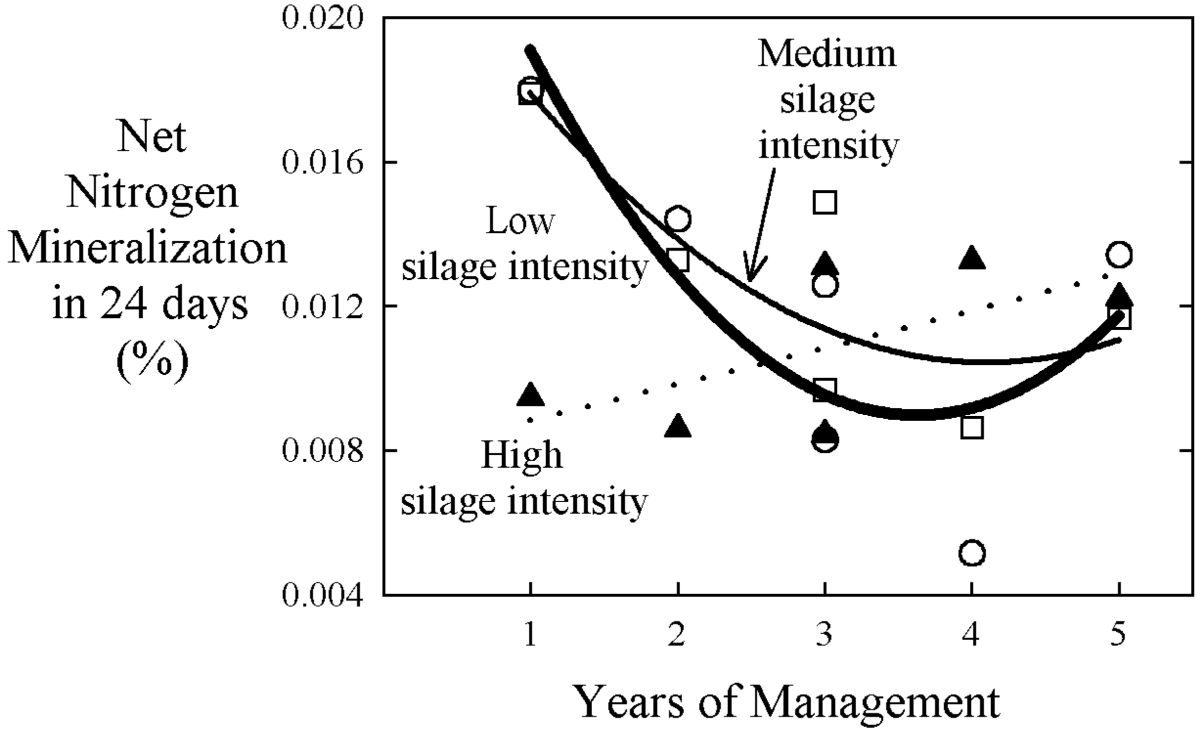
Fig. 4. Temporal changes in net N mineralization at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

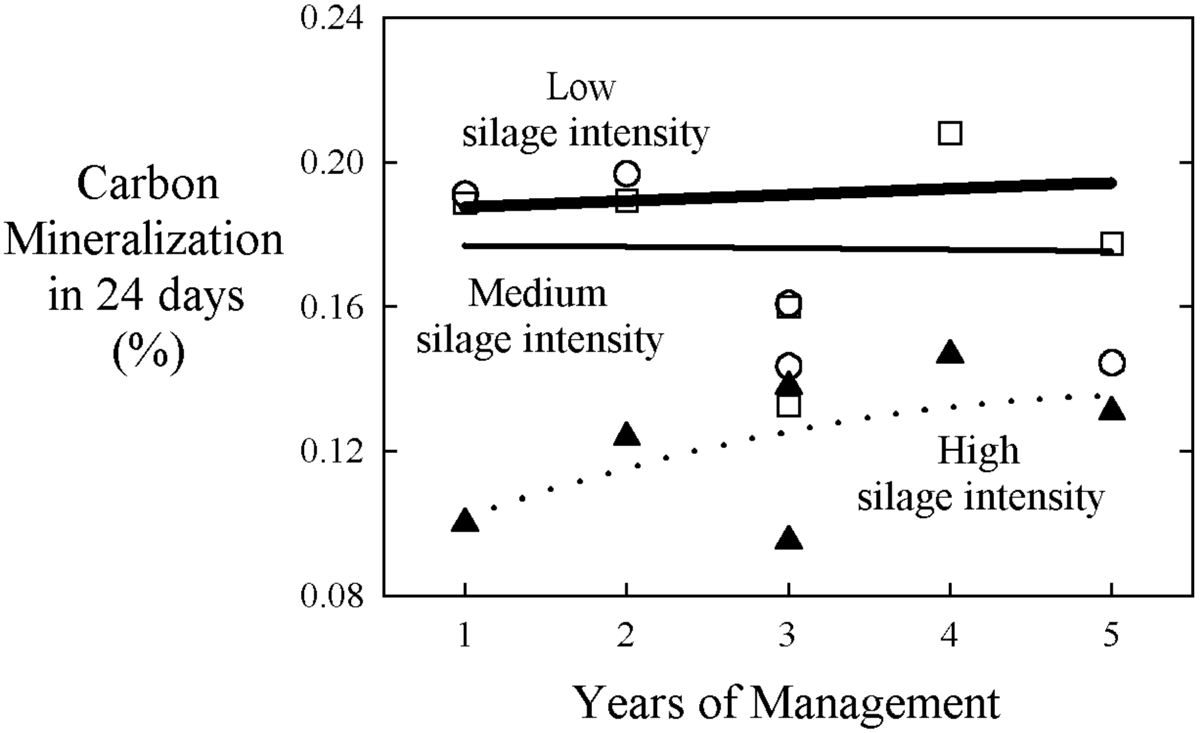
Fig. 5. Temporal changes in the mineralizable C-to-N ratio at a depth of 0-1.2" as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

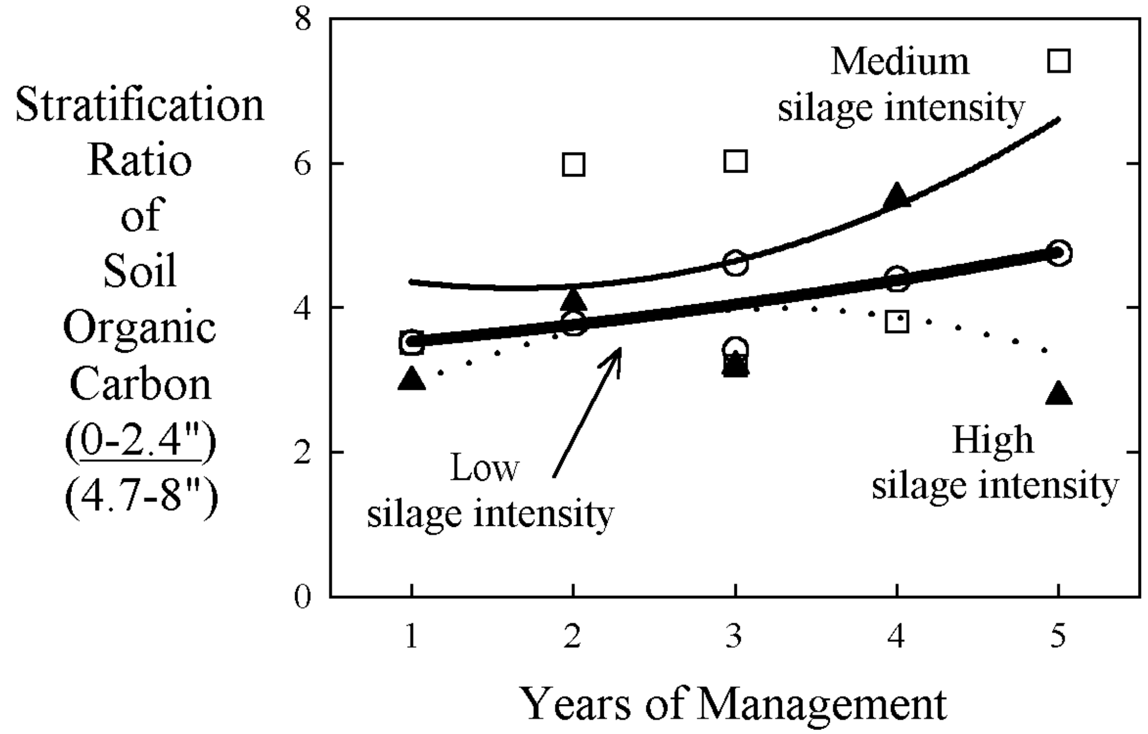
Fig. 6. Temporal changes in the stratification ratio of soil organic C as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and ▲ is high silage intensity.

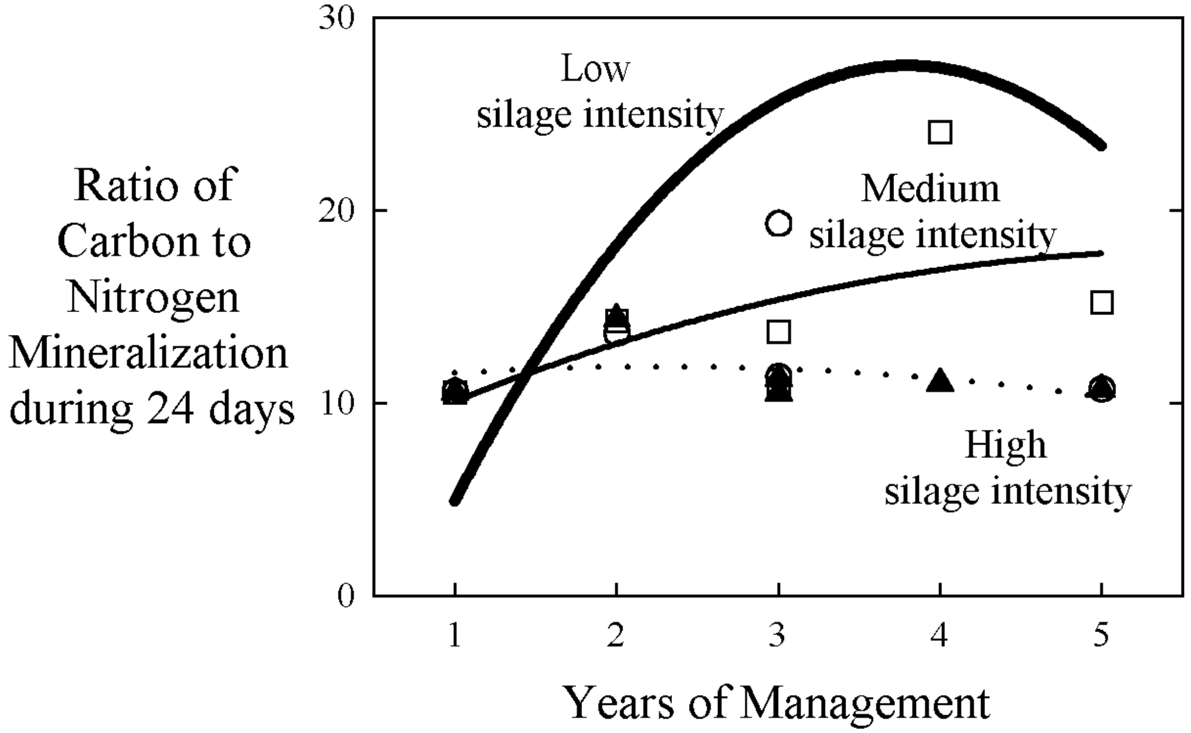

Soil Microbial Biomass Carbon (%)
0.30
0.25
0.20
0.15
0.10
Medium silage intensity
Low silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Soil Organic Carbon (%)
6
5
4
3
2
1
Low silage intensity
Medium silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Net Nitrogen Mineralization in 24 days (%)
0.020
0.016
0.012
0.008
0.004
Medium silage intensity
Low silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Carbon Mineralization in 24 days (%)
0.24
0.20
0.16
0.12
0.08
Low silage intensity
Medium silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Stratification Ratio of Soil Organic Carbon (0-2.4") (4.7-8")
8
6
4
2
0
Medium silage intensity
Low silage intensity
High silage intensity
1
2
3
4
5
Years of Management


Ratio of Carbon to Nitrogen Mineralization during 24 days
30
20
10
0
Low silage intensity
Medium silage intensity
High silage intensity
1
2
3
4
5
Years of Management

QUALITY CONTROL FOR A NEW PERMANGANATE OXIDIZABLE C METHOD

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ABSTRACT

Duration of reaction and soil mass was evaluated as sources of experimental error in a new permanganate oxidizable C (POC) method. The method's short duration of reaction was more sensitive to variation in procedural timing than longer durations of reaction, but small coefficients of variation (< 5%) were achieved using the recommended timing. Sensitivity to management was evaluated using soil from two experiments. The method was found to be sensitive to tillage intensity and level of C inputs. Analysis of multiple soil masses revealed an asymptotic relationship between permanganate availability and reaction efficiency. A computational technique was developed to correct for the method's lack of linearity. Nine quality control protocols are proposed to reduce experimental error.

INTRODUCTION

Weil et al. (2003) recently proposed a permanganate oxidizable C method for evaluating soil management effects on soil quality. The method differs from previously described permanganate methods (Loginow et al., 1987; Blair et al., 1995; Moody et al., 1997; Bell et al., 1998; Blair et al., 2001) in the following substantive ways:

1. Reduced concentration of permanganate solution (easier to prepare, safer)
2. Reduced complexity (elimination of many steps including grinding, filtering and centrifugation).
3. Reduced cost (faster and requires less specialized lab equipment)
4. Increased sensitivity to management

The new method is sensitive to management (e.g. contrasting tillage systems and C input regimes) and correlated with biologically active C parameters (e.g. microbial biomass C, soluble carbohydrates, substrate induced respiration) that are more difficult to measure (Weil et al., 2003)

This paper evaluates sources of experimental error in the method and proposes specific quality control protocols.

MATERIALS AND METHODS

Soils from two cropping systems experiments (Tables 1a and b) and 3 non-experiment areas were used to evaluate the method.

Table 1a. Organic transition experiment.

Geographic location	Goldsboro, NC
Experiment station	Center for Environmental Farming Systems
Year of initiation	1999
Soils	Wickham sandy loam, Tarboro loamy sand
Systems	3 low C input regimes, 3 high C input regimes
Plots sampled	3 reps of all systems
Time of sampling	April 2003

Table 1b. Tillage system experiment.

Geographic location	Reidsville, NC
Experiment station	Upper Piedmont Research Station
Year of initiation	1984
Soil	Wedowee sandy loam
Systems	9 systems with contrasting tillage intensity
Plots sampled	4 reps of 2 systems (plow/disk and continuous no-till)
Time of sampling	June 2003

Experimental plots were sampled at 2 depths (0-7.5, 7.5-15 cm). Field moist cores were gently crumbled and spread on paper to air dry. Air-dry soil was passed through a sieve with 2-mm mesh.

Soil was collected in bulk from the sandy loam surface horizon of a general production area at the Center for Environmental Farming Systems. A dry sieving process was used to isolate a less than 0.5-mm fraction for long-term use as a low C experimental "standard".

Soil was collected in bulk from the sandy loam surface horizons of long-term sod sites at the Center for Environmental Farming Systems (CEFS) and the Upper Piedmont Research Station (UPRS). A dry sieving process was used to isolate a less than 0.5-mm fraction from the CEFS soil for long term use as a high C experimental "standard".

Permanganate oxidizable C analysis.

Permanganate oxidizable C levels (POC) were determined for the soils described above using the lab method proposed by Weil et al. (2003) as well as selected modifications (Table 2).

Table 2. Recommended and modified experimental parameters.

Procedural variable	Weil et al. value	Modified values
Mass of soil	5.0 g	0.25 – 9 g
Initial concentration of MnO_4^-	0.02 M	0.02 M
Volume of MnO_4^- solution	20 ml	20 ml
Duration of shaking	2 min	2, 5, 10 ,15, 18 min
Duration of settling	10 min	10, 30 min

Soil masses ranging from 0.25 to 9.00 g were reacted with 20.0 ml of 0.02 M permanganate solution in 50-ml screw top polycarbonate centrifuge tubes. The soil was added first followed by sequential aliquots of DI water (18.0 ml) and permanganate reagent (2.00 ml) using a mechanical repipetor and electronic pipet, respectively. The permanganate reagent contained 0.2 M $KMnO_4$, 1 M $CaCl_2$ and was adjusted to a pH of 7.2 using NaOH. The $CaCl_2$ was included to promote rapid flocculation of soil colloids. Weil et al. (2003) recommended raising the pH to 7.2 to increase reagent stability.

Tubes were capped and shaken end to end (240 oscillations per minute) for times ranging from 2 to 18 min. Tubes were prepared in sets of 25, with each set including 5 permanganate standards (2, 1.5, 1, 0.5, 0 ml of 0.2 M $KMnO_4$ reagent brought to 20 ml with DI water) and 2 tubes containing a standard soil.

After shaking, the suspensions were allowed to settle for either 10 or 30 min. An electronic pipette was used to transfer 1.0-2.0 ml aliquots of supernatant to clean tubes. The aliquots were diluted 10-20 fold with DI water followed by 5 seconds of orbital shaking with a vortex mixer. Absorbance was promptly measured at 565 nm using a Hitachi 100-60 spectrophotometer.

The following equation was used to calculate POC as a function of the quantity of permanganate reduced (Mn^{+7} -> Mn^{+4}) in each tube:

Equation 1:

POC (g/kg) = [0.02 - (a + b x absorbance)] x 9 x 0.02 / sm

where **0.02** is the intitial MnO_4^- concentration (mol/liter) in each tube, **a** and **b** are the intercept and slope of a standard curve, **9** is the mass (g) of C oxidized by 1 mol of MnO_4^-, **0.02** is the volume (l) of solution in each tube and **sm** is the mass (g) of soil added to each tube (Weil et al., 2003).

RESULTS AND DISCUSSION

Products of soil C:permanganate reaction.

Weil et al. (2003) reported that manganese is reduced from Mn^{+7} to Mn^{+2} during reaction with POC. While it is possible that some Mn^{+2} is produced, we believe that the primary manganese product is manganese dioxide (Mn^{+4}).

The accumulation of a dark brown layer was routinely observed in the tubes during the settling period. We also observed that lab equipment used for POC analysis developed a brownish discoloration that was insoluble in DI water and 0.1 M HCl but was quickly removed by a rinse with 0.1 M ascorbic acid. Manganese dioxide is an insoluble dark brown compound that readily accepts electrons from ascorbic acid (CRC, 1990).

We propose that the following redox half reactions and associated oxidation state transitions occur during the Weil et al. (2003) method.

Reduction half reaction

$MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_2 + 4OH^-$ $\mathbf{E^o = 0.60V}$
$Mn^{+7} \rightarrow Mn^{+4}$

Oxidation half reaction

$CH_20 + O_2 \rightarrow CO_2 + H_2O + 4e^-$
$C^0 \rightarrow C^{+4}$

These half reactions and oxidation state transitions are congruent with the stoichiometric relationship (0.75 mol C : 1 mol Mn) assumed in equation 1.

The permanganate reduction reaction listed above only occurs under alkaline conditions (CRC, 1990). Under acidic conditions, the following two reactions occur (CRC, 1990):

$$MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O \quad \mathbf{E^o = 1.68V}$$
$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O \quad \mathbf{E^o = 1.51V}$$

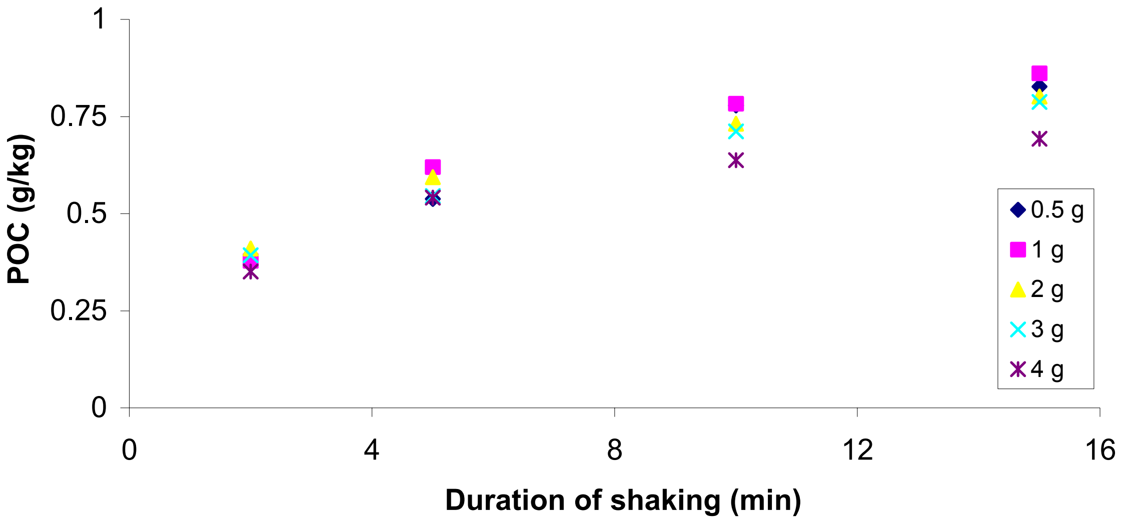
We have not evaluated the sensitivity of the POC method to pH, but the contrasting reactions and electron potentials presented above suggest that the kinetics and stoichiometry of reactions in acid and alkaline solutions will differ.

Duration of shaking.

Weil et al. (2003) evaluated durations of shaking ranging from 1 to 15 min and reported that 2 min of shaking resulted in the best combination of analytical precision, experimental convenience and sensitivity to management. They emphasized that "the duration of shaking should be precisely timed and any further disturbance of the mixture after settling carefully avoided".

We evaluated durations of shaking ranging from 2 to 18 min using different combinations of shake time, pre-shake time, settling time, and mass of soil so that interactions could be identified. An asymptotic relationship was observed between POC and duration of shaking for different masses of the low C standard soil (Fig. 1). The precise duration of shaking emphasized by Weil et al. (2003) appears to decrease in importance as the duration of shaking increases. The divergence of results for different soil masses as the duration of shaking was increased was probably related to changes in reaction efficiency, a source of experimental error that will be discussed later.

Figure 1. Relationship between duration of shaking, soil mass and POC



We evaluated the impact of duration of shaking on sensitivity of POC to management using soils from contrasting management systems in 2 experiments (See tables 1a and 1b for an overview of the experiments and tables 3a and 3b for experimental results).

Table 3a. Effect of tillage system on POC.

Tillage regime	2-min shake	5-min shake POC (g/kg)	18-min shake
Continuous no till	0.53	0.65	1.05
Fall Plow/spring disk	0.06	0.13	0.30
F value	595.30	82.70	73.40

Table 3b. Effect of C input regime on POC.

Carbon input regime	C inputs* (kg/ha)	2-min shake POC (g/kg)	15-min shake POC (g/kg)
High C systems	6990	0.52	0.59
Low C systems	2030	0.43	0.44
F value		12.00	15.10

* Cover crop, manure, and compost applied from 1999-2001.

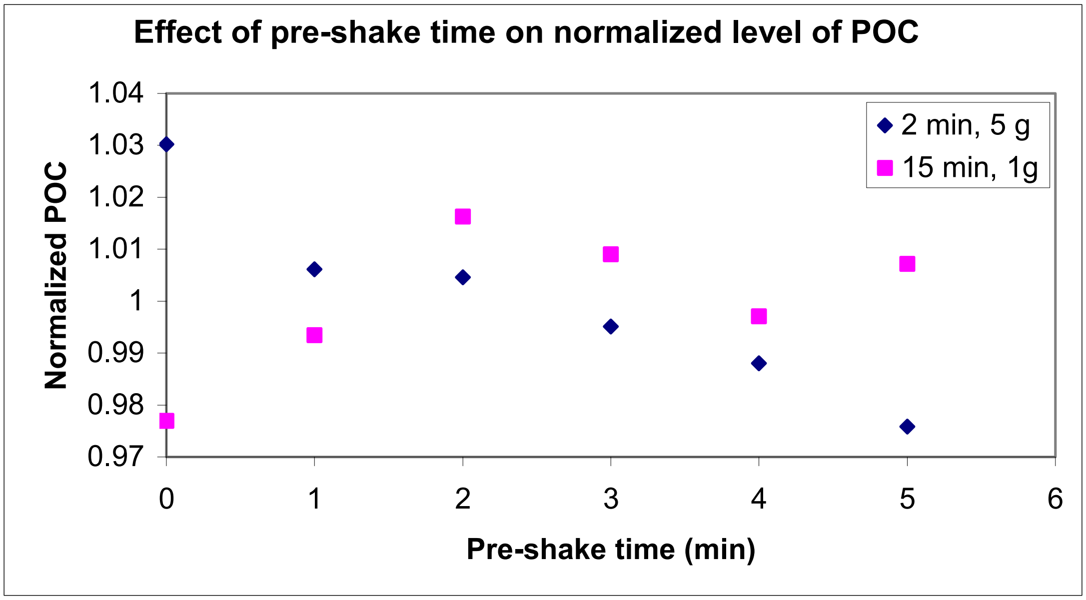
All durations of shaking (2, 5 and 18 min) resulted in POC levels that varied significantly between the fall plow/spring disk and continuous no-till systems but the 2-min duration of shaking produced the most divergent (largest F value) levels of POC (Table 2a).

Both durations of shaking (2 and 15 min) resulted in POC levels that varied significantly between high and low C input systems but duration of shaking had little impact on sensitivity (similar F values) (Table 2b).

Reaction time.

When soils are analyzed in batches, tubes receiving aliquots of permanganate reagent earlier in a batch have greater reaction time than tubes receiving aliquots later in the batch. The difference in pre-shake time between the first and last tube is typically 4 min for a batch of 25 tubes (~ 10 sec per tube). Difference in pre-shake time was observed to be a small but statistically significant source of error when 5 g of soil was analyzed with a 2-min duration of shaking but not when 1 g of the same soil was analyzed with a 15-min duration of shaking (Fig. 2). Smaller soil sub-samples (1 g vs. 5 g) were observed to be less representative (Fig. 2).

Permanganate oxidizable C is also sensitive to duration of settling, as the relative effect of increasing duration of settling from 10 to 30 min was greater when duration of shaking was 2 min as compared to 15 min (data not shown).



Analytical accuracy.

Assessing the accuracy of a method that measures a compositionally diverse pool of electron donors (assumed to be C compounds) by quantifying abundance of the electron recipient (permanaganate) is problematic.

The Weil et al. (2003) method's sensitivity to management and high correlation with standard biologically active C parameters indicate that it is a measure of the intended analyte (i.e. a management sensitive biologically active soil C pool) but the method's range of linearity has not been established.

One option for evaluating linearity would be to spike soils with differing amounts of a specific permanganate oxidizable C compound (e.g. simple carbohydrates, amino acids, amino and amide sugars (Weil et al. (2003)). Another option would be to use different masses of the same soil. We chose the latter option and observed an asymptotic relationship between soil mass and permanganate reduction (Fig. 3 and 4). Soil masses of the high and low C standard soils, ranging from 0.25 to 9 g, were analyzed for POC. Permanganate oxidizable C values were greatest when permanganate availability was high and decreased asymptotically as permanganate availability decreased.

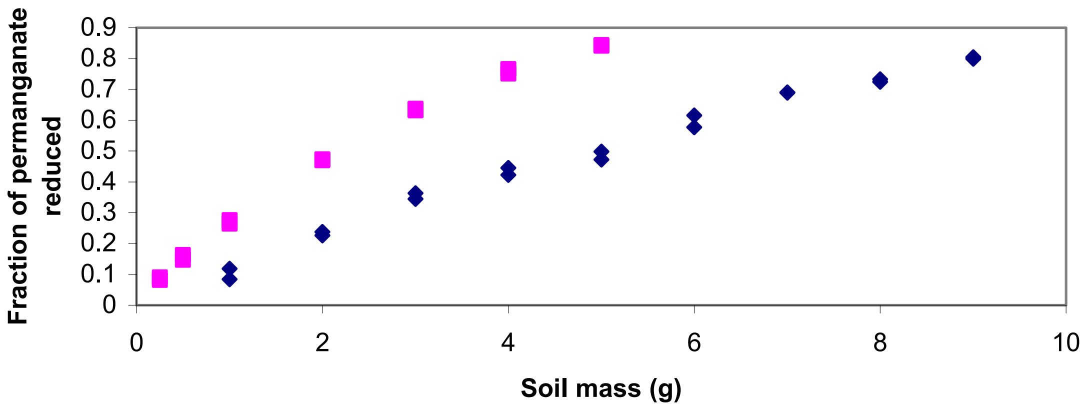


Figure 3. Relationship between soil mass and fraction of permanganate reduced for a high and low C soil

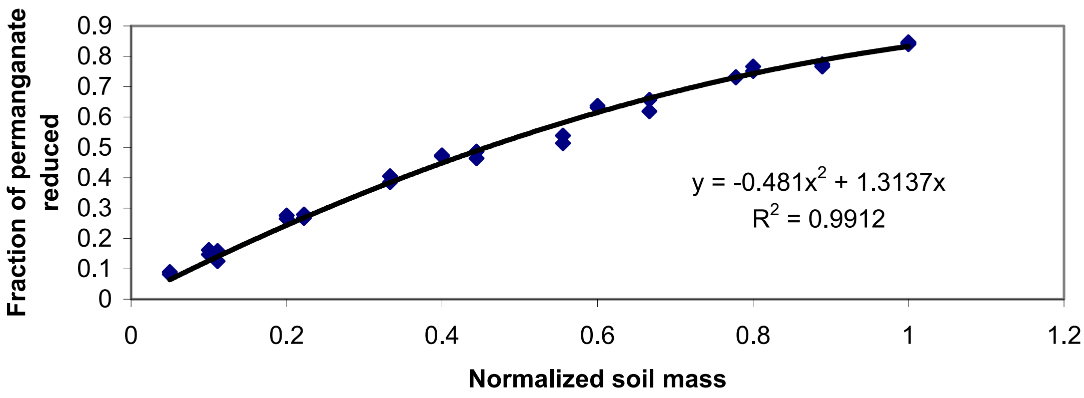


Figure 4. Relationship between fraction of permanganate reduced and normalized soil mass

The excellent fit obtained with the combination of the high and low C soil data sets (Fig. 4) indicates that permanganate availability rather than soil:solution ratio controls reaction efficiency.

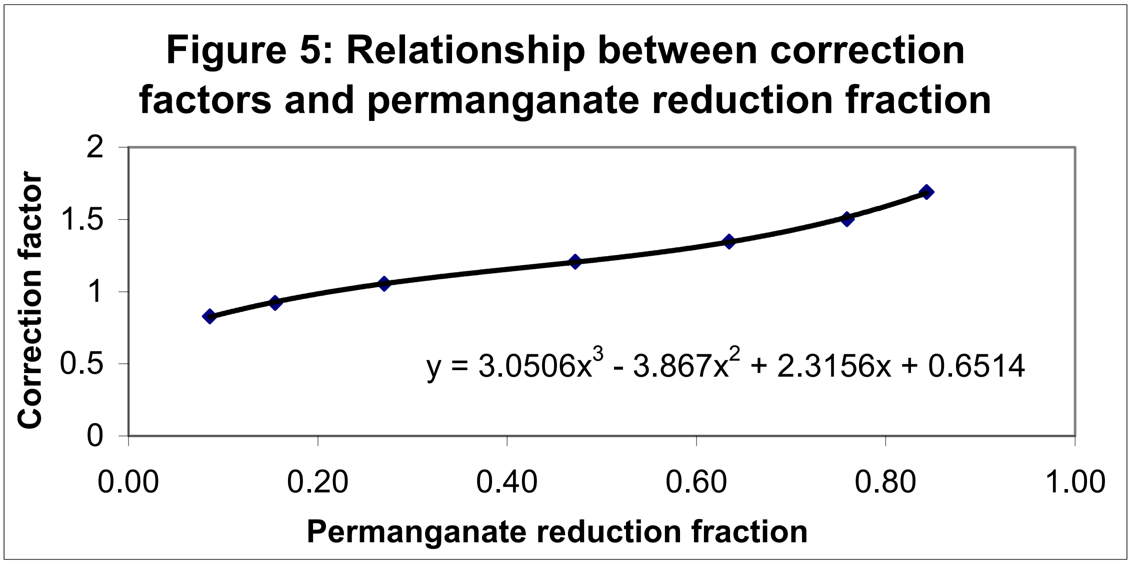
Table 4. Corrected POC results for the high C standard soil.

Soil Mass (g)	Percent MnO_4^- Reduction	Equation 1 g POC / kg soil	Correction factor	Corrected g POC / kg soil
0.25	8.6	1.237	0.824	1.019
0.5	15.5	1.115	0.928	1.035
1.0	27.0	0.973	1.055	1.026
2.0	47.2	0.849	1.203	1.022
3.0	63.4	0.761	1.343	1.022
4.0	75.9	0.683	1.515	1.035
5.0	84.3	0.607	1.683	1.021

The corrected POC values presented in Table 4 were derived as follows:

The linear component of the second order polynomial presented in Fig. 4 was chosen to define the correct permanganate reduction fraction. Consequently, the product of the correction factor and the measured permanganate reduction fractions equaled the chosen linear model.

A third order polynomial was fit to the relationship between correction factors and measured permanganate reduction fractions (Fig. 5):



This third order polynomial was used to generate the correction factors presented in Table 4. Permanganate oxidizable C values calculated using Equation 1 were then corrected by the respective correction factors. The correction technique was evaluated using results from a soil under long-term sod at the UPRS (Table 5).

Table 5. Validation of correction model.

Soil Mass (g)	Percent MnO_4^- Reduction	Equation 1 g POC / kg soil	Correction factor	Corrected g POC / kg soil
0.5	15.6	1.12	0.930	1.04
1.0	28.3	1.01	1.066	1.07
2.0	48.4	0.87	1.211	1.05
3.0	68.7	0.82	1.406	1.15
4.0	82.5	0.74	1.642	1.21

The corrected values were more consistent than those calculated using Equation 1, but there was a small over-correction for the greater masses of soil.

The application of a correction factor (to account for lower reaction efficiency when greater amounts of C are oxidized) would be expected to increase the sensitivity of POC to management-induced differences. Increased sensitivity was observed when the correction factor was applied to data from the long-term tillage system experiment at the UPRS (data not shown).

Proposed quality control protocols.

We have found that adherence to the following quality control protocols reduces experimental error when performing the Weil et al. (2003) method.

1. Always use clean, dry centrifuge tubes. Contamination with dust will result in the reduction of permanganate. Periodically rinse centrifuge tubes and glassware (including cuvettes) with dilute ascorbic acid to remove manganese dioxide precipitate. Rinse tubes and glassware thoroughly to remove all residual ascorbic acid.

2. Include standard soils at the beginning and end of each analytical batch. Standard soils should be selected that are representative of the range of POC that is likely to be found in unknown soils. Standard soils should be pulverized so that they will pass through a sieve with 0.5-mm (or smaller) openings.

3. Replicates of unknown samples should be analyzed in separate analytical batches. It is of some value to include replicates in the same batch but this type of replication is not appropriate for determining true experimental error.

4. Standardize each batch of permanganate reagent by titration of a known mass of sodium oxalate ($Na_2C_2O_4$) - See Appendix A. Standardize reagent again if absorbance values for the standard curve change.

5. Include four or more standards for a standard curve in each analytical batch.

6. Standards can be prepared by adding 0, 0.5, .0, 1.5 and 2.0 ml of permanganate reagent to centrifuge tubes using a high quality electronic pipette and then dispensing an 18.0-ml aliquot of DI water into each tube. Cap and shake tubes as part of a 25-tube analytical batch. The concentrations will be: 0, 0.00541, 0.001053, 0.01538 and 0.02 M. We routinely obtain R-squared values greater than 0.999.

7. Dilute aliquots of supernatant so that absorbance readings have maximum resolution. Appropriate dilution factors will depend on the spectrophotometer. We have had good success diluting 10 to20 fold.

8. Maintain consistent procedural timing (i.e. durations of pre-shake, shaking and settling)

9. Analysis of small sample masses (< 5 g) requires a proportionately greater level of sample homogenization to obtain representative sampling.

CONCLUSIONS

We concur with Weil et al. (2003) that the pool of soil C oxidized during 2 min of shaking in 0.02 M permanganate is a sensitive indicator of management effects on soil quality.

The method's short duration of reaction (pre-shake + shake + settling) is more sensitive to variation in procedural timing than when longer durations of reaction are used, but analytical precision (CV < 5%) can be achieved if the quality control protocols listed above are followed.

Our biggest concern about the Weil et al. (2003) method is its apparent non-linearity. Results from three soils differing in taxonomy and C content (Fig. 3 and 4, Tables 4 and 5) showed similar asymptotic loss of reaction efficiency over the method's entire range of reaction. This non-linearity may be inconsequential for some routine applications (e.g. use of POC as a general indicator of soil quality or response to improved OM management) but correction seems desirable for research applications. We have proposed a correction technique and recommend this technique rather than the specific third order polynomial (Fig. 5) that was derived from a limited number of soils.

Additional research is needed to confirm that asymptotic loss of reaction efficiency is a general attribute of the Weil et al. (2003) method. We plan to investigate this phenomena using a much broader set of soils using both the multiple mass and the matrix spike approach previously described. We also plan to investigate the sensitivity of the method to variation in solution pH.

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Appendix A

Modified from **http://onsager.bd.psu.edu/aronne/labsynfes033.pdf**

Standardizing a permanganate solution with a known mass of sodium oxalate ($Na_2C_2O_4$). The titration reaction is:

$$5\ C_2O_4^{2-}(aq) + 2\ MnO_4^{-}(aq) + 16\ H^{+}(aq) \rightarrow 10\ CO_2(g) + 2\ Mn^{2+}(aq) + 8\ H_2O\ (l)$$

1. Weigh approximately 0.1200 g of sodium oxalate and transfer to a 250 mL Erlenmeyer flask. Add 10 mL of 6 M H_2SO_4 and 65 ml of DI water to the flask.
2. Fill a clean buret with the $KMnO_4$ solution to be standardized. Note that the solution is a very dark purple color so volume readings should be taken from the top edge of the liquid instead of the bottom of the meniscus.
3. Heat the sodium oxalate solution to 80-90 ^{o}C. When you remove the thermometer to perform the titration, be sure to rinse the thermometer into the flask since you do not want to lose any of the sodium oxalate.

4. Record the initial reading on the buret, to the nearest 0.01 mL and begin to add the $KMnO_4$ solution to the flask but do not add too rapidly and be sure to swirl the solution. You should observe that the purple solution loses its colour as it falls into the hot solution.
5. If you add the $KMnO_4$ solution too rapidly, or do not swirl well, you may find you have some brown colouration in your solution. This is due to the formation of manganese dioxide (MnO_2). If you have not added any more $KMnO_4$ than needed to reach the endpoint, the excess oxalate should reduce the MnO_2 momentarily. However, if you fail to swirl the sample and overshoot the endpoint while MnO_2 is formed, the titration is ruined and must be performed again.
6. You should start to notice that as you are nearing the endpoint of your titration that the decolouration of the $KMnO_4$ takes longer and longer. At this time you should add the $KMnO_4$ more slowly, preferably drop by drop. When you have reached the endpoint, there will be a faint colour that persists in the solution
7. It is useful to run a blank for this titration since the sulphuric acid solution may contain some impurities that react with the potassium permanganate and introduce error. Add 10 mL of 6 M H_2SO_4 and 65 mL of DI water to an Erlenmeyer flask and heat it to 80-90 ^{o}C. Titrate until you have a persistent faint pink colouration.
8. Subtract this volume from the volume of $KMnO_4$ used in the titration of the sodium oxalate sample.
9. Molarity of permanganate solution = g of sodium oxalate *2.98507 / mls of permanganate to reach endpoint.

SITE-SPECIFIC SUBSOILING: BENEFITS FOR COASTAL PLAIN SOILS

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ABSTRACT

The negative impacts of soil compaction on crop yields can often be alleviated by subsoiling. However, this subsoiling operation is often conducted at unnecessarily deep depths where it wastes energy and disturbs surface residue necessary for erosion control and soil quality. A corn (*Zea mays* L.)-cotton (*Gossypium hirsutum* L.) rotation experiment was conducted for four years on a Coastal Plain soil with a hardpan in east-central Alabama to evaluate the potential for site-specific subsoiling (tilling just deep enough to eliminate the hardpan layer) to improve crop yields and conserve energy. Both crops showed benefits of subsoiling as compared to the no-subsoiling treatment. Site-specific subsoiling produced yields equivalent to deep subsoiling treatment while not excessively disturbing surface soil and residues.

INTRODUCTION

The depth and degree of soil compaction has been found to vary greatly throughout Southern U.S. fields. Subsoiling at a uniform depth has been found to be particularly effective in reducing the effect of compaction on crop yields (Campbell *et al.*, 1974). However, subsoiling at a depth deeper than necessary wastes subsoiling energy and unnecessarily disturbs excessive amounts of soil and crop residue. Also, subsoiling at a depth shallower than necessary wastes subsoiling energy without eliminating the compacted soil condition.

Adjusting the depth of subsoiling to match the hardpan depth throughout a field, i.e., site-specific subsoiling, was investigated as a potential method for soil compaction management. Measurements of the hardpan depth taken in the Southeastern U.S. indicate that between 25 and 75% of subsoiling energy could be saved if some form of site-specific subsoiling could be developed and used (Fulton *et al.*, 1996; Raper, 1999). Also, some data indicate that subsoiling deeper than necessary may reduce yields (Raper *et al.*, 2000). Therefore, this study was initiated to evaluate whether the concept of site-specific subsoiling was viable.

METHODS AND MATERIALS

A 20-ac field from the Alabama Agricultural Experiment Station's E.V. Smith Research and Education Center in east-central Alabama, USA was used for this experiment. The coastal plain field was comprised of a Toccoa fine sandy loam (coarse-loamy, mixed, active, nonacid, thermic Typic Udifluvents) that had excessive soil strength and required annual subsoiling. A complete set of soil cone penetrometer measurements (ASAE, 1999a; ASAE, 1999b) were obtained with the Multiple-Probe Soil Measurement System (Raper *et al.*, 1999) on an approximate 300-ft grid. Cone index measurements were analyzed to determine depth to the hardpan over the entire field.

The depth of the hardpan that was responsible for restricting root growth was found to range from 6-18 in. over the entire field. This range in depth of compaction was split into three distinct hardpan depth ranges of 6-10 in, 10-14 in, and 14-18 in, with four replications within the field. Three subsoiling treatments were imposed across each of the hardpan depth ranges in the spring of 2000, 2001, 2002, and 2003:

1. no-subsoiling (zero-depth subsoiling)
2. site-specific subsoiling (10-in, 14-in, or 18-in depth subsoiling)
3. deep subsoiling (18-in depth subsoiling)

As an example, for the plots with the shallowest hardpan (the 6-10 in hardpan depth), a 10-in subsoiling depth was selected for the site-specific subsoiling depth. Therefore, three subsoiling treatments were applied in these shallow hardpan areas; (1) no-subsoiling, (2) site-specific subsoiling (with a depth of 10 in), and (3) deep subsoiling. A John Deere (JD) 955 Row Crop Ripper equipped with 2.75-in wide LASERRIP™ Ripper Points was used for all subsoiling operations (Mention of trade names or commercial products in this article does not imply recommendation by USDA or Auburn University.) This subsoiler was supplied as part of a Cooperative Research and Development Agreement with Deere & Co (Moline, IL). Modifications were made to this implement to allow for a subsoiling depth of 10-18 in and to incorporate heavy residue handling attachments supplied by Yetter (Colchester, IL). This subsoiler was manually adjusted for each subsoiling depth by moving the coulters and the residue handling attachments. All subsoiling treatments were conducted as part of a conservation tillage system with limited tillage. The only field operations consisted of rolling the cover crop down, subsoiling, planting, harvesting, intermittent herbicide application as necessary, harvesting, and cover crop seeding.

The field was split (Field 1 and Field 2) to allow for a corn-cotton rotation. Cotton was planted in 40-in rows with 4-row equipment while corn was planted in 30-in rows with 6-row equipment. Plot size was either 4 rows x 100 ft for cotton or 6 rows x 100 ft for corn. Half of each plot was seeded to a cover crop and the other half was left bare. Prior to planting cotton, the cover crop was rye (*Secale cereale* L.). Prior to planting corn, the cover crop was crimson clover (*Trifolium incarnatum* L.).

An Agleader Technology, Inc. (Ames, IA) yield monitor was used to obtain corn yields. Yield data obtained from the middle 4-row section for each plot were averaged to determine a mean value for each plot. A cotton yield monitor from Agriplan (Stow, MA) was used to obtain cotton yield data for each of the plots. Yield data obtained from the middle 2-row section of each plot were averaged to determine a mean value for each plot.

A split plot arrangement of treatments with four replications was imposed in three field locations for each of the three hardpan depths, 6-10 in, 10-14 in, and 14-18 in. Main plots were cover crop and subplots were subsoiling treatments. Data were analyzed with an appropriate ANOVA model using SAS (Cary, NC). A significance level of $P \leq 0.1$ was chosen to separate treatment effects.

RESULTS AND DISCUSSION

Discussions will be limited to main and two-way treatment effects, although some slight three-way interactions were noted.

Corn Yield

Corn yield averaged across replications, depth of hardpan, and cover crop for years 2000-2003 showed yields varied significantly from 94 bu/ac in 2000 and 2003 to 124 bu/ac in 2002 (Figure 1;

P≤0.03). An interaction occurred between cover crop and depth of hardpan for corn yield (Figure 2; *P≤0.08*). In both the shallow (10-in) and deep (18-in) hardpan depth plots, the effect of the cover crop was to slightly decrease corn yields while in the 14-in hardpan depth plots, the cover crop caused slightly increased corn yields.

Subsoiling treatment was found to have a significant effect on corn yield (Figure 3; *P≤0.01*). Deep (18-in) subsoiling resulted in the highest yields (116 bu/ac) although yields were similar to site-specific subsoiling yields (110 bu/ac). Both deep and site-specific subsoiling resulted in greater yields than the no-subsoiling treatment (92 bu/ac). An interaction also occurred between the depth of hardpan and subsoiling treatment (Figure 4; *P≤0.02*) with reduced yields for each of the three subsoiling treatments in the deep (18-in) hardpan depth plots. A general trend seemed to exist where no-subsoiling yielded the least in all three hardpan depth plots. Another trend that all plots exhibited was that site-specific subsoiling yielded similar to deep subsoiling.

Cotton Yield

Seed cotton yield averaged across replications, depth of hardpan, and cover crop for years 2000-2003 showed yields varied significantly from 1776 lb/ac in 2002 to 2248 lb/ac in 2003 (Figure 5; *P≤0.01*). A year by cover crop interaction existed for cotton yield, with cover crops contributing to higher yields in only the first year of the experiment, 2000 (Figure 6; *P≤0.01*).

Subsoiling treatment was also found to have a significant effect on seed cotton yield (Figure 7; *P≤0.01*). Site-specific subsoiling (2030 lb/ac) and deep subsoiling (2151 lb/ac) both resulted in yields which were greater than no-subsoiling (1838 lb/ac), due to yield-limiting soil compaction inherent in this coastal plain soil.

A year by subsoiling treatment interaction also occurred (Figure 8; *P≤0.01*) with the 2000 season resulting in an anomaly; higher yields resulted for the no-subsoiling treatment than for the other two subsoiling treatments in 2000. In each succeeding year, highest yields were found with deep subsoiling (18-in) and site-specific subsoiling compared to the no-subsoiling treatment. A greatly reduced amount of rainfall occurred during the critical period for cotton production from mid-June to mid-July of 2000. Increased evaporation was probably present with the subsoiling treatments, thereby reducing yields from all plots except the no-subsoiling treatments.

Another interaction was found between the depth of hardpan and subsoiling treatment (Figure 9; *P≤0.04*). Similar trends were found for cotton yields and corn yields with slightly reduced yields being found for the deep hardpan (18-in) depths. Within this field, the overall productivity of soils with shallower hardpans tends to be greater than those containing deep hardpans. This is evidenced by noting that the yields from the no-subsoiling treatments declined as depth of hardpan increased.

CONCLUSIONS

1. Site-specific subsoiling produced corn and seed cotton yields similar to those produced by uniform deep subsoiling which were both greater than no-subsoiling treatment yields.
2. A trend existed that suggested cover crops contributed to slightly decreased corn and cotton yields for this soil type.
3. The depth to the hardpan was found to interact with subsoiling treatment. At the shallow hardpan depth, subsoiling didn't increase yields substantially over the no-subsoiling treatment. At the two deeper hardpan depths, subsoiling tended to produce a greater benefit.

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Figure 1. Corn yield averaged over replications, depth of hardpan, subsoiling treatments, and cover crop for years 2000-2003.

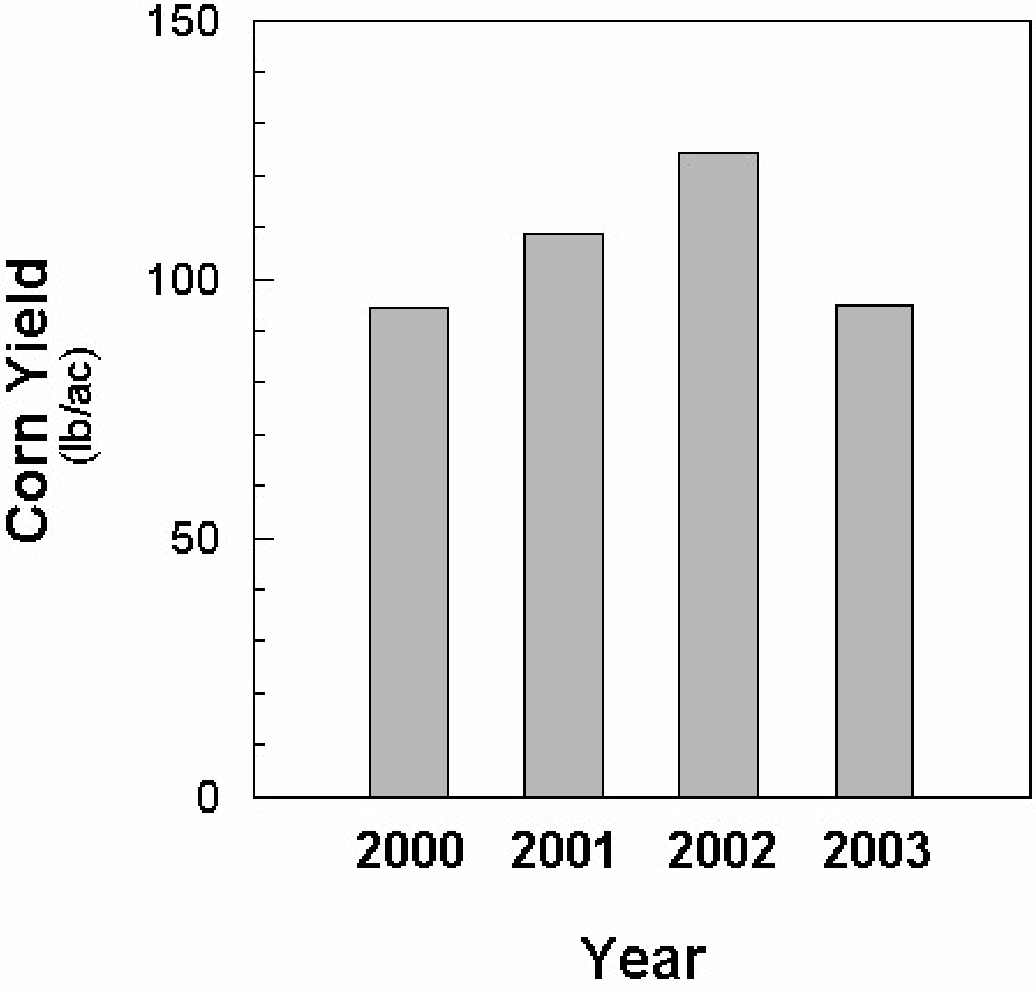


Figure 2. Corn yield averaged over replications, years, and subsoiling treatments showing the effect of cover crops in the three different hardpan depth zones.

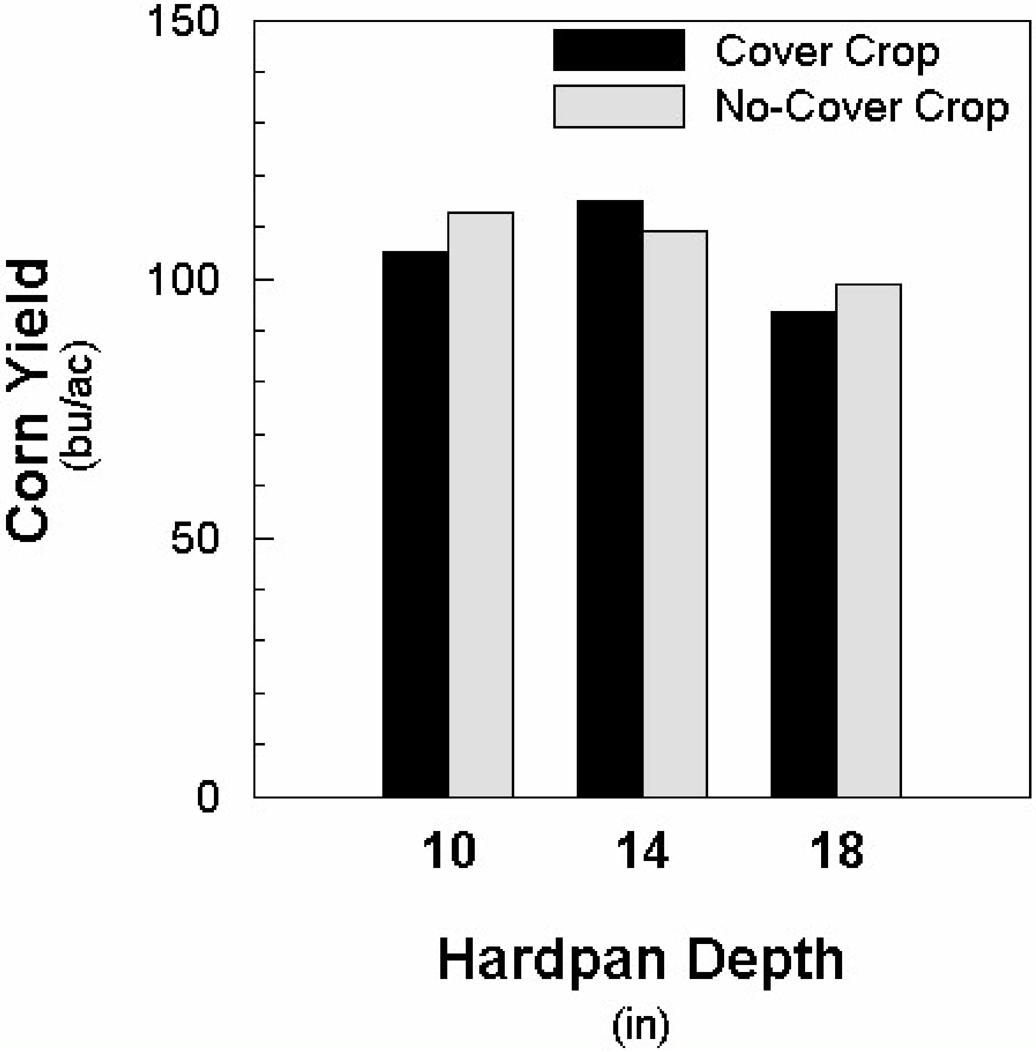


Figure 3. Corn yield averaged over replications, years, depth of hardpan, and cover crops showing the effect of the three different subsoiling treatments.

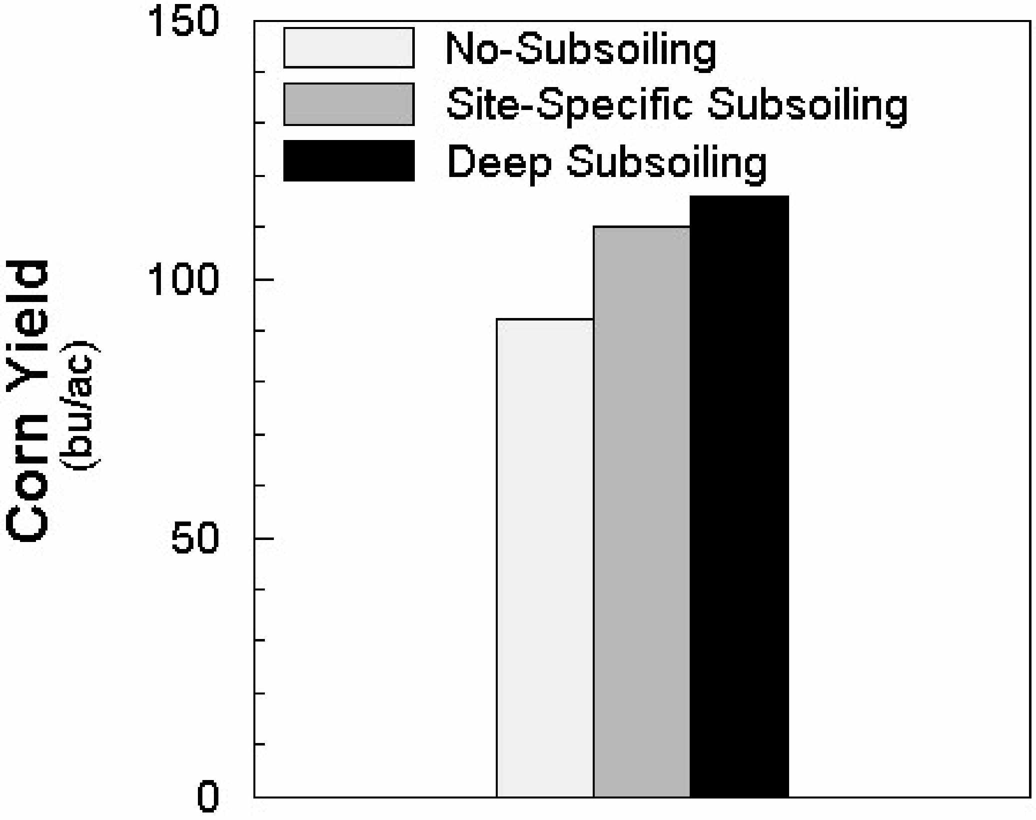


Figure 4. Corn yield averaged over replications, years, and cover crops showing the effect of the three subsoiling treatments in the three different hardpan depth zones.

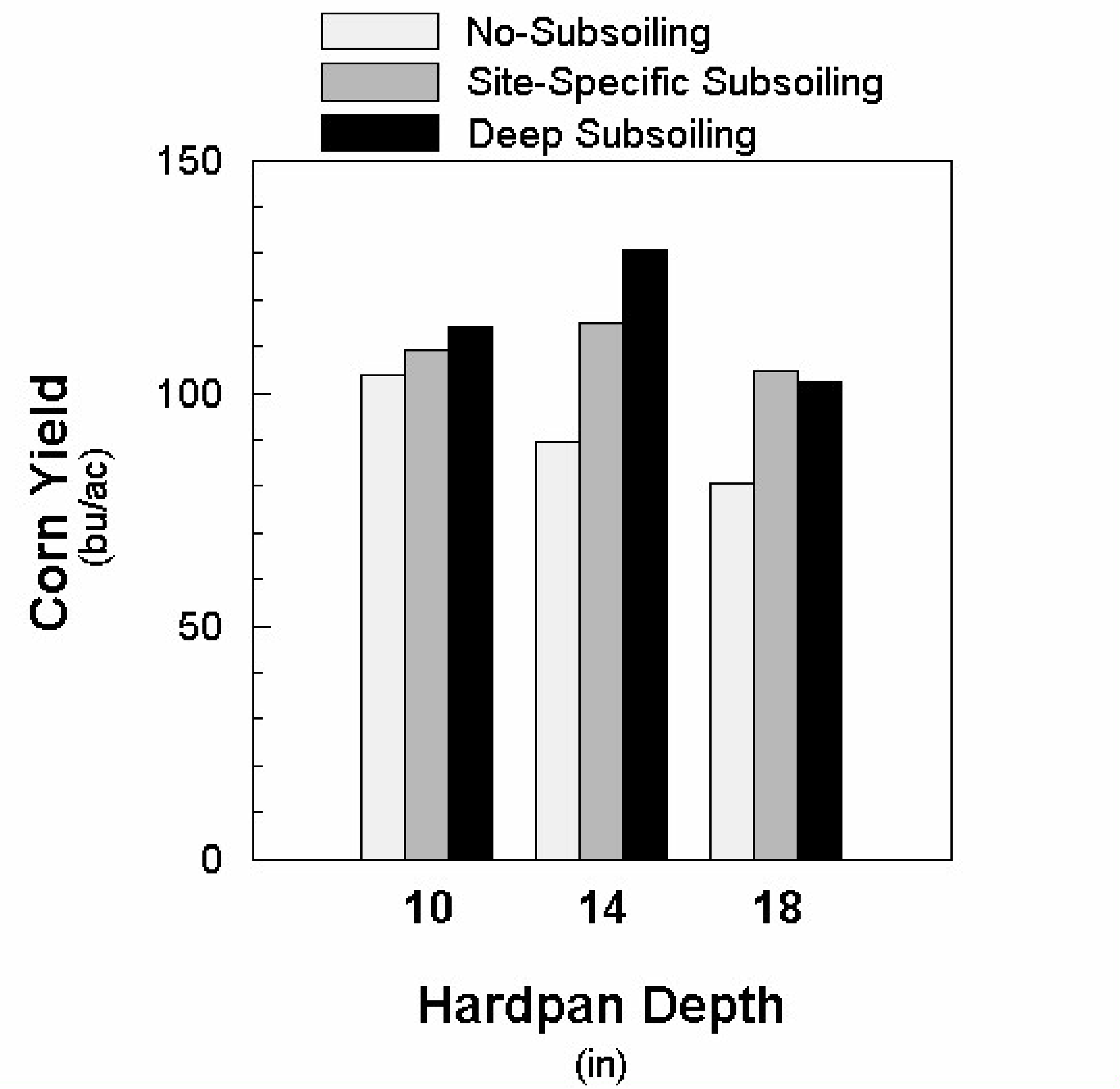


Figure 5. Cotton yield averaged over replications, depth of hardpan, subsoiling treatments, and cover crop for years 2000-2003.

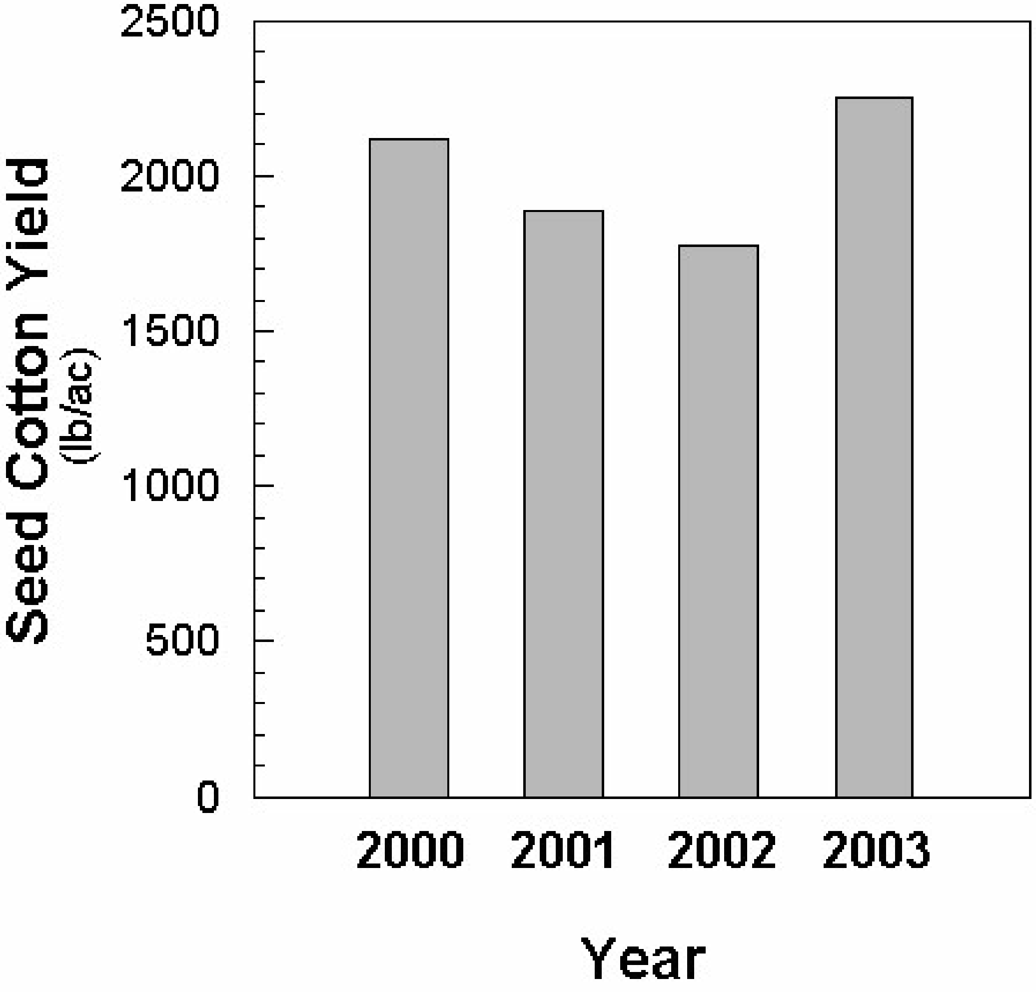


Figure 6. Cotton yield averaged over replications, subsoiling treatments, and hardpan depth zones showing effect of cover crops across years.

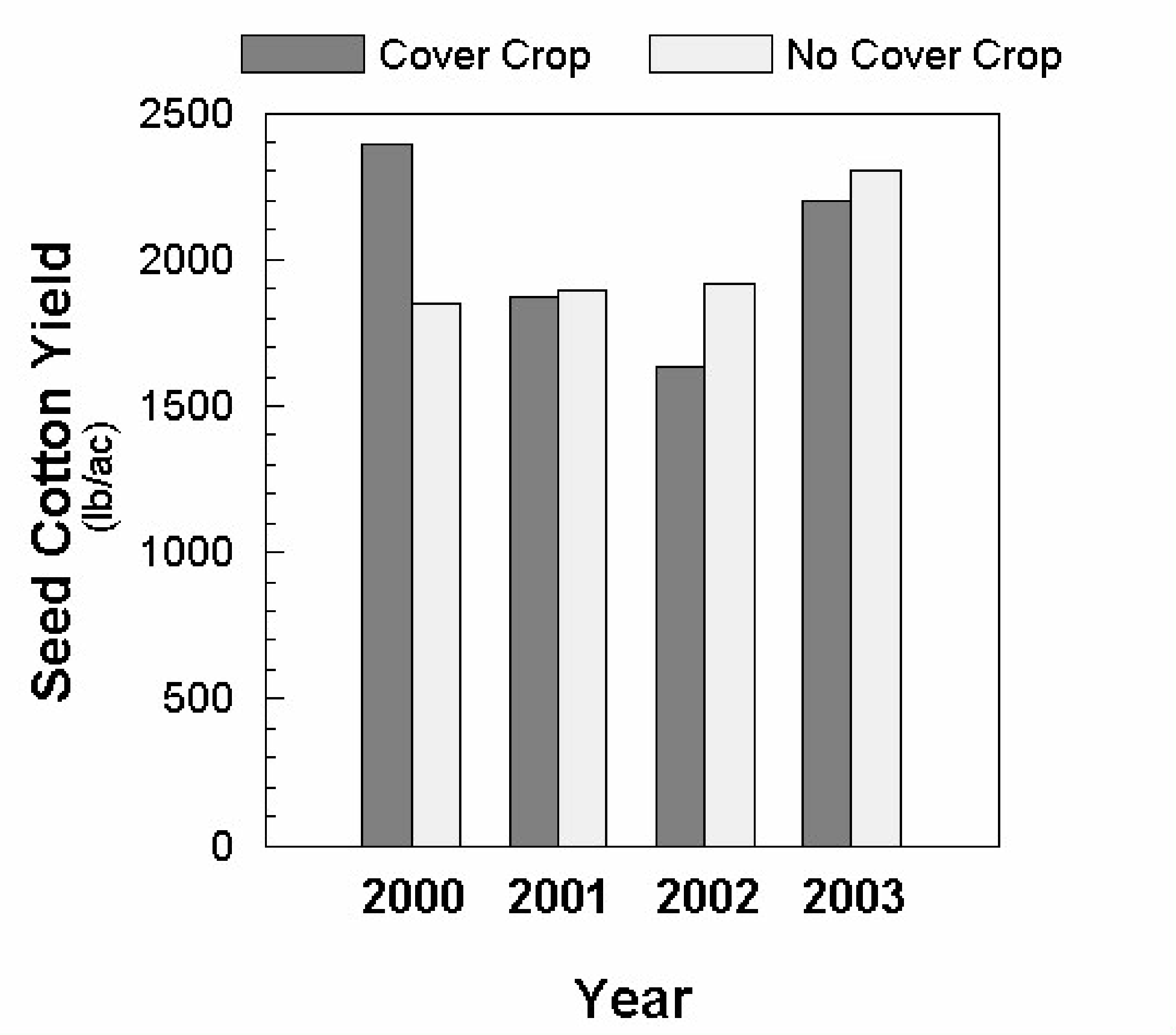


Figure 7. Cotton yield averaged over replications, years, depth of hardpan, and cover crops showing the effect of the three different subsoiling treatments.

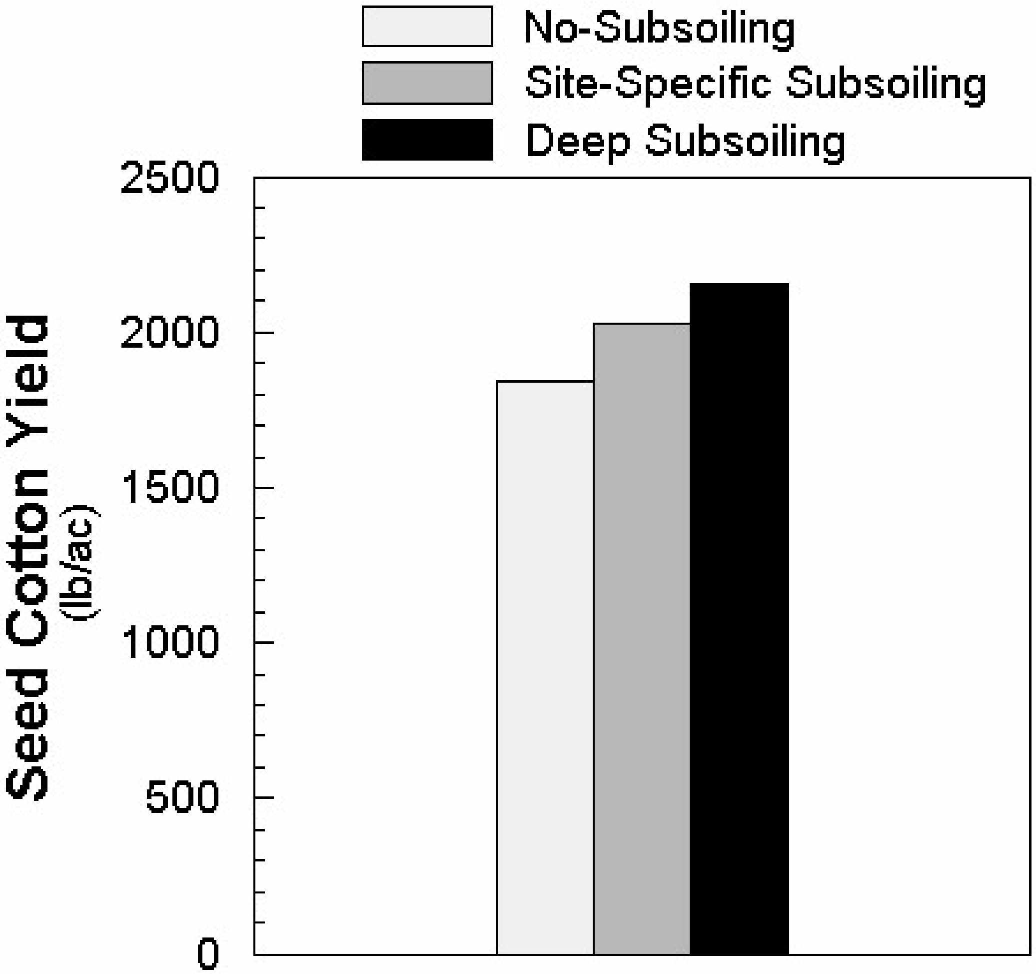


Figure 8. Cotton yield averaged over replications, and cover crops showing the effect of the three subsoiling treatments in the three different hardpan depth zones.

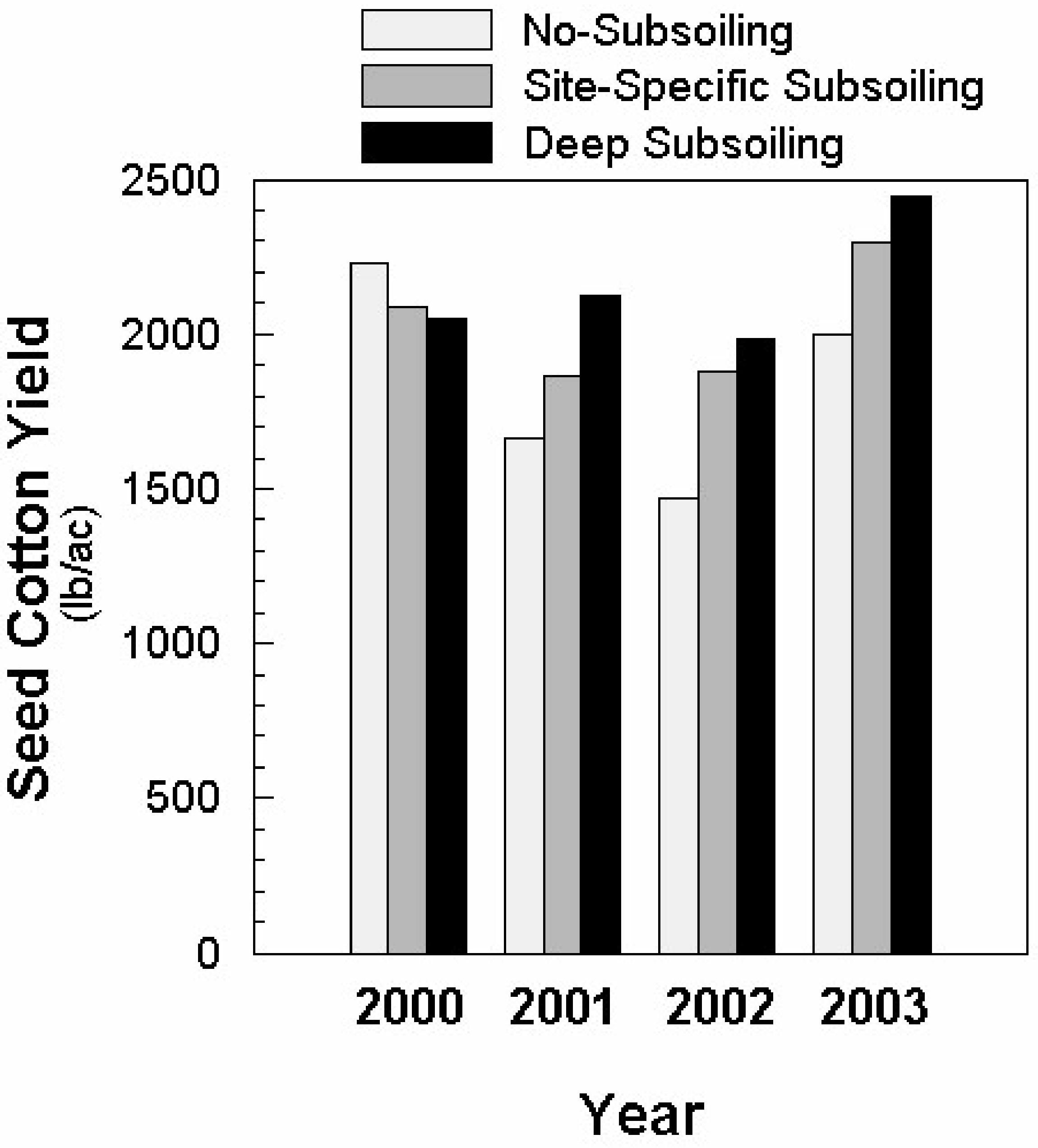
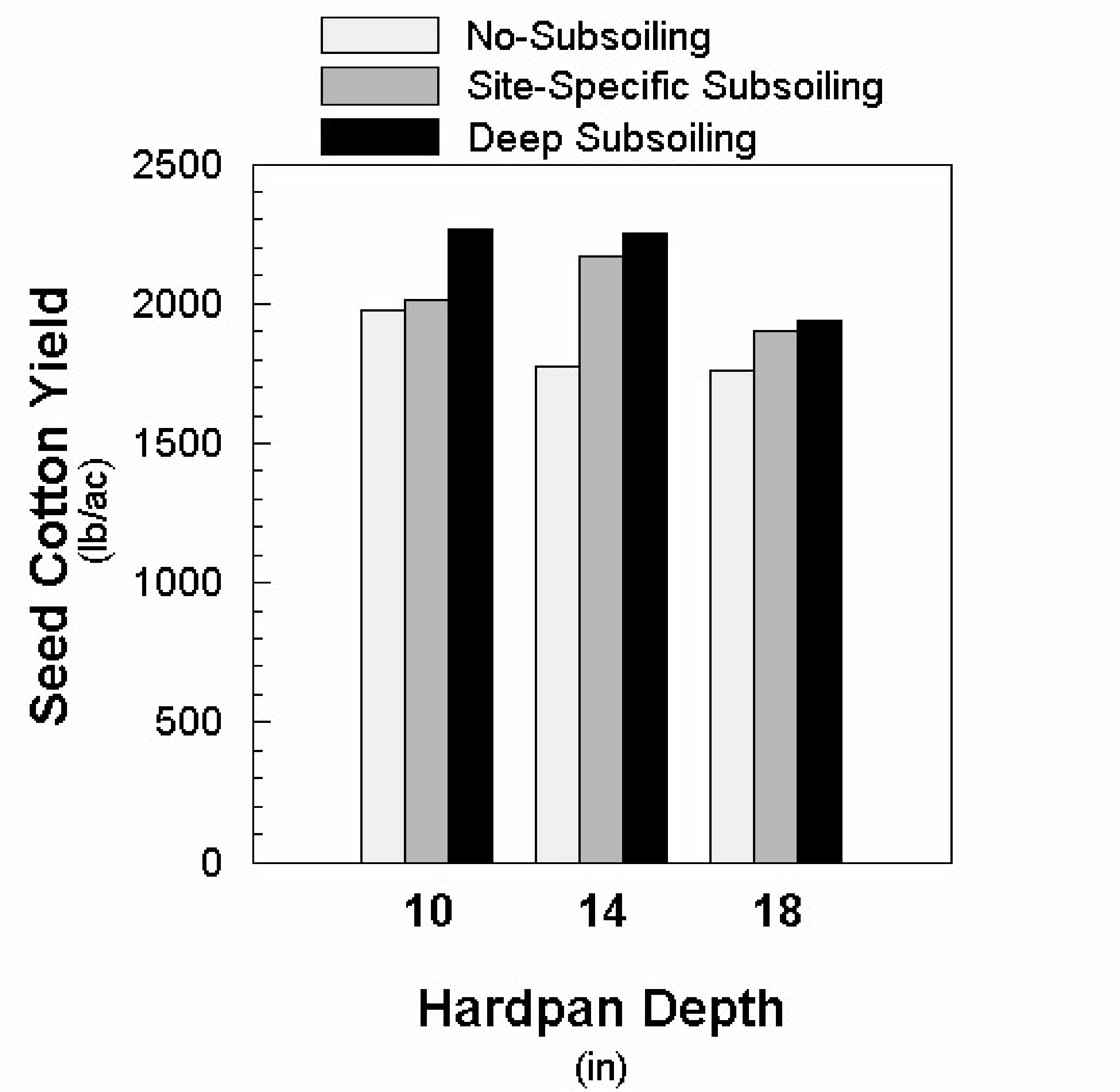


Figure 9. Cotton yield averaged over replications, years, and cover crops showing the effect of the three subsoiling treatments in the three different hardpan depth zones.



ALLEVIATION OF COMPACTION IN A MICROIRRIGATED COASTAL SOIL

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ABSTRACT

Compaction became so severe in a microirrigated loamy sand Aquic Hapludult soil that root limiting values of soil cone index occurred in both the A horizon and the genetic hardpan below it. Surface and deep tillage systems were evaluated for their ability to alleviate compaction. Surface tillage included disking, chiseling plus disking, or none; deep tillage included subsoiling or none. Chiseling and subsoiling were located in row or between rows to avoid laterals that were buried under every other mid-row or every row. Cotton (*Gossypium hirsutum*) was planted in 38-in wide rows. Irrigation improved yield because both 2001 and 2002 were dry years. Tillage tools loosened the soil but compacted zones remained between subsoiled and chiseled areas. Subsoiling improved yield when it was performed in row where laterals were placed in the mid rows; but it did not improve yield when it was performed in mid rows where laterals were placed in the rows. Under this management system, it was just as productive and less expensive to install laterals in every other mid row than every row.

INTRODUCTION

In the southeastern Coastal Plains, three factors combine to cause severe water stress and limit yield: sandy soils with low water holding capacity, short periods of drought, and shallow subsurface hard, structureless root-restricting layers. The shallow subsurface hard layer can restrict roots to the surface Ap horizon (Busscher *et al.,* 1986). Sandy soil above the layer may hold only 1 in of water per foot. At peak bloom, cotton can use up to 0.4 in per day. Crops that are not able to root into the subsoil often do not have enough water to sustain plant growth for the frequent 5 to 20 day droughts that occur seasonally (Sadler and Camp, 1986).

Producers commonly increase access to the soil water supply for plants by subsoiling. Subsoiling loosens the soil down to horizons that have structure and a greater water holding capacity, both of which can encourage root growth. However, subsoiling is expensive because it requires large tractors (18-27 hp per deep tillage shank), 2 to 3 gal of fuel per acre, and 10 to 20 minutes of labor per acre (Karlen *et al.* 1991). Less expensive and more permanent, alternative solutions are desirable.

Irrigation from buried microirrigation laterals have been studied for a number of crops in the southeastern Coastal Plains (Camp *et al*., 1998). However, soils above the laterals have consolidated into hard soils when no tillage was used, probably as a result of settling and traffic when laterals remain buried for several years (Camp *et al.,* 1999).

We hypothesized that disruption of the soil by subsoiling between buried microirrigation tubes or disking above the tubes would loosen soil and permit better root growth and increase yield.

MATERIALS AND METHODS

This study was conducted in 2001 and 2002 on Eunola sandy loam (fine-loamy siliceous, thermic Aeric Hapludult) at the Pee Dee Research Center near Florence, SC. The experimental design was randomized complete block of sixteen 25 by 50 ft plots in each of four replicates. Twelve of the sixteen plots were irrigated with buried microirrigation laterals (Geoflow Rootguard[1]). Laterals had in-line labyrinth emitters 2 ft apart that delivered 0.45 gal hr^{-1} of water. Six plots had laterals buried under each of eight rows at 38-in spacings (IR). Six plots had laterals buried under alternate mid rows at 76-in spacings (MR). Laterals were buried at one-foot depths. Four plots had no irrigation.

Treatments imposed on each plot were subsoiling to a depth of about 1 ft and not subsoiling. Irrigated subsoiled and not-subsoiled treatments were also disked to a depth of about 6 in, chiseled to a depth of 8 in, or not tilled. Non-irrigated subsoiled and not-subsoiled treatments were also chiseled or not tilled. Non-irrigated treatments were not disked. The experiment had been set up in 1991 with a set number of plots and could not be modified.

The recommended practice for this soil includes in-row subsoiling each year. Because of the buried laterals, in-row subsoiling was not feasible in all plots. In 1991, prior to installation of the laterals, all plots had been cross-subsoiled in the direction of the rows and perpendicular to the rows (Camp *et al.,* 1999). In 2001 and 2002, plots with laterals buried below each row were subsoiled in the mid-rows and plots with laterals buried in every other mid-row were subsoiled in every row.

The tillage equipment included: a 15-ft wide John Deere disk (Deere Inc., Moline, IL, USA) in 2001 or Case-IH disk (Case-IH, Racine, WI, USA) in 2002; a KMC (Kelley Manufacturing Co., Tifton, GA, USA) straight 45 degree forward angled subsoiler; and a 7-ft wide seven shank chisel.

Plots were planted to cotton (var DP 458BRR) in summer and flax (*Linum usitatissium* var Laura) in winter. Cotton was planted in 38-in wide rows at 4 plants per foot on 4 June 2001 and 15 May 2002 using a four-row Case-IH 900 series planter equipped with Yetter wavy coulters. Flax was drilled as a winter cover at 100 lbs a^{-1} using a John Deere 750 no-till grain drill. Flax fiber was removed from the plots.

Soil strength measurements were taken in the cotton plots after tillage. Because of the buried irrigation laterals, soil strength data could not be collected at positions in the row for some plots and in the mid row for others. Soil strength, cone index, data were taken with a 0.5-in-diameter cone-tipped penetrometer on 6 June 2001 and 20, 21 May 2002. Cone index data were digitized into the computer at 2-in depth intervals and log transformed before analysis according to the recommendation of Cassel and Nelson (1979).

Gravimetric soil water content samples were taken along with cone indices. They were taken at the first and fifth positions of cone index readings. Since tubes were buried at the first and fifth positions for the MR and IR treatments respectively, samples were taken at either the second or fourth positions respectively in these treatments. Water contents were measured at 4-in depth intervals to the 24-in depth. These water contents were taken as representative of the water contents of the plot.

In mid to late October, cotton was chemically defoliated. On 7 November 2001 and 28 October 2002, seed cotton yield was harvested from the two interior rows using a two-row spindle picker and bagged. Each harvest bag was subsampled; the subsample was saw-ginned to determine lint percent. Lint percentage was multiplied by seed cotton yield to calculate lint yield.

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[2] Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

Cone index, water content, and yield data were analyzed using the ANOVA and the least square mean separation procedures (SAS Institute, 1990). Cone index and water content data were analyzed using a split-split plot randomized complete block design where the first split was position across the row and the second depth. Data were tested for significance at the 5%.

RESULTS AND DISCUSSION

Soil Water Content

Differences in water contents can significantly affect cone index readings, masking strength differences in treatments. To avoid this, we took cone index measurements before irrigation began.

Soil Strength

Cone indices were analyzed separately for irrigated and non-irrigated treatments because non-irrigated did not have a disked treatment, which had been studied previously (Busscher et al., 2001). Additionally, since the non-irrigated treatment had no buried tube, the treatment lent itself to a more traditional annual-subsoiling management system over the years.

For the irrigated treatments: Since mean soil strengths for the two years (23.1 ATM in 2001 and 22.3 ATM in 2002) were not significantly different and no interactions with years were significant, data for both years were analyzed together.

Cone indices for irrigation tube placements were not significantly different because the two had the same treatments. Cone indices differed by depth and position across the row because different tillage treatments disrupted soil to different depths and at different positions across the row to avoid buried laterals. Cone indices also differed with position as a result of higher values caused by wheel traffic seen at the right side of the contour plots (e.g. positions 28 and 38 in as seen in Fig. 1).

Cone indices differed among surface tillage treatments, subsoiling treatments, and their interaction (Table 1). Cone indices were significantly reduced by subsoiling in the disked and no surface tillage treatments, but not in the chiseled treatments. Subsoiling the disked and no surface tillage treatments reduced high soil strength caused by the tillage pan or the genetic pan (Fig. 1). Cone indices of the chiseled treatments that were also subsoiled were lower than the chiseled only treatments; however, these differences were not statistically significant probably because chiseling and subsoiling were performed at the same position in each plot and at depths that differed by only 4 in. This was also observed in the non-irrigated treatments (Fig. 2).

For the non-irrigated treatments: Cone indices differed significantly by year at 24.8 MPa for 2001 and 29.0 MPa for 2002. Though cone indices differed in magnitude between years, there were no significant interactions between year and any treatment; so data for the two years were analyzed together.

Cone indices (Table 1) differed for the subsoiled treatments, the chiseled treatments, and for the interaction of the two. Cone indices were lower for treatments that were chiseled or subsoiled vs. those that were not. Chiseled treatments had a shallower, wider zone of disruption (Fig. 2) compared to subsoiling. The non-tilled treatment still had remnants of previous deep tillage (Fig. 2) that may have been enough to provide adequate root growth (Busscher et al., 2003) unlike the irrigated treatments where the laterals prevented deep tillage on a regular basis (Fig. 1).

Yield

Irrigated treatments: For the MR lateral placement, yield improved with subsoiling regardless of surface tillage; for the IR lateral placement, yield of subsoiled treatments did not differ (Table 2, Fig. 3).

Non-irrigated treatments: Rainfall affected yield; it was lower than normal (47 in y^{-1}) both years but especially low in 2002 (Fig. 4). As a result, yields were lower for non-irrigated than for irrigated treatments with irrigated cotton lint yield averaging 911 lbs a^{-1} and non-irrigated yield averaging 433 lbs a^{-1}. Yields for the non-irrigated treatments averaged 543 lbs a^{-1} for 2001 and 314 lbs a^{-1} for 2002. Non-irrigated yields were unaffected by subsoiling or chiseling. Since non-irrigated plots did not have buried tubes, the were more suited to conventional management; even the plots that were not subsoiled for this study had been subsoiled within the past 2 to 3 years for a previous experiment in these plots. The lack of difference among treatments supports the conclusions of Busscher et al. (2003) that subsoiling is not needed every year for in-row subsoiled cotton grown in conventional row widths and using controlled traffic.

CONCLUSIONS

For the non-irrigated treatments, subsoiling was not effective because even the non-subsoiled treatments had lower strengths from in-row deep tillage in previous years.

For the irrigated treatments, when micro irrigation tubes were buried under the rows, tillage decreased soil strengths in the mid rows; and when tubes were buried under every other mid row, tillage decreased strength in the rows.

When laterals were buried under mid rows, subsoiling improved yield because it softened the soil where roots have to grow to get to the water source. When laterals were buried under rows, subsoiling did not affect yield because roots did not have to grow through it to get to the water.

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Table 1. Mean profile cone indices in atmospheres for irrigated and non-irrigated treatments (treatments with and without buried laterals) averaged over years 2001 and 2002 before irrigation started.

	Irrigated			Non-irrigated		
Tillage	Subsoiled	Non-subsoiled	Mean	Subsoiled	Non-subsoiled	Mean
	---------------------------------- ATM ----------------------------------					
Chisel	19.5c*	21.5c	20.5c**	21.0c*	22.0c	21.5b**
Disk	20.4c	25.5b	22.8b	--	--	--
None	20.9c	30.8a	25.2a	27.4b	34.5a	30.8a
Mean	20.2b**	25.6a		24.0b**	28.0a	

* Means for the interaction of surface tillage with subsoiling with the same letter are not significantly different for lsd mean separation procedure at 5%.

** Means within columns or rows with the same letter are not significantly different for lsd mean separation procedure at 5%.

Table 2. Lint yield of different lateral spacings and subsoiling.

Spacing	Subsoiling	Yield
		lbs a^{-1}
Alternate mid row	Yes	967a*
Alternate mid row	No	850b
In row	Yes	881ab
In row	No	948ab

* Means within the column with the same letter are not significantly different for lsd mean separation procedure at 5%.

Figure 1. Profile cone indices for irrigated treatments averaged over both years and four replicates. Data were adjusted to center the zone of deepest tillage in the contour plots because it was performed in the row or mid-row to avoid buried irrigation tubes.

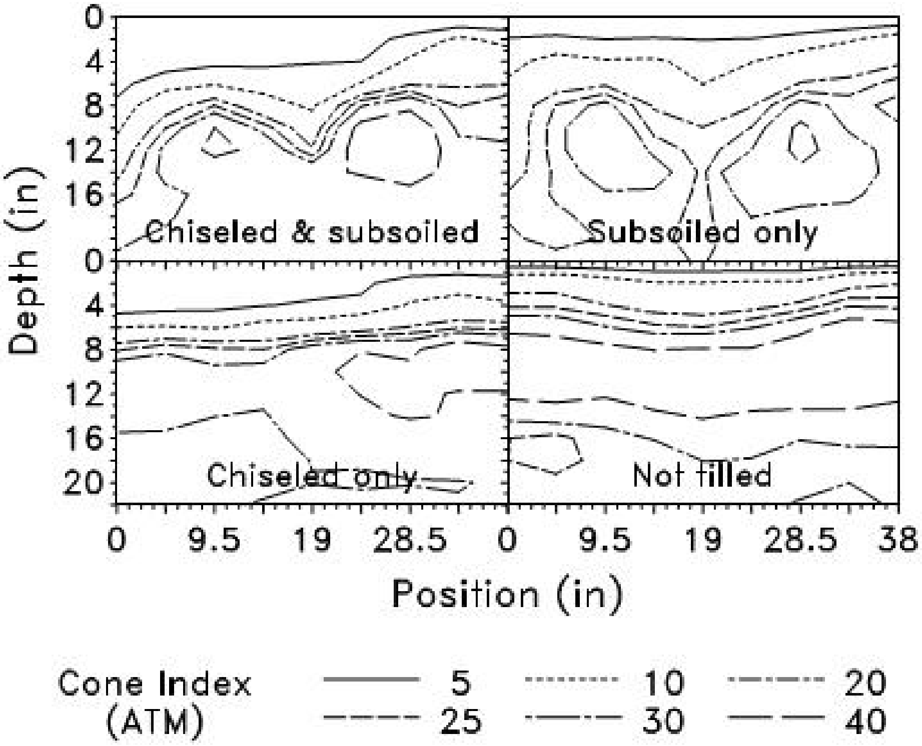


Figure 2. Profile cone indices for non-irrigated treatments averaged over both years and four replicates.

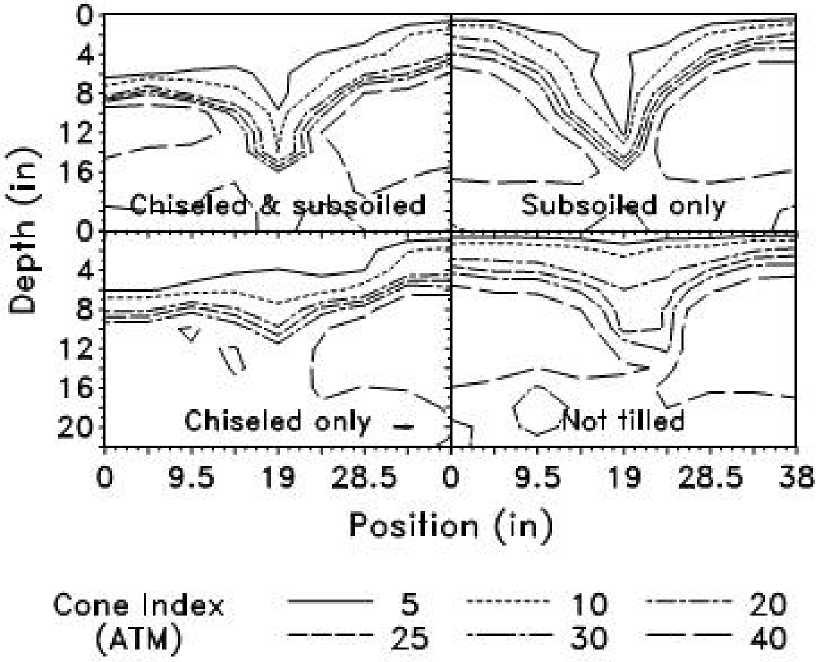


Figure 3. Profile cone indices for subsoiled or non-subsoiled treatments where laterals are placed in alternate mid rows (MR) or in every row (IR).

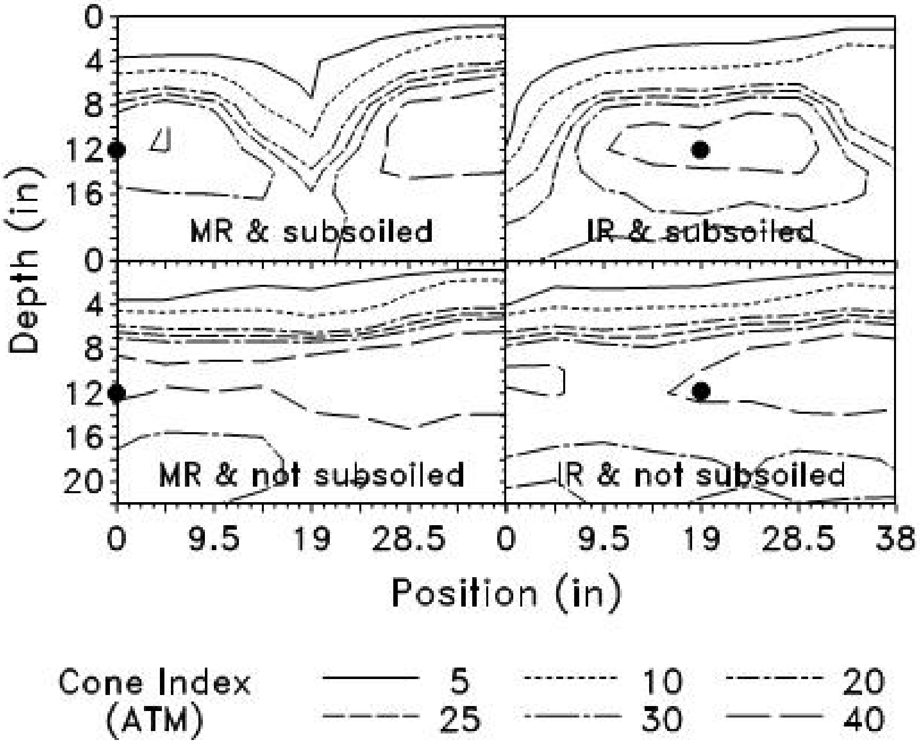
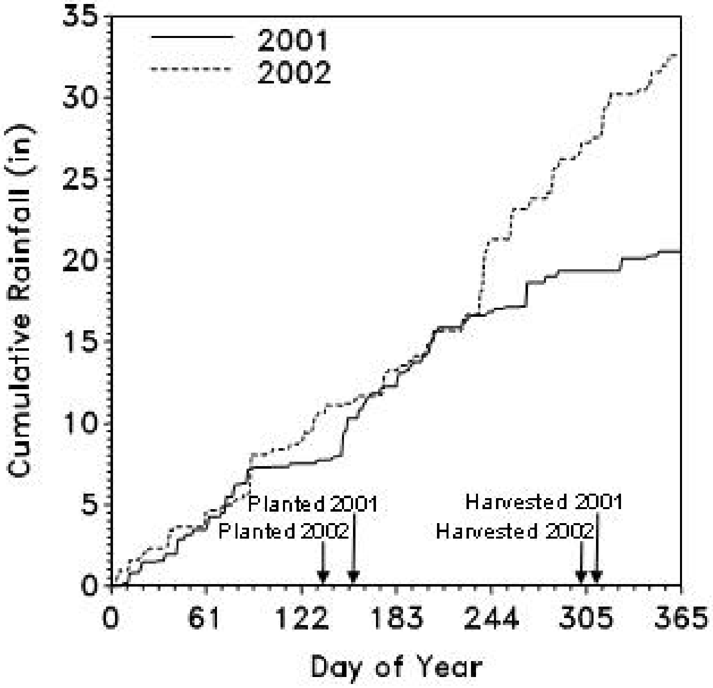


Figure 4. Cumulative rainfall for 2001 and 2002. Both years were dryer than the mean 30 year umulative annual rainfall of 47 in http://www.weather.com/weather/climatology/monthly/29501)



SOIL RESPIRATION RATES AFTER 25 YEARS OF NO-TILLAGE

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ABSTRACT

Long-term conservation tillage management results in changes in the chemical and physical properties of soil, which likely affect CO_2 flux rates to the atmosphere. Our objective was to compare respiration rates of soil that had been in no-tillage management for 25 yrs to soil that was managed with conventional tillage. Soil respiration was measured in disked and no-tillage plots in 2003 on a Norfolk loamy sand soil (fine-loamy, siliceous, thermic *Typic Kandiudult*). This tillage experiment was established in 1978 and the surface 2-in of the no-tillage and disked tillage plots differed in soil C content. Measurements were collected for approximately 50 days during the summer and during the fall. Soil respiration rates during the summer ranged from 0.6 to 22.7 gm CO_2 m^{-2} hr^{-1} for disk tillage and from 0.6 gm to 1.4 gm CO_2 m^{-2} hr^{-1} for no-tillage. Soil respiration rates in the fall ranged from 0.3 to 3.7 gm CO_2 m^{-2} hr^{-1} for disk tillage and from 0.2 gm to 0.6 gm CO_2 m^{-2} hr^{-1} for no-tillage. Respiration rates within a season were highly dependant on soil water content, especially following disk tillage. Although respiration rates were usually much lower for no-tillage, the two tillage systems had generally had similar coefficients of variability for soil respiration. Low respiration rates with conservation tillage even after 25 yrs suggests that intensive cropping with high residue crops should cause the surface soil organic matter content to continue to increase.

INTRODUCTION

Many southeastern USA soils have low water and nutrient holding capacity because of their sandy texture and low organic matter concentrations. Conservation tillage production systems have the potential to increase the productivity of these soils by increasing soil C content. Understanding the dynamics of CO_2 losses to the atmosphere in different tillage systems aids in the development of systems to enhance C sequestration in these soils.

Buyanovsky and Wagner (1983) found that soil air CO_2 concentrations under crops could reach levels approaching 8% depending on time of year and the position in the profile. Tillage causes a high short-term flux of CO_2 from the soil (Reicosky and Lindstrom, 1993; Prior et al., 2000) due to a rapid physical release of CO_2 from the soil. In the weeks following tillage, the burying of crop residues with tillage results in CO_2 flux rates that are higher than when residues are left on the surface (Reicosky and Lindstrom, 1993). Dao (1998) compared moldboard plowing to no-tillage for soil CO_2 flux following wheat in the 11th year of a field tillage study and found the cumulative CO_2 evolved from the soil in a two-month period was much higher for moldboard plowing than for no-tillage.

Increasing soil productivity potential, together with environmental concerns about the rising global atmospheric CO_2 concentration, has created the need for greater knowledge on carbon sequestration in soils and the dynamics of soil C losses. We used plots that were established in 1978 to compare tillage management systems for soil CO_2 flux. The objectives were to compare disk tillage to no-tillage for soil CO_2 flux for several weeks following the disk tillage operation and to determine whether long-term no-tillage reduces the amount of variability for this measurement.

MATERIALS AND METHODS

Data were collected in 2003 during the 26th year of a tillage experiment on a Norfolk loamy sand soil at Clemson University's Pee Dee Research and Education Center near Florence, South Carolina. Two tillage systems, disk tillage and no-tillage, have been maintained since the beginning of the study. Disk tillage consisted of disrupting the soil surface to a depth of 4 to 6 inches with a disk harrow followed by smoothing with a S-tined harrow equipped with rolling baskets. Crops grown during the previous 25 years included corn (*Zea mays* L.), winter wheat (*Triticum aestivum* L.), soybean [*Glycine max* (L.) Merr.], and cotton (*Gossypium hirustum* L.) (Karlen et al., 1996; Hunt et al., 1997). Two identical sets of plots were established in 1978, and there were five replicates of both tillage systems within each set. Each plot was 75 ft wide and 200 feet long.

Since 1996, a two-year corn - winter wheat - soybean rotation was grown on the plots. Each year corn was grown on one set of the plots and doublecropped wheat and soybean were grown on the other set. The wheat and soybeans were grown in 7.5-in wide rows and planted with a John Deere model 750 drill. From 1996 through 2000, corn was grown in 30-in wide rows and planted with a six-row Case-IH model 800 planter. Beginning in 2001, corn was grown in 15-in wide rows planted with a Monosem planter equipped with Yetter wavy coulters. Soil fertility and weed control programs used were typical for these crops in this area.

Soil CO_2 flux was measured during the summer and during the fall of 2003 with a Li-Cor 6000-09 soil respiration chamber connected to a Li-Cor 6250 CO_2 analyzer. Moisture content of the surface 2.5" was determined with a Delta T Soil Moisture Meter at the same time and in the same area (within 12") of each soil respiration measurement. Temperature of the chamber air was also measured.

The summer measurements were collected on 17 dates in one set of plots after wheat harvest. On 9 June, assigned plots were disked twice and then smoothed. On 10, 11, 12, and 13 June, data were collected at 20 places within each plot. Subsequent measurements in the summer were at five places within each plot. Soil respiration measurements were collected on 13 dates following corn during the fall. On 20 October, the assigned plots were disked twice and then smoothed. Soil respiration was measured at 10 places within each plot from 21 October through 3 November and thereafter at five places within each plot. Data were collected from three replicates during each season. Soil CO_2 flux measurements were made in plots that were last subsoiled in 1995.

Means and standard deviations for disk tillage and no-tillage were calculated for each measurement time. Coefficients of variability were calculated for each tillage system at each measurement time.

RESULTS AND DISCUSSION

Tillage had a substantial influence on soil respiration rates. In the summer, average soil CO_2 flux rates did not vary much in the no-tillage plots, ranging from 0.6 to 1.4 gm CO_2 m^{-2} hr^{-1} (Figure 1a). Summer soil CO_2 flux rates were more dynamic in the disk tillage plots, ranging from 0.6 to 22.7 gm CO_2 m^{-2} hr^{-1} (Figure 1a). Similarly, in the fall average soil CO_2 flux rates ranged only from 0.2 to 0.6 gm CO_2 m^{-2} hr^{-1} in the no-tillage plots but from 0.3 to 3.7 gm CO_2 m^{-2} hr^{-1} following disk tillage (Figure 2a). Previous research has shown that tillage increases soil respiration (Reicosky and Lindstrom, 1993; Dao, 1998).

Soil water content was consistently higher in no-tillage than in disk tillage both in the summer and in the fall (Figures 1b and 2b). With only small differences in soil respiration rates within a season for no-tillage, there was little impact of soil water content on respiration rates with that production system. Changes in soil respiration rates were more closely tied to changes in soil water content in the disk tillage system. For example, at the first two measurement dates (10 and 11 June) rates for the disk tillage plots were about 1.1 gm CO_2 m^{-2} hr^{-1}, even though a consider amount of wheat residues were incorporated through disking on 9 June. A 0.86-in rain occurred during the evening of 11 June. Soil CO_2 flux increased dramatically to 13.6 gm CO_2 m^{-2} hr^{-1} on 12 June (11 June was the second and 12 June was the third measurement time in Figure 1a) as a result of this rain wetting the soil surface (Figure 1b). Rates remained very high through the next two measurement times. At the sixth measurement time (23 June, day 174) the soil had dried and soil respiration rates declined. Wetting and drying of the soil had a similar (though less dramatic) affect on soil respiration rates throughout the rest of the summer and throughout the fall.

For both tillage systems, soil respiration rates (averaged over all measurement times) were greater in the summer than in the fall. For no-tillage, the respiration rate during the summer averaged 0.8 gm CO_2 m^{-2} hr^{-1} while the average rate in the fall was 0.4 gm CO_2 m^{-2} hr^{-1}. For disk tillage, the average rates were 6.0 gm CO_2 m^{-2} hr^{-1} in the summer and 1.6 gm CO_2 m^{-2} hr^{-1} in the fall. Part of the reason for the higher rates in the summer could have been due to differences in seasonal temperature as has been reported previously (Buyanovsky et al., 1986). Air temperatures during the summer measurements were between 26.9 C and 36.5 C, while temperatures in the fall ranged from 15.2 C to 28.4 C (Figure 3).

Another reason for the higher respiration rates in the summer could have been the difference in the productivity of the crop grown before these data were collected. The wheat grown prior to collecting the summer measurements was stressed from lack of water in the spring and yielded only 32 bu ac^{-1}. The corn-growing season, on the other hand, was excellent and corn yields averaged 150 bu ac^{-1}. Since 100 lb N ac^{-1} was applied to the wheat and 120 lb N ac^{-1} was applied to the corn, much more N was probably removed prior to the fall soil respiration measurements. This suggests that the C:N ratio in the soil was much more favorable for microbial degradation of residues and soil organic matter in the summer than in the fall. Sarrantonio (2003) measured higher respiration rates on soil with a legume mulch than on soil with a cereal mulch, and soil nitrate-N was greater in soil with the legume mulch. Further, the highest respiration rates in our study with disk tillage were considerably greater than rates found in previous studies (Reicosky and Lindstrom, 1993; Dao, 1998) while rates in the fall were similar to those previously reported. Although further research is needed, these findings may indicate that yield-reducing drought, through both reduced crop residue biomass production and reduced removal of N (which then serves to increase microbial degradation of residues when soil water status is favorable), may have a significant impact on C sequestration.

Although mean respiration rates often differed considerably between the two tillage systems both in the summer and in the fall, coefficients of variability of the two tillage systems were similar (Figure 4). Coefficients of variability ranged from about 20% to 80%. Rochette et al. (1991) found a large sample number is needed to determine statistically significant differences among tillage systems for soil CO_2 evolution because both spatial and temporal variation are usually high with soil respiration measurements. Our data suggest that even long-term no-tillage management will not lessen the need for high sampling intensity.

In summary, rainfall events had little influence on soil respiration in no-tillage, but rates in disked soil were closely related to soil water content both in the summer and in the fall. Our data agree with previous studies (Reicosky and Lindstrom, 1993; Dao, 1998) in that conservation tillage substantially reduces the maximum rates of soil respiration compared to tillage systems that disturb the soil. Low respiration rates with conservation tillage even after 25 yrs suggests that intensive cropping with high residue crops should cause the surface soil organic matter content to continue to increase.

DISCLAIMER

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Figure 1. Soil CO_2 flux (a) and soil water content (b) during the summer of 2003 at Florence, SC in soils that were disked and in soils managed with no-tillage since 1978. Data presented are means plus or minus the standard deviation.

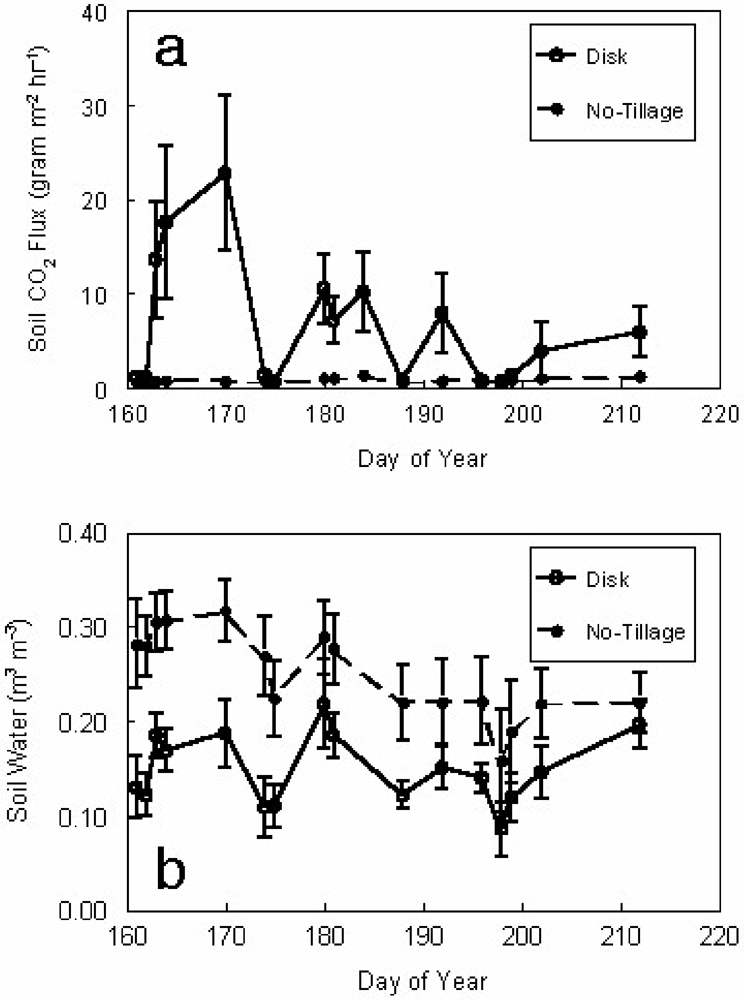


Figure 2. Soil CO_2 flux (a) and soil water content (b) during the summer of 2003 at Florence, SC in soils that were disked and in soils managed with no-tillage since 1978. Data presented are means plus or minus the standard deviation.

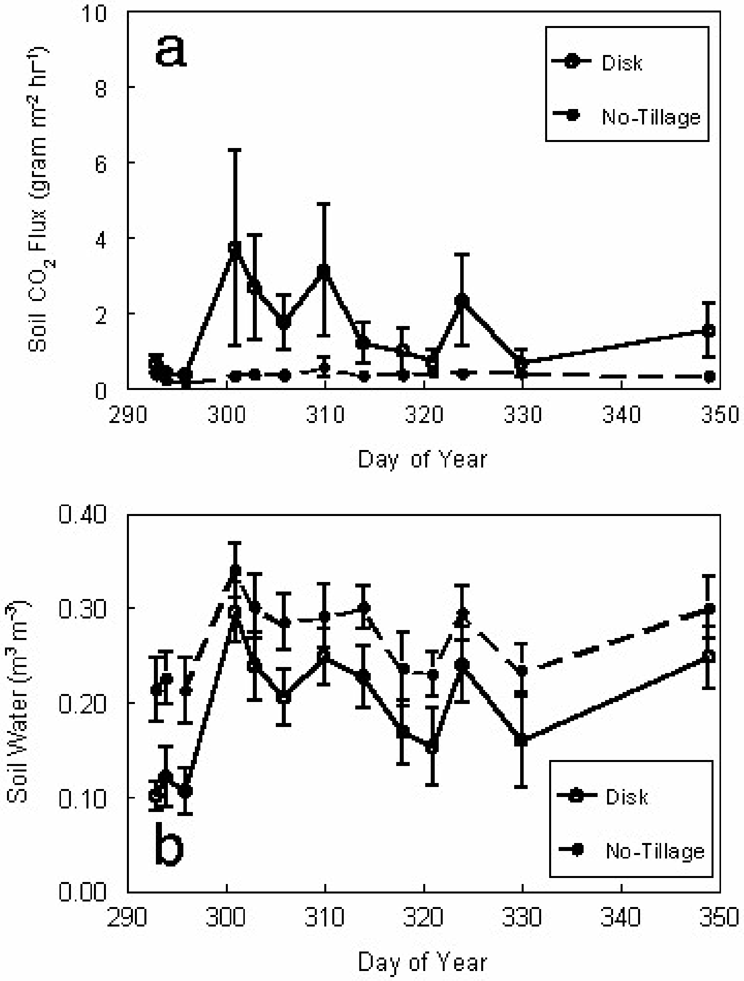


Figure 3. Average air temperature in the soil respiration chamber during the summer and fall measurements in 2003 at Florence, SC.

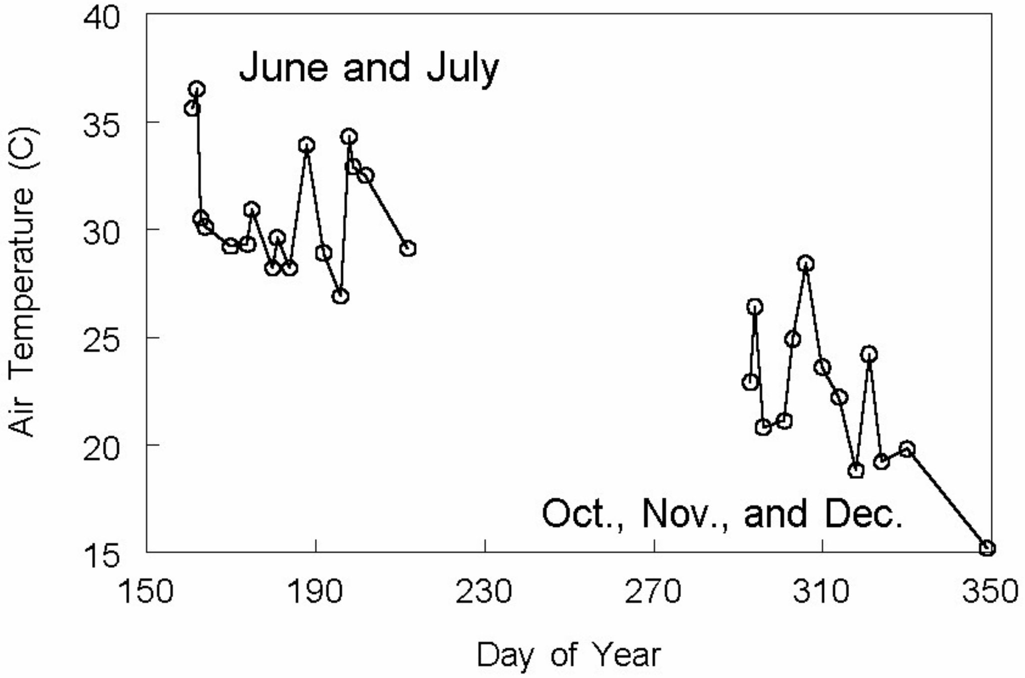
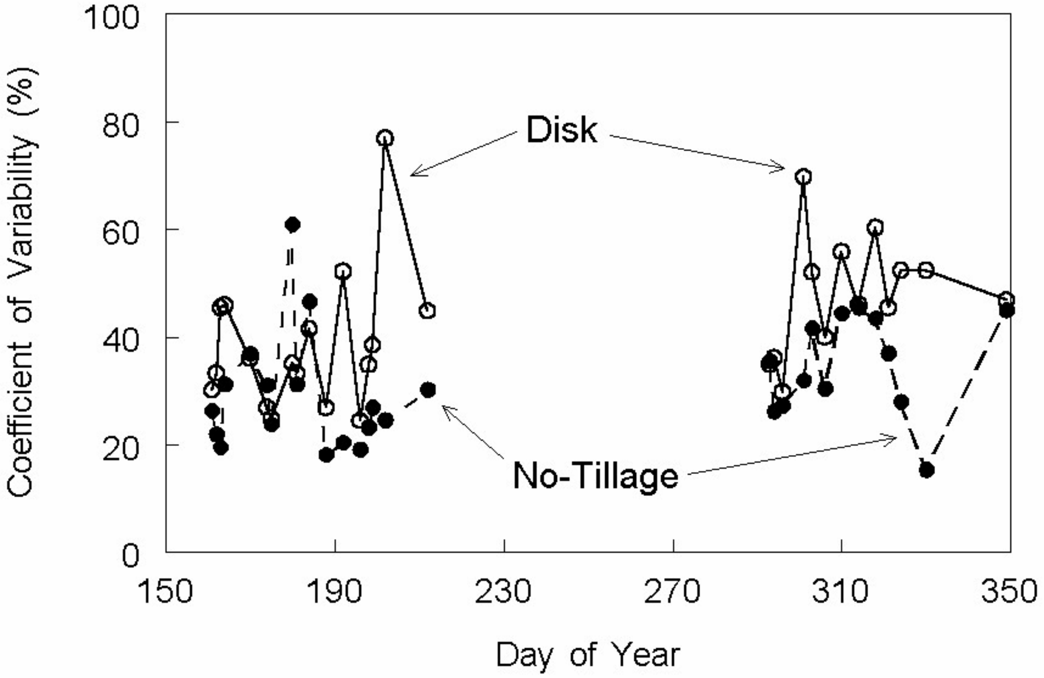


Figure 4. Coefficients of variability for the disk (open circles) and no-tillage (closed circles) soil respiration measurements at each measurement time during the summer and fall in 2003 at Florence, SC.



COMPARING BIOLOGICAL AND STRUCTURAL FEATURES OF SOILS UNDER CONVENTIONAL AND CONSERVATION TILLAGE

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ABSTRACT

The effect of tillage decisions on soil structure is well understood by growers and agricultural researchers. There are, however, biological consequences of tillage operations that have traditionally been less appreciated. The effect of tillage on soil organisms, specifically microorganisms, is an area that has become a focus of research only recently. The effect of tillage on soil organic matter, which includes living microorganisms but additionally encompasses all forms of living and dead plant and animal tissue, has also been underappreciated in many farming operations. Tillage operations significantly affect soil microbial populations and community structure and also reduce organic matter through oxidation. The objective of this research was to investigate the differences between microorganism numbers and soil physical properties and their related functions in different agricultural systems. The agricultural treatments in this study are: conventional tillage vs. conservation tillage and synthetic fertilizers and pesticides vs. organic inputs. We found that microbial respiration and nitrogen mineralization were enhanced in conservation tillage treatments regardless of the fertilizer and pest management sources. Microbial biomass was greatest in the conservation tillage-organic input treatment and was lowest in the conventional tillage-synthetic inputs treatment. Bulk density was slightly lower in the conservation tillage treatments compared to conventionally tilled treatments. Total porosity was very similar for all treatments, but macroporosity was greatest in the conventionally tilled treatments and microporosity was greatest in the conservation tillage treatments. Aggregate stability was greatest for the conservation tillage treatments.

INTRODUCTION

The importance of integrating the biological and physical components of soil in our agricultural management decisions is becoming increasingly apparent. One concept that is still not fully appreciated is the critical role soil organisms have played in soil formation and their current role in soil modification and stabilization. Soil organisms and soil physical properties are highly responsive to tillage regimes in agricultural soils. Tillage has been conclusively shown to exert a powerful influence on the soil ecological community and therebt affects the functional activity of soil microorganisms as well as micro-, meso-, and macroinvertebrates (Doran, 1980; Paul and Clark, 1989). Intensive tillage practices have been shown to result in significantly reduced aggregate stability, which is an important soil structural characteristic as well as a microbially-mediated property (Tisdall and Oades, 1980; Lynch, 1984). Erosion, sedimentation, and damage to soil structure are related problems associated with intensive tillage that can negatively affect both the physical and biological properties of soil and off-site locations.

Tillage systems dramatically influence the microbial population and diversity of a soil by affecting carbon dynamics, such as organic carbon distribution and quality, as well as influencing soil habitat parameters such as pH, temperature, aeration, and water-holding capacity. Tillage systems also play a critical role in determining the structure of a soil by influencing bulk density, pore-size distribution, and aggregate stability. Soil organisms and soil structure are correlated in agricultural systems, such that outside factors having a positive effect on one factor generally have a mutually positive effect on the other (Fig. 1). Soil microorganisms are also known to be sensitive indicators of soil physiochemical changes. It has been shown that microbial populations respond measurably to changes in soils induced by agricultural production practices long before other chemical or physical soil properties show measurable differences (Powlson et al., 1987; Fauci and Dick, 1994).

As a result of regular surface removal of crop biomass, conventionally-tilled crop ecosystems have plant biomass levels similar to that of a desert or tundra, despite having much more favorable growing conditions (Chapin et al., 2002). By increasing the amount of organic matter introduced to the surface of the soil, reduced tillage systems play an important role in affecting soil structure. Organic matter comes from both living and dead sources, including leaves, roots, fauna, and microorganisms. Organic matter can improve the structure of agricultural soil as well as make soils more resistant to structural degradation due to compaction, water logging, and tillage. Roots and mycorrhizal hyphae produce polysaccharide compounds which facilitate organic matter protection through the formation of stable soil aggregates. Cation exchange capacity (CEC) also is affected by organic matter, the effect generally being an increase in CEC with increasing soil organic matter content. Increases in CEC result in greater nutrient retention by soils and increased pH buffering capacity.

The factors of organic matter, biology, and structure act together in cyclical fashion such that each component of the cycle affects, directly and indirectly, each other component. The changes induced by different tillage strategies act to affect this cycle in many ways, making soils more or less suitable for sustainable crop production.

The objective of this research was to characterize and compare the soil microbial and physical properties of vegetable systems that incorporated tillage and production methods in a long-term (9 year) experiment.

MATERIALS AND METHODS

Field History and Design:

The site for this study was located at the Mountain Horticultural Crops Research Station in Fletcher, N.C. The soil type of the field is a Delanco fine-sandy loam (fine-loamy, mixed, mesic, Aquic Hapludult) with 2-7% slopes. The soil is gently sloped, moderately to somewhat- poorly drained and formed from old alluvial deposits. The average length of the growing season is 190 days between April 14 and October 25. Prior to this study being implemented, this field was planted to grain corn for the previous five years and had a pH of between 5.9 and 6.6 with a base saturation between 75 and 100% and a CEC between 4.3 and 6.9 cmol/kg when the study was initiated (Johnson, 1999).

Description:

A long-term vegetable crop experiment was initiated in 1994 to compare two sustainable agriculture practices, 1) conservation tillage vs. conventional tillage and 2) organic fertilizers and pest control vs. chemical fertilizers and pesticides. A vegetable rotation treatment was also implemented on subplots, but this treatment will not be included here. Every combination of treatments, five treatments in all including a control, was replicated 4 times in a completely randomized plot design. Each plot measured 40 feet by 80 feet. There was a distance of at least 40 feet between plots to minimize fertilizer and pesticide drift and pest and pathogen migration between plots. The control plots were established with no inputs to show background values for soil nutrients and pest pressure due to disease, weeds, and insects.

This experiment has been in place for nine years. Based on visible differences in soil physical properties and crop yield among treatments, it is believed by the authors that this was sufficient time to allow the microbial communities to acclimate and equilibrate to representative levels within each plot treatment.

All data presented was collected over a single growing season, in the spring and fall of 2003. The crop planted during this year was staked fresh market tomatoes. A cover crop of wheat and crimson clover had been seeded the previous fall in all plots except the control. In the spring, the winter cover crop was killed with glyphosate (conservation till chemical treatment), tilled under (convention till chemical and organic treatments) or flail chopped (conservation till-organic treatment). The conventionally tilled treatments were disked, bedded, and black plastic applied after plowing. Additionally, the conventional-tilled chemical treatment was fumigated when plastic was applied, usually two weeks prior to planting. The conventionally tilled treatments were disked and bedded after the winter cover was mowed and plowed in. The conservation tillage treatments had 12 inch strips tilled into the plots (strip-tillage) using a Bushhog Ro-till. In the conventionally-tilled organic treatment, rows were bedded and black plastic stretched over beds, just as in the fumigated treatments, but no fumigant was added. All treatments were hand transplanted after tillage, plastic, and fumigation additions.

Synthetic fertilizer and pesticides were applied as needed to the chemical treatments, with 180 lbs N/acre applied each year for each crop and phosphorus, potassium, and limestone added as recommended by soil test results. All chemical herbicide, fungicide and insecticide applications were applied according to standard North Carolina recommendations as determined by the N.C. Agricultural Chemicals Manuals (1995-2003). In the organic treatments no synthetic pesticides were used and fertilizer nutrients were applied as surface banded materials as follows: soybean meal was used as the main fertilizer source (at 180 lbs N/acre rate) and assumed 100% availability. Phosphorus, potassium, and limestone were added when recommended by soil test results and only materials approved by the Organic Materials Review Institute (OMRI) were used. Disease and insects were controlled with materials approved for organic production (OMRI) and weeds were controlled by mowing and hoeing.

Soil samples for microbiological analysis were collected from in-row areas to a depth of 8 inches prior to fumigation in the spring and after the final harvest in the fall. Samples were transported to the lab on ice and were stored at 5 degrees C until all assays were completed. All bioassays were completed within 5 weeks of sampling date. Soil samples taken for physical properties were collected in the fall. Samples for aggregate stability were taken from a depth of 6 inches, air dried, and ground to pass through a 0.3 inch sieve. Bulk density, porosity, and pore size distribution samples were taken using a 3 inch Uhland core sampler (four samples per plot) and were transported and stored at room temperature until analyzed. See Figure 2 for a schematic representation of data collected. We also determined cover crop and vegetable biomass and vegetable crop yields during this study.

Analyses:
Figure 2 describes a conceptual framework for which microbial and physical analyses were performed. This selection of analyses is designed to give broad-ranging indications of soil microbial populations and activity, and nutrient transformations taking place as a result of microbial communities and climatic factors. Tillage-mediated analyses will be evaluated at three different levels: 1) microbial biomass, 2) microbial activity, and 3) soil physical properties. For biomass measurements, we analyzed microbial biomass carbon (MBC), and microbial biomass nitrogen (MBN) using the chloroform fumigation-extraction method. For microbial activity we measured soil respiration with a base trap incubation technique and potentially mineralizable N using salt extractions, both over the course of a 28-day incubation period. For soil physical property changes we analyzed aggregate stability with a wet sieving method, bulk density from intact cores, and porosity, and pore size distribution using a differential pressure saturated hydraulic conductivity apparatus.

RESULTS AND DISCUSSION

Microbial Properties:
Microbial respiration was measured as CO_2 evolution during a 28-day incubation in the spring and fall (Table 1). The conservation till-organic treatment consistently had the greatest soil respiration and the conservation till-synthetic treatment was second-highest for both sampling dates. By the end of the growing season, in the fall, the conventional till-organic and conventional till-chemical treatments had similar, relatively low, respiration rates. The conservation till-organic treatment displayed a relatively large increase in carbon dioxide evolution over the growing season, very similar to the control treatment, indicating that the conservation till-organic treatment produced a soil environment suitable for increased microbial populations over the other treatments. The conservation till-synthetic treatment also showed an increase in respiration over the conventional tilled treatments, but not as great as the conservation till-organic. The reduced values for CO_2 evolution in the two conventionally-tilled treatments indicates a relative decline in the microbial activity, probably due to the reduction in soil organic matter in these treatments over the 9 years of this experiment as cover crop residues were available earlier in the season and were eventually depleted by the second sampling date.

Potentially mineralizable N was also measured among treatments during a 28 day incubation study (Figure 3). Soils were removed from the respiration study after 28 days (with no additional organic amendments) and then extracted with 0.5M K_2SO_4 and analyzed for available NO_3-N and NH_4-N. At the beginning of the season (spring sampling) the two conservation-tilled plots and the conventional till-organic treatments had similar N mineralization values and the conventional till-synthetic and control treatments had somewhat lower values. By the fall sampling date, the conservation till-organic treatment had increased the pounds of N mineralized per acre by about 21 pounds, theoretically representing a net gain in N availability to plants. The other four treatments had varying degrees of negative net N mineralization over the course of the growing season. The greatest decrease in pounds of N mineralized was in the conventional till-organic treatment; in this treatment there was a decrease of about 20 pounds of N per acre. This may be the result of increased immobilization of previously plant-available mineral N or very rapid mineralization of the organic materials early in the season (it was a very wet spring and summer) resulting in the majority of available N being removed from the system by NO_3 leaching or plant uptake by the fall sampling date. This data indicates that tillage plays an important role in the mineralization of organic N sources over the course of the growing season. More research must be conducted to determine the exact fate of the N in the organic systems. The two chemical treatments show similar modest declines (ranging from about 5 to about 9 pounds per acre) in N mineralization over the growing season, indicating that synthetic fertilizers are not as strongly affected by microbial processes as are organic N sources. It should be noted, however, that the absolute values of available N which were salt-extractable were greater in the conservation tilled treatment than in the conventionally tilled treatment when chemical fertilizers and pesticides were applied.

Tables 2 and 3 summarize the results of the microbial biomass C and N (MBC and MBN) analyses, respectively. As would be expected, the relative patterns of change among treatments for the spring and fall sampling dates is the same for both analyses. In the conservation till-organic treatment, the MBC value increased modestly while the MBN value decreased by 23 pounds per acre. This reduction in MBN correlates to the increase in potentially mineralizable N of 21 pounds per acre. In the conservation till-chemical plots, the MBC increased about 137 pounds of C per acre while the MBN values remained essentially the same at the beginning and end of the growing season. The two conventionally tilled treatments demonstrated a reduction in MBC and MBN from the spring to fall. The MBC values in the conventional till-chemical plots decreased by 271 pounds/acre while the MBN decreased by 8 pounds/acre. The control plot exhibited the greatest increases in both MBC and MBN of all the treatments.

Physical Properties:
Similar bulk densities were measured across all tillage and production practice treatments in the top three inches of soil, although plowed soils (including the control) appeared to have higher bulk densities (Figure 4). The control treatment had the greatest bulk density, possibly because they are plowed every year and are not seeded with a cover crop. These plots remain fallow after harvest and are generally overgrown with native grass species during both summer and winter seasons. It may be the combination of these factors which make the soil bulk density relatively high and the MBC and MBN values relatively high as well. Figure 5 depicts the pore size distribution and total porosity of the treatments. The total porosity remains similar across all treatments, but macroporosity is slightly greater in the conventionally tilled treatment soils while microporosity is slightly higher in the conservation tillage treatment soils. The control treatment soil had the lowest macroporosity and the second greatest microporosity. It's combination of low total porosity combined with the high percentage of those which were micropores contribute to our understanding of the high bulk density of the control plots shown in Figure 4. Table 4 describes the soil aggregate stability which was measured as percent water-stable aggregates in the bulk soil and then converted to a single value described by the geometric mean diameter of the water stable aggregates. Soils from the conservation till-organic treatment gave the greatest average diameter for the water stable aggregates, meaning it had the greatest aggregate stability. The control treatment produced the second highest measurement for aggregate stability. These results correlate with the values for MBC and MBN, reinforcing the idea that soil aggregate stability is a microbially-mediated property. These results are not surprising since the visual effects of the treatments were obvious while the wet sieving was being performed during this analysis. Those treatments which were later shown to have fewer water stable aggregates (the conventionally tilled treatments) produced a very turbid water-soil solution, so dense it was difficult to see through. The conservation tilled treatments, on the other hand produced much less turbid solutions during the wet sieving process.

CONCLUSIONS

The cycle portrayed in Figure 1 is clearly being affected by the treatments imposed (tillage and chemical inputs) in the experiment reported here. Respiration levels were greatest in the conservation till-organic treatments followed by the conservation till-chemical treatment. The relatively lower values determined for the conventionally tilled treatments indicates a lower microbial activity under the plowed tillage regime. Potentially mineralizable N (PMN) analysis revealed that the conservation till-organic treatment was the only treatment with a net positive mineralization value between the spring and fall sampling dates. The greatest reduction in PMN over the course of the growing season was found in the conventional till-organic treatment. This indicated that tillage affects N mineralization from organic N sources. The PMN values in treatments fertilized with synthetic fertilizers and using chemical pesticides did not change very much, reinforcing that N from synthetic sources are not as dependent upon microbial processes for transformation into plant-available forms as are organic fertilizers. MBN values in the conservation till-organic treatments were found to decrease to a similar degree that PMN values increased over the growing season. This indicates that the N budget was strongly influenced by microbially-mediated mineralization processes in this system. Other treatments showed trends for MBC and MBN values similar to the trends determined for the respiration measurements.

Physical properties were also influenced by the experimental, but not to the same degree as were microbial properties. This corresponds to the results of other studies indicating that microbial activities are strong indicators of soil biophysical properties. Bulk density values in the top 3 inches of soil were similar among treatments. Conservation tilled plots were slightly less dense than conventionally tilled plots after 9 years of treatment impact. Total porosity was also very similar among treatments, but pore size distribution revealed that there were more macropores in conventionally tilled soils and more micropores in conservation tilled soils. Macropores are not as valuable to crop growth from a moisture-holding perspective because they are too large to retain water against gravitational force; micropores, however, have a greater water-holding capacity due to capillary forces in the smaller diameter pores. Aggregate stability was found to be greatest in the conservation till-organic treatment.

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Table 1. Cumulative respiration measurements of CO_2 over a 28 day incubation period in spring and fall (standard deviations in parentheses)

Treatment	Spring lb CO_2/1000 lb soil	Fall lb CO_2/1000 lb soil
cons/org	0.38 (0.06)	0.57 (0.18)
cons/syn	0.34 (0.12)	0.38 (0.09)
conv/org	0.27 (0.04)	0.17 (0.07)
conv/syn	0.20 (0.07)	0.16 (0.04)
control	0.15 (0.03)	0.37 (0.13)

Table 2. Microbial biomass C and N measurements in spring and fall (standard deviations in parentheses)

Treatment	Spring MBC lb C/acre	Fall MBC lb C/acre	Spring MBN lb N/acre	Fall MBN lb N/acre
cons/org	1355 (214)	1406 (240)	98.2 (31.4)	75.2 (5.2)
cons/syn	855 (122)	992 (214)	40.8 (17.1)	41.3 (7.3)
conv/org	1072 (387)	767 (178)	47.8 (10.0)	36.0 (5.4)
conv/syn	531 (197)	260 (95)	19.4 (13.4)	11.4 (8.0)
control	656 (248)	1138 (291)	36.3 (10.4)	53.9 (17.1)

Table 3. Geometric Mean Diameter (GMD) of Water Stable Aggregates

Treatment	GMD (mm)	Std Dev
cons/org	1.80	0.12
cons/syn	1.12	0.37
conv/org	0.98	0.57
conv/syn	0.96	0.11
control	1.48	0.47

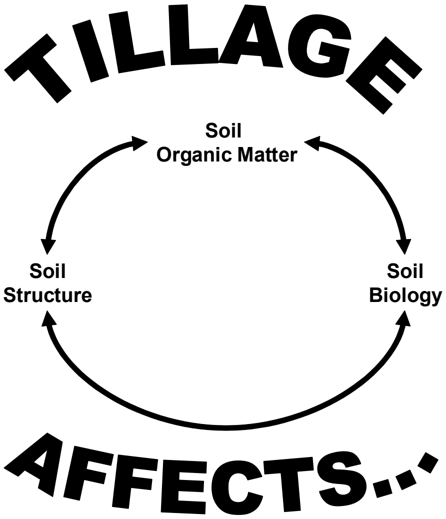

Figure 1. Tillage affects all components of the organic matter-biology-structure cycle. Each component, in turn, can affect the rest of the cycle.

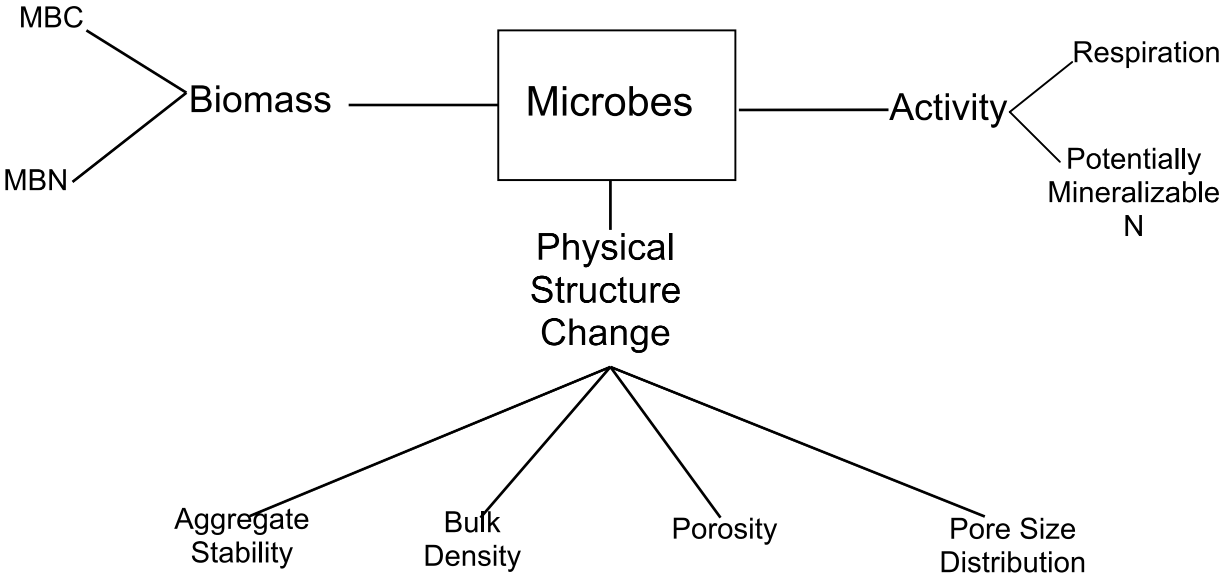

Figure 2. Conceptual diagram of measurements (MBC=Microbial Biomass C; MBN=Microbial Biomass N)

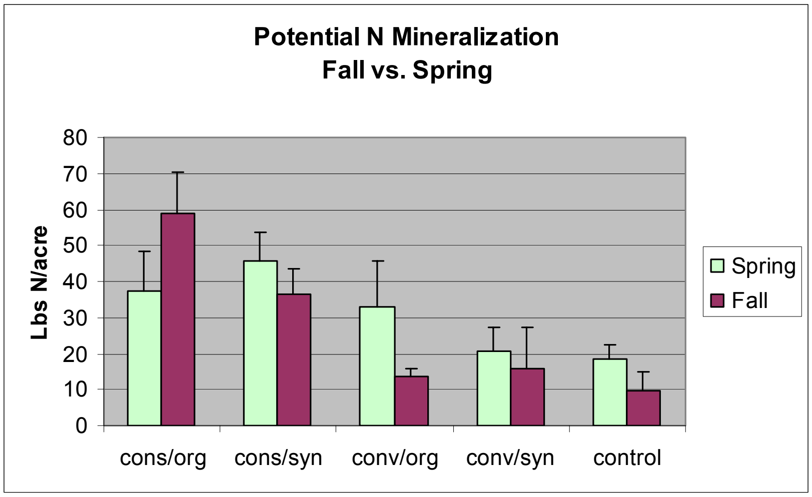

Figure 3. Potentially mineralizable N measurements over a 28 day incubation period in spring and fall

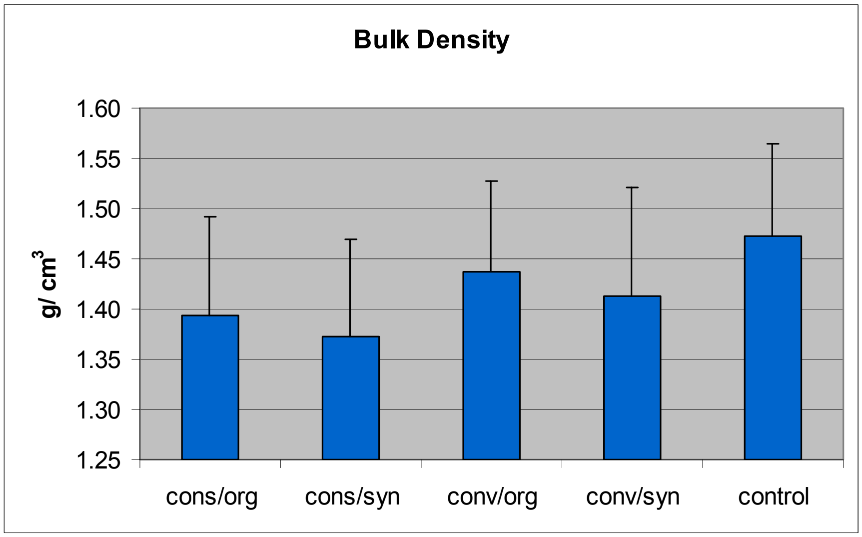

Figure 4. Bulk density measurements of treatments

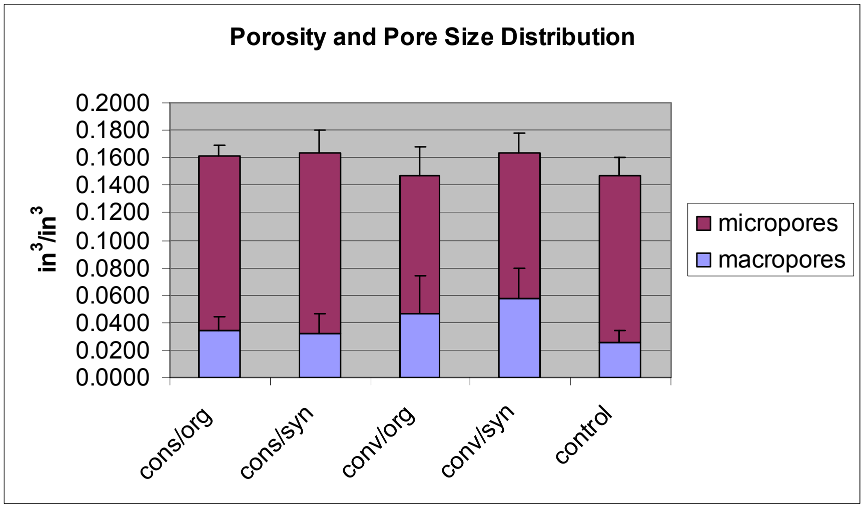

Figure 5. Porosity and pore size distribution of treatments

VALUE OF PERENNIAL GRASSES IN CONSERVATION CROPPING SYSTEMS

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ABSTRACT

Soils in the southeast have low organic matter content, low native fertility, and low water holding capacity which has resulted in stagnant yields. Long term studies across the country (Morrow, Sanborn, Magruder, Old Rotation [Auburn]) have shown that land coming out of long term perennial grasses often has an organic matter content of over 4% and decreases as it stays in continuous annual cropping and levels off after 80-100 years once the level reaches about 1½% with use of conservation tillage, cover crops, proper rotation, and modern fertility practices. Years of research in the southeast have shown that perennial grasses such as bahiagrass can help improve soil structure and reduce pests such as nematodes and increase crop yields, sometimes dramatically. Research in the southeast with this perennial grasses grown in rotation with crops has shown higher yields (50% more peanuts than under conventional annual cropping systems), increased infiltration rates (more than 5 times faster), higher earthworm numbers (thousands per acre vs. none in many cases), and a more economically viable (potential for 3-5 times more profit) cropping system. Diversification into livestock can add another dimension to the farming system making it more intensive and provide a readily available use for perennial grasses.

INTRODUCTION

It is commonly accepted in the agriculture community that organic matter in soils is one of the keys to productive soils in that it aids soil structure, increases fertility and water holding capacity, enhances growth of plants and results in high yields of crops. The history of world agriculture has been of "wearing out land" through growing annual crops for food production and moving to new sites that nature made fertile through many years of native forests and grassland. The region of the U.S., formerly tall-grass prairie under which the world's most fertile soils were formed, was largely converted to annual cropping systems in less than 150 years (Glover, 2003). The result has been irrecoverable soil loss from the fields, widespread contamination of surface waters in the region, and nutrient contamination in the Gulf of Mexico thousands of miles downstream. Conversion of annually cropped land back to perennial cover provides great potential to mitigate these problems. These native perennials protected the soil from erosion while increasing soil organic matter (SOM). However, primitive farming methods used in many newly settled areas or in undeveloped regions of the world result in degradation of SOM until population growth in the area demands and can pay for farming practices that result in consistent quantity and quality of food which tends to slow the loss of SOM and farming becomes more sustainable. Many of these farming methods are still being used in the few virgin areas left in the world. Cutting forests, burning, cultivation, lack of cover crops, monoculture of annual crops, and leaving areas fallow after production decreases, exposing soils to erosion and further loss of SOM and productivity. Research efforts have shown several practices that lead to increased (SOM) formation or at least slower degradation. These practices include: including perennial grass and legume production in rotation or as permanent pasture, manure or other organic additions, year round cover crops, return of high levels of plant residues, crop diversity, reduced tillage, use of stress resistant crops or varieties, and application of needed mineral fertilizer to promote higher yields and increased biomass production. The ultimate goal of agriculture is to be economically profitable while conserving natural resources for future generations. Seldom have all of these practices been used over wide areas. Increased SOM would have a major impact on agriculture by increasing soil fertility, improving water relations and soil structure, and eventually increase productivity and return higher rates of organic matter to the soil. Recent farm programs (Conservation Reserve Program) in the U.S. has led the effort to convert some of these cropped areas and once native grass areas back into perennial grasslands and forests. Diversified farming will become more common in the future which will mean more perennial grasses in rotation with crops allowing farmers to maintain or enhance quality of the soil resulting in long term sustainability of SOM and economic viability.

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. Native vegetation included hardwood and pine forest and small areas that had been cleared by Indians where some grass encroached. As these small patches of bluestem and switch grass were overgrazed, they were replaced with broomsedge and other less desirable grasses. Continuous row cropping has continued to degrade these soils. Improved pastures for beef and dairy production did not begin in the South until the 1930s and 1940s, when Dr. Glen Burton and others began breeding and releasing new grass varieties. During the 1950s and 1960s there were reports that higher crop yields could be attained after perennial grasses and that soil tilth had indeed improved. It is known that rotation with perennial sod crops will increase soil carbon, water infiltration, improve soil structure, and decrease erosion to a higher level than the winter annual cover crops which have been shown to be better than summer annuals. Winter annual cover crops do not do as much to enhance soil quality because of their short duration and fast degradation. Living roots have a tremendous impact on soil quality with annual crops only having active roots for about 3 to 4 months each year. Much of the research in the 20th century looked at cover crops as green manure crops to be turned under for nitrogen benefit or nematode suppression. Recent advances with herbicides and herbicide tolerant crops have allowed crops to be planted directly into standing cover crops. 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), including testimony from growers in the South who plant after bahiagrass. Since soil carbon is increased along with other quality components after permanent grass crops, best crop yields are obtained immediately behind these grass sod crops. 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”. Virginia research showed that winter annual cover crops did not contribute to improved water holding capacity while perennial grasses did. Agriculture has a history of depletion of SOM and subsequent loss of soil fertility and productivity as a result of poor management. At times this is a result of lack of knowledge about agricultural practices or a lack of proper resources to maintain productivity. Farmers are often financially strapped to the point of being concerned about maximizing short term productivity at least cost instead of looking at long term productivity. There are often other factors such as environment or cropping marginal areas or marginal crops that result in minimum income and growers do only the minimum to continue farming at the expense of long term productivity. Extensive cultivation done throughout the Corn Belt, Great Plains, and the Southeast Cotton Belt of the U.S. over the past 150 years resulted in loss of high amounts of SOM, soil nitrogen, and influenced CO_2 levels as well as resulting in abandonment of large areas due to erosion. Crop yields during the first 50 years of cultivation are relatively high without fertilizer as SOM released nutrients, held water, and maintained some aggregation of soil particles. Little fertilizer was available during the 19th century and early 20th century or was of low analysis resulting in a downward spiral of SOM and other soil quality factors. Prairie grasses were plowed under as pioneers moved across the country and settled. Cultivation and cropping resulted in losing ¼ to ¾ of the SOM that was present 100 years ago as seen from some of the long term plots (Magruder, Sanborn, and Morrow plots). Data from the Magruder plots indicated that organic matter dropped at a very rapid rate during the first 50-60 years and has slowed since the 1950s. These plots had about 4% O.M. in 1890 after the prairie grass was plowed under. After 110 years of continuous cultivation, O.M. is around 1.25%. It took more than 50 years to produce a nitrogen deficiency and almost 100 years to note a response to potassium on wheat. Manure slowed the decay of the SOM but still showed the same trend as the unfertilized plots. Many of these long term fertility sites had a rapid decrease in SOM until the 1940s and 1950s when fertilizer use started to become a normal practice resulting in more biomass being produced and returned to the soil. Data from Georgia shows that SOM may be increased fairly rapidly when put back into perennial crops but can be degraded more rapidly. This slowed the degradation of SOM and in some cases has resulted in increases. Soil quality and especially SOM or carbon sequestration is of major concern to the farming community and both agricultural and environmental scientists. A model (Imhoff et. al, 1990) currently in use for SOM by EPA and Natural Resource Conservation Service's Natural Resources Inventory shows a well documented decline between 1910 and 1950 to about one half the original level of SOM and a period of some stability until about 1970 and predicts an increase in the next 30 years due to a higher cropping intensity and use of commercial fertilizer. Other reasons for a predicted increase in SOM are government programs that have promoted grass set aside of crop land and economic benefits of conservation tillage. The economic conditions of rising labor and fuel costs are expected to continue indefinitely. However, long term plots across the U.S. and in other countries are still showing a decline in SOM after 100 years or more though the decline appears to have slowed down from the first half of the last century. Growing continuous annual crops not only results in a decrease of SOM but in a buildup of nematodes and diseases (Dickson and Hewlett, 1989), a depletion of certain nutrients, less organic material left in the soil as compared to perennial crops, and compaction of the soil so roots cannot penetrate to water and nutrients. In crop production guides and many research papers, rotation is listed as an important component of producing crops profitably (Edwards et. al., 1988). George Washington, in his crop rotation plan of 1782, included 3 years of a permanent grass in rotation prior to planting corn (Anonymous, 1997). He believed that soils would not become "exhausted" or depleted of nourishment if crops were rotated and fertilizer was used. Research shows that legumes will add nitrogen to the soil and improve soil health (McGuire et.al.1998). However, legumes contribute little to the long-term build up of organic matter and soil structure because of the rapid break down of the plant material and the flush of nitrogen available for plant growth (Frye et. al.1985). The U.S. Geological Survey has reported that 63% of North America that was in native grasslands is cultivated. The reason for this is that most of these soils were highly productive and high in SOC when initially cultivated and many of these remain highly productive with ½ as much SOM as they started out with. Nitrogen fertilization is the fertilizer nutrient that has kept production of crops up to levels of virgin soil conditions. Temperate grasslands have been estimated to contain 18% of the global SOC reserves (Atjay et al., 1979). This large storage of SOM is attributed to low decomposition rates relative to net production. Perennial grasses contribute little to the immediately available nitrogen pool, but add significantly to the organic base and long-term nitrogen pool as well as well as helping reduce nematodes and other pests normally found in annual grass or legume crops (Boman et.al.,1996, Elkins et. al. 1977). Annual ryegrass has been shown to contribute 3 to 4 times as much organic matter to the soil from its roots as crimson clover or vetch (McVickar, et.al.,1946). The nitrogen concentration of ryegrass roots is 1/3 to ½ that of legumes and yet ryegrass contributes more total nitrogen to the soil because it has considerably more root mass in the soil than any of the legumes. Likewise, animal manure and composts are more effective in building SOM than harvest residue, which is more effective than fresh plant material such as green manure crops. Paustian et al., 1992 showed that when the same rate of residue was added from 4 sources of organic material to the soil, soil organic carbon (SOC) was increased most by peat followed by manure, and then straw which contributed 3 times more SOC to the soil than alfalfa, which degrades so rapidly. Likewise, relative soil carbon is 20-40% higher with grass/forage in a rotation as compared to continuous corn or soybean in rotation with corn. In area with long growing seasons, two to three crops can be planted each year adding to the organic matter base of the soil (Wright, et. al., 1998). However, continuous cropping of either annual grass or legume crops can result in nematode or disease build up to damaging levels as well as decreasing SOM. Uhland, 1949 showed that corn yield was directly related to SOM in Indiana. Hagan, et.al.,1995, noted that bahiagrass and to some degree, bermuda grass is resistant to all of the major nematodes of row crops in the Southeast and can contribute significantly to the "clean up" of soils that have become unprofitable for row crops due to low yield and expense of pesticides needed for pest control. These challenges along with infertile soils, low organic matter, and a natural soil compaction layer have to be over come in any cropping system. However**,** using a sod based rotation of bahia, bermuda, or guinea grass reduces nematode populations and other pests in this cropping system, adds organic matter to infertile soils for better nutrient and water holding capacity, and roots penetrate the natural compaction layer allowing subsequent crop roots to move through it to have access to more water and nutrients. All of these benefits of sod prior to row crop production result in dramatic increases in yield at a lower cost of production with less pesticide use and less negative environmental impact than trying to alter all of these factors with chemicals and tillage tools. Water in the soil profile is conserved and utilized by the crops, since rooting depth is often 10 times deeper following bahia, bermuda, or guinea grass as in conventional cropping systems, reducing irrigation needs from normal applications of about 30cm of irrigation per year to as little as 5 cm with similar or higher yields. This could result in as little as 1/10th the current water use for irrigation, alleviating some of the water problems for annual crops.

MATERIALS AND METHODS

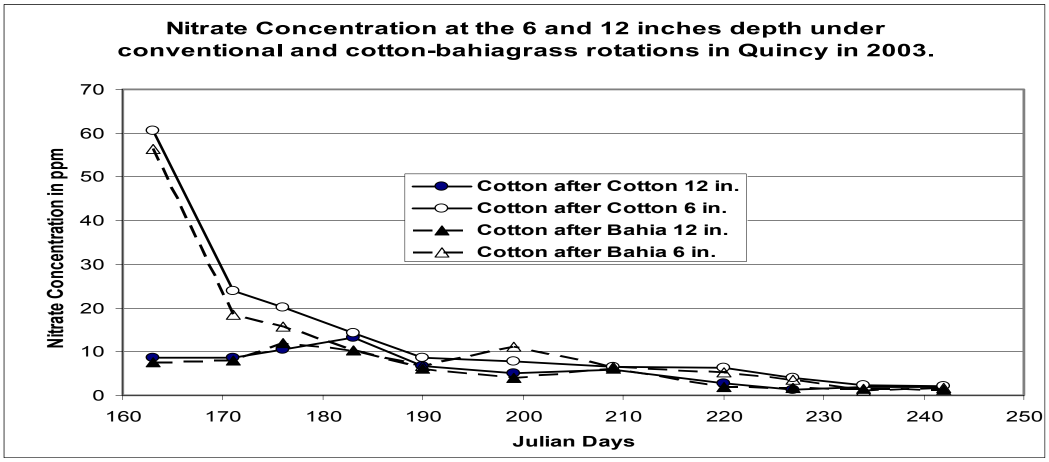
A multi-state project was started in Florida in 2000 and in Alabama and Georgia in 2001 to examine the influence of 2 years of bahiagrass on peanut and cotton in the rotation. The site at Marianna, FL was under a pivot and has a cow-calf operation in rotation with peanut and cotton and winter grazing after these annual crops, while the large site at Headland has stocker cattle on winter grazing after peanut and cotton with the bahiagrass being used for hay in the stocker operation. Small plots at Quincy, Headland, and Tifton utilized the grass as hay and the winter cover crop for planting the next crop into. Various data has been collected from each of these sites including water infiltration, soil carbon, soil fertility, bulk density, weed population, earthworm numbers, penetrometer measurements, soil moisture measurements, yields and grades of crops and various other measurements. The first full cycle of this system will be completed in small plots at Quincy with data being summarized over years and locations. The basic design of the study is shown below:

	Year 1		**Year 2**		**Year 3**		**Year 4**	
Field	**Spring**	**Winter**	**Spring**	**Winter**	**Spring**	**Winter**	**Spring**	**Winter**
1	Cotton	Wheat	Peanut	Wheat	Cotton	Wheat	Bahia	Bahia
2	Bahia	Bahia	Bahia	Bahia	Peanut	Wheat	Cotton	Wheat
3	Peanut	Wheat	Cotton	Wheat	Bahia	Bahia	Bahia	Bahia
4	Cotton	Wheat	Bahia	Bahia	Bahia	Bahia	Peanut	Wheat

RESULTS AND DISCUSSION

The results obtained from the study have been positive and encouraging. We found that including bahiagrass in the cotton/peanut cropping system increases soil water infiltration rates in both the peanut and cotton phases of the cropping system. Higher infiltration rates reduce runoff and soil erosion and subsequently increase soil water content. When we evaluated soil moisture in cotton, the bahiagrass rotation retained more soil moisture as compared to conventional cotton during the 2003 growing season. The increased moisture levels in the bahiagrass rotation was partially attributed to the increased infiltration rates observed in cotton after bahiagrass.

Soil water nitrates were determined at the 6 and 12 inch depth in the conventional and bahiagrass rotated cotton (see figure below). The cotton in the bahiagrass rotation had less soil water nitrate at both depths throughout the growing season. Bahiagrass has deep roots which penetrate deeper soil layers. When the grass dies, the roots decay, leaving root channels. Cotton could have exploited the channels and developed a more extensive rooting system, which utilize more N across a wider soil profile. We observed higher root biomass, root area and root length in the bahiagrass rotated cotton. As with soil nitrate, the bahiagrass rotation had less ammonium nitrogen compared to the conventional cotton. Higher levels of N above the EPA recommended level have been reported in ground water in most states of the US. The levels are higher in states with sandier soils including the Tri-State region. High levels of N in ground water is also responsible for algae blooms in fresh water bodies. Hence rotations which reduces N levels can be a good way to protect the environment.


Nitrate Concentration at the 6 and 12 inches depth under conventional and cotton-bahiagrass rotations in Quincy in 2003.

When we evaluated residual soil nutrients at the end of the season, the cotton in the bahiagrass rotation had less residual nutrients including P, Mg and B. The vigorously growing cotton in the bahiagrass rotation utilized more nutrients, leaving less residual nutrients being susceptible to leaching and erosion. However, the bahiagrass rotation had higher levels of both soil nitrate and ammonium at the end of the season. When the cotton roots died the decaying roots would have mineralized and released the NO3 and NH4. This would have resulted in more N being released from the bahiagrass rotation because it had the larger biomass. A solution to this would be to keep the land under crop cover, so that the residual soil N would be utilized.

Earthworms are a good indicator of a health soil. They increase infiltration rates, aeration, soil nutrient cycling and help achieve good soil crumb structure. Including bahiagrass in the rotation increased earthworm densities, by as much as 7 fold. The higher organic matter and associated high soil moisture in the bahiagrass rotation may have caused the increase in earthworm densities.

The Bahiagrass rotated cotton showed less soil mechanical resistance compared to both cotton and peanuts. High mechanical resistance impedes root growth and subsequently reduces cotton grade and yield. Higher mechanical resistance also retards water movement through the soil profile, thereby increasing the chances of water loss either through evaporation or as runoff.

Cotton in the Bahiagrass rotation had lower bulk density compared to conventional cotton. Bulk density is defined as the mass (weight) of a unit volume of soil. Bulk density takes into consideration total pore space and is an indicator of porosity, infiltration and compaction.

Our results show that including bahiagrass in the traditional peanut/cotton cropping system results in a healthier soil.

Cotton grown after bahiagrass has improved yield component parameters including plant height, plant biomass and LAI. The cotton in the bahiagrass rotation was taller than cotton in the conventional system. In addition, the bahiagrass rotated cotton had greater above ground biomass compared to conventional cotton. The taller plants in the bahiagrass rotated cotton also had greater total root length and root area. The more extensive rooting system in the bahiagrass rotation was able to utilize more soil nutrients across a larger volume of soil and in the process recycle nutrients from deeper soil depths. These nutrients would otherwise have been lost from the nutrient cycle.

Cotton in the bahiagrass rotation had higher LAI compared to the conventional cotton. The high LAI is indicative of more efficient utilization of light. The more developed plant canopy was able to effectively shade the weeds rendering them less competitive to the cotton. The bahigrass rotated cotton also had reduced weed biomass compared to the bahigrass rotated cotton. The reduced weed pressure in the bahiagrass rotated cotton will mean less herbicide application, thus reduce herbicides costs for the growers and also reduces, the potential for pesticide contamination to the environment. This more developed cotton plants in the bahiagrass rotation are indicative of better resource utilization including soil moisture, soil nutrients and light. Bahiagrass contributed to the positive aspects of a health soil which in turn resulted in healthier and more vigorously growing plants which were able to withstand weeds and pest attack.

We monitored disease in peanuts after bahiagrass and conventional peanuts for the major peanut diseases in the Tri-State region. These diseases included, tomato spotted wilt virus (TSWV), cercospora leaf (*Cercosporidium personatum*) spot, peanut rust (*Puccinia arachidis*) and white mold (*Sclerotium rolfsii*). The bahiagrass rotation had less infestation of tomato spotted wilt virus, leaf cercospora and spotted wilt virus. The bahiagrass rotation spaces out the peanut crop in time more than the traditional peanut/cotton rotation. This helps break disease cycles, resulting reduced disease outbreak. Also, the healthier soil after bahiagrass could have supported healthier peanuts which were more tolerant to disease pressure (we will test this this year when we look at peanut plant measurements) There was no differences in infestation levels between the rotations for white mold.

We observed no differences in cotton yield between the conventional and bahiagrass rotated cotton at Quincy. The lack of yield differences was surprising, taking into consideration the differences in soil properties between the rotations. It is possible that the bahiagrass rotated cotton could have developed excessive vegetative growth at the expense of fruiting bodies. Literature reports several cases where excessive vegetative growth has resulted in reduced yield. In 2004, we will reduce N application in the bahiagrass rotated cotton so as to reduce vegetative growth. Reducing N application rates will further reduce N leaching to ground water and also reduce N costs for the growers.

Differences in yield between the rotations were not always consistent in peanuts as was the case with cotton. When combined over years, the peanuts in the bahiagrass rotation had higher yields compared to the conventional peanuts at Quincy. Peanuts in the bahiagrass rotation are likely to have benefited from the positive soil health parameters following the bahiagrass, as described above. At Headland, peanuts in the conventional rotational had slightly higher yield compared to the peanuts grown immediately after bahiagrass. It's not clear why this happened. The field with peanuts after bahiagrass generally tended to have higher soil test nutrient levels and also better soil health properties. This however did not translate into higher peanut yield for the rotation.

There is a growing demand by the livestock industry for forage. Including bahiagrass in the traditional peanut/cotton cropping peanut increases the overall acreage under bahiagrass (forage). Perennial grasses including bahiagrass can be produced at lower production costs compared to other forages. Including bahiagrass in the traditional peanut/cotton cropping system will not only ensure more silage, but will also ensure that large acreage of land in the Tri-state regions would be conserved and protected from potential land degradation. Perennial grasses protect land from erosion and help build up organic matter levels. Having large acreage of land under bahiagrass will also help provide more silage for the dairy industry. The average bahiagrass yields were approximately 7239lbs/acre at Quincy in 2003.The yield and quality of the forage was comparable to the other perennial forages including bermudagrass, digitgrass, stargrass and limpograss.

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PRODUCING VEGETABLES IN CONSERVATION TILLAGE SYSTEMS IN NORTH CAROLINA

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ABSTRACT

Vegetable growers in the Southeast US have tillage alternatives to successfully produce vegetables and provide soil erosion control, water conservation, and improve soil quality. Conservation tillage -primarily no-till and strip-till are being used by growers to produce sweet corn, cabbage, pumpkins, and tomatoes successfully across the state. Available conservation-tillage equipment, weed control, and experience has been the key requirements for this success. We established long term conservation tillage systems ten years ago in an effort to develop a field site that could be used for answering questions related to vegetable production planted with conservation tillage and the resulting soil biological, chemical, and physical property changes that have evolved over the years. Objectives for this experiment were to evaluate whole systems of current technology that growers use in their operation. These include conventional tillage systems with chemicals (what growers are currently using), conventional systems with organic production methods, conservation tillage systems with chemicals, and conservation tillage systems with organic production methods. Tomato production for the past seven years has seen a continuous down trend for most treatments - the plowed systems with either chemical or organic production methods, and the conservation tillage treatment with chemical production methods. The exception to this downward trend was with the conservation tillage treatment with organic production methods. This treatment initially had low yields, but once established (first three years) has seen increased yields over the last four years. Nutrient cycling and nutrient removal by tomato fruit showed similar results for the various treatments, but showed a different path flow for nutrients. Fruit nitrogen and potassium were exported off the field in large quantities, up to 90 lbs N and 130 lbs K/per acre. Phosphorus, calcium and magnesium were exported at a lower removal rate, in the order of 5, 7, and 15 lbs P, Ca, and Mg per acre, respectively. Tomato roots recycled very low amounts of any nutrient, with 5 lbs N and K/acre the highest amount of nutrients measured. A control treatment with no fertilizer input has seen about 25 lbs N, 51 lbs K, and 10 lbs P available from the soil.

INTRODUCTION

Conservation tillage has become a common practice for many row crops in North Carolina and the Southeast. This tillage practice has become successful due to the availability and improvement of surface herbicides and equipment modifications. Horticultural crops are currently being trialed for their use with conservation tillage (Hoyt, 1999).

No-till experiments with vegetables have resulted in various degrees of success. The introduction of a no-till transplanter has provided a means for planting bare rooted or containerized cabbage or broccoli (Hoyt, 1999; Morse, 1993) transplants in undisturbed soil. Sweet corn, dry and field beans, and squash (Cucurbita spp.) can be easily planted by current no-till seeders designed for agronomic row crops. Other vegetable crops have been successfully planted with some form of conservation tillage - popcorn, tomatoes, peppers, potatoes (Hoyt and Monks, 1996; Mundy et al., 1999). Conversely, lower yields with conservation tillage have been obtained with cucumber and carrot.

The benefit of surface residues or mulch in conserving soil moisture in horticultural crops has been known for many years with materials such as black plastic emulating the benefits of crop residues (Estes et al., 1985). Growing winter cover crops for surface residues in conservation tillage provides mulch that may decrease soil temperature and influence vegetable yields, depending on cover residue selection (Hoyt and Konsler, 1988). Legume residues have increased vegetable yields when compared to grass residues (Hoyt and Hargrove, 1986). Both legume and grass winter cover crops increased nitrogen (legumes through biological nitrogen fixation), potassium, and phosphorus recycling within the soil horizon (Johnson and Hoyt, 1999). Winter cover grass residues can produce similar yields as legume cover residues with conservation tillage if fertilizer nitrogen is adequately supplied (Hoyt, 1984; Ranells and Wagger, 1997).

The following experiment compares conventional tillage with black plastic to strip-tillage and the use of winter cover residues as mulch. Each tillage system also has two production methods, a chemical production system using current labeled materials and an organic production system that uses only materials permitted by the Organic Materials Review Institute. This experiment was conducted at the Mountain Horticultural Crops Research Station, Fletcher, North Carolina, in the Mountain region of the Southeastern United States.

METHODS AND MATERIALS

Five production systems were established in 1995 to determine how tillage and management can affect the whole farming system. These systems include: 1.Conventional tillage/chemical management; 2. Conventional tillage/organic management; 3. Conservation-tillage/chemical management; 4. Conservation-tillage/organic management; and 5. Control-conventional tillage (no management). Chemical management methods include the use of synthetic chemicals common to production agriculture. Herbicides, insecticides, fungicides, and chemical fertilizers (P and K at recommended rates and nitrogen at 180 lbs/acre for tomatoes) are used in this treatment. Fumigation was used in the plow/plastic chemical management treatment (Treatment 1). Organic production methods include the use of materials allowable by the Organic Materials Review Institute (OMRI). Although the organic treatments (Treatments 2 and 4) use only allowable materials by OMRI, these plots have not been certified. Soybean meal was used as the nitrogen source, with the same N rate as the chemical treatments. All fertilizer materials were hand broadcast in-row before plastic was established (putting the fertilizer under the plastic) or after strip-tilling. The control treatment had no winter cover crop, no fertilizer or pesticides applied and was plowed similar to the conventional treatments. Irrigation was applied to all production treatments as needed, except for the control treatment which had no irrigation.

All production systems had a winter cover crop of wheat (50 lbs/acre) and crimson clover (20 lbs/acre). Plots that were conventional tillage-chemical were plowed in late April each year and the conventional tillage-organic in early May. Conservation tillage used strip-tillage for the tomatoes, using a Bush Hog Ro-till one week after herbiciding (conservation tillage-chemical) or flail chopping (conservation tillage-organic) and one week before transplanting. All plots were transplanted the third or fourth week of May. Each system had a 3 year rotation of vegetables on one half the plots, and the other half with continuous tomatoes. Only data from the continuous tomato treatments will be discussed in this publication.

RESULTS AND DISCUSSION

Tomatoes were grown each year on the continuous tomato section of each plot. The first few years all treatments steadily had lower tomato yields, with both tillage treatments with chemical management having greater yields (Figure 1). The last 4 years both plowed treatments (chemical and organic management) continued this pattern. The strip-till chemical tomato yields have maintained good yields, while the strip-till organic have increased each year. This contradicts the tomato vine weights 45 days after transplanting, where both plowed/black plastic production systems (both chemical and organic management) have greater growth early in the season compared to the strip-till systems (Figure 2). Conservation tilled vegetable crops with long growing seasons have similar yields to plowed conventional systems because plant (vine or stalk) growth generally is comparable by harvest time (Hoyt, 1999). Vegetable crops that are short season or have multiple harvests will start to produce fruit earlier in the conventional system due to warmer soil conditions compared to the mulch covered soil produced by conservation tilled systems (Hoyt and Konsler, 1988).

Each year we measured end of the season tomato vine, root, and weed biomass, and total fruit removed from the plot treatments. Figures 3 and 4 represent the nutrients removed (fruit) or recycled (vines, roots, weeds) back into the soil for each treatment. Each year variations did occur, but these data do represent similar data for each year. Vine biomass carbon averages around 1000 lbs C/acre, an amount similar to early winter cover crop plowdown. Weeds represent a considerable amount of organic matter going back into the soil for the two organic tillage treatments, the strip-till chemical, and the control treatments (these measurements are at the end of the tomato growing season, when fall weeds were allowed to grow due to the lack of fruit harvested towards the end of the season). The control treatment has nearly all plant components as weed organic C.

Fertilizer nutrients (N,P,K) moved both off the field (fruit) and recycled back into the soil. Fruit nitrogen removed 25 to 85 lbs N/acre from the field (depending on treatment), but recycled 30 to 90 lbs N/acre in the vine. Total N recycled back into the soil by weeds and plant ranged from 95 to 130 lbs N/acre (not counting the control treatment). Potassium was the plant nutrient taken up in the greatest quantity by these plant systems. Potassium too was exported from the field, and in greater amounts than nitrogen. Fruit potassium ranged from 50 to 130 lbs K/acre, compared to vine K of 50 to 85 lbs K/acre. Total recycled potassium to the soil ranged from 150 to 190 lbs K/acre. Roots add less than 5 lbs N or K/acre. The control treatment measures the amount of nutrients available from the soil only, thus the 30 lbs N/acre and 50 lbs K/acre taken up by the plant, fruit, and weeds (mostly weeds) would be the minimum amount these soils provide for any of the treatments. Nitrogen and potassium represent the major fertilizer nutrients needed by the plant (if we consider calcium being supplied by limestone).

Tomato fruit removed only about 15 lbs P/acre from a field, with another 15 lbs P/acre recycled back into the soil (Figure 4). Less than 1 lb of P/acre was measured in the roots for any treatment. Calcium and magnesium movement in plants and fruit were quite different than the potassium and nitrogen. Most of both Ca and Mg taken up by the plants (weeds and tomato) were measured in the vine and weed biomass. Less than 5 lbs Ca/acre and 7 lbs Mg/acre were removed in the fruit, yet the system (tomato and weeds) took up as much as 200 lbs Ca/acre and 80 lbs Mg/acre. Three lbs of Ca and less than one lb of Mg per acre were measured in the roots.

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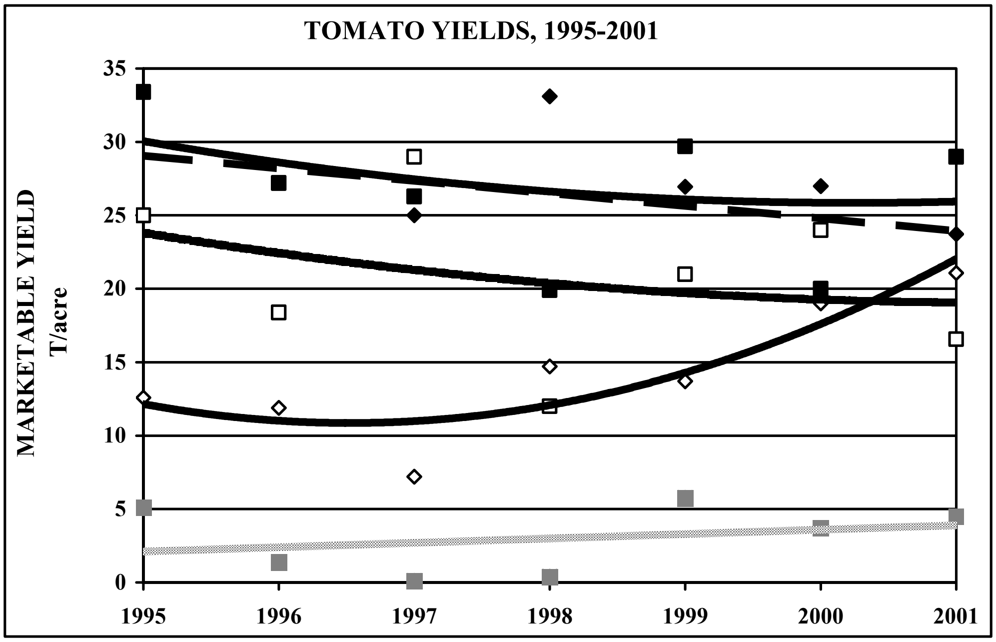

Figure 1. The effect of tillage and production methods on tomato yields from 1995 to 200

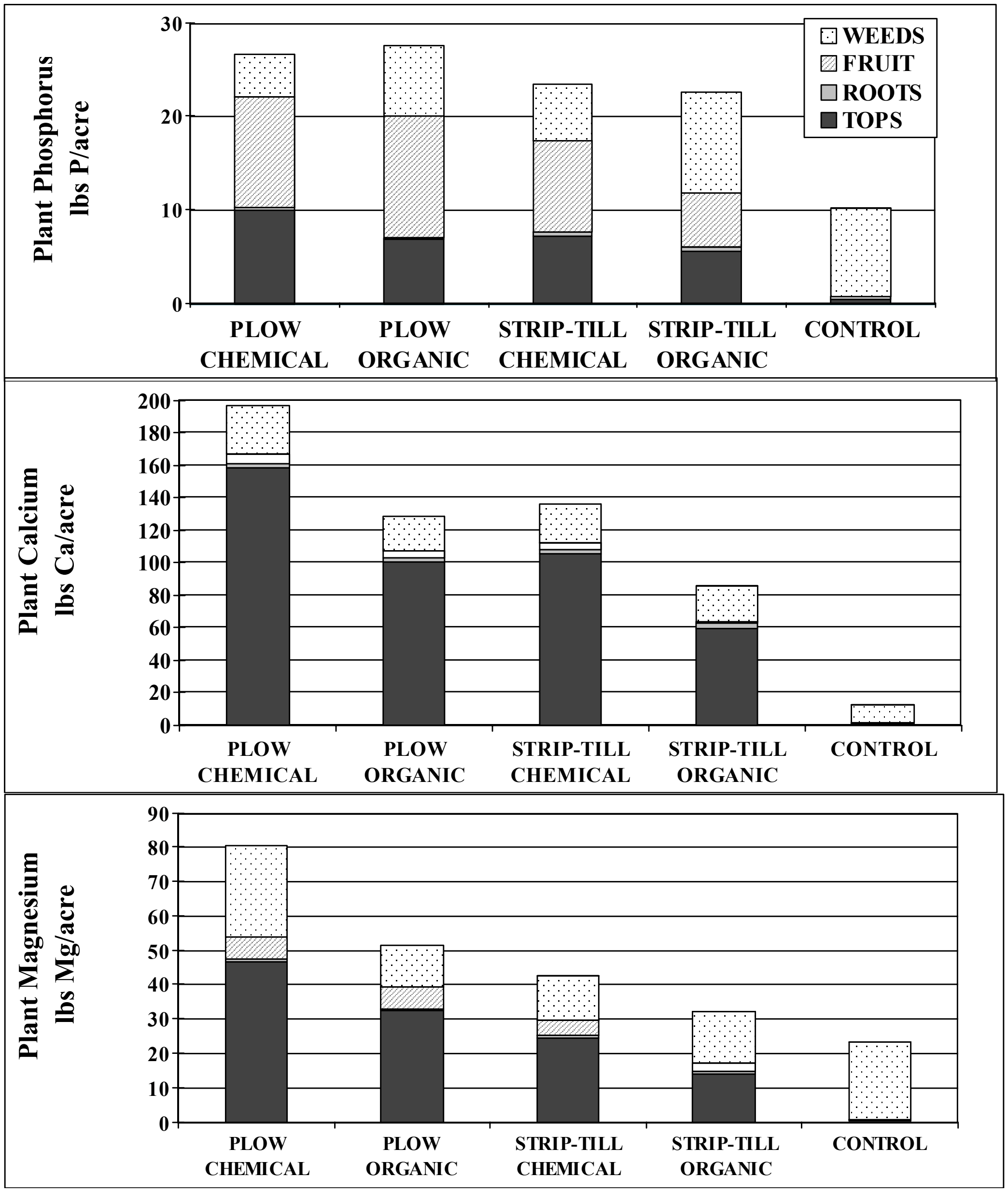

Figure 2. The effect of tillage and production methods on tomato vine growth 45 days after transplanting

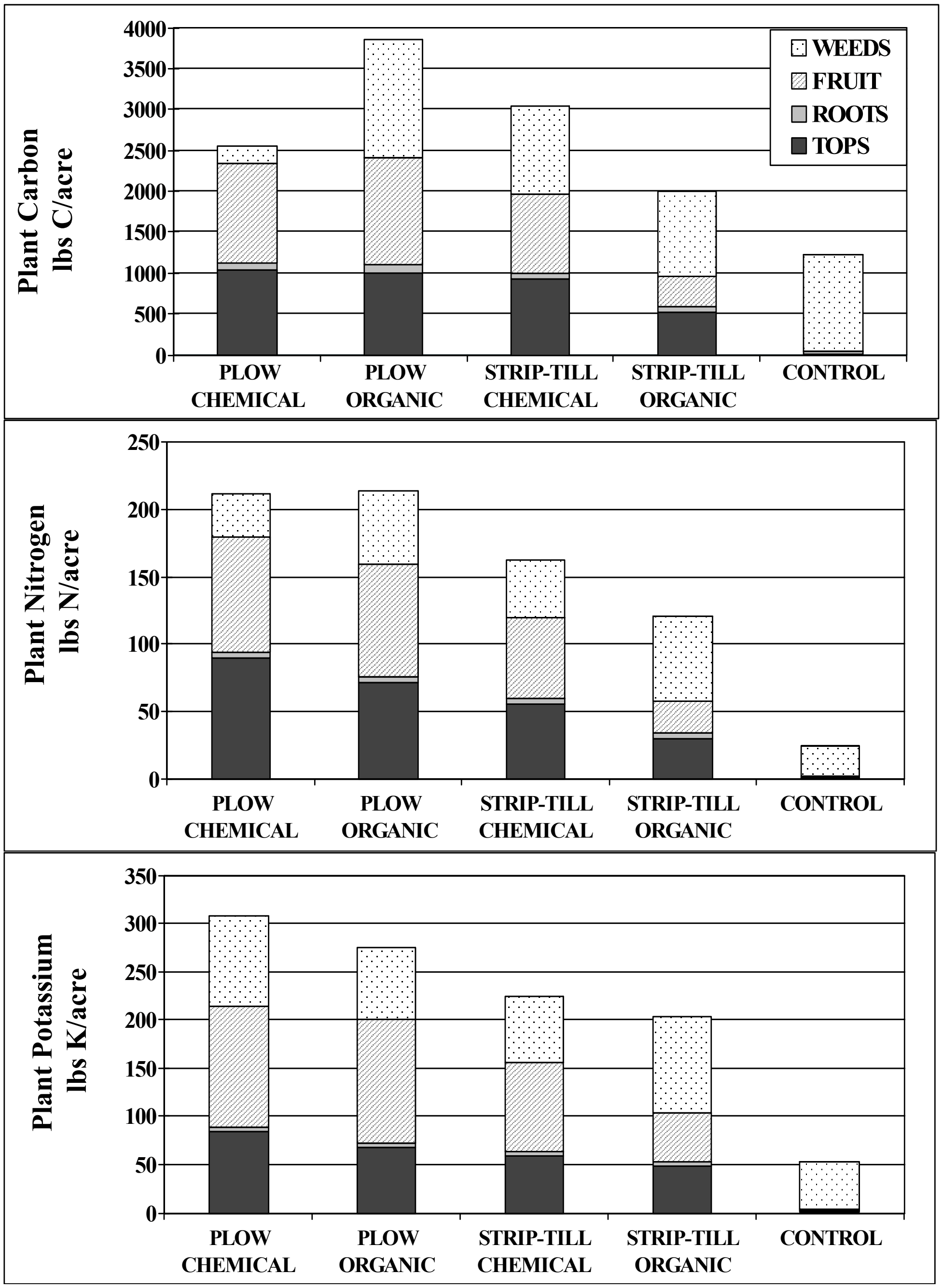

Figure 3. Tomato top (vine), root, fruit, and weed carbon, nitrogen, and potassium uptake measured at final harvest.

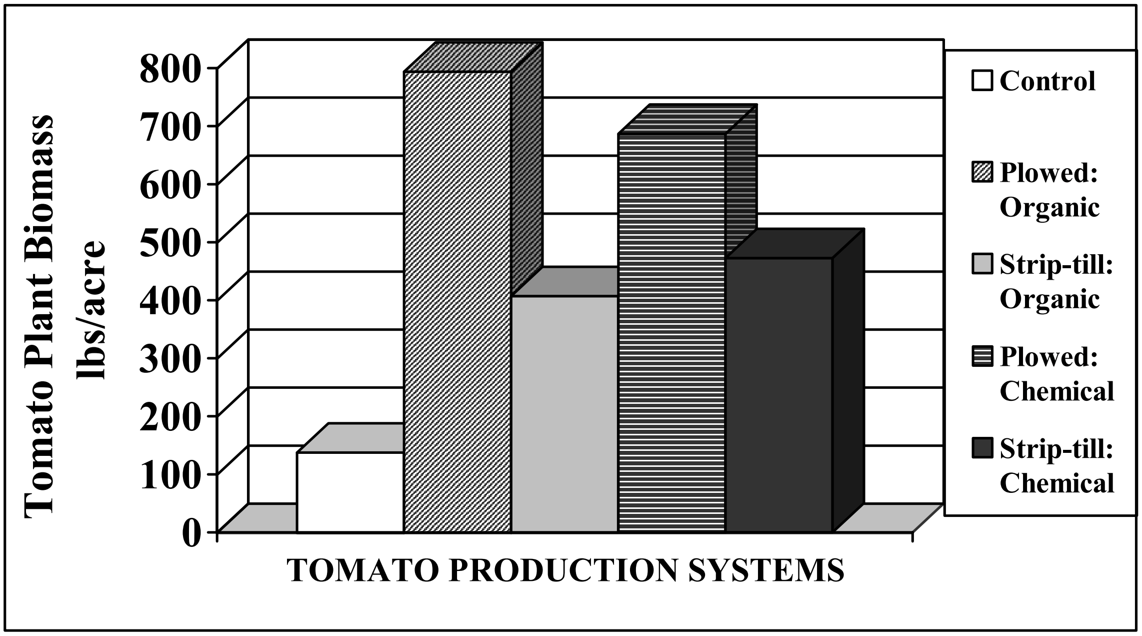

Figure 4. Tomato top (vine), root, fruit, and weed phosphorus, calcium, and magnesium uptake measured at final harvest

GRAIN SORGHUM RESPONSE TO TILLAGE AND CROP ROTATION

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ABSTRACT

Grain sorghum [Sorghum bicolor (L.) Moench] producers are challenged to utilize alternate production methods to slow rising production input costs and improve profitability. Objectives of this research include investigations of fossil fuel saving tillage practices, possible yield enhancing crop rotations and varying levels of fertilizer phosphorus (P) and micronutrients, iron (Fe) and zinc (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. Initial year results for sorghum following cotton compared to sorghum following sorghum showed a significant 30 percent grain yield increase when averaged across all tillage and fertilizer variables. With severe moisture stress in years 2 and 3, the rotation benefit decreased substantially due to drought stress. Phosphorus, Zn and Fe fertilizer response was measured in the third year. Early season plant growth differences in favor of MT failed to translated into final grain yield differences due to moisture stress prior to physiological maturity. Sorghum head insect count differences were largely changed by rotation in the three studies. Grain yields in Year 4 were considerably improved over yields for the past two years. While overall average yields were not significantly affected by treatment, yield breakout within tillage system shows up to 22% yield gain directly attributed to rotation with cotton. Yield response to P approached 28% under MT with sorghum following cotton with a lesser response in continuous sorghum. Sorghum head insect counts were not significantly changed by tillage or rotation alone but were affected by a rotation x tillage interaction in year 4 of the study. However, conclusive evidence of treatment effect on insects is not offered at this time without additional data collection. Preliminary economic evaluation of the positive benefits of reduced tillage, crop rotations and P indicate considerable impact by these variables. Summary of differences in input costs for power unit, equipment and labor allocation for sorghum production using the MT system in contrast to CT showed a savings for approximately $36.40 per acre. The 4-year average yield increase due to rotation was an impressive 21 percent. Assuming this yield increase translates into at least 525 lb grain/ac or some $15-$16 per acre additional net income, the additive benefits of using the MT system and crop rotation practices exceed $50 per acre.

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. Reduction in tillage in the Southeast USA (Motta, et al., 2000) and the Southwest USA (Cripps and Matocha, 1987; Matocha, J.E. and D.R. Sorenson. 1987; Matocha, Provin and Vacek, 1999; Barber and Matocha, 1994) has been shown to improve soil chemical and physical quality parameters.

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 minimum (MT) and conventional tillage (CT) with varying P fertilization.

MATERIALS AND METHODS

Crop rotations included cotton and grain sorghum planted in alternating years compared with continuous sorghum. Tillage comparisons included a CT system involving 7-8 tillage operations per year that was compared with a MT system that reduced tillage operations to 3-4 per year. Tillage depths were restricted to 3 inches or less in MT and 6-10 inches in CT systems.

Soil fertility comparisons in all tillage and cropping systems were evaluated at three levels of P fertilizer; with the MT treatment supplemented with Zn and Fe. For Year 1, P rates were 0, 20, and 40 lb P_2O_5/ac, while in years 2, 3 and 4 rates were decreased to 0, 10, and 20 lb P_2O_5/ac. Nitrogen (N) was blanketed to all treatments except fertilizer control at soil test recommended rate for 5,500 lb/ac grain yield (approx. 60 lb N/Ac). All fertilizer was preplant, banded in a 4"x 3" matrix.

The experimental design was a randomized block design using crop rotation as main blocks, tillage treatments as sub-blocks, fertility levels as split-plots and plant densities as split-split plots. All treatments were studied in three replications.

The experiment was located in all years at the Perry Foundation farm west of Robstown, Texas on a Clareville sandy clay loam (Pachic Argiustoll). History of the experimental site included the field being split into commercial sorghum and cotton production with both crops receiving equal fertilizer N applications in previous seasons. Also, no P fertilizer had been applied for three seasons prior to the initial year of this study.

Other agronomic methodlogies involved in Year 1 included gaucho insecticide treated grain sorghum hybrid, DK-52 (medium maturity) which was planted on February 25, 2000, into seedbeds with marginal soil moisture. Seeding rate was 94,000 seed/ac in 30-inch rows. In years 2, 3 and 4 - the crop rotation, soil fertility, and tillage treatments were studied at two seeding densities (approximately 60,000 and 75,000 seed/ac). Both tillage systems and crop rotations were evaluated at reduced levels of P fertilizer (0, 10, 20, lb P_2O_5/ac) for each of the three seasons. Each split-split plot consisted of 6 rows with 250-foot row lengths.

Planter-box insecticide treated grain sorghum hybrid, DK-52 (medium maturity) was planted in all treatments in March, 2001 and 2002, into seedbeds with marginal soil moisture. In 2003, the same sorghum hybrid was seeded approximately four weeks late (April 10) due to wet fields. Appropriate statistical analyses were preformed on all collected field data.

Insect data were collected as follows. Tillage and crop rotation effects on abundance of soil inhabiting insects such as southern corn rootworm, grubs and borers were assessed in all years by visual inspection of early damage to sorghum plants. Later, three insect samples were taken from all treatments every other week over a 5-week period from May 17 to June 14, in the first three 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. In 2003, insects were sampled from all sorghum plots 3 times, June 27, July 11, and July 27. Sampling methodlogy was identical to that described earlier.

RESULTS AND DISCUSSION

Grain Yields - Year 1:

Yield levels for the first year 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 lb/ac. Average yield for all 24 treatments was 3007 lb/ac. Sorghum grown in rotation with cotton averaged 3384 lb/ac across tillage and fertility regimes while continuous sorghum produced average grain yields of 2605 lb/ac (Figure 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. 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 as expected since initial soil test values failed to indicate a need for P fertilizer.

Insect Evaluations - Year 1:

Damage to sorghum plants by soil inhabiting insects was monitored by visual inspection with no evidence of damage recorded for all years. Sorghum head insect counts were made at two dates. At the mid-May insect count, data indicated only small and largely non-significant differences in numbers of headworms and predators due to treatment. However, insect counts two weeks later, June 1, showed large increases in headworms, stink bugs and predators (Table 1). The headworm numbers were still below threshold levels, but stink bugs increased to an average range of 1.4 to 5.9 per head 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. Insect counts for the third period were not significantly affected by treatment.

Grain Yields - Year 2:

Grain yields for 2001 were drastically reduced by drought and approximated only 33 percent of expected normal yields. Only 3.61 inches of precipitation were recorded for the period following planting through physiological maturity. Grain yields ranged from a high of 2025 to a low of 1108 lb/ac. No yield difference was recorded due to plant density. Conventionally tilled sorghum grown in rotation with cotton yielded 1662 lb/ac when averaged over fertility regimes and population densities, while continuous sorghum produced average grain yields of 1373 lb/ac. or approximately 21% less (Figure 2). The benefit from rotation appeared less consistent and smaller within the MT system. Breakout of yields within the P rates showed larger rotation effects at lower P fertilizer rates.

Grain sorghum response to P fertilizer was variable with tillage intensity and cropping system. A statistically significant grain yield increase of 439 lb/ac was measured from 10 lb P_2O_5/ac in the CT and cotton: sorghum systems. Although variable, there appeared to be better response to rotation under CT as compared to the MT system as P fertilizer rates increased. 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 yield.

Insect Evaluations - Year 2:

Damage to sorghum plants by soil inhabiting insects was monitored by visual inspection with no evidence of damage recorded as was the case in Year 1. Although tillage and fertilizer treatments had no effect on headworms, rotation did significantly affect headworm densities. During sampling periods 1 and 2, headworm densities were greater on sorghum planted in rotation with cotton (0.65 per plant), than for continuously planted sorghum (0.29 per plant). Rice stinkbugs were significantly affected only by an interaction between rotation, tillage, and fertilizer treatment. This interaction occurred because stink bug numbers were higher on the sorghum/cotton rotation than on continuous sorghum for the CT plots. This was also true for the MT system, but only when fertilizer treatments with Fe and/or Zn were excluded from the comparison. Rotation had no effect on stinkbug densities when Fe and/or Zn were added.

Grain Yields - Year 3:

Yields for 2002 were significantly improved over those for the 2001 season (2.23X) due to higher soil profile water at planting. Yields ranged from a high of 4276 to a low of 2241 lb/ac with both extremes measured with the higher plant density. Average yields for the 24 treatments were 3357 and 3231 for the high and low plant densities, respectively. Since data indicate that the small seeding rate variable (22%), had essentially no effect on grain yield, data is presented as averages over plant densities (Figure 3). Sorghum grown in rotation with cotton averaged 3312 lb/ac across treatment variables, while continuous sorghum produced average grain yields of 3073 lb/ac (n.s. difference). The average yield advantage in 2002 attributed specifically to rotation was 239 lb/ac that accounted for an 8% increase. However, further breakout of yields within tillage and plant density systems showed a 563 lb/ac increase due to rotation which reflected a 19% benefit at the higher plant populations.

Grain sorghum response to P fertilizer was variable with tillage intensity and cropping system. A yield increase of 510 lb/ac was measured from 20 lb P_2O_5/ac in the MT cotton: sorghum system. In general, response to P fertilization was less consistent as tillage intensity increased. Response to soil applied Zn and Fe together with 20 lb/ac of P_2O_5 was variable but appeared somewhat more consistent with continuous sorghum. Fluid Zn or Fe fertilizer mixed with the 11-37-0 (ammonium polyphosphate), applied individually, produced 1013 and 1140 lb/ac additional grain, respectively, when sorghum was grown without rotation at the lower plant population (Figure 4). This is the first such significant response measured and could be indicative of a developing nutritional requirement for micronutrients by grain sorghum under these conditions.

Reducing tillage to three operations rather than seven produced essentially no difference in grain yield as was the case in previous season, however soil moisture readings down to 24 inches showed a positive influence from MT earlier in the growing season**.**

Insect Evaluations - Year 3:

Sorghum midge populations definitely were not a yield limiting factor in the 2002 results. Headworms were only present during the first 2 sampling periods. None of the factors, rotation, tillage, or fertilizer treatment significantly affected headworm densities. In part this may have been due to very low densities with only 3.5 headworms per 10 heads during the first sampling period, 0.9 during the second period, and 0 during the 3rd period. Predators were also unaffected by any of the factors examined although their numbers were slightly higher than headworm numbers. Also, the relationship between headworm densities and predator densities was not statistically significant.

Rice stinkbug densities were significantly affected by both rotation and tillage (Table 2). Stinkbug densities were lower on sorghum grown in rotation with cotton (5.8 per 10 heads) than on continuous sorghum plots (8.9 per 10 heads) (F=12.1; df=1, 9; p=0.042). Tillage also significantly affected stinkbug densities, but only during the second sampling period, as demonstrated by the significant tillage by sampling date interaction (F=7.3; df=2, 18; P=0.048).

Grain Yields - Year 4:

Grain yield data are presented in Figures 5-7. Yields for 2003 increased to near long-term average yields and considerably above the yields measured in the first two years. Only 3.60 inches of precipitation were recorded for the period following planting through physiological maturity. This represents approximately 37% of the long-term average. However, substantial precipitation in months prior to planting provided a full profile of soil moisture. Grain yields ranged from a high of 4046 to a low of 2659 (lb/ac) lb/ac. Average yields for the 24 treatments were 3254 and 3219 (lb/ac) for the high and low plant densities, respectively, with no significant response to seeding rate regardless of tillage or cropping system. Sorghum grown in rotation with cotton averaged 3316 lb/ac across tillage, fertility regimes and population treatments, while continuous sorghum produced average grain yields of 3157 lb/ac. The benefit from rotation appeared consistent within tillage systems and for most fertilizer rates. These yields were greater than last season's drought stressed production, but the overall average yield advantage attributed specifically to rotation was nonsignificant. However, further breakout of the yield data within the minimum till systems showed a range of 8 to 19% yield increase from rotation at the lower plant population. Sorghum grown under CT produced yield increases of 14 to 22% attributed to crop rotation. As P fertilizer rates increased, there appeared to be better response to rotation under both MT and the CT systems. Response to P fertilizer was measured under both tillage systems but the largest yield increase occurred with MT. Twenty lb/ac of P_2O_5 applied to sorghum following cotton increased grain yields 850 lb/ac or some 28%. The addition of trace elements, Zn, and Fe, to continuously cropped sorghum produced a slight yield increase, with the largest yield boost was recorded when the two trace elements were supplied in combination (Figure 6). Yield data shows that trace elements were not required by sorghum grown in rotation with cotton. However in a monoculture sorghum system, Zn influenced yields only when chelated Fe was applied.

Headworm densities were low every week, with 0.71 per head during week 1, 0.094 during week 2, and 0.005 during week 3. Due to the very low numbers during weeks 2 and 3, only significant factor effects were tested during week 1. During week 1, mean headworm densities were not significantly affected by fertilizer treatment. Also, headworm densities were not significantly affected by either rotation or tillage alone, but were affected by a rotation by tillage interaction. This occurred because mean headworm density was lower in MT plots in continuous sorghum (0.46 per head) than in MT plots in the sorghum/cotton rotation (0.92 per head). However, mean headworm densities were not significantly different in the CT system in continuous sorghum (0.79 per head) than with CT in the sorghum/cotton rotation (0.71 per head).

Mean rice stinkbug densities increased from week 1 (0.3 per head), to week 2 (0.44 per head) to the highest level during week 3 (0.51 per head), but were not significantly affected by rotation, tillage, or fertilizer treatments. Similarly, treatments did not affect overall predator density.

SUMMARY

Economic Impact:

Preliminary economic evaluations of the positive benefits of reduced tillage, crop rotations and P fertilization indicate considerable impact by these variables, some more than others, on the profitability of grain sorghum production under dryland conditions in South Texas.

Summary of differences in input costs for power unit, equipment and labor allocation for sorghum production using the MT system in contrast to CT showed a savings of approximately $36.40 per acre. These savings coupled with a slight increase in grain yields (approximately 210 lb/ac, 4-year mean) due to reduced tillage pushes the per acre savings to over $40/acre.

In addition to the tillage variable impact on per acre costs of grain sorghum production, this PROFIT project had begun to demonstrate the additional yield benefits due exclusively to rotating sorghum with cotton in a one year system. The 4-year average yield increase was an impressive 21 percent. Assuming the 21 percent yield increase translated into at least 525 lb grain/ac or some $15-$16 per acre additional net income, the additive benefits of using reduced tillage and crop rotation practices exceed $50 per acre. Due to recent budget constraints, unfortunately this project had to be terminated before the full benefits of MT and crop rotation are realized.

ACKNOWLEDGEMENTS

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Table 1. Mean numbers of sorghum head insects & predators for fertilizer, tillage and cropping systems variables (PROFIT-00).

Systems			May 17, avg. of 10 head			June 1, avg. of 10 heads		
Cropping	Tillage	[1]Fertility (lb/Ac)	Head worms	Stink bugs	Predators	Head worms	Stink bugs	Predators
Sorg:Sorg	[2]CT	P = 0	0.17	0.03	0.00	0.57	1.40	0.43
Cot:Sorg	CT	P = 0	0.17	0.21	0.07	0.23	4.73	0.10
Sorg:Sorg	[3]MT	P = 0	0.27	0.57	0.03	0.53	1.70	0.33
Cot:Sorg	MT	P = 0	0.17	0.53	0.00	0.27	4.97	0.50
Sorg:Sorg	CT	P = 20	0.20	0.03	0.13	0.77	2.13	0.20
Cot:Sorg	CT	P = 20	0.20	0.43	0.03	0.27	3.57	0.10
Sorg:Sorg	MT	P = 20	0.23	0.03	0.03	0.50	2.03	0.33
Cot:Sorg	MT	P = 20	0.23	0.67	0.00	0.10	5.90	0.23
Sorg:Sorg	CT	P = 40	0.07	0.07	0.40	0.70	3.27	0.13
Cot:Sorg	CT	P = 40	0.20	.013	0.07	0.23	3.97	0.17
Sorg:Sorg	MT	P = 40	0.00	0.03	0.00	0.63	1.50	0.47
Cot:Sorg	MT	P = 40	0.07	0.77	0.03	0.17	5.60	0.13
Sorg:Sorg	MT	P = 40 + Zn	0.13	0.47	0.00	0.47	2.13	0.43
Cot:Sorg	MT	P = 40 + Zn	0.17	1.67	0.03	0.23	4.83	0.23
Sorg:Sorg	MT	P = 40 + Fe	0.17	0.43	0.03	0.57	1.63	0.23
Cot:Sorg	MT	P = 40 + Fe	0.13	0.23	0.00	0.67	4.60	0.27
Sorg:Sorg	MT	P = 40 + Zn + Fe	0.13	0.03	0.03	0.53	2.60	0.30
Cot:Sorg	MT	P = 40 + Zn + Fe	0.20	0.50	0.07	0.20	4.43	0.33

[1] N fertilizer blanketed to all treatments except fertilizer control. P rates are expressed as lb/ac of P_2O_5. Fe & Zn both applied preplant in band with N & P.

[2] CT=Conventional tillage.

[3] MT=Minimum tillage. Fertility P had no effect on all 3 insects.

Table 2. Mean numbers of rice stinkbug per 10 sorghum plants for different fertilizer, tillage treatments in sorghum: cotton rotation or continuous sorghum plots (Sorghum PROFIT - 2002).

Fertilizer Treatments	Conventional Tillage				Reduced Tillage			
	Sorg:Cott	S.E.	Sorg:Sorg	S.E.	Sorg:Cott	S.E.	Sorg:Sorg	S.E.
N0P0	3.67	0.87	7.56	2.56	5.67	0.60	9.00	
P0	5.78	1.87	12.56	2.80	5.89	0.61	8.00	
P20	5.00	1.55	8.89	1.89	8.11	1.54	9.00	
P40	9.56	4.41	8.00	2.13	4.89	1.81	7.00	
Combined	6.00	1.28	9.25	1.18	6.14	0.64	8.25	
P40Fe	NA		NA		5.22	0.95	12.56	
P40Zn	NA		NA		4.44	0.78	9.11	
P40FeZn	NA		NA		5.11	1.49	5.44	
Combined					4.92	0.97	9.04	

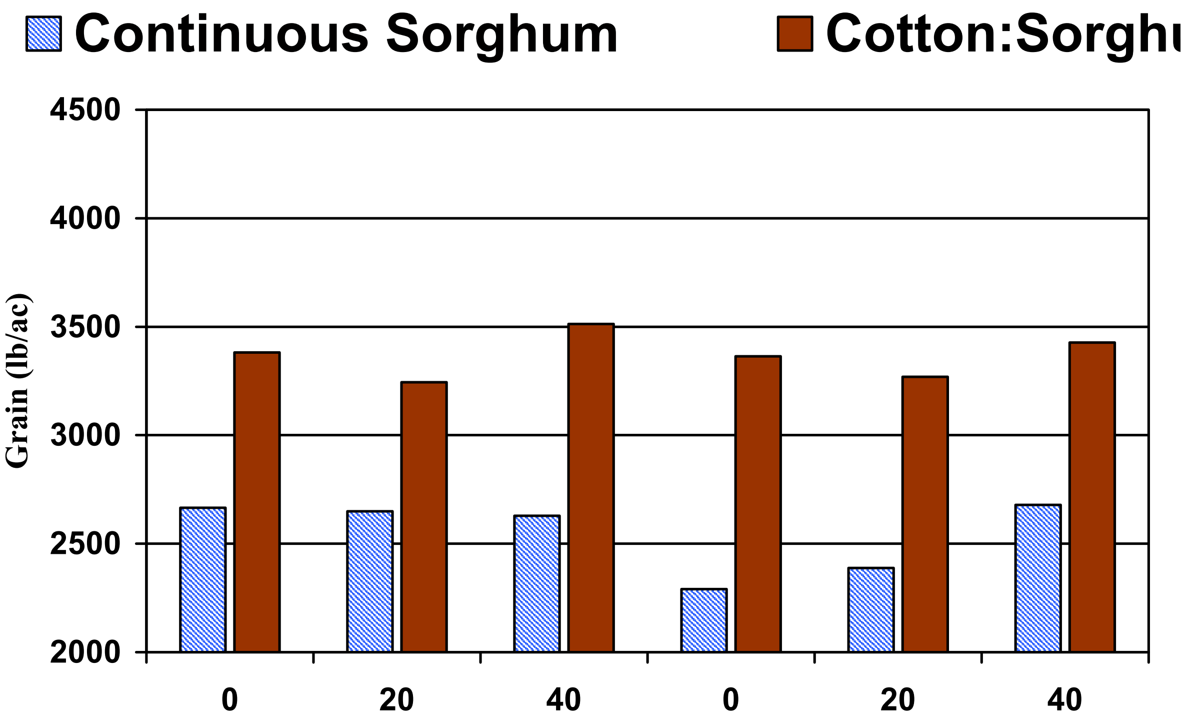

Figure 1. Effects of P fertilization and crop rotation on grain sorghum grown under conventional and minimal till systems (Sorghum PROFIT - 00). LSD (0.05) = 554.

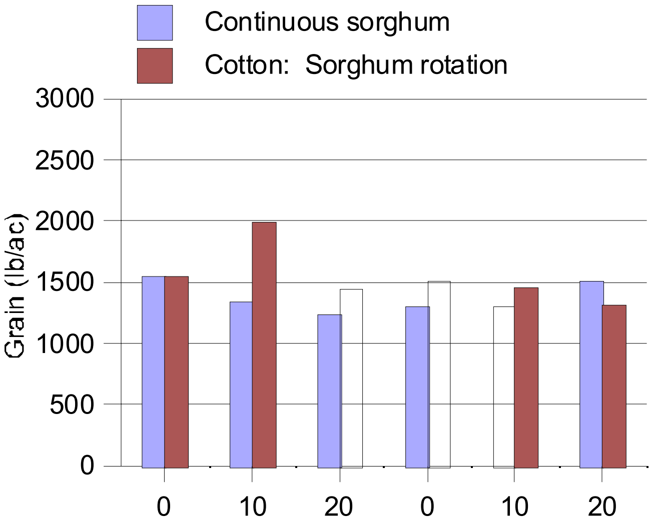

Figure 2. Effects of P fertilization and crop rotation on grain sorghum grown under conventional and minimum till systems, averaged over plant populations (Sorghum PROFIT-01). LSD (0.05) = 429.

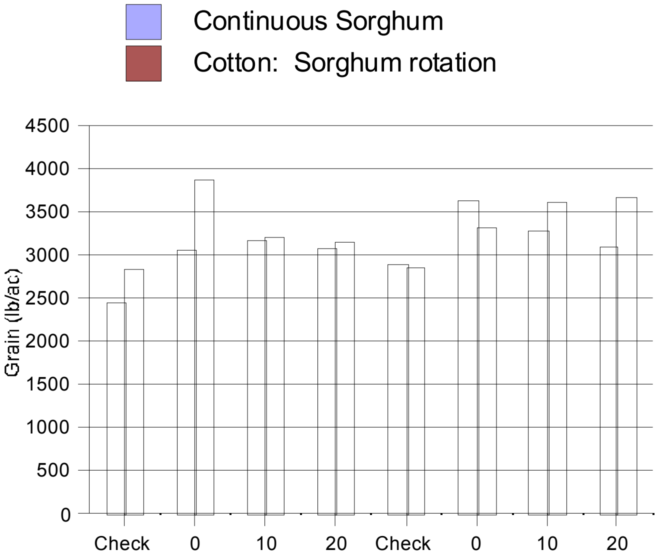

Figure 3. Effects of P fertilization and crop rotation on grain sorghum grown under conventional and minimum till systems, average over plant densities. (Sorghum PROFIT - 02). LSD (0.05) = 1064.

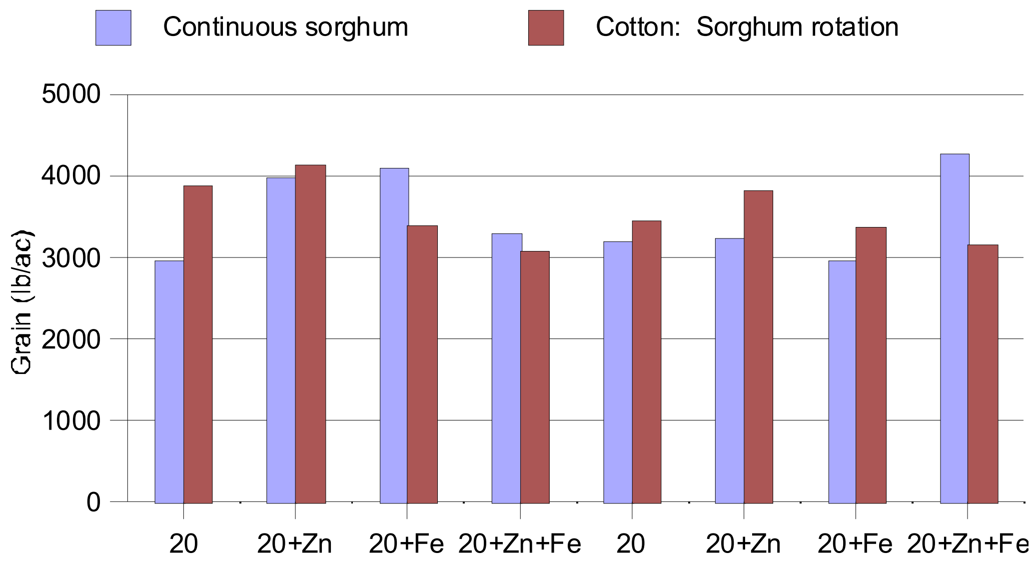

Figure 4. Effects of P, Zn, Fe fertilization and crop rotation on grain sorghum grown under minimum till at two plant populations (Sorghum PROFIT-02). LSD (0.05) = 1064.

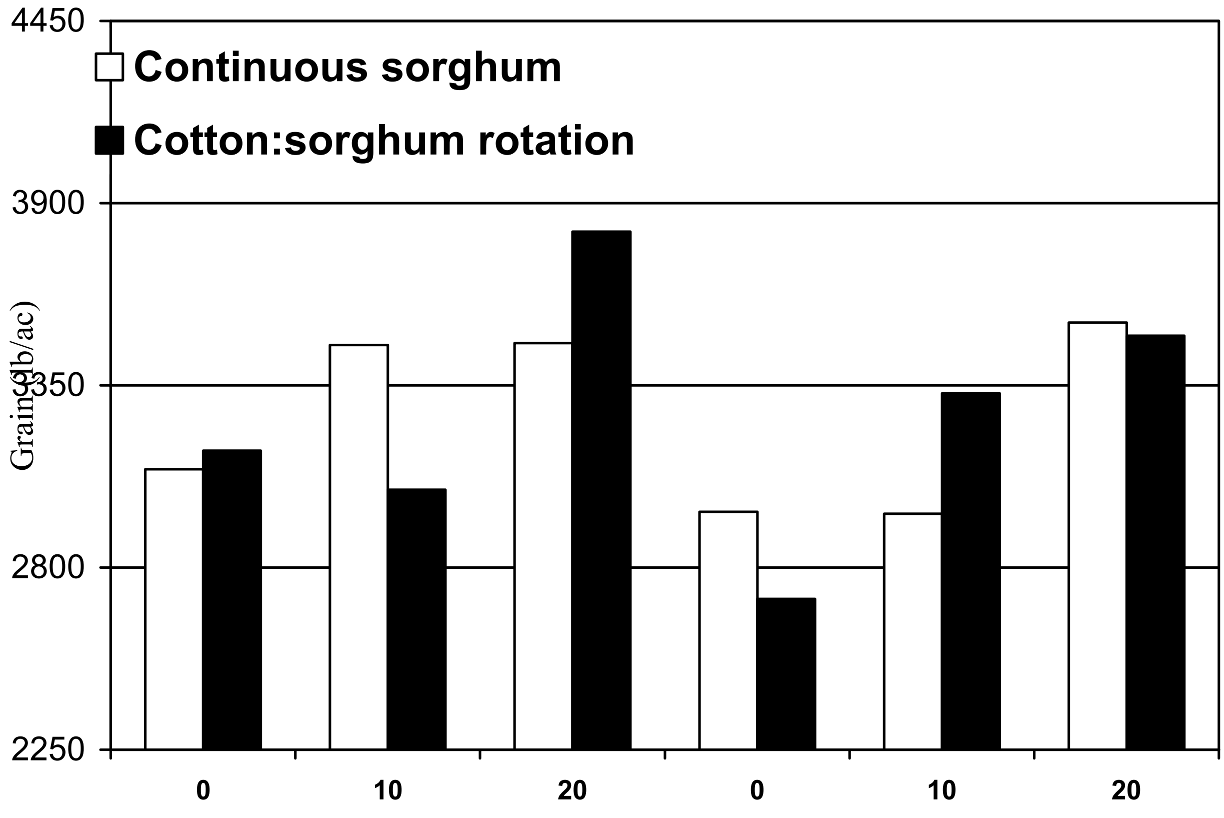

Figure 5. Effects of P fertilization and crop rotation on grain sorghum grown under conventional and minimum till systems at higher plant populations (Sorghum PROFIT - 03). LSD (0.05) = 638.

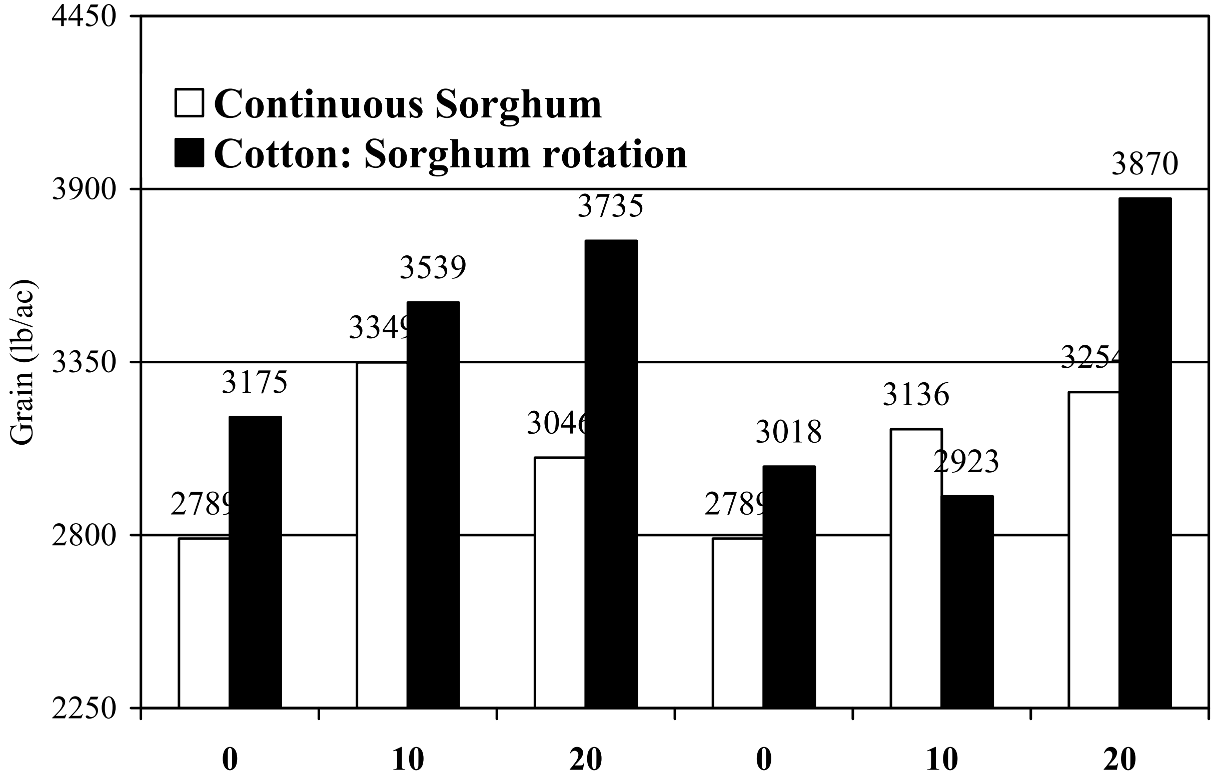

Figure 6. Effects of P fertilization and crop rotation on grain sorghum grown under conventional and minimum till systems at lower plant populations (Sorghum PROFIT - 03). LSD (0.05) = 801

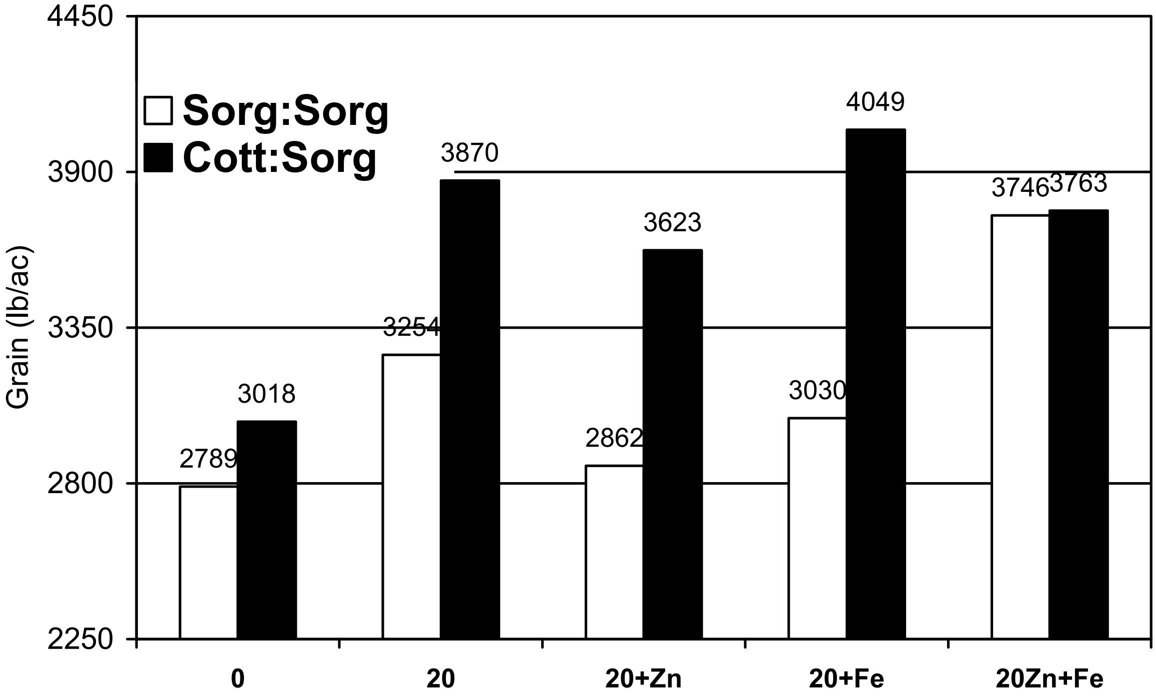

Figure 7. Response to P and trace element fertilizers by grain sorghum grown under rotation, minimum tillage and lower plant population (Sorghum PROFIT - 03). LSD (0.05) = 802.

POTENTIAL FOR REDUCED TILLAGE TOBACCO PRODUCTION IN NORTH CAROLINA

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ABSTRACT

Flue-cured and burley tobacco were grown on approximately 154,000 and 6,000 acres, respectively, in North Carolina in 2003. Burley tobacco is grown in the Mountains of NC and some flue-cured tobacco is grown in the northwestern Piedmont where topography, available farm land for row crop agriculture, and soil conservation requirements have lead to adoption of soil conservation practices including no-till tobacco production. Research on no-till production of burley and flue-cued tobacco has been conducted for many years in NC. No-till systems have been comparable to conventional systems in burley tobacco, but several production-related issues have prevented adoption of no-till systems in flue-cured tobacco. Weed control was the primary limiting factor to successful production of no-till burley tobacco, but was only one of the limiting factors to production of no-till flue-cured tobacco. Clomazone and sulfentrazone were labeled in the late 1990's and dramatically improved weed management in tobacco allowing burley growers to adopt no-till production. However, restricted root growth, lodging, and reduced yields that are common in flue-cured tobacco have limited adoption of no-till. Problems observed in flue-cured production are likely related to restricted root growth in flue-cured soil types that is not observed in burley production areas. Recent research has shown that strip tillage and/or minimum tillage systems have been successful in over-coming many of the soil related problems associated with no-till production with similar soil conservation benefits to no-till.

SUMMARY

Flue-cured and burley tobacco were grown on approximately 154,000 and 6,000 acres, respectively, in North Carolina in 2003. Burley tobacco is grown in the Mountains of NC and some flue-cured tobacco is grown in the northwestern Piedmont where topography, available farm land for row crop agriculture, and soil conservation requirements have lead to adoption of soil conservation practices including no-till tobacco production. Tobacco soils have a high potential for soil erosion. Research in1983 showed that soil loss with a 1.3% slope was 0.05 ton/acre with no-till tobacco versus 1.1 ton/acre with conventional tillage. When the slope was 3.1%, soil losses were 0.05 ton/acre with no-till versus 4.03 tons/acre with conventional tillage.

No-till tobacco is typically grown in a rye cover crop or sod killed with either paraquat or glyphosate. It is transplanted using a modified mechanical transplanter with a fluted coulter, a double disc row opener, and more narrow press wheels with reinforced rims. Some no-till transplanters have also included a straight shank or a winged knife to provide sub-surface tillage, which in some cases improved stands and root development. Sulfentrazone and clomazone are commonly used at transplanting for preemergence weed control because they do not require soil incorporation for activation and control many of the problem weeds in tobacco production. No-till tobacco typically requires about a 25% increase in nitrogen rate. Additional production practices are the same as conventionally grown tobacco.

No-till Burley Tobacco

No-till burley tobacco has been successfully grown in most burley producing areas of NC. However, wide adoption of no-till production has not been observed. It is estimated that less than 5% of the burley acreage is no-till. Acreage of burley tobacco on individual farms is relatively small and growers are able to rotate tobacco on soils that are not highly erodible. Early research with no-till burley tobacco showed that one of the greatest limiting factor to production was weed control. Work in 1986 showed an 18% decrease in yields of no-till tobacco compared to conventional. Reduced yields were related to lack of tillage and weed interference. In later research at the Upper Mountain and Mountain Research Stations from 1989 to 1994, yields of no-till tobacco were greater than conventional five out of six years. Better weed control with new herbicides and improved mechanical transplanters improved yields compared to previous work.

No-till Flue-cured Tobacco

Production of no-till flue-cured tobacco in North Carolina has not been as successful as production of burley tobacco. In research trials in the early 1990's, quality flue-cured tobacco could be produced with no tillage, however, yields of no-till were sometimes reduced and were highly variable. Failures with no-till flue-cured tobacco were related to dry growing seasons, lack of irrigation, and low mulch density. In addition, soils in the Northern Piedmont of NC have a high percentage of clay and may not be as suitable for no-till tobacco as soils commonly found in burley producing areas. Poor root development in no-till flue-cured tobacco compared to conventional tillage was common at locations where yields were reduced, as indicated by a greater incidence of lodging after high winds. Research with strip tillage and minimum tillage has been more successful in reducing soil loss without sacrificing yields of flue-cured tobacco.

EFFECT OF CONSERVATION TILLAGE IN A CORN-OAT ROTATION SYSTEM ON CORN AND FORAGE OAT YIELD IN THE NORTH-CENTRAL REGION OF MEXICO

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ABSTRACT

The objective of this study was to assess the effect of different tillage methods in an irrigated corn-oat rotation system on corn grain, stubble, and forage oat yield. Seven tillage methods were evaluated: 1) traditional plow and disk (P+D), 2) disturbing the upper 0-4 in layer (D), 3) without disturbing the upper 0-4 in layer (ND), 4) zero tillage with 0% soil cover (ZT+0%SC), 5) zero tillage with 33% soil cover (ZT+33%SC), 6) zero tillage with 66% soil cover (ZT+66%SC), and 7) zero tillage with 100% soil cover (ZT+100%SC). In each year from 1996 to 2001, corn was sowed on the spring while forage oat was growth during the fall-winter season. A statistical analysis for the six-year period for grain corn, stubble, and forage oat yield was performed. Corn grain yield results showed statistical differences among treatments ($p \leq 0.05$), where ZT+66%SC was the best treatment, surpassing by 90% the corn yield registered with P+D. The statistical analysis for corn stubble yield showed not differences ($p \geq 0.05$) among treatments, however, with ZT+66%SC corn stubble production was increased 9.35 ton acre^{-1} compared with that of P+D, indicating that farmers can use 5.45 ton acre^{-1} to cover at least 33% of the soil surface. Forage oat yield within the seven treatments were not statistically different ($p \geq 0.05$), but all ZT treatments did not plow the soil. Conclusions for this study were that corn and forage oat can be growth without plowing the soil, increasing corn production and keeping stable that of forage oat.

INTRODUCTION

"The truth is that nobody has ever exposed a scientific reason to till." This phrase was mentioned for Edward H. Faulkner in the decade of the 1940s, and he largely was criticized for his contemporaries (Faulkner, 1974). Nevertheless, currently it is given him the reason by questioning the efficiency of plowing the soil to produce crops. Techniques such as conservation tillage have been developed with excellent results in several regions around the world, but as it happened with plowing and disking, it should not be accepted without local scientific evidences.

With his research results, Faulkner showed that erosion, soil impoverishment, and yield reduction are the results of inadequate soil management by farmers. He challenged the technological advancement at his time about how to produce crops, declaring that plow is and has been the main enemy of soils. He assured that by leaving crop residues on the soil surface, instead of burring them at the bottom of the soil profile removed by plow, and by weathering effects, the necessary soil organic matter for the next crop would be produced. For more than a century, scientists and farmers have accepted the use of plow and disk without any reserve.

Plow's adoption has been without any discrimination for all soil types, climates, and crops. Technical guides recommended by research, teaching, and extension institutions present the use of plow and disk as the only option of soil tillage before sowing. In Mexico, conservation tillage has been promoted to farmers in the last 30 years with unsuccessful results, therefore the actual area at national level with conservation tillage does not surpass 10,000 acres, which is minimum compared with that of other Latin-American countries such as Brazil, where in recent years, conservation tillage has been implemented in 34 million acres (Claverán, 2000).

Soil erosion is one of the main problems that threaten the sustainability of agriculture, so that development of production systems with a sustainable scope should be a priority to satisfy production and quality demands of consumers (Osuna, 2000).

Conservation tillage is one of the most viable options to achieve the sustainability of natural resources such as soil and water, and crop yields (Angeles and Rendón, 1994 and Valdes et al., 1994). With conservation tillage, soil is protected of water and wind erosion, lost of nutriments is reduced, more soil water is available to plants, and soil organic matter, infiltration, and flora and fauna are increased (Figueroa 1975, Figueroa 1982 and 1983, Jasso 1985, Barron 1987 and Osuna 1987).

Among the main constraints to adopt conservation tillage in the semiarid zones in Mexico's north-central region, are: low diffusion among farmers, need of specialized machinery, use of herbicide, and above all that, the utilization of stubble to feed animals (Salazar et al., 1994). The use of crop residues as soil mulch is a key factor to succeed in conservation tillage, given that greater the quantity of residues left as soil mulch, greater will be the soil protection against erosion. The use of crop residues, especially corn stubble, to feed animals is a strong constraint in the north-central zone of Mexico, therefore development of agricultural systems with conservation tillage should contemplates diversification and increase of forage production (Cabrera 1988).

Finally, the conservation tillage concept which involves the combination of zero tillage with 30% of crop residues as soil mulch should be modified according with different agricultural systems, soils, climate and crops to avoid the same mistake made with plowing and disking as a unique option of soil till. (Sanchez 1975 and Ramirez 1982). The objective of this study was to assess the effect of different tillage methods in an irrigated corn-oat rotation system on corn grain, stubble, and forage oat yield.

MATERIALS AND METHODS

From 1996 to 2001, an irrigated corn-forage oat rotation system was conducted in the Experimental Station San Luis, in San Luis Potosi, Mexico. The site has a clay soil texture, a tempered dry climate, an annual average temperature of 61.16 ^{o}F, a frost free period from April to September, and an annual average rainfall of 7.77 inches (CGSNEGI, 1995). Seven tillage methods were evaluated: 1) traditional plow and disk (P+D), 2) disturbing the upper 0-4 inches layer (D), 3) without disturbing the upper 0-4 inches layer (ND), 4) zero tillage with 0% soil cover (ZT+0%SC), 5) zero tillage with 33% soil cover (ZT+33%SC), 6) zero tillage with 66% soil cover (ZT+66%SC), and 7) zero tillage with 100% soil cover (ZT+100%SC). A randomized block design with two repetitions was employed. Corn was seeding in the spring while oat was in the fall of each year. Genotype for corn was the hybrid H-311 with 24,282 plants per acre and the genotype for oat was the variety Cuauhtemoc with a density of 53.54 lb acre^{-1}. It was employed a zero tillage planter with wavy disk al front to cut the stubble. For fertilization and pet's control, local INIFAP's recommendations were followed. Before sowing, weeds in the zero tillage treatments were controlled with Glifosfato (0.214 gal acre^{-1}) and after planting, weeds were eliminated with herbicide (0.214 gal acre^{-1}), which was applied with protected bell type sprayers so the main crop was not damaged. Each crop was irrigated when a deflection of 40% of the available soil moisture was registered. To make easy the conduction of water, beds of 1.7 m were built, and two lines of plants were sowed. Corn was sown in rows separated 0.33 inches among them and 0.078 inches among plants. After harvesting the corn, each year, 5.45 ton acre^{-1} of stubble was chopped on the top of the beds and furrows were reconstructed once a year. Four rows of oat were planted in each bed. Corn and oat forage yield was evaluated by samplings 103.34 ft^2 plots and the average of five years was analyzed. During the growing season of 2001, soil water content was monitored in the stratums of 0-38.1 inches and 38.1-76.2 inches. Results were statistically analyzed according with the experimental design employed by using the Statistical Analyses System (SAS Institute, 1995).

RESULTS AND DISCUSSION

Corn and oat yields are presented in Table 1. There was not statistical difference among tillage treatments ($p \geq 0.05$). However, a trend to increase the productivity of forage oat in 16% with ZT+0%SC compared to that of P+D was observed. These results were an indicator that soil structure destruction by plowing and disking the soil were not a limited factor in the sprout, emergence, establishment, growth, and yield of forage oat. Since the plow was introduced, the affirmation that plowing and disking the soil is beneficial for all crops has been made without local scientific evidences.

Table 1. Forage oat, corn grain, and stubble yiels (ton acre^{-1}) in an irrigated corn-forage oat rotation with different soil tillage. San Luis Potosi, Mexico.

Treatments	Forage oat (DM)	Corn grain (14% M)	Corn stubble (DM)	Total forage (DM)
	---------------------ton	acre^{-1}	---------------------	
Plow and disk.	16.13a	9.82c	19.16a	35.29a
Disturbing the upper 0-10 cm layer.	9.89a	12.63bc	20.68a	30.57a
Without disturbing the upper 0-10 cm layer.	16.42a	16.36ab	28.26a	44.69a
Zero tillage with 0% soil cover.	18.73a	18.37a	26.36a	45.08a
Zero tillage with 33% soil cover.	14.72a	17.47ab	28.60a	43.31a
Zero tillage with 66% soil cover.	13.31a	18.72a	28.51a	30.71a
Zero tillage with 100% soil cover.	10.61a	17.63a	27.98a	38.59a

Means followed by the same letter are not significantly different at the 0.05 level of probability according to the Tuckey test.
DM = Dry matter.
M = Seed moisture

There was a yield reduction of 39 and 34% with D and ZT+100%SC in comparison with P+D. In the case of D, this reduction was explained by a compacted layer, detected at 8 inches depth, indicating that when soil was just disking, a compact layer was developed, impeding an adequate oat root development. Regarding ZT+100%SC, the yield reduction was due to a greater competence for nutriments by soil microorganisms responsible of breaking down the stubble left on the soil surface.

In corn grain yield, a statistical difference among treatments was obtained ($p \leq 0.05$), where the best treatment was ZT+66%SC with 18.72 ton acre^{-1}, representing an increase of 90% in relation with that of P+D. In all the treatments, except P+D and D, there was a reduction of two irrigations during the corn growing season because of the stubble much effect. Soil water content was higher in those treatments compared to that of P+D. The main reason in the different response of corn and oat to the tillage method evaluated was the higher temperatures registered during the spring and summer months than that in the fall and winter where oat was growth. During the growing season of corn, the stubble decreased evaporation, increasing soil moisture, and causing better corn yield. The higher soil moisture registered in ZT treatments than that of P+D was the reason to get superior corn and stubble yields.

Production of higher yields of forage is a challenge in the north-central region of Mexico to implement correctly conservation tillage by farmers before expecting to leave crop residues on the soil surface. Because farmers use to feed animals with stubble, only a part of the total stubble production can be used as mulch. There was not statistical differences ($p \geq 0.05$) among treatments in stubble yield, however there was a trend to increase 50% with ZT+33%SC and ZT+66%SC compared with that of P+D. This difference of 9.39 ton acre^{-1} opens the possibility to leave a stubble mulch of 5.45 ton acre^{-1}, which will cover 50% of soil surface without reducing the quantity of stubble that can be used as forage.

It is important to point out the forage oat, corn grain, and stubble yields obtained with ND, because with this treatment soil profile was not inverted, reducing production costs. With this treatment, a root-cutter type implant was used. This method can be used as an intermediate step between traditional and conservation tillage and it is largely recommendable in soils with compaction and drainage problems. In this study, soil mulch was not left on the surface, so there is a question to be answered in future researchers about the effect of stubble mulch with this tillage method on corn grain and forage oat yields.

It was evident that forage availability was increased 20% with ZT+33%SC and ZT+66%SC in comparison with that of P+D. The kindness of leaving crop residues in the soil surface is justified for the irrigation water which is saved during the cycle of corn, as well as the increment in the organic matter and conservation of the structure of soils.

CONCLUSIONS

Conclusions for this study were that corn and forage oat can be growth without plowing the soil, increasing corn production and keeping stable that of forage oat.

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NO-TILL PUMPKIN PRODUCTION

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ABSTRACT

Although vegetable growers in the Southeast US have successfully cultivated pumpkins, no-till pumpkin production has not been pursued by many growers due to lack of surface applied herbicides, no-till planting equipment, and knowledge of conservation tillage methods. All of these conservation-tillage production aides are now present for successful no-till vegetable plantings. The primary reason reasons to use no-till technologies for pumpkins include improved soil moisture conservation, cleaner fruit and similar yields, and long-term improvements in soil chemical, microbial, and physical properties of the soil. The objectives of the two experiments were to evaluate the influence of surface residue type and amount on yield and quality of no-till pumpkins, and to establish planting date and nitrogen (N) rate recommendations. Results suggest that a minimum amount of residue is required for good no-till pumpkin yields, but increasing residues beyond 5000-6000 lbs/acre will not affect pumpkin yield. Although this range will vary with location, weather conditions, and soil type, a vegetable grower should expect to successfully grow no-till pumpkins at these residue rates. Plant date and N rate greatly influenced no-till pumpkin yields. Planting dates that were earlier than traditional planting dates increased yields at one location where cooler weather conditions persist, but had minimal affect at a second warmer mountain region location. The highest rate of 105 lbs N/acre produced the greatest yields, suggesting that a greater N rate may have further increased yield.

INTRODUCTION

Selecting appropriate planting dates and fertilization rates are critical for producing high yields of marketable no-till pumpkins. In the Piedmont and Mountain regions of North Carolina it is especially challenging to produce a profitable crop due to variations in landscape position and growing season conditions. Much of the land available for use to grow pumpkins in these regions is located on soils classified as highly erodible and may be droughty (especially in the Piedmont) during some periods of the growing season. Conditions of low rainfall, poor weed control, and high pest pressures in the southeastern U.S. can reduce pumpkin yields and profitability (Stanghellini et al., 2003). In the United States, most commercial pumpkin production occurs in the central and northern states (Pierce, 1987). As urbanization expands into rural areas in the Piedmont and Mountain region of North Carolina many consumers of farm products look to local markets for fresh vegetables and value added farm products. North Carolina farmer markets and retail food chains currently are supplied with many out of state pumpkins. In North Carolina local consumer use of pumpkin fruit for both jack o' lanterns and baking provides a market in the fall for growers to increase production of this commodity.

In the Midwest regions of the United States pumpkin growers commonly produce pumpkins under no-tillage. The use of previous crop residues and cover crop residues for no-till planting protects the soil surface from erosion by absorbing the impact energy of raindrops, thus reducing soil particle detachment. No-till systems, which leave the greatest amount of surface residue, reduce erosion by as much as 95% of that occurring from clean tilled systems. The residue from no-till planting also may improve growing conditions by increasing soil moisture compared to conventional tillage (Johnson and Hoyt, 1999). Tillage systems leaving 30% residue or more after planting generally increase growing season soil moisture due to increased infiltration and decreased evaporation. Growers are reluctant to intensively manage a pumpkin crop; thus, irrigation can often be lacking (Stanghellini et al., 2003). The aspect of no-till planting is especially beneficial for vegetable crops not receiving irrigation (Hoyt, 1999). Surface applications of preemergence or postemergence herbicides have become available for weed control in many vegetable systems (Hoyt and Monks, 1996; Hoyt et al., 1996). Weed pressure in no-till pumpkins has become easier to control with the recent introduction of a surface applied herbicide that does not require incorporation into the soil. Many growers are still reluctant to use no-till management due to lack of equipment and experience with no-till production.

The objectives of these experiments were to evaluate the yield potential and fruit quality of no-till pumpkins for the Piedmont and Mountain regions of North Carolina. The production factors evaluated were N rates, planting dates, and cover crop residue amounts and type.

MATERIALS AND METHODS

No-till pumpkin experiments were evaluated from 2001-2003 at four locations in North Carolina. The Mountain Research Station (MRS) near Waynesville, the Upper Mountain Research Station (UMRS) near Laurel Springs, the Mountain Horticultural Crops Research Station (MHCRS) near Fletcher, and the Piedmont Research Station (PRS) near Salisbury. The pumpkin cultivar was ‘Magic Lantern’ which is a large 18 lb, powdery mildew-resistant variety. Soil types were Toxaway loam (a Fine-loamy, Mixed, Nonacid, Mesic Cumulic Humaquept) at UMRS, French loam (a Fine-loamy, over sandy or sandy skeletal, Mixed, Mesic Fluvaquentic Dystrochrepts) at MRS, Comus fine sandy loam (a course-loamy, Mixed, Mesic Fluventic Dystrochrepts) at MHCRS and Hiwassee clay loam (clayey, kaolinitic, thermic Rhodic Kanhapludults) at PRS.

Plots were 20 feet wide and 25 feet long. For the 2001 and 2002 experiments, various varieties of rye, wheat, barley, triticale, and ryegrass were fall planted (120 lbs/acre for small grain and 30 lbs/acre for ryegrass) and these cover crop residue treatments were no-till planted with pumpkins. This experiment compared the type and amount of residue with pumpkin yield. Nitrogen fertilizer rate for this experiment was 90 lbs N/acre for each location. In 2003, the MRS and UMRS locations had experiments using N rate X planting timing as treatments, with a small grain cover crop of rye seeded at 100 lbs/acre in the fall of 2002. All residues were killed between two and four weeks before pumpkin planting. All plots were sprayed with a burn down herbicide on the small grain winter cover crop and summer herbicide applied the day of planting. A John Deere Maxi-merge no-till corn planter was used to open the furrows and simulate the use of a no-till planter within the plots. Two to three seeds were direct seeded by hand at an in-row spacing of 36 inches at each planting date and thinned to one plant per hill after seedling emergence. Between-row spacing was 6 feet resulting in 12 plants per plot with 18 ft^2 per plant.

There were three planting dates at each location for the 2003 experiments. The planting dates for the Mountain Research Station location were June 10, June 24 and July 11. Normal planting dates for this mountain region is the third week in June. The planting dates for the Upper Mountain Research Station were June 11, June 26, and July 9, with an average earlier planting date of around the second week of June for this cooler mountain location. At each planting date four N treatments (0, 35, 70, and 105 lbs N/acre) were surface broadcast applied by hand. There were no other preplant fertilizers applied to the plots. All locations had either 3 or 4 replications.

The following pest management practices were used in these experiments at the suggested label rates. A single application of preplant ethalfluralin and clomazone (Strategy) herbicide was used to control weeds. Insecticide pest control used esfenvalerate (Asana) applied once a week after fruit emergence. Fungicides azoxystrobin (Quadris), and chlorothalonil /mefenoxam (Bravo) were rotated between applications weekly starting mid-July.

Pumpkin fruit were harvested at all locations between the third week of September and the second week of October. All fruit within the plots were measured to calculate number and weight of fruit produced per acre. The experiments were randomized complete blocks at all locations.

RESULTS AND DISCUSSION

In the first experiment, residue amounts varied among locations and years, with the greatest mulch residue at the MHCRS (Mtn. Hort. Crops Res. Station) in 2001 and the MRS (Mtn. Res. Station) in 2002 (Figure 1). Overall, there was no effect of residue type (rye, wheat, triticale, barley, or ryegrass) on pumpkin yields (data not shown). For most locations, there was no increase in pumpkin yield with increasing residues weights where residue weights were greater than 5000 lbs/acre (Figure 1). Two locations (MHCRS2002 and UMRS2002) had lower amounts of residue, which resulted in increased pumpkin yields with increasing residue. Data for these locations indicate that a minimum amount of residue is required for good no-till pumpkin yields, but increasing residues beyond a certain range will not affect pumpkin yield. Although this range will vary with location, weather conditions, and soil type, a vegetable grower should expect to successfully grow no-till pumpkins at residue rates of 5000-6000 lbs/acre. In this experiment only 90 lbs N/acre were applied to all residue treatments and locations. Where high residue amounts were measured, a considerable amount of N could have been accrued by the small grain cover crop. For this reason, it is possible that the amount of N applied may have been insufficient for attaining greater pumpkin yields as residue increased, thus the non-response of increasing pumpkin yields at the higher residue rates.

Additional experiments were conducted in 2003 at two locations (MRS and UMRS) to examine the planting date and N rate needed for no-till pumpkin production (Figure 2). The UMRS location (Laurel Springs) is in the upper Mountain region of North Carolina; where cool nights and early fall weather conditions persist. The late July 9 pumpkin planting date shows the effect of this cooler climate, with low yields observed at any N rate. No-till pumpkin yields overall are low for this location, with the greatest yields at the earliest planting date and greatest N rate. No-till pumpkin yields at the MRS location, Waynesville reflect very good conditions for pumpkin production. At this location, planting date did not influence pumpkin yields, and again, the highest N rate produced the greatest yields. These experiments may confirm the need for more N than the recommended 90 lbs N/acre rate that is currently suggested for cultivated pumpkins (Schultheis, 1998).

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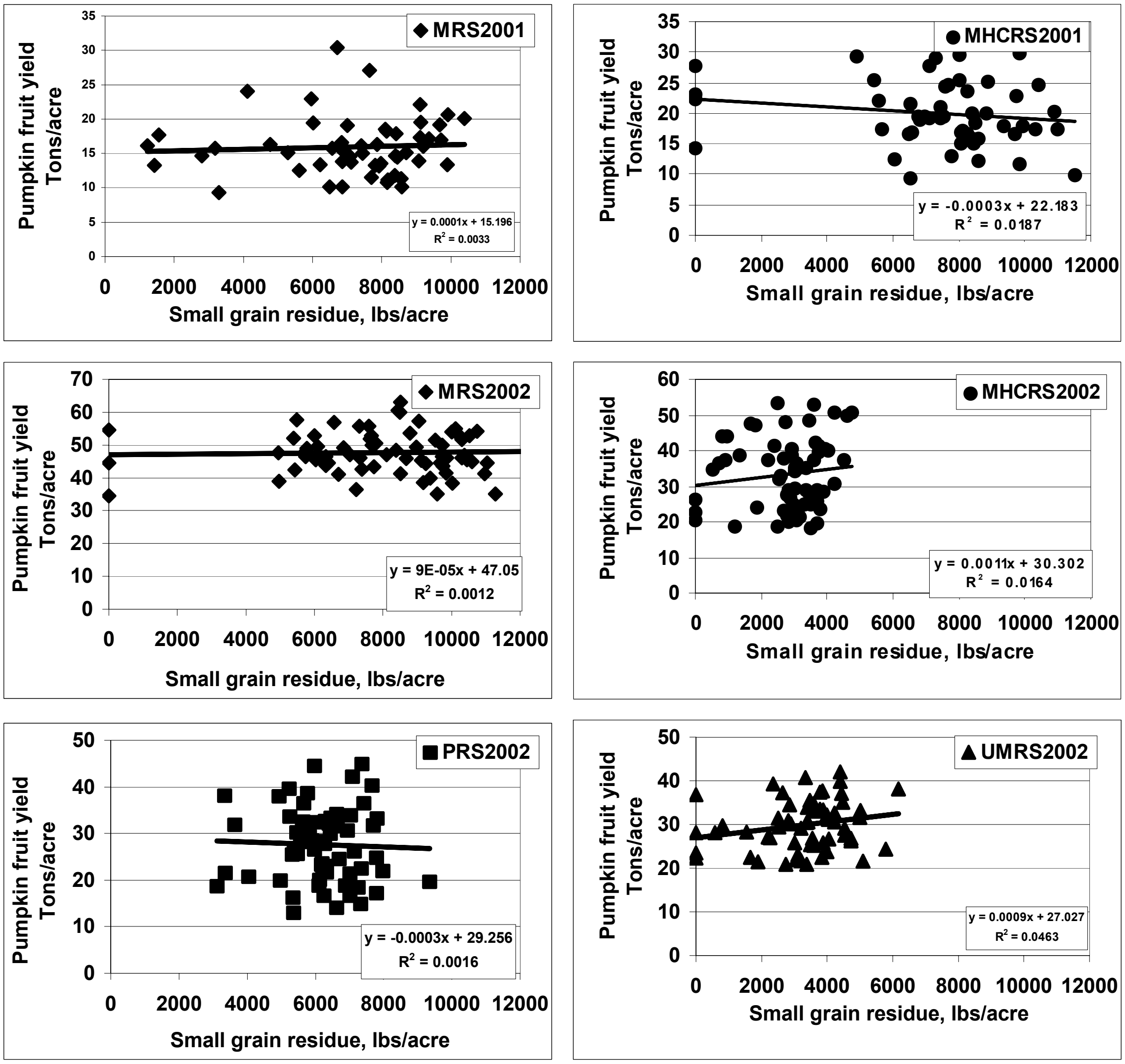

Figure 1. The effect of small grain cover residue on no-till pumpkin yields.

PRS=Piedmont Research Station, Salisbury; MRS=Mountain Research Station, Waynesville; UMRS=Upper Mountain Research Station, Laurel Springs; MHCRS=Mountain Horticultural Crops Research Station, Fletcher.

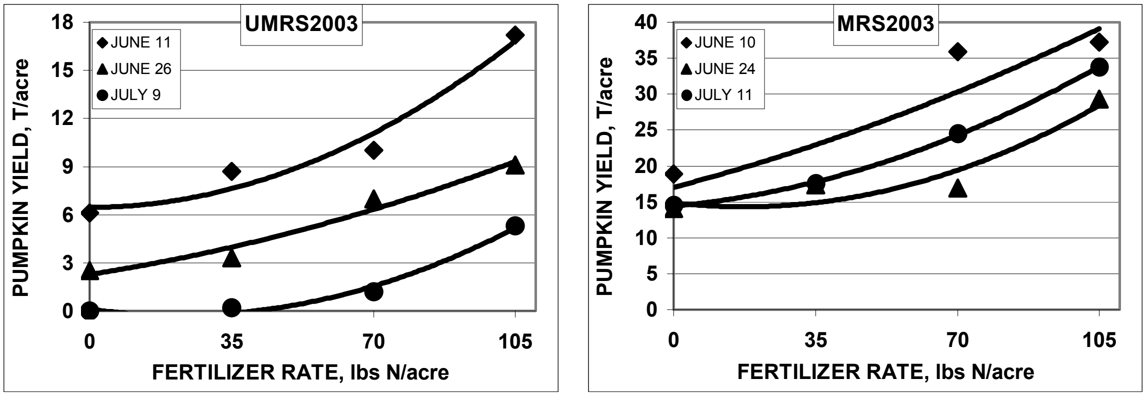

Figure 2. The effect of planting timing and nitrogen rate on no-till pumpkin yields.

MRS=Mountain Research Station, Waynesville; UMRS=Upper Mountain Research Station, Laurel Springs.

REDUCED TILLAGE PRODUCTION IN THE BLACKLAND REGION OF NORTH CAROLINA

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ABSTRACT

Beaufort County is in the lower Coastal Plains of North Carolina. The county is divided by the Suffolk Scarp. The scarp is an old beach front passing north to south through the county at an elevation of about 25 feet. To the east of the scarp is the Pamlico Surface, which is in the Tidewater Area major land resource area. To the west of the scarp is the Talbot Surface, which is in the Atlantic Coast Flatwood major land resource area. The county is also divided into two parts by the Pamlico river, which is a wide, tidewater stream or estuary. In the western end of the county the highest point is 67 feet. The elevation in Washington, the county seat, is 10 feet. The towns of Aurora and Belhaven in eastern Beaufort County the elevation to 2 to 5 feet. The soils in most areas in the county are poorly drained. Strips of well drained soils are near streams, especially in the western part of the county. In most of the county, elevation is so low and slope is so nearly level that a drainage system is necessary for farming. Most farms use a parallel ditch system for drainage. The county is among the state's leading producers of corn, soybeans, and wheat, however, until recently tobacco has been the leading cash crop in the county. Cotton has made a significant come back in the county in the last ten years, and last year was the county's leading cash crop. The primary tillage tools in the 1950s and 1960s was the moldboard plow and disc. In the 1970s and 1980s the chisel plow replaced the moldboard plow as the primary tillage tool. In the mid to late 70's growers adopted the conservation tillage practice of no-tilling doublecropped soybeans. Two-thirds of the soybeans in the county are double-cropped. In 1993-96 the Beaufort County Cooperative Extension Service conducted a series of 14 replicated no-till corn on-farm-tests across the county. These on-farm-tests reported no-till to yield significantly more than conventional till in 4 of the tests, conventional till yield significantly more than no-till in one test, and no significant difference in yield between the two tillage systems in 9 tests. No-till averaged a 3 bushel per acre advantage over conventional tillage across the 14 on-farm-tests. The Beaufort County findings demonstrated an economic advantage to no-till corn verus conventional till corn. In the early 1990s less than 1% of the corn was planted no-till in Beaufort County. Corn producers in the county were planting greater than 65% of their corn no-till by the late 1990s. In 1998-2000 and 2003 nine no-till wheat no-farm-tests were conducted on a wide range of soil types in Beaufort County. There has not been a significant difference in yield between no-till versus conventional till wheat. The adoption of no-till wheat reached a peak of 35% of planted acres in 2000. In recent years wheat yields have been impacted by late spring freezes. In general, there has been a trend of more freeze injury in no-till wheat versus tilled wheat. This freeze injury has caused a reduction in no-till wheat to a 15 to 20% of acres planted. Efforts are underway to reduced the risks of spring freeze injury by screening of wheat varieties and manipulating planting dates. Four no-till cotton on-farm-tests have been conducted over the last six years. In three comparisons there was no significant difference in yield and in one comparison tilled cotton produced significantly more yield. No-till planting of cotton reach a maximum of 10% of planted acres in 2003, but is expected to be significantly lower in 2004.

NO-TILL AND REDUCED-TILL PRODUCTION SYSTEMS IN THE SOUTHWESTERN PIEDMONT OF NORTH CAROLINA

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ABSTRACT

No-till or reduced tillage has been used as a means of reducing erosion and later for program compliance, but its benefits have far exceeded these initial goals. The purpose of our discussion is to provide some of the positives and concerns associated with no-till production in the Southern Piedmont of North Carolina.

SUMMARY

The Southern Piedmont area of North Carolina is composed of six to eight counties, depending on whom you ask. The area is generally characterized as gently sloping with steeper slopes along drainage areas. Slopes range from 0 to 45%. The Catawba, Yadkin and Pee Dee River basins drain the landscape and provide much of the water usage within the area. Groundwater wells supply the rural areas water; wells typically run 90 to over 300 feet in depth.

Badin, Cid, Goldston and Tatum represent a large percentage of the soils from the region. These soils are characterized primarily as clay to clay loam, well- to moderately well-drained and slow to crust. Plow pans or hard pans are not recognized as a problem, although compaction has been observed in the past.

No-till or reduced tillage practices are no longer in the experimental stages for producers in the Southwestern Piedmont of North Carolina. This form of production agriculture is a widely accepted, proven practice that requires little thought for most producers. Area farmers have been utilizing no-till/reduced tillage practices for some 25 plus years. For the younger producers no-till is the only production system they have known.

Like other regions in the state, crops produced include corn, wheat, barley, oats, soybeans, cotton and sorghum. Soybeans represent the largest acreage, followed by wheat, then corn. The no-till concept requires a change in mindset, in that the change in production systems needs to be a long term commitment. Producers must realize that change is slow and should be measured accordingly. We can prosper if we allow our trust in the change to overcome the fear of the uncertain and the future.

The rapid developments and acceptances in agriculture technologies (chemicals, seeds, and equipment) over the past 20 years have all but eliminated the need to fix land prior to crop establishment or for in crop cultivation. Equipment requirements - planters, drills, sprayers mentioned above - are all equally important, but residue management begins at harvest. A good straw/residue spreader on the back of the combine is a must. Start clean. A good burndown program needs to be employed. Generally 21 days prior to crop establishment is sufficient but may need to be longer depending on herbicide selection. Soil temperature will be slightly cooler than conventionally fixed lands, and will warm at a slower rate, and producers may need to delay planting for a few days.

Producers should be mindful of weedshifts; perennial weeds, such as horsenettle, trumpet creeper and dock, to name a few, will become more prevalent. Outside of erosion reduction, the single most realized value from the no-till production practice is moisture conservation. The soil canopy/residue reduces evapotranspiration that can result in crop stress. Producers also realize cost savings on fuel, labor, time and big equipment and are able to get on the land during wet conditions.

REDUCED TILLAGE PRODUCTION IN THE NORTHEASTERN COASTAL PLAIN OF NORTH CAROLINA

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ABSTRACT

Over the last 10 years, farmers in Halifax County have made an almost complete change from conventional tillage in cotton and peanuts to strip till. During that time many growers tried a lot of methods to reduce trips, reduce erosion and improve their soils to meet requirements for Highly Erodible Land (HEL). Many farmers tried terracing, building diversions and waterways, but this required a lot of time and money to install these practices. Cover crops were also a requirement for HEL as a means to reduce erosion during the winter months. Slowly, but surely growers started seeing the results of no-till and strip-till in some areas of the county. Extension conducted several on-farm test plots to compare tillage methods in peanuts and cotton. The results showed that these crops could be produced with comparable and sometimes higher yields than conventional. Each year, more and more producers turned to strip-till as their preferred method of planting. Today, it is estimated that 80% of our cotton is either strip-tilled or no-tilled and although peanut acres are dwindling due to the change in the program most of them are now strip-tilled. Grant Staton, a farmer from Scotland Neck has made a successful transition from conventional to stale seed bed to 100% strip-till in his cotton and peanut crop. Soybeans are either strip-tillled or no-tilled. He will provide insight on the change in tillage on their farm along with the problems he's had and how they are dealing with those.

NO-TILL AND REDUCED TILLAGE PRODUCTION IN THE NORTHERN PIEDMONT OF NORTH CAROLINA

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ABSTRACT

Reduced tillage production of corn and soybeans has become predominant in the Northern Piedmont of North Carolina. Initial research and reasoning for reduced tillage was based on preventing soil erosion on the highly erodible soils of the area. Additional research has quantified the benefits of reduced tillage on rainfall penetration and moisture availability, soil compaction and the resulting yield benefits. Current research grower experience and grower experimentation are centered on reduced tillage economic benefits (reduced labor, equipment, time, etc.), long-term benefits, selective tillage and fine-tuning reduced tillage management practices.

SUMMARY

Reduced tillage production of corn and soybeans has become predominant in the Northern Piedmont of North Carolina. Grower adoption of reduced tillage production of wheat has been slower to occur but continues to increase. Only a limited amount of no-till tobacco has been produced in the northern piedmont area of North Carolina. Initially the impetus for reduced tillage was primarily to prevent soil erosion, which is quite important in this area due to the soil type and slope of much of the cropland. In order to gain increased adoption of reduced and no-till production additional research and ultimately the further benefits of rainfall penetration and moisture availability, reduced soil compaction and the resulting yield benefits were quantified and stressed to growers. More recent research and grower experience has dealt with the positive changes on soil tilth due to long term no-till, economic benefits (reduced labor, equipment, time, etc.), selective tillage or minimal soil disturbance tillage (98% residue remains) and fine tuning reduced tillage management practices.

Growers are managing their reduced tillage production in order to build soil organic matter, improve soil tilth and to provide ideal planting conditions. Growers are also using selective tillage. Many fields in the northern piedmont are small and often bordered by trees. Tillage with a no-till ripper around the borders of a field to sever tree roots and to reduce compaction due to truck traffic around borders may be quite beneficial. Some no-till rippers will leave 98% residue. A no-till corn planter will often cause more soil disturbance than this type of ripper. Growers are managing their production inputs for reduced tillage and are managing the benefits of reduced tillage (improved root development and increased moisture availability) to help alleviate limiting factors to yield (i.e. hot, dry conditions during grain fill for corn). Reduced tillage has become a standard practice. Today, growers are fine-tuning the inputs and other related practices as they relate to reduced tillage and they are using the options and benefits of reduced tillage to address the factors that are limiting yield.

WHOLE FARM PROFITABILITY AS IMPACTED BY TILLAGE, COTTON-CORN ROTATION, AND ACREAGE MIX

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ABSTRACT

Six reduced tillage systems in 30-inch rows were evaluated in continuous cotton and a cotton-corn rotation to determine their yield, production cost, net returns, and crop (cotton/corn) acreage mix effect on whole farm net returns for a simulated 8-row Northeast Mississippi farm and a 12-row Mississippi Delta farm. Yield, gross returns, and total production cost (did not include land, management, and general farm overhead cost) for ridge-till followed by (Fb) a row conditioner at planting, fall terratill-bed-roller, and conventional tillage (fall disk + chisel + bed Fb spring field cultivator + bed Fb a row conditioner at planting and 2 cultivations during the growing season) systems were similar. These treatments had lower yield, gross returns and total production cost than the four fall stale seedbed tillage systems (disk + bed-roller, disk + terratill-bed-roller, coulter-chisel-harrow + terratill-bed-roller, and terratill-bed-roller) Fb a row conditioner at planting. However, net returns were not affected by tillage systems. Whole farm analysis indicated the 12-row system with an additional 600 acres of cropland (total 1800 acres) for a Delta farm resulted in $39/A lower total production cost and $40/A greater net return than the 8-row system 1200 acre Northeast farm. Rotation provided greater whole farm net returns than monocropped cotton and corn acreage mixes. All reduced tillage systems in a cotton-corn annual rotation provided greater whole farm net returns than conventional tillage. Ridge-till and the fall disk + terratill-bed-roller systems in a 50% cotton-corn annual rotation provided the highest whole farm net returns and were 40 and 28% greater than conventional tillage for the Mississippi Northeast and Delta farms, respectively.

SUMMARY

A reduced tillage study was conducted on a Marietta silt loam soil for four consecutive years (1999-2002) to evaluate the effect corn rotation in combination with reduced tillage systems had on 1) cotton lint yield; 2) cost and returns; and 3) the appropriate cotton and corn acreage mix for maximum whole farm net return. Reduced tillage systems were evaluated in continuous cotton, and cotton following ridge-till corn in a rotation. The corn production system across all cotton tillage systems was planted no-till with one ridge-till cultivation during the growing season. A continuous ridge-till corn system was also included in the study.

The seed cotton from each cotton plot was ginned with a mini-gin to determine the percent gin turnout and lint yield. The mini-gin was a state of the art small scale cotton gin equivalent to a commercial gin. Treatment gross returns were based on gin turnout, lint yield, and the 2001 USDA National Commodity Credit Corporation base loan price of 52.91¢/lb with adjustments for treatment fiber quality (staple length, grade, micronaire, fiber color, strength, and uniformity), as determined by high volume instrumentation (HVI) analysis. The cottonseed gross return was derived from the lint yield/A x 1.54 (cottonseed yield to lint yield ratio) x $0.05/lb (cottonseed price). Corn gross

returns were based on treatment yield and the 2001 National Commodity Credit Corporation state loan rate of $1.99/bu.

Eight-row and 12-row equipment complement budgets for each tillage system also were used to simulate a Northeast Mississippi (1200 acres) and a Mississippi Delta (1800 acres) farm for a whole farm maximum net return analysis, respectively. The Mississippi State University Agricultural Economics Department Budget Generator was used to develop annual and 3-yr (2000-2002) average cost and return budgets for each ridge-till corn and cotton tillage system. The cost and return budgets were based on yield, gross returns, inputs used, and operations performed on each treatment. These data were used to determine the appropriate tillage system and cotton-corn acreage mix for maximum whole farm net returns. The net returns were above the total operating and capital recovery costs. The annual recovery cost was determined by using the manufacturer retail equipment purchase price minus 10%, a 5% annual interest rate, and the useful life of the equipment (Mississippi State University Agricultural Economics Department, December 2002). The useful life did not account for any extended life for reduced tillage systems. The estimated annual equipment capital recovery cost required over time would need to be covered in the long run in order to maintain the complement of equipment.

The designated harvesting capacity for the Northeast farm was 800 acres for each crop and 1200 acres of each crop for the Delta farm. If the specified acreage of a crop was less than its capacity (800 or 1200 acres), it was assumed that the excess capacity was used to custom harvest a neighboring farm, and thus generate some additional net revenue. Treatment means of all data except capital recovery and whole farm net returns were separated using Fisher’s Protected Least Significant Difference (LSD) at the 5% significance level.

Costs and returns were affected by equipment size and tillage system. The 12-row system (averaged over tillage system, rotation, and years) showed 8% ($39/A) lower total production cost and 46% ($40/A) greater net returns than the 8-row system. Conventional tillage and ridge-till had similar total cost and were $11 to $32/A less than all other tillage systems. However, lint yield for these treatments was also 55 to 77 lb/A lower than all other systems. This resulted in no difference in net returns for all tillage systems. Rotation interacted with year for lint yield, gross return, total production cost and net returns above total production cost. Although 2003 was the only year rotation had greater lint yield, gross return, total production cost and net returns, the 3-yr average rotation increased lint yield by 100 lb/A and net returns by $57/A.

The annual capital recovery charge ranged from $86,000 to $91,600 for the Northeast farm and $105,300 to $111,800 for the Delta farm. Conventional tillage had the highest cost while ridge-till had the lowest annual recovery cost. Whole farm net returns were maximized with 50% corn acreage and 50% cotton acreage in an annual rotation. This was related to the rotation influence of 100 lb/A lint and 14 bu/A corn yield increase. All reduced tillage systems, except ridge-till, showed greater whole farm net returns than conventional tillage in all monocropped cotton and corn acreage mixes. In the annual cotton-corn rotation, all reduced tillage systems had higher net returns than conventional tillage. In the 50% cotton-corn annual rotation, the ridge-till and fall disk + terratill-bed-roller showed the highest whole farm net returns and were at least 40 and 28% greater than conventional tillage for the Northeast and Delta farms, respectively.

PRODUCING WINTER WHEAT WITH CONSERVATION TILLAGE ON THE SOUTHEASTERN COASTAL PLAIN

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ABSTRACT

Producing winter wheat (Triticum aestivum L. em Thell) with conservation tillage has lagged behind most other major row crops on the southeastern Coastal Plain. Producer reluctance to use this practice has primarily been due to the lower wheat grain yields often obtained with conservation tillage. The objectives of our study were to (i) determine how conservation tillage affects winter wheat fertile tiller number per ft^2, number of kernels per tiller, and/or individual kernel weight and (ii) examine how different management practices affect wheat grain-yield responses to conservation tillage. Three separate field studies were conducted to test treatments of surface and deep tillage (Studies I, II, and III), direction and timing of deep tillage (Study III), fall N fertility rate (Study III), and crop rotation (Study II). In Studies I and II, average grain yield of wheat grown with conservation tillage was 6% less than the average grain yield of wheat grown with traditional tillage (disking). Lower grain yields with conservation tillage were associated with fewer plants per ft^2 after planting and fewer tillers per ft^2 at harvest. Deep tillage, a higher fall N fertility rate, and crop rotation all increased the number of tillers per ft^2 when the conservation tillage treatment was used, but usually not enough to compensate for its lower plant number per ft^2. The timing and direction of deep tillage had little effect on wheat grain yield and tiller number. Results from these studies indicate that obtaining an adequate number of fertile tillers per ft^2 is critical to the success of using conservation tillage for winter wheat production on the southeastern Coastal Plain..

INTRODUCTION

Use of conservation tillage for field-crop production has been steadily increasing in South Carolina over the past decade. A combination of both economic and environmental reasons has caused producers to switch from intensive tillage to conservation tillage, especially on the sandy Coastal Plain where the soils are inherently low in organic matter. In this Region, conservation tillage is especially beneficial during the summer months when the soil is frequently hot and dry (Frederick et al., 1998). The introduction of herbicide-tolerant varieties and the movement towards narrower row widths both have made weed control easier with conservation tillage and increased grower interest in this practice. In most cases, some type of deep tillage is usually necessary on the Coastal Plain to fracture naturally occurring hardpan layers which form just above the B soil horizon (Busscher et al., 1986). Deep-tillage implements with winged-subsoilers have been found to be well suited for use with conservation-tillage and narrow-row width systems (Frederick and Bauer, 1996; Frederick et al., 1998; Khalilian et al., 1991).

Planting winter crops, such as soft red winter wheat, with conservation tillage has lagged behind most other field crops. For example, in 2002, the percentage of South Carolina acres planted in conservation tillage was 19% for winter wheat (*Triticum aestivum* L.), 68% for doublecropped soybean (*Glycine max* L. Merr.), 46% for corn (*Zea maze* L.), and 33% for cotton (*Gossypium hirsutum* L.) [source: USDA-NRCS]. Producers have been reporting consistent lower grain yields when planting winter wheat with conservation tillage, compared to wheat grown with traditional surface tillage (Jay Chapin, 2003, personal communication). Part of this poor response may be due to the impact conservation tillage can have on seedbed conditions. Leaving plant residues on the soil surface generally results in cooler and wetter soils (NeSmith et al., 1987; Wilhelm et al., 1989), which may be advantageous for producing summer crops. However, low soil temperature and wet soils may have a negative impact on the early season growth and, consequently, final yield of winter crops such as wheat.

Winter wheat grain yield is very dependent on the number of kernels produced per ft^2 (Frederick and Bauer, 1999). Kernel number, in return, is determined by the number of fertile (seed-bearing) tillers per ft^2 and number of kernels per tiller. Thus, management practices that affect either of these two yield components should affect grain yield, unless an opposing change in kernel weight compensates for the change in kernel number (termed yield-component compensation). Tiller formation and development generally occur during the fall and early winter months in South Carolina. Tiller initiation at this growth stage is usually temperature dependent, with temperatures below optimum reducing the final number of tillers (Simmons, 1987). Soil water conditions are generally adequate at this time on the Coastal Plain, with drought usually occurring much later in the growing season (Frederick and Camberato, 1994, 1995a, 1995b). Thus, the cooler and wetter soil conditions generally associated with conservation tillage may be of little benefit or even detrimental to winter wheat, especially early in the growing season. If tiller initiation and development are hindered by these soil conditions and consequently, fertile tiller number ultimately reduced, then grain yields may be less with conservation tillage than with traditional surface tillage, as is commonly observed. During planting, if plant residues are not properly cut when the seed furrow is created, the residues may be pushed into the furrow (‘pinning’), resulting in poor seed to soil contact and fewer emerged plants per ft^2. This effect may also reduce the number of tillers per ft^2 and, consequently, final grain yield.

If these negative effects on plant populations occur when producing winter wheat with conservation tillage, producers may be able to use other management practices to promote more tillers per plant or plants per ft^2. These practices may include delaying deep tillage until after planting to provide a firmer soil surface at planting, applying a greater amount of N fertilizer in the fall to promote tillering, and planting earlier in the fall when soil temperatures are warmer. Planting earlier may also give the plants more time for tiller initiation and development. The objectives of our research studies were to determine the impact of conservation tillage on winter wheat grain yield and yield components and to determine if additional management strategies are needed to alleviate the negative effect(s) conservation tillage may have on wheat yield components.

MATERIALS AND METHODS

Three separate research studies were conducted at the Pee Dee Research and Education Center near Florence, SC to determine the optimum tillage systems for producing winter wheat on the southeastern Coastal Plain. The studies are as follows:

Study I.

Soft red winter wheat (Northrup King cv. Coker 9134) was grown with two levels of surface tillage (disked and no surface tillage) and two levels of deep tillage (deep tilled and no deep tillage) during the 1993-1994 and 1994-1995 growing seasons on a Goldsboro loamy sand (fine-loamy, siliceous, thermic Aquic Kandiudult). Phosphorus and K fertilizer was applied before soil preparation in the fall at a rate based upon soil test results. Nitrogen was applied as ammonium nitrate at a rate of 30 lbs a^{-1} prior to planting in mid-November and at a rate of 50 lbs a^{-1} in the early spring at the stem erect growth stage. Appropriate plots were disked twice before planting to a depth of 6 in. After disking, the appropriate plots were deep tilled to a depth of 16 in (approximate depth to B soil horizon) using a four-shanked ParaTill. All plots were 10 feet wide and 50 feet long. Seed were planted with a John Deere 750 grain drill at a rate of 22 seeds ft^{-1} of crop row. Doublecropped soybean was grown after wheat harvest in all years using the same surface and deep tillage as used to produce the wheat crop. Wheat data collected included plant residue cover, plant number per ft^2 measured 3 weeks after planting, grain yield (13% moisture basis), and grain yield components (number of fertile tillers per ft^2, number of kernels per tiller, and individual kernel weight). All data collected in this study were subjected to analysis of variance as a randomized complete block design with four replications.

Study II.

Treatments in this study were very similar to Study I except treatments of soil type and crop rotation were also examined. Treatments included nonrotated winter wheat (Northrup King cv. Coker 9803) grown with all possible combinations of surface and deep tillage (disked/deep tilled, disked/no deep tillage, no surface tillage/deep tilled, and no surface tillage/no deep tillage) and rotated winter wheat (rotated with corn) that received the disked/deep tilled or no-surface-tillage/deep tilled treatments. The experiment was conducted between the 1996/1997 and 2000/2001 growing seasons. Soil fertility rates, equipment, and general production practices used were the same as described in Study I. All plots were 30 feet wide and 500 feet long so that each plot transected a number of different soil types common to the Coastal Plain region. Data collected included grain yield (13% moisture basis) and grain yield components (number of fertile tillers per m^2, number of kernels per tiller, and individual kernel weight). All data collected in this study were subjected to analysis of variance as a randomized complete block design with three replications.

Study III.

Soft red winter wheat (cv. Northrup King Coker 9663) was produced with treatments of timing of deep tillage (before planting, after planting, and no deep tillage), direction of deep tillage (parallel to versus at a 7^o angle across the wheat rows), fall N fertility rate (30 and 60 lbs N a^{-1}) and surface tillage (double disking and no surface tillage) during the 1999/2000 and 2000/2001 growing seasons. The different treatments are shown in Table 1. All wheat was grown no till except for in the second year of the study when the disked treatments were introduced. For the disked treatments, deep tillage was done after planting at a 7^o angle to the wheat rows. Soil fertility rates, equipment, and general production practices used were the same as described in Study I except a Krause 5500 no-till grain drill was used to plant the wheat. All plots were 15 feet wide and 50 feet long. Data collected included plant number per ft^2 measured 3 weeks after planting, grain yield (13% moisture basis), and grain yield components (number of fertile tillers per m^2, number of kernels per tiller, and individual kernel weight). All data collected in this study were subjected to analysis of variance as a randomized complete block design with four replications.

RESULTS AND DISCUSSION

In study I, using conservation tillage decreased seedling emergence by an average of 16%, compared to wheat grown in the disked plots (Table 2). In contrast to what was expected, deep tillage had no effect on plant number per ft^2. We hypothesized that deep tillage would reduce plant number by way of creating a soft seed bed at the time of planting, allowing residues to be pushed into the seed furrow at planting (pinning) and reducing seed-to-soil contact and seedling emergence. Study I was one of the first winter wheat conservation-tillage studies that we conducted. In this study, only an average of 62% of the seed planted in the conservation tillage plots emerged (data not shown). We planted to a depth of about 1.25 – 1.50 inches in this study, which is the recommended seeding depth when using traditional tillage practices. However, we visually observed that many of the seeds were intermixed with plant residues in the seed furrow when the conservation-tillage treatment was used (for both deep tilled and no deep tillage plots), resulting in poor seed to soil contact and poor germination. Previous research conducted in the early 1990s on the Coastal Plain also reported poor plant populations for wheat planted with conservation tillage (Karlen and Gooden, 1997). In subsequent experiments (including Studies II and III), we planted to a depth of 2.0 inch which allowed most of the seed to be placed into the soil below the plant residues, especially when the seed was planted in plots having no deep tillage.

In Study I, fertile tiller number per ft^2 and grain yield were similar for the disked and conservation-tillage plots (Table 2). This finding indicates that the wheat grown with conservation tillage compensated for its fewer number of plants per ft^2 by producing more tillers per plant. Grain yields were higher with conservation tillage than with disking in the second year of Study I when a prolonged period of drought stress began during the stem elongation stage of development. In that year, wheat grown with conservation tillage had a greater number of kernels per tiller than the wheat grown in the disked plots (data not shown). In Study I, deep tillage increased the number of tillers per ft^2 and individual kernel weight (Table 2) but had little effect on kernel number per tiller (data not shown). In Study II, both grain yield and tiller number per ft^2 were less with conservation tillage than traditional tillage in most years of the study, both with and without deep tillage (Table 3). Surface tillage had little effect on the number of kernels per tiller in Studies I or II (data not shown) and only a slight positive effect on kernel weight in Study I (Table 2). Increases in winter-wheat yield due to crop rotation were also due to increases in tiller number per ft^2 (Table 3).

In Study III, plant number per ft^2 was greatest for the conservation tillage/no deep tillage treatment (Table 4). Deep tillage reduced plant number per ft^2, with a greater reduction occurring when deep tillage was done after planting compared to before planting. Over all deep tillage treatments, plant number per ft^2 was lower for the plots that were disked, compared to those that were not. The lower plant populations in the disked plots were due to the severe surface crusting that resulted from compaction caused by the roller bar on the ParaTill (plots were deep tilled after planting) which prevented many seedlings from emerging. This unexpected response suggests that deep tillage should not be done after planting if the soil surface is disked. Deep tillage and applying a higher fall N fertility rate both increased the number of fertile tillers per ft^2. There was little effect of the tillage treatments on the number of kernels per tiller or on individual kernel weight (data not shown).

CONCLUSIONS

Compared to disking the soil, the lower winter wheat yields with conservation tillage in our study were primarily due to fewer emerged plants early in the growing season. The poorer plant population with conservation tillage usually resulted in fewer fertile tillers per ft^2 at harvest. However, in cases where the wheat plants were able to compensate for the fewer emerged plants by producing more tillers per plant, grain yields did not differ for the disked and conservation-tillage treatments. With conservation tillage, increasing the fall N fertility rate stimulated tillering and helped compensate for its lower plant numbers. We also found that management practices such as deep tillage and crop rotation were of greater benefit to the wheat grown with conservation tillage than the wheat grown with traditional tillage. Results from our studies indicate that future success of producing winter wheat with conservation tillage on the southeastern Coastal Plain will depend upon developing management strategies to obtain higher tiller numbers per unit land area.

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Table 1. Production practices used for each deep tillage system in Study III. Practices used included surface tillage (none versus disking), timing of deep tillage (before versus after planting), direction of deep tillage (parallel to crop rows versus across rows), and fall N fertility rate. Deep-tillage systems where the soil was disked (systems 7 and 8) were only used during the second growing season (2000/2001).

Surface Tillage	Timing of Deep Tillage	Direction of Deep Tillage	Fall N Rate	System Number
			lbs $acre^{-1}$	
None	Before	Parallel	30	1
None	Before	Across	30	2
None	After	Parallel	30	3
None	After	Across	30	4
None	None	None	30	5
None	Across	Across	60	6
Disked	Across	Across	30	7
Disked	Across	Across	60	8

Table 2. Wheat seedling number, grain yield, tiller number per ft^2, and individual kernel weight as affected by surface and deep tillage treatments in 1994 and 1995.

Tillage		Seedling No.		Grain Yield		Tiller Number		Kernel Weight	
Surface	Deep	1994	1995	1994	1995	1994	1995	1994	1995
		-------ft^{-2}--------		----bu acre^{-1}-----		-------ft^{-2}--------		--mg kernel^{-1}--	
No-till	No	18.5	25.0	54.0	42.3	41.2	33.1	26.9	26.1
No-till	Yes	19.2	25.3	67.2	61.9	51.7	36.3	28.3	27.2
Disked	No	26.6	27.1	59.3	39.1	51.1	29.3	25.9	25.7
Disked	Yes	24.7	26.3	66.6	49.6	51.0	34.5	28.7	27.0
Effect									
Surface tillage		**	**	**	**	**	*	NS	NS
Deep tillage		NS	NS	**	**	**	**	**	**
Interaction		NS	NS	**	*	**	NS	NS	NS
LSD (0.05)		NS	NS	3.7	6.5	2.7	NS	NS	NS

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
LSD is for comparison of interaction means.

Table 3. Winter wheat grain yield and tiller number per ft^2 as affected by surface tillage, deep tillage, and crop rotation (continuous wheat versus rotated with corn) in years 1997 through 2001. Tiller numbers per ft^2 are shown in parentheses.

Tillage			Grain Yield (Tiller Number)				
Surface	Deep	Rotated	1997	1998	1999	2000	2001
			---------------------bu $acre^{-1}$ (no. ft^{-2})----------------------				
Disked	Yes	No	63 (43.9)	42 (41.3)	33 (36.1)	40 (36.5)	21 (26.1)
Disked	No	No	51 (37.8)	37 (35.5)	22 (33.7)	34 (34.7)	9 (22.8)
No-Till	Yes	No	60 (42.7)	39 (37.3)	26 (33.3)	36 (35.9)	17 (27.7)
No-Till	No	No	46 (35.5)	27 (34.2)	19 (30.7)	29 (31.2)	7 (21.6)
No-Till	Yes	Yes	--	--	41 (41.4)	--	26 (28.2)
Disked	Yes	Yes	--	--	41 (41.0)	--	31 (31.4)
LSD			6 (3.6)	4 (2.7)	4 (2.8)	4 (3.9)	3 (2.9)

Fisher=s protected LSD test at P = 0.05.
Presence of LSD indicates deep-tillage-system effect was significant at 0.05 probability level.

Table 4. Winter wheat plant number per ft^2, grain yield, and fertile tiller number per ft^2 as a function of deep-tillage cropping system during the 2000 and 2001 growing seasons. Production practices used for each deep-tillage system are shown in Table 1.

	Plant Number		Grain Yield		Tiller Number	
System	2000	2001	2000	2001	2000	2001
	----------no. ft^{-2}----------		--------bu $acre^{-1}$---------		----------no. ft^{-2}----------	
1	34.0	34.3	50.0	49.9	44.4	43.8
2	34.1	34.7	55.0	49.5	43.5	44.8
3	32.1	31.6	53.0	52.3	41.2	45.4
4	31.8	31.1	59.5	52.8	43.2	42.5
5	35.5	35.8	47.3	44.5	37.6	39.9
6	30.6	28.5	72.1	58.2	54.2	52.8
7	--	23.2	--	46.9	--	39.8
8	--	23.7	--	57.3	--	52.4
LSD(0.05)	2.5	3.7	4.3	5.7		4.3

Fisher=s protected LSD test at P = 0.05.
Presence of LSD indicates deep-tillage-system effect was significant at 0.05 probability level.

POTENTIAL FOR USING NO-TILL TO INCREASE FORAGE AND GRAIN YIELDS OF WINTER WHEAT

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ABSTRACT

In Oklahoma, more than half of the hard red winter wheat (*Triticum aestivum* L.) produced is grown as a dual-purpose crop (forage plus grain). The objective of this study is to agronomically compare no-till and conventional tillage production systems in continuous wheat grown with five production objective ranging from forage only to grain only. Experiments were initiated at three sites in north central Oklahoma by cutting wheat for hay in May 2002 or grain in June 2002. After wheat hay was cut, foxtail millet (*Setaria itlalicahay* (L.) Beauv) was seeded in appropriate plots and harvested in late August each year. Ok101 hard red winter wheat was seeded in the fall at the dates appropriate for each production objective. In the first year of production, when averaged across locations, the millet produced 4880 pounds of dry matter/ acre in the no-till, which was 630 pounds more than with conventional tillage. During the second year, millet in conventional tilled produced 700 pounds of dry matter per acre more than no-till millet. Wheat forage yields was affected by planting date, tillage, and insertion of a summer foxtail millet crop. Wheat grain yields were reduced with no-till by 5 to 7 bushels/ acre when averaged across locations.

INTRODUCTION

Hard red winter wheat is the primary crop grown in Oklahoma. More than half of the wheat produced in Oklahoma is used as a dual-purpose crop, which means that wheat is produced for grain and forage in the same growing season (Krenzer 2000). In a dual-purpose system, the income from forage often equals the income from grain and increasing either forage or grain should increase net returns.

Seeding date has an effect on the grain yield and the amount of forage that is available for grazing in the fall. Krenzer (1995) recommended planting wheat in the first three weeks of October to maximize grain production in northern Oklahoma. For forage production in Oklahoma, wheat should be seeded as early as late August but no later than early September. Depending on variety, an early planting date can cause poor germination due to warm soils and lack of water required for early seeded wheat (Krenzer 2000). One possible solution to maximize forage production is the use of no-till to conserve soil moisture and cool the soils.

Over the last few years, no-till acreage has increase across the United States (USDA Statistics 2003). Some of the major problems with no-till wheat in the past were: poor seeding equipment, inadequate herbicides to control grass weeds in wheat, and high cost of herbicides. Now, the seeding equipment that is available has been improved, there are more herbicides on the market that grass control in winter wheat and the cost of glyphosate is less.

Epplin et al. (1994) reported the results of a ten-year study that compared the economics of six tillage systems (5 tillage practices and one no-till) in a continuous wheat system. The no-till system produced lower wheat grain yields than conventional systems. Net returns were higher in conventional tillage systems primarily because of the high cost of herbicides used in the no-till treatments. A similar study by Epplin et al. (1983) concluded that no-till did lower fuel and labor cost but the cost of herbicide to control the weeds was greater than the money saved on fuel and labor. In a more recent study, wheat grain yield was consistent for no-till, minimum till and delayed minimum till, but the net return for minimum till and no-till were equal and both slightly more profitable than delayed minimum tillage (Janosy et al. 2002).

Although a number of experiments have been conducted on no-till wheat grain production systems, little research has been conducted on the effects of no-till on dual-purpose wheat. The objective of this study is to compare optional no-till and conventional tillage wheat production systems to determine which is more productive when both forage and grain productions are considered.

MATERIALS AND METHODS

Field experiments are being conducted at three on-site farm locations in north central Oklahoma, to evaluate forage and grain production with various production objectives using conventional tillage and no-till. This three-year study was initiated in 2002 by either cutting existing wheat for hay in May or harvesting the wheat for grain in June.

The experimental design is a complete randomized block with a factorial arrangement. Treatments are replicated four times. The factors are tillage practices (no-till and conventional tillage) and five production objectives. The production objectives are: (1) Maximize fall wheat forage and harvest wheat for hay in the spring; (2) Maximize fall wheat forage, harvest wheat for hay in the spring, and produce a doublecrop forage crop (foxtail millet hay); (3) Maximize fall forage and harvest wheat for grain production; (4) Traditional balance of fall wheat forage and grain production; and (5) No forage, maximize grain production.

For the first two production objectives, wheat was planted in early September, grazed by stocker cattle from fall to March and mechanically cut for wheat forage in late April or early May. After forage removal in May, German foxtail millet was planted and harvested for hay at heading. Approximately two weeks later, Roundup Ultra was applied at 1.5 pints/acre to the no-till treatments to control wheat re-growth. The conventional treatments (CT) were chiseled and then disked. Foxtail millet was then planted at 17 pounds/acre using a no-till drill. In the first year, 110 pounds of nitrogen/acre was applied to millet plots, and 84 pounds of nitrogen/acre in the second year.

For the third production objective, wheat was seeded in early September, grazed from fall to March and harvested for grain in June.

The fourth production objective was considered the traditional balance between forage and grain. Wheat was planted September 20-24, grazed until early March, and harvested for grain in June.

Wheat forage was estimated by clipping quadrats in November at that time cattle were released onto the fields. A 10- by 30-foot portion of each plot was fenced to prevent grazing to determine grazing effects on wheat grain yield. Grazed portions of each plot were topdressed with 60 pounds of nitrogen per acre. Cattle were removed from the plots in March. These experiments are continuing through the 2003-2004 growing season.

The final production objective was to grow wheat for grain only. The wheat was seeded in the middle of October and harvested for grain in June. Cattle were excluded from these plots by a hot wire fence around each plot.

Wheat was seeded using a conventional single disk opener drill for CT treatments and a double disk no-till drill for no-till treatments. Ok101 hard red winter wheat was selected based because of its adaptation to early-planted dual-purpose management systems and also because of its ability to produce abundant wheat forage. The wheat was seeded at 90 pounds per acre for all treatments and 80 to 90 pounds of nitrogen was applied at or before planting (Krenzer, 2001).

In June 2002 following grain harvest all no-till treatments except ones planted to millet received Roundup Ultra at 1.5 pints/acre (for the first year at Hunter, no herbicide was applied because no weeds were present). In August 2002 following millet harvest RT Master was applied at 1 quart/acre to all no-till treatments. June 2003 RT Master at 1 quart/acre was applied to all no-till treatments except those with foxtail millet. Roundup Ultra at 14 oz/acre was applied one week prior to seeding wheat.

Various tillage methods were used to control weeds in the CT treatments grown for grain. June 2002, CT treatments harvested for grain were moldboard plowed and then disked. In August 2002 and 2003, all CT treatments were disked. For fall 2002 and 2003, treatments were disked and tilled with a light cultivator with double rolling baskets at time of planting for each appropriate planting date.

RESULTS AND DISCUSSION

With production objective 1, no-till increased forage production. Averaged across locations, the no-till forage sampled in November '02 and '03 yielded 760 and 420 pounds of dry matter/acre more than the CT. Wheat hay produced in no-till was 5930 pounds of dry matter/ acre, which exceeded CT by 910 pounds (Table 1).

Within production objective 2 the foxtail millet yields were good in the summer of 2002. Averaged across locations, the no-till millet forage yielded 4880 pounds of dry matter/ acre, which was 630 more pounds of dry matter than the CT. The results from the summer of 2003 were different. The CT millet produced 3690 pounds of dry matter/ acre, which was 600 pounds more than the no-till. We believe that the difference in years is due to fertilizer placement. For the second year, the conventional plots were tilled prior to seeding to incorporate the fertilizer into the soil and the no-till needed water to wash the nitrogen to the root zone, which it did not receive. Wheat forage production was greater in the no-till in November 2003. The no-till wheat forage yielded 1940 pounds of dry matter/acre averaged across three locations, which was 365 pound more than CT. Wheat hay yields were 150 pounds less in the no-till.

In production objective 3, the early September planted wheat that was grown for fall forage production and grain yield had higher forage yields in the no-till for both years. When averaged across three locations, no-till yielded 2830 pounds of dry matter/acre in 2002 and 2140 pounds/acre in 2003, which are 540 and 370 pounds more than CT, respectively. Grain yields were reduced 7 to 9 bushels/acre with no-till and grazing reduced yields by 5.5 bushels/acre when averaged across locations. Official test weight was reduced with no-till, which decreased official grade.

The late September planting used for forage and grain had lower forage yields than the earlier planted wheat. In 2003 no-till forage production was greater than the previous years. Wheat grain production was reduced with no-till by 7 to 8 bushels/acre. Wheat quality was the same for CT and no-till.

For the objective with grain production only, CT produced 43 bushels/acre, which was 8 bushels more than the no-till. However official test weight and grade were the same for CT and no-till.

In the first year's observations, the no-till millet forage yields were as good if not better than the CT forage yields. As for the second year, millet yields were reduced with no-till. Fertilizer placement in no-till maybe an issue. Compared to other treatments, the treatments with millet grown for forage reduced the amount of wheat forage produced but the total amount of forage produced averaged over locations, was 14230 for no-till and 14380 for CT treatments. No-till reduced grain yield and slightly lowered wheat quality.

Our future plans are to complete this year's data collection and meet with cooperators to determine plans for the 2004-2005 growing season.

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Table 1: Effect of production objective tillage practice on forage and grain production and grain quality.

Average of three locations (Cherokee, Loyal, and Hunter, OK)

Planting dates and Production objective	**Tillage Practice**	**Millet** Forage[*] Lbs/A	**Wheat** Forage[**] Lbs/A	**Wheat** Hay Lbs/A	**Wheat** Yield[•••] Bu/A	**Wheat** Official Test Wt.	**Wheat** Official Grade	**Wheat** Protein %
1. Wheat planted Sept. 4-6 Winter Graze + Wheat hay	Conventional Tillage		1610 ('02) 1720 ('03)	5020				
	No-till		2370 ('02) 2140 ('03)	5930				
2. Millet planted May 14-22 Wheat planted Sept. 4-6 Winter Graze + Wheat hay + Millet hay	Conventional Tillage	4250 (2002) 3690 (2003)	1300 ('02) 1575 ('03)	5040				
	No-till	4880 (2002) 3090 (2003)	1370 ('02) 1940 ('03)	4890				
3. Wheat planted Sept. 4-6 Winter Graze + Grain	Conventional Tillage		2290 ('02) 1770 ('03)		46.1 (G) 52.6 (U)	58.7	2.0	11.7
	No-till		2830 ('02) 2140 ('03)		38.4 (G) 43.6 (U)	57.1	2.8	11.7
4.Wheat planted Sept. 20-24 Winter Graze + Grain	Conventional Tillage		1025 ('02) 725 ('03)		51.0 (G) 55.9 (U)	58.9	1.9	12.3
	No-till		970 ('02) 900 ('03)		43.5 (G) 47.2 (U)	58.2	2.5	12
5. Wheat planted Oct. 11-15 Grain only	Conventional Tillage				43.0	58.2	2.3	11.7
	No-till				35.0	58.4	2.1	12

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[*] Pounds of dry matter

[**] Wheat forage present when stockers were turned onto the field

[•••] G= Yield from grazed part of each plot and U = Yield from ungrazed part of each plot.

A PRELIMINARY STUDY OF DUAL USE OF COVER CROPS: SORGHUM SUDANGRASS AS BOTH HAY AND SUMMER COVER CROP FOR NO-TILL ORGANIC CABBAGE

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ABSTRACT

Sorghum sudangrass [*Sorghum bicolor* (L.) Moench X *S. sudanense* (Piper) Staph.] may be a suitable summer cover crop for no-till fall vegetable production, considering its potential to suppress weeds, produce high levels of biomass, and double as a hay crop. This study was conducted to identify management practices that lead to effective weed suppression by the sorghum sudangrass without negatively impacting subsequent cabbage cash crop yield and to assess the impact of residue removal on the overall production system. The experimental design was a split-plot, with main plot treatments consisting of drilled or broadcast planting of sorghum sudangrass. Subplot treatments represented four management regimes: no in-season mowing, 100 lb N/A applied prior to planting; no in-season mowing, no N applied; one in-season mowing event with residues removed from the field, 100 lb N/A applied; and one in-season mowing with residues left on the field, 100 lb N/A applied. Mowing reduced both biomass production and C:N ratio of the cover crop, and led to an increased rate of transplant survival. There was no evidence of a positive impact of N fertilization prior to cover crop planting. Cabbage yields were poor in all experimental plots in 2003. Experiments in 2004 will investigate causative factors of the poor cabbage yield and alternative cover crop management regimes to overcome negative impacts of sorghum sudangrass.

INTRODUCTION

There is a growing interest among southeastern vegetable growers, both organic and conventional, in no-till vegetable production. Conservation tillage systems offer advantages such as reduced erosion and runoff, enhanced soil moisture availability, improved crop yields, and improved efficiency in the use of fossil fuel based non-renewable resources (Coolman and Hoyt 1993). Cover crops are a common feature of no-till production systems. The benefits of cover crops are well documented and include management of runoff and soil erosion, enhanced soil fertility, weed suppression, and insect pest control (Lal *et al.* 1991). Though these features are advantageous within conventional production, cover crops are of increased importance for organic systems, and their application will increase with a rising interest in organic vegetable production.

The number of potential no-till vegetable systems appropriate to the Southeastern United States is diverse, as vegetables can be planted to benefit from a winter or summer cover crop, and many vegetable crop rotations are conducive to incorporating cover crops. Due to the economic significance of crops such as cabbage and broccoli in the region, along with prospects for increased organic production of these crops, no-till systems for fall vegetables are of particular interest. Previous research has demonstrated that no-till culture of these crops in winter cover crop residues results in yields comparable to conventional tillage systems (Knavel 1989; Morse and Seward 1986). Abdul-Baki *et al.* (1997) demonstrated that no-till fall broccoli production in summer cover crop residues also produces yields similar to conventional production systems. The use of a summer cover may allow growers to expand their production capability by producing both a spring and fall crop or an over wintered crop such as garlic or flowers, followed by a summer cover and fall crop.

Creamer and Baldwin (2000) assessed the performance of six legume, two broadleaved, and five grass species suitable for use as summer cover crops in North Carolina. Among the crops evaluated as summer cover crops in this study was sorghum sudangrass *Sorghum bicolor* (L.) Moench X *S. sudanense* (Piper) Staph. Sorghum sudangrass has the potential to produce abundant biomass, suppress weeds (Creamer and Baldwin 2000; Weston *et al.* 1989) and decrease soil compaction (Wolfe *et al.* 1998). Growers in North Carolina currently utilize sorghum sudangrass as a summer cover prior to the planting of a winter cover crop (Magdoff and van Es 2000).

Sorghum sudangrass is commonly cultivated as a forage crop for grazing, hay or silage (Chamblee *et al.* 1995). Because of its significance as a forage, there is a considerable body of literature regarding growth and management of sorghum sudangrass. The characteristics of biomass production, response to mowing frequency and stubble height, and re-growth potential are of greatest importance when determining management practices for sorghum sudangrass as a summer cover crop. Sorghum sudangrass is recognized for its high yield potential, though season biomass production is dependent on management. Increased cutting (mowing) frequency will lead to reduced seasonal biomass production (Beuerlein *et al.* 1968), though yield reductions are less severe than other grasses (Muldoon 1985). Generally, a stubble height of 6 to 8 inches is recommended to promote re-growth (Chamblee *et al.* 1995). Re-growth occurs from both terminal buds and basal and axillary tillers, a quality unique among common forage crops (Clapp and Chamblee 1970). Tillering capacity leads to an increased capacity to re-grow following cutting (Muldoon 1985) and allows re-growth from lower stubble heights (Clapp and Chamblee 1970). This is a potential drawback to the use of sorghum sudangrass in rotation with fall organic vegetables, as chemicals cannot be used to suppress re-growth if mowing is not completely effective. Study is needed to evaluate the biomass production, weed suppression, re-growth potential, and management of sorghum sudangrass within a no-till fall vegetable production system.

In addition to providing a base for no-tillage organic vegetable crop production, sorghum sudangrass may be harvested as a hay crop (Chamblee *et al.* 1995). Managing the summer cover crop to allow for a mid-season hay harvest may provide an additional income source for growers. Supplies of organic hay in North Carolina are limited and demand is expected to rise with the adoption of federal organic standards by dairy and livestock producers. The impact of cover crop removal as hay on cabbage yield and weed suppression, however, must be investigated as an initial step in the development of such a cover crop management system.

The objective of this study was to determine the best management practices, including N fertilization, planting method, cutting frequency, and residue management, for sorghum sudangrass grown as a summer cover crop preceding organic no-till production of fall cabbage. Optimal management and the impact of residue removal as hay were assessed based on cover crop biomass production, cover crop re-growth, cover crop C:N, weed biomass, and cabbage stand establishment and yield.

MATERIALS AND METHODS

This study was conducted at the Center for Environmental Farming Systems in Goldsboro, North Carolina in 2003 and will be repeated in 2004. The experimental design was a split-plot with four replications. There were two main plots per block, drilled and broadcast sorghum sudangrass. Drilled plots were planted on 9 June 2003 using a Sukup drill. Initial attempts to broadcast sorghum sudangrass using a Brillion seeder with cultipacker resulted in poor stands. In two attempts using this method, birds were observed eating seeds, indicating a need for improved incorporation. In addition, the hard seed coat and large size of sorghum sudangrass may have contributed to poor stand establishment. In order to improve seed incorporation, a field conditioner (a shallow tillage implement) was used to bury seed following planting with a hand seeder. As a result, broadcast stands were not established until 26 June 2003. Due to the number of growers that rely on broadcast planting of cover crops, the results of this trial are of interest. Sorghum sudangrass may not be well-suited to this planting method, though shallow tillage does appear to improve stand establishment following broadcasting.

Plots were planted at a rate of 43 lb/A of untreated sorghum sudangrass 'Haychow' seed. Following planting, each plot was divided into four sub-plots (10' x 25') representing the four cover management systems listed in Table 1. Prior to planting sorghum sudangrass, 2080 lb/A soybean meal was applied by hand to appropriate plots and all plots were lightly tilled to incorporate fertilizer and remove weeds. Additionally, 2 lb/A of Solubor were applied prior to planting.

Treatments which included in-season mowing were flail mowed to a 6¨stubble height when plants reached a height of 48". Prior to mowing duplicate biomass samples were taken from each sub-plot using a 2'x 2' frame. Aboveground biomass was sorted into crop and weed, dried at 120°F for at least 48 hours, and weighed. Sub-samples of cover crop biomass were analyzed for forage quality and C and N concentration.

On 18 August 2003 the sampling procedure above was repeated in all plots, excluding forage analysis. Sub-plots were flail mowed to a stubble height of 1" or lower on 26 August. Immediately following mowing, a sub-surface tiller transplanter was used to transplant 'Bravo' cabbage plugs. Cabbage was planted in 30" double rows, with an intra-row spacing of 12". An Organic Materials Review Institute (OMRI)-certified 4-2-4 fertilizer was applied in the furrow at the time of planting at a rate of 2300 lb/A. Due to poor cabbage establishment, mowing and transplanting were repeated on 4 September. Stand establishment was recorded 7 days after planting, and cabbage was managed following federal organic standards throughout the growing season. Re-growth of sorghum sudangrass was monitored throughout the season, with a count taken 2 weeks after planting (WAP) and between row biomass sampled at 6 WAP. Prior to cabbage harvest on 25 November, in-row sorghum sudangrass re-growth and weed biomass were sampled using a 2'x 2' frame. Samples were dried and weighed, and re-growth analyzed for C and N concentration. Cabbage was harvested from two ten foot rows per plot on 2 December dried at 120°F for at least 48 hours and weighed. Data were analyzed using analysis of variance procedures for a split-plot design ($P \leq 0.05$).

RESULTS AND DISCUSSION

Cover Crop Biomass Production

Biomass production was affected by both planting method and management treatment (Table 2). Cumulative biomass production was significantly higher in drilled (4.40 t/A) than in broadcast plots (2.87 t/A); however results are confounded by the later planting date of the broadcast treatment which likely reduced biomass production in those plots. The interaction between planting method and management system led to significant differences between management systems only in drilled plots. Again, this interaction may have been due to the truncated growth period of sorghum sudangrass in broadcast plots. Within drilled plots, mowing led to reductions in biomass production compared to the unmowed system with similar fertility. This is consistent with earlier findings that mowing decreases overall season production (Beuerlein *et al.* 1968).

Biomass production following cover crop kill did not vary with planting method or management treatment (data not shown). Mowing did, however, reduce the number of actively growing stems at two weeks after cabbage transplanting compared to the unmowed system with similar fertility (Table 3). As there was not a significant effect of planting method on re-growth at 2 WAP or an interaction of planting method and cover management, means presented represent averages across planting method. Variation between cover management systems may have been due to reduced plant vigor caused by mowing.

Cover Crop C:N

Both planting method and management system had a significant impact on the cover crop C:N ratio (Table 4). The C:N ratio of sorghum-sudangrass in drilled plots was higher (68) than in broadcast plots (53), though this variation was likely due to differences in planting date. Unmowed treatments had a higher C:N ratio than mowed treatments at the end of the cover crop growing season. By the end of the cabbage growing season, the C:N ratio of the sorghum sudangrass residues was no longer different between management systems and averaged 32 (data not shown).

Regardless of planting method, the C:N ratio of sorghum sudangrass prior to cash crop planting was significantly lower in mowed plots than in unmowed plots. Plants mowed at mid-season were in a vegetative growth stage at the time of final mowing (data not shown), leading to a lower C:N ratio. Considering the likelihood of net N immobilization at higher C:N ratios, mowing may lead to more rapid net N mineralization during the cash crop growing season.

Weed Suppression

Weed populations were negligible throughout the growing season (Table 2), indicating that sorghum sudangrass effectively suppressed weed populations. Though populations were minimal, weed biomass did vary with both planting method and management system. Weed biomass was greater in drilled (0.49 lb/A) than in broadcast plots (0.23 lb/A) at the end of the sorghum sudangrass growing season. Due to the interaction between planting method and management system, a significant effect of treatment was present only in drilled plots. Within drilled plots, weed biomass was higher in mowed than unmowed plots, perhaps due to canopy removal by mowing. Comparing residue management in mowed systems, plots from which residues were removed had a greater weed biomass than those in which residues remained on the field, an indication that residue removal as hay may lead to increased weed populations.

Cabbage Stand Establishment

Cabbage stand establishment was not influenced by planting method, though variation in percent transplant survival did exist between management systems across planting method.

There was a weak negative correlation (R=-0.51304, p=0.0027) between cover crop biomass and cabbage stand count, indicating that higher residue biomass may decrease transplant survival. Observations made during the transplant operation indicate that high levels of residue had a tendency to cause residues to build up on cutting implements and drag. This build up, in turn, was observed to cause poor closure of planting furrows and intercepted fertilizer delivery. Knavel and Herron (1985) reported a similar interference for fall cabbage transplants set with a no-till transplanter into sudangrass residues. Proper adjustment of transplanting equipment may mediate this problem.

Cabbage Growth

No marketable heads were produced in this trial. Though a number of factors not analyzed in this trial may have contributed to crop failure, it is likely that sorghum sudangrass re-growth interfered with crop growth. Statistical analysis did not detect a correlation between cabbage dry weight and re-growth density or biomass. However, Weaver (1984) demonstrated that cabbage must be free of weeds for three weeks following planting to avoid yield reduction, and re-growth of sorghum sudangrass was present at 2 weeks after planting. Other studies have shown that persistence and accumulation of re-growth biomass can contribute to cabbage yield loss (Lawson and Wiseman 1978, Brandsæster *et al*. 1998; Nicholson and Wein 1983, Bottenberg *et al*. 1997).

In addition to competing with cabbage for light, nutrients, and water, sorghum sudangrass re-growth may have inhibited cabbage growth through allelopathy. Actively growing sorghum sudangrass exudes sorgoleone (Rimando *et al.* 1998) and other organic acids that have been demonstrated to inhibit seed germination and seedling growth (Weston *et al*. 1989) and reduce growth of transplants (Geneve and Weston 1988). Sorghum sudangrass residues also have allelopathic potential, but may not be as suppressive as living plants. There are no studies of the response of cabbage to sorghum sudangrass allelochemicals, though cabbage is sensitive to other allelopathic species (Qasem 2001).

Forage Analysis

Forage analysis was performed on clippings from one mowed system in the drilled plots, as clippings represent a potential hay crop. The crude protein value of 14.3% and total digestible nutrient value of 64.9% were above the range for high quality forage for ruminants recommend by the North Carolina Cooperative Extension Service (Table 6), indicating that clippings were of saleable quality.

SUMMARY

Planting Method, Mowing, and Fertilization of Sorghum Sudangrass

Due to poor stand establishment using conventional broadcast planting methods, broadcast plots were planted more than two weeks later than drilled plots. Results concerning the significance of planting method are, therefore, confounded by the difference in age of sorghum sudangrass. Sorghum sudangrass may not be readily adaptable to broadcast seeding, though shallow tillage can help to improve stand establishment.

The results of this study indicate that mowing sorghum sudangrass during its summer growing season may be advantageous to no-till organic fall vegetable production. Mowing leads to a lower C:N ratio of residues at the time of transplanting, potentially limiting N immobilization. Sorghum sudangrass biomass reduction due to mowing may also promote transplant survival and did not appear to have a negative impact on weed suppressive qualities of the cover crop.

With regard to fertility management of the summer cover crop, results obtained in 2003 provide no evidence of an advantage to N fertilization of the cover crop prior to planting. As the application of soybean meal can provide additional nitrogen to the subsequent crop, continued studies of nutrient dynamics within the system with and without pre-cover crop N fertilization would be valuable.

Impact of Residue Removal as Hay

As weed pressure was inconsequential in all management systems, this study provided no evidence of a negative impact of residue removal following in-season mowing on weed suppressive qualities of sorghum sudangrass. Due to crop failure, no assessment of the impact of residue removal on crop yield can be made. Future study should include an economic analysis of cover crop harvest for hay.

Further Study

Repetition of this study in 2004 will provide more conclusive results regarding best management practices for sorghum sudangrass as a summer cover/hay crop. Results thus far suggest that sorghum sudangrass may not be a suitable summer cover crop for no-till organic fall vegetable production, largely due to crop persistence following mowing. Limiting sorghum sudangrass re-growth appears to be essential for the system to be successful. Two possible strategies to limit re-growth are increased mowing and effective mechanical kill. The effect of increased mowing on re-growth capacity should be investigated. Further study of alternative mechanical methods to provide a more consistent and effective means of killing the cover crop also merit investigation. Another concern with the use of sorghum sudangrass in a no-till system is its allelopathic potential. Investigations to elucidate the allelopathic interaction of both sorghum sudangrass re-growth and residues with transplants are needed to determine if sorghum sudangrass is detrimental to no-till fall vegetable culture.

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Table 1. Sorghum sudangrass management systems applied at Goldsboro, NC, in 2003.

#	Cut 1†	Cut 2	N applied‡
1	None	End of season, 1” stubble height residues left on field	100 lbs/acre
2	None	End of season, 1” stubble height residues left on field	None
3	At 48”, 6” stubble height residues removed from field	End of season, 1” stubble height residues left on field	100 lbs/acre
4	At 48”, 6” stubble height residues left on field	End of season, 1” stubble height residues left on field	100 lbs/acre

†In drilled plots, cut 1 occurred on 9 July 2003 (29 DAP). Cut 1 in broadcast plots occurred on 28 July 2003 (32 DAP). Cut 2 occurred in all plots on 18 August 2003.
‡N was applied on 5 June 2003.

Table 2. Aboveground biomass for sorghum sudangrass and weeds on 18 August 2003 in relation to planting method and cover crop management at Goldsboro, NC.

Planting method	Cover management	Cover biomass: (t/A) cut 1	cut 2	total	Weed biomass (lb/A)
Drilled	End of season cut w/ N		5.72	5.72a†	0.155c‡
	End of season cut w/o N		5.21	5.21ab	0.250c
	Mid & end of season cuts w/ N, residues removed	1.85	1.16	3.00c	0.995a
	Mid & end of season cuts w/ N, residues left	1.87	1.78	3.65bc	0.545b
Broadcast	End of season cut w/ N		3.31	3.31	0.177
	End of season cut w/o N		2.61	2.61	0.214
	Mid & end of season cuts w/ N, residues removed	2.68	0.51	3.19	0.085
	Mid & end of season cuts w/ N, residues left	1.75	0.61	2.37	0.442
<u>Mean values:</u>					
Drilled				4.40a	0.486a
Broadcast				2.87b	0.230b
<u>Treatment effects:</u>					
Planting method				**	*
Cover management				**	*
Planting method x cover management				**	*

†Mean values followed by the same letter are not significantly different (P = 0.05) according to pairwise comparisons using Fisher’s LSD.
‡LSD applied to square root-transformed data

Table 3. Sorghum-sudangrass re-growth averaged over planting method at 2 weeks after cabbage transplanting on 18 September 2003 in Goldsboro, NC.

Cover management	stems/ft^2
End of season cut w/ N	6.6a†
End of season cut w/o N	6.5ab
Mid & end of season cuts w/ N, residues removed	4.1c
Mid & end of season cuts w/ N, residues left	4.4bc

†Mean values followed by the same letter are not significantly different (P = 0.05) according to pairwise comparisons using Fisher's LSD.

Table 4. C:N ratio of sorghum-sudangrass biomass at the end of summer growth season from samples collected on 18 August 2003 at Goldsboro, NC.

Planting method	Cover management	C:N
Drilled	End of season cut w/ N	81a†
	End of season cut w/o N	100a
	Mid & end of season cuts w/ N, residues removed	44b
	Mid & end of season cuts w/ N, residues left	45b
Broadcast	End of season cut w/ N	83a
	End of season cut w/o N	80a
	Mid & end of season cuts w/ N, residues removed	23b
	Mid & end of season cuts w/ N, residues left	28b
Mean values:		
Drilled		68a
Broadcast		53b
	End of season cut w/ N	82a
	End of season cut w/o N	90a
	Mid & end of season cuts w/ N, residues removed	33b
	Mid & end of season cuts w/ N, residues left	37b
Treatment effects:		
Planting method		**
Cover management		**
Planting method x cover management		NS

†Mean values followed by the same letter are not significantly different (P = 0.05) according to pairwise comparisons using Fisher's LSD.

Table 5. Percent cabbage transplant survival averaged over planting method at 1 week after planting on 11 September 2003 in Goldsboro, NC.

Management system	% transplant survival
End of season cut w/ N	63c†
End of season cut w/o N	71bc
Mid & end of season cuts w/ N, residues removed	86a
Mid & end of season cuts w/ N, residues left	80ab

†Mean values followed by the same letter are not significantly different (P = 0.05) according to pairwise comparisons using Fisher's LSD.

Table 6. Forage quality indicators for ruminants and experimental forage analysis for clippings from drilled plots on 9 July 2003 at Goldsboro, NC.

Forage type	High quality†	Average quality	Low quality	Experimental
Grass	CP 12-14% TDN 57-60%	CP 9-11% TDN 54-57%	CP below 7% TDN below 54%	CP 14% TDN 65%

†Indicators published by North Carolina Cooperative Extension

WINTER ANNUAL GRAZING AND TILLAGE SYSTEMS EFFECTS ON SWEET CORN

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ABSTRACT

Winter annual grazing can supplement vegetable grower income, but can also decrease vegetable yields through excess soil compaction. We initiated a study to determine the optimal tillage system for sweet corn (*Zea mays*, L.) production on a Wynnville fine sandy loam (Fine-loamy, siliceous, subactive, thermic Glossic Fragiudults), in north central Alabama from 2001-2003. A factorial arrangement in a randomized complete block design of three surface tillage treatments (chisel/disk/level, disk/level, no surface tillage) and three deep tillage treatments (no deep tillage, in-row subsoiling, paratill) with four replications were administered to plots planted to ryegrass (*Lolium multiflorum* L.) cv. 'Marshall' each fall. Winter annual grazing generated an average net income over the 3 yr period of \$268.75 ac^{-1} minus labor. Both surface tillage treatments were superior to no surface tillage each year. In-row subsoiling produced higher fresh corn ear weights in 2001, while both deep tillage treatments produced higher yields than no deep tillage in 2003. Leaf temperatures differences of less than 2 F° were observed between surface and deep tillage treatments in 2001 and 2002. Differences of 1/16" were observed in average ear diameters between surface tillage treatments in 2001 and 2002 and between deep tillage treatments in 2002. Preliminary results indicate that a combination of surface and deep tillage is required to maximize sweet corn yields following winter annual grazing.

INTRODUCTION

In Alabama, over 400,000 ac. of winter annuals are grazed prior to planting summer row crops (Ball, 1988). Research indicates profits of \$70 to \$224 ac^{-1} for cattle grazed on ryegrass pastures over the winter months in Alabama (Bransby et al., 1999). These profits document the potential that exists for growers to supplement their income over the winter months after the summer growing season.

Vegetable growers typically produce higher net returns per acre compared to growers that plant only summer field crops, due to the higher prices received for vegetables. For example, Alabama growers planted 1700 ac. of sweet corn in Alabama with an average yield of 68 cwt ac^{-1} that sold for an average price of \$17 cwt^{-1} (NASS, 2003). These statistics indicate an average gross income of over \$1100 ac^{-1}. Vegetable growers capable of integrating winter grazing into their operations can potentially increase their profit margins substantially.

Unfortunately, winter grazing creates excessive compaction, which adversely affects yields of subsequent summer crops (Miller et al., 1997). Although, vegetable growers can supplement their income and reduce economic risk by incorporating winter grazing into their operation, this increase in profitability over the winter months should not be at the expense of vegetable yields the following year.

The objective of this study was to determine the optimal tillage system for sweet corn production following winter grazing.

MATERIALS AND METHODS

An experiment was established at the Sand Mountain Research and Extension Center in Crossville, AL. Treatments were a factorial arrangement of three surface tillage treatments and three deep tillage treatments in a randomized complete block design with four replications, established for each of three crops (sweet corn, southern pea (*Vigna unguiculata* L.), watermelon (*Citrullus lanatus* L.)) grown simultaneously. The crops were rotated each year in a southern pea-sweet corn-watermelon sequence for 3 yr. Plot dimensions were 11 ft. wide and 45 ft. long, allowing for a 1 ft. buffer between plots. Data presented will only be for sweet corn production.

Beginning in September of 2000, ryegrass cv. ‘Marshall’ was planted at 25-30 lb ac^{-1} on a Wynnville fine sandy loam with a no-till drill. Plots were grazed, beginning in late November to early December, at a stocking rate of three cattle ac^{-1} and removed by early to mid-April to facilitate sweet corn planting. Cattle performance was determined each year by weighing each animal prior to grazing and at the time of removal from grazing. Biomass samples were collected after cattle removal by cutting all aboveground ryegrass tissue from two areas, within each plot, measuring 2.7 ft^2 each. Glyphosate was used to terminate ryegrass, tillage treatments were administered, and pre-emergence herbicides (atrazine and s-metolachlor) were applied, prior to sweet corn planting. Typical cultural practices to control weeds and insects were utilized throughout the season to maximize yields.

Sweet corn cv. ‘Silver Queen’ was planted at 26,000 plants ac^{-1} in mid-April of each year. Sweet corn row spacing was 30” in 2001 and 2002 and 36” in 2003. In 2001, three treatments (no surface tillage and no deep tillage; no surface tillage and in-row subsoiling; no surface tillage and paratill) were replanted on 8 May, due to poor stand establishment. All sweet corn plots were replanted in 2003 because of poor seed germination. Leaf temperatures, an indication of plant stress, were collected from five leaves plot^{-1} on eight different dates in 2001, six different dates in 2002, and four different dates in 2003 beginning immediately prior to silking. Fresh corn ear weights were measured by hand harvesting ears from the two center rows of each plot and summing the weights from three different harvest dates. The length and diameter of two randomly selected ears from each harvest date were measured and averaged to estimate quality.

Fresh sweet corn ear weights and average length and diameter of ears were analyzed by analysis of variance using a general linear model procedure provided by Statistical Analysis System (SAS Institute, 2001) within years. Dates of leaf temperatures were analyzed by date within years using the same general linear model procedure provided by Statistical Analysis System. Treatment differences were considered significant if $P > F$ was equal to or less than 0.10.

RESULTS AND DISCUSSION

Combined cattle gain over each grazing period was 2415, 3015, and 2350 lb. for 2001, 2002, and 2003, respectively. This weight gain generated an average net income over the 3 yr period of \$268.75 ac^{-1} minus labor. After cattle were removed, ryegrass biomass production was low due to close grazing by the cattle. In 2001, ryegrass was heavily grazed, so no biomass measurements were collected. Ryegrass biomass, prior to the initiation of tillage treatments, averaged 357 lb ac^{-1} in 2002 and 1214 lb ac^{-1} in 2003.

In 2001, fresh sweet corn ear weights ranged from 73.6 cwt ac^{-1} (no surface tillage; no deep tillage) to 213.1 cwt ac^{-1} (disk level; in-row subsoiling). Fresh sweet corn ear weights ranged from 206.1 cwt ac^{-1} (chisel/disk/level; paratill) to 124.6 cwt ac^{-1} (no surface tillage; paratill) in 2002. Yields across all treatments were lower in 2003 due to wind damage from a tropical storm. Yields ranged from 105.1 cwt ac^{-1} (disk/level; paratill) to 40.9 cwt ac^{-1} (no surface tillage; no deep tillage). Chisel/disk/level and disk/level produced higher yields above no surface tillage, when averaged across all deep tillage treatments for each year of the study (Table 1). In-row subsoiling was superior to no deep tillage when averaged across all surface tillage treatments in 2001 and 2003 (Table 1). No yield differences were detected between deep tillage treatments in 2002. The paratill treatment also produced higher fresh sweet corn ear weights than no deep tillage in 2003.

A significant interaction was observed between surface tillage and deep tillage in 2002 and 2003. A combination of surface and deep tillage produced higher yields than deep tillage alone in 2002 (Fig. 1A). However, the results were not consistent. In-row subsoiling produced higher yields when the disk/level treatment was applied, and the paratill treatment produced higher yields in combination with the chisel/disk/level treatment. Both surface tillage treatments produced higher yields than no surface tillage in combination with no deep tillage and the paratill treatment in 2003 (Fig. 1B). In-row subsoiling with no surface tillage produced similar yields as in-row subsoiling with both forms of surface tillage.

Sweet corn leaf temperatures were similar between tillage treatments within sample dates and years, but small temperature differences of 2 F° or less were detected in 2001 and 2002 (data not shown). No differences in leaf temperatures were observed for any treatments in 2003. Leaf temperatures were different for two sample dates from surface tillage treatments and one sample date for deep tillage treatments in 2001. In 2002, leaf temperature differences were only detected from the deep tillage plots for two sample dates. Generally, leaf temperatures measured from plots with no surface tillage or deep tillage were higher than leaf temperatures measured from plots with surface tillage or deep tillage, indicating more plant stress.

Ear quality measurements included length and diameter of two randomly selected ears from each harvest date, but no differences were observed between any treatments for ear lengths. Small differences (1/16") between average ear diameters were detected for two years (2001 and 2002) between surface tillage treatments and one year (2002) between deep tillage treatments (data not shown).

CONCLUSIONS

Fresh sweet corn ear weights increased all three years with chisel/disk/level surface tillage and two years with disk level surface tillage. In-row subsoiling produced higher fresh sweet corn ear weights in 2001 over no deep tillage and both deep tillage treatments produced higher ear weights over no deep tillage in 2003. Leaf temperatures were higher in plots receiving no surface tillage compared to other surface tillage treatments at two sample dates. Leaf temperatures from no deep tillage plots were also higher than deep tillage treatments at one sample time. Small differences were detected in average ear diameters in 2001 and 2002 for surface tillage treatments and in 2002 for deep tillage treatments.

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Table 1. Fresh sweet corn ear weights for three surface tillage treatments and three deep tillage treatments recorded at the Sand Mountain Research and Extension Center in Crossville, AL during 2001-2003 growing seasons.

	Surface tillage				Deep tillage			
Year	None	Chisel disk level	Disk level	$LSD_{0.10}$†	None	In-row subsoiling	Paratill	$LSD_{0.10}$
	cwt ac^{-1}				cwt ac^{-1}			
2001	92.9	195.7	185.3	20.7	144.3	174.7	154.9	20.7
2002	127.8	176.1	166.2	13.3	153.3	153.0	163.8	NS‡
2003	74.3	97.7	94.1	12.7	76.2	93.3	96.6	12.7

† Least significant difference at the P=0.10 level of significance.
‡ Not significant.

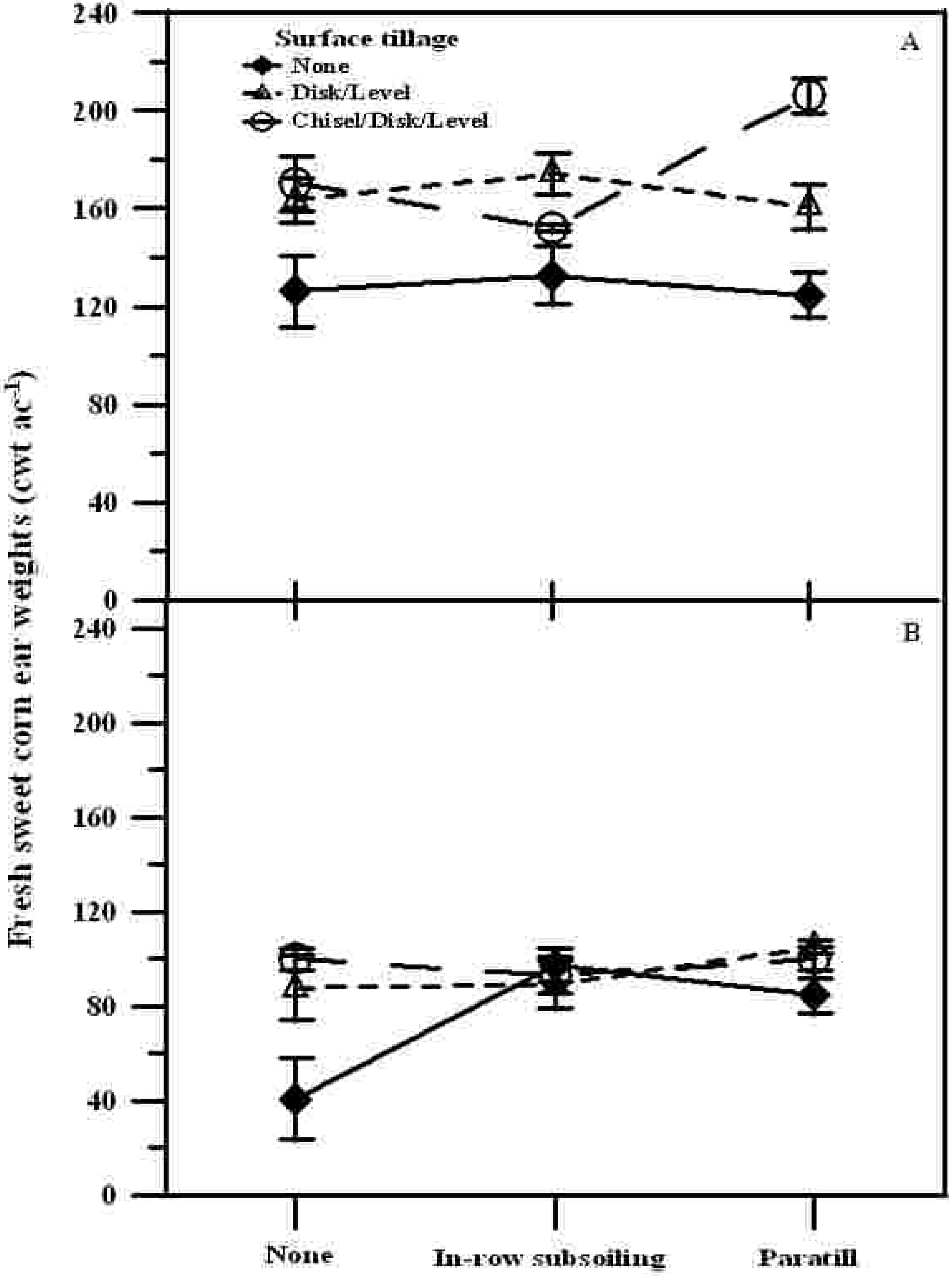

Figure 1. Effect of surface tillage and deep tillage on fresh sweet corn ear weights at the Sand Mountain Research Center in Crossville, AL for 2002 (A) and 2003 (B) growing seasons. Error bars indicate standard errors (n=4).

RYE COVER CROP MANAGEMENT IN CORN

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ABSTRACT

Rye cover crops can have multiple environmental benefits, such as erosion control, reduced nitrate leaching, soil organic matter increases, moisture savings in summer, and supplemental weed control. Recent research suggests that late killing of a rye cover crop is possible without corn yield losses. We planted corn 7-10 days after killing a rye cover crop in early and late boot stage, and compared the results with a control (no rye cover crop) in central Pennsylvania. We also investigated the benefits of in-row cultivation (zone-tillage), and compared weed control with full and half rates of pre-emergence herbicides as well as a complete post-emergence herbicide program. In this study we determined that approximately 4 times more rye biomass can be expected if rye cover crop kill is delayed from early to late boot stage. We did not observe a benefit to zone-tillage in recently killed rye cover crop. The root system of the rye was still completely intact at the time of zone-till, which made preparation of the zones with the coulter system challenging. This problem was exacerbated in late-killed rye. Weed control programs did not differ in efficacy, showing it may be possible to reduce reliance on pre-emergence herbicides in no-till if weed pressure is low. We observed no significant differences between corn yields with or without a cover crop or due to planting date if straight no-till was used. The use of late-killed rye cover crop seems therefore possible without a yield penalty in no-till. Multiple environmental benefits would be accompanying the higher rye biomass production in this system that may pay off in the long run. They include: better erosion control, higher residue input for organic matter increases, and reduced bulk density due to high rye root biomass input.

INTRODUCTION

Rye is the most common cover crop in Pennsylvania because of its ability to withstand low winter temperatures (Duiker and Curran, 2003). Rye helps reduce erosion, especially after low-residue crops such as soybean and corn silage, and protects nitrate from leaching (Brandi-Dohrn et al. 1997, Kessavalou and Walters, 1997). The addition of above and below ground rye residue contributes to increases in soil organic matter and soil aggregation (Oades 1984; Tisdall and Oades, 1982). Moisture conservation by a dead rye mulch cover can help alleviate main crop moisture stress in the summer. Rye cover crops have been found to reduce weed populations and weed growth (Reddy, 2003). Because of its multiple benefits, many producers are already using rye as a cover crop and environmental organizations are actively promoting it to protect water quality.

Most rye is followed by corn in Pennsylvania. The Penn State Cooperative Extension Service recommends farmers in the center of the state to finish corn planting by the 10th of May, which allows for limited rye biomass accumulation (Roth and Beegle, 2003). A threat associated with high rye biomass production is surface moisture depletion, which might harm the corn crop (Ebelhar, et al., 1984; Raimbault et al., 1991). In a recent study in Maryland, however, late kill of rye was not found to be detrimental to corn yield and beneficial for moisture conservation (Clark et al., 1997).

Compared to early killed rye, a mulch of rye killed late will last much longer and provides more environmental benefits.

Rye cover crop management has not always been without problems. Eckert (1988) observed significant stand reductions when planting into a living rye cover crop that was subsequently desiccated. Raimbault et al. (1990) observed 11-17% corn yield reduction after rye, which they attributed to phytotoxic (allelopathic) compounds released by rye. In a subsequent study, they found that the allelopathic effect was eliminated if the rye was killed some 2 weeks prior to planting and if in-row cultivation preceded planting operations (Raimbault et al., 1991).

Rye mulch retained on the surface can physically and chemically suppress weeds (Mohler and Teasdale, 1993). The rye mulch will reduce light penetration to the soil surface and lower soil temperatures, slowing weed seed germination and early growth. Rye is also known to release allelopathic compounds that can inhibit weed germination and growth. Although very high weed control has been reported (Putnam and DeFrank, 1983; Shilling et al., 1985) there are also reports in the literature of insufficient weed control as well as weed increases due to a rye cover crop (Masiunas et al., 1995; Koger et al., 2002; Reddy, 2003).

The objectives of the present study were to evaluate (1) early versus late planted corn into small and large amounts of rye residue; (2) benefits of in-row tillage with small and large amounts of rye mulch; (3) effectiveness of pre- and post- herbicide programs with no, small and large quantities of rye mulch.

MATERIALS AND METHODS

Field Operations

The experiment was conducted from 2001-2003. A different field was used each year. The fields were in close vicinity of each other on the Russell E. Larson Agricultural Research Center in Rock Springs, central Pennsylvania. The soil was a Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalf) in 2001 and 2002 and a Murrill channery silt loam (fine-loamy, mixed, semiactive, mesic Typic Hapludult) in 2003. The previous crop was oats in all years. Cereal straw and grain was removed before rye cover crop establishment. The experiment was a split-split-plot design with four replicates. Two planting dates were main, 3 rye management treatments sub-, and 3 herbicide programs sub-sub-plots. Sub-sub-plots were 15 ft wide by 30 ft long. Early and late planting dates for corn were respectively: May 9th and 22nd 2001, May 1st and 11th 2002, and May 2nd and 22nd 2003. Agway 5206 was planted in 2001 and 2002 and Pioneer 34H31 in 2003. The two planting dates were approximately 7-10 days after early and late booting stage of rye, when rye was dessicated with 1 lb/A glyphosate for early and late planting of corn. The three rye treatments were no-till corn without a rye cover crop (NO-RYE), no-till corn into a rye cover crop (RYE-NT) and zone-till corn into a rye cover crop (RYE-ZT). To obtain these treatments, the whole experimental area was planted to rye (Secale cereale, L.) with a no-till drill in the fall (100 lbs/A seeding rate). The No-Rye plots were sprayed with Roundup shortly after the rye came up, resulting in no rye being left at planting. The whole experimental area was topdressed each spring with nitrogen (65 lb/A N). Zone-tillage was done with the Rawson Zone Tillage system, each row unit consisting of three 17.5”, 13-wave fluted coulters that till up a 6” wide, 4” deep zone in which corn is planted. In 2001, the zone-till coulters were mounted on the frame of the no-till planter. Results of zone-till were poor that year because the zone-till coulters did not penetrate the soil adequately (most significantly in the late-killed rye treatments). This resulted in poor corn plant populations. To avoid further problems, zone-till was performed prior to planting with a zone-till cart in 2002 and 2003.

The three herbicide treatments were FULLPRE (full rate of pre-emergence herbicide applied at planting), HALFPRE (half rate pre-emergence herbicide applied at planting), and POST (full rate of post-emergence herbicide applied in June). Herbicide applications for the FULLPRE program were 2.25 fl oz Balance Pro plus 1.5 lbs/A Atrazine in 2001 and 2002. In 2003, 0.75 pt/A Dual II Magnum was added to these products for better yellow nutsedge control. Half these rates were applied in the HALFPRE program. Herbicide applications for the POST program were 14 fl oz/A Basis Gold plus 4 fl oz/A Clarity in a 0.25% nonionic surfactant and 2% urea ammonium nitrate solution. Both PRE and POST herbicide mix target a wide spectrum of both annual and perennial grass and broadleaf weeds and are commonly used in Pennsylvania. The herbicides were applied at different times depending on the corn planting date. Pre-emergence herbicides were applied shortly after planting. The post emergence herbicides were applied approximately 4 weeks after planting.

The whole experimental area was treated uniformly except for the treatments in each year. Corn was planted with a 6-row John Deere Max Emerge no-till planter on 30” row spacing, at a seeding rate of 28,000 seeds/A. Force soil insecticide was applied with the corn seed at planting time every year. Fertilizer application followed Penn State Cooperative Extension recommendations, based on soil fertility tests. Starter fertilizer was injected 2” besides and 2” below the corn seeds at planting.

Data Collection and Analyses

Above-ground rye dry matter production at early and late boot stage was measured by harvesting 5-8 5.4 ft^2 areas in the alleys between the plots. The rye was dried at 94 F until dry prior to weighing. Soil dry bulk density and water content in the top 8 “ was measured 8 weeks after planting in No-Rye and Rye-NT treatments with a Troxler moisture/density gauge in 2001. Three moisture/density measurements were taken in the center of each plot (4 reps). Corn yield was determined with a plot combine harvesting 25 ft of the three center rows of each plot. Results were analyzed with SAS.

RESULTS AND DISCUSSION

Rye Biomass Production

Rye biomass production differed greatly between years, despite the fact that rye was killed at approximately the same growth stage in each year (early and late boot) (Fig.1). Lowest rye biomass accumulation was in 2001, and the highest biomass accumulation occurred in 2003. Growth of rye was probably limited in 2001 because of low precipitation in January, February and March. The high biomass production at the late planting date of 2003 was because the kill date was delayed by one week due to extremely wet field conditions. These results indicate the challenges of rye cover crop management due to weather conditions. A one week delay in kill date can mean easily a doubling of the rye biomass the producer will have to deal with. On average, approximately 1000 lbs/A biomass accumulation can be expected at early boot stage, and 4000 lbs/A at late boot stage. Based on other work we estimate that the C:N ratio for early and late killed rye will be approximately 20 and 40, respectively. The succulent early killed rye will decompose quickly whereas the late killed rye mulch will be present for a prolonged period, possibly until the end of the corn growing season. The late planting date therefore offered increased benefits associated with mulch, such as protection against erosion, reduction of evaporation losses during the growing season, and increased (below and above-ground) biomass inputs for soil organic matter increases.

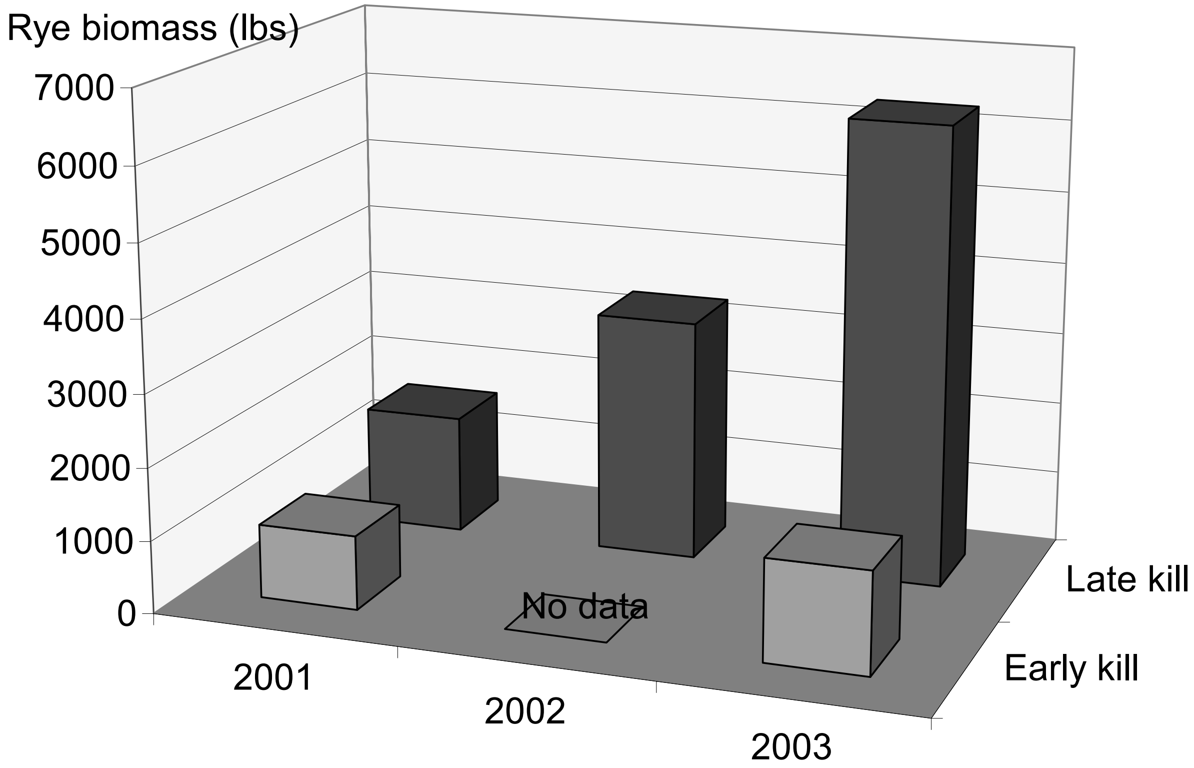

Figure 1. Above-ground rye biomass production killed at early and late boot stage.

Corn Yields

Corn yields were significantly different in each year, and they were affected by planting date and rye management. There were significant year x planting date x rye management interactions. However, yields did not differ between herbicide programs. The absence of a herbicide program effect is probably due to the very low weed pressure in these fields at the onset of our trials. Over the three years of the study (which included a dry, a wet and an optimal year), NO-RYE and RYE-NT produced similar yields but RYE-ZT produced significantly lower yields. On average over the three years of this study, there was no planting date effect for the NO-RYE and RYE-NT treatments, but a significant reduction in yield due to later planting in the RYE-ZT treatment. The average yield reduction in RYE-ZT was only due to its poor performance in the first year of this study (results not shown). RYE-ZT produced significantly lower yields than the other rye management treatments in 2001, and the highest yield reduction was obtained at the second planting date in this year. In 2001, NO-RYE and RYE-NT produced the same yields irrespective of planting date. Poor ZYE-ZT performance was due to a low plant population and shallow planted corn with the Rawson Zone-Till coulters mounted on the planter. The reduced soil moisture content due to water uptake of late killed rye in 2001 caused poor coulter penetration with zone-tillage. It was evident that extra weight should have been placed on the planter for good performance with zone-till. A general challenge of zone-till in rye cover crop is that the root system of the rye is still completely intact at the time of zone-till. This makes preparation of the zones with the coulter system challenging. This problem is exacerbated in late-killed rye.

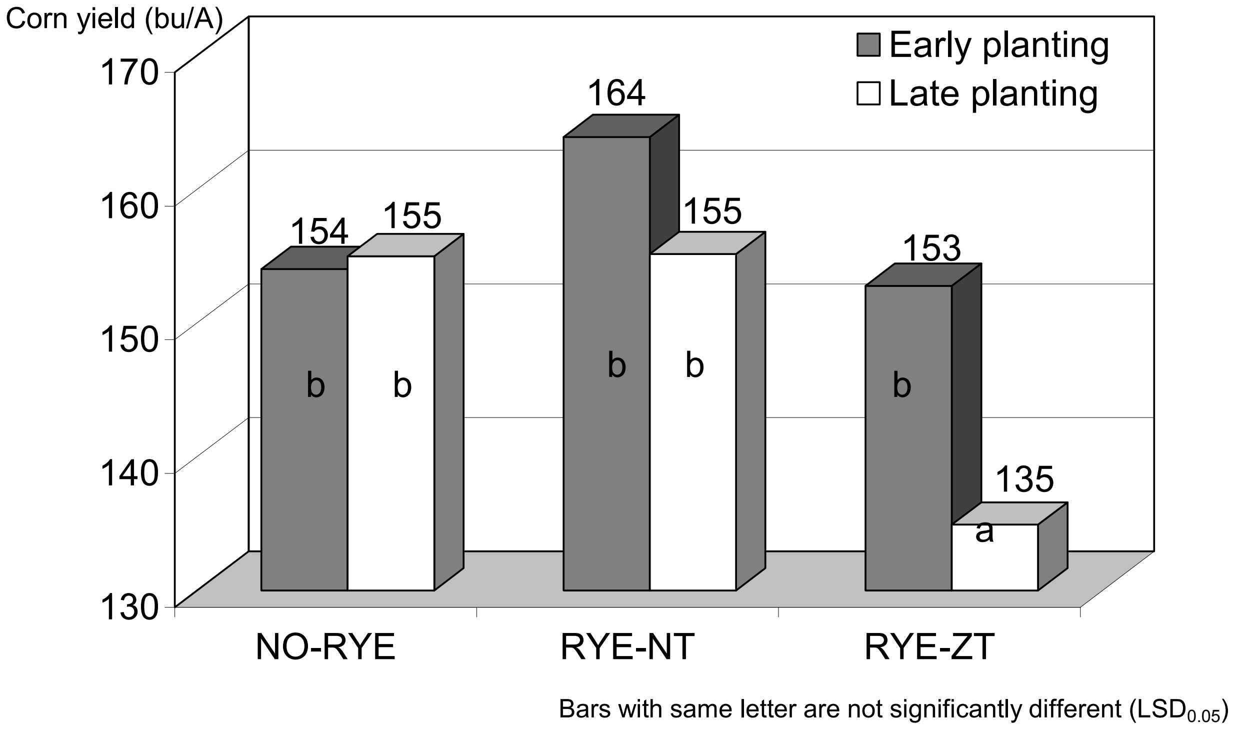

Figure 2. Rye management effects on average corn yields in Central Pennsylvania (2001-2003).

Our results show a non-significant 10 bu/A yield increase due to no-tilling corn into rye killed at the early boot stage compared to not using a rye cover crop. These results contrast with studies in Ohio and Ontario, where a rye cover crop resulted in significant yield reductions of the following no-till corn crop (Eckert, 1988; Raimbault et al., 1990). In the Ohio study corn yield was not reduced, and occasionally increased, if the rye cover crop followed soybeans instead of corn (Eckert, 1988). Thus we suggest that an early killed rye cover crop will boost yields if corn follows low-residue crops in our agro-climatic zone. Allelopathic effects of rye on corn such as those reported in Ontario (Raimbault et al., 1990) and Nebraska (Kessavalou and Walters 1997) were not observed in our study. In Ontario, in-row tillage techniques and residue removal from the row resulted in yield increases compared to straight no-till (Raimbault et al., 1991). In our study we did not see a benefit to zone-tillage, even in the years when zone-tillage performance was not compromised due to problems at planting time. Our results also show that it is possible to delay corn planting two weeks in central Pennsylvania without a significant yield penalty, which allows growth of a rye cover crop to the late boot stage. These results are similar to those obtained with rye in Maryland (Clark et al., 1997).

Bulk Density

There was a planting*rye interaction effect on bulk density. Dry bulk density in the 0-4"depth was significantly lower in the late planted RYE-NT treatment compared to the other planting*rye combinations. The bulk density of the soil under late-killed rye was 1.40 Mg m^{-3}, whereas the bulk density of the soil without rye, or with rye that was killed early, was 1.48 Mg m^{-3}. A similar trend was present in the 4-8" depth. We suggest that the reduction in bulk density was due to the large root system of the rye cover crop that grew to late boot stage. (Raper et al. 2000) reported a reduction in penetration resistance due to rye mulch, but no reduction in bulk density. The potential to reduce soil compaction by letting a rye cover crop grow to late boot stage deserves further attention.

CONCLUSIONS

In this study we determined that approximately 4 times more rye biomass can be expected if rye cover crop kill is delayed from early to late boot stage. We did not observe a benefit to zone-tillage in recently killed rye cover crop. The root system of the rye was still completely intact at the time of zone-till, which made preparation of the zones with the coulter system challenging. This problem was exacerbated in late-killed rye. Weed control programs did not differ in efficacy, showing it may be possible to reduce reliance on pre-emergence herbicides in no-till if weed pressure is low. We observed no significant differences between corn yields with or without a cover crop or due to planting date if straight no-till was used. The use of late-killed rye cover crop in no-till seems therefore possible without a yield penalty. Multiple environmental benefits would be accompanying the higher rye biomass production in this system that may pay off in the long run. They include: better erosion control, higher residue input for organic matter increases, and reduced bulk density due to high rye root biomass input.

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PEANUT RESPONSE TO TILLAGE AND ROTATION IN NORTH CAROLINA

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ABSTRACT

Research was conducted at two locations in North Carolina from 2000 to 2002 to compare yields of peanut, cotton, and corn grown in various rotation sequences in conventional and strip tillage production systems. Peanut yield was similar when comparing conventional and reduced tillage systems within similar rotation sequences at one location on a Norfolk loamy sand soil. At a second location on a Goldsboro sandy loam soil, peanut yield in a short rotation with cotton was lower when peanut was strip tilled into stubble from the previous crop compared with yield in conventional tillage. When a longer rotation between cotton and peanut was established, peanut yield was similar between the two tillage systems. In both trials during the final year of the study, peanut yield was similar between strip tillage in stale seedbeds (beds established during the early spring prior to planting) and conventional tillage. At one location, peanut yield from both of these tillage systems exceeded that of strip tillage into stubble from the previous crop. It is suspected that peanut pod loss during the digging and inverting operation was greater when peanut was strip tilled into crop stubble than when strip tilled into stale seedbeds. The experiment is being continued for an additional cycle to compare long-term response to tillage and rotation.

INTRODUCTION

Peanut (*Arachis hypogaea* L.) in North Carolina is typically grown in conventionally tilled systems (Jordan, 2003). Peanut response to reduced tillage has been inconsistent, and on average was reported to be 5% lower than yields in conventional tillage in studies conducted in North Carolina from 1997 through 2001 (Jordan et al., 2002). Although yields were similar in many of the trials, when major differences in yield were noted they often occurred on finer-textured soils and favored conventional tillage. Many of these trials were conducted in short-term or transition (from conventional to reduced tillage) circumstances. It is suspected that response to reduced tillage would be more favorable if peanut and rotation crops are grown in reduced tillage cropping systems for multiple years. Therefore, experiments were established in North Carolina to compare pod yield of peanut and rotation crops grown in conventional tillage and strip tillage systems in various rotation systems.

MATERIALS AND METHODS

Experiments were conducted in North Carolina from 2000 through 2002 at two locations in North Carolina near Lewiston-Woodville on a Norfolk loamy sand soil (fine-loamy, siliceous, thermic Aquic Paleudalts) with 2.1% organic matter content and pH 5.8 and near Rocky Mount on a Goldsboro sandy loam soil (fine-loamy, mixed, thermic Arenic Hapludults) with 1.7% organic matter and pH 6.0. Treatments consisted of conventional tillage or strip tillage into stubble from the previous crop (Rocky Mount) or strip tillage into crop stubble with a desiccated wheat cover crop present (Lewiston-Woodville) (Table 1). At Lewiston-Woodville, cotton and corn were included in 1999 for both tillage systems. However, three hurricanes and a severe hailstorm during the summer greatly reduced yield; therefore, data from 1999 are not presented. In the final year of the study, when peanut was planted into all plots (Table 1), elevated beds were prepared in early March on four of the eight plot rows in the reduced tillage system (referred to as stale seedbeds). Stalks from the previous crop had been shredded in the fall following harvest. Rows were reestablished using a disk bedder (subsoiler shanks removed) with no other tillage operations to establish the stale seedbeds. Peanut was strip tilled into stubble from the previous crop and stale seedbeds using a KMC strip tillage implement consisting of in-row subsoiler followed by two sets of coulters and two basket attachments to smooth the tilled zone. The tilled zone was approximately 16 to 18 inches wide. Conventional tillage seedbeds were prepared by disking the field twice and ripping and bedding within one week prior to planting. With the exception of tillage systems, all other production and pest management practices were held constant over the entire test area and were based on Cooperative Extension recommendations. Plot size was eight rows (36-inch spacing) by 50 feet long at Lewiston-Woodville or 75 feet long at Rocky Mount. Peanut and cotton were planted in early May within one week following strip tillage. Corn was planted in early April within one week after strip tillage. Crops were harvested using standard equipment designed for small-plot harvesting. Tomato spotted wilt virus and *Cylindrocladium* black rot (CBR) incidence was determined in the final year of the experiment. Data are referred to, as percent of plants diseased because differentiation between tomato spotted wilt virus and CBR symptoms was difficult to achieve late in the season. Weed species and density, including volunteer peanut, were also determined in early July of 2002. The experimental design was a randomized complete block with four replications. Means were separated using Fisher's Protected LSD Test at $p \leq 0.05$.

RESULTS AND DISCUSSION

No differences in yields for specific crops at either location were noted when comparing tillage system or rotation systems in 2000 or 2001 at either location (Table 2). In contrast, peanut yield differed among rotation systems at Lewiston-Woodville in 2002, the year when all tillage and rotation systems were planted in peanut (Table 3). Peanut yield was generally higher when peanut was rotated with either corn or cotton for a longer period of years. At this location, there was no difference in yield when comparing yields within the same rotation system from conventional tillage and strip tillage systems. At Rocky Mount in 2002, peanut yield was lower when strip tilled in the short rotation sequence compared with strip tillage into a longer rotation, or when peanut was planted into conventional tillage regardless of rotation system (Table 3). Although not substantiated, greater pod loss during the digging process may have contributed to the lower yield when peanut was strip tilled in the shorter cotton-peanut rotation. For this cotton-peanut rotation, peanut was planted into essentially flat ground, whereas in the longer cotton-peanut rotation peanut was strip tilled into partially elevated bed where cotton had been grown for the previous two years. In the shorter rotation, the digging process in 1999 eliminated existing elevated beds, and no additional tillage or bed formation was incorporated into the cotton planting operation in 2001 or in the peanut planting operation in 2002. Results from the comparison of strip tillage into stale seedbeds versus strip tillage into stubble from the previous crop supports this suggestion, at least partially. When peanut was strip tilled into stale seedbeds that were established approximately two months earlier in the spring, peanut yields were higher than those when peanut was strip tilled into crop stubble (Table 4). Although other agronomic and possibly soil fertility factors could have been affected by the bedding operation, it is also plausible that digging and inverting peanut growing on flat ground compared with digging and inverting peanut grown on elevated beds explains partially the difference in yields among these treatments. Previous research (Jordan et al., 2002) indicated that yields in conventional tillage and strip tillage into stubble from the previous crop often differ. When substantial yield differences between these systems were noted, yield in conventional tillage systems were generally higher than yield in strip tillage. Results also suggested that strip tillage into stale seedbeds, where elevated beds were established the previous fall, resulted in yields that approached yields in conventional tillage systems and exceeded those of peanut strip tilled into stubble from the previous crop. In virtually all trials, conventional tillage consisted on ripping and bedding while stale seedbeds were established using a bedder with the ripper shanks removed. In both instances when strip tillage was performed (crop stubble and stale seedbeds), a subsoiler was included at a depth similar to the depth used in conventional tillage bedding operation.

At Lewiston-Woodville when data were pooled over rotation systems, 69, 59, and 70% of plants presented symptoms characteristic of tomato spotted wilt and/or CBR during mid August in the conventional tillage system and systems where peanut was strip tilled into stubble from the previous crop or stale seedbeds, respectively (data not shown). When pooled over tillage systems at this location, 71, 70, 60, and 64% of plants expressed disease symptoms for peanut-cotton-peanut, peanut-corn-peanut, cotton-cotton-peanut, and cotton-corn-peanut rotation systems, respectively. Stale seedbeds were established in early spring, and therefore very few winter weeds and emerged summer weeds and crop residue were present when peanut emerged. This may explain partially similar disease levels in stale seedbed and conventional tillage systems. In contrast, less disease was noted when peanut was strip tilled into stubble from the previous crop when compared with either stale seedbed or conventional tillage systems. Attractiveness of thrips to reduced tillage fields with crop residue or desiccated cover crop is suspected to play a role in tomato spotted wilt virus incidence when compared with conventional tillage systems. While the majority of disease appeared to be caused by tomato spotted wilt virus, less disease when peanut was included in longer rotations suggests that disease ratings also were composed of CBR. Although crop rotation has not been shown to be affect incidence of tomato spotted wilt, rotation can have a major impact on incidence of CBR. Additionally, incidence of CBR is generally not affected by tillage system. Utilization of immunoassay techniques would have assisted in differentiation among these diseases. At Rocky Mount, there was no difference in incidence of tomato spotted wilt regardless of tillage system or rotation sequence (data not presented).

No differences in weed density were noted when comparing rotation sequences at Lewiston-Woodville (data not shown). When pooled over rotation sequence at this location, higher numbers of smooth pigweed were noted when peanut was strip tilled into stubble from the previous crop when compared with strip tillage into stale seedbeds or conventional tillage (data not shown). No differences in densities of yellow nutsedge, eclipta, and broadleaf signalgrass were noted among tillage systems at Lewiston-Woodville (data not shown). At Rocky Mount, density of volunteer peanut was higher in strip tillage than in conventional tillage but was similar to density in stale seedbeds (data not shown). Tillage did not affect density of yellow nutsedge, entireleaf morningglory, or pitted morningglory at this location. A higher density of pitted morningglory was observed in long rotations compared with the shorter rotation. In contrast, a higher density of volunteer peanut was noted in the peanut-cotton-peanut rotation compared with the cotton-cotton-peanut rotation.

Collectively, results from these studies suggest that cotton and corn yields will often be similar when comparing reduced tillage and conventional tillage systems. Many practitioners have adopted reduced tillage systems for these crops in North Carolina. While peanut yield was often similar in strip tillage and conventional tillage, some variation in yield was noted at one location when compared tillage systems, with conventionally tilled peanut yielding higher than strip tilled peanut in the peanut-cotton-peanut rotation. The stale seedbed approach in this rotation overcame the yield differential between conventional tillage and strip tillage into stubble from the previous crop. While yields were similar between both tillage systems within a rotation system at the other location when peanut was strip tilled into crop stubble or stale seedbeds, this may have been partially attributed to soil characteristics. The Norfolk loamy sand soil at Lewiston-Woodville is considered to be a better peanut soil than the finer-textured and more poorly drained Goldsboro sandy loam soil at Rocky Mount. It is possible that the importance of having peanut on elevated beds would be more critical on the Goldsboro soil series than on the Norfolk soil series, and hence the positive response to stale seedbeds.

These studies are being conducted for additional cycles, with peanut being planted in the entire test during 2006. Along with monitoring of pest development and crop yield, a more complete measure of soil characteristics will be quantified. Results from these studies continue to document the advantages of extending rotations in peanut production.

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Table 1. Tillage and rotation systems at Lewiston-Woodville and Rocky Mount.

	Rotation system*			
Tillage systems	1999	2000	2001	2002
Conventional	Cotton	Peanut	Cotton	Peanut
Conventional	Cotton	Cotton	Cotton	Peanut
Strip tillage	Cotton	Peanut	Cotton	Peanut
Strip tillage	Cotton	Cotton	Cotton	Peanut
Conventional	Corn	Peanut	Corn	Peanut
Conventional	Cotton	Cotton	Corn	Peanut
Strip tillage	Corn	Peanut	Corn	Peanut
Strip tillage	Cotton	Cotton	Corn	Peanut

*Rotation systems including corn were present only at Lewiston-Woodville. Tillage and rotation systems were not established until 2000 at Rocky Mount.

Table 2. Crop yield at Lewiston-Woodville as influenced by tillage and rotation systems.

Tillage systems	Rotation system			
	1999	2000	2001	2002*
	lb/acre			
Conventional	250 (Cotton)	3370 (Peanut)	1030 (Cotton)	2020 (Peanut)
Conventional	260 (Cotton)	960 (Cotton)	950 (Cotton)	2560 (Peanut)
Strip tillage	210 (Cotton)	3420 (Peanut)	880 (Cotton)	2300 (Peanut)
Strip tillage	240 (Cotton)	1040 (Cotton)	960 (Cotton)	2780 (Peanut)
Conventional	2180 (Corn)	2980 (Peanut)	6550 (Corn)	2030 (Peanut)
Conventional	270 (Cotton)	890 (Cotton)	6660 (Corn)	2420 (Peanut)
Strip tillage	1900 (Corn)	2910 (Peanut)	6440 (Corn)	2000 (Peanut)
Strip tillage	230 (Cotton)	1020 (Cotton)	7060 (Corn)	2790 (Peanut)
LSD (0.05)	NS (within crops)	NS (within crops)	NS (within crops)	LSD=493

Table 3. Crop yield at Rocky Mount as influenced by tillage and rotation systems.

Tillage systems	Rotation system		
	2000	2001	2002*
	lb/acre		
Conventional	3770 (Peanut)	860 (Cotton)	3830 a (Peanut)
Conventional	920 (Cotton)	840 (Cotton)	3820 a (Peanut)
Strip tillage	3490 (Peanut)	820 (Cotton)	3120 b (Peanut)
Strip tillage	870 (Cotton)	800 (Cotton)	3870 a (Peanut)
LSD (0.05)	NS (within crops)	NS	

*Means followed by the same letter are not significant according to Fisher's Protected LSD Test at $p \leq 0.05$.

Table 4. Peanut yield in 2002 at Lewiston-Woodville and Rocky Mount when peanut is strip tilled into stubble from the previous crop or stale seedbeds established in early spring.

	Lewiston-Woodville		Rocky Mount	
Rotation system*	Crop stubble	Stale seedbed	Crop stubble	Stale seedbed
	lb/acre			
CT-PN-CT-PN	2300	2010	3120	3610†
CT-CT-CT-PN	3050	2700	3870	3670
CR-PN-CR-PN	2000	2090	-	-
CT-CT-CR-PN	2790	2500†	-	-

*Abbreviations: CR, corn; CT, cotton; PN, peanut.

†Significant for comparison of strip tillage into crop stubble or stale seedbed within a location and rotation system.

ADVISORY INDEX FOR TRANSITIONING TO REDUCED TILLAGE PEANUT

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ABSTRACT

An advisory index was developed in North Carolina to help growers determine risks associated with planting peanut in reduced tillage systems. This index is modeled after risk advisories developed for management of southern corn rootworm and tomato spotted wilt virus. Points are used to define risks associated with cultivar selection, ability to irrigate, soil series, tillage intensity within the reduced tillage system, presence of a small grain cover crop, and history of tomato spotted wilt virus. Compiling values associated with each of these practices gives an indication of potential for peanut yields in reduced tillage systems to be lower than yields in conventional tillage systems. This index does not consider savings often associated with labor and time in with reduced tillage production, and it does not consider the long-term benefits of reduced tillage production on soil properties. This advisory index is designed to help growers assess risk during the transition from conventional to reduced tillage production.

INTRODUCTION

Peanut (*Arachis hypogaea* L.) in North Carolina is typically grown in conventionally tilled systems. However, interest in growing peanut in reduced tillage systems has increased in part due to concerns of tomato spotted wilt virus and reduction in profit at the farm level. Because peanut response to reduced tillage has been inconsistent (Jordan et al., 2001), growers need assistance in determining when reduced tillage peanut production will be successful. Risk indices for southern corn rootworm and tomato spotted wilt virus management have been developed for peanut (Herbert, 2003; Hurt et al., 2003). An advisory index was developed for tillage using a similar concept.

The advisory does not incorporate the economical impact of each component. Savings in costs associated with less tillage are often offset by increased herbicide costs to manage winter weeds and emerged summer annual and perennial weeds. Investment in reduced tillage equipment is important to consider. Two of the more difficult management factors to place an economic value on is savings in labor and the ability to enter fields in a more timely manner in reduced tillage systems. These factors are not considered in the advisory.

Management Considerations in Reduced Tillage Systems

Growers adopting reduced tillage systems may need to devote more time to overall management of peanuts, particularly early in the season. This especially applies to weed management. Establishing adequate fertility levels, especially pH, is critical as peanut is transitioned into reduced tillage systems. Movement of lime into the root zone may be slow in reduced tillage systems. Potassium applied to the soil surface at planting that does not leach through the pegging zone can interfere with calcium absorption by developing pegs. Stand establishment may be more difficult depending upon crop residue and existing winter vegetation. Early-season weed management will be critical, with selection and proper application timing of burndown herbicides being essential to providing a weed-free seedbed when peanut is emerging and growing early in the season. Benefits of soil-incorporated herbicides will be minimized in reduced tillage systems. Although some tillage can be performed in the strip tillage operation, the degree of incorporation of herbicides is limited and often not uniform. Weed management with preemergence and postemergence herbicides will become more critical. Thrips and some other insects may be less of a problem in reduced tillage systems. With the exception of tomato spotted wilt (TSWV), which is less prevalent in reduced tillage systems compared with conventional tillage systems, incidence of other diseases is not generally affected by tillage. Digging may be less efficient in reduced tillage systems. Soils can be harder and digging losses greater under some conditions, especially when soils are dry. Long-term benefits in soil tilth have been observed for many crops that are produced in reduced tillage systems, and this may also hold true for peanut.

Component of the Advisory Index

Peanut Variety[1]

Virginia market type	5
Runner market type	0

[1] Pods and kernels for runner market type varieties are considerably smaller than pods and kernels for Virginia market type varieties, especially when comparing the runner market type Georgia Green with the Virginia market type Gregory. During the digging and inverting process, there is greater resistance from soil as Virginia market types are removed from the ground than there is for runner market types. Greater resistance can cause a higher percentage of pods to strip away from vines and can increase digging loss.

Irrigation[2]

No irrigation	10
Irrigation	0

[2] Irrigation or timely rainfall can create soil conditions that minimize pod loss during the digging and inversion process. Access to irrigation serves as insurance if soil conditions are less than favorable for digging.

Soil series[2]

Roanoke and Craven	40
Goldsboro and Lynchburg	20
Norfolk	10
Conetoe and Wanda	0

[3] Pod loss on finer-textured soils such as those in the Roanoke and Craven series is often greater than on coarser-textured soils such as Conetoe and Wanda series regardless of tillage system. Difficulty in digging can increase when these soils become hard in the fall if rainfall is limited.

Tillage intensity[4]

No tillage into flat ground	40
Strip tillage into flat ground	20
Strip tillage into stale seedbeds	0

[4] Peanut response to reduced tillage systems is invariably correlated with the degree of tillage. Efficient digging can be difficult when peanuts are planted in flat ground in reduced tillage systems. While fields may appear to be flat and uniformly level, often times fields are more rugged than they appear, and setting up the digger to match unforeseen contours in the field can be difficult. Strip tillage into flat ground is a better alternative than no tillage into flat ground, although digging peanut planted on flat ground can be more challenging regardless of the tillage system. Strip tillage into preformed beds often results in yields approaching those of conventional tillage.

Small grain cover crop[5]

Not present	5
Present	0

[5] Cover crops serve several purposes, including conservation of soil moisture and reduction in wind and water erosion. Cover crops also contribute to soil tilth, and they can minimize winter weed populations. The decision of which burndown herbicide to apply is often made easier by having a cover crop.

History of tomato spotted wilt virus[6]

No tomato spotted wilt in the past	10
Tomato spotted wilt present in the past	0

[6] Less tomato spotted wilt virus and fewer thrips have been seen in reduced tillage peanut production. Lower risk (value of 0) associated with having had tomato spotted wilt in the past is because pod yield might increase in reduced tillage when tomato spotted wilt is present due to suppression of tomato spotted wilt by reduced tillage systems. Increased yield as a result of tomato spotted wilt suppression may offset a at least a portion of yield loss associated with reduced tillage systems as a result of other agronomic or pest management factors. Consistent trends for other diseases have not been observed in North Carolina, and overall effects of disease on response to tillage appear to be negligible.

Risk of Yield Being Lower in Reduced Tillage than in Conventional Tillage

30 or Less……………………………………………………….Low Risk

35-65……..……………………………………………...……Moderate Risk

70 or More……………..……………………………………..High Risk

CONCLUSIONS

This advisory index was developed based on research conducted in North Carolina over the past decade (Jordan et al., 2001). Additional research is needed to validate the advisory and to define other factors or improve conclusions about the factors listed here to help growers in the decision-making process.

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MICROBIAL AND BIOCHEMICAL CHANGES INDUCED BY ROTATION AND TILLAGE IN A CALCAREOUS SOIL UNDER MELON, TOMATO, WHEAT AND COTTON PRODUCTION

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ABSTRACT

The aim of this study was to was to evaluate changes in soil microbial community in response to tillage, rotation and seasons throughout the melon, tomato, wheat and cotton growing season in a calcareous soil Uzbekistan semi arid region. The number of ammonifying bacteria, oligonitrophilic bacteria, oligotrophic bacteria and nitrogenase activity in Calcisol soil under different agricultural crops in Surhandarya region Uzbekistan were compared. Soil samples were collected from the soil under cotton, melon, tomato, wheat in spring, summer, autumn, and winter. We measured the microbial population after tillage at depth intervals of 0-10 cm, 10-20 cm, and 20-30 cm. The results revealed that the number and enzymatic activity of microorganisms depended upon plant type, depth and date of sampling. The total number of ammonifying bacteria, and oligotrophic bacteria tended to be highest under tomato and wheat. The number of ammonifying and oligotrophic bacteria were higher at the 20-30 cm soil depth of soil than at the 0-10 cm depth regardless of plant type. Seasonal changes in the numbers of soil microorganisms were marked in all agricultural crops, with the lower numbers in winter and higher numbers in spring and summer. This experiment indicated that different agricultural crops ad tillage practice affected the microbial characteristics of soil.

INTRODUCTION

Soil microorganisms play important roles in maintaining soil quality and plant production. The study of diversity, distribution, and behavior of microorganisms in soil habitats is essential for a broad understanding of soil health. Agricultural management practices, particularly inputs of manure and cover crops, can have large impact on the size and activity of soil microbial communities (Atlas et al., 1991; Klug and Tiedije, 1993; Overas and Torsvik, 1998; Buckley, 2001). Some authors identified patterns of microbial population that are consistent across sites that vary in plant composition and agricultural treatment (Broughton and Gross, 2000; Felske and Akkermans, 1988). Also in comparative studies have been observed differences between microbial communities in field with different histories of soil amendment, irrigation, tillage and plant community structure (Baath, et al., 1995; Bloem et al., 1992; Bossio et al., 1998). Tillage practices have a considerable effect on the quantity and quality of soil organic matter especially in the near-surface layers (Angers et al., 1993). Tillage leads to the development of soil microbial communities dominated by aerobic microorganisms with high metabolic rates, typically bacteria, whereas under conservation practices, plant residues left at or near the soil surface encourage fungal growth and the temporary immobilization of nutrients (Panhust et al., 2002)..

Soil enzyme activities are believed to be able to discriminate between soil management treatments (Dick, 1993) probably because they are related to microbial biomass, which is sensitive to such treatments. It is well-documented that N_2- fixation is an important process in the soil biological activity. Nitrogenase activity in soil depends on ecological conditions in association with the specific N-fixation capabilities of certain microorganisms, plant genotypes, and climatic conditions.

Soil with high organic substance will have higher nitrogenase activity. Biotic factors can influence the bacterial activity in soil. The degree of nitrogenase activity is plant-specific (Rennie, 1983). Several studies have been carried out to characterize the nitrogenase activity in many types of soils. However the studies of microbial communities in calcareous soil with conventional tillage practices of southeastern part Syrhandarya province Uzbekistan semi arid region not yet performed. The objectives of this study were to determine the influence of the plant type, conventional tollage, soil depth and seasonal change on the microbial population and activities in calcareous soil Uzbekistan semi arid region.

MATERIAL AND METHODS

Study Site and Soil Sampling

Sites used in this study represent continuously cultivated (more than 50 years) fields located in Surhandarya province, southeastern part of Uzbekistan. Soil is calcareous serozem soil (1 % organic matter, 0.6 mg N 100 g-1 soil; 3.0 mg P 100 g $^{-1}$; 12 mg K 100 g^{-1}; 6 mg Mg 100 g^{-1} soil; pH 7.4) having a calcic horizon within 50 cm of the surface. The orchic horizon is low in organic matter. The climate is semi arid with mean annual air temperatures of 16^{o}C and 18^{o}C, and mean annual rainfalls of 200 mm. The conventional tillage consisted of moldboard plowing to 20 cm depth after harvest and offset disking, to a depth of 10 cm, prior to planting in the spring. Soil samples of 0-10 cm, 10-20 cm, 20-30 cm depth were taken with a soil corer (3,5 cm dia) between the rows of melon, tomato, wheat and cotton at assistance of 20 cm from the center of the plants. Samples were collected at 3-month intervals in October (autumn), January (winter), April (spring), and July (summer). Conventional mineral fertilizers N, P, K input rates range from 150 to 200 kg ha^{-1}yr^{-1} for cotton and wheat. For tomato and melon range from 60 to 140 kg ha^{-1}yr^{-1}. The cores were pooled; 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.

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 natrium 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 (Schachtschnabel and Heinemann, 1974). Soil pH-value was measured by means of electrometer.

Soil microbiological analyses

Plate dilution method was used for 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 triplet and incubating until growth occurred (usually 3-7 days). CFU of ammonifying bacteria were enumerated on glycerin peptone agar. Oligotrophic bacteria on soil agar containing 900 ml water, 100g soil, 18g agar L^{-1}, oligonitrophilic bacteria was 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, agar 15 gl^{-1}. Microbial density was expressed as colony forming units (CFU). Nitrogenase activity was measured using acetylene reduction assay. The data were analyzed using the statistical analysis of variance by (ANOVA).

RESULTS AND DISCUSSION

Microbial Population

Marked effects were found to have taken place on the bacterial populations under melon, tomato, wheat and cotton. This is clearly demonstrated by the total number of bacteria colony-forming units (cfu) recorded from the plates. Our results showed that microbial population was different in soils under different agricultural crops with different soil depths. The highest density of ammonifying bacteria was observed under tomato and wheat during summer and the lowest in winter (Fig.1). After tillage we found higher ammonifying bacterial population at 20-30 cm depth.

Microbial diversity was significantly higher under wheat preceded by red clover green manure or field peas than under wheat following wheat (Lupwayi, 1998). According to Merckx et al., (1987), obviously the input of nutrient by the roots into surrounding soil as well as the mineral nutrients levels in the soil are of considerable importance. Rovira (1965) was convinced that root exudates play a key role in the selective stimulation of microorganisms and the view has shared by others (Atkinson et al., 1975).

The total number of oligonitrophil bacteria decreased on soil planted to melon and wheat and increased in soil under cotton (Fig.2). These bacteria populations are distributing well, when soil has low N content. Uzbekistan soil is nitrogen deficient soil, and oligonitrophil bacterial strains are higher than other microbail populations. Bacterial density was the lowest in winter and increased gradually through spring and autumn. According to Entry et al., (1996) soil microbial biomass N was lower in the cotton grown soil.

The number of oligotrophic bacteria tended to be lowest under melon and cotton and highest under wheat and tomato (Fig.3). Also (Govedarica et al., 1995; Egamberdiyeva, 1997).found that total number of oligotrophic and oligonitrophilic bacteria decreased in soil under maize and cotton Seasonal changes in the number of oligotrophic bacteria showed that with increase in the atmospheric temperature, their numbers increasing. The highest number was found in summer, and lowest in winter. Also Zou Li et al., (2000) found similar changes in microbial population during different seasonal time that in winter the total number of microorganisms decreased.

The differences of microbial populations varied between depth distributions after conventional tillage practices. The total number of microorganisms was higher at the 20-30 cm soil depth of soil than at the 0-10 cm and 10-20 cm depth regardless of plant type. Also some authors suggest that the number of ammonifying bacteria, oligonitrophilic, oligotrophic bacteria decreased in soil sampled from 10-20 cm. layers (Govedarica et al., 1995; Zou Li, et al., 2000).

Nitrogenase Activity

The results revealed that tomato and cotton cultivated in the Surhandarya region contributed to the high nitrogenase activity (Fig.4). Soil without plant cover had a lower nitrogenase activity in comparison to soil with plant cover. According to Govedarica (1995), soil with high organic substance will have higher nitrogenase activity. Plants, which produce exudate, exhibit higher N_2-Fixation. N_2- fixation bacteria are active in the root area (Egamberdiyeva, 1997). This source of energy is an important basis for the heterotrophic soil microflora, which can for N_2 – Fixation. It has also been found that nitrogenase activity was higher during the spring. Nitrogenase activity was higher in the 10-20-cm. horizons. In this soil depth, microbial activity was higher as a result of the root system.

CONCLUSION

In conclusion, this experiment indicated that conventional tillage practices and different agricultural crops affected the microbial characteristics of soil. Soil microbial population and activities were stimulated in soil under wheat and tomato at 20-30 cm soil depthh in this study. Seasonal changes in the numbers of microbial population were marked in soil under all plant types, soil layers, with the numbers increasing with increase in the atmospheric temperature.. To increase the soil fertility, particularly the soil biological fertility of Calcisol Uzbekistanian soil, it is necessary to plant crops, which can increase microbial biomass and nitrogenase activity in the soil and reduce tillage practices. This is especially important for the low organic-content soils of the region.

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CROP MANAGEMENT AND ANIMAL PRODUCTION IN YEARLY ROTATIONS UNDER INVERSION AND NO TILLAGE

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ABSTRACT

Integration of crops and livestock could provide benefits to both crop and livestock production systems, as well as provide economic opportunities and environmental protection. We are currently in the middle of a multi-year study to evaluate the impacts of tillage, cover crop management, and timing of grazing animals on crop and livestock production characteristics. With soil organic matter at a high level following termination of perennial pasture, we determined crop yield and animal production during the first three growing seasons of two cropping systems (sorghum/rye and wheat/pearl millet) managed under conventional tillage (CT) or no tillage (NT) and whether cover crop was grazed by cattle or not. Sorghum grain yield during the first year (52% of normal precipitation) was lower under NT (10 bu/acre) than under CT (20 bu/acre). Wheat grain yield in 2003 (39 bu/acre) and sorghum grain yield in 2003 (63 bu/acre) were unaffected by tillage regime and whether previous cover crop was grazed by cattle or not. Ungrazed cover crop biomass production was 12% greater under NT than CT for millet in 2002, 23% greater under NT than CT for rye in 2003, and 82% greater under NT than CT for millet in 2003. Cattle live-weight gain was not statistically different between tillage systems, but average daily gains were 0.5 ± 0.2 lb/day greater under NT than under CT during the first three growing seasons. Results are yet incomplete to make a system-level assessment, but these initial results suggest that (1) NT is preserving the benefits of long-term accumulation of organic matter following perennial pasture and (2) no negative effect of cattle grazing cover crops is being carried over to subsequent grain crops.

INTRODUCTION

Soil organic matter is a critical component in maintaining soil quality in the southeastern USA. Pastures are known to improve soil organic C and N, which leads to retention of organically-bound nutrients and improved water relations. Cropping systems that are appropriate in this region under conditions of high soil organic matter have not been evaluated since much of the cropland has been stripped of soil organic matter from previous degradative cropping practices. Crop productivity response to tillage management following pasture termination may be significantly different than following a previously degraded land usage due to the presence of a large storage of nutrients, soil biological potential, and improved physical structure.

Climatic conditions in the Southern Piedmont are characterized by high precipitation-to-potential evapotranspiration during the winter growing season, but low precipitation-to-potential evapotranspiration during the summer growing season. The impact of time of grain cropping (i.e., spring versus summer) on grain yield, forage availability, and soil properties has not been well described, especially under conditions of initially high soil organic matter following pasture. Under a potentially double-cropping environment in the southeastern USA, a cover crop following grain cropping could provide high-quality forage to supplement shortages in supply from perennial pastures.

The impact of grazing animals on the environment is more often than not viewed as negative. A large portion of the land area in the Southern Piedmont USA is devoted to pasture production of cattle. Our previous work has shown that grazing of warm-season grasses in the summer can have positive impacts on soil organic C and N accumulation and no observable detriment to surface soil compaction (Franzluebbers et al., 2001). However, the role of grazing animals in pasture–crop rotations does not have to be limited to the medium- or long-term pasture phase alone. Cover crops following grain crops can be an excellent source of high quality forage to be utilized in small, mixed-use farming operations, such as those commonly found in the Southern Piedmont region. A potential impact of animals grazing cover crops, however, could be compaction due to hoof action, as observed in Southern Piedmont soils under relatively low soil organic matter conditions (Tollner et al., 1990). Surface residue cover may provide a significant buffer against animal trampling effects, such that no tillage crop production following long-term pasture could alleviate negative animal trampling effects.

Our objective was to quantitatively evaluate three management factors (i.e., tillage, time of grain cropping, and cover crop management) for their impacts on plant and animal productivity. The factorial arrangement of treatments allowed us to isolate interactions among management factors, which should lead to a better understanding of the processes controlling productivity and environmental quality. Specific objectives during the course of this mult-year project will be to (1) quantify the responses in plant and animal productivity due to tillage management under cropping systems that include grazing cattle and high cropping intensity, (2) quantify the relative stability of plant production during winter versus summer growing seasons, (3) quantify cattle productivity and performance during short-term grazing alternatives to perennial pastures, and (4) eventually to evaluate the interrelationships among soil properties following adoption of land management systems, which may alter soil organic matter dynamics and plant and animal productivity.

MATERIALS AND METHODS

The experiment is located at the J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville GA on Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult). A set of 18 experimental paddocks (1.7 acres each) were previously arranged as six cattle grazing treatments in three blocks. Previous treatments included low (134-15-56 kg N-P-K · ha^{-1} · yr^{-1}) and high fertilization rates (336-37-139 kg N-P-K · ha^{-1} · yr^{-1}) imposed upon four grass variables [‘Kentucky-31' tall fescue (*Festuca arundinacea* Schreb.) with low and with high endophyte infection, ‘Johnstone’ tall fescue with low endophyte infection, and ‘Triumph’ tall fescue with low endophyte infection]. Previous treatments were part of a long-term experimental design initiated in 1981 to study tall fescue–endophyte effects on cattle productivity, performance, and other miscellaneous animal response variables until 1997. Fertilization was terminated prior to 1998 and forage grazed on an *ad hoc* basis thereafter. Pasture growth during the past three years without fertilization was expected to remove any differences among paddocks in residual inorganic soil N. All paddocks were limed (1 ton/acre) immediately prior to termination of the tall fescue. The 18 experimental paddocks were regarded as an excellent starting point for the proposed research because soil organic matter was at a high level (Franzluebbers et al., 1999) and grazing infrastructure was mostly in place at the site (fencing, gates, shades, mineral feeders, watering troughs, and animal handling facility).

The experimental design of the current investigation consisted of a completely randomized design with a split-plot arrangement within main plots. Main plots were a factorial arrangement of (a) tillage and (b) time of grain cropping and split plots within main plots were (c) cover crop management. Main plots were replicated four times. Grazed plots were 1.1 acre in size and ungrazed plots were 0.6 acres. Two paddocks remained in perennial pasture to serve as uncropped controls.

Tillage management was with (1) conventional disk tillage (CT) following harvest of each grain and cover crop and (2) no tillage (NT) with glyphosate to control weeds prior to planting. Conventionally tilled plots were broken from sod with a moldboard plow to a depth of 10 to 12" and disk plowed (6 to 8") thereafter.

Cropping systems included (1) winter grain cropping [wheat (*Triticum aestivum* L.); November planting and May harvest] with summer cover cropping [pearl millet (*Pennisetum glaucum* (L.) R. Br.]; June planting and October termination) and (2) summer grain cropping [grain sorghum (*Sorghum bicolor* (L.) Moench]; May-June planting and October harvest) with winter cover cropping [cereal rye (*Secale cereale* L.); November planting and May termination]. ‘Tifleaf 3' pearl millet was drilled in 6.75"-wide rows under CT and 7.5"-wide rows under NT at a rate of 14 lb/acre on 12 June 2002 and at a rate of 13 lb/acre on 26 June 2003. ‘Pioneer 83G66' grain sorghum was drilled in 13.5"-wide rows under CT and 15"-wide rows under NT at a rate of 5 lb/acre from 13-14 June 2002 and at a rate of 6 lb/acre from 2-5 June 2003. Due to poor stand of sorghum in 2002, especially under NT, portions of plots were replanted on 17 July 2002. Ammonium nitrate was spread on sorghum and millet at 44 lb N/acre on 18 June 2002, on sorghum at 46 lb N/acre on 12 June 2003, and on millet at 40 lb N/acre on 9 July 2003. Sorghum was harvested for grain from 15-22 November 2002 and from 17-20 October 2003. ‘Crawford’ wheat was drilled in 7.5"-wide rows at a rate of 106 lb/acre on 28 November 2002 and ‘518W’ wheat was drilled at 99 lb/acre on 4 November 2003. ‘Hy-Gainer’ rye was drilled in 7.5"-wide rows at a rate of 111 lb/acre on 2 December 2002 and at a rate of 102 lb/acre on 5 November 2003. Ammonium nitrate was spread on wheat and rye at 47 lb N/acre on 25 February 2003 and at 36 lb N/acre on 20 February 2004. Wheat was harvested for grain from 11-19 June 2003.

Cover crops were managed to assess the impact of grazing cattle on crop production as (1) without cattle by mechanical rolling at maturity and (2) stocking with cattle for 60-90 days to consume available forage produced. Cover crops were stocked with yearling Angus steers in Summer 2002 (initial weight 578 ± 48 lbs) and in Spring 2003 and with cow/calf pairs in Summer 2003 (initial cow weight 1107 ± 88 lbs and initial calf weight 370 ± 33 lbs). Ungrazed cover crops were grown until 2-4 weeks prior to planting of the next crop and either (1) mowed prior to conventional tillage operations or (2) mechanically rolled to the ground in the no-tillage system.

Each grain and cover crop received a top-dressing applications of –40 kg N · ha^{-1} as ammonium nitrate shortly after planting and no other fertilizer amendment. The basal application of N assured early plant growth and development with further growth dependent upon the mineralization of stored nutrients in soil organic matter. Extractable P and K concentrations in the surface 3 inches of soil were greater than 100 mg P · kg^{-1} soil and 400 mg K · kg^{-1} soil, levels considered adequate for crop production (Schomberg et al., 2000).

Grain production was determined by weighing the contents of the entire experimental unit harvested with a field combine following unloading onto a truck with scales placed under all tires. A subsample of grain was collected for moisture determination. Yield was adjusted to 14% moisture for sorghum and 13.5% moisture for wheat. Standing stover following grain harvest was determined from 0.5- x 3.3-ft areas (3 in ungrazed plots and 5 in grazed plots). Cover-crop above-ground biomass was collected in the same manner. Grain, stover, and forage components were weighed before and after oven drying (131 EF). Stand count of crops beginning with the 3rd growing season

Table 1. Crop grain yield and standing stover as affected by cropping system, tillage, and cover crop management during the first three growing seasons on a Typic Kanhapludult in Watkinsville GA.

			Summer 2002		Spring 2003		Summer 2003	
Cropping system	Tillage	Cover crop	Grain	Stover	Grain	Stover	Grain	Stover
			bu/a	lb/a	bu/a	lb/a	bu/a	lb/a
Sorghum/rye	CT	Ungrazed	18	1687	-	6437	61	3167
		Grazed	23	1582	-	558	59	2538
	NT	Ungrazed	9	1933	-	7902	72	6524
		Grazed	11	2030	-	815	61	4508
LSD (*p* = 0.05)			9*	1184	-	1355*	21	1152*
Wheat/millet	CT	Ungrazed	-	4712	38	1152	-	3254
		Grazed	-	359	39	1256	-	171
	NT	Ungrazed	-	5256	38	1312	-	5907
		Grazed	-	873	40	1427	-	403
LSD (*p* = 0.05)			-	941*	7	344	-	2109*

were determined by counting plants in 2 adjacent rows 40" long at 3 locations in ungrazed plots and 5 locations in grazed plots.

Cattle live-weight gain was determined from initial and final weights during several 2-3-week stocking periods within each growing season. Live weights were shrunk body weights following 12-16 hours without water. Stocking density varied based on quantity of forage available. Animal unit days were adjusted to a common animal unit of 1102 lbs using the suggested power function of 0.75 (Forage and Grazing Terminology Committee, 1991).

The general linear model procedure of SAS was used to analyze variances for each of the plant and animal responses during each growing season separately (SAS Institute, 1990).

RESULTS AND DISCUSSION

Crop Production Characteristics - Sorghum/Rye Production System

The summer of 2002 (the first year of this study) continued to be drier than normal, just as it had been during the past 3 years. From 1 May 2002 until 13 September 2002, only 9.2" of rainfall was received (52% of normal precipitation for this period). Sorghum production during the first growing season (Summer 2002), therefore, was very low in both tillage systems (Table 1). Perhaps due to the unusually dry conditions, sorghum grain yield was statistically lower with NT than with CT in 2002. It is possible that soil moisture from deeper in the profile was redistributed for utilization early in the growing period when tilled. Standing sorghum biomass at the end of the growing season was not different between tillage systems.

Rainfall from 1 October 2002 to 30 April 2003 was 29.0", the same as the long-term normal for this period. Rye dry matter production without cattle grazing was 23% greater under NT than under CT during this period (Table 1). A combination of moisture and nutrient conservation may have contributed to this difference in production between tillage systems. Stocking cattle on the rye cover crop reduced standing forage at the end of the growing season to −10% of total above-ground production under both tillage systems.

In Summer 2003, rainfall from 1 May to 30 September was 26.1", which was 6.4" greater than the long-term normal for that period. Grain yield of sorghum averaged 63 bu/acre, with no differences due to tillage regime or previous exposure of cover crop to grazing animals (Table 1). Standing sorghum biomass as the end of the growing season averaged 93% greater under NT than under CT when averaged across cover crop management systems. There was a significant interaction between tillage and cover crop management on sorghum stover, due to a greater difference between tillage systems without (106%) than with (78%) cattle grazing. It is possible that the conservation of surface-soil nutrients under NT compared with the rapid mineralization and previous utilization of nutrients with under CT may have contributed to the difference in sorghum stover production. Due to the relatively abundant precipitation in 2003, it is unlikely that conservation of water with NT was a major factor that contributed to this difference in stover.

Plant population of sorghum in July 2003 averaged 2.5ft^{-2} and was not different among tillage regimes and cover crop management (Table 2). Likewise, rye population averaged 13.7 · ft^{-2} and was not different among tillage regimes and cover crop management. These data provide evidence that soil surface conditions could be suitably managed to provide adequate seedling emergence under both tilled and untilled conditions, as well as when cattle have grazed a previous cover crop or not.

Wheat/Millet Production System

Despite the dry conditions in Summer 2002, millet biomass production averaged 4984 lb/acre without cattle grazing and was not affected by tillage regime (Table 1). Cattle grazing of the millet reduced standing millet biomass at the end of the growing season to 8% under CT and 17% under NT.

In Spring 2003, wheat grain yield averaged 39 bu/acre and was not different between tillage systems (Table 1). Standing wheat biomass at the end of the growing season averaged 1287 lb/acre and was not affected by tillage regime or cover crop management. Wheat yield response to no-tillage management has been variable in the southeastern USA. On a Cecil sandy loam in Georgia under a wheat/sorghum cropping system, wheat grain yield during 4 years averaged 46 bu/acre under CT and 47 bu/acre under NT (Langdale et al., 1984). In South Carolina under a wheat/soybean cropping system, wheat grain yield during 2 years averaged 54 bu/acre under CT and 56 bu/acre under NT (Frederick and Bauer, 1996). In North Carolina under a wheat/soybean-corn rotation, wheat grain yield during two years averaged 56 bu/acre under CT and 52 bu/acre under NT at a Piedmont location and 51 bu/acre under CT and 49 bu/acre under NT at a Coastal Plain location (Wagger and Denton, 1989).

Table 2. Plant population (plants · ft^{-2}) as affected by cropping system, tillage, and cover crop management during the 3rd and 4th growing seasons on a Typic Kanhapludult in Watkinsville GA.

Cropping system	Tillage	Cover crop	July 2003	December 2003
Sorghum/rye	CT	Ungrazed	2.5	13.6
		Grazed	2.5	13.0
	NT	Ungrazed	2.4	13.5
		Grazed	2.8	14.7
LSD ($p = 0.05$)			0.5	2.7
Wheat/millet	CT	Ungrazed	10.4	14.6
		Grazed	10.5	12.9
	NT	Ungrazed	6.7	12.4
		Grazed	6.4	16.4
LSD ($p = 0.05$)			3.3*	1.6*

In Summer 2003, millet biomass production without cattle grazing was 82% greater under NT than under CT (Table 1). Greater millet biomass under NT than under CT in 2003 was consistent with the production difference in sorghum biomass in 2003, pointing to a consistency in the possibility for greater conservation of nutrients with NT during these first three growing seasons following termination of perennial pasture. Millet utilization by grazing cattle was greater in 2003 (93-95%) than in 2002 (83-92%).

Plant population of millet in July 2003 was −37% lower under NT than under CT, whether system was grazed or not (Table 2). It is not likely that the reduced plant population was the reason for the enhanced millet biomass production with NT (Table 1). These data do suggest that tillering in millet is significantly vigorous to compensate for reduced plant stand with NT, perhaps due to inadequate seed/soil contact with abundant surface residue mulch. Plant population of wheat in December 2003 was 15% lower under NT than under CT in ungrazed plots, but 27% greater under NT than under CT in grazed plots (Table 2). It is possible that the large quantity of previous millet biomass laying on the soil surface under NT may have prevented adequate seed/soil contact for optimum wheat germination and development. Since millet biomass was grazed and processed through cattle, there would have been less surface residue mulch to inhibit wheat seedling development in grazed plots. During 2 years on a Goldsboro sandy loam, wheat population averaged 25 plants · ft^{-2} under CT and 21 plants · ft^{-2} under NT (Frederick and Bauer, 1996).

Cattle Production Characteristics

Cattle live-weight gain during Summer 2002 averaged 444 lb/acre and was not different between tillage systems (Table 3). Despite the abnormally low precipitation, millet biomass production was excellent, resulting in stocking of cattle for 11 weeks with an average of 1.8 animal units/acre under CT and 1.6 animal units/acre under NT. Average daily gain was 3.1 lb/day under CT and 3.6 lb/day under NT. Compared with the control paddocks containing perennial grass (total gain of 252 lb/acre, 1.1 animal units/acre, 3.0 lb gain/day), cattle performance and production was improved even under these relatively dry first-year conditions.

Table 3. Cattle live-weight gain (lb/acre) and animal unit days (AUD) as affected by cropping system and tillage during the first three growing seasons on a Typic Kanhapludult in Watkinsville GA. Note: Yearling steers stocked in Summer 2002 and Spring 2003 and cow/calf pairs stocked in Summer 2003.

Cropping system	Tillage	Summer 2002		Spring 2003		Summer 2003		
		Gain	AUD	Gain	AUD	Cow gain	Calf gain	AUD
Sorghum/rye	CT	-	-	234	70	-	-	-
	NT	-	-	278	70	-	-	-
LSD (*p* = 0.05)		-	-	68	0	-	-	-
Wheat/millet	CT	443	142	-	-	100	181	118
	NT	446	125	-	-	123	204	123
LSD (*p* = 0.05)		99	14*	-	-	180	73	10

In Spring 2003, grazing season length was relatively short due to a combination of factors including late planting of rye cover crop and the need to improve fencing for future handling of cow/calf animal units, which delayed stocking until 25 March 2003. Cattle live-weight gain averaged 256 lb/acre and was not different between tillage systems (Table 3). Stocking rate was 1.7 animal units/acre for 6 weeks. Average daily gain was 3.3 lb/day under CT and 4.0 lb/day under NT.

In Summer 2003, cow live-weight gain averaged 111 lb/acre and was not different between tillage systems (Table 3). Calf live-weight gain was also not different between tillage regimes, averaging 192 lb/acre. Stocking rate averaged 2.1 animal units/acre for 8 weeks. Grazing season was shorter in 2003 than in 2002 partly because of a difference in animal class, in which cow/calf units were stocked in Summer 2003 and utilized hereafter. Stocking with cow/calf pairs resulted in a minimal animal unit size of 1.44 compared with 0.62 for yearling steers. Average daily gain of cow/calf pairs was 2.4 lb/day under CT and 2.7 lb/day under NT.

CONCLUSIONS

An evaluation of converting perennial pasture to different annual cropping systems with multiple objectives to achieve grain and cattle production has been initiated and is partly completed. We have planned this evaluation to last 3 years, but may extend this timeframe. Through the first 1.5 years, crop production characteristics have been generally improved with NT compared with CT, especially with regards to plant biomass production for cattle consumption. The impact of cattle grazing previous cover crops on grain yield has been minimal. Although not significant in any of the individual growing seasons, cover crop utilization as forage has led to a trend for greater cattle performance and production under NT compared with CT. At the end of this evaluation, we plan an integrative assessment of crop and livestock production, environmental, and economic outcomes of these systems. Such an assessment should lead to better knowledge of how crops and livestock can be integrated for profit and environmental protection.

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IMPACT OF SOYBEAN CONSERVATION SYSTEMS ON BOBWHITE QUAIL HABITAT AND MORTALITY

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ABSTRACT

Conservation-tillage systems on the Southeastern Coastal Plain now utilize practices such as minimum surface tillage, narrow row widths, and planting of herbicide-tolerant varieties. These systems can result in many economical, environmental, and ecological benefits, including providing a more suitable habitat for wildlife such as the northern bobwhite quail (*Colinus virginianus*). Our research objectives were to assess the possible ecological impacts of both an innovative soybean (*Glycine max* L. Merr) tillage system (no-till) and traditional soybean system (tilled) on quail habitat and preference. Variables measured were insect abundance, canopy closure and pen-raised quail habitat use. No-till soybean fields were found to have the greatest abundance of orthopteran (crickets/grasshoppers), arachnid (spiders), and coleopteran/hemipteran (centipedes/beetles) insects. Insect numbers were higher in the no-till system than in the tilled system, field borders, and forested areas. The tilled system generally had the second highest number of insects, followed by field borders and forested areas. Canopy closure as estimated by light transmittance through the canopy, was faster and more complete in the no-till system than the tilled system due to the narrower row width used with the no-till system. Pen-raised quail were found more frequently in the no-till system than the tilled system a majority of the time. Greater quail use of the tilled system only occurred at one field. Field borders and forested areas were used less than either tillage systems. Averaged over treatments and release days, the greatest cause of mortality was due to mammals. These results indicate that no-till systems are more beneficial to quail than traditional systems in terms of habitat quality.

INTRODUCTION

Methods used by farmers to produce agronomic crops have changed dramatically in recent years. Practices such as conservation tillage, use of narrow row widths, and herbicide-tolerant varieties enhance yields, as well as provide environment benefits. Planting using narrow row widths and the use of glyphosate-tolerant varieties can be a tremendous aid for controlling weeds in no-till systems where cultivation is not feasible. The ease of weed control and the potential environmental benefits from using glyphosate-tolerant varieties has resulted in a majority of South Carolina's soybean acres being planted in these varieties. Because of the increased popularity, more information is needed about the benefits or problems that can occur when these practices are used collectively as one integrated soybean production system, especially with respect to impact on non-targeted species. For example, no-till systems utilizing narrow row widths and herbicide-tolerant varieties may influence the number and type of insects in a field due to the presence of plant residues, the rapid canopy closure that occurs with narrow row widths, and differences in weed species (compared to traditional tillage). These changes, in return, can affect quail which feed upon these insects. Information on the positive aspects of new technologies is needed due to the negative publicity these advances have received in recent years.

Quail numbers in South Carolina have declined in recent decades. Current estimates put the decline at about 4.5% per year in the Southeast (Sauer et al., 2001). This reduction has partially been attributed to the use of "clean farming practices" and the application of ecologically unfriendly pesticides. Leaving residues on the soil surface should enhance the number and diversity of soil insects and, with the addition of narrow row spacing, provide a better habitat in terms of protection from predators. The switch to Roundup-Ready® programs should be less detrimental to wildlife with respect to toxicology and nest disturbance, compared to traditional systems. Therefore, the use of newer, integrated pest management practices aimed at weed control in soybean should improve the habitat of quail, a non-targeted species. More wildlife-friendly cropping systems are needed on the Coastal Plain because of the dramatic rise in ecotourism industries in the region in recent years. In many cases, leasing of land for hunting purposes provides more income to farmers than can be obtained from crop production. In this study, we plan to test an innovative soybean conservation tillage system that utilizes narrow row widths and Roundup Ready® technologies to determine its impact on quail habitat ecology and habitat preference.

MATERIALS AND METHODS

Treatment Arrangement:

This project was conducted at the Pee Dee Research and Education Center in Florence, South Carolina during the 2001/2002 and 2002/2003 growing seasons. Seven fields (minimum of 12 acres each) were selected that were at least 500 yards apart, contained similar soil types and had consistent surrounding habitat. The number of fields used was dependent upon the variable measured. Each field was split in half, with one half planted using conservation tillage and the other using traditional surface tillage for doublecropped wheat and soybean. On the traditional side of the field, the soil was disked twice prior to planting each crop and the soybean was planted using 30-inch row widths and a conventional variety. On the conservation tillage side of the field, Roundup Ready® soybean was planted no-till using 7.5 inch row widths. Herbicides were applied based upon field-scouting results and Clemson University Extension Service recommendations. Fertilizer was applied at rates based upon soil test results. Details on the equipment and specific agronomic practices used have previously been described (Frederick, et al., 1998; Busscher et al., 2001).

Movement Patterns/Habitat-Use:

Flight-conditioned, pen-raised bobwhites were purchased which were certified and disease free. Upon arrival, quail were fitted with a 4-g, necklace-style radio transmitter, each quail having a unique tracking frequency. The first quail release was conducted on 23 July 2003, the second on 5 August 2003, and the third on 19 August 2003. Three female and three male quail were released on each side of the field at each site. All quail were tracked using homing techniques discussed by White and Garrott (1993) where the observers used a "dialing down" procedure to approach birds within 30 ft. Tracking equipment included a 3-element yagi antenna and ATS receiver. Daily locations were classified as being within four prominent habitat groups: no-till crop production system, tilled crop production system, field borders and woods (forested areas).

Food Supply (Insects):

Tillage systems may also impact quail food supply in direct or indirect ways such as altering insect species diversity, and/or causing population shifts or fluctuations of insects during the growing season. To test how these tillage systems affect insect prey of quail, insects were sampled within four main types of habitat over the breeding season: conservation tillage, traditional tillage, the strip-disked buffer zone and the forested area. Two pitfall insect traps were randomly placed within each of the four habitats and collected weekly for insect identification to genus or lowest level possible.

Cover and Edge Management:

Canopy closure was estimated by canopy light interception measured using a LiCor light rod. Measurements were taken at 12:00 noon approximately every 10 days. Data was used and compared temporally to movement and mortality rates of all radio-tagged quail.

Predation Indices:

All radio-tagged transmitters were equipped with a mortality signal that could be identified by simply scanning with the radio receiver. The mortality signal was activated when movement ceased for a continuous 12 h period. Quail were located and post-mortem inspections were used to record the type of mortality. If killed by a predator, the kill was classified as either avian, mammalian, reptile, or unknown. Data were analyzed to determine cause of mortality for each treatment.

RESULTS AND DISCUSSION

The orders Orthoptera (crickets and grasshoppers), Arachnida (spiders), and Coleoptera/Hemiptera (centipedes and beetles) were the most common insects found in this study (Fig. 1 and Table 1). Previous research has shown that 84% of a quail chick's diet is comprised of macroinvertebrates including beetles, grasshoppers, crickets, caterpillars, and moths (Jackson et al. 1987; Handley, 1931). Palmer (1995), using human-imprinted, pen-raised birds as surrogate wild chicks, reported that Orthoptera, Coleoptera, Heteroptera, Arachnida, and Lepidoptera were the most commonly ingested insects by quail. In our studies, insect numbers were usually highest in the no-till system, followed by the tilled system, field borders, and forested areas (Fig. 1). These results indicate that the supply of important food insects for quail should be greatest in no-till systems.

The amount of canopy provided by a crop has been reported to be very important for determining bobwhite habitat use (Puckett et al., 1995; Palmer, 1995). Ideal brood habitat usually includes at least 50% overhead cover for protection from predators (DeVos and Muellar, 1993). Use of crop fields for nesting and brooding purposes generally increases during the growing season as the crop develops, with at least 60% canopy closure needed for sufficient brooding to occur (Palmer, 1995). In our study, canopy closure, as estimated by light interception (Fig. 2), was much more rapid and complete for the no-till system which included the use of narrow row widths (7.5 inch). Canopy development in the tilled system which used a 30-inch row width was later to occur than in the no-till system and 60% light interception was not achieved in either year.

When comparing habitat use (Fig. 3, Table 2), quail were found in the no-till system an average of 56% of the time, followed by the tilled fields (26%), field borders (2%), and forested areas (16%). Results from release date I were not used in the analysis since soybean crop development was minimal at that time. For release dates II and III, only in one field were quail numbers significantly higher with the tilled system than with the no-till system. Percent mortality was also less with the no-till system (data not shown). Across release dates and sites, mortality was greatest due to mammalian predators (average of 55%), followed by avian (26%), reptilian (1%), and other (18%) predators (Table 3).

CONCLUSIONS

The no-till system had a greater number of insects than the tilled system. The types of insects found were those reported to be important to the diet of quail, especially baby chicks and brooding females. Assuming that insect availability is the same for both no-till and tilled systems, our data would suggest that no-till systems would be a more suitable habitat for insect foraging by quail. In addition, the more rapid and complete canopy closure provided by the narrow row width used in the no-till system should provide more protection from predators. These beneficial aspects in terms of quail habitat for the no-till system would explain the greater quail preference we found for the no-till system.

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Table 1. Insect abundance for different orders of insects as a function of habitat type. Numbers shown are averages across sampling dates and years

Grouping (Order or Class)a	No-Till	Till	Field Border	Forested Area
Orthoptera	40.70	18.98	27.10	9.15
Arachnida	2.90	1.46	0.84	1.05
Coleóptera/ Hemiptera	32.20	23.46	12.45	6.42
Hymenóptera	37.49	15.30	23.04	7.15
Blattaria	0.09	0.10	1.63	1.67
Isopoda	0.09	0.17	5.69	5.30
Chilópoda/Diplopoda	0.41	1.59	4.93	6.63
Diptera	0.72	0.70	0.59	0.26
Dermaptera	0.06	0.08	0.31	0.40

a All groups are orders except for Chilopoda/Diplopoda, which represents class.
b Orders were combined for analysis
c Classes were combined for analysis

Table 2. Habitat use by pen-raised quail during the summer of 2003 by field/release date as a function of release date and habitat type.

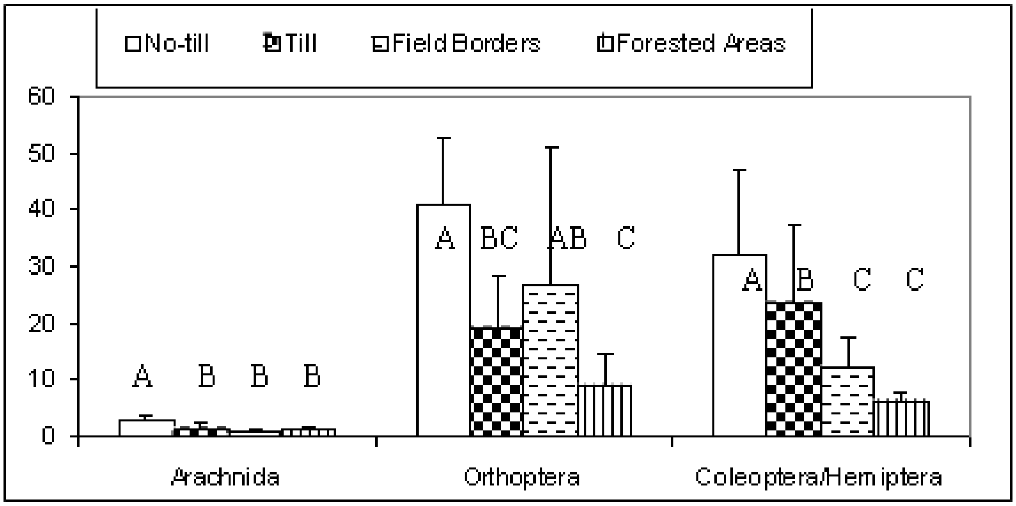
Release Site	Release Date	No-Till	Till	Field Border[a]	Forested Area
Field A	2	52%	35%	10%	3%
Field B	2	57%	27%	2%	14%
Field C	2	46%	37%	-	17%
Field D	2	62%	23%	0%	15%
Field G	2	84%	0%	-	16%
Field A	3	65%	18%	1%	16%
Field B	3	28%	37%	2%	33%
Field E	3	27%	50%	2%	21%
Field F	3	75%	18%	-	7%
Field H	3	64%	18%	-	18%
Average Use		56%	26%	2%	16%

A dash indicates that habitat type was not available within or surrounding treatment field.

Table 3. Cause-specific mortality for pen-raised quail released on three different dates in 2003.

Mortality Agent	**Release Date I 7/22/03**	**Release Date II 8/5/03**	**Release Date III 8/19/03**	**TOTAL**
Mammalian	46 (56%)	28 (42%)	35 (66%)	109 (54%)
Avian	18 (22%)	19 (28%)	16 (30%)	53 (26%)
Reptilian	1 (1%)	1 (2%)	0	2 (1%)
Other	17 (21%)	19 (28%)	2 (4%)	38 (18%)
* Dog	3 (4%)	4 (6%)	0	7 (3%)
* Stress	6 (7%)	4 (6%)	0	10 (5%)
* Unknown	8 (10%)	11 (16%)	2 (4%)	21 (10%)
TOTAL	82	67	53	202
Mammalian vs. Avian (P<0.0001) and Reptilian (P<0.0001)				
Avian vs. Reptilian (P<0.0001)				
Puckett et al. (1995) found higher predation rate for avian than mammalian species				
Groton Plantation Study: pen-raised quail mortality was due to 70% avian, 24% mammalian and 6% other				

Figure 1. Insect abundance in each of the four habitats examined. Data shown are averages over sampling dates and years



Habitat Type (Soybean Fields Only)	Arachnida	LSD	Orthoptera	LSD	Coleoptera/ Hemiptera	LSD
No-till	2.90	A	40.70	A	32.21	A
Till	1.47	B	18.99	BC	23.46	B
Field Borders	0.84	B	27.10	AB	12.45	C
Forested Areas	1.05	B	9.15	C	6.42	C

LSD: Fischer's Least Squared Differences (0.05 significance level).
Orders Coleoptera / Hemiptera were combined.

Figure 2. Estimated canopy closure during the 2002 (Year 1) and 2003 (Year 2) growing seasons for the tilled and no-till systems.

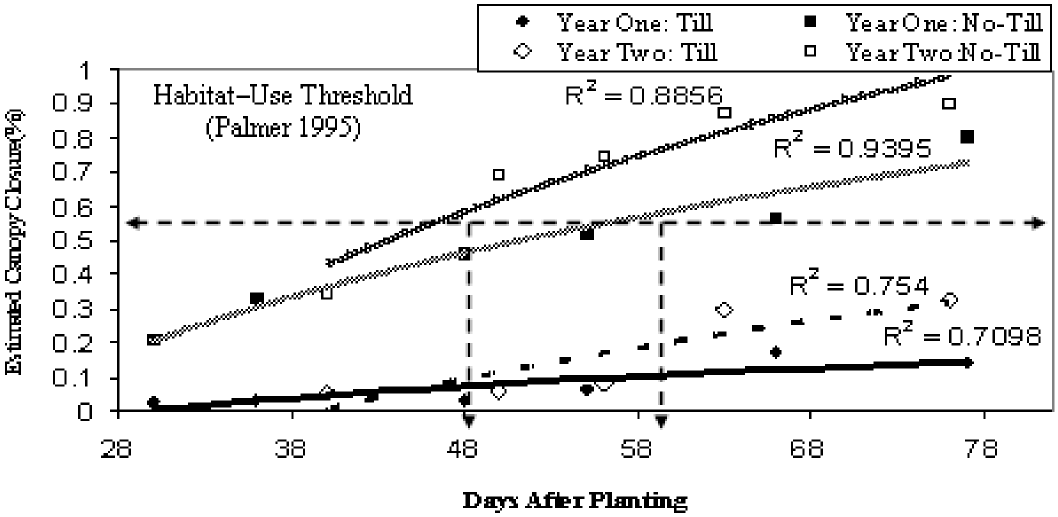
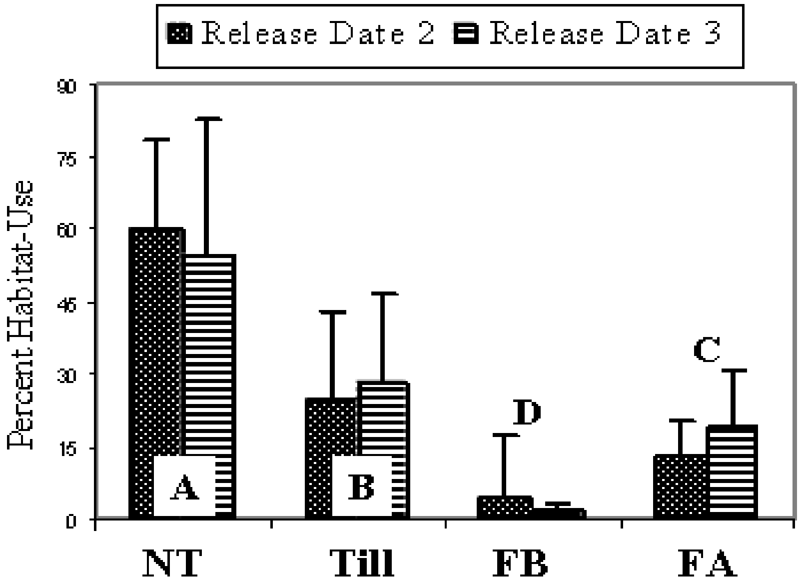


Figure 3. Habitat use of pen-raised quail for the second and third release dates in 2003. Habitats were no-till system (NT), tilled system (Till), field borders (FB) and forested areas (FA)



ECONOMIC ASSESSMENT OF WEED MANAGEMENT FOR TRANSGENIC AND NON-TRANSGENIC COTTON (*GOSSYPIUM HIRSUTUM*) IN CONVENTIONAL AND NO TILLAGE SYSTEMS

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ABSTRACT

Studies were conducted to evaluate weed management programs in non-transgenic, Buctril-resistant, and Roundup-resistant cotton in no-tillage and conventional-tillage environments. Tillage did not affect the level of weed control provided by herbicides evaluated. Early season stunting in no-tillage cotton was 3% regardless of herbicide system and was transient. Conventionally tilled cotton yielded 17% more on average than no-tillage cotton. Excellent (> 90%) velvetleaf, common lambsquarters, jimsonweed, *Ipomoea* morningglory spp., and prickly sida control was achieved with programs containing Staple, Buctril, and Roundup. Residual herbicide inputs were necessary for adequate large crabgrass and goosegrass control. Buctril and Staple postemergence did not control sicklepod unless supplemented with MSMA and followed by a late post-directed treatment of Bladex plus MSMA. Herbicide programs that included Roundup controlled sicklepod regardless of late postemergence-directed treatment. When Cotoran applied preemergence was included in Buctril programs, net returns were at least \$375 A^{-1} and not different from the higher-yielding programs in non-transgenic cotton. Late-season weed control was usually greater than 90% from Roundup programs and net returns from Roundup programs were as high or higher than net returns from programs that utilized mid-season treatments of Buctril, Staple, or Cotoran plus MSMA.

INTRODUCTION

Preplant-incorporated (PPI) herbicides and cultivation, formerly the primary methods of weed control in cotton (*Gossypium hirsutum* L.), have recently been augmented with new postemergence over-the-top (POT) herbicide options. In addition to cultivation, which precludes no-tillage cotton production, formerly available postemergence weed control options usually required high use rates of relatively non-selective herbicides and specialized equipment for postemergence-directed (PD) applications (Wilcut et al. 1996, 1997). Heightened concerns over the environmental impact of pesticides and conventional tillage practices have increased demand for no-tillage crop production (Wauchope et al. 1985).

Poor weed control was previously cited as the greatest limitation to successful cotton production in conservation-tillage (McWhorter and Jordan 1985). Recent developments in POT technology have allowed cotton producers to explore reduced-tillage or no-tillage production options and total postemergence weed management (Culpepper and York 1997, 1999; Wilcut et al. 1996). Herbicides registered for POT broadleaf control in cotton include Buctril, Roundup, MSMA, and Staple (Culpepper and York 1997, 1999; Jordan et al. 1997; Wilcut and Askew 1999). Roundup and MSMA control many broadleaf and grass weeds; however, when applied POT, lower rates of MSMA are required to minimize crop injury (Anonymous 1999). Buctril and Staple control many broadleaf weeds, but do not control most grass weeds (Culpepper and York 1997; Jordan et al. 1993; Paulsgrove and Wilcut 1999). As the weed control spectrums of these herbicides differ, the need for additional inputs of preemergence (PRE) and/or PD herbicides also varies.

Low commodity prices and a competitive market place requires cotton producers to reduce inputs and increase efficiency of cotton production. No-tillage cotton production may reduce inputs and save time by eliminating tillage requirements. Previous studies have evaluated herbicide systems in non-transgenic, Buctril-resistant, and Roundup-resistant cotton in conventionally tilled seedbeds and cultivation early and late in the season (Culpepper and York 1999). Since many producers are adopting conservation tillage systems with the advent of herbicides registered for POT application in cotton, an economic evaluation of cotton cultivars in programs employing POT herbicides in no-tillage and conventional-tillage production is needed. Studies were conducted to compare weed control, cotton response and yield, and net economic returns in no-tillage and conventional-tillage cotton using Buctril, Roundup, MSMA, and Staple herbicide programs.

MATERIALS AND METHODS

Site Preparation

Field studies were established in 1997 and 1998 at the Central Crops Research Station located near Clayton, NC and at the Cherry Farm Unit near Goldsboro, NC. Soils were a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults) with 1.8% organic matter and pH 5.8 at Clayton and a Wickham loamy sand (fine-loamy, mixed, thermic Typic Hapludults) with 2.1% organic matter and pH 5.2 at Goldsboro.

Land preparation began with desiccation of a wheat (*Triticum aestivum* L.) cover crop with Roundup at 1 lb ai A^{-1} 2 wk prior to planting. For conventionally tilled plots, soil was disked and smoothed, and PPI herbicides were applied and incorporated 1.5 to 3 in deep. Soil was then bedded at Clayton only. In no-tillage plots, crop seed was planted directly into cotton residue on existing beds from the previous season. Cotton cultivars, ‘Paymaster 1220RR’ (Roundup-resistant), ‘Stoneville BXN47’ (Buctril-resistant), and ‘Stoneville 474’ (non-transgenic), were planted on May 21, 1997 and May 5, 1998 at Clayton and May 28, 1997 and June 2, 1998 at Goldsboro. Cotton was seeded at 4.5 seed ft^{-1} of row. Plots were 25 ft long and four 38-in rows wide.

Experimental Design and Herbicide Programs

The experimental design was a randomized complete block with each block replicated three times. A split-plot treatment arrangement with main plot tillage and subplot herbicide program was utilized to facilitate tillage and planting. Fourteen herbicide programs were evaluated in each main plot and differ between the tillage regimes only with respect to Prowl application method. Prowl was applied PPI in conventional-tillage plots and PRE in no-tillage plots.

Three cotton cultivars were required to evaluate the fourteen herbicide programs in each tillage regime. Six herbicide programs in non-transgenic cotton included: no herbicide treatment, Prowl at 1 lb ai A^{-1} (PPI in tilled plots or PRE in non-tilled plots) plus Cotoran at 1 lb ai A^{-1} PRE, Prowl and Cotoran PRE followed by (fb) Cotoran at 1 lb ai A^{-1} plus MSMA at 2 lb ai A^{-1} PD, Prowl and Cotoran PRE fb Cotoran and MSMA PD fb Bladex at .8 lb ai A^{-1} plus MSMA at 2 lb ai A^{-1} late PD, Prowl and Cotoran PRE fb Staple POT at .06 lb ai A^{-1} fb Bladex plus MSMA late PD, and the aforementioned program with MSMA at .75 lb A^{-1} mixed with Staple POT. Herbicide programs for Buctril-resistant cotton included: Prowl PRE or PPI fb Buctril at .5 lb ai A^{-1} POT as needed spray (ANS) for weed control fb Bladex plus MSMA late PD, the aforementioned program with MSMA at 840 g ha^{-1} mixed with the first Buctril application, Prowl and Cotoran PRE fb Buctril POT fb Bladex plus MSMA late PD, and the aforementioned program with MSMA at .75 lb A^{-1} mixed with Buctril POT. Herbicide programs for Roundup-resistant cotton included: Prowl and Cotoran PRE fb Roundup at .75 lb ai A^{-1} ANS (applied POT if cotton had less than five leaves and PD if cotton had more than four leaves), Prowl and Cotoran PRE fb Roundup POT fb Bladex plus MSMA late PD, Roundup ANS, and Roundup ANS fb Bladex plus MSMA late PD.

Buctril and Roundup ANS treatments were applied when visually estimated weed control dropped below 80% (Askew and Wilcut 1999). The number of ANS applications necessary varied from two to four depending on weed management program and location. In all instances, the first Roundup ANS treatment was applied POT of two- to four-leaf cotton. Subsequent ANS treatments were applied PD to minimize Roundup contact with cotton foliage as specified by the Roundup label (Anonymous 1999).

Application Information

Nonionic surfactant[1] at 0.25% (v/v) was included with PD, POT, and late PD herbicides except Buctril and Roundup. Herbicides were applied with a compressed-CO^2 sprayer calibrated to 15 gal A^{-1} at 21 PSI. Application dates were May 25 to June 2 (PPI and PRE), June 15 to June 20 (POT, PD, and first ANS), and June 29 to July 16 (late PD) depending on location and year.

Data Collection

Late-season weed control, based on leaf discoloration and biomass reduction, was estimated visually on a scale of 0 to 100 where 0 = no control and 100 = death of all plants (Frans et al. 1986). Three separate injury parameters (stunting, discoloration, and stand reduction) were visually estimated for cotton 1 to 2 wk after POT treatment and late in the season. Overall injury was also estimated as a combination of the three injury parameters. The two center rows of each plot were harvested once with a spindle picker modified for small-plot harvesting. Lint and seed yield were adjusted based on the 2-year statewide average percent lint composition of each cultivar (Bowman 1998).

Economic Analysis

An enterprise budget developed by the North Carolina Cooperative Extension Service (Brown and Cole 1997) that included operating inputs, fixed costs, and cotton yield value was modified to represent the various weed management programs. Cost of seed, technology fee, herbicides, and adjuvants were based on averages of quoted prices from two local agricultural suppliers. Planting costs including costs of seed and technology fees were \$11.80 A^{-1}, \$18.00 A^{-1}, and \$22.00 A^{-1} for non-transgenic, Buctril-resistant, and Roundup-resistant programs, respectively. Estimated costs of POT, PD, and PPI applications were \$1.20, \$2.20, and \$3.20 A^{-1}, respectively, (Anonymous 1998b; Askew and Wilcut 1999). Chemical costs per A were as follows: Buctril, \$12.80; Bladex, \$5.40; Cotoran, \$8.90; Roundup, \$7.60; MSMA POT, \$1.90; MSMA PD, \$5.20; Prowl, \$7.70; Staple, \$21.50; and nonionic surfactant, \$0.60. Crop value was adjusted in the budget by multiplying the lint yield from each herbicide program by an estimated market price of \$0.60 lb^{-1}.

Statistical Analysis

Nontreated control plots could not be harvested due to weed interference with machinery. Therefore, the nontreated control was removed prior to analysis to improve homogeneity of variance. Percent data were arcsine square-root transformed to stabilize variance. Data were subjected to ANOVA and treatment sums of squares were partitioned to reflect the split-plot treatment design and year-location effects (McIntosh 1983). Where year and location effects were not significant, data were pooled. Data were analyzed separately if significant year by location effects resulted. Appropriate transformed means were separated using Fisher's Protected LSD at P = 0.05, however, non-transformed means are presented for clarity.

RESULTS AND DISCUSSION

Cotton Response

Early season injury was minimal. Averaged over years, locations, and tillage options, Prowl and Cotoran PRE fb Cotoran plus MSMA PD discolored cotton 2% (data not shown). No other herbicide program significantly discolored cotton (data not shown) and the slight discoloration, chlorosis on the lower cotton leaves, was transient and indicative of a urea herbicide (Ahrens 1994; Anonymous 1998a).

A tillage main effect existed for early season cotton stunting (data not shown). Averaged over years, locations, and treatments, non-tilled cotton was stunted 3% while no stunting occurred in conventionally tilled cotton (data not shown). This stunting may be due to cooler soil temperature in non-tilled cotton. Soil-temperatures were 3 C lower in non-tilled compared to conventionally tilled cotton at planting (data not shown). Soil warming is often slower in non-tilled environments, and cool temperatures may delay cotton development (McWhorter and Jordan 1985). The stunting observed in non-tilled cotton could explain a yield reduction observed between non-tilled and conventionally tilled cotton to be discussed later. No significant stand reduction or overall injury was observed early season and no differences were noted in cotton response late in the season (data not shown).

Weed Control

A herbicide-program main effect was observed on all weed control data, and tillage did not affect weed control by the herbicides evaluated (Table 1).

Prowl and Cotoran PRE controlled common lambsquarters 87% while control was > 98% with programs that contained POT or PD herbicides (data not shown). Buctril and Roundup control common lambsquarters (Askew and Wilcut 1999; Culpepper and York 1997; Paulsgrove and Wilcut 1999). In Staple programs, Prowl, Cotoran, and Bladex controlled common lambsquarters.

The soil-applied only program controlled goosegrass 79% late in the season (Table 1). Subsequent application of Cotoran plus MSMA PD or Staple POT improved control to at least 88%. The program containing a single POT application of Buctril plus MSMA with soil-applied and late PD herbicides improved control (95%) compared to a similar program that excluded Cotoran and contained ANS Buctril applications (87%). Goosegrass was controlled at least 94% when soil-applied or late PD herbicides were included with either Roundup POT or ANS while Roundup ANS alone controlled goosegrass 86% late in the season.

Postemergence herbicide-containing programs controlled jimsonweed at least 98% (data not shown). Prowl and Cotoran PRE controlled large crabgrass 91% late in the season (data not shown). Programs containing Cotoran and MSMA PD, Staple plus MSMA POT, or Buctril plus MSMA POT improved control compared to soil-applied herbicides alone.

Soil-applied herbicides alone controlled prickly sida 55% late-season (Table 1). Programs using Cotoran plus MSMA PD controlled prickly sida 86% without late PD herbicides and 98% with Bladex plus MSMA late PD. Staple, Buctril, and Roundup programs controlled prickly sida at least 96%. Prowl and Cotoran do not provide acceptable control of prickly sida (Paulsgrove and Wilcut 1999). Herbicide systems that included Buctril, Roundup, and Staple in conjunction with cultivation controlled prickly sida at least 97% in other studies (Culpepper and York 1999).

Prowl and Cotoran PRE controlled morningglory species no more than 52% (Table 1). Programs using Cotoran plus MSMA PD controlled these species 86 to 92% without late PD herbicides and 94 to 99% when Bladex plus MSMA was applied late PD. Buctril, Staple, and Roundup programs controlled morningglory at least 93%. Although Staple controls tall morningglory less than other *Ipomoea* spp. (Sunderland et al. 1995), plants were suppressed such that control was improved following Bladex plus MSMA late PD (data not shown).

Soil-applied herbicides controlled velvetleaf only 56% and control increased to 80 and 91% with the addition of Cotoran plus MSMA PD and Cotoran plus MSMA PD fb Bladex plus MSMA late PD, respectively (Table 1). Staple, Buctril, and Roundup programs controlled velvetleaf at least 98%.

Prowl plus Cotoran alone controlled smooth pigweed 81% and control was increased with all other herbicide programs (Table 1). Staple and Roundup programs controlled smooth pigweed more than Buctril programs that did not contain Cotoran PRE. Buctril does not provide complete control of smooth pigweed (Culpepper and York 1997).

Soil-applied herbicides alone controlled sicklepod 34% (Table 1). Cotoran plus MSMA PD following soil-applied herbicides controlled sicklepod 64% and the addition of Bladex plus MSMA late PD improved control (80%). In programs where Staple POT was applied alone, sicklepod control was 59% and the addition of MSMA to Staple improved control (80%). Likewise, Buctril programs controlled more sicklepod when MSMA was included with early POT Buctril application. When MSMA was included with either Staple or Buctril, sicklepod was stunted such that a height differential was obtained between cotton and sicklepod. This height differential allowed for more effective control by subsequent application of Cotoran or Bladex PD. Sicklepod control by late PD herbicidal applications was increased when MSMA was added to Buctril (Paulsgrove et al. 1998) and Staple (Wilcut and Hinton 1997) EPOST. Roundup programs controlled sicklepod at least 97%.

Cotton Yield

In non-transgenic cotton, the soil-applied-only program of Prowl fb Cotoran yielded less (110 lb A^{-1} lint) than all other programs (data not shown). When Cotoran plus MSMA PD was applied following soil-applied herbicides, lint yield increased 70 lb A^{-1}. The addition of Bladex plus MSMA late PD following the early PD herbicides did not further improve yield.

In Buctril-resistant cotton in 1997, programs using Buctril ANS without Cotoran PRE resulted in yield equivalent to programs using single applications of Buctril with Cotoran PRE (data not shown). Early season weed interference reduces more cotton yield than late-season interference (Buchanan and Burns 1970) and may have reduced yield value from multiple Buctril applications when Cotoran PRE was not used. Yields from Buctril programs were not different from the higher yielding programs in non-transgenic cotton in 1997. In 1998, exclusion of Cotoran from Buctril ANS systems decreased yield compared to Buctril programs that contained Cotoran PRE (data not shown).

In 1997, Roundup programs had equivalent yield and averaged 230 lb lint A^{-1} regardless if soil-applied or late PD residual herbicides were used (data not shown). These yields were not different from the higher yielding Buctril or Staple programs. In 1998, weed densities were higher and the Roundup ANS program that contained soil-applied Prowl and Cotoran yielded more than Roundup-only or Roundup fb Bladex plus MSMA late PD programs. Roundup programs that did not contain soil-applied herbicides resulted in decreased yield that may be attributed to early season interference from weeds prior to the first Roundup applications (Buchanan and Burns 1970).

The interaction of tillage by year averaged over herbicide programs was significant for cotton yield (Table 2). In both years, average yield from conventionally tilled cotton was higher than yield from no-tillage cotton. Conventionally tilled cotton yielded 20 lb lint A^{-1} more in 1997 and 40 lb lint A^{-1} more in 1998 than no-tillage cotton. Differences in soil temperature were noted at planting time and likely stunted growth of non-tilled cotton as mentioned earlier. Since weed control did not differ by tillage regime, decreased early season vigor of no-tillage cotton (McWhorter and Jordan 1985) may have caused the reduction in yield.

Economic Returns

Trends in net returns were similar to yield trends, however no year effect existed for net returns. Programs that had lower weed control and yield resulted in lower net returns and a higher coefficient of variation (CV). In non-transgenic cotton, the soil-applied only program resulted in a net loss of \$140 A^{-1} while addition of Cotoran plus MSMA PD to this program resulted in a net return of \$180 A^{-1}. Addition of Bladex plus MSMA late PD to the program of Prowl and Cotoran PRE fb Cotoran plus MSMA PD increased net returns 93% and decreased the CV by 107%. The preceding program resulted in net returns equal to programs where Staple or Staple plus MSMA were used instead of Cotoran plus MSMA PD.

In Buctril-resistant cotton, exclusion of Cotoran PRE resulted in lower net returns. When Cotoran PRE was included in Buctril programs, net return was at least \$380 A^{-1} and did not differ from the higher-yielding programs in non-transgenic cotton. Soil-applied herbicides and MSMA POST did not affect net returns from Buctril systems in other studies where cultivation was utilized (Culpepper and York 1999).

When Roundup ANS followed Prowl and Cotoran PRE, net returns were \$460 A^{-1} and 31% higher than Roundup ANS alone. The program of Prowl and Cotoran PRE fb Roundup POT fb Bladex plus MSMA late PD increased net returns 24% compared to Roundup ANS alone.

As with yield, a tillage by year interaction averaged over herbicides existed for net returns (Table 2). Average net returns in conventional-tillage cotton increased \$70 A^{-1} in 1997 and \$180 A^{-1} in 1998 compared to the average net return from no-tillage cotton. These increases reflect the differences in yield observed between the two tillage regimes. In addition to decreased net returns, no-tillage programs increased CV values 12% in 1997 and 85% in 1998. Less productive programs often result in higher CV values (Johnson et al. 1997).

Herbicide-resistant cultivars are an important tool to improve weed control and reduce herbicide inputs while increasing flexibility for producers. For instance, the addition of soil-applied Prowl and Cotoran decreased the number of sequential ANS treatments, subsequently increasing net profits for Buctril- and Roundup-tolerant cotton. Furthermore, efficacious systems often resulted in lower coefficients of variation, which suggest improved consistency in profits for the producer. Although poor weed control has been indicated as the primary limitation to no-tillage cotton production (McWhorter and Jordan 1985), weed control did not differ in this study due to highly efficacious weed management systems.

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Table 1. Effect of herbicide programs on late-season goosegrass, prickly sida, morningglory, velvetleaf, smooth pigweed, and sicklepod control averaged over location, years, and tillage[a].

	Herbicide program[b]									
Cultivar	Prowl[b]	Cotoran[b]	POST[b]	Late PD[b]	ELEIN	SIDSP	IPOSS	ABUTH	AMACH	CASOB
					%					
ST474	yes	yes	none	no	79 e	55 d	49 d	56 d	81 d	34 f
	yes	yes	early PD	no	88 bcd	86 c	86 c	80 c	99 a	64 de
	yes	yes	early PD	yes	95 ab	98 ab	94 a	91 b	99 a	83 b
	yes	yes	Staple	yes	91 bcd	100 a	94 a	100 a	100 a	59 de
	yes	yes	Staple + MSMA	yes	96 ab	100 a	94 a	100 a	100 a	80 b
BXN47	yes	no	Buctril*	yes	87 cde	97 b	100 a	100 a	91 c	51 e
	yes	no	Buctril* + MSMA	yes	93 abc	99 a	99 a	100 a	93 bc	77 bc
	yes	yes	Buctril	yes	91 bcd	100 a	98 a	100 a	97 ab	65 cd
	yes	yes	Buctril + MSMA	yes	95 ab	100 a	97 a	98 a	97 ab	84 b
PM1330RR	yes	yes	Roundup*	no	94 ab	100 a	96 ab	100 a	100 a	97 a
	yes	yes	Roundup	yes	98 a	100 a	98 a	100 a	100 a	98 a
	no	no	Roundup*	no	86 d	96 b	95 a	100 a	99 a	98 a
	no	no	Roundup*	yes	94 ab	100 a	97 a	100 a	100 a	99 a

[a] The analysis of variance and the LSD comparison were performed on data that were arcsine square-root transformed. Means within a column followed by the same letter are not different based on a Fisher's Protected LSD test ($P < 0.05$).

[b] Herbicide options were: Prowl, “yes” denotes Prowl applied PRE in no-tillage cotton or PPI in conventional-tillage cotton; Cotoran, “yes” denotes Cotoran applied PRE; POST, “none” indicates no postemergence herbicides, “early PD” denotes Cotoran plus applied early PD; “Buctril”, “MSMA”, “Staple”, and “Roundup” denote these herbicides were applied POT; late PD, “yes” denotes Bladex at plus MSMA was applied late post-directed. A (*) indicates applied ANS for weed control until the time of late PD applications.

[c] Abbreviations: ELEIN = *Eleusine indica*, SIDSP = *Sida spinosa,* IPOSS = *Ipomoea* species, ABUTH = *Abutilon theophrasti*, AMACH = *Amaranthus hybridus*, CASOB = *Senna obtusifolia*.

Table 2. Effect of tillage on cotton lint yield and economic returns averaged over locations and herbicide programs.

	Lint yield[a]		Economic returns[ab]			
Tillage regime	1997	1998	1997		1998	
	——lb A^{-1}——		\$ A^{-1}	CV (%)[c]	\$ A^{-1}	CV (%)
Conventional tillage	220 a	230 a	310 a	91	340 a	87
No tillage	200 b	190 b	240 b	103	160 b	172

[a] Means within a column followed by the same letter are not different based on a Fisher's Protected LSD test ($P < 0.05$).

[b] Economic returns are based on an enterprise budget that included costs for seed and technology, herbicidal application, herbicides, and adjuvants in addition to fixed farm costs unrelated to weed management.

[c] Abbreviations: CV, coefficient of variation.

INVESTIGATIONS OF WEEDS AS RESERVOIRS OF PLANT-PARASITIC NEMATODES IN AGRICULTURAL SYSTEMS IN NORTHERN FLORIDA

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ABSTRACT

In addition to their direct effects on crop production through competition and allelopathy, weeds can serve as reservoirs of other pests including plant-parasitic nematodes, resulting indirectly in yield loss. Weeds enable plant-parasitic nematodes to survive in the absence or even presence of the crop, thus providing a source of nematode infection for the following season. The purpose of this study was to conduct a survey of common weeds and associated plant-parasitic nematodes at four agricultural sites, thereby demonstrating the importance of weeds as reservoirs of these pests. Two organic farms and two conventional farming systems were visited. Soil samples were taken from the root zones of predominant weed species at each site, and nematodes were extracted, identified, and counted. Purple nutsedge (*Cyperus rotundus* L.), pigweed (*Amaranthus* spp.), lambsquarters (*Chenopodium album* L.), and crabgrass (*Digitaria* spp.) were the weeds most frequently encountered. Root-knot nematodes (*Meloidogyne* spp.) were the major plant-parasitic nematodes frequently found in association with these weeds in relatively high numbers. A greenhouse experiment confirmed the susceptibility of American black nightshade (*Solanum American* Mill.), yellow nutsedge (*Cyperus esculentus* L.), purple nutsedge (*C. rotundus* L., Florida pusley (*Richardia scabra* L.), and bermudagrass (*Cynodon dactylon* (L.) Pers.) to *M. incognita*, but Virginia pepperweed (*Lepidium virginicum* L.) was relatively resistant to this nematode. The implications of these results and importance of weeds as hosts for plant-parasitic nematodes are discussed.

INTRODUCTION

Weeds have long been recognized as a major constraint to agricultural production. Weeds can interfere with crops by competing for soil nutrients, water, and light, and by allelopathic inhibition of crop growth. They also affect crop production indirectly by providing food, shelter, and a reproductive site to maintain populations of pests (Bendixen et al., 1979). Many weeds associated with agricultural crops have been reported as hosts of plant-parasitic nematodes (Hogger and Bird, 1976; Bendixen et al., 1979,1988 a, b, c; Noling and Gilreath, 2002a).

In southeastern states such as Florida, the role of weeds as alternate hosts for plant-parasitic nematodes has become increasingly important (Hogger and Bird, 1976; Tedford and Fortnum, 1988; Noling and Gilreath, 2002a). Their importance is related to the dynamic nature of weed populations in fallow situations and their influence in crop rotations in shifting agriculture (Desaeger and Rao, 2000; McSorley and Parrado, 1983; Powell, 2001). Crops grown on the sandy soils of Florida are typically prone to nematode problems because of environmental conditions that favor nematode development and reproduction. As a result, there has been a heavy reliance on chemical control, especially soil fumigation with methyl bromide, as a "silver bullet" to control these pests. However, these organisms can never be eradicated and hence a focus on management is now warranted. Due to health and environmental concerns, the continued availability and use of methyl bromide are uncertain, and the search for alternative control measures has become increasingly important (Noling and Gilreath, 2002b). Non-conventional systems such as organic farming are presently prohibited from using synthetic chemicals and rely on nonchemical methods, particularly cultural practices, for the management of plant-parasitic nematodes and weeds. The development of an integrated approach to weed and nematode management will require pertinent information in order to make informed management decisions. Despite our anthropocentric views and compartmentalization of pest management practices, the interrelationships among organisms in the field has continued, and hence knowledge regarding these relationships will serve us in developing sustainable management practices.

The objectives of this study were to 1) illustrate the role of weeds as reservoirs of plant-parasitic nematodes in Florida agricultural fields, 2) compare the nematode host status of major weeds encountered in agricultural fields, 3) examine the host status of several common weeds to the root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood in the greenhouse.

MATERIALS AND METHODS

Field visits were made to four agricultural fields, including two certified organic farms: Rosie's Organic Farm, Gainesville, FL (located near 29° 32' N, 86° 26' W), Hammock Hollow Farm, Cross Creek, FL (located near 29° 30' N, 82° 11' W), the University of Florida's Plant Science Research and Education Unit, Citra, FL (located near 29° 25' N, 82° 10' W), and the University of Florida Plant Science Field Teaching Laboratory, Gainesville, FL (located near 29° 39' N, 82° 21' W). At each location, the types and distribution of major weed species were noted. The field was divided into three blocks, each containing representatives of the predominant weed species. Weeds that could not be easily identified in the field were collected and taken to the Weed Science Laboratory in the Horticultural Sciences Department at the University of Florida for identification. Representatives from each weed species were randomly selected and soil samples taken from the root zones. Each composite nematode sample consisted of five soil cores (2.5 cm diameter × 20 cm deep) collected from five plants per weed species per block. Composite samples were placed in a plastic bag and stored in a cooler to protect samples from sunlight. Samples were taken to the University of Florida in Gainesville where they were stored in a cold room at 10^{o}C until processed. Soil subsamples of 100-cm^3 were taken for nematode extraction using a modified sieving and centrifugal flotation procedure (Jenkins, 1964). An inverted microscope was used to identify and count extracted nematodes.

Plant Science Field Teaching Lab (PSFTL). Sampling was done on 21 May 2003. Soil type was Arredondo fine sand. This site had experienced little or no rainfall within the week prior to sampling. Soil samples were taken from a 50-m^2 weedy fallow area. The area was previously cropped in sesame (*Sesamum indicum* L.) and cowpea (*Vigna unguiculata* (L.) Walp.). Blocking was done according to the major weed types present. The predominant weeds at this site were Virginia pepperweed (*Lepidium virginicum* L.), volunteer cowpea, Florida pusley (*Richardia scabra* L.), johnsongrass (*Sorghum halepense* (L.) Pers.), and purple nutsedge (*Cyperus rotundus* L.). However, only Virginia pepperweed and volunteer cowpea were consistently present in each block, so only soil at the root zone of these weeds were sampled. A total of six composite samples were collected.

Rosie's Organic Farm. Sampling was done on 9 June 2003. Soils were of the Jonesville Cadillac Bonneau complex with good organic matter content. Rainfall had occurred three days prior to sampling. Soil samples for nematode analysis were taken from an experimental site of 480 m^2 that had been used by the grower to compare the effectiveness of various types of mulch in suppressing weed populations under pepper (*Capsicum annuum* L.), muskmelon (*Cucumis melo* L.), or no crop. This site was blocked according to crop planted. The predominant weeds present in each block that were sampled at this site were smooth pigweed (*Amaranthus viridis* L.), lambsquarters (*Chenopodium album* L.), purple nutsedge, and signalgrass (*Brachiaria platyphylla* (Griseb.) Nash). Crabgrass (*Digitaria* sp.) was also present, but in only two of three blocks. Soil samples were taken from the unmulched row middles around the root zone of the above mentioned weeds. In addition, soil samples were also taken from purple nutsedge in a mulch treatment. A total of 18 composite samples were collected.

Plant Science Research and Education Unit (PSREU). Sampling was done on 16 June 2003. Soil type was Candler sand. This site had been in weedy fallow for 20 years prior to cultivation to establish an experiment consisting of plots with 'Iron Clay' cowpea cover or fallow with weeds. Soil samples were taken from weedy fallow plots in each of three blocks over a 260-m^2 area. The predominant weeds at this site were spiny amaranth (*Amaranthus spinosus* L.), purple nutsedge, hairy indigo (*Indigofera hirsuta* L.), and crabgrass. Thus, 12 composite soil samples were taken from root zones of these 4 weeds.

Hammock Hollow Farm. Sampling was done on 11 July 2003 at the end of the growing season. Soil type was Pomona sand. This site has been in organic vegetable and herb production for 17 years. The grower used crop rotation and cover crops such as browntop millet (*Brachiaria* sp.) and sunn hemp (*Crotalaria juncea* L.) to suppress weeds and nematodes. At the time of sampling, three areas each about 200 m^2 had been planted with a browntop millet cover crop. The predominant weeds at this site were redroot pigweed (*Amaranthus retroflexus*), spiny amaranth, Florida pusley, purple nutsedge, and crabgrass (*Digitaria* sp.). Weeds at this site were localized in a few areas including red-rooted pigweed that was frequently observed within the millet cover crop. Due to the irregular distribution of weeds, only soil samples taken from the root zones of pigweed and millet in the millet cover crop were included in data analysis, although other weeds previously mentioned were also sampled.

Greenhouse Experiment. This experiment was carried out in a greenhouse on the University of Florida campus in Gainesville, FL. Seeds, tubers, or nematode-free cuttings of several common weed species were obtained and germinated in early summer, 2003. Weed species included yellow nutsedge (*C. esculentus* L.), purple nutsedge, Florida pusley, bermudagrass (*Cynodon dactylon* (L. Pers.), johnsongrass (*Sorghum halepense* (L.) Pers.), American black nightshade (*Solanum americanum* Mill.), and Virginia pepperweed. 'California Wonder' pepper, an excellent host of *M. incognita* (Taylor and Sasser, 1978), and two cover crops, velvetbean (*Mucuna deeringiana* (Bort.) Merr.) and 'Iron Clay' cowpea, known to have a high level of resistance to *M. incognita* (McSorley, 2001) were also included. In July 2003, seedlings were transplanted into plastic pots (12.5-cm-diam) containing approximately 1100 cm^3 of soil. The soil used was a nematode-free 4:1 (v:v) mixture of sand:potting soil (Greenleaf Products, Inc., Haines City, FL), providing a final mix containing 97.0% sand, 0.5% silt, and 2.5% clay, with 3.0% organic matter.

On 4 August 2003, each pot was inoculated with 1000 second-stage juveniles (J2) of *M. incognita* race 1. The nematodes used for inoculation had been maintained in a greenhouse on 'California Wonder' pepper. One week before inoculation, nematode eggs were extracted from pepper roots in 0.394% NaOCl using the method of Hussey and Barker (1973). Eggs were incubated at room temperature for seven days on modified Baermann trays (Rodriguez-Kabana and Pope, 1981) containing two pieces of tissue paper (Kimwipes, Kimberly Clark Corp., Roswell, GA) for collection of J2. Nematode inoculum was delivered into holes (2 cm deep) near the base of the seedlings.

Pots were arranged in a randomized complete block design on greenhouse benches, with each of the 10 plant species replicated four times. Plants were watered daily and fertilized weekly with 50 ml/pot of a 0.54 g/L solution of a 15-30-15 ($N:P_2O_5:K_2O$) fertilizer (Miracle-Gro, Scotts Miracle-Gro product Inc., Marysville, OH). No pesticides were applied, except for an occasional application of Safer Brand Insecticidal Soap (Safer, Inc., Bloomington, MN) for management of whiteflies.

The experiment was harvested by replication from 11-21 December 2003, by cutting plants at the soil surface, and removing, washing, and weighing the root system. Root-knot nematode galls present on each root system were rated on a 0 to 5 scale, where 0 = 0 galls, 1 = 1-2, 2 = 3-10, 3 = 11-30, 4 = 31-100, and 5 = >100 galls per root system (Taylor and Sasser, 1978). Three grams of the root system was removed from selected plants that showed no galling and stained in a solution (0.15g/L) of Phloxine B (Daykin and Hussey, 1985) to reveal egg masses. Another portion of the root system was used for extraction and incubation of eggs as described above to obtain the number of viable J2 hatched per g of fresh root weight. Total J2 present per root system was also computed. A soil subsample (100 cm^3) was removed from each pot for extraction of nematodes.

Data Analysis

Data were subjected to analysis of variance (ANOVA). For the field surveys, results of each location were analyzed separately, because host × location interaction was significant ($P \leq 0.05$) for some parameters. Analysis was done using the PROC GLM procedure of SAS (SAS Institute, Inc., Cary, NC). Nematode populations in soil or root were transformed by $\log_{10}(x + 1)$ to ensure that the data followed a normal distribution before conducting ANOVA. ANOVA was followed by Duncan's new multiple-range test to compare means among hosts and blocks at each location in the field survey, or among plant species in the greenhouse test.

RESULTS AND DISCUSSION

Weeds frequently encountered at most locations were pigweed, crabgrass, and purple nutsedge (Table 1). Weeds encountered at specific sites were hairy indigo at PSREC, lambsquarters and signalgrass at Rosie's Organic Farm, and Virginia pepperweed at PSFTL (Table 1). Root-knot nematodes (*Meloidogyne* spp.) and ring nematodes (*Mesocriconema* spp.) were encountered at all sites even if at least one member of the population was detected (Table 2).

PSFTL. Lesion nematodes (*Pratylenchus* spp.) and ring nematodes were the predominant nematodes at this site. Lesion nematode population density was higher ($P \leq 0.05$) on Virginia pepperweed than on volunteer cowpea (Table 2). Ring nematode population means were not significantly different between hosts.

Rosie's Organic Farm. The predominant nematodes at this site were root-knot, ring, and stubby-root (*Paratrichodorus* sp.). Lesion and lance nematodes (*Hoplolaimus* sp.) were less frequently encountered and were not included in the analysis. Significant differences among blocks ($P \leq 0.05$) were only observed for the root-knot nematode population, with the highest mean for the pepper block (349/100 cm^3 soil), compared with the muskmelon (84/100 cm^3) and non-crop (53/100 cm^3) blocks. Root-knot nematode population was higher ($P \leq 0.05$) on purple nutsedge and pigweed than on lambsquarters and signalgrass (Table 2). The population mean for root-knot nematode on crabgrass (3.72/100 cm^3 soil) was very low (data not shown). Ring nematodes population densities were higher ($P<0.05$) on lambsquarters, nutsedge, and signalgrass than on pigweed (Table 2). Stubby-root nematode population means were lower ($P \leq 0.05$) on purple nutsedge (mulch) than on pigweed or signalgrass (Table 2). Comparisons between nematode populations associated with purple nutsedge in unmulched row middles and under mulch showed no significant differences for root-knot and stubby-root nematodes, but more ring nematodes were observed in soil collected from row middles than under the mulch (Table 2).

PSREU. The nematodes most frequently encountered at this site were the same as those in Rosie's Organic Farm. Ring nematode was the most abundant, with highest population means on pigweed and crabgrass, and lowest on hairy indigo (Table 2).

Hammock Hollow Farm. Root-knot, ring, lance, and sting (*Belonolaimus* sp.) nematodes were frequently encountered at this site. However, only sting nematode population means were significantly ($P \leq 0.05$) different between pigweed and the millet cover crop at this site (Table 2). Ring nematodes were the most common nematodes found at this site (Table 2). Root-knot nematode population levels were moderate (36.0/100 cm^3 soil) on pigweed soil samples from one of three blocks with the counts remaining very low to zero in the other two blocks.

Other weeds not equally represented among blocks and therefore not included in the analysis were purple nutsedge, crabgrass, and Florida pusley, with low root-knot nematode population means of 1.5, 3.0, and 8.0 per 100 cm^3, respectively. Ring nematode means on these weeds were 20.0, 13.7, and 8.5 per 100 cm^3, respectively. Population means for lance nematode were 35.5, 27.7, and 7.0 per 100 cm^3 on Florida pusley, crabgrass, and nutsedge, respectively. Sting nematode population means for crabgrass and nutsedge were 2.0 per 100 cm^3.

Most weeds showed no signs of nematode attack and were growing vigorously while supporting high root-knot nematode populations. Purple nutsedge in particular had no visible root galls but root-knot nematode egg masses and females became visible after staining and teasing of the root in the vicinity of the egg masses. However, root galls were observed on pigweed and lambsquarters where root-knot nematode associations were found.

Greenhouse experiment: Pepper was heavily galled by root-knot nematodes, American black nightshade was intermediate, and the other plants showed only sparse or no galling (Table 3). However, while the nutsedges showed no visible galling, staining of their roots revealed a mean (standard deviation) of 27.5 (50.4) egg masses per 3 g of roots on yellow nutsedge and 48.2 (62.4) egg masses per 3 g on purple nutsedge. Root-knot nematodes reproduced well on pepper, which harbored higher numbers of hatched J2 per g (fresh weight) of root than any of the other plant species tested (Table 3). Among the weed species tested, American black nightshade had higher ($P \leq 0.05$)) numbers of J2 per g than five other plant species. While numbers of nematodes per g of root were low in several cases, some weeds, such as purple nutsedge, bermudagrass, and johnsongrass, had large root systems, so that total numbers of nematodes per root system were relatively high (Table 3). Four of the weed species had higher ($P<0.05$) numbers of nematodes per root system than did cowpea and Virginia pepperweed, which showed the highest levels of resistance among the plants tested (Table 3). Nematode numbers in soil around the weed species tested were sparse and not particularly informative (Table 3).

Pigweed (annual dicot), lambsquarters (annual dicot), purple nutsedge (perennial monocot), crabgrass (annual monocot), signalgrass (annual monocot), Florida pusley (annual dicot), and hairy indigo (perennial dicot) are weeds commonly encountered in north Florida cropping systems. Pigweed, lambsquarters, purple nutsedge, and crabgrass are considered to be among the worst weeds in the world, as well as the USA (Bendixen, 1988c). According to Bendixen (1988c), the factors that define this category as worst weeds may not be limited to their level of competition in cultivated fields, which limits crop productivity and yield, but might also be based on their indirect effects as hosts of nematodes in crop production. Effects from weeds could be complicated by a number of factors, such as the number of nematode species hosted, severity of damages by the nematodes, the number of crops involved, and the area occupied by those crops as well as weed distribution Bendixen (1988c). Weed populations are dynamic and the presence of certain weed types is often dependent on local weed seed banks, cropping and land history, and farming practices at any particular site.

The primary purpose of this preliminary investigation was to draw attention to the importance of weeds that can serve as hosts of nematodes and thus have an indirect effect on crop production. In this investigation, root-knot nematode was the nematode of greatest economic importance most frequently encountered. This nematode is considered the worst nematode worldwide and has an extensive host range, attacking many vegetable crops (Shurtleff and Averre, 2000).

In this survey, nematode population levels differed from one site to another, which could be explained in terms of varying local soil and weather conditions, weed types, cropping and land history, and farming practices. Of the two organic farms, root-knot nematode populations were higher at Rosie's Organic Farm than at Hammock Hollow Farm. The Hammock Hollow site has a history of cover crop use and crop rotation that could have influenced nematode populations directly or indirectly by suppressing weed host species.

Root-knot nematodes were frequently associated with pigweed, purple nutsedge, and lambsquarters, indicating that these weeds were likely hosts for this nematode. Moderate to high levels of root-knot nematode populations were found associated with these weeds at Rosie's Organic Farm. At this site, 1ow to moderate levels of root-knot nematodes were associated with signalgrass. According to Bendixen (1988c), purple nutsedge is by far the most serious weed in the world based on data supporting certain major weeds as nematode hosts. The list (Bendixen, 1988c) includes crabgrass, lambsquarters, and pigweed among the 10 most significant weed hosts of nematodes. Nutsedge, crabgrass, lambsquarters, and pigweed have been reported as major weed hosts of root-knot nematodes (Bendixen, 1979; Bendixen, 1988abc; Schroeder et al., 1993; Thomas et al., 1997). Although crabgrass has been reported as a host of root-knot nematodes, low nematode population means were reported here. Noling and Gilreath (2002a) reported that several species of crabgrass served as hosts of root-knot nematode but were relatively poor hosts. The greenhouse results reported here confirm the importance of yellow and purple nutsedge as hosts of *M. incognita*, but illustrate that American black nightshade and bermudagrass root systems can support similar high levels of this important nematode. In addition, common weeds like Florida pusley and johnsongrass may also support low to moderate levels of *M. incognita*. However, susceptibility of weed might vary according to species and races of root-knot nematode inoculated. For example, a pot test in North Carolina revealed that yellow nutsedge is a poor host to *M. incognita* race 3 and *M. arenari*a (Tedford and Fortnum, 1988).

Sting and stubby-root nematodes, although not as important as root-knot nematodes worldwide, are nematodes of economic importance in Florida. These nematodes occur in sandy soils (>85% sand) and sandy to sandy loam soils, respectively (Shurtleff and Averre, 2000). Both attack many vegetable crops and, like root-knot, have an extensive host range. Stubby-root nematode population means were low (<10 nematodes/100 cm^3 soil) on weeds surveyed in the present study. Previous reports indicate that crabgrass, nutsedge, pigweed, and Florida pusley are suitable hosts for stubby-root nematodes (Bendixen, 1979). Sting nematode was only encountered at the Hammock Hollow site and was present at very low numbers (<5 nematodes/100 cm^3 soil) on nutsedge, crabgrass, pigweed, and millet. Of the three weeds, only nutsedge and crabgrass have been reported as suitable weed hosts of sting nematode (Bendixen, 1988c).

Lesion and lance nematodes are considered of economic importance on some crops in Florida such as sweet corn and turfgrass. Relatively low numbers of lance nematode were associated with purple nutsedge at Rosie's Organic Farm and moderate levels on Florida pusley at Hammock Hollow Farm. Purple nutsedge and Florida pusley have previously been reported as hosts of lance nematode (Bendixen, 1979; Bendixen, 1988c). The association of lesion nematode with Virginia pepperweed in this study is supported by a study by Hogger and Bird (1976).

Ring nematodes usually are not considered of economic importance unless present in very high numbers. Ring nematodes are very common on numerous hosts and usually associated with grasses and trees. Ring nematode populations in this survey ranged from low to moderate, depending on the weed species.

Some weed hosts showed no effects of nematode damage, such as purple nutsedge infected with root-knot nematode. Casual inspection of roots may not reveal galls, and could lead to the erroneous conclusion that the roots were free of nematodes.

Current results suggest that economically important plant-parasitic nematodes cannot be effectively managed unless weeds are managed. These are important implications for cover crop use, in that, a cover crop may be a non-host for plant-parasitic nematodes but infestations of weed hosts may cause a build up of nematodes capable of attacking subsequent crops. Weeds that are allowed to grow and increase in numbers, particularly in areas between rows, covered with polyethylene mulch, can serve to increase nematode population densities. This is of considerable importance in organic farming systems where synthetic herbicides are prohibited and nonsynthetic herbicides are limited, and their use is often restricted.

Further research on weeds as nematode reservoirs is critical to emphasize and understand the role of weeds and the importance of weed control in crop production. Research could be conducted to monitor nematode populations on major weeds in various cropping systems over time to better understand weed-nematode interactions. The information generated will be critical to organic growers and even to conventional growers in the advent of methyl bromide withdrawal. Bendixen (1988c) even suggested the probability that weeds provide a very favorable environment for race or isolate development in nematode species. Race development in nematodes reduces the effectiveness of resistance bred into crops to withstand specific infection. Consequently, the cost of breeding for crop resistance and the costs of sustained yield losses are increased (Bendixen, 1988c). It is still unclear whether the nematodes in this study have any effect on their weed hosts, since most weeds in this study were growing vigorously in spite of the infestation.

CONCLUSIONS

In the field, plant-parasitic nematodes, including root-knot nematodes, were found associated with many common weed species in northern Florida. A greenhouse test confirmed that American black nightshade, yellow nutsedge, purple nutsedge, and bermudagrass supported relatively high levels of *M. incognita*, whereas Florida pusley and johnsongrass supported intermediate to low levels, and Virginia pepperweed was nearly immune. It is clear that weed management is critical if plant-parasitic nematodes are to be successfully managed in cropping systems in northern Florida.

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Table 1. Predominant weed flora in natural fallows and cropping systems at four sites in Florida.

Weeds	PSFTL[†]	Rosie's Organic Farm	PSREC[‡]	Hammock Hollow Farm
Amaranthaceae				
Amaranthus spp.	---	+	+	+
Cruciferae				
Lepidium virginicum	+	---	---	---
Chenopodiaceae				
Chenopodium sp.	---	+	---	---
Cyperaceae				
Cyperus rotundus	+	+	+	+
Graminae				
Brachiaria sp.	---	+	---	+
Digitaria spp.	---	+	+	+
Sorghum halepense	+	---	---	---
Leguminosae				
Indigofera hirsuta	---	---	+	---
Vigna unguiculata	+	---	---	---
Rubiaceae				
Richardia scabra	+	---	---	+

[†] Plant Science Field Teaching Laboratory.

[‡] Plant Science Research and Education Center.

Table 2. Nematode population densities on weeds and cover crops at four sites in Florida.

	Nematodes per 100 cm^3 soil[†]					
Plant host	Root-knot	Ring	Stubby-root	Lesion	Lance	Sting
PSTFL[†]						
Virginia pepperweed	---	6.5 a[‡]	---	29.0 a	---	---
Volunteer cowpea	---	6.5 a	---	8.2 b	---	---
Rosie's Organic Farm						
Pigweed	208.3 a	34.8 c	7.17 a	---	---	---
Purple nutsedge RM[§]	226.3 a	95.0 a	1.67 ab	---	---	---
Purple nutsedge (mulch)	237.5 a	56.2 b	1.17 b	---	---	---
Lambsquarters	97.3 bc	110.8 a	6.33 ab	---	---	---
Signalgrass	40.0 c	78.7 a	4.67 a	---	---	---
PSREU[¶]						
Pigweed	0.3 a	73.7 a	0.17 b	---	---	---
Purple nutsedge	1.2 a	11.5 b	1.50 ab	---	---	---
Hairy indigo	0.2 a	3.2 c	1.33 ab	---	---	---
Crabgrass	0.5 a	19.7 ab	5.17 a	---	---	---
Hammock Hollow Farm						
Pigweed	12.0 a	50.7 a	---	---	4.8 a	1.5 a
Millet cover crop	0.8 a	18.7 a	---	---	4.7 a	0.2 b

[†] Plant Science Field Teaching Laboratory.

[‡] Data are untransformed arithmetic means of three replications. At each location, means in columns with the same letters are not significantly different (*P≤0.05*), according to Duncan's new multiple-range test performed on log-transformed data.

[§] RM = unmulched row middles.

[¶] Plant Science Research and Education Center.

Table 3. Root-knot nematode galling and population levels in roots and soil in greenhouse test.

Plant tested	Root gall rating[†]	Nematodes per g fresh root wt	Nematodes per root system	Nematodes per 100 cm^3 soil
Yellow nutsedge	0[‡] c	25.4 bc	1,082.4 bcd	1.2 b
Purple nutsedge	0 c	2.3 c	260.2 bc	0.0 b
Florida pusley	0 c	4.1 bc	78.2 cde	1.8 b
Bermudagrass	1.0 c	5.3 bc	565.9 b	0.0 b
Johnsongrass	0 c	0.3 c	90.6 cde	0.0 b
Velvetbean	0 c	0.2 c	4.7 de	0.0 b
American black nightshade	3.2 b	42.6 b	532.6 b	2.2 b
I C Cowpea	0.2 c	0.0 c	0.0 e	0.5 b
Virginia pepperweed	0 c	0.1 c	0.2 e	0.0 b
Pepper	4.5 a	323.7 a	11,576.4 a	86.8 a

[†] Root galling rated on 0 to 5 scale, where 0 = 0 galls, 1 =1-2, 2 = 3-10, 3 = 11-30, 4 = 31-100, 5 = >100 galls per root system (Taylor and Sasser, 1978).

[‡] Data are untransformed arithmetic means of 4 replications. Means in columns followed by the same letter do not differ (*P* ≤ 0.05) according to Duncan's new multiple-range test performed on log-transformed data.

BIOLOGY OF CUTLEAF EVENINGPRIMROSE

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ABSTRACT

Experiments were conducted at the Upper Coastal Plain Research Station (Location 1) and the Fountain Research Farm (Location 2), Rocky Mount, NC. A completely randomized design was employed with fifty cutleaf eveningprimrose seedlings selected at the 4-leaf growth stage and monitored from October to early April prior to planting. Dependent variables included leaf number, whole-plant diameter, leaf area, and above-ground dry biomass per plant and were determined bi-monthly. Statistical analysis was performed on data collected from the four harvested plants (4 reps) at each timing. Data were subjected to ANOVA with sums of squares partitioned to evaluate linear and nonlinear effects of time. Location was considered random and time effects were tested by the appropriate interaction with the random variable. Regression analysis was used to describe the growth trends over time. Cutleaf eveningprimrose leaf number increased exponentially over time. Lack of location effect ($P > 0.05$) indicates that cutleaf eveningprimrose leaf number is not environmentally dependent. Cutleaf eveningprimrose diameter increased exponentially over time, but variation existed between locations. Location 1 is adjacent to a swine farm and had a higher fertility rate. This location is sprayed by lagoon effluent and thus future work will investigate cutleaf eveningprimrose growth under different soil nitrogen fertility regimes. Cutleaf eveningprimrose leaf area increased exponentially over time. Although leaf number per plant was not environment dependent, the rate of leaf expansion was much greater in the location of higher fertility and may explain trends in whole-plant diameter. Cutleaf eveningprimrose above ground dry biomass also exhibited an exponential trend similar to leaf area. Trends indicate that most of the above-ground biomass can be attributed to leaf material. This is not uncommon for rosette-forming plants, like cutleaf eveningprimose, in the vegetative stage. Cutleaf eveningprimrose growth exhibited an exponential trend from October to early April. The normal sigmoidal growth trend likely did not occur because field preparation halted growth during the linear phase and prevented an asymptotic response. The growth rate is slow between October and mid-February and the rapid linear phase of growth occur after this period. Thus reduced-tillage fields planted late are more likely to be problematic with large cutleaf eveningprimrose plants. Leaf area, whole-plant diameter, and aboveground dry biomass did exhibit environmental dependency, but leaf number was not affected by location.

INTRODUCTION

Historically, cotton has been grown in a conventional-tillage environment using primary and secondary tillage. Prior to the registration of postemergence (POST) herbicides with over-the-top selectivity in cotton, producers were required to use intensive soil-applied herbicide treatments and high use rates of relatively non-selective herbicides and specialized equipment for postemergence-directed (PDS) applications (Buchanan, 1992; McWhorter and Bryson, 1992; Wilcut et al., 1995, 1997). These operations require considerable fuel, labor, and time. Increasing economic inputs, low commodity prices, and concerns for declining soil organic matter, subsoil compaction, and water stress damage have led to interest in alternative tillage options such as strip-tillage production systems (Troeh et al., 1991; Wauchope et al., 1985). Strip-tillage cotton acreage is increasing across

North Carolina and the Southeastern Coastal Plain. There are several advantages for utilizing strip-tillage production systems. These advantages include: (1) water conservation and reduction of sand blasting on sandy soils, (2) elimination of seedbed preparation reduces tillage operations and the number of trips made across the field, and (3) soil tilth and water-holding capacity are improved over time (Bradley, 1995). Strip-tillage production systems work well where soils are prone to develop a hardpan or plow layer that impedes root growth (Sholar et al., 1995). With this shift away from fall and winter tillage it has allowed the establishment of cool-season weeds, such as cutleaf eveningprimrose (*Oenothera laciniata* Hill). Successful elimination of vegetation prior to planting cotton in reduced-tillage production is critical for adequate stand establishments, eliminating early-season weed interference and maintaining yields. Poor weed control has been cited as the major limitation to adoption of cotton in conservation-tillage cotton production (McWhorter and Jordan, 1985). Weed management in cotton often requires both soil-applied and postemergence-applied herbicides for maximum effectiveness (Buchanan, 1992; Wilcut et al., 1995). Soil-applied herbicides do not provide season-long weed control in cotton, therefore proper selection of POST herbicides and other inputs are crucial for maximum weed control, cotton yield, and economic returns (Crowley et al., 1979; Culpepper and York, 1997; Wilcut et al., 1995, 1997). In the past 5 yrs, advances in biotechnology and new postemergence over-the-top (POT) technology have broadened cotton growers' options for weed management strategies (Culpepper and York, 1997, 1999; Wilcut et al., 1996). Bromoxynil, glyphosate, and pyrithiobac control a broad spectrum of weeds POST (Askew and Wilcut, 1999; Culpepper and York, 1997, 1998, 1999; Dotray et al., 1996; Jordan et al., 1993a; Scott et al., 2001). Bromoxynil and glyphosate can only be used in their respective transgenic herbicide-resistant cultivars (York and Culpepper, 2000). However, with this technology, farmers have become more reliant on fewer herbicide applications and with delaying burndown applications. This has led to the presence of cutleaf eveningprimrose at cotton planting. Traditional burndown chemistry is being replaced with glyphosate applications that are not effective on large cutleaf eveningprimrose plants.

Cutleaf eveningprimrose is an herbaceous winter annual or biennial native to Eastern North America (Uva et al., 1997). Cutleaf eveningprimrose can be found throughout the southeastern US. It is found in cultivated fields, sandy waste areas, and roadsides throughout the Southeast. Cutleaf eveningprimrose is a member of the Onagraceae family. It is a basally prostrate or weakly ascending plant with stems branching at the base. It has a fibrous tap root system. In its juvenile stages its stems are simple or many branched from the base up to 8 dm long and are hairy (Uva et al., 1997). The leaves are alternating oblong to lanceolate (3-8 cm long), coarsely toothed to irregularly lobed, dull green with short hairs present. The hypocotyl is short, smooth and not evident above the soil the second leaf develops. The cotyledons are kidney-shaped with flat petioles on the upper surface. Mature plants have flowers single in the leaf axils, lacking stalks, with large, yellow petals fused basally into a long narrow tube. The fruit is a four-lobed capsule (2-4 cm long) that is cylindrical and hairy becoming smooth with age (Uva et al., 1997). Cutleaf eveningprimrose seed are thick ellipsoid, sharply angular seed varying in shape (1.2-1.4 mm long and 0.8 mm broad). The seed are pale-brown and are strongly pitted (Uva et al., 1997).

Reduction in fall and winter tillage allows for the establishment of cool season species, including cutleaf eveningprimrose (Fairbanks et al., 1995). In March and April, the presence of very diverse cool season annuals makes it hard to identify some of these species. With the use of natural cover (i.e., winter weeds), the need for an early burndown treatment will depend upon the weed species present along with the size of the weeds (York et al., 1999). Early burndown is advantageous with ryegrass (*Lolium mutliflorum* Lam.), cutleaf eveningprimrose, and wild mustard (*Brassica kaber* (D. C.) L. C. Wheeler), wild radish (*Raphanus raphanistrum* L.), or curly dock (*Rumex crispus* L.) are present (York et al., 1999). Legume cover crops that reseed contribute nitrogen, avoid the cost and problems of annual seeding and suppress the growth of troublesome winter weeds such as cutleaf eveningprimrose or horseweed (*Conyza canadensis* (L.) Cronq.) (Dabney et al., 1993). However, they will not produce adequate suppression of summer weeds as rye since they are maturing and dying back at the same time that the summer weeds begin to grow (Dabney et al., 1993). Since cotton is a poor early-season competitor, it is important that weeds be controlled during early growth (McClelland et al., 1993). Preplant burndown practices are also beneficial for conservation of moisture, nutrients and time in preparation of difficult-to-manage seedbeds (King, 1994).

If control efforts, such as 2, 4-D [2, 4-(dichlorophenoxy) acid] are delayed until April or May, then cutleaf eveningprimrose can be difficult to control (Reynolds et al., 2000). Cutleaf eveningprimrose is becoming a hard-to-kill winter annual and is one of the most prevalent spring weeds on the Coastal Plain of North Carolina. Of the commonly found broadleaf weeds listed, cutleaf eveningprimrose and horseweed are the most troublesome. This is because these weeds are usually spread across entire fields and can be difficult to control. Silt or sandy loam fields generally have more horseweed and, especially, more cutleaf eveningprimrose (Guy, Jr., 1995). The growth characteristics and development of winter weeds determine the impact they may have on cotton growth. Some winter annuals such as henbit (*Lamium amplexicaule* L.), common chickweed (*Stellaria media* (L.) Vill.) and annual bluegrass (*Poa annua* L.) do not persist throughout the entire cotton-growing season whereas weeds such as horseweed or cutleaf eveningprimrose will interfere with cotton the entire growing season (Guy, Jr., 1995). To date there is very limited research on this weed and no research data concerning cutleaf eveningprimrose growth, development, or the environmental affects that promote this species. Since cultural and chemical control practices targeted at weed management depend on knowledge of the basic growth characteristics and life cycle of weeds, we initiated this study. The purpose of this investigation is to study the growth and development of cutleaf eveningprimrose, a recent problem weed in early season strip-till cotton production in North Carolina. Based on these experiments, we hope to first learn of the optimal condition in which cutleaf eveningprimrose thrive in and draw a correlation to early-season problems reported by local farmers in controlling this species. Studies of germination and seedling establishment requirements yield basic ecological information for soil emergence (Bhowmik, 1997). Such information can be used to characterize the competitiveness and the potential infestation range of the weed as well as enhance management practices, allowing biological, chemical, or mechanical control options to be properly timed (Bhowmik, 1997; Dyer, 1995; Potter et al., 1984; Wilson, 1988). Therefore, research was initiated to gain an understanding of the germination requirements of this problematic early-season weed in cotton.

The objectives of this research will be evaluated in laboratory and field studies. For the laboratory work, we hope to determine the optimal germination factors for cutleaf eveningprimrose including temperature (constant and alternating regimes) and depth of emergence. The objectives of the field studies will be to determine the growth and development of cutleaf eveningprimrose throughout the winter and spring until cotton planting. Factors to be evaluated will be plant diameter, leaf area and number and plant above ground dry biomass.

METHODS AND MATERIALS

Cutleaf eveningprimrose seed was harvested from fallow fields near Rocky Mount, NC in mid-April 1999 and 2000. The seed were stored in refrigerator. The seed were sieved to remove any extraneous plant or floral material. The sieved seed were divided in an air column separator[1] and separated into light and heavy fractions. The heavy fraction, the majority of which were fully developed seed, was used in germination and emergence experiments. Seed tested for viability using

1% tetrazoleum chloride solution prior to each trial (Peters, 2000). Cutleaf eveningprimrose seed tested % viable by tetrazoleum chloride tests before each study was conducted (data not shown).

A randomized complete block design was used for experiments in seed germination chambers. Experiments performed on the gradient table precluded randomization as the zones of temperature were fixed in position (Larson, 1971). There were six flasks per temperature zone on the gradient table and each flask represented one replication. Studies in seed germination chambers[2] had four replications of treatments, each of which was arranged on a different shelf within the respective seed germination chamber.

Preliminary experiments indicated cutleaf eveningprimrose germinated dependent of light in experiments in growth chambers. Therefore, light was provided for 8 h to coincide with the length of the high temperature component of the temperature regime for all studies conducted in growth chambers. Observations were made during the 8 h light period.

Growth and Development.
Field studies will be conducted near Upper Coastal Plain Research Station (Location 1) and the Fountain Research Farm (Location 2), Rocky Mount, NC in the fall of 2002 and 2003. Approximately 50 germinating cutleaf eveningprimrose plants were flagged and monitor throughout the fall and up to planting. Plant size, growth in diameter and leaf number will be taken bi-monthly throughout the season. In addition to these measurements, four plants from each site will be harvested during each visit. The roots will be removed from these plants and fresh weight determined. The plant's leaf surface area will be measured using a leaf surface area meter and the plants will then be placed into a dryer for 3-5 d. After drying, the plants will be removed and dry weight measurements determined. This data will be replicated at two locations in Rocky Mount, NC over two seasons.

Effect of Temperature.
The effect of constant temperature will be evaluated by evenly spacing 20 cutleaf eveningprimrose seed in 25 ml Erlenmeyer flasks containing three pieces of filter paper[4] and 8 ml of deionized water. Experiments performed on the gradient table precluded randomization as the zones of temperature are fixed in position (Larsen 1965). The flasks will be arranged on a thermogradient table (Larsen 1965) in six lanes corresponding to constant temperatures of 15, 20, 25, 30, 35, and 40 C, with six replicate flasks per temperature lane. Flasks will be sealed using Parafilm to retain moisture. Light will provided by fluorescent overhead bulbs set for an 8 h light 16 h dark regime with a light intensity of 30.2 μmol m^{-2} s^{-1}. Daily germination counts will be made for the first 7 d, and then every 3 d until no seed germination was observed for two observations. Each seedling will then be removed when a visible radicle could be discerned (Baskin and Baskin, 1998). The study will be conducted twice and the data combined for analysis.

A second study will be conducted in growth chambers to determine cutleaf eveningprimrose response to diurnal temperature. A randomized complete block design with four replications of treatments will be used and the study was conducted twice. Each replication will be arranged on a different shelf within the respective germination chamber. Blocks will be considered study replication over time. Twenty-five cutleaf eveningprimrose seed will be evenly spaced in 110 mm diameter by 20 mm Petri dishes containing 2 pieces of germination paper[2] and 10 ml of deionized water. Four temperature regimes will be selected to reflect typical seasonal variation in North Carolina. The regimes 10/25, 15/30, 20/30, and 20/35 C, correspond to mean daily low and high temperatures for the months of May, June, July, and August, respectively, in Rocky Mount, NC

(Owenby and Ezell, 1992). The high temperature component of the regime will be maintained for 8 h. Light will be provided by fluorescent overhead bulbs set for a 8 h light 16 h dark regime with a light intensity of 34.9 µmol m^{-2} s^{-1}. Daily germination counts will be made for 7 d, and then every 3 d until no seed germination is observed for 7 continuous days. Each seedling will then be removed upon germination as previously mentioned. The study will be conducted twice and the data combined for analysis.

Depth of Emergence.

A depth of emergence study will be conducted to examine the effect of burial depth on cutleaf eveningprimrose seed emergence. The study design will be a randomized complete block with treatments replicated four times in a glasshouse at an average daily temperature of 33 ± 5 C and a nightly temperature of 23 ± 5 C. Natural light supplemented with fluorescent lamps at a light intensity of 300 ± 20 µE m^{-2} s^{-1} will be used to extend the day length to 14 h in the glasshouse study and to simulate field conditions in June. Containers will be filled to a depth of 10 cm with a Norfolk loamy sand soil (fine-loamy, siliceous, thermic, Typic Paleudults). Containers will be 15 cm in diameter by 18 cm tall. Twenty cutleaf eveningprimrose seed will then be placed on the soil surface or covered to depths of 0.5, 1, 2, 4, 6, or 10 cm with the same soil. Pots will be sub-irrigated prior to planting to field capacity, and then surface irrigated daily to field capacity. Emergence counts will be recorded daily for the first 7 d, and then every 3 d until no seed germination is observed for 7 continuous days. Plants will be considered emerged when a cotyledon can be visibly discerned. The study will be conducted three times and the data combined for analysis.

Statistical Analysis.

Data variance was visually inspected by plotting residuals to confirm homogeneity of variance prior to statistical analysis. Both non-transformed and arcsine-transformed data were examined, and transformation did not improve homogeneity. Analysis of variance (ANOVA) was therefore performed on non-transformed percent germination. Trial repetition and linear, quadratic, and higher order polynomial effects of percent germination over time were tested by partitioning sums of squares (Draper and Smith, 1981). Regression analysis was performed when indicated by ANOVA. Nonlinear models were used if ANOVA indicated that higher order polynomial effects of percent germination were more significant than linear or quadratic estimates. Estimation used the Gauss-Newton algorithm, a nonlinear least squares technique[6].

Germination resulting from constant temperature treatments was described by a parabolic model of the form:

$$y = \beta_0 + \beta_1\text{temp} + \beta_2\text{temp}^2 \qquad [1]$$

where β_0, β_1, and β_2 are the intercept, first and second order regression coefficients, respectively, and y is the cumulative germination at temperature *temp*. A parabolic model was used to describe the germination of cutleaf eveningprimrose as the constant temperature used in the experiment allowed direct correlation of germination response.

ANOVA indicated higher order polynomial effects for germination resulting from alternating temperature treatments, solution pH treatments, and water potential treatments. Thus, the germination response for each treatment was modeled using the logistic function:

$$y = M\,[1 + \exp(-K(t - L))]^{-1} \qquad [2]$$

where y is the cumulative percentage germination at time t, M is the asymptote or theoretical maximum for y, L is the time scale constant or lag to onset of germination, and K is the rate of increase (Roché et al., 1997). Estimation used the Gauss-Newton algorithm, a nonlinear least squares technique[6]. When a non-linear equation was fit to the data, an approximate R^2 value was obtained by subtracting the ratio of the residual sum of squares to the corrected total sum of squares from one (Askew and Wilcut, 2001; Draper and Smith, 1981).

Depth of emergence data was subjected to an ANOVA using the general linear models procedure SAS[6]. No cutleaf eveningprimrose plants emerged from 10 cm, and consequently these data were not included in the analysis. Sums of squares were partitioned to evaluate planting depth and trial repetition. Both study replication and repetition were considered random variables and main effects and interactions were tested by the appropriate mean square associated with the random variable (McIntosh, 1983).

RESULTS AND DISCUSSION

Growth and Development.

All growth and development data were subjected to ANOVA with sums of squares partitioned to evaluate linear and nonlinear effects of time. Location was considered random and time effects were tested by the appropriate interaction with the random variable (McIntosh 1983). Regression analysis was used to describe the growth trends over time. Cutleaf eveningprimrose leaf number increased exponentially over time (Figure 6). Lack of location effect (P>0.05) indicates that cutleaf eveningprimrose leaf number is not environmentally dependent. Cutleaf eveningprimrose diameter increased exponentially over time, but variation existed between locations (Figure 7). Location 1 is adjacent to a swine farm and had a higher fertility rate. This location is sprayed by lagoon effluent and thus future work will investigate growth under N_2 fertility regimes. Cutleaf eveningprimrose leaf area increased exponentially over time (Figure 8). Although leaf number per plant was not environment dependent (Figure 6), the rate of leaf expansion was much greater in the location of higher fertility (Figure 8) and may explain trends in whole-plant diameter (Figure 7). Cutleaf eveningprimrose above ground dry biomass also exhibited an exponential trend similar to leaf area (Figure 9). Trends indicate that most of the above ground biomass can be attributed to leaf material. This is not uncommon for rosette-forming plants, like cutleaf eveningprimrose, in the vegetative stage. Cutleaf eveningprimrose growth exhibited an exponential trend from October to early April. The normal sigmoidal growth trend likely did not occur because field preparation halted growth during the linear phase and prevented an asymptotic response. The growth rate is slow between October and mid-February and the rapid linear phase of growth occurs after this period. Thus reduced tillage fields planted late are more likely to more problematic with large cutleaf eveningprimrose plants. Leaf area, whole-plant diameter, and aboveground dry biomass did exhibit environmental dependency, but leaf number was not affected by location effects. Even though one location was a swine waste management area and had a higher fertility, trends in leaf number per plant were similar for both experiments.

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Figure 1. Influence of six constant temperature regimes on cutleaf eveningprimrose germination for 1999 seed lot.

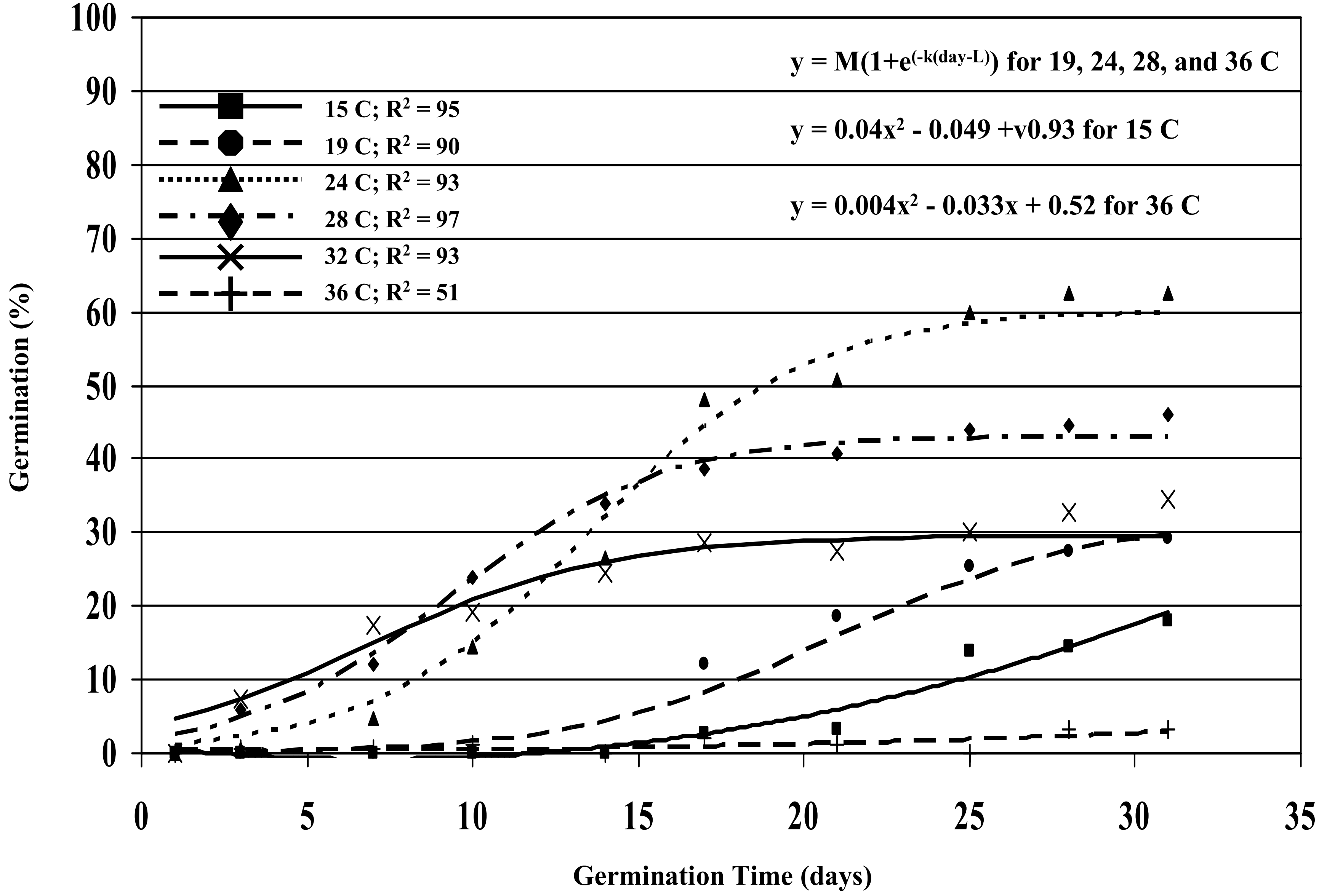


Figure 2. Influence of six constant temperature regimes on cutleaf eveningprimrose germination for 2000 seed lot.

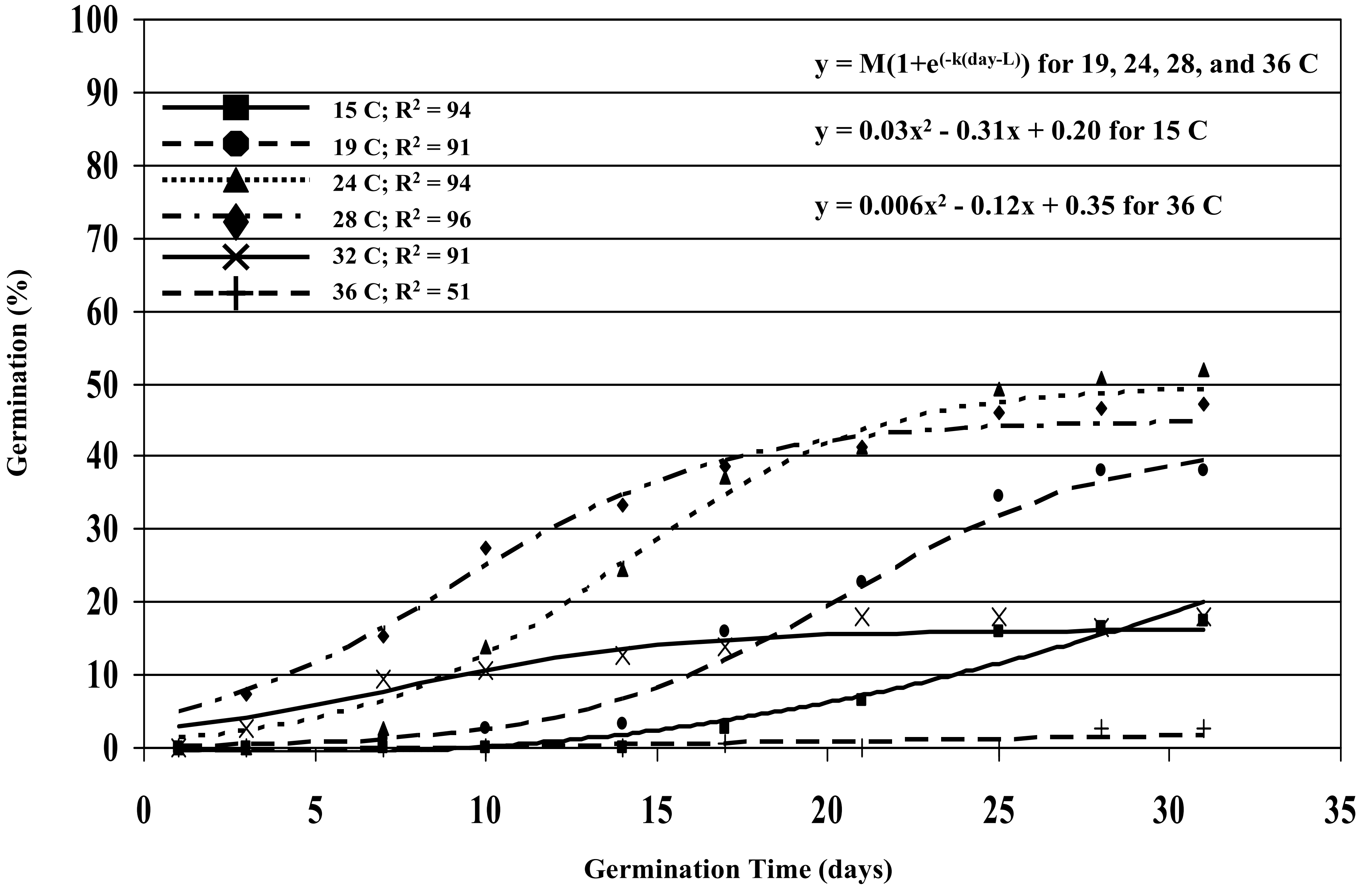


Figure 3. Influence of six temperature regimes on cutleaf eveningprimrose germination for 1999 seed lot.

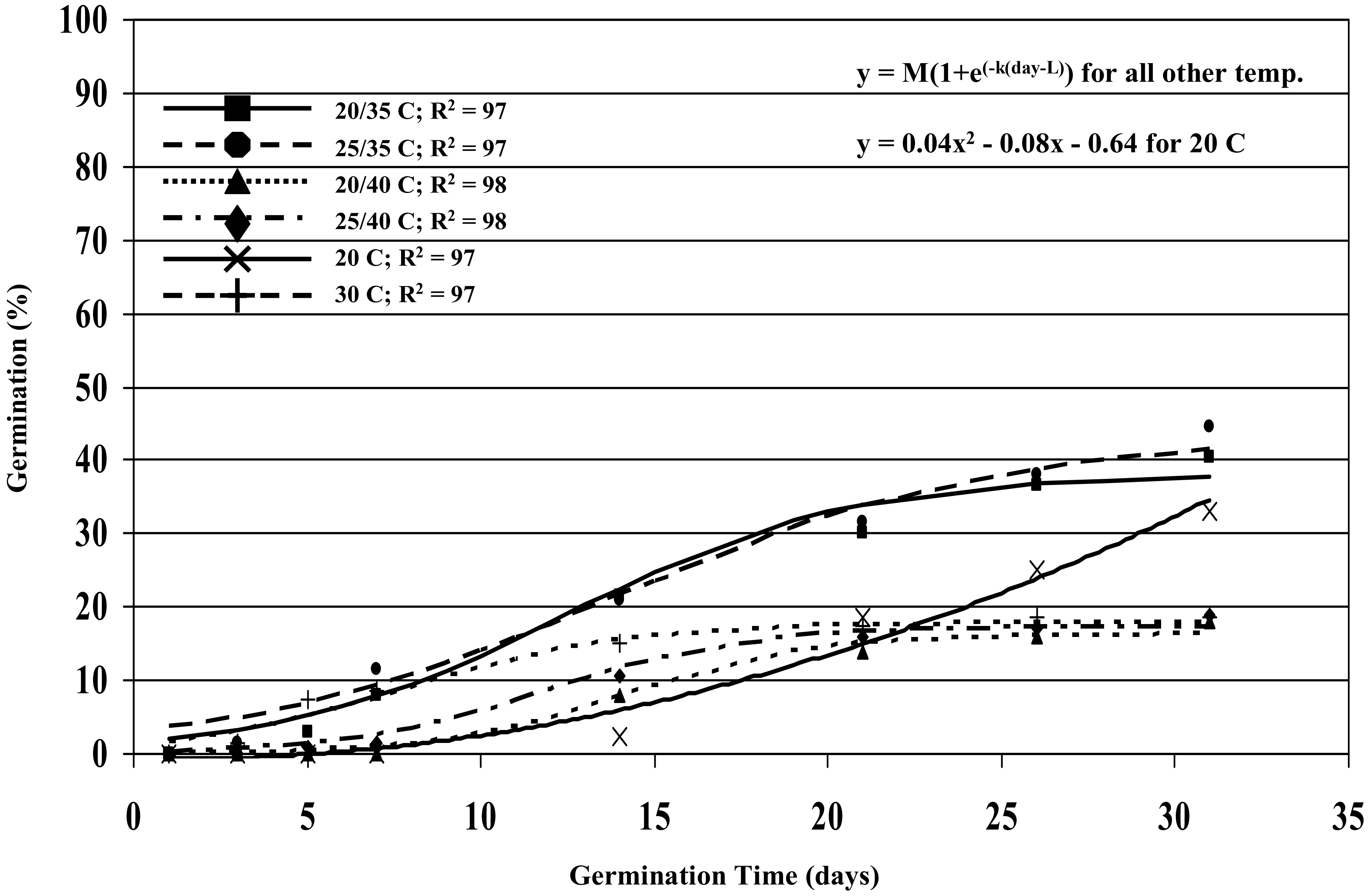


Figure 4. Influence of six temperature regimes on cutleaf eveningprimrose germination for 2000 seed lot.

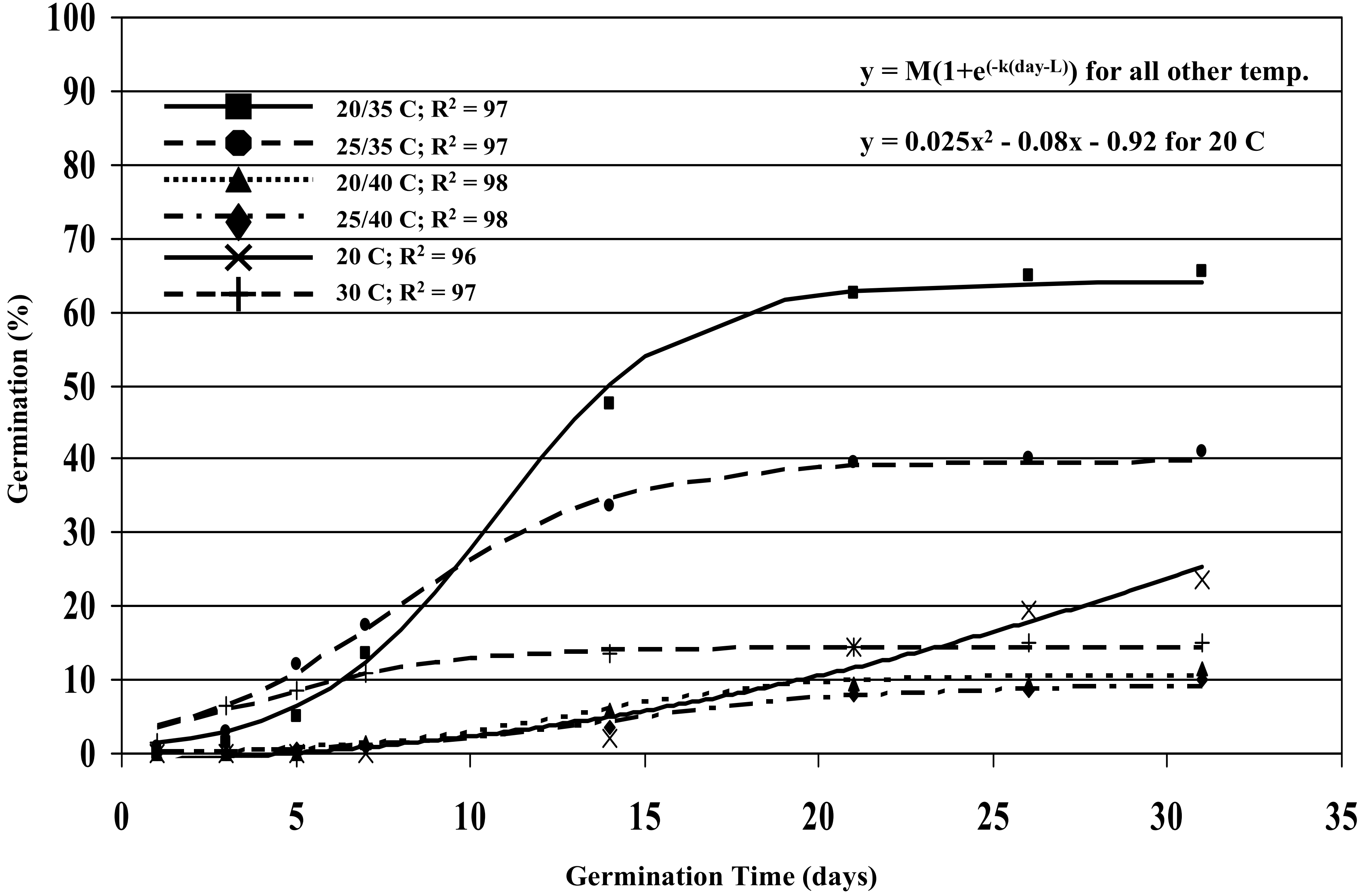


Figure 5. Four-Year Mean Maximum and Minimum Temperatures for North Carolina.

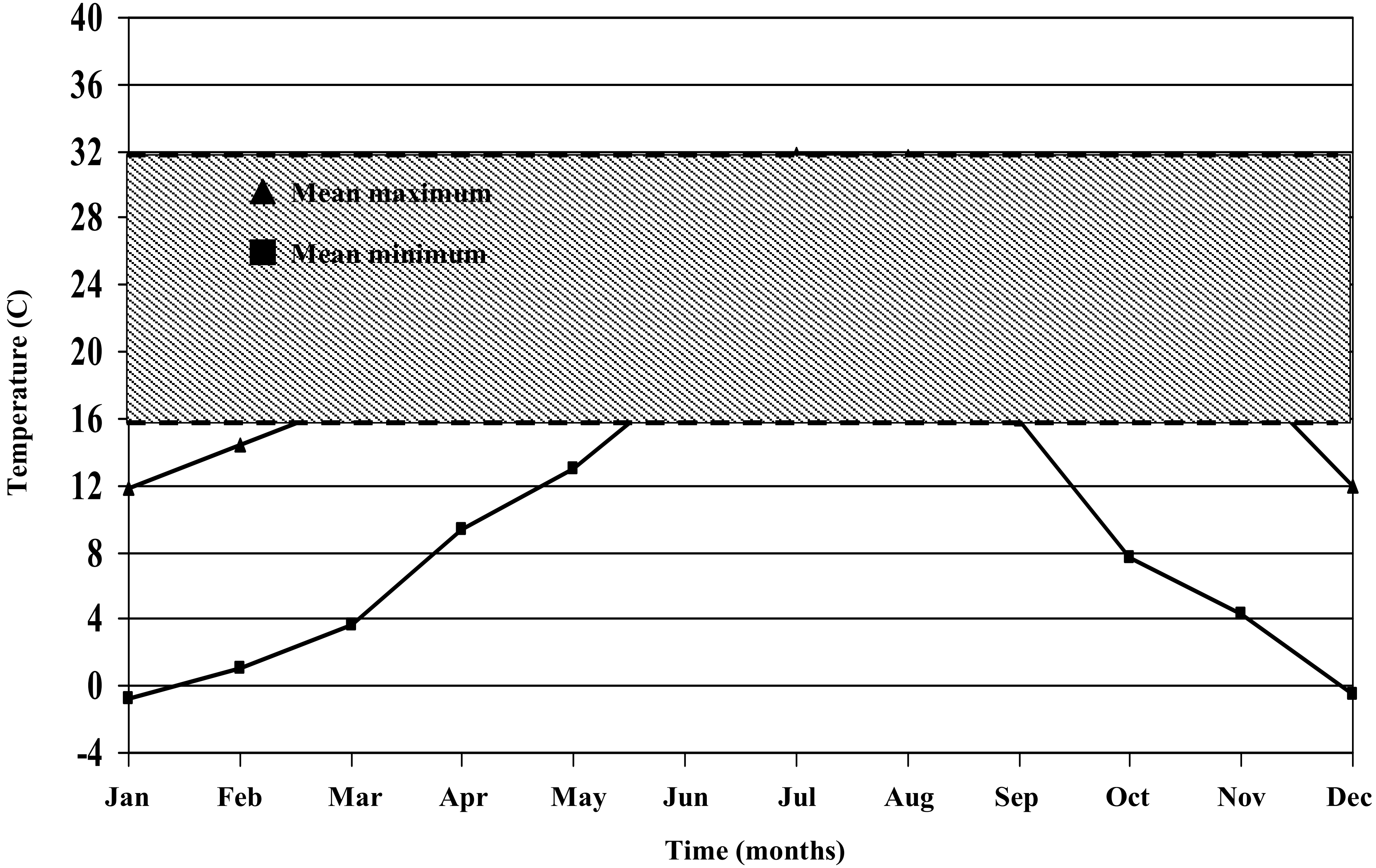


Figure 6. Average exponential increase in *O. laciniata* leaf number over time at two locations between October 2001 and April 2002.

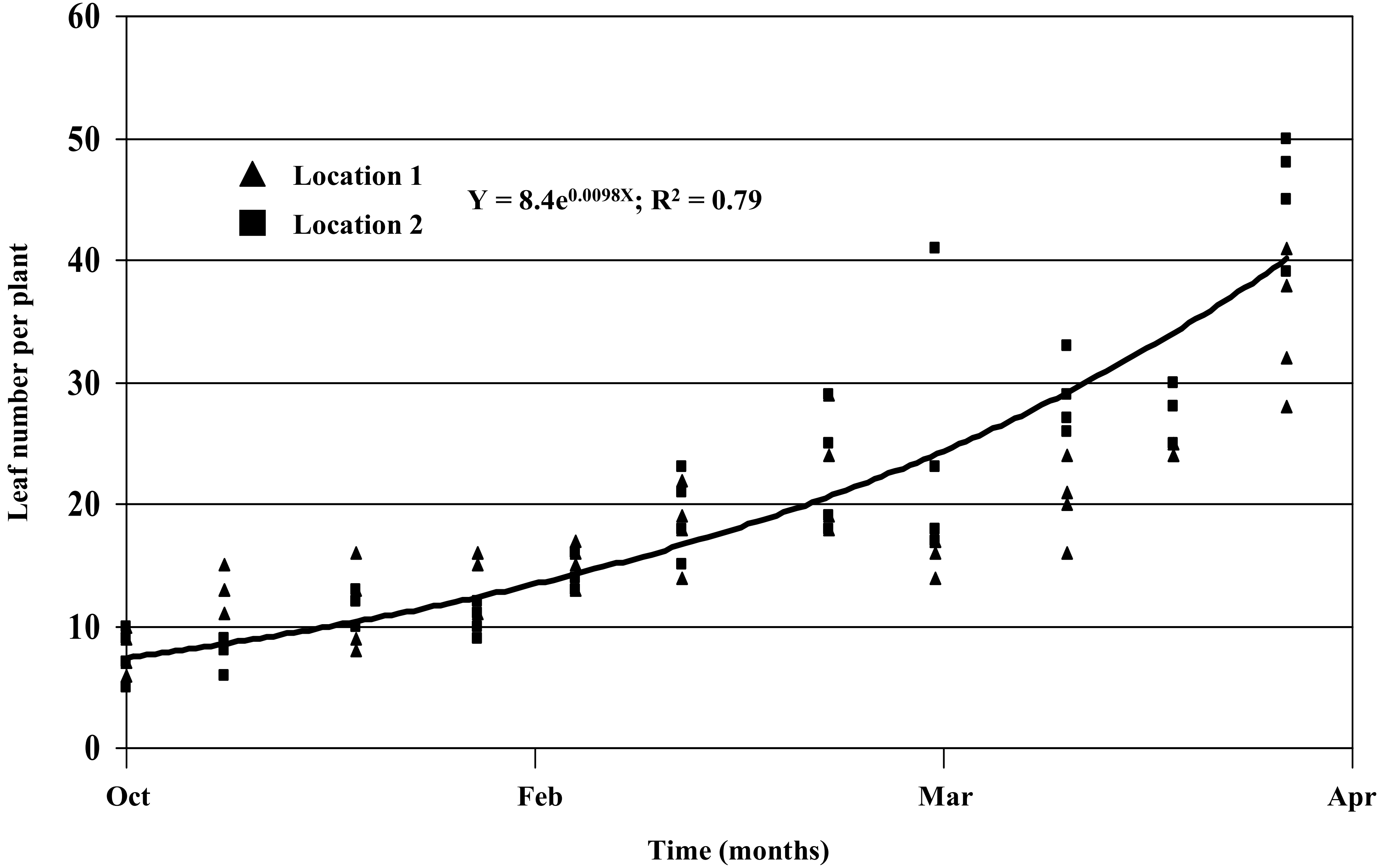


Figure 7. Exponential increase in *O. laciniata* diameter over time between October 2001 and April 2002.

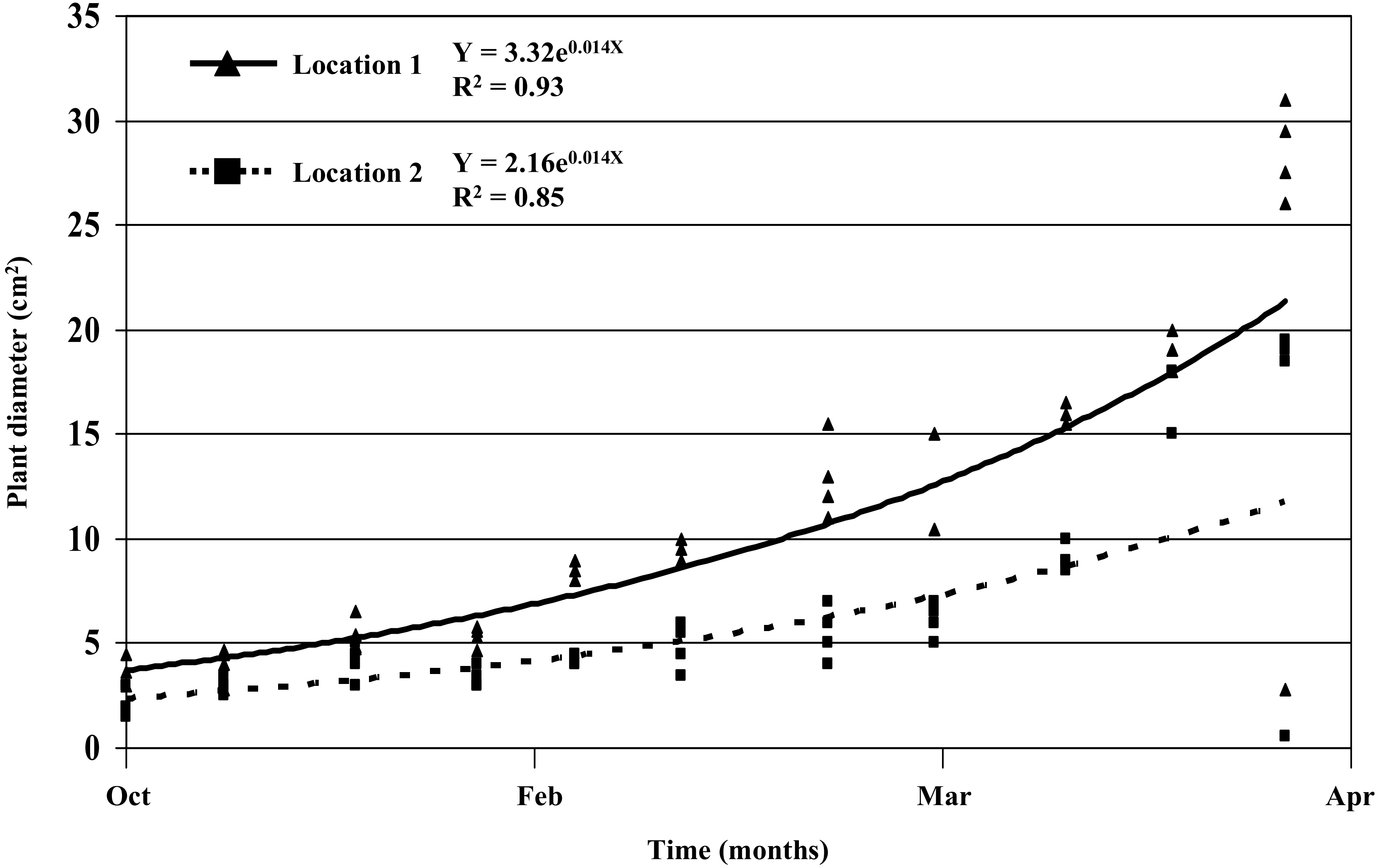


Figure 8. Exponential increase in *O. laciniata* leaf area over time between October 2001 and April 2002.

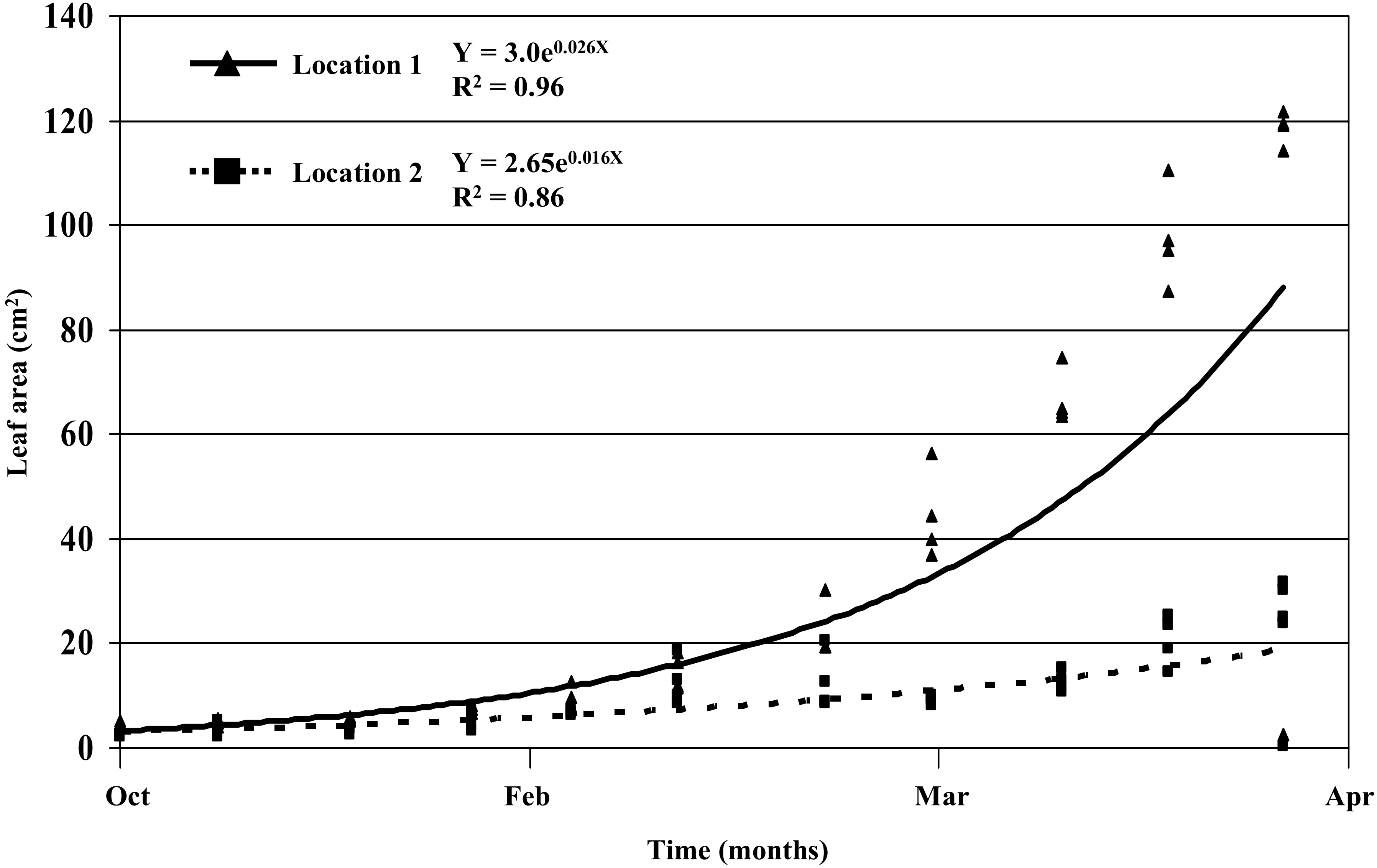
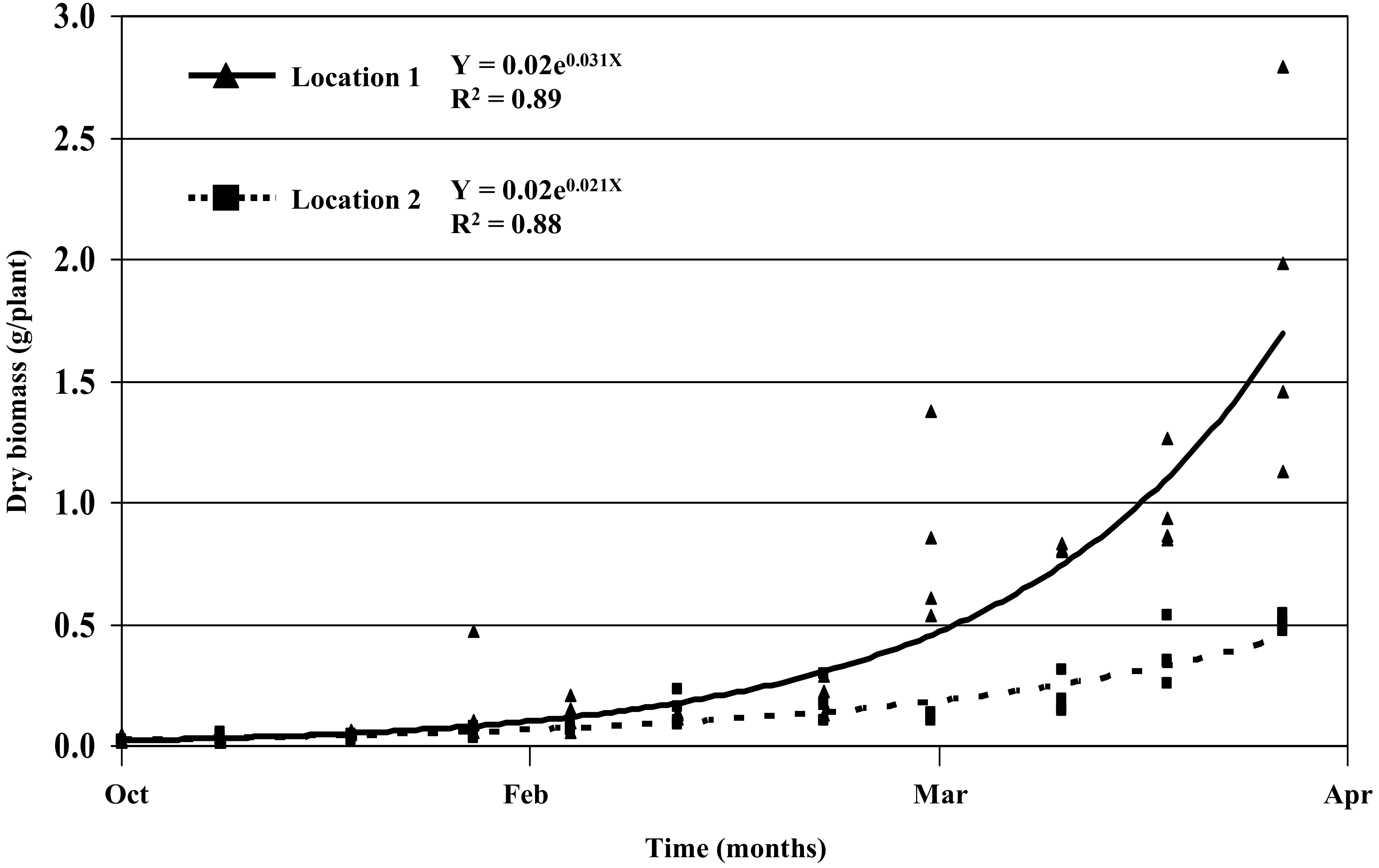


Figure 9. Exponential increase in *O. laciniata* dry biomass over time between October 2001 and April 2002.



WEED MANAGEMENT IN STRIP- AND CONVENTIONAL-TILLAGE NON-TRANSGENIC AND TRANSGENIC COTTON

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ABSTRACT

Studies were conducted to evaluate weed management systems in non-transgenic, bromoxynil-resistant, and glyphosate-resistant cotton in strip- and conventional-tillage environments. Tillage did not affect weed control, cotton lint yields, or net returns. Early season stunting in strip-tillage cotton was 5% or less, regardless of herbicide system or cultivar and was transient. Excellent (>90%) control of common lambsquarters, common ragweed, *Ipomoea* species including entireleaf, ivyleaf, pitted, and tall morningglories, and prickly sida was achieved with systems containing bromoxynil, glyphosate, and pyrithiobac early postemergence (EPOST). Glyphosate systems provided better and more consistent control of large crabgrass than bromoxynil and pyrithiobac systems. Bromoxynil and pyrithiobac EPOST did not control sicklepod unless applied in mixture with MSMA and followed by (fb) a late postemergence-directed (LAYBY) treatment of prometryn plus MSMA. Palmer amaranth was controlled (>90%) with all glyphosate and pyrithiobac systems and the bromoxynil system that included a broadcast soil-applied herbicide treatment. Bromoxynil systems without a broadcast soil-applied herbicide treatment controlled Palmer amaranth 87% or less. Herbicide systems that included glyphosate EPOST controlled sicklepod with or without a soil-applied herbicide treatment. The highest yielding cotton included all the glyphosate systems and bromoxynil systems that contained a soil-applied herbicide treatment. Non-transgenic systems that included a soil-applied herbicide treatment yielded less than soil-applied treatment plus glyphosate EPOST system. Net returns from glyphosate systems were generally higher than net returns from bromoxynil or pyrithiobac systems.

INTRODUCTION

Historically, cotton has been grown in a conventional-tillage environment using primary and secondary tillage. Prior to the registration of postemergence (POST) herbicides with over-the-top selectivity, cotton producers used intensive soil-applied herbicide treatments and high rates of relatively non-selective herbicides and specialized equipment for postemergence-directed (PDS) applications (Buchanan, 1992; McWhorter and Bryson, 1992; Wilcut et al., 1995, 1997).

Strip-tillage cotton acreage is increasing across North Carolina and the Southeastern Coastal Plain (Anonymous 2002). There are several advantages for utilizing strip-tillage production systems. These advantages include: (1) water conservation and reduction of sand blasting of cotton on sandy soils, (2) reduced tillage operations and the number of trips made across the field, and (3) improvement in soil tilth and water-holding capacity over time (Bradley, 1995). Strip-tillage production systems work well in soils that develop a hardpan or plow layer that impedes root growth (Sholar et al., 1995).

Low weed control has been cited as the major limitation to adoption of cotton in conservation-tillage cotton production (McWhorter and Jordan, 1985). Soil-applied herbicides do not provide season-long weed control in cotton, therefore proper selection of POST herbicides and other inputs are crucial for maximum weed control, cotton yield, and economic returns (Crowley et al., 1979;

Culpepper and York, 1997; Wilcut et al., 1995, 1997). In the past 5 years, advances in biotechnology and new postemergence over-the-top (POT) technology have broadened cotton growers' options for weed management strategies (Culpepper and York, 1997, 1999; Wilcut et al. 1996). Bromoxynil, glyphosate, and pyrithiobac control a broad spectrum of weeds POST (Askew and Wilcut, 1999; Culpepper and York, 1997, 1998, 1999; Dotray et al., 1996; Jordan et al., 1993a; Paulsgrove et al., 1998; Scott et al., 2001). Bromoxynil and glyphosate can be used only in their respective transgenic herbicide-resistant cultivars (York and Culpepper, 2000).

In previous studies have evaluated weed management with bromoxynil, glyphosate, and pyrithiobac in non-transgenic, bromoxynil-resistant, and glyphosate-resistant conventional- and no-tillage cotton environments have been evaluated (Askew et al., 2002; Culpepper and York, 1999). The recent increase in reduced-tillage cotton production on the mid-Atlantic and Southeastern Coastal Plain and the lack of data concerning weed management in reduced-tillage systems necessitates additional research. The objectives of this research were to evaluate weed control, cotton response and yield, and net economic returns in strip-tillage and conventional-tillage non-transgenic and transgenic cotton using pyrithiobac, bromoxynil, and glyphosate weed management systems.

MATERIALS AND METHODS

Site Preparation.

Field studies were established at the Central Crops Research Station located near Clayton, NC in 1999; the Cherry Farm Unit near Goldsboro, NC in 1999 and 2000; the Peanut Belt Research Station near Lewiston-Woodville, NC in 1999; and the Upper Coastal Plain Research Station near Rocky Mount, NC in 1999 and 2000. Soils were a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudult) with 1.0% organic matter and pH 5.9 at Clayton; a Wickham loamy sand (fine-loamy, mixed, thermic Typic Hapludult) with 2.1% organic matter and pH 6.2 at Goldsboro; a Norfolk loamy sand (fine-loamy, siliceous, thermic Aquic Paleuduls) with 1.1% organic matter and pH 5.9 at Lewiston-Woodville; and a Goldsboro loamy sand (fine-loamy, siliceous, thermic Typic Paleudult) with 1.0% organic matter and pH 6.0 at Rocky Mount.

Land preparation began with desiccation of a wheat (*Triticum aestivum* L.) cover crop with glyphosate at 1.0 lb ai/acre 2 wk prior to planting. For conventionally tilled plots, soil was disked and smoothed and seed were planted with conventional equipment. In strip-tillage plots, the subsoiler shank of a strip-till rig with the planter units removed was utilized to open the soil and destroy plowpans beneath the rows. The fluted coulters smoothed the soil and broke up large clods. Rolling crumblers mounted immediately behind the fluted coulters served to further smooth the seedbed. Seed were then planted using a conventional planter. Cotton cultivars, 'Paymaster 1220RR' (glyphosate-resistant), 'Stoneville BXN 47' (bromoxynil-resistant), and 'Stoneville 474' (non-transgenic), were planted on May 13, 1999 at Clayton, May 17, 1999 and May 25, 2000 at Goldsboro; May 10, 1999 at Lewiston; and May 11, 1999 and May 9, 2000 at Rocky Mount. Cotton was seeded at 4 seed/foot of row. Plots were 25 feet long and four 38-inch rows wide at Clayton and Goldsboro and 25 feet long and four 36-inch rows wide at Rocky Mount and Lewiston.

Experimental Design.

The experimental design was a randomized complete block with treatments replicated three times. A split-plot treatment arrangement with main plot tillage and subplot herbicide system was utilized to facilitate tillage and planting. Fifteen herbicide systems were evaluated in each main plot and differed between the tillage regimes. The difference between the tillage regimes was due to the additional paraquat PRE treatment in strip-tilled cotton for control of emerged weed vegetation at planting.

Herbicide Programs. Five herbicide systems were evaluated for each cotton cultivar and three cultivars were grown in each tillage regime for a total of 15 herbicide systems in each tillage regime. The five herbicide systems in non-transgenic cotton included: 1) no herbicide treatment, 2) pendimethalin at 0.75 lb ai/acre plus fluometuron at 1.0 lb ai/acre PRE fb pyrithiobac at 0.032 lb ai/acre plus MSMA at 1.0 lb ai/acre EPOST fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY, 3) the aforementioned system with hand weeding as needed (ASN) to keep plots weed-free, 4) pendimethalin at 0.75 lb ai/acre PRE banded (46 cm wide) on the seed drill (PREBAN) fb pyrithiobac at 0.032 lb ai/acre plus MSMA at 1.0 lb ai/acre EPOST fb pyrithiobac at 0.032 lb ai/acre plus clethodim at 0.125 lb ai/acre POST fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY, and 5) pyrithiobac at 0.032 lb ai/acre plus MSMA at 1.0 lb ai/acre EPOST fb pyrithiobac at 0.032 lb ai/acre plus clethodim at 0.125 lb ai/acre POST fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY. Herbicide programs for bromoxynil-resistant cotton included: 1) no herbicide treatment, 2) pendimethalin at 0.75 lb ai/acre plus fluometuron at 1.0 lb ai/acre PRE fb bromoxynil at 0.35 lb ai/acre plus MSMA at 1.0 lb ai/acre EPOST fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY, 3) the aforementioned system with hand weeding ASN to keep plots weed-free, 4) pendimethalin at 0.75 lb ai/acre PREBAN fb bromoxynil at 0.35 lb ai/acre plus MSMA at 1.0 lb ai/acre EPOST fb bromoxynil at 0.35 lb ai/acre plus clethodim at 0.125 lb ai/acre POST fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY, and 5) bromoxynil at 0.35 lb ai/acre plus MSMA at 1.0 lb ai/acre EPOST fb bromoxynil 0.35 lb ai/acre plus clethodim at 0.125 lb ai/acre POST fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY. Herbicide programs for glyphosate-resistant cotton included: 1) no herbicide treatment, 2) pendimethalin at 0.75 lb ai/acre plus fluometuron at 1.0 lb ai/acre PRE fb glyphosate at 1.0 lb ai/acre EPOST fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY, 3) the aforementioned system with hand weeding ASN to keep plots weed-free, 4) pendimethalin at 0.75 lb ai/acre PREBAN fb glyphosate at 1.0 lb ai/acre ANS fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY, and 5) glyphosate at 1.0 lb ai/acre ANS fb prometryn at 1.0 lb ai/acre plus MSMA at 2.0 lb ai/acre at LAYBY.

Glyphosate ANS treatments were applied when visually estimated weed control dropped below 80% (Askew and Wilcut, 1999). The number of ANS applications necessary varied from two to four depending on weed management program, weed densities, and location. In all instances, the first glyphosate ANS treatment was applied POST on two- to four-leaf cotton. Subsequent ANS treatments were applied PDS.

Application Information. Nonionic surfactant at 0.25% (v/v) was included with EPOST, POST, and LAYBY herbicide treatments except bromoxynil, clethodim, and glyphosate treatments. Crop oil concentrate at 1.0% (v/v) was included with all clethodim treatments. Herbicides were applied with a compressed-CO_2 sprayer calibrated to 15 gallons per acre at 30 PSI. Application dates were May 9 to May 25 (PRE and PREBAN), May 28 to June 25 (EPOST and POST), and June 30 to July 10 (LAYBY) depending on location and year.

Data Collection. Late-season weed control, based on leaf discoloration and biomass reduction, was estimated visually on a scale of 0 to 100 where 0 = no control and 100 = death of all plants (Frans et al., 1986). Three separate injury parameters (stunting, discoloration, and stand reduction) were visually estimated for cotton 2 to 3 wk after POST treatment and late in the season using the aforementioned scale. Overall injury was also estimated as a combination of the three injury parameters. The two center rows of each plot were harvested once with a spindle picker modified for small-plot harvesting. Lint and seed yield were adjusted based on the 2-year statewide average percent lint composition of each cultivar (Bowman, 1998).

Economic Analysis. An enterprise budget developed by the North Carolina Cooperative Extension Service (Brown and Cole, 1997) that included operating inputs, fixed costs, and cotton yield value was modified to represent the various weed management programs. Adjustments to operating costs included crop seed and technology fees (where applicable), herbicide application and incorporation costs, and herbicide and adjuvant costs. Cost of seed, technology fee, herbicides, and adjuvants were based on averages of quoted prices from two local agricultural suppliers. Planting costs including costs of seed and technology fees per acre were \$11.75, \$18.00, and \$22.00 for non-transgenic, bromoxynil-resistant, and glyphosate-resistant cotton, respectively. Estimated costs of POST, LAYBY, and PRE applications were \$1.17, \$2.23, and \$3.16 ha^{-1}, respectively, based on performance rates of machines and hourly operation costs (Anonymous, 1998b). Chemical costs per acre were as follows: bromoxynil, \$9.17; clethodim, \$10.30; crop oil concentrate, \$0.68; fluometuron, \$8.10; glyphosate, \$9.10; MSMA POST, \$2.77; MSMA LAYBY, \$5.53; pendimethalin, \$4.06; prometryn, \$7.49; pyrithiobac, \$10.21; and nonionic surfactant, \$0.22. Crop value, based on seasonal averages of the New York Cotton Exchange minus normal discounts, was adjusted in the budget by multiplying the lint yield from each herbicide program by an estimated market price of \$0.64 per lb.

Statistical Analysis.

Nontreated control plots could not be harvested due to uncontrolled weed biomass interference with machinery. The nontreated control and the weed-free checks for each variety were removed prior to analysis to improve homogeneity of variance in the weed control data. Percent data were arcsine squareroot transformed to stabilize variance. Data were subjected to ANOVA and treatment sums of squares were partitioned to reflect the split-plot treatment design and year-location effects (McIntosh, 1983). Where year and location effects were not significant, data were pooled. Data were analyzed separately if significant year by location effects resulted. Appropriate transformed means were separated using Fisher's Protected LSD at $P = 0.05$, however, non-transformed means are presented for clarity.

RESULTS AND DISCUSSION

Cotton Response.

Early season cotton injury for no PRE treatments was 4, 12, and 14% for glyphosate-tolerant, bromoxynil-tolerant, and non-transgenic cultivars, respectively (data not shown). This injury was indicative of early season weed pressure due to lack of soil-applied herbicide treatment. Glyphosate is a better broad-spectrum herbicide, controlling more broadleaves and grasses, than the other two herbicides resulting in less cotton stunting due to reductions in early-season weed interference. Averaged over years, locations, and tillage options, EPOST herbicides did not injure cotton (data not shown) and the slight discoloration (<5%), chlorosis on the lower cotton leaves, was transient and indicative of a urea herbicide (Ahrens, 1994; Anonymous, 1998a). Averaged over years, locations, and tillage option, there was no significant stand reduction and no differences in late-season injury among the various herbicide systems. Untreated cotton, regardless of cotton cultivar was stunted at least 80% late season (data not shown). Cotton tolerance to pyrithiobac is generally excellent unless applications are made during cold wet conditions (Allen et al., 1997; Harrison et al., 1996; Jennings et al., 1999).

Weed Control.

A herbicide system main effect was observed on all weed control data, and tillage did not affect weed control (Tables 2, 3, 4, and 5). Furthermore there was no herbicide system or tillage system interaction among locations or over years. Thus all weed control data were pooled over location and year. Observed weed densities and growth stages were recorded in the non-treated plots at time of EPOST applications (Table 1).

Common lambsquarters was controlled ≥98% with all bromoxynil- and glyphosate-containing herbicide systems and with pyrithiobac systems that used a broadcast treatment of PRE herbicides (Table 2). Bromoxynil EPOST and glyphosate EPOST control common lambsquarters (Askew and Wilcut, 1999; Culpepper and York, 1997; Paulsgrove and Wilcut, 1999, 2001). Pyrithiobac EPOST does not control common lambsquarters (Culpepper and York, 1997; Porterfield et al., 2002). Pendimethalin plus fluometuron PRE and prometryn LAYBY control common lambsquarters (Paulsgrove and Wilcut, 1999, 2001; Wilcut et al., 1995; York and Culpepper 2000). The lower levels of common lambsquarters control with the no PRE and banded PRE systems in non-transgenic cotton, results from the lack of EPOST control from pyrithiobac and the resultant poor coverage of common lambsquarters with the LAYBY treatment of prometryn plus MSMA (data not shown).

Common ragweed was controlled at least 98% with all herbicide systems (Table 2). Fluometuron PRE, prometryn LAYBY, and glyphosate and bromoxynil EPOST control common ragweed (Culpepper and York, 1997, 1998; York and Culpepper, 2000). Pyrithiobac does not control common ragweed but does suppress it long enough to allow adequate coverage with the LAYBY treatment of prometryn plus MSMA (Paulsgrove et al., 1996).

All glyphosate systems controlled large crabgrass at least 98% (Table 2). Most bromoxynil- and pyrithiobac-containing systems controlled less large crabgrass than glyphosate systems but control was still at least 91%. As previously mentioned, neither bromoxynil nor pyrithiobac control annual grasses like large crabgrass. Clethodim, fluometuron, glyphosate, pendimethalin, prometryn, and MSMA control annual grasses like large crabgrass (York and Culpepper, 2000).

Yellow nutsedge was controlled at least 97% with all herbicide systems except one bromoxynil system which controlled 92% (Table 2). Pendimethalin, fluometuron, bromoxynil, and prometryn do not control yellow nutsedge. Glyphosate, MSMA, and pyrithiobac control yellow nutsedge (Wilcut et al., 1995; Wilcut, 1998).

Ipomoea morningglories are not controlled adequately full-season with current registered soil-applied herbicides in cotton (Crowley et al., 1979; Culpepper and York, 1997). All herbicide systems controlled the four morningglory species at least 92% with only minor differences among systems (Table 3). Although pyrithiobac controls tall morningglory less than other

Ipomoea spp. (Sunderland et al., 1995), the plants were suppressed and controlled by the later prometryn plus MSMA LAYBY treatment (data not shown). Bromoxynil, pyrithiobac, and glyphosate EPOST control *Ipomoea* morningglory species as does prometryn plus MSMA LAYBY (Askew and Wilcut, 1999; Culpepper and York, 1997, 1998; Webster et al., 2000). The vining growth nature of *Ipomoea* morningglories interferes with harvesting efficiency in cotton resulting in yield and fiber quality reductions (Wood et al., 1999). Thus near complete control of these weeds is desired to optimize harvesting efficiency.

All glyphosate systems and pyrithiobac systems that used soil-applied herbicide(s) controlled Palmer amaranth ≥96% (Table 3). Less effective control was provided by pyrithiobac systems that did not use a soil-applied herbicide treatment and by all bromoxynil systems. Previous research has also shown less effective control of Palmer amaranth with bromoxynil while glyphosate and pyrithiobac are considered effective EPOST treatments (Culpepper and York, 1998; Dotray et al., 1996; Scott et al., 2001).

Prickly sida was controlled at least 98% with all glyphosate systems and with bromoxynil and pyrithiobac systems that used a broadcast PRE soil-applied treatment (Table 3). The total POST bromoxynil and pyrithiobac systems controlled less prickly sida (87 to 91%). POST prickly sida control with bromoxynil and pyrithiobac requires timely application (Culpepper and York, 1997; Paulsgrove and Wilcut, 1999). Pendimethalin and fluometuron do not provide acceptable control of prickly sida (Paulsgrove and Wilcut, 1999; Wilcut et al., 1988).

Glyphosate systems controlled sicklepod at least 98% (Table 3). Several bromoxynil systems controlled less sicklepod than other systems. When MSMA was included with either pyrithiobac EPOST or bromoxynil EPOST, sicklepod was stunted such that a height differential was obtained between cotton and sicklepod. This height differential allowed for more effective control by the subsequent application of prometryn or MSMA LAYBY. Sicklepod control with LAYBY treatments was increased in other research when MSMA was added to bromoxynil EPOST (Paulsgrove and Wilcut, 1999, 2001) and pyrithiobac EPOST (Wilcut and Hinton, 1997).

Cotton Yield and Economic Returns.
All glyphosate herbicide systems were among the highest yielding with equivalent yields also obtained with bromoxynil and pyrithiobac systems that included the use of a soil-applied PRE herbicides (Table 4). High yields reflect high levels of weed control obtained with each herbicide system (Tables 2 and 3). Although cotton treated with the total POST bromoxynil, pyrithiobac, and glyphosate yielded similarly to cotton treated with the soil-applied treatments plus the aforementioned EPOST herbicides, the yield in the total POST system was 9% less. The lower yields in all cultivars from the total POST system reflects stunting from uncontrolled weeds due to the lack of a soil-applied herbicide treatment. Similar results have been reported for non-transgenic, transgenic bromoxynil-resistant, and transgenic glyphosate-resistant cotton (Askew and Wilcut, 1999; Buchanan and Burns, 1970; Culpepper and York, 1999; Scott et al., 2001). Glyphosate cotton that included a soil-applied herbicide treatment yielded ≥98% of the weed-free yield for the glyphosate-resistant cultivar. Equivalent protection of weed-free cotton yield was also achieved with bromoxynil EPOST plus a soil-applied herbicide treatment, and with pyrithiobac EPOST plus a broadcast PRE soil-applied treatment.

Net returns were similar to yield returns (Table 4). The highest net returns were obtained with all glyphosate systems. While several bromoxynil and pyrithiobac EPOST systems provided net returns equivalent to several of the glyphosate systems, they provided lower net returns than the best glyphosate system. High cotton yields and net returns were reflective of high levels of weed control (Tables 2 and 3). Total POST systems provided net returns that were statistically equivalent to the same herbicide systems with a soil-applied herbicide treatment. However total POST systems had net returns that were 11, 23, and 31% less for glyphosate, bromoxynil, and pyrithiobac systems, respectively, that included a soil-applied herbicide system. These differences likely reflect lower yields from early season weed interference and the increased cost of herbicide systems in the bromoxynil and pyrithiobac systems. Similar results for net returns in conventional tillage non-transgenic and transgenic cotton have been reported (Scott et al., 2001; Vencill, 1998).

These data show that economically effective weed management can be obtained in both conventional- and strip-tillage cotton production environments. The registration of POST herbicides for non-transgenic and transgenic cotton has provided producers new options for broad-spectrum weed control if used in a system that includes soil-applied, EPOST, and LAYBY herbicide treatments. Glyphosate in particular, provides broad-spectrum weed control, high cotton yields, and net returns while requiring minimal inputs of soil-applied herbicides. Tillage production systems did not influence weed control, yield, or net returns in non-transgenic and transgenic cotton.

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Table 1. Effect of herbicide systems on late season common lambsquarters, common ragweed, large crabgrass, yellow nutsedge, Palmer amaranth, prickly sida, and sicklepod control averaged over locations and/or years and tillage options[a].

Cultivar[b] and herbicide system[c]	Common lambsquarters	Common Ragweed	Large crabgrass	Yellow Nutsedge	Palmer amaranth	Prickly sida	Sicklepod
	%						
Bromoxynil-resistant							
Broadcast PRE	100 a	98 B	92 de	92 B	92 b	98 ab	95 ab
Banded PRE	100 a	100 A	97 abc	98 A	87 c	96 abc	87 cd
No PRE	100 a	100 A	94 cde	96 Ab	78 d	87 d	85 d
Glyphosate-resistant							
Broadcast PRE	100 a	99 Ab	99 a	98 A	100 a	99 a	100 a
Banded PRE	100 a	100 A	99 a	98 A	100 a	99 a	100 a
No PRE	99 a	100 A	98 ab	95 Ab	100 a	99 a	98 ab
Non-transgenic							
Broadcast PRE	99 a	100 A	91 e	99 A	100 a	98 ab	93 abc
Banded PRE	82 b	99 Ab	95 bcd	98 A	96 ab	93 bcd	92 bc
No PRE	53 c	100 A	92 e	97 A	92 b	98 ab	95 ab

[a] Numbers within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] Cultivars were 'Stoneville BXN 47', 'Paymaster 1220 RR', and 'Stoneville 474' for bromoxynil-resistant, glyphosate-resistant, and non-transgenic cotton, respectively.

[c] Herbicide programs for bromoxynil-resistant cotton included: 1) pendimethalin at 0.75 lb ai/acre plus fluometuron at 1.0 lb ai/acre PRE fb bromoxynil at 0.35 lb ai/acre plus MSMA at 1.0 lb ai/acre EPOST, 2) Pendimethalin PREBAN fb bromoxynil plus MSMA EPOST fb bromoxynil plus clethodim at 0.125 lb ai/acre, and 3) bromoxynil plus MSMA EPOST fb bromoxynil plus clethodim POST. Herbicide programs for glyphosate-resistant cotton included: 1) pendimethalin and fluometuron PRE fb glyphosate at 1.0 lb ai/acre EPOST, 2) pendimethalin PREBAN fb glyphosate ANS (applied POT if cotton had less than five leaves and PDS if cotton had more than four leaves), and 3) glyphosate ANS. Herbicide programs in non-transgenic cotton included: 1) pendimethalin plus fluometuron PRE fb pyrithiobac at 0.032 lb ai/acre plus MSMA at EPOST, 2) pendimethalin PREBAN fb pyrithiobac plus MSMA EPOST fb pyrithiobac plus clethodim, and 3) pyrithiobac plus MSMA EPOST fb pyrithiobac plus clethodim POST. All herbicide systems included a LAYBY of prometryn at 1.0 lb ai/acre, MSMA at 2.0 lb ai/acre, and NIS at 0.25% v/v.

Table 2. Effect of herbicide systems on late season entireleaf, ivyleaf, pitted, and tall morningglories, prickly sida, and sicklepod control averaged over locations and/or years and tillage options[a]. Effect of herbicide systems on cotton yield, percentage of weed-free yield potential, and economic return averaged over locations and/or years and tillage options[a].

Cultivar[b] and herbicide system[c]	Entireleaf morningglory	Ivyleaf morningglory	Pitted morningglory	Tall morningglory	Yield	Weed-free yield	Return
	%				lb/acre	%	$/acre
Bromoxynil-resistant							
Broadcast PRE	98 a	96 Abc	98 ab	98 A	820 abc	94 ab	294 bcd
Banded PRE	98 a	95 Abc	98 ab	98 A	810 abc	92 ab	270 cde
No PRE	99 a	97 abc	98 ab	100 A	720 cd	80 c	215 f
Glyphosate-resistant							
Broadcast PRE	98 a	93 bc	95 b	99 A	930 a	99 a	349 ab
Banded PRE	99 a	95 abc	96 ab	99 A	930 a	98 a	379 a
No PRE	98 a	92 c	96 ab	97 A	880 ab	91 ab	312 abc
Non-transgenic							
Broadcast PRE	99 a	99 a	98 ab	97 A	770 bcd	92 ab	241 cdef
Banded PRE	99 a	98 ab	98 ab	96 A	750 bcd	97 bc	217 def

[a] Numbers within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] Cultivars were 'Stoneville BXN 47', 'Paymaster 1220 RR', and 'Stoneville 474' for bromoxynil-resistant, glyphosate-resistant, and non-transgenic cotton, respectively.

[c] Herbicide programs for bromoxynil-resistant cotton included: 1) pendimethalin at 0.75 lb ai/acre plus fluometuron at 1.0 lb ai/acre PRE fb bromoxynil at 0.35 lb ai/acre plus MSMA at 1.0 lb ai/acre EPOST, 2) Pendimethalin PREBAN fb bromoxynil plus MSMA EPOST fb bromoxynil plus clethodim at 0.125 lb ai/acre, and 3) bromoxynil plus MSMA EPOST fb bromoxynil plus clethodim POST. Herbicide programs for glyphosate-resistant cotton included: 1) pendimethalin and fluometuron PRE fb glyphosate at 1.0 lb ai/acre EPOST, 2) pendimethalin PREBAN fb glyphosate ANS (applied POT if cotton had less than five leaves and PDS if cotton had more than four leaves), and 3) glyphosate ANS. Herbicide programs in non-transgenic cotton included: 1) pendimethalin plus fluometuron PRE fb pyrithiobac at 0.032 lb ai/acre plus MSMA at EPOST, 2) pendimethalin PREBAN fb pyrithiobac plus MSMA EPOST fb pyrithiobac plus clethodim, and 3) pyrithiobac plus MSMA EPOST fb pyrithiobac plus clethodim POST. All herbicide systems included a LAYBY of prometryn at 1.0 lb ai/acre, MSMA at 2.0 lb ai/acre, and NIS at 0.25% v/v.

ECONOMIC ASSESSMENT OF DICLOSULAM AND FLUMIOXAZIN IN STRIP- AND CONVENTIONAL-TILLAGE PEANUT

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ABSTRACT

Experiments were conducted in Lewiston, NC in 1999 and 2000 and Rocky Mount, NC in 1999 to evaluate weed management systems in strip- and conventional-tillage peanut. The peanut cultivars grown were 'NC 10C', 'NC 12C', and 'NC 7', respectively. Weed management systems consisted of different combinations of preemergence (PRE) herbicides including diclosulam and flumioxazin plus commercial postemergence (POST) herbicide systems. Dimethenamid plus diclosulam or flumioxazin PRE controlled common lambsquarters, eclipta, and prickly sida at least 91%. Both diclosulam and flumioxazin provided variable control of three morningglory species (59 to 91%), but bentazon plus acifluorfen POST was required for >90% control. Only diclosulam systems controlled yellow nutsedge 90% late season. Annual grass control required clethodim late POST, regardless of tillage system. Dimethenamid plus diclosulam or flumioxazin PRE produced equivalent yields and net returns with no significant differences between the two PRE options. Both systems produced higher yields and net returns than dimethenamid regardless of the POST herbicide option. The tillage production system did not influence weed control of eight weeds, peanut yields, or net returns. The addition of diclosulam or flumioxazin to dimethenamid PRE improved weed control compared to dimethenamid PRE alone.

INTRODUCTION

Historically, peanut has been grown as a conventionally planted crop utilizing production systems of primary and secondary tillage operations resulting in a friable, residue free, flat or slightly raised seedbed (Samples, 1987). These operations require considerable fuel, labor, and time. Increasing economic inputs and concerns for declining soil organic matter, subsoil compaction, water stress damage, and sandblasting have led to interest in alternative tillage options, such as strip-tillage productions systems (Troeh et al., 1991). Strip-tillage peanut and cotton (*Gossypium hirsutum* L.) hectarage is increasing across North Carolina and the Southeastern Coastal Plain. Since peanut are often grown in rotation with cotton more farmers will be inclined to follow strip-till cotton with a strip-till peanut production system.

In strip-tillage systems, primary tillage is replaced by herbicides applied preplant to control emerged weedy vegetation; preplant incorporated herbicides are replaced by preemergence (PRE) herbicides, and herbicide band applications to the drill and cultivation are replaced by broadcast herbicide applications maintaining the same objectives of controlling weeds without injuring the crop (Patterson et al., 1994a). There are many advantages for utilizing strip tillage production systems including: (1) water conservation and reduction of sand blasting on sandy soils, (2) elimination of seedbed preparation reduces tillage operations and the number of trips made across the field, and (3) soil tilth and water-holding capacity are improved over time (Bradley, 1995). Strip-tillage production systems work well where soils are prone to develop a hardpan or plow layer that impedes root growth or pegging (process where gynophore grows down into the soil after fertilization) (Sholar et al., 1995).

The ultimate goal is to reduce economic inputs while maintaining equivalent yields. Several studies conducted in the Southeastern United States have identified strip tillage production practices that have produced yields equivalent to conventional-till peanut (Colvin et al., 1988; Colvin et al., 1986; Wilcut et al., 1987). However, since the late 1980's a number of changes have occurred in herbicide options in peanut including the cancellation or withdrawing of dinoseb and naptalam registrations. Additionally, concerns about alachlor-treated peanut have eliminated this herbicide from use in U. S. peanut production (Bridges et al., 1994; Wilcut et al., 1995). Furthermore, new registrations of herbicides since the late 1980's include clethodim, diclosulam, dimethenamid, imazapic, imazethapyr, paraquat, and pyridate. Data for weed management systems for strip tillage remains limited for peanut compared with other agronomic crops (Colvin et al., 1986; Colvin et al., 1985; Wilcut et al., 1987; Worsham, 1985). Diclosulam has recently been registered for PPI and PRE use in peanut (Anonymous, 2000) and flumioxazin was registered in April 2001.

Diclosulam is a soil-applied herbicide belonging to the triazolopyrimidine sulfonanilide family developed for weed control in soybean (*Glycine max* L.) and peanut (Bailey et al. 1999; Barnes et al. 1998). Previous research has shown diclosulam PRE to control a variety of broadleaf weeds in soybean and peanut while exhibiting excellent tolerance to diclosulam (Bailey et al. 1999, 2000; Baughman et al. 2000; Dotray et al. 2000; Main et al. 2000; Prostko et al. 1998; Sheppard et al. 1997).

Flumioxazin is an N-phenyl phtalimide herbicide that inhibits protoporphy-rinogen oxidase (Anderson et al. 1994; Hatzios 1998; Yoshida et al. 1991). Previous research has shown flumioxazin PRE to control Florida beggarweed, morningglories, and prickly sida in Georgia (Wilcut 1997). Flumioxazin PRE controls common lambsquarters, common ragweed, and jimsonweed with good crop tolerance (Wilcut et al. 2000). However, in Texas and Georgia, flumioxazin has failed to control yellow nutsedge, sicklepod, and annual grasses consistently (Grichar and Colburn 1996; Wilcut 1997).

The recent increase in reduced-tillage peanut production on the mid-Atlantic and Southeastern Coastal Plain and the lack of data concerning weed management in reduced-tillage systems necessitates additional research. Therefore, studies were conducted to evaluate weed management systems with diclosulam and flumioxazin PRE for weed control in strip- and conventional-tillage peanut production, and to evaluate peanut response, yield potential and economic returns to peanut in these two tillage systems.

MATERIALS AND METHODS

Field experiments were conducted at the Upper Coastal Plain Research Station located near Rocky Mount, NC in 1999 and at the Peanut Belt Research Station located near Lewiston-Woodville, NC in 1999 and 2000 to evaluate weed management systems in strip- and conventional-tillage peanut. Soils were a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudults) with 1.0% organic matter and a pH 5.9 each year at Lewiston and a Rains fine sandy loam (fine-loamy, siliceous, thermic Typic Paleaquults) with 1.1% organic matter and a pH 5.8 at Rocky Mount. These experimental sites are representative of the major peanut-producing areas of North Carolina.

Peanut cultivars included 'NC 10C' and 'NC 12C' at Lewiston, NC in 1999 and 2000 and 'NC 7' at Rocky Mount, NC in 1999. These cultivars are among the more widely planted in North Carolina (Spears, 2000). Peanut was planted 2 in deep at 107 to 116 lb ac^{-1} in 36-in rows into corn (*Zea mays* L.) stubble in 1999 and into cotton stubble in 2000 at Lewiston. Peanut was planted in wheat at

Rocky Mount in 1999. Seeding rates were typical for North Carolina according to state extension recommendations (Jordan, 2000). Pest management programs other than herbicide programs were based on Cooperative Extension Service recommendations (Bailey 2000, Brandenburg 2000).

Weed species evaluated at two or more locations included common lambsquarters, eclipta, entireleaf morningglory, ivyleaf morningglory, pitted morningglory, prickly sida, purple nutsedge, and yellow nutsedge. At the time of early postemergence (EPOST) and POST applications, broadleaf weeds were in the one- to seven-leaf stage while yellow nutsedge was 6 to 10 in tall, with densities ranging from 3 to 10 plants per species m^{-2}. EPOST treatments were applied 7 to 10 days after peanut emergence and POST treatments were applied approximately 2 wk after EPOST treatments. These application timings are typical of commercial postemergence systems in peanut (Wilcut, 1991; Wilcut et al. 1994).

Paraquat at 0.625 lb ai ac^{-1} was applied to all plots three weeks before planting to control existing vegetation. Diclosulam was evaluated with registered preemergence (PRE) and POST herbicides. The PRE herbicide options included: 1) dimethenamid alone at 1.25 lb ai ac^{-1}, dimethenamid plus diclosulam at 0.024 lb ai ac^{-1}, dimethenamid plus flumioxazin at 0.063 lb ai ac^{-1}, or no soil-applied herbicide treatment. Postemergence herbicide options included: 1) bentazon at 0.25 lb ai ac^{-1} plus paraquat at 0.125 lb ai ac^{-1} EPOST followed by a pre-packaged mixture[1] of acifluorfen at 0.25 lb ai ac^{-1} plus bentazon at 0.5 lb ai ac^{-1} POST, 2) paraquat EPOST followed by a pre-packaged mixture of acifluorfen plus bentazon POST at the aforementioned rate, and 3) no POST herbicide treatment. A nonionic surfactant[2] (NIS) at 0.25% (v/v) was included in all EPOST and POST treatments and in the paraquat burndown treatment in strip-tillage. The paraquat burndown treatments served as the untreated check for visual evaluations of weed control and crop injury. Clethodim late POST at 0.125 lb ai ac^{-1} plus crop oil concentrate[3] at 1% (v/v) was needed for all treatment combinations for adequate season-long control of annual grasses including broadleaf signalgrass (*Brachiaria platyphylla* (Griseb.) Nash), goosegrass (*Eleusine indica* L. Gaertn.), and large crabgrass (*Digitaria sanguinalis* L. Scop.). This treatment was needed to facilitate harvest as the fibrous root systems of annual grasses interfere with digging and harvesting operations (Wilcut et al. 1994a). Plot size was four 36-in rows that were 20-ft in length. The experimental design was a randomized complete block with each block replicated three times. A split-plot treatment arrangement with main plot tillage and subplot herbicide program was utilized to facilitate tillage and planting.

Visual estimates of weed control were recorded early (mid-June) and late in the season (late August) just prior to harvest. Weed control and peanut injury based on leaf discoloration and biomass reduction as compared to the untreated control, was visually estimated on a scale of 0 (no injury symptoms) to 100 (complete death of all plants or no plants present) (Frans et al., 1986). Peanut injury was visually estimated 3 weeks (mid-June) after application of PRE herbicides and again 3 weeks (mid July) after POST herbicides. Weed control of common lambsquarters, eclipta, entireleaf morningglory (*Ipomoea hederacea* var. *integruiscula* Gray), ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.), pitted morningglory (*Ipomoea lacunosa* L.), prickly sida, and yellow nutsedge, was visually estimated early (mid June) and late (late August) season. Since late season weed control influenced peanut yield and harvest efficiency, only late season evaluation of weed control will be presented (Wilcut et al., 1994). The center two rows of each plot were harvested in mid-October of each year using conventional harvesting equipment.

Economic Analysis.

An enterprise budget developed by the North Carolina Cooperative Extension Service (Brown, 2000) that included operating inputs, fixed costs, and peanut yield value was modified to represent the various weed management programs. Adjustments to operating costs included crop seed and technology fees, herbicide application and incorporation costs, and herbicides and adjuvant costs. The production costs included cultural and pest management procedures, equipment and labor, interest on operating equipment, harvest operations including drying and hauling, and general overhead costs. Cost of seed, technology fee, herbicides, and adjuvants were based on averages of quoted prices from two local agricultural suppliers. Costs of application were $4.28 per application, based on computer models developed by the Department of Agriculture and Resource Economics at North Carolina State University. Chemical costs ac^{-1} were as follows: clethodim at $4.84 ac^{-1}, crop oil concentrate at $0.95 ac^{-1}, dimethenamid at $16.14 ac^{-1}, bentazon at $4.09 ac^{-1}, paraquat at $7.82 ac^{-1}, pre-packaged mixture of acifluorfen plus bentazon at $12.80 ac^{-1}, diclosulam at $21.99 ac^{-1}, flumioxazin at $9.93 ac^{-1}, and NIS at $0.56 ac^{-1}. Herbicide system costs represent the sum of all application, herbicide, and adjuvant costs (Table 6). Net returns were calculated by multiplying yield/ha by 100% of the price support ($0.30 lb^{-1}) and subtracting total production costs for each treatment.

Statistical Analysis.

Data were tested for homogeneity of variance by plotting residuals. An arcsine square-root transformation did not improve variance homogeneity, thus non-transformed data were used in analysis and presentation for clarity. Data from the non-treated control was deleted prior to analysis to stabilize variance since visually estimated weed control ratings were set to zero and peanut yield could not be harvested due to weed biomass interference with machinery. To recognize structure in the treatment arrangement, analysis of variance was conducted using the general linear models procedure in SAS (SAS, 1998) to evaluate the effect of various PRE herbicide systems (four levels) and postemergence herbicide options (three levels) on crop injury, weed control, and crop yield. Sums of squares were partitioned to evaluate location and year effects that were considered separate random variables. Main effects and interactions were tested by the appropriate mean square associated with the random variables (McIntosh 1983). Mean separations were performed using Fisher's protected LSD test at $P=0.05$.

RESULTS AND DISCUSSION

Peanut Response.

Injury at 2 weeks after planting at Lewiston 1999 was minimal with less than 8% for any PRE herbicide systems. However, at Rocky Mt. 1999 and Lewiston 2000, early season injury was noticeable with ranges from 0 to 25 and 0 to 15%, respectively. The same trend in injury was evident with the POST herbicides at the three locations. Most injury was transient, and 8% or less by the late injury rating (Table 1). Injury was expressed as stunting at the late evaluation. This level of stunting is not a concern with producers as excessive vine growth can lead to more disease problems and digging problems at harvest due to poor row definition (Young et al., 1982).

Weed Control.

Tillage did not influence weed control, except for eclipta, thus all weed control data excluding eclipta was pooled over tillage (Tables 2, 3, 4, and 5).

Annual grasses. When compared to non-treated plots, all herbicide treatments improved control of annual grass complex that included broadleaf signalgrass, goosegrass, large crabgrass, and Texas panicum (data not shown). Dimethenamid systems controlled these species better than systems that did not include dimethenamid. However control was 60% or less which would interfere with harvesting operations. Thus, clethodim late POST was needed for all weed management systems for adequate control (>95%) of annual grasses late season.

Yellow nutsedge. There was a significant treatment by location interaction for yellow nutsedge control thus data are presented separately by location. Dimethenamid PRE alone controlled yellow nutsedge 17 to 65% depending on location (Table 2). The additional use of paraquat EPOST fb acifluorfen plus bentazon POST to dimethenamid increased control only at one location. The further addition of bentazon plus paraquat EPOST fb acifluorfen plus bentazon POST increased control at two locations 19 to 73 percentage points. At all locations, yellow nutsedge control with dimethenamid plus diclosulam or flumioxazin PRE was better than control with only dimethenamid PRE. Both diclosulam and flumioxazin PRE controlled yellow nutsedge similarly. The addition of either POST systems to dimethenamid plus diclosulam or flumioxazin PRE did not increase yellow nutsedge control at any location.

Common lambsquarters. There was a significant treatment by location interaction, therefore, data are presented by location. Dimethenamid PRE controlled common lambsquarters 59% or less, while dimethenamid plus diclosulam or flumioxazin PRE controlled 78 to 99 with no differences in treatments (Table 2). The additional use of either POST system to dimethenamid PRE alone increased common lambsquarters control to at least 84% at all locations. Additional use of POST systems with diclosulam and flumioxazin PRE improved control at two of the three locations. At Lewiston in 2000, common lambsquarters was controlled at least 96% with diclosulam or flumioxazin PRE. Since this level of control was so high, no further improvements in control were seen.

Prickly sida. There was a significant treatment by location interaction, therefore, data are presented by location. Dimethenamid PRE did not control prickly sida when compared to nontreated border areas (Table 3). However, prickly sida was controlled 100% with all other herbicide combinations at Lewiston 1999 and 2000. Prickly sida control was more variable at Rocky Mount in 1999. Dimethenamid PRE did not control prickly sida, however the addition of diclosulam or flumioxazin PRE increased control to 61 and 59%, respectively. Dimethenamid PRE plus paraquat EPOST fb acifluorfen plus bentazon POST controlled prickly sida 80% compared with at least 98% control when diclosulam or flumioxazin PRE was included in the aforementioned system. A similar trend was seen with dimethenamid PRE plus bentazon plus paraquat EPOST fb acifluorfen plus bentazon POST, which controlled prickly sida 79% compared to at least 96% control with diclosulam or flumioxazin PRE in this system. It is common for season-long control of prickly sida to require two postemergence treatments (Wilcut et al., 1994).

Pitted morningglory. There was a significant treatment by location interaction and no tillage effect for pitted morningglory control; thus data are presented by location. Dimethenamid PRE did not control pitted morningglory at any location while dimethenamid plus diclosulam or flumioxazin PRE controlled 59 to 89% of the pitted morningglory populations with no differences in treatments (Table 3). The additional use of either POST system to dimethenamid PRE alone increased pitted morningglory control 64 to 88 percentage points, depending on location. Pitted morningglory control with diclosulam and flumioxazin PRE systems was not consistently improved by additional use of POST treatments. Similar results have been seen with diclosulam PRE in conventional-tillage peanuts (Scott et al., 2001).

Entireleaf morningglory. Because there was a significant treatment by location for entireleaf morningglory control, data are presented separately by location. As noted with pitted morningglory, dimethenamid PRE did not control entireleaf morningglory while dimethenamid plus diclosulam or flumioxazin PRE controlled 80 to 90% of the populations with no significant differences in treatments (Table 4). The addition of either POST systems to dimethenamid PRE alone increased entireleaf morningglory control to at 69% at all locations. Additional use of POST systems to diclosulam PRE systems improved control at both locations while it only control for flumioxazin PRE systems at Rocky Mount in 1999.

Ivyleaf morningglory. There was a significant treatment by location interaction for ivyleaf morningglory control, therefore, data are presented by location. Many of the trends observed with the other two morningglory species were also noted with ivyleaf morningglory. Dimethenamid PRE did not control ivyleaf morningglory while the addition of diclosulam or flumioxazin PRE controlled 75 to 91% of the ivyleaf morningglory populations (Table 4). The additional use of either POST systems to dimethenamid PRE alone improved ivyleaf morningglory control to at least 70% at both locations. Ivyleaf morningglory control was improved with the addition of either POST herbicide system to diclosulam or flumioxazin PRE systems at Rocky Mount in 1999 but not at Lewiston. The level of control with diclosulam or flumioxazin PRE was so high (89 to 91%) that improvements were not noted.

Eclipta. There was a significant treatment by location interaction for eclipta control, therefore data are presented by location. Dimethenamid PRE alone did not control at any location while dimethenamid plus diclosulam or flumioxazin PRE controlled 86 to 98% of eclipta populations with no differences in treatments (Table 5). The additional use of either POST system to dimethenamid PRE alone increased eclipta control 84 to 100 percentage points, depending on location. Eclipta control with diclosulam and flumioxazin PRE systems was not consistently improved by additional use of POST treatments. Similar results were reported with diclosulam applied PRE (Bailey et al., 1999).

Peanut Yield.

There was a location by treatment interaction for peanut yield, thus data are presented by location. Dimethenamid PRE treated peanut yielded 1205 to 2580 lb ac^{-1} and these yields were always improved by additional inputs of diclosulam or flumioxazin PRE or by either POST herbicide systems (Table 6). These increased yields reflect the increased levels of weed control provided by the additional herbicide inputs (Tables 1 to 5).

These data show that diclosulam or flumioxazin PRE offers more effective broad-spectrum control of yellow nutsedge, common lambsquarters, prickly sida, eclipta, and three *Ipomea* morningglory species than the commercial standard for North Carolina. In a majority of the comparisons, weed management systems utilizing diclosulam or flumioxazin applied PRE provided better and more consistent broadleaf weed control and higher peanut yields than weed management systems using standard POST herbicides. Peanut yields were indicative of the level of weed management provided by diclosulam- or flumioxazin-containing systems.

Economic Return.

There was a location by treatment interaction for economic net returns, thus data are presented by location. As with peanut yield, economic net returns from each herbicide system followed similar trends (Table 6). Systems that included dimethenamid PRE alone netted -$24 to $146 ac^{-1} while additional inputs of diclosulam and flumioxazin PRE or by either POST herbicide systems to dimethenamid PRE alone increased control. Diclosulam PRE added to dimethenamid PRE use resulted in net returns of $154 to $1178 ac^{-1} at all locations. Additions of flumioxazin PRE to dimethenamid PRE resulted in net returns of $85 to $1206 ac^{-1} at all locations. The additional use of POST herbicide systems to all PRE systems increased net returns.

Early POST and POST herbicides used in this study usually increased weed control when used with dimethenamid PRE but were not always needed with diclosulam or flumioxazin PRE. Our data indicates that diclosulam and flumioxazin PRE in strip- and conventional-tillage production systems controls common lambsquarters, eclipta, and prickly sida without additional herbicide inputs. However, control of yellow nutsedge and three *Ipomea* morningglory species frequently required additional POST herbicide treatments for season-long control. Annual grass control was inadequate and required clethodim for season-long control. The use of diclosulam or flumioxazin PRE can improve weed control, yield, and net returns over traditional systems of dimethenamid PRE herbicides in strip- and conventional-tillage peanut.

SOURCES OF MATERIALS

[1] Storm® contains 29% sodium salt of bentazon [sodium (3-isopropyl-1-*H*-2, 1, 3-benzothiadiazin-4(3*H*)-one-2, 2-dioxide)], 13% sodium salt of acifluorfen (sodium 5-[2-chloro-4-(trifluoromethyl) phenoxy]-2-nitrobenzoate, and 57% inert ingredients, manufactured by BASF Corporation, Agricultural Products Group, P.O. Box 13528, Research Triangle Park, NC 27709.

[2] Induce® nonionic low-foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylarylpolyoxyalkane ether and isopropanol), free fatty acids, and 10% water, manufactured by Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

[3] Agri-dex® contains 83% paraffin base petroleum oil and 17% surfactant blend, manufactured by Helena Chemical Company, Suite 500, 60755 Poplar Avenue, Memphis, TN 38137.

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Table 1. Effect of PRE and POST herbicide systems on peanut injury at three North Carolina locations.[a]

Herbicides			Early injury			Late injury		
			Lewiston 1999	Rocky Mount 1999	Lewiston 2000	Lewiston 1999	Rocky Mount 1999	Lewiston 2000
PRE[b]	EPOST[c]	POST[d]	%					
Dimethenamid	None	None	0 c	0 e	0 c	0 a	1 b	1 c
Dimethenamid + diclosulam	None	None	6 b	15 c	15 b	0 a	0 b	8 a
Dimethenamid + flumioxazin	None	None	7 ab	25 b	15 b	0 a	0 b	8 a
Dimethenamid	Paraquat	Acifluorfen + bentazon	0 c	3 d	0 c	0 a	2 ab	1 c
Dimethenamid + diclosulam	Paraquat	Acifluorfen + bentazon	7 ab	17 c	16 ab	0 a	0 b	7 a
Dimethenamid + flumioxazin	Paraquat	Acifluorfen + bentazon	7 ab	30 a	16 a	0 a	4 a	6 ab
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	0 c	2 d	0 c	0 a	1 b	2 bc
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	6 b	16 c	15 b	0 a	0 b	4 abc
Dimethenamid + flumioxazin	Bentazon + paraquat	Acifluorfen + bentazon	8 a	27 b	16 ab	0 a	0 b	8 a

[a] Values of injury within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] The PRE herbicide rates were dimethenamid at 1.4 kg ai ha^{-1}, diclosulam at 0.027 kg ai ha^{-1}, and flumioxazin at 0.071 kg ai ha^{-1}.

[c] The EPOST herbicide rates were paraquat at 0.14 kg ai ha^{-1} and bentazon at 0.28 kg ai ha^{-1} and included NIS at 0.25% (v/v).

[d] The POST herbicide rates were acifluorfen at 0.28 kg ai ha^{-1} and bentazon at 0.56 kg ai ha^{-1} and included NIS at 0.25% (v/v).

Table 2. Effect of PRE and POST herbicide systems on yellow nutsedge and common lambsquarters control at three North Carolina locations.[a]

Herbicides			Yellow nutsedge			Common lambsquarters		
			Lewiston 1999	Rocky Mount 1999	Lewiston 2000	Lewiston 1999	Rocky Mount 1999	Lewiston 2000
PRE[b]	EPOST[c]	POST[d]	%					
Dimethenamid	None	None	17 d	54 b	65 b	0 d	58 c	59 c
Dimethenamid + diclosulam	None	None	91 a	87 a	84 a	78 c	93 b	99 a
Dimethenamid + flumioxazin	None	None	90 ab	75 a	86 a	84 bc	89 b	96 a
Dimethenamid	Paraquat	Acifluorfen + bentazon	44 c	55 b	65 b	84 bc	99 a	89 b
Dimethenamid + diclosulam	Paraquat	Acifluorfen + bentazon	87 ab	82 a	81 ab	91 ab	99 a	100 a
Dimethenamid + flumioxazin	Paraquat	Acifluorfen + bentazon	83 ab	76 a	81 ab	94 a	99 a	99 a
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	78 b	77 a	77 ab	88 ab	99 a	100 a
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	90 ab	85 a	92 a	91 ab	99 a	100 a
Dimethenamid + flumioxazin	Bentazon + paraquat	Acifluorfen + bentazon	88 ab	87 a	86 a	96 a	99 a	100 a

[a] Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] The PRE herbicide rates were dimethenamid at 1.4 kg ai ha^{-1}, diclosulam at 0.027 kg ai ha^{-1}, and flumioxazin at 0.071 kg ai ha^{-1}.

[c] The EPOST herbicide rates were paraquat at 0.14 kg ai ha^{-1} and bentazon at 0.28 kg ai ha^{-1} and included NIS at 0.25% (v/v).

[d] The POST herbicide rates were acifluorfen at 0.28 kg ai ha^{-1} and bentazon at 0.56 kg ai ha^{-1} and included NIS at 0.25% (v/v).

Table 3. Effect of PRE and POST herbicide systems on prickly sida and pitted morningglory control at three North Carolina locations.[a]

Herbicides			Prickly sida			Pitted morningglory		
			Lewiston 1999	Rocky Mount 1999	Lewiston 2000	Lewiston 1999	Rocky Mount 1999	Lewiston 2000
PRE[b]	EPOST[c]	POST[d]	%					
Dimethenamid	None	None	30 b	0 d	21 b	67 ab	0 d	0 d
Dimethenamid + diclosulam	None	None	100 a	61 c	100 a	75 ab	84 b	85 ab
Dimethenamid + flumioxazin	None	None	100 a	59 c	100 a	59 b	86 b	89 ab
Dimethenamid	Paraquat	Acifluorfen + bentazon	100 a	80 b	100 a	67 ab	74 c	64 c
Dimethenamid + diclosulam	Paraquat	Acifluorfen + bentazon	100 a	98 a	100 a	68 ab	100 a	90 ab
Dimethenamid + flumioxazin	Paraquat	Acifluorfen + bentazon	100 a	98 a	100 a	71 ab	100 a	92 ab
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	100 a	79 b	100 a	88 a	72 c	82 b
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	100 a	97 a	100 a	90 a	100 a	93 a
Dimethenamid + flumioxazin	Bentazon + paraquat	Acifluorfen + bentazon	100 a	96 a	100 a	91 a	100 a	91 ab

[a] Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] The PRE herbicide rates were dimethenamid at 1.4 kg ai ha^{-1}, diclosulam at 0.027 kg ai ha^{-1}, and flumioxazin at 0.071 kg ai ha^{-1}.

[c] The EPOST herbicide rates were paraquat at 0.14 kg ai ha^{-1} and bentazon at 0.28 kg ai ha^{-1} and included NIS at 0.25% (v/v).

[d] The POST herbicide rates were acifluorfen at 0.28 kg ai ha^{-1} and bentazon at 0.56 kg ai ha^{-1} and included NIS at 0.25% (v/v).

Table 4. Effect of PRE and POST herbicide systems on entireleaf morningglory and ivyleaf morningglory control at two North Carolina locations.[a]

Herbicides			Entireleaf morningglory		Ivyleaf morningglory	
			Rocky Mount 1999	Lewiston 2000	Rocky Mount 1999	Lewiston 2000
PRE[b]	EPOST[c]	POST[d]	%			
Dimethenamid	None	None	0 d	0 d	0 d	0 d
Dimethenamid + diclosulam	None	None	80 b	81 b	75 bc	89 a
Dimethenamid + flumioxazin	None	None	81 b	90 ab	80 b	91 a
Dimethenamid	Paraquat	Acifluorfen + bentazon	73 c	69 c	70 c	73 b
Dimethenamid + diclosulam	Paraquat	Acifluorfen + bentazon	100 a	93 a	100 a	90 a
Dimethenamid + flumioxazin	Paraquat	Acifluorfen + bentazon	100 a	91 ab	100 a	88 a
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	74 bc	85 ab	74 bc	88 a
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	100 a	95 a	100 a	94 a
Dimethenamid + flumioxazin	Bentazon + paraquat	Acifluorfen + bentazon	100 a	95 a	100 a	94 a

[a] Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] The PRE herbicide rates were dimethenamid at 1.4 kg ai ha^{-1}, diclosulam at 0.027 kg ai ha^{-1}, and flumioxazin at 0.071 kg ai ha^{-1}.

[c] The EPOST herbicide rates were paraquat at 0.14 kg ai ha^{-1} and bentazon at 0.28 kg ai ha^{-1} and included NIS at 0.25% (v/v).

[d] The POST herbicide rates were acifluorfen at 0.28 kg ai ha^{-1} and bentazon at 0.56 kg ai ha^{-1} and included NIS at 0.25% (v/v).

Table 5. Effect of PRE and POST herbicide systems on eclipta control at three North Carolina locations.[a]

Herbicides			Eclipta		
			Lewiston 1999	Rocky Mount 1999	Lewiston 2000
PRE[b]	EPOST[c]	POST[d]	%		
Dimethenamid	None	None	43 d	40 c	38 b
Dimethenamid + diclosulam	None	None	86 c	93 ab	98 a
Dimethenamid + flumioxazin	None	None	89 bc	97 a	97 a
Dimethenamid	Paraquat	Acifluorfen + bentazon	95 ab	85 b	95 a
Dimethenamid + diclosulam	Paraquat	Acifluorfen + bentazon	98 a	98 a	100 a
Dimethenamid + flumioxazin	Paraquat	Acifluorfen + bentazon	99 a	97 a	100 a
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	100 a	84 b	100 a
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	100 a	96 a	100 a
Dimethenamid + flumioxazin	Bentazon + paraquat	Acifluorfen + bentazon	100 a	97 a	100 a

[a] Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] The PRE herbicide rates were dimethenamid at 1.4 kg ai ha^{-1}, diclosulam at 0.027 kg ai ha^{-1}, and flumioxazin at 0.071 kg ai ha^{-1}.

[c] The EPOST herbicide rates were paraquat at 0.14 kg ai ha^{-1} and bentazon at 0.28 kg ai ha^{-1} and included NIS at 0.25% (v/v).

[d] The POST herbicide rates were acifluorfen at 0.28 kg ai ha^{-1} and bentazon at 0.56 kg ai ha^{-1} and included NIS at 0.25% (v/v).

Table 6. Effect of PRE and POST herbicide systems on yield, herbicide application cost, and economic return at three North Carolina locations.[a]

Herbicides			Peanut yield				Economic return		
			Lewiston 1999	Rocky Mount 1999	Lewiston 2000	Production cost	Lewiston 1999	Rocky Mount 1999	Lewiston 2000
PRE[b]	EPOST[c]	POST[d]	kg ha^{-1}			\$ ha^{-1}	\$ ha^{-1}		
Dimethenamid	None	None	2270 d	1350 d	2890 c	1560	-60 d	-670 d	360c
Dimethenamid + diclosulam	None	None	3010 bc	5900 abc	6780 ab	1615	380 bc	2320 abc	2910 ab
Dimethenamid + flumioxazin	None	None	2730 cd	5580 bc	6830 ab	1585	230 cd	2140 bc	2980 ab
Dimethenamid	Paraquat	Acifluorfen + bentazon	3150 bc	5750 abc	6440 b	1602	480 abc	2220 abc	2690 b
Dimethenamid + diclosulam	Paraquat	Acifluorfen + bentazon	3740 a	6130 ab	6870 ab	1657	820 a	2430 ab	2920 ab
Dimethenamid + flumioxazin	Paraquat	Acifluorfen + bentazon	3560 ab	6300 a	7150 a	1627	730 ab	2570 a	3140 a
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	2740 cd	5300 c	7080 ab	1613	220 cd	1930 c	3130 a
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	3800 a	5490 c	7140 a	1667	870 a	2010 c	3110 ab
Dimethenamid + flumioxazin	Bentazon + paraquat	Acifluorfen + bentazon	3440 ab	5750 abc	6940 ab	1637	660 ab	2210 abc	3010 ab

[a] Values of yield and economic return within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] The PRE herbicide rates were dimethenamid at 1.4 kg ai ha^{-1}, diclosulam at 0.027 kg ai ha^{-1}, and flumioxazin at 0.071 kg ai ha^{-1}.

[c] The EPOST herbicide rates were paraquat at 0.14 kg ai ha^{-1} and bentazon at 0.28 kg ai ha^{-1} and included NIS at 0.25% (v/v).

[d] The POST herbicide rates were acifluorfen at 0.28 kg ai ha^{-1} and bentazon at 0.56 kg ai ha^{-1} and included NIS at 0.25% (v/v).

EVALUATION OF HERBICIDE PROGRAMS IN NO-TILL AND CONVENTIONAL TILLAGE CORN

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ABSTRACT

Experiments were conducted with corn at two sites in 2003 to compare glyphosate-based herbicide programs to conventional herbicide programs in conventional and no-till tillage systems. Herbicide treatments included: *s*-metolachlor plus atrazine preemergence (PRE) or no PRE; postemergence (POST) herbicide treatments were nicosulfuron plus rimsulfuron plus dicamba, glyphosate alone or with atrazine, and no POST herbicide; and postemergence-directed (PDIR) treatments included glyphosate, ametryn, or no PDIR herbicide. Entireleaf morningglory, ivyleaf morningglory, pitted morningglory, and tall morningglory where controlled 93% or greater 2 wk after POST herbicide application (WAP) with all treatments including POST herbicides. By 2 wk after PDIR herbicide treatment (WAPD), control was higher when a PDIR herbicides were applied. Broadleaf signalgrass, fall panicum, large crabgrass, and sicklepod were controlled 96% or greater 2 WAP with all treatments receiving a POST herbicide application. However, in the absence of a PDIR herbicide application, control was lower 2 WAPD. Palmer amaranth and common ragweed were controlled 99% or greater in the no-till tillage system by both herbicide programs, however in the conventional tillage system control was reduced with the conventional herbicide program compared to the glyphosate system. Smooth pigweed was controlled completely by both herbicide programs regardless of the tillage system used. Corn yield in the conventional tillage system was 1010 kg/ha higher than in the no-till. Net returns varied according to grain yield, which varied between tillage systems.

INTRODUCTION

Corn development and grain yield are influenced by the duration of weed interference, weed species, density, and the environment in which corn grows (Knake and Slife, 1961; Staniforth, 1957; Tapia et al., 1997; Vangessel et al., 1995; Young et al., 1984). Weeds compete with corn for sunlight, water, nutrients, and space. Numerous studies have shown that weed control early in the growing season is necessary to reduce yield losses in corn. Giant foxtail [*Setaria faberi* (L.) Herrm.], barnyardgrass [*Echinochloa cruss-galli* (L.) Beauvi.], and *Amaranthus* spp. emerging with corn reduced yields up to 13, 35, and 50%, respectively (Bosnic and Swanton, 1997; Fausey et al., 1997; Knake and Slife, 1965; Vizantinopoulos and Katranis, 1998). Carey and Kells (1995) found that a mixed weed population competing with corn until the weeds reached 20 cm tall reduced corn grain yield up to 20%.

Soil-applied herbicides, such as atrazine plus metolachlor or atrazine plus alachlor, have been used to control weeds in corn for many years, primarily because of their effectiveness and reasonable cost (Swanton et al., 2002). However, with reductions in atrazine use, due to limitations imposed because of atrazine found in ground water in areas of North Carolina and in other states (Cohen et al. 1986; Holden et al. 1992; Wade et al. 1998), growers are moving toward total POST weed management systems. Reduced tillage systems may help reduce growers' dependence on the use of PRE herbicides and help them transition into a total POST weed management program. In no-till tillage systems weed seedlings tend to emerge later, but at greater densities compared with conventional tillage systems (Halford et al., 2004). Also, in no-till systems, annual grass species often dominate the weed population (Johnson et al., 1998).

Applied POST, nicosulfuron is effective on many annual grass species (Tapia et al., 1997). However, there are limitations to using nicosulfuron. Nicosulfuron cannot be used on corn that has been treated with organophosphate insecticides because of the potential for interactions that negatively affect corn growth and development (Bailey and Kapusta, 1994; Kapusta and Krausz, 1992). However, glyphosate used in conjunction with glyphosate-resistant corn cultivars may allow growers to better control weeds in a no-till tillage system and still use organophosphate insecticides. Glyphosate-resistant (GR) corn would allow for a total POST herbicide program because of its broad spectrum of weed control, convenience of POST application without crop injury, and rotational crop flexibility (Ateh and Harvey, 1999; Culpepper and York, 1999; Culpepper et al., 2000).

Experiments were conducted to evaluate weed control, grain yield, and net economic returns in no-till and conventional tillage systems. Conventional and glyphosate-based herbicide programs were evaluated for each tillage system.

MATERIALS AND METHODS

The experiment was conducted in North Carolina at the Central Crops Research Station located near Clayton and at the Upper Coastal Plain Research Station located near Rocky Mount. Soils at Clayton and Rocky Mount were a Johns sandy loam (Fine-loamy over sandy or sandy skeletal, siliceous, thermic Aquic Hapludults) with 0.86% organic matter and pH 5.8 and a Goldsboro fine sandy loam (Fine-loamy, siliceous, thermic Aquic Paleudults) with 0.97% organic matter and pH 5.6, respectively.

Corn GR hybrids ‘DKC 69-71 RR/YG’ and ‘DKC 697' in 2003 were planted in mid-April. Plots were four rows 9 m long with row spaced 97 cm apart at Clayton and Goldsboro. Plots were conventionally tilled and bedded for the conventional tillage system or received a burndown herbicide application for the no-till system. No-till system was planted into a wheat cover crop after being bedded in the fall. Seed populations were 24,000 kernels per acre. No infurrow insecticide was applied. Soil amendments were applied according to North Carolina Department of Agriculture soil test recommendations.

Treatments are as follows: PRE herbicides were *S*-metolachlor plus atrazine at (1.1 + 1.4 kg ai/ha) or no PRE herbicide, POST herbicides were nicosulfuron plus rimsulfuron plus dicamba plus surfactant at [0.026+ 0.013 + 0.14 kg/ha + surfactant at 0.25% (V/V)], glyphosate at 0.8 kg ae/ha, or no POST herbicide; and PDIR herbicides were ametryn at 1.1 kg/ha, glyphosate at 0.8 kg/ha, or no PDIR herbicide treatment. Two non-treated checks were also included with each tillage system. PRE herbicides were applied at immediately after planting. PRE and POST herbicides were applied with a CO_2-pressurized backpack sprayer equipped with extended range flatfan nozzles delivering 140 L/ha at 160 kPa. Corn had 5 to 6 leaves when POST herbicides were applied. PDIR herbicide treatments were applied to 8- to 9-collar corn with a CO_2-pressurized backpack sprayer equipped with one flood nozzle per row calibrated to deliver 140 L/ha at 310 kPa.

The experimental design was a split split-block design with tillage systems as the main plot, hybrids as the sub-plot, and herbicide treatments as the sub sub-plot. Treatments at all locations were randomized four times except in Rocky Mount were treatments were replicated six times.

Morningglory species consisted of pitted morningglory (*Ipomoea lacunosa* L.), ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], and entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray) in both tillage systems. Annual grass species consisted of fall panicum (*Panicum dichotomiflorum* Michx.), large crabgrass [*Digitaria sanguinalis* (L) Scop.], and broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash]. Other weeds present included, Palmer amaranth [*Amaranthus palmeri* S. Wats.], smooth pigweed (*Amaranthus hybridus* L.), and common ragweed *(Ambrosia artemisiifolia* L.). Weed control was estimated visually 2 wk after POST application (WAP2), and 2 and 8 wk after PDIR application (WAPD) using a scale of 0 to 100 where 0 = no weed control and 100 = complete weed control or plant death (Frans et al., 1986). Annual grasses and morningglory species were evaluated as a category; no attempt was made to evaluate control of grasses and morningglories by species. The center two rows were harvested mechanically in mid-September and corn grain yields were adjusted to 15.5% moisture.

An enterprise budget for all herbicide inputs was calculated using prices from the HADSS[1] program for corn production in North Carolina. Additionally, available equipment from these budgets was used to calculate cost of disking land ($5.96/A), bedding land ($6.11/A), herbicide burndown, PRE, or POST application ($4.87/A), PDIR application ($3.71/A), planting crop ($6.57/A), and harvesting crop ($19.42/A) (Bullen, 2004). Costs were calculated for the 2003 growing seasons.

Data were subjected to analysis of variance, and treatment sums of squares were partitioned to reflect the split-plot design when evaluating herbicide system effects on GR corn. Non-transformed data for weed control are presented as arcsine square root transformation did not affect data interpretation. Means for all variables were separated using Fisher's Protected LSD Test at $P \leq 0.05$. Data from all non-treated checks were removed before analysis of variance was conducted.

RESULTS AND DISCUSSION

Corn Tests 2003.

There was a location by herbicide treatments within corn hybrid interaction for morningglory control 2 WAP, 2 WAPD, and 8 WAPD. The glyphosate herbicide system controlled morningglory 96 to 100% 2 WAP at both locations (data not shown). The conventional herbicide system controlled morningglory 72 to 100% 2 WAP. Differences among herbicides in the conventional program were due to treatments which only received *s*-metolachlor plus atrazine PRE and no POST herbicide. At Clayton, all glyphosate treatments controlled morningglory 97% or greater 2 WAPD except for the glyphosate POST only treatment. There were no differences in the glyphosate herbicide system at Rocky Mount. Trends remained the same for the conventional system at both locations , were the PRE herbicide only treatment was 22 to 24 percentage points lower than all other treatments.

There was a location by herbicide program interaction for control of annual grasses. Annual grass control was at least 80% (data not shown). However, the glyphosate POST only treatment and PRE herbicide only treatment controlled annual grasses less effectively than all other treatments 2 WAPD. Trends remained the same 8 WAPD.

Glyphosate controlled grasses completely 2 WAP at Rocky Mount. Additionally, *s*-metolachlor plus atrazine followed by nicosulfuron plus rimsulfuron plus dicamba controlled grasses 100%, which was better than all other conventional treatments 2 WAP. By 2 WAPD, glyphosate POST or glyphosate plus atrazine followed by glyphosate or ametryn PDIR controlled grasses 100%, which was greater than glyphosate or glyphosate applied POST alone. All conventional treatments

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[1] HADSS, Herbicide Decision Support System. 2004. Web page: http://www.hadss.com/.

controlled annual grass 99% or greater 2 WAPD, except for the PRE herbicide only treatment. Trends for annual grass were similar 8 WAPD.

There was a tillage by herbicide system interaction for control of Palmer amaranth. Therefore, data were pooled over herbicides within a system and locations. There were no differences in Palmer amaranth control among herbicide programs in the no-till tillage system (data not shown). However, in the conventional tillage system, the conventional herbicide controlled Palmer amaranth 97%. There were no differences in control 2 WAPD or 8 WAPD for control of this weed (Data not shown).

There were no differences in control of smooth pigweed. Smooth pigweed was controlled 100% with both herbicide systems 2 WAP, 2 WAPD, and 8 WAPD (data not shown). Tillage systems had no effect on control of smooth pigweed.

There was a location by herbicide system interaction for control of common ragweed. Data were pooled over herbicides within a system and tillage systems. There were no differences in control of common lambsquarters at Clayton (data not shown). However, at Rocky Mount the glyphosate herbicide system controlled common lambsquarters 99% or greater 2 WAP, while the conventional herbicide system controlled common lambsquarters 96% 2 WAP. This small difference could be due to glyphosate being very good at controlling *Amaranthus* spp (York, 2004). No differences were found for control of common lambsquarters 2 WAPD or 8 WAPD among treatments.

There was a location by tillage system interaction for corn grain yield. Data were pooled over hybrid and herbicide systems due to lack of interaction or main effect. Corn grain yield at Rocky Mount averaged 6640 and 6570 kg/ha for no-till and conventional tillage systems, respectively, with no differences between tillage systems (data not shown). However, at Clayton the conventional tillage system yielded 175 bu/A, which was 15 bu/A higher than the average yield for the no-till system.

There was a tillage system by herbicides interaction for net return. Net returns in the conventional system were similar for all treatments, ranging from $210 to $230/A (Table 5), except for the s-metolachlor plus atrazine PRE herbicide treatment followed by nicosulfuron plus rimsulfuron plus dicamba. Trends were similar within the no-till tillage system. However, net returns from the no-till systems averaged $20/A less than with the conventional tillage system. This is a direct reflection in the differences observed from the yields when comparing tillage systems.

Results from these experiments indicate that herbicide programs that include glyphosate can control weeds as effectively as conventional herbicide programs in both conventional and no-till tillage systems. Corn grain yields did not differ among herbicide systems. However, in 2003 yields did vary by tillage systems. Net returns were similar in the fact that they only varied with yield. Combining herbicide programs which include glyphosate plus a conventional herbicide that will increase morningglory control and provide some residual control. Under similar weed complexes this would be a better system than trying to go with a total glyphosate herbicide system.

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INFLUENCE OF COVER CROPS ON INSECT PESTS AND PREDATORS IN CONSERVATION-TILLAGE COTTON

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ABSTRACT

In the fall of 2000, an on–farm sustainable agricultural research project was established for cotton, *Gossypium hirsutum* L., in Tift County, Georgia. The objective of our 2-yr research project was to determine the impact of several cover crops on pest and predator insects in cotton. The five cover crop treatments included: 1) cereal rye, 2) crimson clover, 3) a legume mixture of balansa clover, crimson clover, and hairy vetch, 4) a legume mixture + rye combination, and 5) no cover crop in conventionally-tilled fields. Three main groups of pests were collected in cover crops and cotton: 1) the heliothines, *Heliothis virescens* (F.) and *Helicoverpa zea* (Boddie), 2) the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and 3) stink bugs. The main stink bugs collected were the Southern green stink bug, *Nezara viridula* (L.), the brown stink bug, *Euschistus servus* (Say), and the green stink bug, *Acrosternum hilare* (Say). For both years of the study, the heliothines were the only pests that exceeded their economic threshold in cotton, and the number of times this threshold was exceeded in cotton was higher in control cotton than in crimson clover and rye cotton. Heliothine predators and aphidophagous lady beetles occurred in cover crops and cotton during both years of the experiment. *Geocoris punctipes* (Say), *Orius insidiosus* (Say) and red imported fire ants, *Solenopsis invicta* Buren were relatively the most abundant heliothine predators observed. Lady beetles included the convergent lady beetle, *Hippodamia convergens* Guerin-Meneville, the seven-spotted lady beetle, *Coccinella septempunctata* [L.], spotted lady beetle, *Coleomegilla maculata* (De Geer) and the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas). Density of *G. punctipes* was higher in cotton fields previously planted in crimson clover compared to control cotton fields in 2001. Intercropping cotton in live strips of cover crop was probably responsible for the relay of *G. punctipes* onto cotton in these crimson clover fields. Conservation of the habitat of fire ants during planting probably was responsible the higher density of red imported fire ants observed in all conservation-tillage cotton fields relative to control cotton fields. Reduction in the number of times in which economic thresholds for heliothines were exceeded in crimson clover and rye compared to control fields indicated that the build up of predaceous fire ants and *G. punctipes* in these cover crops subsequently resulted in reduction in the level of heliothines in conservation-tillage cotton with these cover crops compared to conventional-tillage cotton without cover crops.

INTRODUCTION

As a result of frequent and intense disturbance, many agricultural systems are recognized as particularly difficult environments for natural enemies (Landis and Marino, 1999). Conservation tillage along with cover crops reduces this frequent disturbance and helps promote year-round natural enemy and pest species interactions by providing alternate prey or hosts, reproductive sites and protection from adverse conditions. Cover crops in reduced tillage systems offer a simple approach to pest management, but more information on the impact of cover crops on targeted pests and predators are needed to facilitate design of appropriate landscapes. A significant amount of research has been conducted on using rye, crimson clover and hairy vetch as cover crops in conservation-tillage systems the south (Reeves, 1994). Further research has focused on the use of these cover crops with conservation tillage in cotton, *Gossypium hirsutum* L., in the south to enhance beneficial insects (Bugg et al., 1991: McCutcheon et al., 1995: Ruberson et al., 1995; Ruberson et al., 1997; McCutcheon, 2000). Most studies have focused on comparisons among single species of legumes and non-legumes (Reeves, 1994). No studies have addressed the impact of using mixtures of legume species as winter cover crops in cotton on natural enemies even though they can provide a more diverse biological habitat through an extension of availability of nectar and other food sources (Altieri, 1995). The objective of our 2-yr on-farm research project in Tift County, Georgia was to determine the impact of cereal rye, crimson clover, a legume species mixture (balansa clover, crimson clover, and hairy vetch) and a combination of this legume mixture and rye on pest and predator insects in cotton.

MATERIALS AND METHODS

The five cover crop treatments included: 1) cereal rye 2) crimson clover, 3) legume mixture of balansa clover, crimson clover and hairy vetch, 4) legume mixture + rye combination, and 5) no cover crop in conventionally-tilled fields. The mixture of an early (balansa clover), mid (crimson clover) and late (hairy vetch) flowering legume was chosen to extend the availability of a habitat of flowering plants in the field that could be attained from planting any legume species alone. For the legume mixture-rye treatment, the rye was planted in the center of the row where the cotton would be planted in the summer while the legume mixture was planted on each side of the rye. The combination of the legume mixture and rye was chosen in an effort to combine the benefits of legume nectar production and N fixation with enhanced biomass production of rye.

Cover crops were planted in the fall using a grain drill. Rye and crimson clover treatments were planted at a rate of 56 and 16.8 kg of seeds per ha, respectively. For the legume mixture, rates of 1.01, 3.47, and 2.13 kg of seeds per ha were used for balansa clover, crimson clover, and hairy vetch, respectively. All of the cover crops, except for rye, were strip-killed in the center of the row with an herbicide approximately 2 weeks before cotton planting. In the spring of 2001, a 46-cm strip of cover crop was killed in the center of the row leaving a 46-cm strip of live cover crop between dead strips. In the spring of 2002, a strip of cover crop ca. 53 cm wide was killed in the center of the row leaving 38-cm strips of live cover crop.

Cotton was strip-tilled using cotton producers' strip-till rigs. Cotton was planted at 11.2 kg/ha on all fields using planters either during or after strip-tilling the cover crops. Cotton varieties included DP 458, DP 5415, DP 5690 and Delta Pearl. Cotton was harvested using cotton pickers. Four-row swaths of cotton 120–150 m long were picked in each field. Cotton was weighed immediately after machine harvest in the field to determine seed-cotton yields. Seed-cotton yield data were analyzed by PROC MIXED followed by least significant difference (LSD) separation of means (SAS Institute 1999) where appropriate. Fixed effects were cover crop treatments and random effects were cotton producers' fields and residual error.

Twenty fields were located in various locations in Tift County, Georgia. Large, 4-ha fields were used for each cover crop treatment to limit dispersal of predators from the fields. Each cover crop treatment was assigned randomly to 4 fields similar to a completely randomized design. In the second year of the project, one crimson clover and one rye field were eliminated from the study. The completely randomized design served as the main plot portion of the following split plot description. Each field was completely subdivided into 50 m^2 sampling plots. Insect pests and predators on plants were sampled each sampling week in each cover treatment for cover crops in the spring and cotton in the summer using sweep nets. In each field, 20 to 21 sampling plots were sampled. The experimental design describes a split plot in space (sampling location) and time (sampling weeks) with subsamples present in the sections.

Exhaustive whole plant sampling was done to monitor heliothine species in cotton. Sampling occurred weekly before the heliothines, *Heliothis virescens* (F.) and *Helicoverpa zea* (Boddie), occurred on cotton and biweekly thereafter. The sampling scheme was similar to that for sweep sampling, except that a single plant was sampled in each of the 50 m^2 sampling areas.

Insect pest and predator density data from sweep and whole plant samples were analyzed by PROC MIXED (SAS Institute, 1999) to obtain least squares means and their associated standard errors. Fixed effects were sample location, sample week, and sample location × sample week. Comparisons between least squares means between cover crop treatments were then performed for each crop type using one-tailed *t*-tests. Comparisons between least squares means were performed using square-root transformed data.

Economic threshold for heliothines was 5% infestation of first instars on cotton plants. For stink bugs (nymphs and adults), the economic threshold was 20% of the medium-sized bolls (ca. 14 d-old) with internal feeding damage. Economic threshold for the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (nymphs and adults), was considered to be reached when plants were retaining less than 85% of the pinhead squares. Economic threshold for the cotton aphid, *Aphis gossypii* Glover (all forms), was abundant aphids with slightly curled seedling leaves. The number of dates where the level of *H. virescens* and/or *H. zea* exceeded the economic threshold was analyzed by PROC GLM followed by LSD separation of means (SAS Institute 1999) where appropriate.

RESULTS AND DISCUSSION

Four main groups or species of pests were collected in sweep samples: 1) aphids, 2) tarnished plant bugs, 3) stink bugs and 4) the heliothines, *H. virescens* and *H. zea*. In our study the cotton aphid infested only cotton plants. The main stink bugs collected in this study were the Southern green stink bug, *Nezara viridula* (L.), the brown stink bug, *Euschistus servus* (Say) and the green stink bug, *Acrosternum hilare* (Say). For both years of the study, the heliothines were the only pests that exceeded their economic threshold in cotton. The number of times in which the heliothines exceeded their economic threshold in cotton was significantly higher in control cotton than in crimson clover and rye cotton in 2001 ($F = 3.04$, df = 4, 13, $P = 0.05$) and 2002 ($F = 3.07$, df = 4, 13, $P = 0.05$) (Table 1).

The main predators in cover crops and cotton during both years of the experiment were heliothine predators and aphidophagous lady beetles. The major heliothine predators were *G. punctipes*, *O. insidiosus* and red imported fire ants, *Solenopsis invicta* Buren. Lady beetles included the convergent lady beetle, *Hippodamia convergens* Guérin-Méneville, the seven-spotted lady beetle, *Coccinella septempunctata* [L.], spotted lady beetle, *Coleomegilla maculata* (De Geer) and the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas).

Red imported fire ants were highest in the legume mixture and lowest in the rye in comparisons among the four cover crop treatments in the spring of 2001 (Table 2). Crimson clover was the only cover crop in which fire ants were present every sampling period. The next spring, fire ants were not significantly different in crimson clover, the legume mixture and the legume-rye combination, but significantly lower in the legume mixture compared to the other three cover crops (Table 3). In the summer of both years of the study, red imported fire ant were significantly greater in conservation-tillage cotton fields planted with cover crops than in conventional-tillage cotton fields left fallow during the winter (Tables 2 and 3). In the summer of 2001, crimson clover and rye cotton harbored significantly higher numbers of the red imported fire ants than legume and legume-rye cotton. The next cotton season, though, numbers of this predator were significantly lower in rye than in the other three treatments with cover crops.

For both years, crimson clover and the legume mixture cover crops harbored significantly higher numbers of *G. punctipes* and *O. insidiosus* compared to the two cover crop treatments with rye, and numbers of these two predators were significantly greater in the legume-rye combination treatment than in rye (Tables 2 and 3). Only the crimson clover and legume cover crop treatments harbored significantly higher numbers of *G. punctipes* in the cover crops in the spring compared to cotton in the summer. All legume treatments harbored significantly higher numbers of *O. insidiosus* in the cover crops compared to cotton. In the spring of 2001, *G. punctipes* was significantly higher in crimson clover treatments than in any of the other cover crop treatments indicating that this predator was highly attracted to this legume (Tables 2). In 2001, density of *G. punctipes* was significantly higher in cotton fields previously planted in crimson clover compared to control cotton fields. In contrast, for both years of the study there was no significant difference in number of *O. insidiosus* between crimson clover cotton and control cotton.

For both years, crimson clover and the legume mixture harbored significantly higher levels of lady beetles compared to the two cover crop treatments with rye indicating that the legumes were a more suitable habitat for lady beetles than the grass in the spring (Tables 2 and 3). In 2001, the number of lady beetles was significantly higher in cotton for all cover crop treatments, except the legume mixture, than for the cover crops in the spring. Nevertheless, the number of lady beetles in control fields was still significantly higher than in the other four cover crop treatments in cotton. In 2002, the number of lady beetles was significantly higher in cotton than in cover crops for only the legume-rye and rye treatments. In cotton, lady beetles were significantly higher in rye cotton than in cotton intercropped in the three other cover crops, but no significant differences occurred in numbers of lady beetles between the fields with cover crops and control fields.

Seed-cotton yields were significantly different among treatments for 2001 (F= 4.07, df = 4, 25, P = 0.01) and 2002 (F = 6.2, df = 4, 17, P = 0.01) (Table 4). In the first year of the test, seed-cotton yields were significantly higher for cotton with crimson clover and legume mixture-rye combination than for control cotton without cover crops while the yields for the legume mixture and rye treatments were not significantly different from those for the controls. In 2002, all cover crop cotton fields, except for the rye fields, had significantly higher seed-cotton yields compared to control fields. Since yields for cover crop treatments were never lower than those for control cotton, we concluded that planting cotton in strip-killed/tilled cover crops did not adversely affect cotton production.

In this on-farm study, we compared conventional tillage and winter-fallow practices to strip-tillage with four diverse cover crops designed to enhance natural enemies in cotton by promoting the increase of populations of these natural enemies in the spring and encouraging these natural enemies to relay from the spring cover crops into cotton. The goal of mixing the three legume species was to extend flowering to promote better relay of predators from the cover crop to cotton. Timing of initial flowering and seasonal succession of flowering for these cover crops occurred so that the numbers of *G. punctipes*, *O. insidiosus* and lady beetles built up in the spring in the cover crops especially in the legume mixture and crimson clover treatments. By strip-killing and strip-tilling the legume cover crops, a live strip of cover crop was available as a habitat for the natural enemies in the late spring when cotton was planted.

Enhancement of *G. punctipes* in conservation-tillage cotton has not been previously reported for this predator for any cover crop. Gaylor et al. (1984) reported that at the time of peak heliothine population density on cotton, significantly more predators, *Geocoris* spp. and spiders, existed on cotton in the conventional tillage treatments than in the conservation tillage treatments with cover crops. The stressed condition of the cotton grown under conservation-tillage with crimson clover as a cover crop may have been responsible for the lower populations of these predators observed in crimson clover cotton compared to control cotton. Ruberson et al. (1995) reported that in the summer of 1994 populations of *G. punctipes* were reduced in a conservation-tillage cotton field relative to a conventional-tillage cotton field. In a second study conducted by Ruberson et al. (1997) no differences in *G. punctipes* populations were detected between crimson clover cotton and conventional-tillage cotton without a cover crop. In our study, we maintained a strip of live crimson as a habitat for *G. punctipes* whereas in the other reported studies the crimson clover was completely killed before planting the main crop. Maintaining this live strip of cover crop was probably responsible for the relay of *G. punctipes* in crimson clover cotton fields.

Conservation of habitat of fire ants during planting probably was responsible the higher density of red imported fire ants in conservation-tillage cotton with cover crops relative to control cotton. Similarly, Ruberson et al. (1995) reported that the presence of red imported fire ants in clover fields might have been a function of reduced tillage than use of the cover crop. McCutcheon et al. (1995) demonstrated that densities of the red imported fire ant were highest in cotton in non-cultivated plots that had a crimson clover cover than in cultivated plots. In a later study, McCutcheon (2000) determined that fire ants were more abundant in rye/no-till treatments than in rye/disk treatments.

Reduction in the number of dates in which economic thresholds for heliothines were exceeded in crimson clover and rye compared to control fields indicates that the build up of predaceous fire ants and *G. punctipes* in crimson clover and rye subsequently resulted in reduction in the level of heliothines in these cover crop compared to control cotton fields. *Geocoris punctipes* is known to be one of the most predominant and effective predators of *H. zea* and *H. virescens* in cotton (Bell and Whitcomb, 1963; Lopez et al., 1976), and fire ants have been reported to be excellent predators of a variety of cotton pests (Showler and Reagan, 1987). McCutcheon et al.'s (1995) report that the higher densities of fire ants in non-cultivated compared to cultivated plots possibly resulted in the reduced densities of heliothine eggs in non-cultivated plots versus cultivated ones is in agreement with our conclusions about the suppressive activity of fire ants against heliothines in conservation tillage cotton.

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Table 1. Mean number of dates in which heliothines exceeded the economic threshold in cotton for all cover crop treatments in 2001 and 2002

	Times exceeded economic threshold in 2001		Times exceeded economic threshold in 2002	
Treatment	**n[a]**	**Mean**	**n[a]**	**Mean**
Control	**4**	**2.0 ± 0.41a**	**4**	**3.3 ± 0.63a**
Legume mixture[b] + rye	**3**	**1.3 ± 0.33ab**	**4**	**2.3 ± 0.48ab**
Legume mixture	**4**	**1.0 ± 0.41 ab**	**4**	**2.0 ± 0.41ab**
Crimson clover	**4**	**0.75 ± 0.25b**	**3**	**1.7 ± 0.33b**
Rye	**3**	**0.3 ± 0.33b**	**3**	**1.0 ± 0.33b**

Means within a column followed by the same letter are not statistically different between treatments (PROC GLM, LSD, $P > 0.05$).

[a] Refers to the number of fields for each cover crop treatment.

[b] Legume mixture = balansa clover, crimson clover and hairy vetch.

Table 2. Least squares means for predators in sweep samples in all cover crops treatments in 2001

Crop type	Treatment	n[a]	Fire ants	N	*G. punctipes*	n	*O. insidiosus*	n	Lady beetles
Cover crop	Legume mixture[b]	1067	0.61 ± 0.02a2	1067	0.77 ± 0.03b1	780	1.55 ± 0.06a1	1067	0.96 ± 0.03a1
	Crimson clover	1004	0.56 ± 0.01b2	1004	0.86 ± 0.02a1	1004	0.97 ± 0.03b1	1004	0.74 ± 0.02b2
	Legume[c] + rye	738	0.56 ± 0.02b2	738	0.53 ± 0.01c2	536	0.70 ± 0.03c1	738	0.67 ± 0.02c2
	Rye	724	0.51 ± 0.01c2	362	0.51 ± 0.01d2	724	0.55 ± 0.01d1	724	0.65 ± 0.02c2
Cotton	Legume mixture	439	1.00 ± 0.06b1	439	0.66 ± 0.03ab2	439	0.51 ± 0.01b2	439	0.88 ± 0.04c1
	Crimson clover	384	1.22 ± 0.07a1	384	0.75 ± 0.03a2	384	0.54 ± 0.02a2	384	0.91 ± 0.04bc1
	Legume + rye	315	1.04 ± 0.06b1	315	0.65 ± 0.03b1	315	0.52 ± 0.01ab2	315	0.90 ± 0.04bc1
	Rye	315	1.23 ± 0.07a1	315	0.67 ± 0.03ab1	315	0.54 ± 0.02ab1	315	1.01 ± 0.06b1
	Control	420	0.76 ± 0.03c	420	0.63 ± 0.03b	420	0.59 ± 0.02ab	420	1.19 ± 0.04a

Least squares means within a column followed by the same number are not significantly different between crop types for a single cover crop treatment, and least squares means within a column followed by the same letter are not significantly different between cover crop treatments for a single crop type (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

[a] Refers to the number of sweep samples for each cover crop treatment field for each sampling location for each sampling week. Degrees of freedom for rye and legume mixture + rye treatments are n-30 for cover crop type. Degrees of freedom for crimson clover and the legume mixture are n-33 for cover crop type. Degrees of freedom for all treatments in the cotton crop type are n-15.

[b] Legume mixture = balansa clover, crimson clover and hairy vetch.

[c] Legume mixture.

Table 3. Least squares means for predators in sweep samples in all cover crops treatments in 2002

Crop type	Treatment	n[a]	Fire ants	n	*G. punctipes*	n	*O. insidiosus*	n	Lady beetles
Cover crop	Legume mixture[b]	891	0.53 ± 0.01b2	891	0.90 ± 0.02a1	891	0.94 ± 0.02b1	891	0.75 ± 0.02a1
	Crimson clover	729	0.58 ± 0.01a2	729	0.88 ± 0.02a1	729	1.03 ± 0.02a1	729	0.76 ± 0.02a1
	Legume[c] + rye	891	0.57 ± 0.01a2	891	0.54 ± 0.01b1	891	0.58 ± 0.01c1	891	0.61 ± 0.01b2
	Rye	729	0.57 ± 0.01a2	405	0.51 ± 0.01c2	567	0.55 ± 0.01d1	729	0.57 ± 0.01b2
Cotton	Legume mixture	336	0.86 ± 0.03ab1	336	0.58 ± 0.01a2	192	0.55 ± 0.01a2	336	0.71 ± 0.02b2
	Crimson clover	264	0.87 ± 0.03ab1	264	0.60 ± 0.01a2	120	0.51 ± 0.01b2	264	0.70 ± 0.03b2
	Legume + rye	336	0.91 ± 0.03a1	264	0.53 ± 0.01b1	264	0.53 ± 0.01b2	336	0.75 ± 0.02b1
	Rye	264	0.80 ± 0.03b1	192	0.59 ± 0.02a1	264	0.55 ± 0.01a1	264	0.88 ± 0.03a1
	Control	192	0.59 ± 0.02c	336	0.58 ± 0.01a	336	0.56 ± 0.01a	336	0.77 ± 0.02ab

Least squares means within a column followed by the same number are not significantly different between crop types for a single cover crop treatment, and least squares means within a column followed by the same letter are not significantly different between cover crop treatments for a single crop type (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

[a] Refers to the number of sweep samples for each cover crop treatment field for each sampling location for each sampling week. Degrees of freedom for all treatments are n-27 for cover crop type. Degrees of freedom for all treatments in the cotton crop type are n-12.

[b] Legume mixture = balansa clover, crimson clover and hairy vetch.

[c] Legume mixture.

Table 4. Least squares means for seed-cotton yield for all cover crop treatments in 2001 and 2002

	Seed-cotton yield (kg/ha) 2001		Seed-cotton yield (kg/ha) 2002	
Treatment	**n**[a]	**Mean ± SE**	**n**	**Mean ± SE**
Crimson clover	**3**	**3778.2 ± 249.6a**	**3**	**2026.2 ± 235.8a**
Legume mixture[b] **+ rye**	**3**	**3586.0 ± 249.6ab**	**3**	**2161.3 ± 164.1a**
Rye	**3**	**3304.2 ± 249.6abc**	**3**	**1390.4 ± 222.8b**
Legume mixture	**4**	**3045.4 ± 222.8bc**	**4**	**2031.0 ± 244.4a**
Control	**4**	**2822.2 ± 222.8c**	**4**	**1072.4 ± 57.3b**

Least square means within a column followed by the same letter are not significantly different between treatments (PROC MIXED, LSD, $P > 0.05$).

[a] Refers to the number of fields for each cover crop treatment.

[b] Legume mixture = balansa clover, crimson clover and hairy vetch.

EVALUATION OF WEED CONTROL PROGRAMS AND SALT FORMULATIONS IN GLYPHOSATE-RESISTANT COTTON

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ABSTRACT

The purpose of this study was to evaluate the influence of glyphosate and glyphosate potassium salt on weed control, plant growth and yields of glyphosate-resistant cotton (*Gossypium hirsutum* L.). Field research was conducted at the University of Florida's North Florida Research and Education Center in Quincy, FL in 2002. Evaluated treatments were glyphosate and glyphosate potassium salt herbicides at 0.38, 0.56, and 0.75 lb ae/A, and glyphosate and glyphosate potassium salt herbicides at 0.75 lb ae/A with ammonium sulfate at 2% v/v. The sicklepod (*Cassia obtusifolia* L.) weed control was generally great, except less control for treatments with glyphosate at 0.75 lb ae/A and glyphosate potassium salt at 0.38 ae/A (68 and 75%, respectively) at 10 days after treatment (DAT). However, sicklepod control was not significantly different among herbicide treatments at 21 DAT. Dayflower (*Commelina communis* L.) control was great for most herbicide treatments, except least control obtained with glyphosate application at 0.56 lb ae/A at 10 and 21 DAT (53 and 76%, respectively). Ammaranth spp. (*Amaranthus* ssp.) control was above 90% for all herbicide treatments. Compared to glyphosate treatment at 0.56 lb ae/A, the application of glyphosate potassium salt at 0.56 lb ae/A increased boll number per cotton plant from 8.4 to 11.6 bolls/plant and lint cotton yields from 445 to 609 lb/A, respectively. However, cotton lint yields decreased from 559 lb/A to 381 lb/A when ammonium sulfate (2% v/v) was mixed with glyphosate potassium salt (0.75 lb ae/A). The results of this study indicate that application of glyphosate potassium salt may help to increase the boll number and lint yields of glyphosate-resistant cotton.

INTRODUCTION

With the recent introduction and growing interest in glyphosate-resistant cotton more herbicide programs are needed to effectively control weeds. Glyphosate-resistant cotton has been available for research testing at Universities since 1995 (Hayes et al., 1996). Glyphosate-resistant cotton was introduced to farmers in 1997 with little variety trial testing (May et al., 2000). Generally, glyphosate can be applied broadcast up to the four-leaf stage and followed by post-directed application in glyphosate resistant cotton (Kerby and Voth, 1998). Foliar herbicide applications were intended to replace soil-applied herbicides used in standard systems (Askew and Wilcut, 1999), because weed management systems that included a post-directed or postemergence herbicide application provided greater weed control than those with preemergence herbicides only (Vencill et al., 1994). According to McCarty (1997), a glyphosate weed control program may allow the reduction of herbicide rates or the elimination of certain preemergence herbicides in sandy, low organic matter soils, thereby preventing herbicide injury to seedlings. The objective of this study was to evaluate treatments with glyphosate, glyphosate potassium salt, and a mix of these herbicides with ammonium sulfate on weed control, plant growth, and yields of glyphosate-resistant cotton.

METHODS AND MATERIALS

Field research with glyphosate-resistant cotton was conducted during 2002 on a Dothan sandy loam (fine, loamy siliceous, thermic Plinthic Kandiudults) at the North Florida Research and Education Center / University of Florida in Quincy, FL. The rows were ripped with the Brown Ro-till implement (Brown Manufacturing Co., Ozark, AL) on 15 April. The following day, the study was fertilized with 5-10-15 ($N-P_2O_5-K_2O$) at 500 lbs/A material and planted with DP 458 B/RR cotton at 4 seeds/ft of row and 36 inch row spacing using a Monosem air planter. Herbicide treatments were applied broadcast postemergence in cotton on 7 May (the targeted weed species were approximately 2 - 4 inch tall). The experiment was sprayed with mepiquat chloride (0.7 oz a.i./A) + Induce (0.5% v/v) on 12 June and 3 July, and mepiquat chloride (0.35 oz a.i./A) + Agridex (0.5% v/v) on 23 July to control plant height. Cotton was defoliated with ethephon (1.14 lb a.i./A) + thidiazuron (0.1 lb a.i./A) on 17 September and picked with the International Spindle Picker on 23 October. Cotton was irrigated with 0.5 and 0.6 inch water on 18 April and 4 June, respectively.

Sickepod, dayflower, and amaranth spp. weed control was evaluated at 10 and 28 days after treatment (DAT) application. Weeds were evaluated based on the visual scale from 0 (no weed control) to 100% (complete weed control). The plant height, node number and plant ratio (plant height divided by node number) were obtained at 90 and 150 days after planting. The number of bolls per plant was recorded at 120 days after planting. Lint yields were calculated by multiplying seed cotton yields by lint percent.

The experimental design was a Randomized Complete Block with four replications. Data were analyzed using the general linear models (SAS, 1999), and means were separated using Fisher's Least Significant Difference Test ($P \leq 0.05$).

RESULTS AND DISCUSSION

The influence of herbicide treatment on weed control at 10 and 28 days after treatment (DAT) application is shown in Table 1. The sicklepod weed control was generally great for most herbicide treatments at 10 and 21 DAT. Among herbicide treatments, the least sicklepod control was obtained with glyphosate at 0.75 lb ae/A and glyphosate potassium salt at 0.38 ae/A (67.5 and 75.0%, respectively) at 10 DAT. However, at 21 DAT, sicklepod control was not influenced by herbicide treatment. Dayflower control was also great for most herbicide treatments, except least control with glyphosate application at 0.56 lb ae/A at 10 and 21 DAT. Among herbicide treatments, amaranth spp. control was above 90% with the least control for treatment with the application of glyphostate at 0.38 lb ae/A at 10 DAT and 28 DAT, and glyphosate potassium salt at 0.56 lb ae/A at 28 DAT. The herbicide treatment of glyphosate potassium salt at 0.38 lb ae/A provided greater (100%) amaranth ssp. control than glyphosate application at 0.38 lb ae/A (93.2%). Vencill et al. (1994) also noted that weed management systems that included a postemergence herbicide application provided great weed control. According to Wiatrak et al. (2002), post applications of glyphosate provided weed control ranging from 82 to 89%.

Glyphosate-resistant cotton plant height and node number at 90 and 150 DAP, and plant ratio at 90 DAP were greater from herbicide treatments than the untreated control (Table 2). Plant ratio at 150 DAP was generally high, except the plant ratio for untreated check and treatments with glyphosate potassium salt at 0.56 lb ae/A and glyphosate application at 0.56 lb ae/A. However, Wiatrak et al. (2002) showed no significant influence of herbicide treatment on cotton plant height, node number, and plant ratio 90 DAP.

Boll number per plant was relatively high, except least number from untreated control and treatments with glyphosate potassium salt at 0.75 lb ae/A + ammonium sulfate and glyphosate at 0.56 lb ae/A (Table 2). Moreover, application of glyphosate potassium salt at 0.56 lb ae/A significantly increased boll number per plant compared to the treatment with glyphosate at 0.56 lb ae/A. Herbicide treatment did not affect percent lint. Greatest lint yields of cotton were obtained from treatments with glyphosate potassium salt at 0.56 lb ae/A, glyphosate at 0.75 lb ae/A, glyphosate potassium salt at 0.75 lb ae/A, glyphosate potassium salt at 0.38 lb ae/A, and glyphosate at 0.75 lb ae/A + ammonium sulfate at 2% v/v.

CONCLUSIONS

Generally, weed control was relatively high with the application of most herbicide treatments. At 10 and 28 DAT, herbicide treatments provided at least 68 and 71% sicklepod control, 53 and 76% dayflower control, and 93 and 92% amaranth ssp. weed control, respectively. Glyphosate-resistant cotton plant height, node number, and plant ratio were greater from herbicide treatments than untreated control at 90 and 150 DAP, except less plant ratio for untreated control and treatments with glyphosate potassium salt at 0.56 lb ae/A and glyphosate at 0.56 lb ae/A at 150 DAP. Compared to the treatment with glyphosate at 0.56 lb ae/A, glyphosate potassium salt at 0.56 lb ae/A significantly increased the number of bolls per plant and lint yields of cotton.

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Table 1. Influence of herbicide treatment on sicklepod, dayflower, and amaranth ssp. control at 10 and 28 days after treatment (DAT) application at Quincy, FL.

Product	Rate	Sicklepod control (DAT)		Dayflower control (DAT)		Amaranth ssp. control (DAT)	
	lb ae/A	10	28	10	28	10	28
Glyphosate	0.38	85	85	66	81	93	93
Glyphosate	0.56	90	84	53	76	100	100
Glyphosate	0.75	68	88	81	95	100	98
Glyphosate potassium salt	0.38	75	88	68	85	100	98
Glyphosate potassium salt	0.56	79	71	58	84	95	92
Glyphosate potassium salt	0.75	98	89	73	93	95	100
Glyphosate + amm. sulfate (2% v/v)	0.75	79	89	71	94	100	100
Glyphosate potassium salt + amm. sulfate (2% v/v)	0.75	84	75	65	95	100	100
Untreated control	-	0	0	0	0	0	0.0
$LSD_{(0.05)}$		21	21	27	14	5	6

Table 2. Influence of herbicide treatment on plant height, node number, and plant ratio (plant height / node number) at 90 and 150 days after planting (DAP), and yields and percent lint of glyphosate-resistant cotton at Quincy, FL.

Product	Rate	90 DAP			150 DAP			Boll number	Percent lint	Lint yield
	lb ae/A	Plant height	Node number	Plant ratio	Plant height	Node number	Plant ratio			
		- inch -	#/plant	- ratio -	- inch -	#/plant	- ratio -	#/plant	-- % --	- lb/A -
Glyphosate	0.38	31.0	18.1	1.72	35.9	23.8	1.51	9.5	43.4	442
Glyphosate	0.56	29.9	17.3	1.73	35.4	24.2	1.46	8.4	46.2	445
Glyphosate	0.75	32.2	17.8	1.82	36.9	23.4	1.58	11.0	42.7	574
Glyphosate potassium salt	0.38	31.2	17.7	1.76	36.6	23.9	1.53	9.7	44.7	557
Glyphosate potassium salt	0.56	31.6	18.0	1.76	35.2	24.3	1.45	11.6	43.6	609
Glyphosate potassium salt	0.75	31.1	17.3	1.80	36.2	22.8	1.59	9.3	42.4	559
Glyphosate + amm. sulfate (2% v/v)	0.75	32.0	17.9	1.79	37.5	24.0	1.57	10.7	39.1	480
Glyphosate potassium salt + amm. sulfate (2% v/v)	0.75	31.9	17.7	1.80	35.2	22.8	1.55	8.3	38.0	381
Untreated control	-	21.1	13.0	1.60	23.4	18.4	1.27	2.5	40.9	123
LSD$_{(0.05)}$		2.71	1.08	0.12	2.9	1.9	0.09	3.2	NS	144

ESTABLISHMENT OF NON-TOXIC NOVEL ENDOPHYTE TALL FESCUE

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ABSTRACT

Toxic tall fescue (*Festuca arundinacea*) infected with the *Neotyphodium coenophialum* endophyte reduces animal gain, calf crop, milk production, and can be lethal to mares and foals. Destruction of the stand eliminates forage production for six to twelve months. The advent of glyphosate tolerant corn (*Zea mays*) and soybean (*Glycine max)* opens up new possibilities for toxic tall fescue renovation. A pasture containing toxic tall fescue was sprayed with paraquat in March and glyphosate tolerant corn and soybean were no-till planted in April. Glyphosate was applied in May. The corn and soybean were harvested for grain in September. MaxQ tall fescue was planted in October. Half the plots were also over-seeded to wheat. Forage yield of tall fescue and wheat were determined twice each spring for two years. Stand of tall fescue was evaluated after one year. The entire sequence of killing toxic tall fescue, planting corn and soybean, and planting tall fescue and wheat was repeated over two years. Inclusion of wheat increased first year forage yield without substantial effects on tall fescue stand. Forage yield was 162 to 188% greater following soybean compared with following corn.

INTRODUCTION

Summer annual crops have been used successfully to destroy existing tall fescue (Defelice and Henning, 1990; Munson and Bailey, 1991; Bagegni et al, 1994). Corn and soybean can be successfully grown as cash crops in tall fescue pastures (Broome et al, 2000). Glyphosate tolerant corn and soybean has opened the way for new renovation sequences for destroying toxic tall fescue infected with the *Neotyphodium coenophialum* endophyte (Triplett et al, 2002). Corn and soybean offer the potential for a cash crop thereby reducing the cost of destruction and reestablishment of tall fescue. Alternately, corn and soybean can be grazed by heavy stocker steers from July to October (Lang et al, 2003).

The toxicity of tall fescue has been eliminated with the discovery of novel non-alkaloid producing endophyte lines (Latch (1997; Bouton et al. 2002). The objective of this study was to re-establish non-toxic tall fescue following glyphosate tolerant corn and soybean.

MATERIALS AND METHODS

In early April of 2001 and 2002, glyphosate tolerant corn and soybean were no-tillage planted into pastures containing both tall fescue and warm season perennial grasses on a Bude silt loam soil (fine, silty, mixed, thermic, Glossaquic Fragiudalf) at the Pontotoc Flatwoods-Ridge Experiment Station. Paraquat at 1.5 pts/Acre was applied in April followed by glyphosate at 1.5 qts/Ac in May. New land was utilized each year. Following grain harvest, 'Jessup' MAXQ tall fescue was no-tillage drilled at 25 lbs/Ac in October of each year. There were four replications of each of each planting mixture in a strip-block design across ten soybean herbicide combinations and 15 corn herbicide combinations (reported elsewhere, Shankle et al., 2003). Herbicide treatments were randomized within 10x40" plots within each replicate while strips of 'Mixed' wheat (*Triticum aesitivum*) at 60 lbs/Ac were no-tillage drilled parallel to the rows of tall fescue. Half of each plot was planted to tall fescue alone.

Stand of tall fescue and wheat was determined visually as a percentage of ground cover; botanical composition was estimated visually. Herbage yield was determined by clipping in February and April in 2002 and in March and May in 2003. Data were analyzed as a strip plot design with mean separation by Fisher's LSD (P,0.05).

RESULTS AND DISCUSSION

Soybean yield was 30-35 bu/Ac and corn yield was 90-120 bu/Ac each year (Shankle et al., 2003). Control of existing tall fescue was 90 to 100 % (Triplett et al, 2002). An excellent stand ((82-88 %) of MAXQ tall fescue was obtained in 2002 following corn or soybean (Tables 1 and 2). In 2003 tall fescue stand was good (50-68 %) following corn or soybean (Tables 3 and 4). Inclusion of wheat only slightly reduced tall fescue stand both years, however, the reduction was not substantial.

Inclusion of wheat increased forage yield by 338 % following corn and by 234 % following soybean in 2002. In 2003, inclusion of wheat increased forage production by 212 % following corn, but yield was reduced by inclusion of wheat following soybean by 4.5 %. Total forage yield in 2002 was 188 % greater following soybean compared forage yield following corn. In 2003 total forage yield was 162 % greater following soybean compared with forage yield following corn. This was likely due to soil nitrogen status differences following soybean and corn.

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Table 1. Effect Of Planting Mixture on Tall Fescue Stand and Yield Following Corn at Pontotoc, MS, 2002.

Planting Mixture	**TF Stand**		**TF Yield**		Wheat		Total Yield
	February	April	February	April	February	April	
	%		**Lb/Acre**				
Tall Fescue	78	88	NH[†]	102	0	0	388
TF + Wheat	60	86	27	78	239	540	1311
LSD $_{(0.05)}$	5	2	NA[‡]	27	**NA**		172

[†] NH = Not Harvested

[‡] NA = Not Applicable

Table 2. Effect Of Planting Mixture on Tall Fescue Stand and Yield Following Soybean at Pontotoc, MS, 2002.

Planting Mixture	**TF Stand**		**TF Yield**		Wheat		Total Yield
	February	April	February	April	February	April	
	%		**Lb/Acre**				
Tall Fescue	84	86	NH	344	0	0	1010
TF + Wheat	75	82	96	266	892	280	2360
LSD $_{(0.05)}$	8	7	NA	79	**NA**[†]		872

[†] NA = Not Applicable

Table 3. Effect Of Planting Mixture on Tall Fescue Stand and Yield Following Corn at Pontotoc, MS, 2003.

Planting Mixture	**TF Stand**		**TF Yield**		Wheat		Total Yield
	March	May	March	May	March	May	
	%		**Lb/Acre**				
Tall Fescue	51	59	862	1555	0	0	2417
TF + Wheat	39	50	370	868	2701	1193	5132
LSD $_{(0.05)}$	7	7	241	282	**NA**[†]		872

[†] NA = Not Applicable

Table 4. Effect Of Planting Mixture on Tall Fescue Stand and Yield Following Soybean at Pontotoc, MS, 2003.

Planting Mixture	**TF Stand**		**TF Yield**		Wheat		Total Yield
	March	May	March	May	March	May	
	%		**Lb/Acre**				
Tall Fescue	ND	68	1417	4143	0	0	6275
TF + Wheat	ND	57	966	2823	402	1176	5992
LSD $_{(0.05)}$		9	147	429	**NA**[†]		595

[†] NA = Not Applicable

EFFECTIVENESS IN TERMINATING COVER CROPS USING DIFFERENT ROLLER IMPLEMENTS

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ABSTRACT

Rollers may provide a valuable alternative to herbicides for terminating cover crops, however, research has shown that excessive vibration that is caused by the roller passing over the cover crop. To avoid excessive vibration, users must limit their operational speed which reduces the number of producers willing to use this technology. To improve the roller's performance, three different rollers designs were compared: (1) a roller with long blunt ¼ inch steel angle bars equally spaced), (2) a roller with elliptical blunt bars, and (3) a smooth roller with an oscillating crimping bar behind the roller. Preliminary data have shown that the smooth roller with crimping arm produced the highest kill rate of the cover crop (rye, *Cecale cereale L.*). Data indicate that operating rollers at higher speed (5 MPH) produced significantly higher kill rate of the cover crop compared to low speed (1 MPH). Also, the kill rate evaluated at the end of second week from rolling/crimping was 2 times higher as compared to the kill rate at the end of the first week. The minimum vibration levels measured on tractor's frame were produced by smooth roller with oscillating crimping arm. This study provides valuable information to further improve mechanical rollers' effectiveness to terminate cover crops and to give design guidance to researchers who are in the process of developing a mechanical roller widely acceptable to producers in conservation systems.

INTRODUCION

Cover crops are a vital part of conservation tillage systems, but they have to be managed appropriately to get their full benefit. This includes weed pressure reduction and improving soil properties, caused by alleopathy, mulch affects, and increased soil organic matter. In the Southern United States, rye is commonly used as a winter cover crop. Timely termination of cover crops before cash crop planting provides maximum benefits to the main crop (i.e. cotton). Mechanical rollers have been used in some conservation systems but high vibrations and low operating speeds associated with current roller designs have resulted in a low rate of adoption by farmers.

A report by CTIC (2003) shows that between 1990 and 2002, the number of U.S. cropland acres planted in conservation systems without surface tillage increased from 73.2 million acres to 103.1 million acres. This significant increase can be attributed by positive benefits of winter cover crops as an integral component of conservation tillage systems. Several studies have identified these benefits, such as increased water infiltration, reduced runoff, reduced soil erosion, and reduced detrimental effects of soil compaction (Reeves, 1994; Raper et al., 2000a; Raper et al., 2000b).

Most agricultural extension services recommend terminating the cover crop at least two weeks prior to planting the cash crop. This should prevent the cover crop from using valuable spring moisture that could be used by the main cash crop after planting. Killing cover crops has been accomplished mainly by use of herbicides, since spraying is relatively fast and inexpensive. However, for a cover crop (rye) that is very tall and lodged in multiple directions planting may be affected. According to Raper (2004) flattening and crimping cover crops by mechanical rollers is widely used in South America, especially Brazil to successfully terminate cover crops without a need to use herbicides.

Because of potential environmental and monetary benefits (no use of herbicides) this technology is now receiving increased interest in North America. Cover crop rollers have historically consisted of round drums with equally spaced blunt blades around the drum's perimeter. The function of the blades is to crimp or crush the stems of the cover crops without cutting them, otherwise, the cover crops can re-sprout and residue may interfere with planting operations. Ashford and Reeves (2003) investigated benefits of rolling a cover crop. They indicated that when rolling was conducted at the correct stage of plant growth, the roller was equally effective as chemical herbicides at terminating the cover crop. Also, the power required for rolling was significantly reduced as compared to the amount of power required to mow. Another important aspect of rolling is that a flat mat of cover crop lies in the direction of travel. This allows for farmers to use planter-seeders operating in parallel to rolled cover crop direction, which has been successful in obtaining proper plant establishment. Using rollers alone to flatten the cover crop and prevent multiple-direction lodging could be also beneficial.

Some North American producers have reported problems with these implements. The main complaint has been the excessive vibration that the rollers generate. The most effective method of alleviating the vibration, but not desirable and not economical, has been to reduce travel speed. However, most producers find this to be an unacceptable solution due to the much higher operating speeds that they were able to previously spray herbicides onto their cover crops.

The objectives of this paper are therefore: to compare effectiveness of three rollers to terminate cover crops, to compare vibration levels generated by the three rollers, and to determine effect of speed on cover crop termination and vibration levels.

MATERIALS AND METHODS

Experiments were conducted at the Alabama Agricultural Experiment Station E.V. Smith Research Station on Compass sandy loam soil (thermic Plintic Paleudults) near Shorter, Alabama. Rye was planted in fall 2003. Before testing of different roller designs, height (10 counts per plot) of rye was recorded. The experiment was conducted in mid-April, 2004 when the cover crop was in the soft dough growth stage (Nelson et al., 1995) which is a desirable growth stage for termination. Measurements of cover crop biomass were taken from a 0.25-m^2 area within each plot. The kill rate was evaluated on a weekly basis by visual ratings (0 to 100% control scale) at one, two, and three weeks after rolling treatments.

Experiment design.

Three different roller designs of a 5.8-ft single section width were used to determine performance of each roller design in terms of maximizing termination rate and minimizing vibrations while operating at the optimum speed. A completely randomized block experiment was conducted with four replications comparing three crimper designs and three tractor speeds. Three different treatments of various roller designs were used: (1) long-straight blades (Fig 1a), (2) curved blades (Fig 1b), and (3) smooth roller with an oscillating crimping arm (Fig 1c). The operating speeds were setup to 1, 3, and 5 mph. Accelerometers from Crossbow Technology Inc. (San Jose, CA) were mounted on the roller's frame to measure vibrations due to roller motion (Fig 2a) and on the tractor's frame to measure vibration levels to which driver was subjected (Fig 2b). The data were analyzed with SAS Analyst linear model. A significance level of $P \leq 0.1$ was chosen to separate treatment effects.

RESULTS AND DISCUSSION

Discussions will cover main treatment effects: type of roller, speed of implement and time (week) elapsed from rolling/crimping procedure.

Type of roller.

Following two weeks of rolling/crimping of rye, the smooth roller with crimping arm had a significantly higher kill rate (33% kill) as compared to the roller with curved blades (29%) (Fig. 3; $P \leq 0.04$). Also, there was no statistical difference between smooth roller with crimping arm and the design with long blunt blades (31%).

Speed of implement.

With increased speed of implement, there was an increase in killing rates. Significant differences were observed between speeds of 5.0 MPH (33%) and 1.0 MPH (30%), (Fig. 4; $P \leq 0.09$). There was no statistical difference between speeds of 5.0 MPH (33 %) and 3.0 MPH (32 %).

Time (in weeks) following rolling/crimping.

There was a significant difference between the time elapsed since rolling/crimping. After the first week, 21% of the cover crop was killed and after the second week, 41% of the cover crop was killed, (Fig. 5; $P < 0.0001$). For the second week after rolling, the highest kill rate was produced by the smooth roller with the oscillating crimping arm (44% kill) followed by straight roller (40.8% kill) and curved blade roller (39% kill).

Vibration level.

There was a significant difference in increasing the vibration levels on roller frame with increased operating speeds for all the roller types (Fig. 6; $P < 0.0001$). The lowest vibration level at roller's frame was recorded for curved blades roller's frame (0.21 G-accel.) which was significantly lower than for straight long blades (0.50 G-acc) and smooth roller with crimping arm (0.47 G-accel.) (Fig. 7). However, there was no statistical difference in vibrations levels measured on roller's frame for smooth roller with crimping arm and the original design with long blunt blades. The vibration levels measured at the tractor's frame for all roller types and speeds is shown in Fig. 8. There was no significant difference in vibration levels transferred to tractor for 1.0 MPH and 3.0 MPH, however, significant differences occurred at 5.0 MPH for all roller types (Fig. 8; $P \leq 0.014$). Vibrations transferred to the tractor from the straight long blades roller across all speeds were significantly greater (twice higher, 0.22 G-accel.) than for rollers with curved (0.10 G-accel.) and smooth with crimping arm (0.09 G-accel.) blades (Fig.9).

CONCLUSIONS

Kill rates of cover crop (rye) differed significantly among roller types for the first 2 weeks of the test, with the maximum kill rate being obtained by the smooth roller with crimping arm.

Higher operating speeds of the roller produced significantly larger kill rates as compared with lower operating speeds.

Increasing time from rolling/crimping significantly increased kill rate between the first and second week.

At the maximum speed of operation, the minimum vibration levels measured on the tractor's frame were produced by the smooth roller with oscillating crimping arm, followed by higher (but not significantly different) for the roller with curved blades. The roller with straight long blades produced the maximum and significantly higher (twice) vibration levels on the tractor's frame in comparison with curved blades and smooth-crimping arm rollers.

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Figure 1-Roller types. (a) Roller with attached long straight crimping blunt blades, (b) roller with attached curved elliptical crimping blunt blades, (c) smooth roller with an oscillating crimping arm with blunt blades.

A.

B.

C.

Figure 2-Location of accelerometers mounted: (a) roller's frame, (b) Tractor's frame

A.

B.

Figure 3-Percent kill of cover crop (winter rye) for different roller types averaged over time and speed.

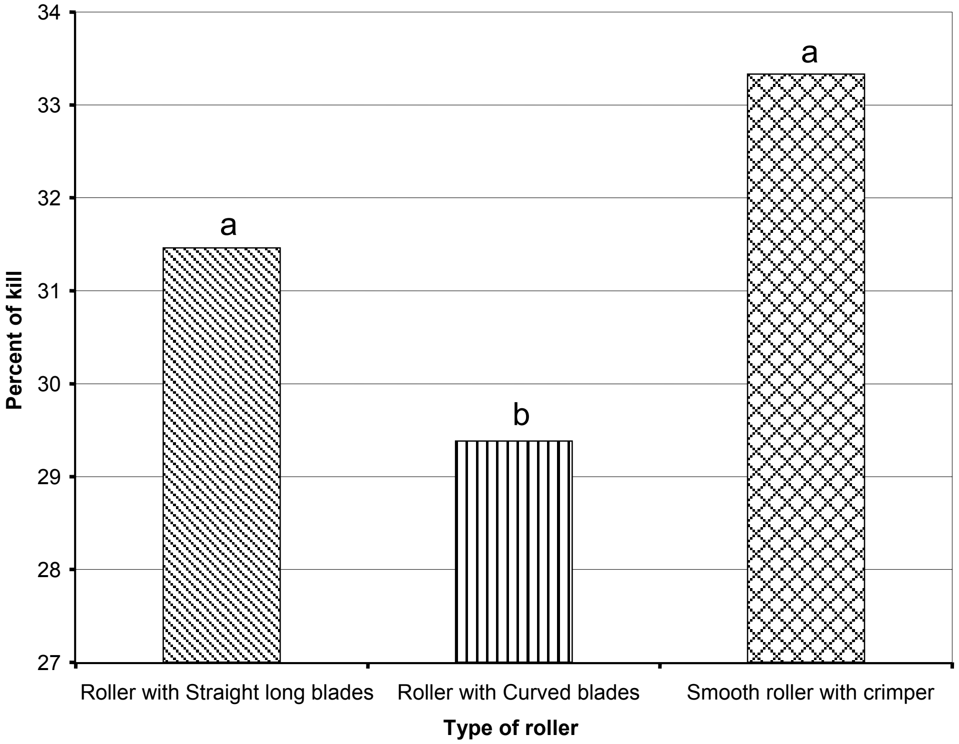


Figure 4- Percent kill of cover crop (winter rye) for three different speeds and roller types averaged over time.

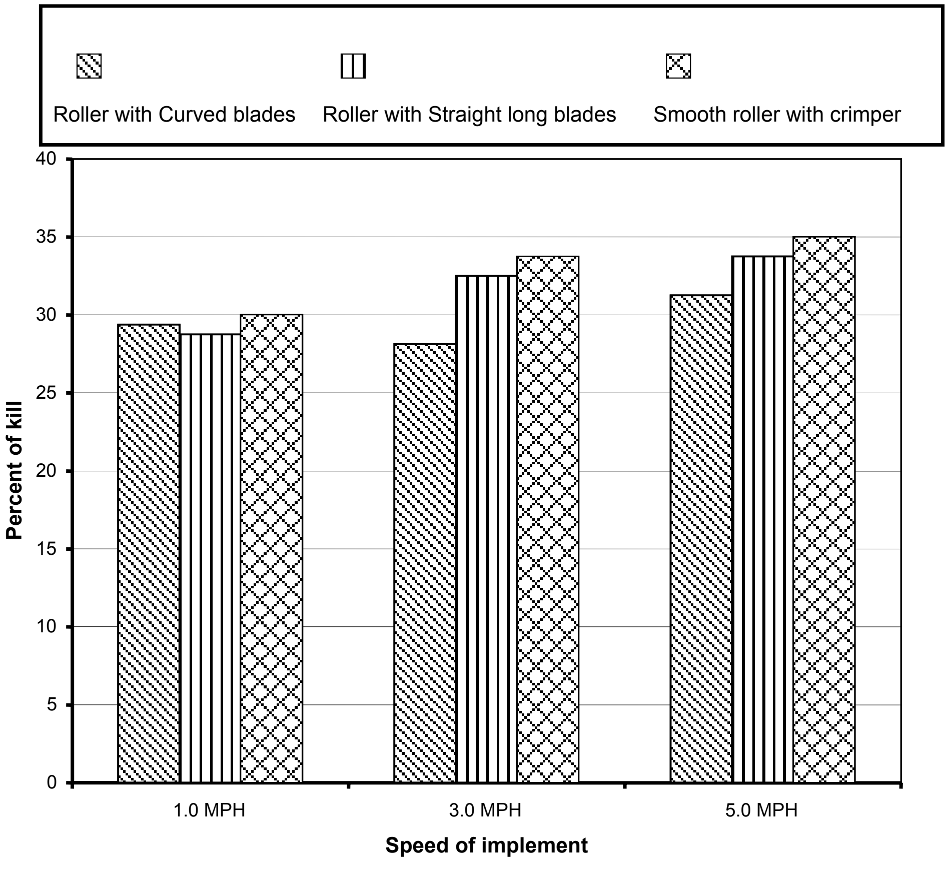


Figure 5-Percent kill of cover crop (winter rye) for time elapsed (weeks) from rolling and roller types averaged over speeds.

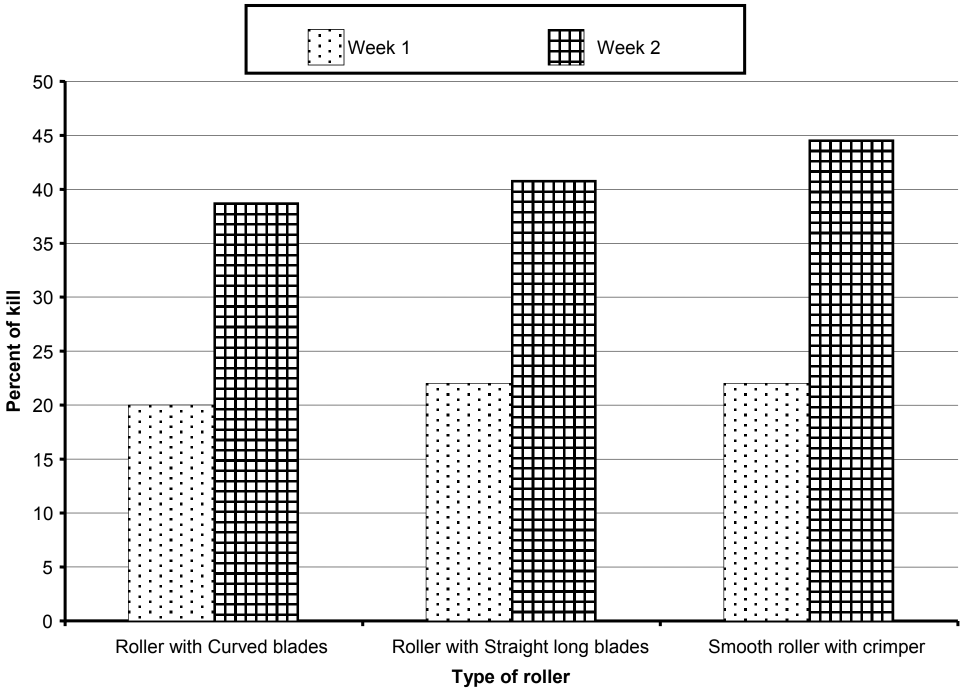


Figure 6-Vibrations levels measured at roller's frame produced by different roller types for 3 different speed levels.

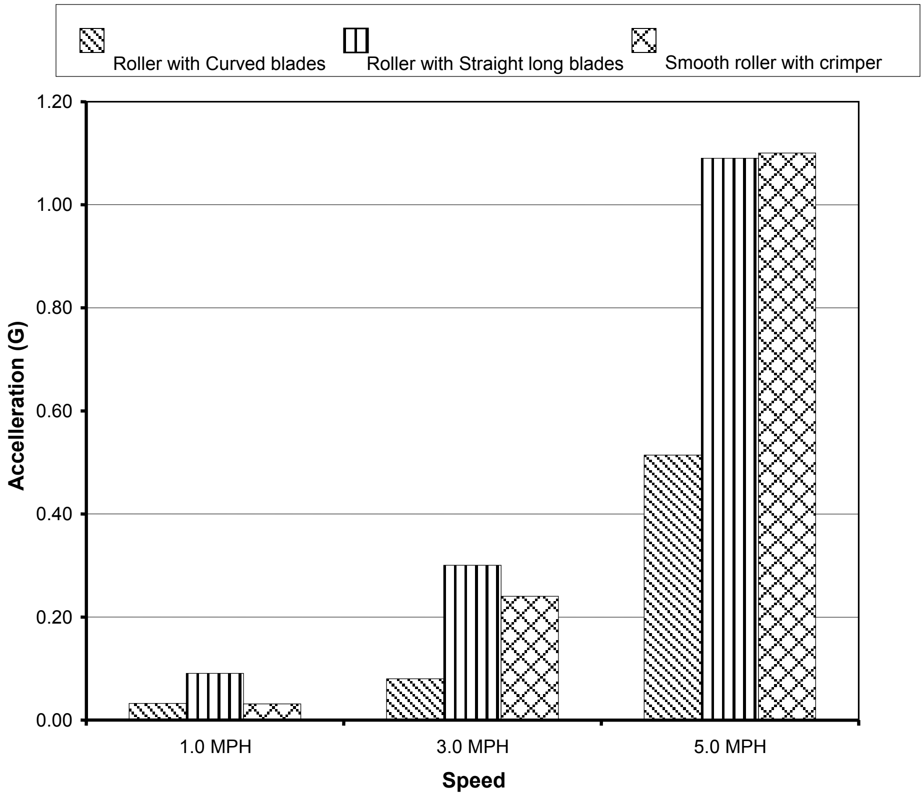


Figure 7-Vibrations levels measured at roller frame produced by different roller types across all speeds.

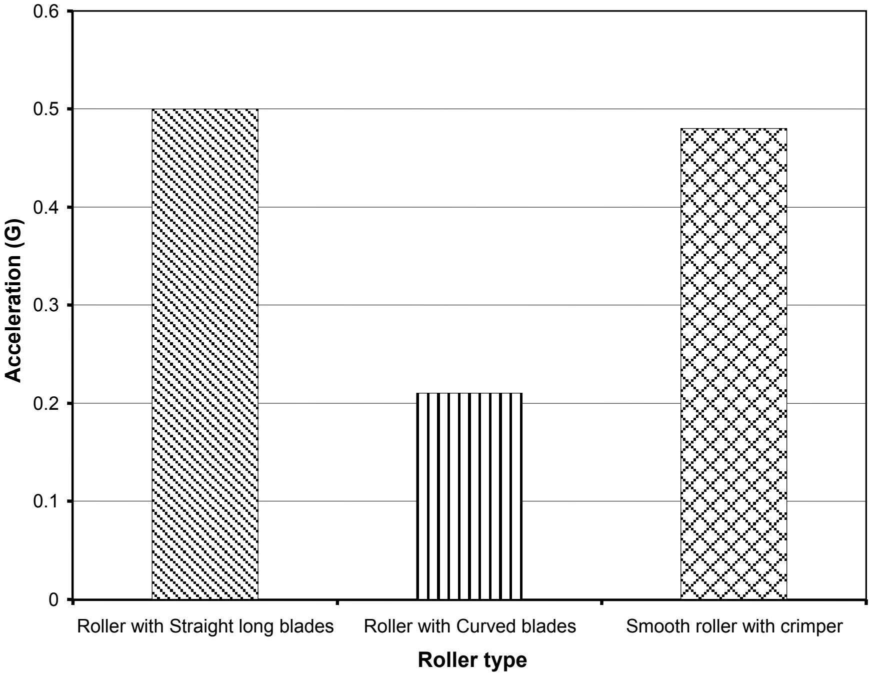


Figure 8-Vibrations levels measured at tractor's frame produced by different roller types for 3 different speed levels.

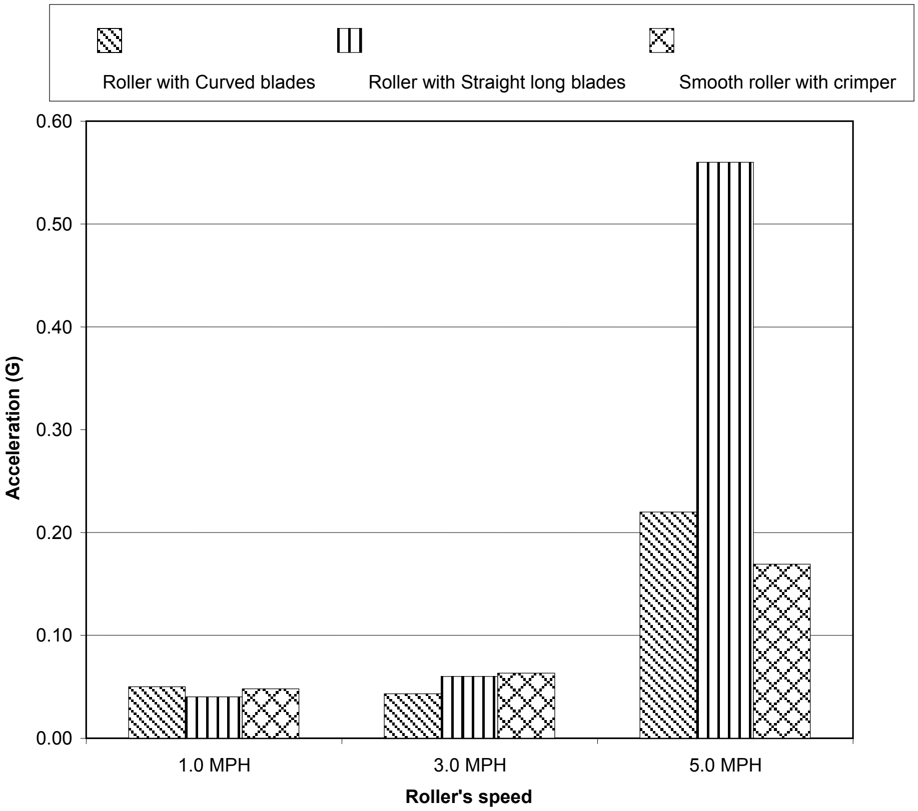
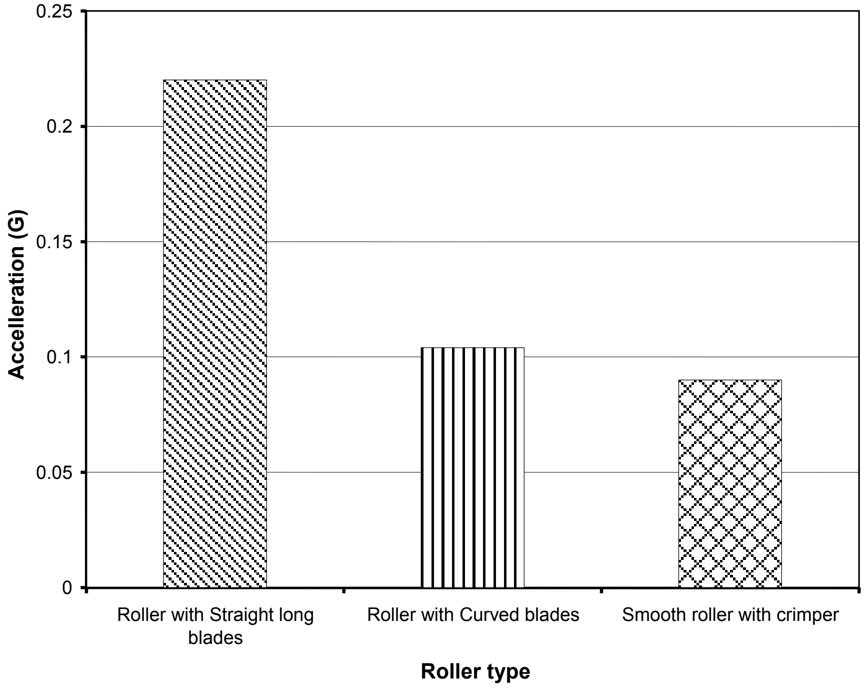


Figure 9-Vibrations levels measured at tractor frame produced by different roller types across all speed levels.



ASRED

Association of Southern Region Extension Directors

Welcome to the web site for the Association of Southern Region Extension Directors. The purpose of this site is to serve as an information source for ASRED members, to promote multi-state programming, and to inform other interested readers about Extension in the Southern Region.

Special Notices:

- **Joint Meeting of PLN, AEA and ASRED, August 29 - September 2, Biloxi, MS**
- **April 4-7 Spring ASRED Meeting Draft Minutes**
- **June 23-24 ASRED Retreat Draft Minutes**
- **National e-Extension Initiative**

Calendar of Events
Multi-state Activities
Southern Links
Directory
Southern Directors
Other Links
ECOP
Search
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Home | | **Calendar of Events** | | **Directory** | | **ECOP** | | **FAQs** | | **Multi-state Activities** | |
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This site was designed and created by Emily Elliott Shaw.