Conservation Tillage for Agriculture in the 1990s

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1990 Southern Region
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Edited by

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FOREWORD

Conservation tillage is a farming practice that has matured since its inception during the 1960's and is sure to contribute significantly to agriculture during the years ahead. Researchers as well as thousands of farmers in the southern region have helped in the understanding of important scientific principles and in putting this knowledge into practice. From the beginning the concept of conservation tillage has been perceived as a cost-effective method of meeting crop production goals and at the same time conserving soil and water resources.

In North Carolina conservation tillage farming is currently being applied on well over one million acres. In addition, conservation tillage practices are helping many farmers to address the important conservation provisions of the 1985 farm bill. These practices fit well into the conservation farm plans required to be in place by 1990 and in the subsequent implementation of the plan by 1995.

As we look ahead to the 1990's and beyond to the 21st century, it seems certain that issues just now emerging will be the dominate force influencing agricultural policy makers. The issues of food safety, environmental quality and the sustainability of agriculture will be among the most important.

Perhaps more than any other farming practice, conservation tillage stands ready to address the concerns of a "sustainable agriculture." The need to respond to the issues surrounding the loosely defined concept of sustainable agriculture will probably require an ever closer link between research, extension and farmers than exists today. It is clear that sustainable agriculture of the future must address the environmental and social expectations of society as well as assure the economic success of farmers. This will require that farmers gain a better understanding of the biological principles that provide the basis for agriculture. To this end, regional conferences that address research needs and act as important methods for exchange among scientists, agricultural industry personnel and farmers are of great benefit. It is our hope that the information contained in this bulletin will provide useful information and at the same time be thought provoking; stimulating new ideas and approaches for overcoming the many problems that confront todays farmers.

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Using Winter Cover Crops to Recycle Nitrogen and Reduce Leaching

J. J. Meisinger, P. R. Shipley, and A. M. Decker[1]

Introduction

Farmers and their advisors are becoming increasingly aware of the interconnections between the use of nitrogen (N) in agriculture and ground water quality. Farmers face a difficult task as they seek to balance the competing goals of maintaining farm profitability, by ensuring an adequate supply of N to the crop, yet avoiding excessive N rates that could degrade groundwater quality. A farmer has several tools at his disposal to work toward this goal, such as: i) adjusting the rate of N to reflect the soils ability to supply N, the farmers expected yield, the previous crop, and recent manure additions; ii) adjusting the time of N application to harmonize with the crop N demand; iii) adjusting the N placement to increase crop N uptake; and iv) modifying the cropping system to take advantage of N conserving crops. This paper will focus on the last tool by discussing the use of winter cover crops to retain N within the soil-crop system and thereby reduce nitrate leaching.

Cover Crops in General

To understand how cover crops can influence nitrate leaching into ground water one must first understand the leaching process in a humid climate such as the Southeastern U.S. Soil nitrate is vulnerable to leaching because it is water soluble and it is not held by soil clays. Therefore, nitrate readily moves through soil with percolating water which ultimately feeds into ground water or surface water. In the Southeast the yearly pattern of percolation is determined by the difference between water inputs (precipitation plus irrigation) and water use through evaporation and crop transpiration. Figure 1 summarizes the estimated monthly percolation for two locations in the Southeast along with the estimated dry matter production rates for corn and a typical grass cover crop. Most of the leaching occurs in December through April (see Figure 1) with little or no percolation occurring in the warm summer months when corn is rapidly growing and crop water use is high. Note that the dry matter production cycle of a typical grass cover crop overlaps with the leaching season in the Southeast. Growing a winter cover crop can reduce nitrate leaching by i) utilizing water for growth and thereby reducing the quantity of percolation, and ii) by absorbing nitrate N to meet the nutritional needs of the cover crop. Winter cover crops can also supply N to the next crop and reduce soil erosion by providing plant cover of bare soil.

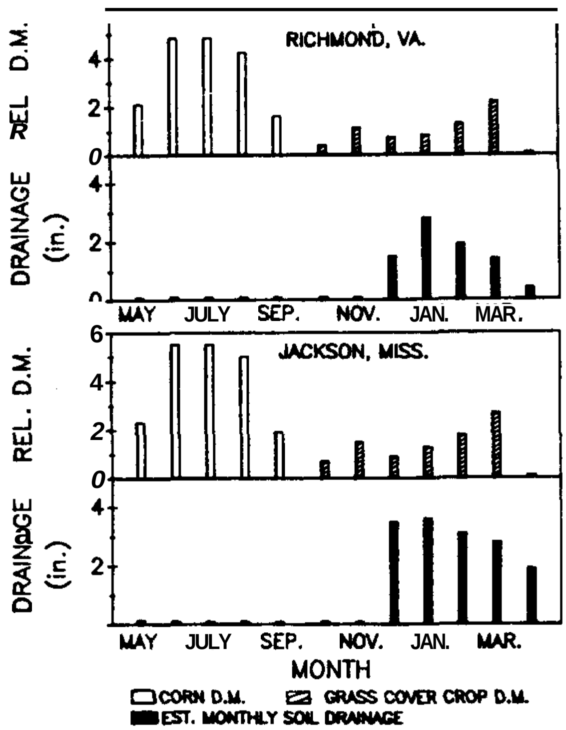

Figure 1. Estimated monthly drainage (solid), corn relative dry matter production (open), and grass cover crop relative dry matter production (cross hatched) at two Southeastern U.S. locations (van Bavel, 1959; Van Bavel and Lillard, 1957).

Cover Crops to Conserve Nitrogen

Recent Field Studies With Nitrogen

The winter cover crops which have been successfully used in the Southeast can be generally classed as legumes or grasses. The legumes have been studied most intensively because of their clearly demonstrated superiority in supplying N to the next crop. For example, typical fertilizer N credits for legumes range from 70 to 100 lbs N/acre for hairy vetch and from 50

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to 80 lbs N/acre for crimson clover. Grass cover crops, on the other hand, generally supply little N to the next crop and often require an additional 10 to 25 Ibs of fertilizer N per acre to compensate for N used during residue decomposition (Ebelhar et al. 1984; Hargrove, 1986; Holderbaum et al. 1990; Mitchell and Teel, 1977; Wagger, 1989). However, if one of our goals is to use winter cover crops to utilize left-over fertilizer N and thereby reduce N leaching, then we should re-examine the ability of legumes vs grasses to achieve this recycling objective. Accordingly, the ARS Beltsville soil N research group, in cooperation with the University of Maryland, conducted a two year field experiment from 1986-1988 on an Atlantic Coastal Plain silt loam soil (near Salisbury, MD) to directly measure the ability of grass vs legume winter cover crops to utilize fertilizer N applied to a preceding corn crop.

The above objective was accomplished by growing corn and adding isotopically labelled fertilizer N (N-15 depleted) as ammonium nitrate at sidedressing, allowing the tagged fertilizer to distribute throughout the corn root zone during summer, and then planting fall cover crops. A direct field measurement of the cover crops ability to recover corn fertilizer N was then made by measuring the uptake of tagged fertilizer in the above ground dry matter of the various cover crops during the following spring. Allowances were also made for tagged N in the root system by reviewing the scientific literature and estimating the percentage of total plant N accounted for in the root system of each cover crop. An intentionally high rate of fertilizer N was applied to the corn (300 Ibs N/acre) in order to ensure an adequate pool of labelled N in the fall and to assess the capacity of the various cover crops to retain N within the soil-crop system. The average recovery of corn fertilizer N by the various cover crops is shown in Figure 2, expressed as a percentage of the labelled mineral N which was present in 32 inches of soil at the time the cover crops were planted. Thus, if the soil contained 100 lbs/acre of corn fertilizer N in the fall and the cover crop contained an estimated 55 Ibs/acre of fertilizer N in mid-April, then the percent recovery would be 55%. The data of Figure 2, clearly show that grasses are superior to legumes in recovering corn fertilizer N. Cereal rye (variety 'Abruzzi') accumulated about 60% of the left-over corn fertilizer N at mid-April, which is its normal kill date in Maryland. Rye accumulated an average of 0.8 percent of the residual corn fertilizer N per day between the breaking of winter dormancy (mid-March) and mid-April. The decline after mid-April is due to N loss associated with the shift to reproductive growth (leaf loss, ammonia loss, lodging). Annual ryegrass (variety 'Marshall') was less aggressive than cereal rye in its early spring growth but by mid-May it had recovered about 53% of the corn fertilizer N. The hairy vetch, crimson clover (variety 'Dixie'), and the native weeds (chickweed) recovered not more than 10% of the corn fertilizer N. Nonetheless, the legumes contained an average of 150 Ibs of total N (fixed N plus soil N plus residual fertilizer N) per acre compared to an average of 80 Ibs N/ac in the grasses. The legume covers were therefore vigorous and healthy but relied more on N fixation to meet their N needs than on recycling fertilizer N (Shipley and Meisinger, 1988).

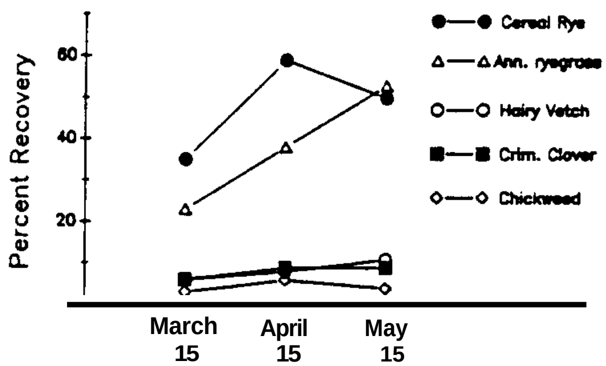

Figure 2. Average percent recovery of residual corn fertilizer N (N-15 labelled) by various winter cover crops in Maryland (Shipley and Meisinger, 1988).

The superior N retaining ability of grass cover crops should also translate directly into lower nitrate concentrations in percolating water. Shallow water table wells were installed in field plots of the above cover crop study and recent percolate draining into these wells was sampled throughout the spring of 1988. The average spring nitrate-N concentrations below cover crop plots corresponding to the data of Figure 2 were: 12 ppm below cereal rye, 18 ppm below hairy vetch, and 17 ppm below weeds (Meisinger and Shipley, 1989). Therefore the greater recovery of corn fertilizer N with cereal rye was also translated into lower nitrate-N concentrations in drainage water.

Lysimeter Studies with Cover Crops

Further confirmation of lower nitrate leaching under grass cover crops can be found in the older lysimeter data from the Southeast. A four year lysimeters study in Alabama was reported by Jones in 1942, which used 30 inch dia. by 30 inch long filled lysimeters and three soil types. Soybean residues containing 75 lbs N/acre were spaded into the soils each October and rapidly decomposed producing nitrate-N. The annual nitrate leaching was determined without cover crops and with winter cover crops of oats or hairy vetch. Results from this study (Table 1) show that the oat cover crop was very effective in reducing leaching with average annual leaching being about 13% of the no-cover treatment. In contrast, the hairy vetch cover had little or no effect on N leaching compared to the control. There was also a marked effect of soil type in this study with the fine textured clay loam soil losing very little N through leaching, compared to the coarse textured soils in which leaching was a major loss mechanism. Conserving N with cover crops should therefore have its largest impact on coarse textured soils that are prone to leaching.

Table 1. Average annual N Leaching losses (Ib N/acre) from lysimeter in Alabama as affected by winter cover crop treatment and soil type (Jones, 1942).

Winter Cover Crop Treatment	Soil Type: Norfolk sa. lm.	Soil Type: Hartsells f. sa. lm.	Soil Type: Decatur cl. lm.
No Cover	**51 (-)**	**38 (-)**	**5 (-)**
Oat Cover	**11 (22%)[1]**	**6 (16%)**	**0 (0%)**
Hairy Vetch Cover	**45 (88%)**	**39 (100%)**	**5 (100%)**

[1]N leached as a percentage of the No cover treatment.

Another long-term lysimeter study (11 years) was reported from Kentucky by Karraker et al., 1950; using 22 inch dia. by 26 inch long lysimeters of disturbed Maury silt loam soil. Annual seedings of Korean Lespedeza added about 180-210 Ibs N/acre to each lysimeter through N fixation. Most of the fixed N was removed through harvested crops, but about 60 Ibs N/acre was added to the lysimeters annually in October through root plus crown residues. These residues decomposed rapidly and liberated N which was vulnerable to leaching. On one set of lysimeters the Korean Lespedeza was not followed by a winter cover crop, but on another set, a rye cover crop was grown. The average drainage, nitrate concentration, and mass of N leached from these lysimeters during the year is summarized in Table 2. It is apparent that the rye cover crop did an excellent job of reducing N leaching. The rye cover crop reduced both the mass of N leached (from 58 to 15 Ibs N/acre) and the nitrate concentration of the leachate (from 16 ppm to 4 ppm) compared to the no-cover lysimeters. The rye cover crop achieved these N leaching reductions primarily through N uptake during the winter and early spring leaching season. Rye also reduced drainage volumes somewhat, but this was not of major importance in this study compared to direct N uptake by the rye.

Table 2. Average N Leaching dynamics during the year from Kentucky lysimeters containing Maury silt loam as affected by cropping system (Karraker, et al., 1950).

Cropping Syskn Description	N Leaching Variable Observed (units)	Winter Jan Feb March	Spring April May June	Svmrnrr July Aug Sept	Fall Oct Nov Dec	Yearly Total
Precipilation	Quantity (in).	11.2	120	11.3	8.1	42.6
Korean	Drainage (in.)	9.2	3.9	1.0	2 0	16.1
Lespedeza	N Leached (lb/ac)	39.0	10.0	1.5	8.0	58.0
No Cover	NO_3 Conc. (ppm)	18.7	11.3	6 6	17.7	15.9
Korean	Drainage (in.)	9.0	3.0	1.0	2 2	15.2
Lespedeza	N Leached (lb/ac)	7.0	0.5	1.0	6.5	15.0
Rye Cover	NO_3 Conc. (ppm)	3.4	0.7	0.4	13.1	4.4

Summary and Practical Applications

The above labelled-N results from our direct field measurements of cover crop utilization of corn fertilizer N, and the earlier lysimeter work in other areas of the Southeast, clearly demonstrates that grass cover crops are superior to legumes in recovering previously applied nitrogen. Grass covers have the potential to markedly increase N retention within the soil-crop system and thereby reduce N leaching into ground water. However, grass cover crops can also have negative effects on the next crop by requiring extra fertilizer N (usually about 10-20 Ibs N/acre) and by using water in the late spring which could reduce germination.

Our goal as applied agriculture researchers should therefore be to integrate current knowledge on grass cover crops into modern cropping systems to improve their capacity to conserve N. Such systems could include i) timely killing of grass cover crops to maximize recycling of fertilizer N and minimize adverse effects on the next crop, ii) using grass-legume mixtures as cover crops to incorporate some of the benefits of each type of cover, and iii) evaluating a broader range of grass cover crop genotypes to select improved types for N conservation. Policy makers can also speed the farmer acceptance of cover crop systems by devising appropriate cost-share programs or other incentives.

The use of winter cover crops to conserve N and reduce leaching is an old practice which has not been exploited in modern agriculture systems. It is time to incorporate this practice into modern conservation tillage systems of the Southeast.

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Herbicide Mobility During Initial Infiltration Events

D. E. Radcliffe, S. C. Chiang, and J. A. Tindall[1]

Introduction

In an earlier field study comparing herbicide mobility in conventional tillage *(CT)* and no-tillage (NT), all of the downward movement of two herbicides occurred in the first infiltration event (Radcliffe et al., 1989). The herbicides in the previous study were metribuzin (4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one) and alachlor (2-chloro-N-(2,6-diethylpheny1)-N-methoxymethylacetamide). In the spring of 1987 and 1988, straw from the previous winter wheat crop was removed, tillage treatments were established (main plots), and herbicides applications were made. To one half of each main plot, straw was returned to the surface after herbicide application. Plots were further subdivided into a heavy (1.4 inch per week) and light (0.7 inch per week) irrigation treatment. No crops were planted and water was applied to the plots for 6 weeks. Soil cores for herbicide analysis were taken to a depth of 60 cm on four dates during this period. At the first sampling date (5 and 7 days after application in 1987 and 1988, respectively) alachlor moved to an average maximum depth of 2.7 inches and metribuzin to a depth of 5.0 inches. No further downward movement occurred after the first sampling date. The depth of initial movement was affected by treatments in that heavy irrigation, straw cover, and no-tillage favored slightly deeper movement. These are the treatments that should have had deeper movement of the initial infiltration event water due to greater water application (heavy irrigation), higher initial water content (straw cover), or more continuous large pores (no-tillage).

The results of the above experiment implied that herbicide mobility was relatively high during the initial infiltration event, but once water stopped flowing, irreversible adsorption took place. The purpose of this study was to test this concept under more controlled laboratory conditions.

Material and Methods

The herbicide used in this study was atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine), a compound that is similar to metribuzin and considered to be mobile in soils (Jury et al., 1987). Columns 14 inches in length were constructed by cementing together 9 plexiglass cylindrical sections 1.55 inches in height and 2.72 inches in diameter. The columns were packed with air-dry, sieved Worsham sandy loam soil (clayey, mixed thermic family of the Typic Ochraquults) to a depth of 11.4 inches. The soil contained 14.1% clay, 19.2% silt, 66.7% sand, and 0.8% organic carbon. Water content of the air-dry soil was 0.1% by weight.

Atrazine was added to the surface of the soil at a rate of 2 lb ai per acre in a mixture with methanol and deionized water using a small mist applicator. Two treatments were imposed that differed in the amount of water added to the column immediately after herbicide application: in the small-event treatment, 0.1 pore volume of water was added and in the large-event treatment, 1.0 pore volume was added. The columns were allowed to sit overnight and the following day 1.4 and 0.5 pore volumes of water were added to the small-event and large-event columns so that the total amount of water added to the two treatments was the same. The experiment was repeated three times.

After each experiment, the columns were disassembled into 1.55 inch sections and the soil air-dried. A 0.7 oz sample of soil was taken from each depth increment and combined with 1.4 oz of 90% methanol and 10% water, shaken for 2 hours, and centrifuged. The supernatant was collected, filtered and analyzed on a high performance liquid chromatograph (HPLC).

The experimental design was a randomized complete block with strip subplots. Each repetition of the experiment over time was considered a block with the small-event and large-event columns as main plots. Soil column depth was considered a strip subplot, as opposed to a split subplot, in that depths could not be randomized. The overall error was used to test for an interaction between depth and treatment and since this was significant, an LSD was computed to test differences between treatment concentrations at each depth.

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Results

Although the total amount of water added to the columns in two days was the same in both treatments, mean atrazine distribution in the soil differed (Fig. 1). More atrazine moved to deeper depths when most of the water was applied in the initial event (large-event treatment), compared to when most of the water was applied on the second day (small-event treatment). In the small-event treatment, the greatest adsorption occurred in the top 2 inches of soil. In the large-event treatment, adsorption was nearly uniform to a depth of 9 inches.

These results imply that for a significant fraction of the atrazine, adsorption and desorption take time. Maximum adsorption took place near the surface in the small-event treatment because the atrazine "pulse" resided at a shallow depth in the 24 hour interval between the initial and subsequent events. Water added on the second day moved atrazine to the bottom of the column but did not remove the peak in the top 2 inches because there was not enough time for the atrazine to desorb after the pulse moved deeper.

This pattern of mobility can be attributed to either one of two types of adsorption kinetics that have been proposed: (1) adsorption takes time because an activation energy is required or, (2) adsorption takes time *because* water in the smaller soil pores is immobile and, to reach the adsorption sites in these pores, chemicals must move throught the immobile water by diffusion which is a slow process compared to mass flow in the larger pores (Pignatello, 1989). Desorption may not occur readily because of irreversible adsorption (Clay et al., 1988) or due to time that it takes for the chemical to diffuse out of immobile water regions.

The results are consistent with our field observations that all of the movement of alachlor and metribuzin seemed to occur in the first 5 to 7 days and that this initial movement was greater in NT than CT (Radcliffe et al. 1988). The pulse of herbicide probably moved deeper with the first irrigation in NT than in CT because of more continuous large pores and wetter soil in NT. In the one week interval before the next irrigation event, adsorption of the "slow" fraction occurred and subsequent infiltration events did not cause desorption. Since we did not observe any movement after the initial event in the field, it appears that more of the herbicide was in the "slow" fraction under field compared to laboratory conditions. This could be due to a greater proportion of immobile water in the undisturbed soil compared to the packed columns.

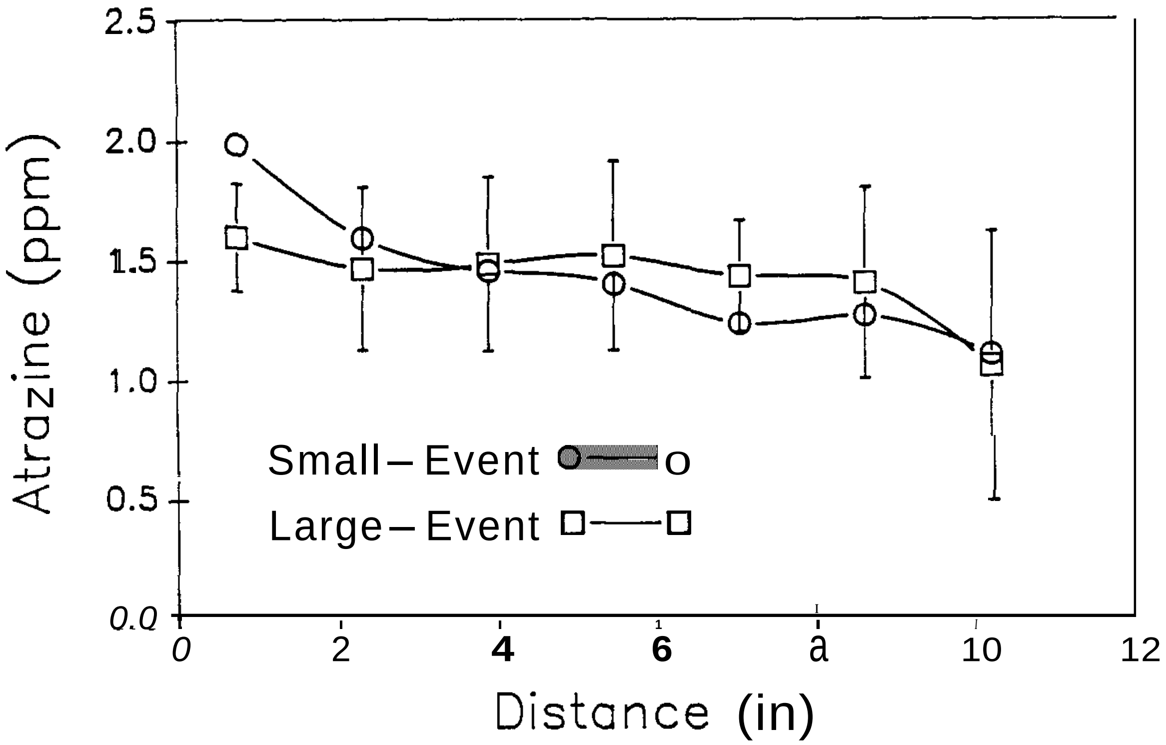

Figure 1. Mean atrazine concentration as a function of soil depth in the small-event and large event treatments. Error bars for signiIicant differences at the 0.05 level are shown.

Conclusions

Mobility of some herbicides appears to be greatest during the initial infiltration event. If a rain or irrigation occurs shortly after application or if a herbicide is added by chemigation, deeper movement can be expected. Adsorption of a significant faction of the herbicides appears to take time and does not occur when water is moving through the soil. This fraction will be likely to move deeper in NT compared to CT systems because water flow will be more rapid in the large continuous pores in NT. Once the water stops moving, however, adsorption takes place and may be irreversible.

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Pesticide Concerns in Conservation Tillages

William W. Witt[1]

Pesticides are an integral component of successful crop production by conservation tillage methods. There has been much conjecture and discussion over the years about increases in pest populations as primary tillage is reduced and the need for greater pesticide quantities to control the greater number of pests. Herbicides are the most widely used pesticide in agronomic crop production, and as a result, have received the most notoriety for misuse and water contamination. My comments will address primarily herbicides for weed management in conservation tillages and concerns I have about their proper and improper use, specifically as it relates to water quality.

Herbicides must be used to manage weed infestations in conservation tillages. The potential for between row cultivation as a weed control method decreases as the amount of plant residue on the soil surface increases. Additionally, growers do not have the labor needed for the timely removal of weeds by hoeing. The concern is not whether or not herbicides will be used, but rather, which type of herbicides should be used to ensure economical weed control without contamination of the environment. The public concern for drinking water free of pesticides and other organic and inorganic contaminants will likely increase during the next few years. There are groups of people already calling for the elimination of pesticides and inorganic fertilizers for the production of food, feed and fiber. While I do not believe that to be practical, I do believe that we, as agriculturalists and pesticide users, should be at the forefront of demanding food and water supplies free of harmful chemical residues. I believe that herbicides, and other pesticides, can be used safely in various conservation tillages. All of us--farmers, scientists, the general public--must be aware of the need for conserving our soil and water resources throughout the South. Conservation tillage is one means of accomplishing this conservation and much of the South's crops are grown on land that is subject to soil erosion.

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The Southern Conservation Tillage Conference has been instrumental in promoting crop production by conservation tillage methods and several people have discussed weed control and herbicide use at these meetings. At the earliest conferences, conservation tillage most often meant no-tillage, and weed control in no-till and conventionally tilled soil was compared. The general perception at these meetings was that more herbicide was required for weed control in no-till compared to conventional tillage. In actuality, whether or not additional herbicides were required depended on the type and quantity of plant residue on the soil surface at the time of planting and/or herbicide application. We have learned that less herbicides, particularly soil-active herbicides, are needed in some types of conservation tillages. The point of this short history is that some conservation tillage practices may require less dependence on soil-active herbicides for weed control and that the long held belief that more herbicides are required for all conservation tillages is not true.

Asstated earlier, herbicides will beused for weed management in conservation tillage we be concerned about herbicides used in conservation tillages being a contaminant of our surface and ground waters? As with most biological system, the answer is "that depends". It depends on the type of soil, the depth to groundwater or proximity to surface waters, the amount of plant residue on the soil surface, the amount and timing of rainfall, the type(s) of tillage operations and chemical and physical properties of the herbicide. Recently there has been concern expressed about the rapid movement of pesticides by macropore flow in no-tillage. The jury is still out on whether or not this does occur, but if it does, then a major soil and water conservation practice will be implicated as causing groundwater contamination. I point this out because, at some point, the agricultural community may be asked to say which is the lesser evil—potential herbicide contamination of groundwater or erosion of an essential resource for crop production. We--scientists, farmers, agricultural industry--should be diligent in our efforts to make sure that day never comes. We should insist on more research efforts to answer the questions before us. Does conservation tillage, as now practiced, rely too heavily on herbicides instead of cover crops and crop rotations? Do some types of conservation tillages lead to greater herbicide leaching into groundwater? Should the reliance on soil-active herbicides for weed management in conservation tillage be reduced? If the answers to the above questions are yes, then we have a large task facing us. What will be the response of farmers, the agricultural industry, university research and extension personnel, and state or federal agencies if the answers are yes?

Too often, the response of governing agencies to pesticide related problems has been based on emotion and not on scientific fact. I am concerned that herbicides will be targeted indiscriminately as major contaminants and all of us involved with conservation tillage should actively pursue the facts. If a herbicide is found to contaminate groundwater, then let us be the first to say its' registration should be canceled. Likewise, we should be vocal in supporting the continued use of herbicides that do not present a health risk.

I believe we will see major efforts to restrict certain types of pesticides in the next few years. This belief is based on the number of reports, confirmed and unconfirmed, of herbicides in water supplies. Major research efforts are being conducted in many states to monitor water supplies for the presence of pesticides. Herbicides, being the most widely used, will bear the brunt of the publicity as the results of these studies are published. Atrazine and alachlor are the herbicides most often mentioned as contaminants of well water. These two herbicides have served as the "backbone" of weed management programs in corn grown with conservation tillages. The corn grower, either conventional or conservation tillage, will be hardpressed to effectively manage weeds in corn without these herbicides. Other herbicides with similar chemistry are also widely used in corn production and will be closely monitored in the future.

I do not wish to be totally negative regarding herbicides for conservation tillage and I certainly do not advocate going back to conventional tillage methods on the erodible soils of this country. The herbicides used most widely for control of weeds at or before planting (glyphosate, paraquat) are tightly adsorbed to soil and do not pose a risk of water contamination. There are many foliarly applied herbicides to manage weeds in conservation tillage; however, many growers will have to change their attitudes and equipment to effectively use them. Finally, although several soil-applied herbicides are "under fire" for contamination of surface ground waters, ample data exists to show conservation tillages reduce total herbicide runoff in surface waters, and generally, herbicides degrade faster under conservation tillages.

Elements for Sustainable Farming

What Conservation Compliance Means to Farmers

Maurice G. Cook[1]

Introduction

The Conservation Title of the 1985 Food Security Act has been described as the most comprehensive conservation legislation to be enacted in 50 years. For the first time in history, receipt of most federal farm program benefits, e.g., commodity price supports, agricultural credit, and crop insurance, became legally contingent on the application of appropriate land stewardship practices by agricultural producers.

Congress authorized this sweeping policy change, in part, because of the shared belief within much of the agricultural and environmental communities that federal farm programs should promote natural resource conservation instead of operating at cross purposes with conservation goals as the programs had sometimes done in years past. The legislation gives major attention to two areas: 1) Highly erodible lands and 2) wetlands. It prescribes specific requirements regarding the use and management of these lands. This presentation will focus on compliance provisions for highly erodible land because they are particularly relevant to a conservation tillage conference.

Compliance Provisions for Highly Erodible Land

Two specific provisions apply to highly erodible land: 1) Sodbuster and 2) conservation compliance. Sodbuster applies if one breaks out highly erodible land that was not used for crop production at any time during the period 1981 to 1985. If such a field is brought into production of an annual crop, the farmer must do so under an approved conservation system in order to remain eligible for farm program benefits.

Conservation compliance applies if one continues to plant annually tilled crops on highly erodible fields. To remain eligible for farm program benefits, the farmer must follow a locally approved conservation plan for those highly erodible fields. The plan, approved prior to January 1, 1990, must be fully implemented by January 1, 1995.

Because most farmers are in the very early stages of implementing conservation compliance plans, any assessment of the effects of the compliance provisions on them must be inconclusive at this time. The full impact of the legislation will probably be realized during the latter part of the implementation period, say, 1993-95. Nevertheless, it is appropriate to make a preliminary evaluation of the possible influence of the compliance provisions on farmer attitudes and behavior. This should help in identifying potential problems and taking appropriate steps to overcome them.

Implications for the Farmer

A. Sodbuster

During the 1970's and 1980's, large acreages of native grass and trees were converted to cropland. The possibility that federal farm programs were subsidizing this conversion prompted the Congress to include the sodbuster provision in the Conservation Title of the Food Security Act.

A farmer considering sodbusting must remember that he needs an approved conservation plan and any required structures in place before the crop is to be planted. Where native vegetation is present, a basic conservation system plan is designed to reduce post-treatment erosion to the soil loss tolerance level(T) or below. Sodbusted fields in introduced species of vegetation can be planned to whatever level of soil erosion control is allowed by any of the conservation systems in the local Soil Conservation Service (SCS) field office technical guide, including alternative conservation systems. Alternative conservation systems are offered as an option to basic conservation systems. They must achieve a "substantial reduction" in erosion. The technical guide contains lists of treatment alternatives by soil groups and indicates for typical slope lengths and other conditions which alternatives will achieve T and which will not. SCS officials thus know which alternatives are eligible for use on sodbusted land. Conservation plans would be more complete and technically defensible for producers, however, if preplan and postplan erosion rates were documented for all sodbusted fields.

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The sodbuster provision appears to have slowed the conversion of highly erodible land in grass or trees to cropland. No records of sodbusting activity exist beyond the USDA field office level, so there is no way of determining just how much sodbusting is occurring from either the state or national perspective. In regions such as the southeastern United States, the potential for sodbusting is limited because the most productive land is already farmed.

B. Conservation Compliance

Of all the provisions in the Conservation Title, conservation compliance is the most sweeping in scope and in its potential to reduce soil loss on highly erodible land. Producers who have highly erodible cropland must "actively apply" the plan according to the schedule set forth in it during the period of January 1, 1990, through December 31, 1994

Significant reductions in soil erosion will result if conservation compliance plans are implemented as written. But implementation will be difficult for a significant number of plans, and the soil erosion reduction overall may be less than reported or anticipated. First, some plans call for crop residue levels that will be difficult to achieve and maintain. Other plans entail installation of structural practices that may not be affordable with available public and private funds for cost-sharing and technical assistance. Second, preplan erosion estimates in some cases may understate existing erosion conditions. These observations suggest that while erosion will be reduced significantly, average reductions may be less than estimated in the plans.

U.S. Department of Agriculture (USDA) policy requires that the erosion reduction be "substantial". It gives all affected producers the option of filing and applying either a basic conservation system that will reduce erosion to rates equal to or less than T, or an alternative conservation system that will reduce erosion substantially but the rates will exceed T. It would be helpful to both the producer and USDA to know how serious the erosion problems were at the time of planning and the degree to which those problems would be solved if the plans were implemented.

C. Conservation Awareness

Through the Food Security Act, conservation programs were integrated with commodity programs for the first time. Heretofore, conservation programs were entirely voluntary. Many farmers on their own initiative developed and implemented conservation plans through the local conservation districts. Although there were secondary economic incentives, e.g., tax benefits for practicing conservation, there were no penalties for failing to practice conservation on highly erodible land. In fact, conservation programs and commodity programs were often conflicting. For example, strong commodity prices encouraged the plowing of erodible land and deterred interest in soil conservation practices.

It is imperative now, though, that farmers growing annual crops on highly erodible land think about conservation and its implications for the total farm operation. The potential loss of federal farm program benefits is too great an economic risk for farmers to ignore conservation compliance. Essentially all producers who have highly erodible land are now aware of that fact, and this enhanced awareness alone should improve soil conservation efforts.

D. Cropping Systems

Changes in farming practices—most of them modest and in-expensive--and application of special conservation measures called for in conservation compliance plans will significantly improve erosion control on highly erodible cropland. Maintenance of crop residue cover on the soil surface will be the key to success for most producers. It appears that in some plans, however, residue cover goals are unrealistic, given the agronomic potential of the soil and expected crop yields. For example, some plans call for keeping as much as 60 percent residue cover with continuous soybeans. Producers may have to adapt additional, low cost practices such as stripcropping or contouring to attain the erosion reduction goals set forth in the plans.

Because of the overwhelming importance of residue management practices to control erosion, conservation tillage will likely assume a greater role in achieving conservation compliance. By definition, conservation tillage embraces any tillage technology that leaves a crop residue cover of at least 30 percent on the soil surface at planting time. Various states have modified this percentage upward. For example, North Carolina requires 50 percent residue cover as a conservation tillage standard. The higher residue requirements are consistent with the percentages observed in many compliance plans. Such levels, though, will require producers to adopt rigorous conservation tillage practices. This will pose a major challenge to many producers in many locations.

In those instances where highly erodible land is dominant and the amount of land for annual crops is limited, farmers may need to change their traditional farming methods. An example of this is the northern Piedmont region in North Carolina where it is customary to grow flue-cured tobacco continuously in the same fields. Due to the high erodibility of the soils plus the clean-tilled characteristics of tobacco culture, crop rotation is required to achieve conservation compliance. Even where some kind of rotation is currently employed, it should include more grass sod in the cycle.

Cropping system changes are perceived more as an inconvenience, though, rather than imposing a lasting economic hardship on the farmer. Referring again to the tobacco example, growers tend to have their curing barns close to the fields where the tobacco is grown. Introducing a crop rotation will likely mean a greater hauling distance from the field to the barn, and increased time and labor requirements. These changes may have a negative agronomic impact initially, but it should be offset by improved management of all the fields used in the cropping system.

Some farmers fear that the change in cropping system will reduce their crop production and thus their economic returns. This may be true in the short run. It is generally believed, though, that well-managed rotations can produce crop yields comparable to monoculture. The net income is even likely to be higher due to increased biological control of pests and reduced requirement for costly chemical inputs.

E. Technical Assistance

Farmers will require technical assistance from SCS to implement many of the compliance provisions. The SCS workload may exceed available staff capacity in many field offices between 1990 and 1995 because of a heavy demand for technical assistance to implement and monitor existing plans. Furthermore, a substantial proportion of the plans may need to be revised. A technical assistance shortfall could seriously compromise the effectiveness of conservation compliance.

Implementation and spot-checking of conservation compliance plans could require a great deal of technical assistance during a period when staff load is greatest. Compounding this problem is the likelihood that many conservation compliance plans will have to be revised, some them substantially and perhaps more than once, as implemcntation begins in 1990. Plan revisions have long been a part of SCS procedures, e.g., Great Plains Conservation Program, but never on such a large scale. Both revision and implementation of plans will be primarily conducted "one-to-one" with producers, intensifying demands on staff. Other Conservation Title provisions, notably swampbuster, will further stretch the technical assistance workload.

As a result of these concerns, a widening gap is anticipated between technical assistance needs and staffing that could seriously compromise implementation of conservation compliance as early as the end of 1990. The problem could become acute by 1993, particularly if enforcement challenges prove substantial and require routine field inspections. Farmers arc encouraged to initiate revisions early in the implementation period to avoid a possible crisis as 1995 approaches.

F. Financial Assistance

Actually putting certain practices contained in the recommendations on the ground will likely require financial assistance. Almost one-half of the producers queried in a national survey (1) indicated they would need some financial assistance to implement their plans. This appears to be less than what has been generally expected, however. This indicates that farmers are seeing recommendations that arc agronomically and economically sound.

Financial help is available through various sources in addition to federal cost-sharing. Some states now offer cost-share programs. In North Carolina, cost-sharing is available for practices that promote water quality. This embraces many of the traditional soil conservation practices. Also, there are incentive payments for practicing conservation tillage.

G. Attitudes

There appears to be widespread support for cross-compliance, i.e., that a producer should conserve the soil on highly erodible cropland in return for federal program payments. In a producer survey(l), 74% of all respondents agreed with the conservation compliance philosophy. Of those who had obtained a conservation plan, 80 percent said they considered the plan reasonable and practical. Nearly the same percentage said implementation of the plan would have a positive impact or no impact on the profitability of their farming operation. A majority (55%) expressed support for the sodbuster provision, including its enforcement, that could result in the loss of fcderal farm program benefits.

Summary

Current federal farm policy holds that producers who wish to avail themselves of commodity price support, agricultural credit, and crop insurance programs must take proper care of the soil and water resources on which the long-term sustainability of their farms and the nation's food and fiber supply depends. Decisions about conservation activity are now among the most important business decisions they must make from year to year.

At the same time, conservation compliance has abruptly changed the programs and priorities of federal soil and water conservation agencies along with those of many cooperating state and local agencies. These are agencies that previously did business with their producer clients on a voluntary, first-come, first-served basis. The conservation planning and enforcement mandates associated with implementation of the provisions in particular pose workload and other challenges heretofore unconfronted by many of the agencies involved.

Many important questions about conservation compliance and its implementation cannot be answered yet. To this point it appears that the conservation infrastructure is in place throughout the American countryside to deliver programs of the magnitude required by the Conservation Title. There is a clear indication of positive producer attitudes toward these revolutionary conservation policies. This speaks well for the farmer in his/her role as a producer of food and fiber, and protector of the environment.

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The Role of Integrated Pest Management in Sustainable Agricultural Systems

H. Michael Linker[1]

Low input, sustainable (LISA) or alternative agricultural systems are characterized by proponents as a system which maximizes the internal resources of the farm, eliminates or at least minimizes environmental impacts and increases profits by reducing purchased inputs (Hodges, 1982; Harwood, 1985; Francis et al., 1986, Madden, 1987; Francis and King, 1988). Lockeretz (1988) adds that "the term [sustainable agriculture] particularly emphasizes avoidance of synthetic pesticides". Thus a major emphasis in sustainable systems is the reduction of pesticide use to the lowest amount possible and total elimination where practical.

Achieving this goal will be a difficult and complex task requiring creative pest management thinking. The success of pest management in LISA systems will depend upon modifying known integrated pest management (IPM) practices to function in this new arena. This appears to be an achievable task because sustainable and conventional agricultural systems are governed by the same fundamental practices and mechanisms and IPM programs have successfully implemented pesticide reducing programs on conventional farms for over 20 years.

The National Academy of Sciences report on alternative agriculture (Pesek et al. 1989) described 11 case studies of alternative agriculture farms. In several of the studies the "alternative agriculture" part of the farm was the adoption of IPM practices. In these cases the crop production practices could be considered "conventional." Thus the most comprehensive study of alternative agriculture to date relies heavily on IPM.

How will the marriage of IPM and LISA work? Since there appears to be little LISA experience in the south, one can only guess at to where IPM will fit. It seems that IPM can support and contribute to sustainable agriculture both philosophically and functionally. However, there are fundamental differences which must be resolved. It may be best to first look at the common ground of IPM and LISA then examine where differences exist.

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Philosophical Support for Sustainable Agriculture.

IPM has had a traditional "low input" approach. Rabb (1972) defined pest management as the "intelligent selection and use of pest control actions that will ensure favorable economic, ecological, and sociological consequences". Thus from the beginning of what may be called the "IPM era" the judicious use of pesticides was emphasized. This is underlined in the economic threshold concept whereas pesticides are not applied unless pest levels are high enough to potentially reduce profits. Economic thresholds ensure that there is a sound economic foundation for the use of pesticides.

From this stated philosophy of economics, IPM programs have reduced costs yet preserved crop quality and yield. For example, in North Carolina studies in corn, soybean and peanut indicated that pesticide savings of 17 - 29% were possible with IPM programs (Weathers 1979). Thus IPM programs can provide the practical programs to reduce pesticide inputs.

IPM founded on systems approach. The National Academy of Sciences report on alternative agriculture (Pesek et al. 1989) admonished agricultural scientists to increase interdisciplinary research and extension programs and to develop a systems approach to crop and pest management. IPM practitioners have observed the futility of attempting to control pests without an agroecosystem perspective. Pest problems are influenced by previous crops, current crops grown nearby and regionally, past and present pesticide use, crop phenology and myriad other factors. To manage pests, as opposed to controlling them, a systems approach is necessary.

Stimac and Barfield (1979) describe a systems approach as "actions are taken to dominate or direct the system toward achievement of a particular state of behavior by incorporation of or preservation of homeostatic regulatory mechanisms". This approach requires that all crop management practices be carefully evaluated with respect to its impact on the system and utilized, modified or rejected based upon its influence upon the entire system.

This well founded philosophy of pest management coincides and supports the stated objectives of sustainable agriculture. Sustainable systems are not conventional systems with certain inputs withheld but are systems within which changes are made which make certain inputs unnecessary. This is possible through the approach advocated by Stimac and Barfield wherein actions are taken to stabilize the system and make pesticide use unnecessary.

IPM recognizes the importance of protecting the environment. In the preface to the proceedings of a pest management conference, Rabb and Guthrie (1970) stated that "the chemical weapon alone is not tenable. The application of pesticides to large acreage with little or no regard for deleterious side effects can no longer be ignored". This goal has guided the development of pest management programs in North Carolina for 20 years. Consideration for off-site effects, non-target organisms, pesticide resistance, destruction of beneficial organisms, and other negative aspects of pesticide use are avoided in pest management programs to the extent possible.

IPM as a challenge to traditional economic, social and political policies. Many IPM extension demonstration programs began in the early 70's and struggled against the established concept of prophylactic treatments. The concept of treat as needed and scouting met with skepticism and in some cases, ridicule. An attitude prevailed that there was no reason to "take a chance" on economic thresholds when schedule pesticide applications allowed growers to sleep peacefully. However, IPM challenged conventional thinking and successfully demonstrated the many benefits of a systematic approach.

It appears that sustainable agriculture will have to survive the same gauntlet. And, like IPM, will be proven or disproved on the farm. Sustainable practices will have to contribute to the economic well being of the agricultural community or face rejection. Current changes to the farm bill being considered may aid in the adoption of certain sustainable practices. However, the final verdict will rest with the jury of growers. They alone will determine the outcome.

Practical Support for Sustainable Agriculture.

Proven methodology for pest management. IPM has shown the flexibility necessary to adapt to many crops and situations. LISA proponents have advanced the concept of what may be called "an experiment of one". This concept proposes that growers take an active role in customizing production systems to their farm and management style. This system will require flexible pest management programs which will allow growers to test various components and utilize tactics which prove useful. IPM programs have developed this flexibility through the years and will be able to help growers devise an individualized plan.

IPM has an established demonstration system. Growers respond slowly to changes in production practices. For a system such as sustainable agriculture to be adopted, a vigorous demonstration system should be established to show growers first, what a sustainable practice is, and second, how the practices are implemented, and third, the potential economic impact of the practice. Extension IPM programs have had over 10 years of experience demonstrating methodology to reduce pesticide use. These programs have been encompassing and information intensive. Sustainable agriculture demonstrations can benefit from this experience.

Changes required in IPM systems.

IPM often pesticide dependent. IPM programs have not stated as a goal the elimination of pesticides. It was the legislative intent of Congress in funding the extension IPM system that IPM be a .mechanism for reducing pesticide use but not necessarily eliminate use. IPM systems have always depended upon the pesticide safety net to prevent economic loss. And there appears to be little change in the near future.

If LISA systems are a fundamental redesign of production methods then additional reductions may be possible. For example, poor rotation patterns are perhaps the single biggest contributor to institutionalizing pesticide use. If changes being considered for future farm bills encourage long rotations then additional, significant, pesticide reductions are possible.

Agronomist often not consulted when designing IPM systems. Anyone responsible for developing pest management programs realize the impact that crop management has on subsequent pest problems. Yet the designers of those systems, agronomists, are often not consulted when pest management strategies are constructed. Too often pest management recommendations conflict with agronomic recommendations leaving our clientele confused, and in some cases, angry. LISA systems emphasize the interrelationship of the crop and pest management. This emphasis will strengthen and improve pest management.

IPM dependent upon economics. IPM has provided a timely and needed service to growers in the south by showing them how to reduce pesticide use during a period of economic difficulty. However, although IPM has been an program of environmental stewardship, it has traditionally been promoted as a way to reduce costs. This close linkage with economics has hurt the furtherance of IPM in some cases. For example, fresh market tomatoes in N. C. may have a total value of $10,000 to $15,000 an acre. The best IPM program for tomatoes can save the grower $150 to $250 an acre. A grower is highly unlikely to make many changes for a potential savings of 1.6% of the crop value. But from a food safety and environmental perspective, any pesticide reduction is worthwhile. The food safety and environmental concerns which have been the hallmark of LISA proponents will strengthen the arguments for some pest management programs.

The Role of IPM in LISA Systems,

It seems that a synergism can result from the combined expertise of IPM and LISA programs. IPM has the practical experience and proven results which can provide reliable pest management options as productions systems vary. It may be useful to look at the practical contributions IPM can make to a LISA system.

1) proven scouting procedures and economic thresholds for a wide array of crops and pests.
2) crop management considerations when designing pest management programs.
3) practical experience on designing and operating large scale on-farm tests and demonstrations.
4) an established and proven relationship of trust with a wide array of grower groups.

These characteristics of IPM will be useful to the testing and implementation of LISA principles. LISA has much to prove under southern growing conditions and there is little indication thus far as to the direction of LISA in the south. Whatever the outcome, IPM programs will be a positive contributor to the effort.

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Conservation Tillage and Soil Tilth: A Sustainable Combination

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Abstract

A need for favorable soil tilth to sustain productive agriculture has been recognized for many years, but quantitatively soil tilth remains a mystery. Soil tilth is dynamic, temporal, and affected by many factors. Measurements including aggregation, bulk density, porosity, structure, infiltration rates, surface roughness, and relative tendency to puddle, slake, or form surface crusts are used to characterize soil tilth. A recognition that soil tilth has a role in long-term soil productivity and sustainable agriculture, resulted in establishment of the National Soil Tilth Laboratory (NSTL) in Ames, IA Objectives of this report are to share the vision that scientists at the NSTL have with regard to soil tilth research priorities, identify cooperative research opportunities, and to discuss their relationship to conservation tillage throughout the southern U.S.

Introduction

Soil tilth is a very old concept that describes the soil condition created by an integration of the physical, chemical, and biological processes occurring within the soil matrix. Karlen et al. (1990) suggested changing the Soil Science Society of America definition of soil tilth to "the physical condition of a soil described by its bulk density, porosity, structure, roughness, and aggregate characteristics as related to water, nutrient, heat and air transport; stimulation of microbial and micro-fauna populations and processes; and impedance to seedling emergence and root penetration". They also defined *tilth forming processes* as "the combined action of physical, chemical, and biological processes that bond primary soil particles into simple and complex aggregates and aggregate associations that create specific structural or tilth conditions".

Soil tilth, tillage, and crop rotation are factors that are considered to affect soil productivity and sustainability. Whiteside and Smith (1941) stated that from the earliest days of agriculture, gradual changes in soil productivity had been observed because of crop production. They found that cropping systems had a great influence on the amount and direction of change in N and organic C concentrations, and that crops differed in their ability to preserve, amend, or deplete soil productivity.

Optimum seedbeds became synonymous with optimum soil tilth because of the difficulty in quantifying desireable tilth characteristics. Multiple tillage operations were considered essential to create a favorable seedbed, to achieve good soil-seed contact, and to ensure rapid, uniform crop emergence. After World War II, Melsted (1954) addressed the effects of tillage on tilth and suggested that by substituting capital for labor, the science of farming could replace the art of farming. He suggested that by using fertilizer N and reduced tillage, erosion could be controlled, organic matter increased, and optimum soil tilth developed.

The emotional perception that intensive tillage created good tilth was evident in early soil management information. Fream (1890) stated that in the minds of tillers, being told a soil is "open, free-working, mellow, or in good heart" makes one feel good, but if a soil is "hungry, stubborn, stiff, cold, or unkind" we immediately perceive it as being nonproductive. Recognizing that many people perceive that intensive tillage is essential for crop production makes it easier to understand the resistance that Jackson (1980) identified with regard to farmers adopting changes in soil management such as implementation of no-till or other conservation tillage practices. Fortunately, through meetings such as the Southern Conservation Tillage Conference, U.S. farmers have been provided information and techniques that can correct the misconception that intensive tillage is essential.

The objective of this presentation is to share the vision that scientists at the National Soil Tilth Laboratory (NSTL) have with regard to soil tilth research priorities and their relationship to conservation tillage.

Importance of Soil Tilth

Soil tilth is important because it affects all processes occurring in, the soil matrix, including crop growth. Soil tilth is often inversely related to soil strength which is associated with aggregate disintegration. As tilth is degraded, aggregate stability is often decreased

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allowing surface crusts and dense, compacted zones to form. These conditions increase the potential for soil erosion and often affect plant growth by reducing emergence, aeration, root growth, and total biomass production. This may decrease the amount of carbon returned to the system and further decrease aggregate formation. Degradation of tilth can be accelerated by poor management decisions such as performing an excessive number of unneeded or poorly timed tillage operations.

Tilth affects crop growth by influencing infiltration, movement, and retention of water within the soil profile. It influences chemical and biological processes occurring within the soil matrix by influencing aeration, heat transport, and profile water relationships. Tilth interactions are often complex and temporal. They are affected by many factors but have significant impact on crop growth, nutrient and water use efficiencies, and profitability of crop production. One example is mineralization organic N sources including organic matter, manure, sludge, or crop residue into inorganic N forms that can be cycled through subsequent crops or lost through leaching and denitrification.

Many soil chemical and biological processes also influence degradation of herbicides, insecticides, and fungicides (Moorman, 1989). When combined with water movement within the profile, these processes influence runoff, erosion, percolation, and ultimately transport of agrochemicals from or through the soil matrix and into surface or groundwater resources. This suggests that developing an interdisciplinary understanding of soil tilth is a high priority soil-related research topic for economically and environmentally sustainable agricultural growth.

Factors Affecting Soil Tilth

Many factors, including compaction by agricultural equipment, tillage, crop rotation, application of fertilizer and lime, freezing and thawing, wetting and drying, earthworms, arthropods, and other soil insects have been shown to influence soil tilth (Karlen et al., 1990). Soil organic matter is also a primary factor needed to sustain or improve soil tilth.

Developing management practices to create desired soil tilth conditions is difficult because tilth is a dynamic condition and processes that affect it are poorly understood. Research is needed to quantify the mechanisms through which soil organic matter, soil flora, fauna and microorganisms, as well as other physical, chemical, and biological processes affect soil tilth. This information is needed to better understand relationships among tilth and soil management problems, such as surface and groundwater quality, crop water use efficiencies, and long-term productivity, in order to quantitatively define and prescribe practices for sustainable agricultural growth.

National Soil Tilth Laboratory

History: Need for a National Agricultural Research Service Laboratory to study soil tilth was identified by the 86th U.S.Senate in Senate Document No. 59 (U.S. Senate, 1959). Planning for the laboratory involved many people, from many disciplines, and from all parts of the U.S. All efforts were fulfilled when the NSTL was dedicated on 6 July, 1989, thirty-years after it was officially recommended.

Mission: The mission of the NSTL, stated at the dedication is "to gain an understanding of the fundamental processes that occur in the soil as a result of physical, chemical, and biological interactions and tillage operations, and the effect of these processes on soil structure, environmental quality, and sustainability of agriculture." This mission emphasizes that soil tilth is considered to be a basis for sustainable agriculture in the United States and around the world.

Research Programs: The NSTL will provide a focal point for a national research initiative and program on soil tilth. The research focus will be on quantitatively understanding soil tilth and its relationship to national problems including issues such as groundwater quality and conservation tillage. In cooperation with scientists located at other ARS, Soil Conservation Service (SCS), State Experiment Station (SES), and Cooperative Extension Service (CES) locations throughout the U.S., research will be conducted to develop basic principles that can be integrated into complete management systems for improving, maintaining, or restoring soil tilth on agricultural lands. This program will provide many opportunities for cooperatively developing conservation tillage practices that sustain or improve soil tilth. The NSTL research program will provide a mechanism for interfacing state and federal research activities and opportunities for visiting scientists and graduate student programs.

Facility: The building has four levels, each with approximately 20,000 ft^2 of floor space. There are 43 laboratories and 52 offices. A unique feature of the NSTL is an indoor rhizotron that will allow research in which both above- and below-ground environments can be controlled. Undisturbed soil monoliths and reconstructed soil profiles can be studied in four chambers designed to grow plants to maturity. The building has a "terminal velocity tower" for research that requires rainfall simulation. There are laboratories with specialized analytical equipment, including a carbon-nitrogen-sulfur analyzer, an inductively coupled plasma spectrometer, an image analyzer, and an Instron universal testing instrument. Several laboratories are also being equipped with state-of-the-art robotics, gas chromatographs, high-pressure liquid chromatographs, and mass spectrometers to analyze for agrochemical residues and their decomposition products in soil, plant, and water samples.

When fully operational, there will be a research staff of 20 to *25* scientists. Graduate students associated with Iowa State University, post-doctoral research associates, and visiting scientists will be important contributors to interdisciplinary research teams within the laboratory. The teams will have active cooperation with several other research programs and scientists from other organizations at locations throughout the United States and around the world.

Research Approach: Interdisciplinary teams at the NSTL are conducting research to define and investigate physical, chemical, and biological factors that influence soil tilth. Those factors are then being integrated into farm management practices that can be used to develop sustainable agricultural production systems. This approach will provide the coordinated effort needed to quantitatively understand tilth and to learn how to maintain and improve tilth and thus optimize productivity and environmental quality. Typical soil physical investigations include: (a) developing techniques for measuring soil structure to better predict solute movement through soil, soil erosion, water infiltration, root growth, energy exchange at the soil surface, and tillage processes; (b) quantifying effects of tillage or wheel traffic on soil aggregation and formation or modification of soil pores; and (c) defining how tillage affects movement of agricultural chemicals from the zone of soil managed for crop production.

The soil chemical studies include: (a) measuring interactions among chemical and biological processes resulting from tillage and crop management systems that affect availability, sorption, transformation, and losses of agricultural chemicals; (b) assessing effects of different long-term cropping histories and agricultural management systems on soil chemical properties; and (c) identifying soil nitrogen-crop-tillage interactions that are required to synchronize soil nitrogen transformations and applied nitrogen with plant nitrogen requirements.

Biological investigations include: (a) quantifying the distribution, roles, and modes of action that earthworms, insects, and plant roots have on the development of macropores and chemical movement under various short- and long-term management practices; (b) quantifying effects of microbial and earthworm populations and distributions on the physical-chemical-biological interactions within the soil volume; and (c) developing integrative models for soil biological components related to tillage and management practices that predict nutrient movement, pesticide degradation, and groundwater quality.

Summary and Conclusions

The United States has a tremendous soil resource, but poor soil and crop management practices in some areas are allowing it to diminish by failing to control erosion, compaction, and other forms of soil deterioration. These processes affect soil tilth which influences almost every physical, chemical, and biological process occurring within the soil. The interaction between soil management and soil tilth has been recognized in a general manner for centuries, but now there is an opportunity to quantify effects of various soil management practices on soil tilth through research programs at the NSTL. One result of these new research efforts will hopefully be development and implementation of conservation tillage practices that improve soil tilth. Achieving that goal will create more economically and environmentally sustainable crop production systems.

Interpretive Summary

The USDA-Agricultural Research Service (ARS) has established the National Soil Tilth Laboratory (NSTL) in Ames, IA. This is important because good soil tilth is thought to be important for maintaining long-term soil productivity and sustained agricultural growth. This paper will be presented at the Southern Regional Conservation Tillage Conference. This forum will also provide an opportunity to discuss the Aldo Leopold Center for Sustainable Agriculture that the State of Iowa established on the Iowa State University campus. Cooperatively, the NSTL and the Leopold Center will provide many opportunities for cooperative research and generation of information for farmers and the general public. This report outlines initial research programs that will establish soil tilth as a fundamental basis for an economically and environmentally sustainable agriculture.

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Waste Management Alternatives

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Waste generation is accelerating at an unprecedented rate in the United States. Almost every phase of production, regardless of the sector of society (industrial, municipal, domestic or agricultural) you choose to explore, produces waste. In some cases, waste products have been integrated into other processes. However, for the most part it seems that we have become a throw away nation that would rather pay for losses in product and possibly environmental quality than a loss of personal time.

Attitudes are rapidly changing, however, with the increased visibility of environmentalists, media exploitation of human induced pollution, and increased costs of waste disposal, abatement and remediation. Governments, municipalities and the public are beginning to sense the magnitude of the situation and the seemingly limited number of technical options available to combat the problems. The need to know unbiased facts about waste management and reduction, as well as, pollution prevention and remediation is great. The "teachable moment" has arrived.

North Carolina, like the rest of the nation, has waste concerns. The current population is expanding at a rate equivalent to a city of 100,000 people every year. This increase in growth is accompanied by an increase in demand for consumable goods and waste disposal including solid goods, municipally treated waste water and sludge, septage and industrial byproducts. Municipal sludge alone amounts to over 116,000 dry tons per year. Animal production is also growing in the state an with it the amount of manure (20,713,427 wet tons/year), animal processing wastes and dead animals requiring disposal.

Waste management strategies are generally based on three options: waste reduction at the source, alternative uses and disposal. The remainder of this paper will discuss waste management alternatives that relate to either agriculture usage or generation.

Many waste products of industries, municipalities and agriculture contain nutrients from the organic material in the waste. If the product can be placed in an environment that permits biological decomposition, these nutrients can be released and made available for plant growth. The recycling of nutrients from waste products through the soil/plant ecosystem is an excellent alternative to disposal. The key to a successful land application operation is knowing the characteristics and contents of the waste product, the nutrient requirements of the plant system and the potential risk of contamination due to specific site conditions. With a comprehensive knowledge of these factors, an efficient and environmentally safe management plan can implemented for most waste products.

Waste products, such as dead animals, are not amenable to direct land application systems. Because of this most dead animals are either buried or put in underground disposal pits. Both these methods pose a potential risk to groundwater contamination. When large animals or large quantities of small animals are buried and begin to decompose, nutrients are released and the volume of the organic matter decreases. This decrease in volume permits the soil above the buried animals to settle forming a concave depression at the soil surface that promotes water infiltration to the decaying organic matter. Likewise, while a properly constructed disposal pit that sheds water is less likely to promote water infiltration, there is still a concentration of organic matter that will decompose with no opportunity to recover the released nutrients. Management alternatives for these types of waste can include composting and/or rendering.

Rendering is a process that recycles dead animals and animal parts into a marketable feed like dog food. This is an excellent alternative to burial that is environmentally sound and has little residue that would require final disposal in a landfill. Rendering, however, is iimited by the availability of a specific market/industry.

Composting is a process that promotes the microbial decomposition of organic matter. The process relies on a supply of carbon and energy (nitrogen) and can be preformed in the presence or absence of oxygen. The end product of high temperature composting is a stable product low in nutrient availability and with few pathogens. Composting, however, is not a complete disposal alternative in that a product still exists. Final use of the product can be through marketing as a potting media, or land application.

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Another alternative to disposal that may exist for some waste products is direct feeding to livestock. Many food industry and some pharmaceutical by-products contain sufficient quantities of amino acids, proteins and nutrients to serve as a feed. When fed, some animals are less efficient at extracting nutrients from feed than others and many of the nutrients are excreted in their feces. This in turn can be feed to a more efficient animal group that is capable of further extracting the nutrients. This type of feed recycling is practiced in many underdeveloped nations with limited resources. Principal drawbacks to this type of system is the need to have the different animal groups within a reasonable distance of each other to reduce the cost of handling and transportation.

Summary

Waste disposal in landfills should be the last option employed when all other management alternatives have been exhausted. Other waste management strategies include reduction at the source and alternative uses including: land application, composting, rendering and direct feeding.

Role of Conservation Tillage in Sustainable Agriculture

W. L. Hargrove[1]

Conservation tillage management can reduce soil erosion, enhance soil productivity, decrease dependency on fossil fuels and minimize water, nutrient, and pesticide runoff. It is my hypothesis that no-till management is necessary for sustainable crop agriculture. The objective of this paper is to outline the benefits of no-tillage in light of sustainability.

Soil Erosion Control

Crop residue on the soil surface is one of the most effective means of controlling soil erosion, and no-tillage management is an effective means of maintaining ground cover by crop residues. The landmark paper by Beale et al., (1955) was one of the first to demonstrate the importance of reduced tillage in controlling soil erosion. As equipment and chemical weed control practices were developed, no-tillage production became possible. Subsequent work by McGregor et al., (1975), Triplett and Van Doren (1977), and Langdale et al., (1978) showed that no-tillage with complete groundcover reduced soil erosion to less than T and in some cases to almost nothing. Data from Langdale and Leonard (1983), shown in Table 1, illustrate the erosion control afforded by no-tillage.

Table 1. Effect of tillage on runoff and soil loss in individual storms during high-energy rainfall months

Date	Rainfall (in.)	Rainfall Energy ($lb\text{-}a/ft^2$)	Runoff (in.)	Soil Loss (t/a)
	-------------Conventional Tillage----------------			
May 28, 1973	3.9	7.18	2.0	7.8
June 06, 1973	1.5	3.49	0.8	6.0
July 30, 1973	1.1	3.02	0.5	0.7
	No-tillage			
June 11, 1975	1.9	7.24	1.0	<0.01
July 13, 1975	1.0	2.82	<0.1	<0.01
July 24, 1975	1.7	2.68	<0.1	<0.01

Erosion has both on-site and off-site impacts. The on-site impact is rcduced productivity, while the off-site impact is degraded water quality as a result of scdimcnt loading and associated nutrients and pesticides. However, no-tillage can halt the deterioration of the soil by erosion. Furthermore, there is evidence that no-tillage can even reverse the deterioration and help restore productivity on eroded soils (Langdale et al., 1987). The significance of this to sustainability is obvious.

Soil Improvement

An important benefit of no-till production is grcatcr soil organic matter concentrations, especially near the soil surface (Blcvins et al., 1983; Dick, 1983; Hargrove et al., 1982; Lal et al., 1980). Our results in Georgia have shown that soil organic matter accumulation is significant with no-till management, and the degree of accumulation dcpcnds largely on the amount of organic C returned to the soil (Table 2).

Table 2. Influence of 5 years of various cropping sequences and tillage on soil organic C and N concentrations in the surface 3 in. of soil (from Hargrove and Frye, 1987).

Crop Sequence	Tillage	Organic C %	Organic N %
Wheat-Soybean	Conventional	1.4	0.12
Wheal-Soybean	No-till	1.6	0.15
Clover-Sorghum	No-till	2.2	0.17

Soil Water Relations. The benefits of no-tillage with respect to improved soil water relations have been well documented (Blevins et al., 1971; Triplett et al., 1968; NeSmith et al., 1987). The improvement in soil water relations afforded by no-tillage is generally by virtue of soil surface mulch cover. Mulch cover generally increases water infiltration and/or decreases evaporation from the soil surface. Results obtained in Georgia using a sprinkling rate of 1.5-in per hr, showcd the mean final infiltration rate after 60 min of sprinkling was 1.4-in per hr for the no-till soil compared to 0.6-in per hr for the plowed soil. It was subsequently determined that the greater infiltration rate of the no-till soil was primarily a result of surface cover which intercepted the raindrops and preventcd the crust formation which occurred on the bare soil.

The net effect of improved water infiltration and decreased evaporation is greater amount of soil water available for plant growth. This improved soil water

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availability has been well documented in Georgia, and has generally resulted in greater plant growth and crop yields (Hargrove and Hardcastle, 1984; Hargrove, 1985; NeSmith et al., 1987).

Soil Biological Activity. No-tillage results in an increase in soil biological activity, especially near the soil surface. Doran and co-workers (Doran, 1980a, 1980b; Broder et al., 1984) have shown that maintenance of crop residues on the soil surface generally results in increascd populations and activity of most soil microorganisms in the surface 10 cm of soil. The effcct of soil disturbance on levels of microbial biomass, soil water content, and organic matter in surface soil is shown in Table 3. As soil disturbance increased, the amount of microbial biomass decreased. The reason for this is the combined effects of the concentration of organic substrate near the soil surface and the bcttcr environment, in terms of moisture and temperature, for microbial growth. More recently, Power ct al., (1986) showed that one of the results of the increased microbial activity near the soil surface of undisturbed, mulched soils was increased mineralization, availability, and crop utake of indigenous soil N.

Table 3. Effect of degree of soil disturbance on levels of microbial biomass, water content, and organic matter of the surface 3 in. of soil (taken from Power and Doran, 1984).

Management	Degree of Disturbance	Microbial Biomass lb C/a	Volumetric Water Content %	Organic Matter %
Sod	None	955	17.7	4.49
No-till	Minimum	790	14.3	3.80
Subtillage	Moderate	739	12.1	3.28
Plow	Maximum	587	10.6	2.42

In addition to the increase in soil microbial biomass, it has been demonstrated that earthworm populations increase with no-tillage compared to conventional tillage (Edwards, 1975; Edwards and Lofty, 1980; House and Parmelee, 1985). In long-term tillage plots in Georgia, we have observed as many as 50 earthworms square yard in the surface 6-in of soil with continuous no-tillage compared to 0 earthworms in a plowed soil. This increase in earthworm activity results in increased soil burrows and macroporosity (Edwards, 1975; Edwards and Lofty, 1980), which, in turn, promotes good soil aeration and root growth. In fact, we have obscrvcd root growth using minirhizotrons in our long-tcrm, no-till plots and found that relative root growth is grcatcr for long-term no-till managcmcnt compared to a plowcd soil (Hargrove, 1985; Hargrove et al., 1988a; Hargrove et al., (1988b).

Soil Aggregation and Macroporosity. The effect of increased organic matter and biological activity is improved soil physical condition including increased aggregate stability and macroporosity. Research in the 1940's and 1950's documented improved soil tilth, aggregate stability, and soil macroporosity with increases in soil organic matter (Lutz, 1954; Pieters et al., 1950; Uhland, 1949; and Welch et al., 1950). Allison (1968) found that returning crop residues to the soil improved aggregation chiefly by furnishing a carbon source for microorganisms which produce mucus and other binding agents. This is particularly important with no-tillage as crop residues and soil microbial activity are concentrated near the soil surface. The potential for improved aggregate stability near the soil surface is therefore great. Results from aggregate stability measurements in experiments conducted in Georgia are shown in Table 4. Although tillage was not a variable in this experiment, the data show that aggregate stability increased as the amount of organic matter returned to the soil surface increased. Tillage would not only destroy aggregates, but would dilute the effcct of residues.

Table 4. Influence of cover crops on soil aggregate stability after 3-yrs of no-till sorghum production.

Cover crop	Annual C Input from Cover crop lb/a	Soil Organic Carbon %	Water-Stable Aggregates %
None		0.85b	28.9b
Wheat	812	0.89b	32.6ab
Hairy Vetch	1103	1.02a	36.7a

Macropores are important to soil aeration and root growth. Wc have demonstrated that although no-tillage can result in compacted soil horizons, macropores can allow root growth through these horizons (Hargrove et al., 1988a,b).

Reduced Fossil Fuel Use

No-tillage has a much lower fuel requirement because primary and secondary tillage operations are eliminated. For a moldboard plow/disk tillage system, this would eliminate about 4 gallons of diesel fuel per acre per year, a significant energy savings.

In addition, the use of a legume cover crop to replace some of the fertilizer-N requirement along with no-till management could reduce the total fossil fuel requirement by as much as 27% (Neely et al., 1987). This would have both a significant economic and environmental impact.

Crop Growth and Yield With Long-Term No-Till Management

The net effect of improved soil erosion control, increased soil organic matter, increased water availability, increased biological activity, and soil structure is improved crop growth and yield. Many published studies have shown a yield increase from no-till management (Adams et al., 1973; Van Doren et al., 1976; Langdale et al., 1984; Beale and Langdale, 1967; Campbell et al., 1984; Griffith et al., 1973; and NeSmith et al., 1987; Hargrove, 1985). Generally, yield responses in short-term (<5 yrs) experiments occur in years when significant moisture stress also occurs and are due to increased soil water supply afforded by the surface mulch. The other benefits of no-till management with respect to erosion control and soil improvement are more long-term in nature and are poorly documented in the literature.

In Georgia, we have been comparing no-tillage to moldboard plowing in a field experiment over a thirteen-year period. Relative crop yields from this experiment are shown in Fig. 1. No-till yields were significantly greater than conventional tillage in seven years (1979, 1981, 1983, 1985, 1986, 1987, 1988), but the same in three years (1976, 1982, 1984). The three years in which equal yields were obtained were years with good rainfall distribution. In one year, no-tillage resulted in significantly lcss yield due to failure to get a plant stand with the no-till treatments. The mean ratio of yield for no-tillage compared to conventional tillage was 1.40. These results indicate that no-tillage through improved crop productivity can play a significant role in a sustainable agriculture.

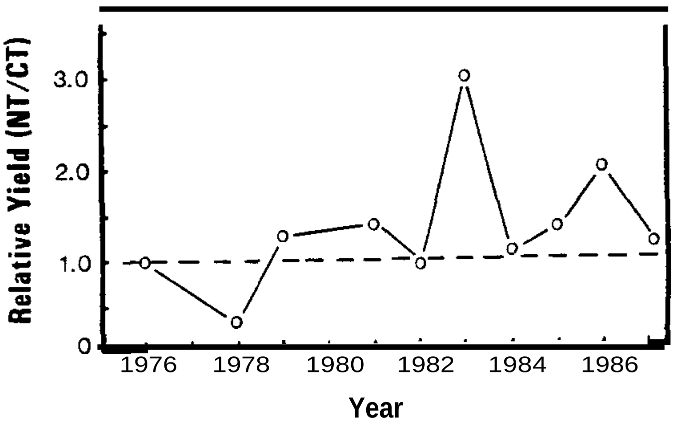

Figure 1.

Conclusions

The beneficial effects of no-till management include the following:

1) soil erosion control, which will both maintain soil productivity and lessen off-site environmental damage,

2) Soil improvement including

   a) soil organic matter maintenance or even enhancement
   b) reduced water runoff and improved soil water storage
   c) improved soil biological activity
   d) improved soil structure, aggregate stability, and macroporosity,

3) Lessened dependence on fossil fuel energy,

4) Improved crop growth and yield.

These benefits form a core of criteria which need to be met in order to achieve a sustainable crop agriculture. The importance, then, of no-till management to the development of sustainable crop production systems is self-evident. We conclude that no-till management forms the fundamental foundation of a long-term strategy for crop production and should play a key role in the development of a sustainable crop agriculture.

A challenge facing agricultural scientists and conservationists is to develop strategies for no-till production with reduced dependence on pesticides and other chemicals. Practices and innovations which might make this integration possible include, 1) improved crop pest resistance and nutrient utilization through plant breeding and biotechnological advances, 2) improved crop management in terms of diversification and crop rotation, 3) judicious use of pesticides, and 4) maintenance of mulch on the soil surface.

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Pest Management in Conservation Tillage Systems

Integrating Conservation-Tillage and Crop Rotation for Management of Soybean Cyst Nematode

S. R. Koenning, D. P. Schmitt, and B. S. Sipes[1,2]

Abstract

A long-term rotation by tillage experiment was established to determine the effects of no-till planting. on the soybean cyst nematode *(Heterodera glycines* Ichinohe) and associated effects on the yield of soybean [*Glycine max* (L.) Merr.]. No-till resulted in significantly ($P = 0.01$) lower numbers of cysts, eggs, and juveniles in 1986 and 1988. There was a trend toward lower soybean yield, at the outset of the experiment, in no-till. The trend to lower yields in no-till was reversed after five years with higher yields in no-till. Yield differences as a result of tillage were not, however, statistically significant. Rotation was effective in managing *H. glycines.*

Introduction

A major constraint on soybean production in North Carolina is the soybean cyst nematode. Soybean yield losses in response to this pest range from minimal to crop failure in individual fields. Tactics for managing soybean cyst nematode are the use of resistant cultivars, crop rotation, cultural practices, and nematicides. The use of nematicides has given little economic gain even though the increase in yield is often statistically significant (3). Resistant cultivars are effective against only 20% of the SCN populations in North Carolina. Most growers must rely on crop rotation and other cultural practices to manage SCN and produce a profitable soybean crop. Conservation tillage needs to be integrated with tactics for managing soybean cyst nematode if it is to be a viable production practice.

The effects of conservation tillage on nematode population dynamics and disease development is not clear-cut. No-till production can suppress nematode numbers, but it generally requires several years to have a measurable effect. The short-term effects on nematode populations and yield of double cropping soybeans with wheat have been relatively small.

Distinct nematode population patterns are developing in fields farmed without tillage over the long term. The soils usually contain more free-living nematodes and fewer plant-parasitic nematodes than in conventionally tilled fields (Tables 2-4). Unfortunately, yields are sometimes lower with no-till treatments than with conventional tillage.

The current research was undertaken to evaluate the long-term effects of no-till soybean production on soybean yield and *H. glycines.* The objectives of this research were to: (i) evaluate soybean yield under no-till versus conventional tillage in fields infested with *H. glycines,* (ii) determine the effects of tillage on *H. glycines* population dynamics, and (iii) study the effects of rotation on *H. glycines* and soybean yield.

Materials and Methods

A tillage study was initiated at the Tidewater Research Center near Plymouth, NC, in 1985. Plots were established in a Portsmouth fine sandy loam with 4.2% organic matter. Experimental plots were 40 ft. long with eight rows, 36-inch row spacing and 10 ft. alleys. The soil in conventional-tillage plots was disked and then tilled with a tilrovator. All plots were planted with a no-till planter.

Soybean cultivar Coker 156 was used until 1987, and the cultivar DPL-105 was used in subsequent years. Soybeans were planted in selected plots mid-May of each year except for the corn-wheat-soybean rotation which was planted in mid- to late-June.

Soybean and corn yields were collected from the two center rows of each plot. Soil samples for nematode enumeration and identification were collected from the center two rows. Nematode samples consisted of 10-15 cores, one-inch in diameter taken to a depth of six to nine inches and composited. Nematodes were extracted from one pint of soil by elutriation and centrifugation (1).

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The experiment was a randomized complete block with four replications. Experimental design was for a 4 X 2 factorial with four rotations and two tillage regimes, conventional and no-till. Rotations were continuous soybean, corn-soybean, corn-corn-soybean, and corn-wheat/soybean double-cropped. Rotations were established such that all four rotations appear every year after 1986. Data were subjected to analysis of variance (ANOVA) and orthogonal contrasts were used where appropriate.

Results

Soybean yields were unaffected by tillage in 1985 (Table 1). One-year rotations were analyzed in 1986. There was a trend toward lower soybean yield in the no-till aspect although the difference was not significant. The corn-soybean or corn-wheat/soybean double cropped rotations gave significantly ($P = 0.001$) greater soybean yield than did continuous soybean (Table 1). Complete rotations were in place after 1987. A one- or a two-year rotation gave significantly greater ($P = 0.001$) soybean yield compared to monoculture during the 1987 growing season (Table 2). Late-planted soybean following wheat yielded the same as monoculture. There were no significant effects of rotation or tillage on 1988 soybean yield. Rotations of one or two years (excluding late-planted soybean after wheat) resulted in greater soybean yields ($P = 0.01$) compared to continuous soybean in 1989 (Table 2). No-till yields were somewhat greater than conventional tillage in 1989, but not significantly (Table 2). Numbers of *H. glycines* eggs were lower ($P = 0.05$) under no-till than conventional till after two years of no-till in the fall of 1986 (Table 3). Rotations with corn were effective in lowering population densities of *H. glycines* in every year. *H. glycines* cysts, eggs, and juveniles were significantly less ($P = 0.001$) in no-till plantings than in conventional till at the end of the 1986 growing season (Table 4). Rotations of one or two years resulted in lower numbers of *H. glycines* in the experiment in every year.

Table 1. Influence of tillage and rotation on soybeon yield (Bu/acre) at Ihe beginning *of* lhis study at the Tidewater Research Station.

Year crop sequence1	Tillage: Conventional	Tillage: No-till
1985		
S-S	33.0	32.0
ANOVA: tillage ($P = 0.7185$)		
1986		
S-S	35.9	36.4
C-S	50.7	45.5
C-W-S	48.4	44.2
ANOVA: rotation ($P = 0.0001$), tillage ($P = 0.2300$), tillage X rotation ($P = 0.5984$)		

[1] S-S indicates continuous soybean, C-S is a one-year corn-soybean rotation, and C-W-S denotes corn-wheat-soybean.

Table 2. Effects of tillage and rotation on soybean yield (Bu/acre) at the Tidewater Research Station In a field Infested wilh soybean cysl nemalode.

Year crop sequence[1]	Years[2] between soybean crops	Tillage: Conventional	Tillage: No-till
1987			
S-S-S	0	30.7	33.8
S-C-S	1	39.4	42.2
S-C-W-S	1+	29.2	24.6
C-C-S	2	38.2	40.8
ANOVA: rotation ($P = 0.001$), tillage ($P = 0.4903$); orthogonal contrasts one- and two-year rotations vs. no rotation ($P = 0.001$).			
1988			
S-S-S	0	28.0	22.6
S-C-S	1	28.1	27.8
S-C-W-S	1+	27.0	27.8
C-C-S	2	29.0	31.5
ANOVA: rotation ($P = 0.1823$), tillage ($P = 0.6929$); all contrasts NS.			
1989			
S-S-S	0	28.4	33.2
S-C-S	1	35.9	38.5
S-C-W-S	1+	23.8	26.4
C-C-S	2	39.3	35.6
ANOVA: rotation ($P = 0.0001$), tillage ($P = 0.3150$); orthogonal contrasts one- and two-year rotations vs. no rotation ($P = 0.01$).			

[1] S-S-S denotes continuous soybean, S-C-S indicates a one-year soybeancorn rotation, S-C-W-S denotes soybean followed by corn then double-cropped wheat-soybean, C-C-S indicates two-yean of corn followed by soybean.

[2] The one 1+ years rotation applies to soybean double-cropped with wheat. This is a short-season soybean crop and thus has somewhat lower yields than full-season crops.

Discussion

No-till resulted in lower numbers of *H. glycines* life stages in 1986 and 1988 when compared to conventional tillage. The effects of no-till on *H. glycines* were generally not significant in other years probably because of environmental factors. High rates of irrigation in 1987 and high rainfall in 1989 resulted in lower numbers of *H. glycines* possibly confounding the effects of tillage treatments in these years. soybean yields tended to be lower in no-till treatments at the outset of the experiment, but were higher than

Table 3. Population change of the soybean cyst nematode eggs from Spring 1985 to Fall 1986. at (he Tidewater Research Station.

Rotation	Conventional till P_i	Conventional till P_f	No-till P_i	No-till P_f
Continuous soybean	**1800**	**13000**	**8275**	**8300**
Corn-soybean	**2075**	**10300**	**1700**	**2200**
Soybeancorn	**1725**	**0**	**2325**	**0**
Corn-corn	**1950**	**0**	**1575**	**0**

ANOVA: tillage (P = 0.0788), rotation (P = 0.003), tillage X rotation (P = 0.1803) for final population densities (P_f).

Table 4. Numbers of *Heterodera glycines* cycsts, eggs, and juveniles/pint of soil at the end of the 1988 growlng season from the Tidewater Research Station

Crop sequence	Tillage: Conventional Cyst	Conventional Eggs	Conventional Juveniles	No-till Cyst	No-till Eggs	No-till Juveniles
Continuous soybean	**150**	**14475**	**305**	**52**	**3675**	**80**
Soybean after corn	**122**	**11388**	**163**	**57**	**4513**	**105**
Soybean aftercorn &wheat	**126**	**12200**	**275**	**15**	**1625**	**8**
1-year corn after soybean	**1**	**13**	**1**	**4**	**388**	**0**
1-year corn after wheat & soybean	**0**	**0**	**3**	**2**	**75**	**8**
2-years corn after soybean	**0**	**0**	**0**	**2**	**75**	**0**

ANOVA: cyst-tillage (P = **0.005),** rotation (P = **0.0001),** tillage X rotation **(P = 0.0801);** eggs-tillage (P = **0.004).** rotation (P = **0.0002),** tillage X rotation (P = **0.0773);** juveniles-tillage (P = **0.0024).** rotation (P = **0.0265).**

conventional till in later years. These trends were not statistically significant but may be a result of long-term benefits to be derived from no-till plantings. The experiment was designed to continue for another five years. Rotation effects were highly significant in every year except 1988.

Crop rotation must be integrated with tillage practices to obtain optimal soybean yield. No-till planting may be an effective tool in managing soybean cyst nematode provided it is combined with other tactics to manage soybean cyst nematode.

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Early Planting Reduces Fall Armyworm Problems in No-till Tropical Corn

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Abstract

The 1989 tropical corn *[Zea mays* (L.)] double-crop growing season in north Florida was characterized by excessive rainfall from 21 May to 27 June, resulting in late planting of most of the tropical corn and the subsequent infestation of fall armyworm [*Spodoptera frugiperda* (J.E. Smith)]. The objective of this note is to document the effect of late planting and fall armyworm injury on selected tropical hybrids. In 1989, two fields were early planted to X-304C (after harvesting wheat) on 26 May and 4 June in a moderate energy input system. Other tropical corn plantings were delayed until after 29 June.

Early planted X-304C yielded 61 bu/A at North Florida Research and Education Center and 65 bu/A in the farmers field. Fall armyworm was not a severe problem in either early planted field. Lower yields were more a function of excess soil water, nitrogen leaching, and oxygen stress in the corn plants. Fields of X-304C planted after 29 June were heavily attacked by fall armyworm. The highest farmer field yields were 30 bu/A. The poorer fields were plowed under. Pioneer X-304C in a tropical corn hybrid yield trial, planted 29 June 1989, yielded 42 bu/A. This experience suggests that planting after 24 May and prior to 10 June could possibly allow X-304C to escape armyworm injury and reduce crop risk.

Introduction

Farmers in the Southeast became interested in tropical corn [*Zea mays* (L.)] in 1984 and planted about 5,000 A predominately Pioneer Brand X-304C hybrid [coded X-304C]. By 1988, plantings had increased to about 10,000 A with good yields and in 1989 approximately 40,000 A were sown to tropical corn. A moderate energy input system for tropical corn was described by Teare, et al. (1989) based on four years research growing X-304C when planted after winter wheat *[Triticum aestivum* (L.)] (harvested around 24 May each year).

Overman and Gallaher (1989) conducted a date of planting study in 1988, where X-304C was grown in a high energy input system (no-till planting at 34,400 plants/A, 270 lb N/A and irrigation) with three planting dates (Mar, May, Aug). These authors reported yields of 150, 114, 78 bu/A for the three respective planting times and attributed yield reduction to differences in temperature and day length. Increased pest problems were only mentioned. Bustillo and Gallaher (1989) state "insect control needs further research [on tropical corn], to determine the most effective and economical control program." Experience in South America (J.E. Funderburk, 1988, personal communication) indicated that IPM practices must be adhered to for control of lesser cornstalk borer [*Elasmopalpus lignosellus* (Zeller)] and fall armyworm [*Spodoptera frugiperda* (J.E. Smith)]. Few insect or disease problems were experienced during 1985 to 1988, but the 1989 season was different.

Fall armyworm is a polyphagous, highly mobile insect that normally arrives in North Florida by late-May. The population probably originates each spring from continuous breeding populations in southern latitudes (Barfield, et al., 1980). The erratic occurrence of fall armyworm "outbreak years" and irregular distribution of heavy infestations indicate that fall armyworm is a "boom or bust" pest. The last "boom" year in the southeastern US was in 1977. Fall armyworm larva developing on corn usually has six larval instars requiring a period of 21 days. However, the life cycle is temperature dependent and can range from 66 to 18 days at temperatures of 64 to 95°F (Barfield et a1.,1978).

Fall armyworm eggs laid on leaves in the whorl, generally escape most natural predators, but egg masses laid after the tassel has emerged are subject to greater predation (Martin et aL.1979). Natural enemies have been observed to move sequentially through crops

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coupled by pest flows and reduce population densities of fall armyworm in a very short period (Martin et a1.,1979).

Many practices are employed to plant, maintain, and harvest any crop. Pest injury avoided by producing a crop at times when pest populations are in nondamaging stages or at low population levels is recognized (Herzog and Funderburk, 1986).

Our experiences in 1989 with tropical corn indicates a cultural practice that improves the wheat-tropical corn doublecrop system proposed by Teare et al. (1989) in relation to planting and fall armyworm. The objective of this note is to document our observations during 1989 on the effect of early and late planting on the susceptibility of X-304C to fall armyworm and to suggest a planting window after wheat harvest (24 May) where tropical corn scems to escape the fall armyworm in a production environment.

Materials and Methods

The fall armyworm observations reported in 1989 are from an on-going tropical corn research program at the North Florida Research and Education Center (NFREC) and surrounding tropical corn fields in Gadsden county. The soils are a Norfolk sandy loam soil [fine-loamy, siliceous, thcrmic, Typic Kandiudult]. All plantings were grown under the moderate energy input system: no-till planting at a plant population of 18,000 plants/A 120 Ib N/A [20 Ib/A as starter fertilizer at planting and 100 Ib/A when the corn was 12 inches tall (approximately 31 days after planting)], and no irrigation. The major difference from previous years was rainfall, date of planting, and incidence of fall armyworm. Rainfall data was collected at the NFREC weather station located approximately 200 to 800 yd from the tropical corn experiments. The early planted experiment at the NFREC was planted 26 May 1989 to X-304C (four rcplications in a randomized block design). The 1989 early planted farmer field was planted 4 June eight miles west of Quincy. The excessive rainfall from 21 May to 27 June delayed other tropical corn plantings and flooded poorly drained areas. About half of the early planted farmer field was not harvested because of excessive soil-water causing oxygen stress in tropical corn. Only the yield of the well-drained area is given. The 1989 late planted (29 June) study was a tropical corn hybrid yield trial (four replications in a randomized block design) containing X-304C. Grain yields were corrected to 15.5 % moisture content.

Results and Discussion

Excessive rainfall, delayed planting, and fall armyworm injury were the major differences that we observed between the years of 1989 and 1985 through 1988. Rainfall from 21 May to 27 June 1989 was 20 inches. Rainfall during the tropical corn growing season of 1989 can be compared with the rainfall for 1988 (Fig. 1). Only two fields of X-304C were planted early in North Florida that we knew of, the rest were delayed until after 27 June. The yield of the early planted tropical corn in 1989 was 61 bu/A at NFREC and 65 bu/A in the farmers field compared to 94 bu/A yield average for 1986, 1987, and 1988 at NFREC Fall armyworm damage in the 1989 early planted X-304C was only noticeable on leaves about the same as observed in 1985 to 1988. The 1989 late planted, fall armyworm infested X-304C (planted 29 June) yielded 42 bu/A. Therefore, we have suggested a window between 24 May and 10 June where fall armyworm damage is at a low risk.

Under severe infestations as observed in 1989 late planted tropical corn, the fall armyworm will skeletonize leaves in early instars or produce ragged holes in later instars and eat the tassels and silks. We have not observed much fall armyworm damage on the ears or stems of the ears of X-304C, but grain fails to develop from lack of pollination. Percent tasseling and silking curves for early planted X-304C in relation to day of year for 1988 show little observable fall armyworm damage (Fig. 2), but percent tasseling and silking curves for late planted X-304C in 1989 show extensive fall armyworm damage. The 1989 change in tasseling pattern was observed on 240 day of year (28 Aug) when fall armyworm consumption of tassels made it appear that tasseling had ceased, followed by a slight increase and then a negative slope at 250 day of year (7 Sept). The consumption of silks in 1989 reduced the silking slope at 244 day of year and it became negative after 250 day of year. This indicates that fall armyworm populations were at their highest levels during tasseling and silking. A very susceptible stage of growth for X-304C in relation to grain yield.

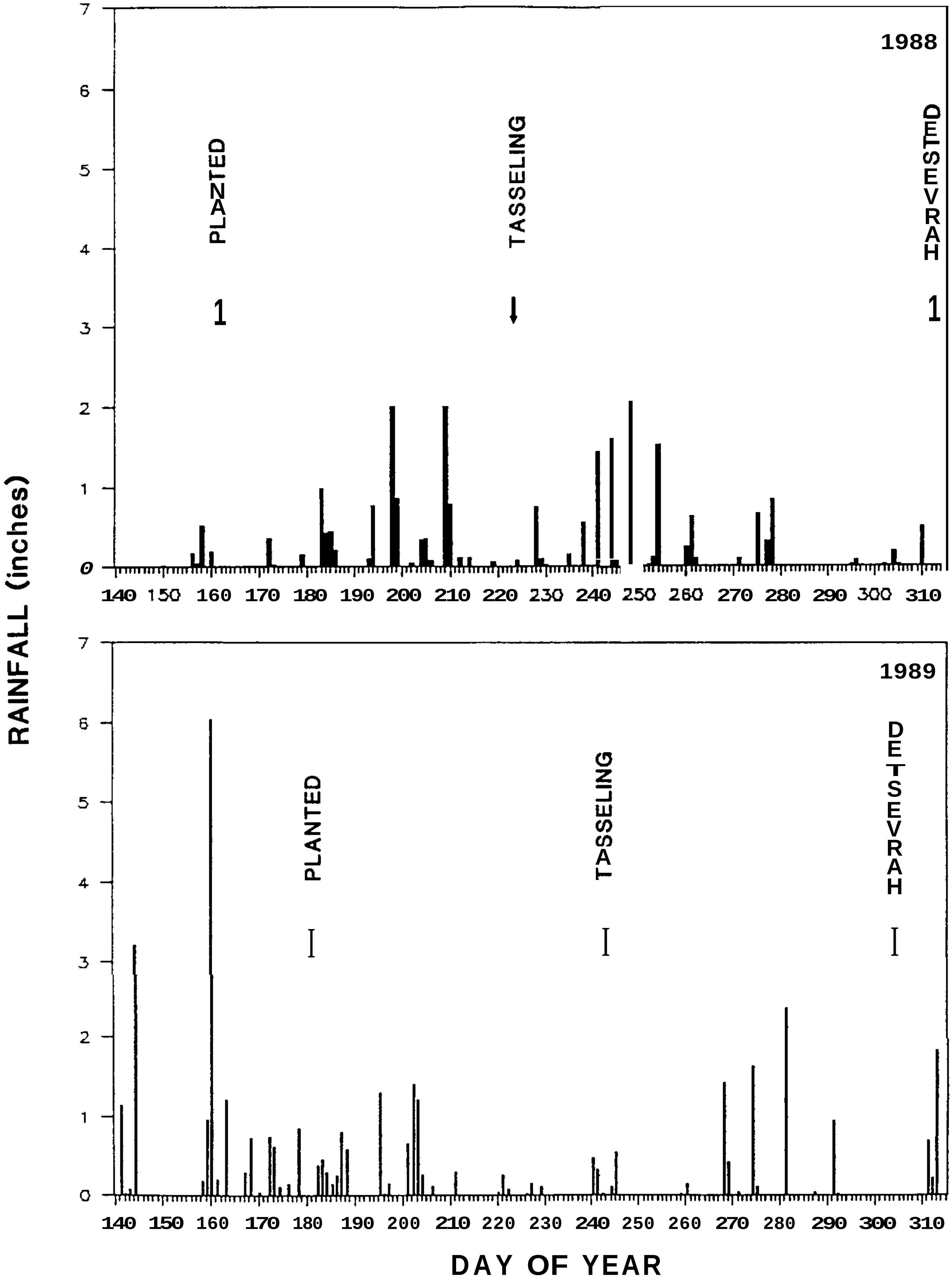

Figure 1. Rainfall, planting date, 50% tasseling, und harvest date during 1989 and 1988 tropical corn growing seasons in relation to day of year.

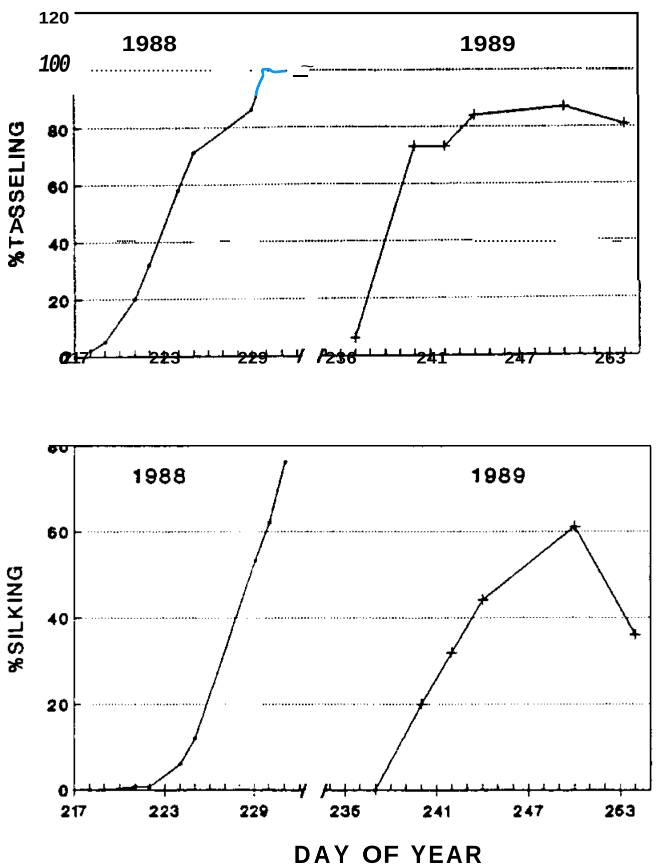

Figure 2. Comparison of tasseling and silking for 1989 in relation to 1988. Negative slope after 250 day of year (7 Sept) indicated time of severe fall armyworm damage in 1989.

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Weed Management Strategies for Conservation Tillage in the 1990's

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Introduction

Surveys in past years among no-tillage and conservation-tillage practitioners and professional workers usually indicated that obtaining adequate weed control was the greatest problem encountered in no-till and the greatest deterrent to expansion of this practice (22). This led Worsham and Lewis to state in the Proceedings of the 8th Southern No-Tillage Conference that weed management was the key to successful no-tillage crop production (24).

Now, however, a survey recently conducted by the National Conservation Tillage Information Center revealed that grower resistance to change was the major deterrent to adopting conservation tillage methods. Weed control was the second most important problem.

Weed management strategies for no-tillage and conservation-tillage cropping systems will be similar in the early 1990's as they have been for the past several years. These strategies in no-tillage depend almost entirely on foliar and surface-applied herbicides because mechanical seedbed preparation, soil-incorporated herbicides, and postemergence mechanical cultivation are eliminated. Some use of soil-incorporated herbicides and cultivation in row-crops could still be made in conservation-tillage systems, depending on the amount of surface residue left after minimum tillage seedbed preparation.

Currently, for example, most no-tillage cropping systems in the southern U.S. employ a mixture of a "burndown" herbicide plus one or more residual herbicides. The burndown herbicide kills emerged grass and broadleaf weeds and any cover crop present at or before planting. Residual herbicides are needed to control weeds germinating from seed later in the season. To complete the weed management program, a postemergence herbicide or herbicides may also be needed for additional control of broadleaf weeds, grasses, or both. In some crops, such as in soybeans, postemergence grass and/or broadleaf herbicides may be substituted for residual herbicides.

Many of these strategies should change or shift in emphasis in the 1990's. Some predictions as to changes in weed management strategies will be made in following sections of this paper.

Weed Management Tools and Changes for the 1990's

The time proven weed management tools of crop rotations, crop competition, cultivation and seedbed preparation, and herbicides will remain with us through the 1990's. There will be changes, however, even within these weed management tools.

Rotations: Crop rotation will play a greater role in weed management in the future. There will be a general public demand and acceptance by growers for a reduction in pesticide use, including herbicides. More legislative or regulatory agency regulations will be enacted. Therefore, there will be more reliance on non-chemical methods of weed management, including rotations, to help reduce weed problems.

Crop Competition: Greater use of crop competition will help fulfill the prediction made above. Growers will move toward planting all row crops in more narrow rows, making greater use of cover crops to suppress weeds (more details will be given on this aspect later) and planting cover crops to more dense stands.

Cultivation and Seedbed Preparation: Currently the presence of certain weeds, mainly perennials, causes cultivation or tillage to be recommended for seedbed preparation. New herbicides now expected to be on the market within a few years and possible yet undiscovered herbicides may make this recommendation obsolete. With better no-till drills becoming more widespread in use, more crops, including winter cover crops, will be planted satisfactoriIy without tillage. Tillage for successful establishment of fall-seeded cover crops has been recommended in the past. These new developments should allow for a system of continuous no-till crops in many areas, thus allowing growers to realize the full, long-term benefits of no-tillage.

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Another innovation in the machinery area is the development of "no-tillage" cultivators. These implements are designed to operate to control weeds in soils with mulch present, leaving the mulch on the surface to conserve soil and moisture.

Herbicides: There will be an overall reduction in total herbicide use, partially the result of new regulations and partially made possible by the adoption of the new practices described in the previous sections and the advent of new herbicides which are being used in fractions of an ounce per acre. However, there will still be heavy reliance on herbicides in no-tillage and conservation-tillage systems.

There will be a move toward more reliance on postemergence herbicides applied on an as-needed basis instead of routine applications of soil-applied herbicides at planting. New herbicides, some of which will be discussed later, will allow a total postemergence approach to weed management in more crops, particularly corn.

Current Management Strategies

In the chapter on weed management in the N.C. State University publication, "Conservation Tillage for Crop Production in North Carolina", there is a detailed discussion of weed management programs covering control of existing vegetation, residual weed control and postemergence weed control in corn, soybeans, grain sorghum and cotton (7). Weed management systems in forage and vegetable crops are covered in other chapters in the same publication.

These recommendations are still current except for a few additions in corn and soybeans: Buctril or Brominal postemergence in corn; Roundup + Prowl + Scepter; Roundup + Squadron or Turbo; Gramoxone Extra + Prowl + Scepter, or Gramoxone Extra + Squadron preemergence in soybeans; and Pursuit postemergence in soybeans.

All situations which may be encountered in weed management inconservation tillage productionof these crops are adequately covered in the previously mentioned publication and will not be repeated here.

Future Weed Management Strategies

The 1990's will see tremendous changes in weed management strategies in conservation tillage cropping systems as well as conventionally tilled systems. Some of these changes in conservation tillage crops will be in the areas of: (1) new herbicides, (2) more use of allelopathic (phytotoxic) cover crop mulches to suppress weeds, and (3) genetically engineered crops which will have tolerance to different herbicides.

New Herbicides: The first new herbicides to be marketed in the early 1990's that will have a significant impact on no-till corn will be the over-top grass herbicides Accent, from duPont, and Beacon, from Ciba-Geigy. A major advantage will be that no-till or conservation-till corn canbe planted intojohnsongrass-infested fields. A standard surface applied herbicide can be used at planting for other weeds and johnsongrass can be controlled postemergence. Both compounds have activity on annual grasses and some broadleaf weeds. Use of these compounds, and in some cases, with the addition of a broadleaf herbicide, will for the first time allow a total postemergence approach to weed management in corn. The major advantage of these new herbicides in conservation cropping systems, however, is the fact that in johnsongrass infested fields, preplant soil-incorporated herbicides will not be required, thus allowing more soil-conserving, crop production practices.

Since these new herbicides will be used at rates of fractions of an ounce per acre and are moderate in soil mobility, they should pose less potential for groundwater contamination and be more environmentally acceptable.

Another herbicide expected to be marketed in the early 1990's as a non selective 'burndown' chemical in no-till crops is Ignite, from American Hoechst. This herbicide is moderately translocated and is faster acting than Roundup. It is expected that this herbicide will fill a gap in controlling certain weeds present at planting that are tolerant or require higher rates of Roundup or Gramoxone Extra.

While it is expected that there will be a great reduction in the number of new herbicides reaching the market in the 1990's, those that do will probably be "new generation" compounds used at extremely low rates and more environmentally acceptable.

Use of Allelopathic Cover Crops: With growers meeting full compliance of the conservation requirements of the 1985 Food Security Act by 1995, more and more will turn to conservation- or no-tillage. With this move, there will be more use of cover crops in general. Also, since North Carolina's requirement to meet conservation tillage on highly erodible land is 50% ground cover, ad compared to 30% for the rest of the U.S., more use will have to be made of cover crops. Research and farmer experience in North Carolina and in a few other states has shown that a considerable degree of early-season weed suppression can be gained by use of certain winter annual cover crops.

The presence of crop residues has been reported to both increase and decrease crop yields and not tilling to increase certain difficult-to-control weeds (7). However, other reports indicated that the presence of certain mulches can reduce the biomass of certain weeds and allow for higher crop yields (1,13,15,25). Research to date indicates that both mulch and the lack of soil disturbance contributes to the suppression of weeds in no-till cropping systems (15).

Crop and weed scientists traditionally have viewed allelopathic interactions in agriculture as detrimental (14). Many of the world's weeds have been reported to have allelopathic properties which reduce crop growth and yield. In fact, 13 of the world's 18 "worst weeds" have been reported to produce allelochemicals (10). Allelopathic potential has now been suggested for about 90 species of weeds (11).

In recent years, however, more attention has been given to possibilities of exploiting allelopathy to aid in weed management. This approach gains importance as growers try to adopt crop production methods which rely less on high chemical (pesticide) inputs (25). Cover crops of wheat, barley, oats, rye, grain sorghum, and sudangrass have been used effectively to suppress weeds, primarily annual broadleaf weeds (1,12,13,15,17).

Weed suppression has also been noted in the U.S. from residues of several winter annual legume crops. White et al. (21) reported inhibition of several weeds from field residues and leachates of crimson clover and hairy vetch. Teasdale (18) showed some weed suppression from hairy vetch residues, but concluded that other methods of weed control would be needed. Enache and Ilnicki (6) concluded, however, that subterranean clover had a definite potential for controlling weeds in corn. Else and Ilnicki *(5)* studied growth and species composition of weeds in four mulch and tillage systems, with A living subterranean clover mulch provided nearly complete weed control. Evidence of allelopathic activity was found in extracts of clover leaves and in dead residue. The authors concluded that some mulches can, in the presence of a corn crop, provide adequate weed control without the use of herbicides or mechanical control.

Among five no-tillage systems studied by Shilling et al. (17) using desiccated small grains for weed suppression, rye generally provided the best broadleaf weed control (Table 1). Rye has also been particularly effective in studies by Putnam and DeFrank (12), Barnes et al. (2), and Worsham (23). The high biomass production of shoots and roots, winter hardiness, and phytotoxicity of the residues make this grass cover crop very effective in no-tillage soil conservation cropping systems.

Chou and Patrick (4) identified nine acids from ether extracts of decaying rye residues in soil. Phenylacetic, 4-phenylbutyric, vanillic, ferulic, *p*-coumaric, p-hydroxybenzoic, o-coumaric, and salicylic acids all inhibited the growth of bioassay plants. Two different groups of investigators isolated compounds from water extracts of above-ground rye mulch that inhibited weed growth in laboratory bioassays. Shilling et al. (15,16,17) found ß-phenyllactic acid (PLA) and *p*-hydroxybutyric acid (HBA) provided 20 to 60% inhibition of common lambsquarters and redroot pigweed. Barnes et aL(2) isolated two hydroxamic acids, 2,4-dihydroxy-l,4(2H)-benzoxazin-3-one (DIBOA) and 2(3H)-benzoxyazolinone (BOA), with phytotoxicity on a large number of weed test plants. These two compounds were more phytotoxic than PLA or HBA and DIBOA was shown to maintain toxicity for an extended period following addition to soil.

Table 1. Effects of Small Grain Mulch and Tillage on Weed Control at Two Locations Over Two Years in North Carolina[a]

Mulch type[b]	% Weed Control[d] Broadleaf[e]	Grass[f]
Rye	85 ab	70 b
Wheat	74 c	61 bc
Barley	75 c	54 bc
Oats	80 bc	64 b
None	63 d	41 d
None[c]	90 a	81 a

[a]Modified from Shilling et. al. (17).
[b]All treatments had 6 lb/A diphenamid and 3 lb/A glyphosate applied to kill grain and provide residual weed control.
[c]Tilled and rebedded prior to transplanting tobacco and cultivated twice.
[d]Means within a column followed by the same letter are not significantly different. Ratings are in early-season.
[e]Redroot pigweed, common lambsquarters, and common ragweed.
[f]Large crabgrass and goosegrass.

The collective allelochemical action of rye mulch on weed suppression in the field is outstanding. Barnes et al. (2) reported that weed biomass in a cover crop of living rye was reduced 90% over unplanted controls. A mulch of 40-day-old spring-planted rye gave 69% reduction. Shilling et al. (15) found rye mulch and root residues to give over 90% early-season reduction in the biomass of common lambsquarters, redroot pigweed, and common ragweed in no-till planted soybean, sunflower, and tobacco compared to tillage and no rye. Liebl and Worsham (8) reported significant reductions in morningglory and prickly sida in field studies involving wheat mulch and isolated ferulic acid as the most phytotoxic compound from foliar wheat extracts.

Weston et a1 (20) investigated the apparent allelopathic effects of sudex on weed and vegetable species. Two major phytotoxins, *p*-hydroxybenzoic acid and p-hydroxybenzaldehyde, were isolated and identified from shoot tissue. These compounds are potentially the enzymatic breakdown products of the cyanogenic glycoside dhurrin.

Recent discoveries concerning microbial transformation of certain allelochemicals from wheat and rye may be significant in increasing phytotoxicity of these residues to weeds. Liebl and Worsham (8) reported that ferulic acid in the presence of prickly sida seed carpels was decarboxylated by a bacterium living on the seeds to a styrene derivative, 2-methoxy-4-ethenylphenol. The styrene was more phytotoxic to prickly sida than ferulic acid and may play an important role in control of this weed in natural conditions under wheat mulch.

More recently Muraleedharan et al. (9) isolated a microbially transformed allelochemical, 2,2'-epidioxy-1,l’-azobenzene [2,2’-oxo-l,l’-azobenzene] (AZOB) from a soil supplemented with 2,3-benzoxazolinone (BOA). AZOB was more toxic to curly cress and barnyardgrass than either DIBOA or BOA. Although there were no detectable amounts of the biotransformation product in soil under rye residues, the implications of such phytotoxic bio-magnification of allelochemicals may be very significant in helping to explain allelopathic weed suppression under field conditions.

Although there is great promise in using cover crops and mulches to aid in weed control, much research needs to be done to gain full advantage of the system. Some problems that need attention are the lack of suppression of perennial weeds and annual and perennial grasses, the cost of establishing and killing the cover crop, allelopathic effects on the crop itself (19), and compatibility of rotations.

Our work in North Carolina over a number of years has indicated that leaving a small grain mulch and not tilling gives 75 to 80% early-season control of a number of annual broadleaf weeds (Table 2). Removing straw, tilling and replacing straw gives 60% control. Removing straw and not tilling gives 40 to 50% control and removing straw and tilling the soil, without herbicides, gives little or no control of these weeds. It was concluded that not tilling accounted for some weed control, but having straw alone contributed even more. Not tilling plus having a straw mulch gave the highest degree of weed control.

Table 2. Effects of straw management and tillage on weed suppression in no till planted crops in North Carolina.[a] (25)

Straw and tillage treatment	% Control [b] Rye Mulch[c]	% Control [b] Wheat Mulch[c]
Remove straw & till soil	9 a	30 a
Remove straw, no-tillage	43 b	50 b
Remove straw, till & replace	60 c	60 c
Leave straw, no-tillage	76 d	81 d

[a]Average results from research in corn, soybeans, sorghum, and tobacco, 1980-1986
[b]Early-season ratings on redroot pigweed, common lambsquarters, common ragweed, morningglory sp., prickly sida, sicklepod
[c]Means within a column followed by the same letter are not significantly different.

Shilling et al. (17) reported research in which they attempted to partition the weed control effects from tillage alone, no-tillage, and no-tillage plus mulch with and without a prcemergence herbicide in tobacco (Table 3). Tillage alone without herbicide gave 8% early-season control of broadleaf weeds and 47% control of annual grasses. Adding a soil-applied herbicide gave 52 and 67% control of broadleaf weeds and grasses, respectively. Not tilling, without herbicide or mulch, gave 68 and 71% control. The no-till treatment without mulch plus herbicide yielded 87 and 94% control. Rye mulch, no-till without herbicide gave 79 and 54% control, respectively, of broadleaf and grass weeds and rye mulch plus herbicide in no-till gave 97 and 80% control. Results from the same treatments with wheat, oats and barley were similar. These results confirm the need for not tilling plus having a mulch to achieve the highest degree of weed control without a preemergence herbicide.

Farmers interested in reducing or eliminating chemical inputs in cropping systems often ask if the allelopathic cover crops or mulches will do the whole weed control job so herbicides won’t be needed. Our experience in North Carolina indicates that most of the time herbicides are still needed, especially postemergence herbicides in late-season. The allelopathic suppression effect usually is adequate only for the first few weeks for a crop. In research plots, however, we have been able to grow crops and attain adequate weed control with only a heavy mulch of killed rye. These crops have been corn, soybean, grain sorghum and sunflower. The rye cover was killed before planting with a herbicide. In 1989, corn soybeans and grain sorghum were grown in a killed rye cover crop without the need of additional herbicides. We believe that the unusually wet season allowed the allelopathic weed control results to be more effective than usual. Additional research on this aspect was begun in 1990 with corn, tobacco, cotton and soybeans in cover crops of rye, crimson clover, hairy vetch and subterranean clover.

Table 3. The effects of mulch, tillage, and diphenamid on weed control in flue-cured tobacco at two locations in North Carolina.[a]

	% Weed control [b]	
Treatment	**Broadleaf**	**Grass[d]**
Tilled no herbicide	**8 e**	**47 c**
Tilled plus herbicide	**52 d**	**67 bc**
No-till, no herbicide	**68 bc**	**71 abc**
No-till plus herbicide	**87 ab**	**94 a**
No-till, rye mulch, no herbicide	**79 bc**	**54 bc**
No-till, rye mulch plus herbicide	**91 a**	**80 ab**

[a]Modified from Shilling et al. (17)
[b]Ratings taken four weeks after transplanting. Means within a column followed by the same letter are not significantly different.
[c]Redroot pigweed, common lambsquarters, and common ragweed.
[d]Goosegrass and large crabgrass.

Use of Genetically Altered Crops: Sometime during the 1990's we may see the release of crop varieties which have been genetically altered to be tolerant to herbicides that they were previously sensitive to. These endeavors are in various stages of development, with some having reached the field testing stage (3). Ciba-Geigy has field-tested a line of tobacco tolerant to the triazine herbicides, although they do not plan to commercialize this discovery. DuPont has ficld-tcsted tobacco and soybeans tolerant to certain sulfonylurea herbicides. American Cyanamid, working with biotechnology and seed companies, is developing corn tolerant to imidazolinone herbicides (3). Monsanto is working to produce various crops tolerant to Roundup. American Hoechst is interested in developing crops tolerant to Ignite. Various other biotechnology companies are working on Roundup tolerant tomato, corn, and cotton; bromoxynil tolerant sunflower; atrazine tolerant canola; and corn tolerant to Treflan (3).

The development and marketing of some of these new crop varieties should make the control of some difficult to control weeds easier in conservation and no-till cropping systems. The anti-synthetic pesticide forces, however, are mounting increasing opposition to this approach. A bill may be introduced in Congress to prohibit any federal funds from being used for this purpose.

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Evidence For Weed Suppression Due To Intercepted Paraquat On A Rye *(Secale cereale)* Straw Mulch

T. Wiepke and A. D. Worsham[1]

Abstract

Greenhouse experiments were conducted in 1987 and 1988 to test the hypothesis that intercepted paraquat in a paraquat-killed rye cover crop is responsible for some of the weed suppression observed in no-tillage field experiments. Field-grown rye, either paraquat-killed (0.5 Ib/A) or mowed (air-dried), was placed on top of pots at a level comparable to 4,000 Ib/A (100% coverage). Pots were either watered from above or below the straw. The survival rate of redroot pigweed (A. *retroflexus* L.) seedlings was used to measure the effects of a factorial set of treatments (2-straw types X 2-watering methods). A significant statistical interaction was found in both years between straw type and watering method. In both years the paraquat-killed rye straw and above-watering method treatment combination significantly reduced pigweed seedling survival compared to all other treatments, indicating that the intercepted paraquat was moving off the straw and killing seedlings. Rainfall of 1.0 in. and 1.5 in., in 1987 and 1988, respectively, on paraquat-killed rye prior to collection for greenhouse experiments did not diminish the phytotoxic effect of the straw. These results suggest that intercepted paraquat on straw may be responsible for some of the weed suppression attributed to paraquat-killed cover crops.

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Evaluation of Rye Varieties for Weed Suppression in No-Till Corn

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Abstract

An increase in the use of conservation and no-tillage practices is expected in the future as the soil conservation provisions of the 1985 farm bill must be complied with by 1995. In order to meet conservation compliance, it is expected that the use of small grains as cover crops will increase. Winter rye residues have been shown not only to help conserve soil and soil moisture, but also to be effective in reducing weed problems through allelopathic chemical activity. No comparisons, however, have been made among rye varieties in the southeast as to their relative weed suppressing abilities or possible effects on corn yields. The objectives of this research were to evaluate eight varieties of rye, one wheat + rye mixture, and one triticale variety for differences in weed suppressing ability in no-till corn and to determine if the cover crop mulch exhibits any varietal effect on corn yield.

Ten small grain varieties were established at the Clayton and Rocky Mount, NC research stations on October 27, 1988 and October 31, 1988 respectively, in 12' x 40' plots. The varieties were AFC 2020, Athens Abruzzi, Bonel, Gurley Grazer, Mayton, Vita Graze, Wheeler, and Wrens Abruzzi ryes along with a wheat + rye and a Florico triticale treatment. Paraquat was applied to all treatments on April 21, 1989 at Clayton and May 20, 1989 and Rocky Mt. at a rate of 1 Ib ai/acre as a burndown. The corn was subsequently no-till planted through the treated residue. No additional herbicides were used pre or postemergence except 2,4-D postemergence for redroot pigweed at one location.

Weed sampling began approximately two months after planting. A 0.5 x 0.5 meter square was randomly thrown three times into each plot and all broadleaves and grasses falling inside were counted, collected, dried and weighed. This procedure was conducted over three time periods at Clayton and two at Rocky Mount. Yield data was also obtained for each plot.

Observations of the weed pressure in check rows compared to that in the treatment rows revealed that all treatments exhibited weed suppressing ability. Broadleaf densities and biomass indicated that no rye variety was significantly different from any other variety of rye for weed suppressing abilities. The Florico triticale treatment, however, showed significantly higher broadleaf and grass densities as well as biomass values at Clayton. This result was observed in both the individual sampling date comparisons as well as the data pooled over sampling times. These results were not apparent for either individual or pooled comparisons at Rocky Mount. The Vita Graze and Athens Abruzzi treatments, although non-significant, were noted to produce the lowest broadleaf densities at both locations. The Athens Abruzzi treatments were also noted to give consistently lower grass densities. Corn yields were unaffected by all cover crop varieties at both locations.

The results of this research indicate that Florico triticale as a mulch exhibits the least amount of weed suppression and that there is no difference in the weed suppressing abilities of the rye varieties. The results might also indicate that Vita Graze and Athens Abruzzi may be the varieties of choice for weed suppression in no-till corn. These results are preliminary and based on data obtained during the 1988-89 and the lack of significance may be partly due to the highly irregular environmental conditions (above normal rainfall) during this growing season. Weed suppression by the rye cover crop mulches was much better than normally might be expected. The same test is being repeated during the 1989-90 growing season.

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Energy and Equipment Considerations

Energy and Conservation for the 1990s

W. W. Frye[1]

The 1980s were ushered in under a cloud of uncertainty in the world energy picture. During the decade of the 80s, phenomenal developments occurred in energy that are certain to influence the energy situation in the 1990s. Perhaps the most important of these developments was energy conservation, both mandated and voluntary. Other factors were the development of additional energy reserves, nuclear energy becoming more and more unpopular, and acid rain becoming a critical environmental concern.
How will these developments affect energy in the 1990s? Already some energy conservation efforts are being relaxed. With neither nuclear energy nor high-sulfur coal, more emphasis will have to be placed on gas, oil, and low-sulfur coal. The U.S. is still highly dependent upon imported oil, making the supply vulnerable to the whims of foreign governments. These factors coupled with the fact that energy demand is likely to increase substantially during the next few years make very real the possibility of an energy shortage and escalating energy prices in the 1990s.

Meanwhile, agriculture has entered a new era of Conservation farming that potentially could have a revolutionary effect in the 1990s. Soil erosion control and water quality protection has been mandated by Federal law, and energy conservation will likely come about as a part of low input sustainable agriculture resources and seeking ways to reduce production inputs and conserve energy to cut production costs. Fortunately, many of the same practices that conserve soil, water, fossil fuels, labor, and money are effective LISA practices. Reducing production inputs, such as fertilizers, pesticides, and tillage, reduces production costs and conserves energy.

The purpose of this paper is to outline the energy requirements of various crop production practices and indicate ways that farmers can conserve energy through tillage, N fertilizer practices, legumes, and animal manures.

Energy Used in Crop Production

Although large in total amount, the energy used in production agriculture is only about 3% of the total energy used in the U.S. This energy is divided among a number of direct and indirect uses in crop and livestock production. The various energy uses in crop production are grouped into several categories with total consumption for each shown in Table 1.

Table 1. Estimated annual energy use for crop production. (Adapted from Stout et al., 1977.)

Use	Annual amount DFE† (billion gallons)
Fertilizer - production and application	4.55
Farm vehicles - pickup, auto, truck	1.95
Irrigation	1.85
Weed control - herbicide manufacture and application and cultivation	1.40
Harvesting and handling	1.25
Tillage - preplant	1.15
Crop drying	0.75
Planting	0.30
Other - frost protection, electricity, misc.	0.70
Total	13.90

†Diesel fuel equivalent (155 MJ/gal)

The larger the energy requirement for a practice or input, the greater the potential for conserving energy and the greater the benefits of energy conservation on the overall economics of the system. Some uses, e.g., irrigation in arid and semi-arid climates, offer little opportunity for appreciable energy conservation without jeopardizing yields. At today's relatively low energy prices, a high risk of decreasing crop yields would not make sound economic sense. Nevertheless, energy used in many facets of crop production can often be decreased or managed more efficiently to produce equal yields with less energy or greater yields with the same amount of energy.

Tillage

Wittmus and Yazar (1981) compared inputs and practices for several corn production systems in Nebraska. Energy values were assigned by Frye (1984) to three of those systems--moldboard-plow, chisel-plow, and no-tillage--based on energy values shown in Table *2* for various inputs and operations. Total production energy values were estimated at 44.3, 42.7, and 40.0 gal DFE/acre for the respective tillage systems. Nitrogen

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Table 2. Estimated average energy requirements of crop production inputs and operations. (Adapted from Frye, 1984.)

Management input or operalion	Unit	DFE† (gaUunil)
	100 lb machinery	24
Primary tillage		
Moldboard-plow (8 inches depth)	ac	1.82
Chisel-plow (8 inches depth)	ac	1.18
disk (once)	ac	0.64
Secondary tillage		
Disk	ac	0.64
Spike-tooth harrow	ac	0.32
Field cultivator	ac	0.64
Subsoiler (14 inches depth)	ac	2.14
Plant (36 inch rows)		
Moldboard-plow and reduced tillage	ac	0.43
No-tillage	ac	0.53
Weed Control		
Herbicides	lb a.i.	0.48
Spray herbicides	ac	0.11
Apply herbicides and disk second time	ac	0.75
Cultivate (each time)	ac	0.43
Fertilizer		
Nitrogen	lb N	0.17
Phosphorus	lb P_2O_5	0.02
Potassium	lb K_2O	0.01
Broadcast granular fertilizer	ac	0.21
Spray liquid fertilizer	ac	0.21
Apply anhydrous ammonia (no-tillage)	ac	1.18
Apply anhydrous ammonia (plowed soil)	ac	0.75
Irrigation	ac	30.91
Harvest		
Cornpicker-sheller	ac	1.39
Combine	ac	1.60
Miscellaneous		
Shred cornstalks	ac	0.75
Disk cornstalks	ac	0.43
Grain drill	ac	0.53
Seed (production)	lb	0.05

†Diesel fuel equivalent (155 MJ/gal)

fertilizer applied at the moderate rate of 150 lb N/acre (25.5 gal DFE/acre) for each system accounted for 58, 60, and 64% of the total energy used in moldboard-plow, chisel-plow, and no-tillage systems, respectively. This emphasizes the importance of N fertilizer in the crop-production energy budget and the potential to conserve energy through N management.

Fertilizers

Fertilizers represent energy used in manufacturing, transporting, handling, and applying the materials, and in the case of N, the raw material is a direct energy resource, natural gas. According to Nelson (1975), about 83% of the energy used in manufacturing fertilizers goes for N. Phosphorus and K manufacture use about 11 and 6%, respectively. Thus, to save substantial energy with fertilizers, it is necessary to concentrate efforts on N fertilizers. Energy conservation can be realized from practices that improve the efficiency of N fertilizers or practices that decrease the need for N fertilizer, such as the use of legume crops or animal manures.

Nitrogen Efficiency in Relation to Tillage

Nitrogen fertilizer efficiency has been shown to be greater in no-tillage than in moldboard-plow tillage when based on the amount of grain produced per unit of fertilizer N used (Frye, 1984). Generally, N efficiency (thus energy efficiency) is higher for moldboard-plow tillage than no-tillage at low N rates and lower yield levels, about equal for the two systems at moderate N rates, and higher for no-tillage at higher N rates where yields are more nearly optimized.

Although more fcrtilizer N is usually required to obtain peak yields of no-tillage corn, the N and the energy it represents are used more efficiently, because of the greater biological energy resulting from higher yields. The biological energy of corn is about 2.6 gal DFE/bu. This point is usually overlooked by those who cite higher N fertilizer requirement as a disadvantage to no-tillage corn production when comparing the two systems.

Timing of Nitrogen Application

Crops need only a small amount of N during the early stage of growth. Therefore, if much N is available during that time, it will not be used by the crop but will be subject to leaching and denitrification. Research in Kentucky and elsewhere has shown that delaying N application until the crop enters its rapid growth stage, when it has a high N demand, will usually increase N efficiency. For corn, that time is about 4 to 6 wk after planting.

In Kentucky, it is recommended that fertilizer N rates be decreased by 35 lb N/acre when at least two-thirds of the N is applied 4 to 6 wk after planting corn no-tillage on moderately well-drained soils or with moldboard-plow tillage on moderately well-drained or poorly drained soils. Nitrogen can be delayed on well-drained soils, but research results show little or no advantage over at-plant application. The energy represented by the 35-lb N/acre is about 5.95 gal DFE/acre (Table 2); however, if delayed application requires an extra trip over the field, the energy conserved will be 0.21 gal DFE/acre less, or about 5.74 gal DFE/acre.

Nitrogen Fertilizer Placement

Placement of N fertilizer affects its efficiency in two ways: volatilization loss of ammonia and N immobilization in decomposing crop residue. Subsurface injection of N fertilizers provides advantages over surface broadcast application with respect to both of these. Urea or urea-ammonium nitrate (UAN) solutions and solid urea are particularly susceptible to ammonia volatilization when surface-applied, especially in no-tillage (Murdock and Frye, 1985). Also, immobilization of N is greater in no-tillage than moldboard-plow tillage (Rice and Smith, 1984). Subsurface injection of N fertilizer prevents ammonia volatilization loss and places the N below crop residues on the surface that might result in N immobilization. Increased N efficiency has also been found when liquid N fertilizer was dribbled in a band instead of sprayed broadcast (Fox and Bandel, 1986).

If subsurface placement of fertilizers is done as a separate operation, substantially more fuel is required than for surface broadcast or spray application, especially for no-tillage. The energy requirement for subsurface injection has been estimated at 1.18 gal DFE/acre for no-tillage and 0.75 gal DFE/acre for moldboard-plow tillage (Frye, 1984). Because of the increased N efficiency, farmers can decrease the rate of urea or UAN fertilizers required to obtain optimal yields when applied subsurface injected or surface banded compared to surface broadcast. A reasonable estimate of the amount, based on research findings under a wide variety of conditions, might be about 15%. At 0.17 gal DFE/lb of N (Table 2) that could save energy equivalent to as much as 3 or 4 gal DFE/acre.

Adequate but not Excessive Nitrogen

Ideally N fertilizers should be applied to achieve optimal economic crop yields. This means obtaining and following a good N recommendation. In doing so, the amount of N should be adequate but not excessive. This is difficult to achieve since there is no suitable soil test on which to base N recommendations. Nevertheless, in many cases N fertilizer rates could be decreased on the basis of cropping history and commonsense judgement without decreasing crop yields. Studies in Nebraska and Iowa suggested that about half of all farmers may over-fertilize with N as a result of 20 to *25%* over estimations of their yield goals (Hallberg, 1986).

If one-half the farmers of the U.S. decreased N rates by 20%, about 1.06 million tons of N would be saved annually based on an estimated annual use of 10.6 million tons of N. At 0.17 gal DFE per lb of N, about 360 million gal DFE of energy could be saved in this way annually in the U.S. Again, this is small in relation to the total U.S. energy demand, but it would be profitable and environmentally prudent for individual farmers.

Nitrogen from Legumes

A leguminous crop in rotation or as a winter cover or green-manure crop can be used to provide N for subsequent nonleguminous crops. The amount of N provided, especially the first year, depends greatly upon conditions. For example, the longer a soil has been in a legume meadow, the more N will be provided to a grain crop in the rotation. Also, the percent of the stand composed of legumes and the kinds of legumes will influence the amount of N supplied. In the case of winter cover crops, important factors include the kind of legume, the amount of growth made before killing or plowing under, whether the grain crop is grown under moldboard-plow tillage or no-tillage, and the number of years that the cover crop has been used consecutively.

Voss and Shrader (1984) estimated that the amounts of N provided to grain crops by legume meadows the first year of rotation were equivalent to 138, 100, and 20 lb/acre, where the percent of legumes in the stand were greater than SO%, 20 to 50%, and less than 20%, respectively. Based on a 5-ycar study in Kentucky, Ebelhar et al. (1981) estimated that a hairy vetch cover crop supplied N equivalent to 80 to 90 lb/acre of fertilizer N.

Even if one could estimate accurately the amount of N supplied by a legume crop to a nonlegume crop, it does not mean that a farmer should reduce the fertilizer N application by that amount. Hargrove (1986) found that a crimson clover cover crop provided all the N needed by grain sorghum, but results in Kentucky and elsewhere (Frye et al. 1988) indicate that a legume cover crop with corn tends to add on yields instead of replace N fertilizer, especially with no-tillage. That is, the corn yield response to a combination of N fertilizer and a legume cover crop tends to parallel at a higher level the crop's response to N fertilizer without a legume cover crop. Thus, it would be economically unwise for farmers to decrease N application for corn by more than a modest amount. In Kentucky, for example, it is recommended that the fertilizer N rate be decreased by 25 lb/acre for corn following a legume winter cover crop. This is equivalent to about 4.25 gal diesel fuel per acre.

Animal Manures

Animal manures arc a valuable source of N that can substitute for commercial N fertilizer. The N content of manures is highly variable and impossible to predict without a laboratory analysis; however, as a rule-of-thumb, 0.5% N, 0.25% P_2O_5, and 0.5% K_2O are generally accepted when an analysis is unavailable. About one-half of the nutrients are considered to be available to the crop the first year (Anderson, 1985). Using these values, a ton of manure would supply 5 lb N, 2.5 lb P_2O_5, and 5 Ib K_2O the first year of application. In terms of energy value of the nutrients, manure would be equivalent to about 0.95 gal DFE/ton. In most cases, this estimate would be very conservative because additional nutrients would be available in future years.

As in the case of legumes, manure can increase crop yields beyond that which can be obtained with N fertilizers suggesting unknown benefits in addition to N. Animal manure has the advantage over cover crops and green manure crops of being higher in N content (on a dry-weight basis), decomposing faster, and releasing more of its N the first year.

Energy Conservation with LISA Practices

The practices discussed above probably represent the best opportunities to conserve energy through LISA practices. Table ***3*** is a list of practices and an estimate of the amount of energy that could be saved by adopting each in crop production. The estimates are based on research information mostly from Kentucky. Research elsewhere might suggest different values. Energy values listed in Table 2 can be used to calculate estimates for any situation where N fertilizer, tillage, herbicides, or other energy-consuming production inputs arc reduced by a known amount.

Table 3. Estimated energy saving for various LISA cropping practices

Practice	Unit	DFE┼ (gal/unit)
No-tillage vs moldboard-plow tillage corn	ac	4.3
Chisel-plow vs moldboard-plow tillage corn	ac	1.5
No-tillage vs chisel-plow corn	ac	2.8
Delayed application of N fertilizer	ac	5.95
Subsurface placement of N for no-tillage	ac	3.0
Subsurface placement of N for moldboard-plow tillage	ac	3.6
Accurate estimate and supply of N needs	lb	0.17
Rotation with meadow:		
Four years or less	ac	4.25
Five years or more	ac	8.50
Legume winter cover crop	ac	4.25
Animal manure	ton	0.95

┼Diesel fuel equivalent (155 MJ/gal). Based on energy values shown in Table 2.

Conclusions

Many conservation practices in crop production that fit the concept of low input sustainable agriculture (LISA) arc energy conservation practices. Chief among these arc conservation tillage, improved N fertilizer efficiency, and use of legumes and animal manures. No-tillage and chisel-plow tillage use less tractor fuel than moldboard-plow tillage. Delayed application and subsurface placement of N fertilizer, especially urea or UAN, decrease N losses and increase N-use efficiency, particularly in conservation tillage systems. The result is lower rates of fertilizer N needed to obtain optimal yields. Considerable energy can be saved by realistic estimates of yield goals and N rates consistent with those yield goals. Legumes in rotations or as winter cover crops and animal manures can be used to substitute for a portion of the needs. Both legumes and manure seem to provide benefits in addition to the N supplied, adding to their energy efficiency.

Production agriculture uses only a small portion (about *3%)* of the total U.S. energy budget, and conservation efforts by farmers have little effect on the overall energy demand. Nevertheless, energy conservation on the farm can improve efficiency in the use of resources and increase profitability while contributing to an effective national energy conservation program.

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Tillage Requirements for Corn as Influenced by Equipment Traffic on a Compactible Coastal Plain Soil

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Abstract

Deep tillage and controlled traffic have been utilized to manage soil compaction, but there remains the need to develop tillage systems that integrate conservation-tillage practices, deep tillage, and controlled traffic. In 1988, a study was initiated to determine the interactive effects of traffic, deep tillage, and surface residues on corn (*Zea mays* L.) grown on a Norfolk sandy loam (Typic Paleudult). Corn was planted into a winter cover crop of 'Cahaba White' vetch (*Vicia sativa* L.). Treatments included traffic (none or conventional equipment), deep tillage (none, in-row subsoiling [SS], or complete disruption [CD]), and surface tillage (none or disk + field cultivate). Complete disruption was accomplished by subsoiling 16-17 inches deep on 10-inch centers. When traffic was applied, the increased bearing capacity of no-till (no-surface tillage) plots resulted in reductions in compaction in the top 8 inches of soil of up to one half that found following disking and field cultivation. Soil strength patterns suggest that reductions in rooting and water extraction correlated well with increased soil water measured from tasseling through black layer. Although tillage X traffic interactions affected soil strength and soil water, the only grain yield response was due to a surface tillage X deep tillage interaction. In 1988 (a drought year), surface tillage yields averaged 56, 44, 22 bu/acre with CD, SS, and no deep tillage, respectively. Without surface tillage, respective yields averaged 60, 50, and 18 bu/acre. In 1989, yields with CD, SS, and no deep tillage averaged 124,113, and 103 bu/acre, and 118, 110, and 75 bu/acre with and without surface tillage, respectively.

Introduction

Deep tillage, especially subsoiling, often results in yield increases for crops grown on coarse-textured Coastal Plain soils (Box and Langdale, 1984; Reeves and Touchton, 1986). Restricting equipment operations to certain areas in the field, i.e., controlled traffic, has also been shown to increase crop yield on these highly compactible soils (Nelson et al., 1975; Williford, 1982). Previous research, however, has generally been with conventional-tillage systems and has focused on single components of the compaction problem, i.e., tillage or traffic. The interactive roles that tillage systems (especially conservation-tillage systems) and traffic have on soil compaction and resultant crop responses have not been clarified.

The objective of this study was to evaluate the roles and interactions of residue management practices, deep tillage, and traffic on soil compaction and crop response, using corn as the test crop, on a highly compactible Coastal Plain soil.

Materials and Methods

This field study was conducted for 2 years (1988-1989) on a Norfolk sandy loam (fine, loamy, siliceous, thermic Typic Paleudult) located in east-central Alabama. The soil is highly compactible and has a well developed hardpan at the 7 to 12 inch depth.

A winter cover crop of 'Cahaba White' vetch was planted in the fall of 1987 and 1988. The cover crop was killed with an application of paraquat (0.94 lb ai/acre) 4 to 7 days prior to planting corn each spring. Pioneer 3165 hybrid corn was planted in 30-inch rows, and thinned to 20,000 plants/acre. The eight-row plots were 70 ft. long. Plots were established on different halves of the test site in 1988 and 1989 to avoid confounding from residual tillage effects. At planting, 30 Ib N/acre and 44 Ib P/acre was applied over the row in a four-inch band. Four weeks after planting, 120 Ib N/acre and 26 Ib S/acre was applied in a narrow stream 10 inches from the row. Weeds were effectively controlled with recommended practices.

The experimental design was a strip-split design of four replications. Vertical factors were deep tillage: 1) no deep tillage; 2) in-row subsoiling; and 3; complete disruption. Subsoiling depth was 16-17 inches. Complete disruption was accomplished by subsoiling on 10-inch centers. Horizontal factors were traffic: 1) no-traffic and 2; traffic. All operations were done with an experimental wide frame vehicle, which allows for 20 ft.-wide untrafficked research plots. A John Deere 4230 tractor was driven through appropriate plots to simulate traffic that would have been applied by an operation. Random traffic patterns were applied in the

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fall, simulating land preparation/planting operations for planting the cover crop; uniform traffic patterns were established in corn to simulate operations done by a farmer with four row equipment. Intersection or subplot treatments were surface tillage: 1) no surface tillage; and 2) disk-field cultivate.

Grain yields were determined from 100 ft. of row selected from the middle four rows of each plot. Grain yields were corrected to 15.5% moisture.

In 1989, parallel paired 6 mm-diameter stainless steel rods were installed at three depths (8, 16, and 32 inches) 15 inches on either side of a row in all plots. A Tektronix 1502B TDR cable tester was used to measure soil water using the time-domain reflectometry method as developed by Topp (Topp et al. 1980). Mcasurements were taken 11 times over a 38 day period from tasseling through black layer formation.

Penetrometer recordings were made in 1989, when corn was at tasseling. Readings were made after a period of sustained heavy rainfall, when the soil was saturated. Penetrations were made at three positions within each plot; in-row, and in the middles on either side of the row. In trafficked plots, the middle positions corresponded to wheeled (tire) and non-wheeled (no-tire) positions.

Results and Discussion

Grain Yields

In 1988, yields were limited by an extreme drought. Traffic had no effect on grain yields. There was a deep tillage X surface tillage interaction effect on yields, however (Table 1). Maximum yields, in both surface-tilled and no-surface tilled plots, were obtained with complete disruption of the plowpan. With both complete disruption and in-row subsoiling, yields were greatest when vetch residue was not incorporated by surface tillage. Without the benefit of deep tillage, however, surface tillage increased yields.

Table 1. Influence of deep tillage and surface tillage on corn grain yield in 1988 and 1989.

	1988		1989	
	Surface tillage		Surface tillage	
Deep tillage	yes	no	yes	no
	-----------------	bu/acre	--------------	
None	22.4	17.9	102.6	75.0
In-row subsoil	43.9	50.0	112.8	110.1
Complete disruption†	56.4	60.1	124.2	118.0
LSD 0.10	4.3		9.4	

†Subsoiled 16-17 inches deep on 10-inch centers.

With favorable rainfall in 1989, there was no beneficial effect of surface residues as in 1988 (Table 1). However, yields again increased with the intensity of deep tillage. Also, as in 1988, surface tillage increased yields when no deep tillage was performed.

Soil Water

The detrimental effect of wheel traffic on root growth and water infiltration is reflected in the average soil water content maintained from tasseling through black layer in trafficked plots (Table 2). In the no-tire middles, at the 0-8 inch depth, the lower soil water content with surface tillage can be explained by increased root growth and consequent extraction of water. Soil water was highest in the wheeled or tire middles, especially with surface tillage. Soil compaction in the wheel tracks resulted in reduced root growth and water extraction. Wheel compaction was especially severe with surface tillage as compared to no-surface tillage, as evidenced by increased soil water. In the no-tire middles, the increased soil water at the 16-32 inch depth with no-surface tillage compared to tilled plots probably indicates greater infiltration of water through the zone of maximum extraction by roots (0-16 inch depth). The decrease in soil water with surface tillage, as compared to no-surface tillage, at the 8-16 inch depth in wheeled middles is likely due to reduced infiltration from the greater compaction from wheel traffic in surface-tilled plots compared to no-surface tillage.

Table 2. Influence of interrow position and surface tillage on average volumetric soil water content from tasseling to black layer. Menns from trafficked plots.

	Tire-Middle		No-Tire Middle		
Dcpth	**Surface Tillage**	**No-Surface Tillage**	**Surface Tillage**	**No-Surface Tillage**	**$LSD_{0.10}$**
inches	------------	------------ %	------------	------------	
0-8	15.01	13.97	10.23	12.48	0.84
8-16	21.32	22.96	18.96	18.24	0.96
16-32	23.08	22.56	22.48	23.58	0.84

Within no-deep tillage plots, at the 0-8 inch depth, surface tillage had no effect on soil water when traffic was applied (Table 3). However, in the absence of traffic, water content remained higher with no-surface tillage. This is likely due to less water extraction by fewer plant roots as a result of surface compaction.
The lowest water content, regardless of surface tillage, was maintained in the complete disruption treatment with no traffic. This treatment would minimize compaction and maximize root growth and water extraction. With in-row subsoiling, surface tillage

reduced soil water content, compared to no-surface tillage, in no-traffic plots but increased soil water content when traffic was applied. The decreased soil water due to surface tillage with in-row subsoiling in no-traffic plots is likely explained by increased rooting and water extraction as a result of reducing soil compaction in this soil depth zone. In contrast, traffic applied following surface-tillage recompacts the soil to a greater extent than when applied without surface tillage, resulting in a zone more restrictive to root growth. A consequent reduction in soil water extraction from fewer roots is the likely explanation for increased soil water maintained in surface tilled plots compared to no-surface tilled plots with in-row subsoiling and traffic applied.

Table 3. Influence of deep tillage, traffic, and surface tillage on volumetric soil water content from tasseling to black layer. Means from wheeled interrow position.

		Traffic		No-Traffic	
Depth	Deep Tillage	Surface Tillage	No-Surface Tillage	Surface Tillage	No-Surface Tillage
inches		------------- % -------------			
0-8	In-Row Subsoil	15.85	13.57	11.98	13.34
	Complete Disruption	14.48	13.56	10.54	10.28
	None	14.71	14.78	10.33	12.31
	LSD $_{0.10}$	0.99		0.99	
8-16	In-Row Subsoil	22.65	23.25	22.53	21.20
	Complete Disruption	20.51	23.76	12.53	16.93
	None	20.80	21.87	21.26	21.30
	LSD $_{0.10}$	1.27		1.21	
16-32	In-Row Subsoil	22.61	21.07	23.50	22.51
	Complete Disruption	23.98	23.61	20.06	22.48
	None	22.65	23.00	24.05	23.63
		NS		NS	

At the 8-16 inch depth, with complete disruption, traffic resulted in incrcased water content, regardless of surface tillage, due to less root extraction of soil water (Table 3). No-surface tillage resulted in greater soil water content than surface tillage, regardless of traffic; probably due to lcss soil water extraction from decreased root growth, as well as increased infiltration with no-surface tillage. Maximum root growth and water extraction with the combination of intensive tillage, i.e., complete disruption and surface tillage, and no-traffic is indicated by the extreme decrcase in soil water content in this treatment. Treatments had minimum effect on soil water use below the 16 inch depth.

Soil Strength

Both in-row subsoiling and complete disruption eliminated compaction to the 16-17 inch depth in the row (Figure 1). Subsoiling on 10-inch centers did

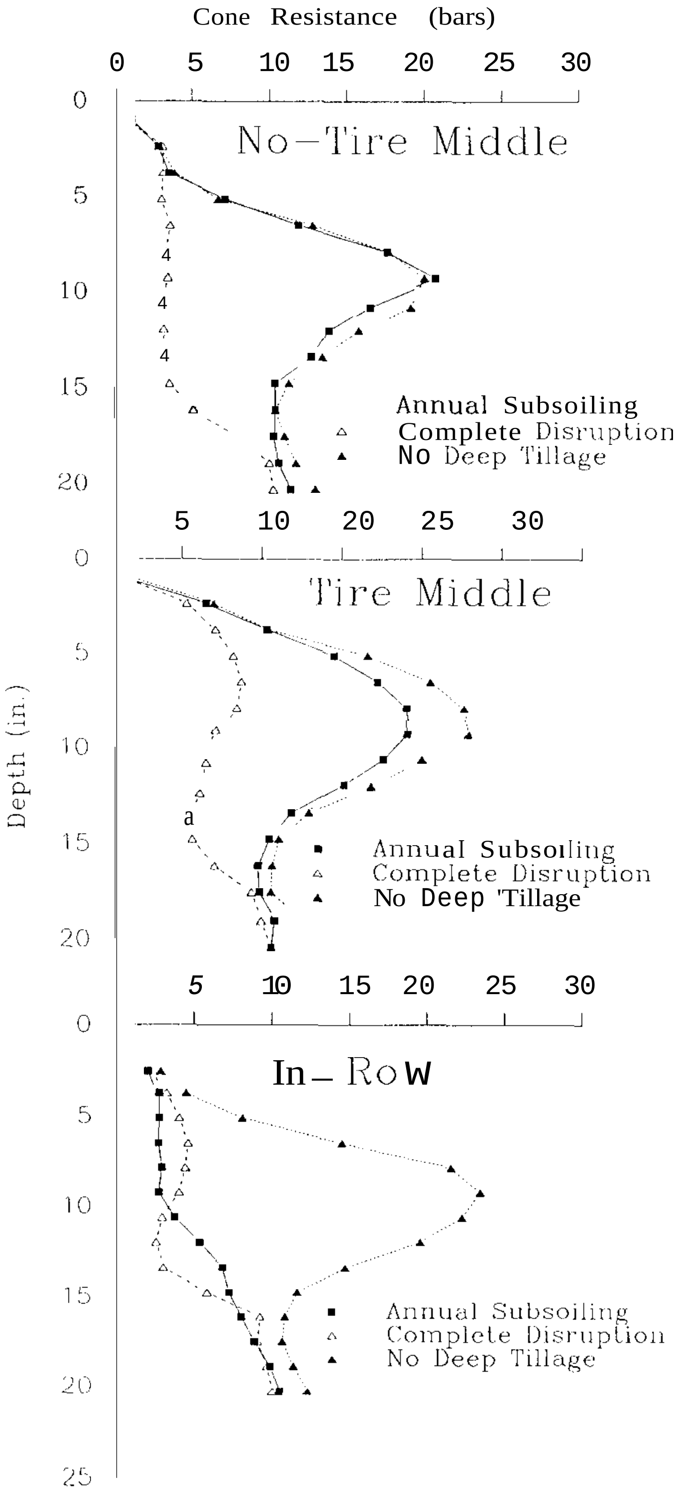

Fig. 1. Soil strength relative to row position as influencedby deep tillage. Means averaged over traffic and surface tillage treatments.

completely disrupt the tillage pan, as evidenced by reduced soil strengths to the 16-inch depth in all measured positions (in-row, tire middle, and no-tire middle). The affect of recompaction from equipment traffic is evident in the slight increase of soil strength with complete disruption in wheeled (tire) interrows as compared to non-wheeled (no-tire) interrows.

The detrimental effect of traffic after surface tillage as opposed to traffic on plots without surface tillage is seen in Figure 2. When traffic was applied, the increased bearing capacity of no-till (no-surface tillage) plots resulted in reductions in compaction in the top 8 inches of up to one half that found following disking and field cultivation. Soil strength patterns suggest reductions in rooting that correlate well with increases in soil water discussed previously.

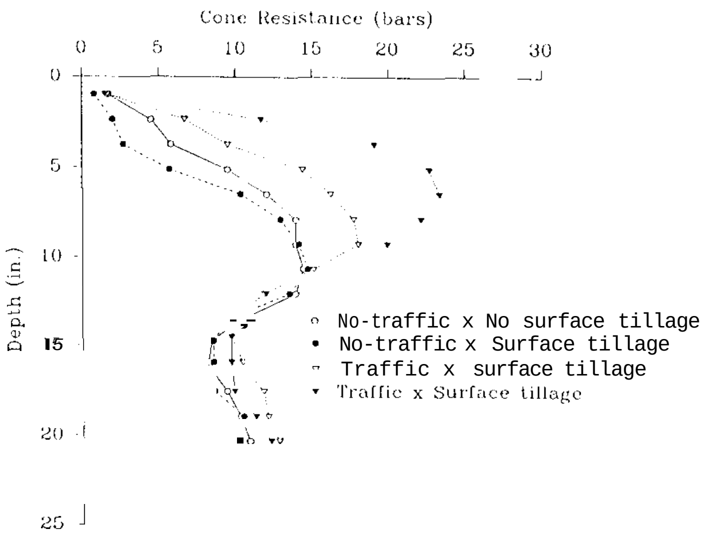

Fig. 2. Influence of traffic and surface tillage on soil strength. Means averaged over deep tillage treatments within tire interrow position.

Recompaction by traffic following surface tillage was not contained within the row middles. Soil strength increased in the 7-11 inch depth under the row following traffic (Figure 3). To a lesser degree, traffic following complete disruption also increased soil strength under the row (data not shown).

Summary

In a drought year, yields increased with intensity of deep tillage; deep tillage without surface tillage optimized yields. In both a drought year and a year of above average rainfall, surface tillage, in the absence of deep tillage, increased grain yield. Soil strength and soil water measurements confirm the detrimental effect of traffic after intensive tillage. The lack of any yield response to applied traffic, however, indicates that corn may compensate for reduced rooting capacity in wheeled interrows by increased rooting in non-wheeled interrows. This study will be continued in order to determine the long-term effects of traffic and tillage interactions on soil properties and crop responses.

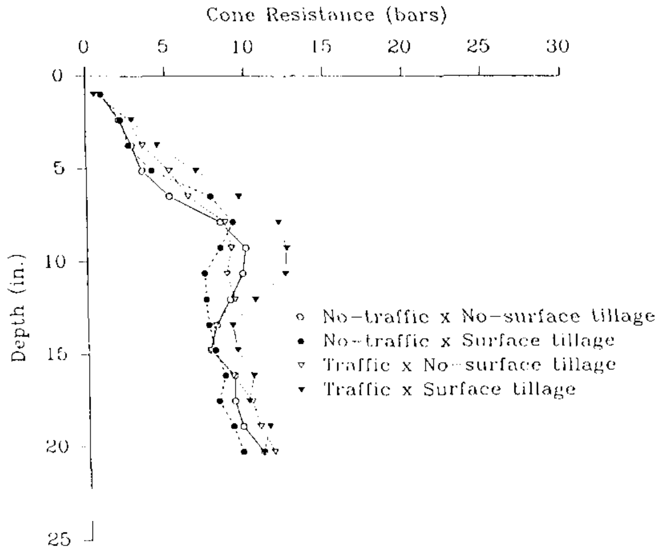

Fig. 3. Influence of interrow wheel traffic and surface tillage on soil strength under the row. Means averaged over deep tillage treatments.

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Georgia Rent-a-Drill Program "No-Till Saves Oil and Soil"

J. M. Hayes[1]

Abstract

What started out as a single RC&D project has turned into a state wide RC&D program. Recent droughts and fescue endophyte fungus have damaged 90% of the fescue pastures in Georgia. Farmers could not afford to buy no-till equipment to overseed these pastures; and if they were planted using conventional tillage methods, thousands of tons of soil and oil would be wasted. The RC&D Councils applied for grants to purchase equipment for use by the farmers. Funds were supplied by the Georgia Energy Office through the State Soil and Water Conservation Commission to the RC&D Councils. These funds were used to purchase tractors and grassland drills. the equipment was then furnished to local districts. The districts administered the program. The program worked *so* well that the Georgia Energy Office, The State Soil and Water Conservation Commission, Soil Conservation Service and RC&D wanted to make this a state wide program.

Since RC&D Areas only covered 39 of the States 159 counties, something had to be worked out to make this a state program. The State Soil and Water Conservation Commission and the State RC&D Council agreed to act as a clearing house for applications coming in from outside districts. The Georgia Energy Office pledged *$200,000* toward the project each time they have a funding cycle which has been twice a year. Local RC&D Councils agreed to work with districts outside their RC&D area boundaries. SCS gave support by allowing RC&D Coordinators to work across area boundaries. Local District Conservationists support the program in many ways.

The program works in the following manner. Districts send applications to the State Soil and Water Conservation Commission who reviews the applications and sends them to the State RC&D Council. The Council assigns a numerical ratings to the application based on information provided in the application. When the energy office has a funding cycle, the State RC&D Council recommends the districts with the highest numerical ratings be funded. The districts that are funded are assigned a RC&D Council to work with them. The RC&D Council then receives a grant to purchase the equipment. The Council purchases the equipment and provided it to the local districts for a five dollar per acre maintenance fee. The districts contract with operators to run the equipment and do the planting. The RC&D furnishes forms, fact sheets, training and acts as a data base for soil and energy saved. The districts supply the equipment to the landowner for a fee which covers operator, fuel and maintenance of equipment. The fees range from $12 to $15 per acre.

When fall planting seasons rolled around, The Rent-A-Drill program was available to farmers and landowners in 78 of the States 159 counties. The equipment represents $895,500 of Oil overcharge funds.

We feel that our RENT-A-DRILL PROGRAM is an excellent example of "MAKING CONSERVATION HAPPEN, TOGETHER."

[1]Georgia Rent-A-Drill Program.

Conservation Tillage Production Systems

Long Term Wheat and Soybean Response to An Intercropping System

N. W. Buehring, D. B. Reginelli, and M. A. Blaine[1,2]

Introduction

Doublecropped soybeans following wheat in the Mid-South commonly produce lower yields than monocropped soybeans. The lower yields are usually associated with straw management problems and delayed planting. The delay in planting is often caused by delayed wheat harvest, straw residue management, and inadequate soil moisture for germinating soybeans. Straw residue management problems are often associated with planting no-till into the straw which was either unevenly distributed or the planter colter was unable to cut through the straw residue which resulted in the straw being pushed into the seed-furrow.

Relay planting or intercropping is an alternate doublecropping system where one crop is planted into another crop before it is harvested. A soybean-wheat intercropping system, where soybeans are planted between wheat rows when the wheat crop is beginning to mature, has the potential not only to insure more optimum soybean planting but also eliminates the wheat straw residue management problems. The relay system removes the potential yield reduction from delayed planting caused by lack of soil moisture for germinating soybeans after wheat harvest. This system also eliminates the need for burning wheat straw residue or the use of a burndown herbicide to kill vegetation when planting soybeans in wheat stubble residue.

Objective

The objective of the study was to evaluate long-term wheat and soybean growth and yield response in a doublecropped wheat-soybean rotation where soybeans were both relay planted into a maturing wheat crop at the medium to soft dough stage of maturity and planted no-till in the wheat stubble in late June.

[1]North Mississippi Research and Extension Center and Mississippi Cooperative Extension Service.
[2]Research supported in pan by grants from Deere % Co, Moline, III. in 1981-86 and the Mississippi Soybean Promotion Board in 1987-89.

Materials and Methods

The study was conducted as a randomized complete block design from 1982-89 at the Northeast Branch of the Mississippi Agricultural and Forestry Experiment Station, Verona, MS. Except for 1986, the study was conducted on a Leeper silty clay bottomland soil with about a 0.25% slope. In 1986 the study was conducted on an upland Ora fine sandy loam. The study was planted in a rotation that followed a previous soybean crop of either maturity group IV or V in a monoculture.

Equipment Modifications

In order for the relay planting system to be successful, a few equipment modifications were made before the study was initiated. A 20 ft wide John Deere Soybean Special 3-point hitch planter equipped with bubble colters and heavy duty down-pressure springs was used to plant both wheat and soybeans in 1982-87 and only soybeans in 1988-89. The planter's common rubber tire press wheels were replaced with cast iron press wheels for added weight and good seed-furrow closure in the clay soil. The 4 inch wide planter unit gauge wheels were replaced with 2 inch wide gauge wheels to minimize wheat plants being tracked down during the soybean planting operation. In order to further minimize wheat damage, a 2 ft long v-shaped 0.5-inch diameter rod shield was constructed and mounted in front of each unit *so* the rod extended in a horizontal plane across the side of each gauge wheel. The rod shielded the wheat plants from the path of the gauge wheel as the planter passed between the wheat rows.

The planter tool-bar row-configuration for planting wheat in 1982-84 was 12 rows arrangcd in 15 inch wide rows with no skips for the tractor wheel. The planter unit hopper boxes rubbed against each other and did not allow each individual unit to flex independently on the tool-bar during the planting operation. The wheat in the tractor wheel track path was also tracked down when the soybeans were relay planted into the wheat in mid-May. In 1985-87 a 16-inch wheat row spacing with two 32 inch wide skips were incorporated on the planter tool-bar to eliminate these problems. The planter configuration consisted of

4 units spaced 16 inches apart in the center of the tool-bar followed by a 32-inch skip on each side for tractor wheels and 4 additional units spaced 16 inches apart. The monocropped wheat in 7-inch rows were planted with a John Deere grain drill in 1982-87.

In 1988 and 1989 a Great Plains® 20 ft wide grain drill with 7.5-inch row spacings was used to plant the 7.5-inch monocropped wheat rows and 15 inch wide wheat rows for the soybean relay and stubble planted systems. The drill units were arranged with the center unit and every other unit plugged to make a 15-inch row spacing pattern. Two additional units that followed the tractor wheels were plugged in order to leave a skip for the tractor wheels.

In 1982-84 a tractor was used with 15.5 inch wide rear tires spaced on 80-inch centers. In 1985-89 a tractor with 18.4 inch wide rear tires spaced on 72-inch centers was used. The tractor wheel spacings matched the wheel track skips made by the wheat planter in 1985-89. Tractor rate of travel for relay planting soybean in wheat was 2-3 mph in 1982-84 and 5-6 mph in 1985-89.

Wheat and soybeans were harvested with a John Deere 55® combine in 1982-85 and a John Deere 6600® combine in 1986-89. The 55 combine equipped with a sacking unit, straw chopper and 13 ft wide cutter-bar was used to harvest the center 13 ft of a 16 ft wide X 40 ft long plot in 1982-85. The 6600 combine equipped with a 20 ft wide cutter-bar and a straw chopper was used to harvest plots 20 ft wide X 600 ft long. A weigh wagon equipped with electronic scales was used to obtain the harvested seed weights in 1986-89.

Cultural Practices

Fall land preparation was done on all plots and involved the broadcast surface application of about 450 lb/acre of 0-20-20 fertilizer with incorporation by chiseling 6-8 inches deep followed by disking and smoothing with a harrow before planting wheat. Wheat cultivar and row spacings are listed in Table 1. Wheat seeding rates were 45 Ib/acre in 1982-87 and 80 lb/acre in 1988 and 1989. Nitrogen fertilization program was ammonium nitrate applied at 75 lb/acre surface broadcast prior to planting wheat and 250-300 Ib ammonium nitrate applied in mid to late February of each year. Monocropped soybean plots were shallow tilled with a field cultivator at least once or twice in the spring before soybean planting for weed control.

The wheat and soybean row spacings combinations in each system are listed in Table 1. Weeds, insects, and disease pests were controlled in both crops as necessary with appropriate pesticides applied at labeled rates. Wheat and soybean planting and harvest dates are listed in Table 2. Wheat for both doublecropping systems were planted in the same row spacing configuration. 'Centennial' (maturity Group VI) soybean was planted at 9 seeds/ft of row in 32-inch rows in 1985-87 and in 30-inch rows in 1982-84 and 1988-89. The monocrop and relay soybeans were planted about mid to late May when wheat was in the soft to medium dough stage. Soybeans were planted no-till in wheat stubble residue in late June or early July. In one of 8 years (1986), the wheat crop was mature and ready for harvest when soybeans were relay planted into the wheat. The high humidity and previous wet soil conditions allowed soybeans **to** be relay planted in the early morning with no wheat seed shatter loss. In 1988, howcver, soybean had to be replanted due to mechanical failure of the plantcr.

Table 1. Wheat cultivar and wheat-soybean cropping system row snacine combinations in 1982-1989.

		Wheal-Soybean Cropping System Row Spacing				
				Wheat-SoybeanDoubleCropping*		
	Wheat	Monocrop		Relay and Stubble Planted		
Year	Cultivar	W	SB	W	SB	TWS
				--inches---------------------		
1982	S. Belle	7	30	15	30	--
1983	S. Belle	7	30	15	30	--
1984	S. Belle	7	30	15	30	--
1985	Coker 916	7	32	16	32	32
1986	F1 302	7	32	16	32	32
1987	F1 302	7	32	16	32	32
1988	Fl 302	7.5	30	15	30	30
1989	F1 302	7.5	30	15	30	30

*W = wheat; SB = soybean; TWS = tractor wheel track skip; the wheat row configuration as indicated included two 30- or 32-inch wide skips (TWS) per 20 ft wide wheat planter swath for the tractor to relay plant soybeans between wheat rows.

Wheat harvest dates ranged from 10 to 27 June and soybean harvest ranged from 27 October to 18 November (Table 2). Wheat stubble cutting height, except for 1989, was about 8-12 inches above the soil surface and 3-4 inches above the soybeans. In 1989, due to a delay in harvest caused by rainy weather, relay planted soybeans were about 15 inches tall and wheat stubble cutting height was adjusted to about 17 inches.

All data were subjected to analysis of variance procedures at the 5% probability level. Least significant difference (LSD) at the 5% probability level was used to separate data means.

Table 2. Planting and harvest dates for wheat and soybeans in monocropped and doublecropped systems in 1981-1989.

	Planting Dates			Harvest Dates	
		Soybean*			
Year	Wheat	MC & RP	SP	Wheal	Soybean
1981	10/21	--	--	--	--
1982	10/23	5/5	6/26	6/25	10/28
1983	11/2	5/30	7/8	6/20	11/9
1984	11/7	6/2	7/3	6/18	11/14
1985	11/11	5/15	7/7	6/16	11/5
1986	11/4	5/14	6/29	6/16	10/29
1987	11/16	5/29	6/29	6/10	11/3
1988	10/27	5/26	6/26	6/13	11/18
1989	--	5/17	6/28	6/27	10/27

***Soybean monocrop (MC), relay planted (RP) between standing wheat rows, and planted no-till in wheat stubble (SP).**

Results and Discussion

Wheat

1982-84

Since 1982-84 studies were conducted with no skip for tractor wheel tracks in the relay system as was conducted in 1985-89 the results and discussion are reported accordingly. Wheat yields (Table 3) varied widely across years and were very low in 1983 due to excessive spring rains and flooded fields. Although there was no difference 2 of 3 years, the lower yield for the relay planted system was observed to be due to the tractor wheel tracking down wheat in its path during the relay planting operation. The wheat planted in 15-inch rows that were harvested before soybeans were planted (SB stubble) produced yield equal to 7-inch monocropped wheat all 3 years. The lack of difference between the 7-and 15-inch rows is attributed to the study site, which had both poor surface and internal drainage. The data also indicated that to minimize the relay planting effect on yield, a skip for the tractor wheels was necessary so that no wheat was tracked down.

1985-89

Wheat yields (Table 3) varied across years and these data indicated that the system where soybeans were relay planted between maturing wheat in wide rows with skips for the tractor wheels did not reduce yields when compared to 7-inch monocropped wheat 3 of 5 years. Comparing relay planting with stubble planting with the same wheat row configuration, relay planting had no effect on wheat yield in 1985-87 but reduced yields in 1988 and 1989.

In 1988, the significantly lower yield from the relay planting system was caused by seed shatter losses. Drought delayed planting into the wheat until the hard dough stage, and having to replant after mechanical failure of the planter caused wheat seed to shatter. Visual estimates indicated a 15% yield loss from seed shatter was caused by the planter tool-bar (20 inches above the ground) forcing the wheat to bend about 75" from its vertical position and shatter seed as the tool-bar moved across the wheat. In 1989 all yields were low due to the late harvest and spring freezes. However, the relay planted system had lower yield than the stubble system and monocropped wheat system. This difference may be related to early spring freezes that weakened the wheat stems. It was observed after relay planting that about 10 to 15% of the wheat stems were broken off about 4-6 inches below the base of the spiklet. This was the only year that wheat stems were broken off by the relay planting operation.

The 5-year average yield indicated that wheat in the relay planting system produced 44 bu/acre in comparison to 49 bu/acre for the monocrop system. Wheat in the stubble planted system, in the same row configuration as the relay system, produced yields equal to the 7-inch monocropped wheat.

Table 3. Yield of monocropped and doublecropped wheal in 1982-89.

			Douhlecropping System		
Year	% CV	LSD 0.05	SB Relay Planted*	SB Stubble	7-inch Row PlantedMonocrop
			--Bu/acre--		
1982	13	11	38	54	53
1983	49	NS	4	6	6
1984	22	NS	35	48	39
		Mean	26	36	33
1985	15	NS	40	40	44
1986	7	NS	45	40	45
1987	9	NS	46	49	49
1988	4	4	60	73	75
1989	9	5	24	30	33
		Mean	44	48	49

***SB = Soybeans.**

Soybean

1982-84

Soybean yields were similar all 3 years (Table 4). However, relay planted soybeans produced a higher yield than those planted no-till in the wheat stubble residue in 1 of 3 years and was equal to the monocropped soybeans all 3 years. The 3 year average indicated that monocrop and relay planted soybean yields were equal and both were 4 bu/acre more than planted in wheat stubble.

1985-89

Monocropped soybeans planted at the same time that soybeans were relay planted into wheat in mid-May, produced significantly higher yields than both relay planted and stubble planted soybeans 4 of 5 years (Table 4). Monocrop yields ranged from 23 bu/acre in 1988 to 48 bu/acre in 1989. Although in 4 of 5 years relay planted soybean yields were lower than monocrop yields, they were significantly higher than those planted into wheat stubble in late June or early July. Our research in other studies has shown that when soybeans were planted in wheat stubble on or before about June 21, little or no differences in yield were measured in comparison to yields from the relay planted system.

Table 4. Soybean yield response in three cropping systems in 1982-89.

Year	% CV	LSD 0.05	Soybean Cropping System Monocrop	RP*	SP*
			Bu/acre		
1982	11	NS	39	36	34
1983	23	NS	31	33	32
1984	10	7	41	42	31
		Mean	37	37	33
1985	12	6	36	40	13
1986	13	4	27	16	6
1987	11	5	41	27	15
1988	17	4	23	9	14
1989	9	4	48	33	15
		Mean	35	25	13

*RP = soybeans relay planted in wheat; SP = soybeans planted in wheat stubble.

The low yield of soybeans relay planted in 1988 was a result of drought conditions until late June before rains began to occur which favored the late June planting. The 5-year average indicated that relay planted soybeans produced 10 bu/acre less than the monocrop system, but was 12 bu/acre more than soybeans planted into wheat stubble in late June or early July.

Summary

Relay planting soybeans between wide wheat rows with no skips for the tractor wheels (1982-84) resulted in reduced wheat yields 1 of 3 years. Wide wheat rows, however, with appropriate skips (1985-89) for the tractor wheels resulted in yields that were equal to yields from 7-inch monocrop rows in 3 of the 5 years. The 5-year average (1985-89) data indicated that the wheat-soybean relay intercropping system with tractor wheel skips and wider than monocropped wheat rows produced about 13% less yield than monocropped wheat.

Soybean yields (1982-84) in the relay planted system were the same as those in the monocropped system and 4 bu/acre (3-yr ave.) more than yields from soybeans planted into wheat stubblc residue in late June. Although relay planted soybeans in 1985-89 produced a 5-year average yield of 25 bu/acre in comparison to 35 bu/acre for the monocrop system, the relay planted system produced 12 bu/acre more than soybeans planted in wheat stubble residue in late June or early July. These results indicate that for successful wheat-soybean intercropping systems the wheat row spacing configuration should match the soybean planter and tractor wheel tracks so that soybeans are planted between the wheat rows and no wheat is tracked down during soybean planting. Soybeans should be neither relay planted nor replanted into wheat when the wheat crop has matured to the hard dough stage and is under dry environmental conditions. However, under wet and high humidity conditions, relay planting can be done in the early morning without causing any wheat seed to shatter. About 13% wheat yield will be sacrificed in the relay system. However, soybean yield can bc increased by 100% in comparison to no-till soybeans planted in wheat stubble residue in late June. Research is currently being conducted to determine whether narrow wheat rows (6, 7, and 15 inches) can be utilized in this system to further minimize the reduction in wheat yield. This system offers an alternative to farmcrs who plant soybeans into wheat stubble in late June.

Performance of Corn, Wheat, and Cotton in a Two-year Rotation on a Norfolk Loamy Sand Soil after 10 Years of Conservation or Conventional Tillage

P. G. Hunt, T. A. Matheny, D. L. Karlen, and S. H. Roach[1,2]

Abstract

Conservation tillage offers the possibility of conserving natural resources and optimizing crop productivity through controlled soil erosion, reduced soil compaction, increased water use efficiencies, and reduced energy costs. Fulfillment of this possibility in a particular physiographicregion requires adaptation to the soils and cropping systems of that region. A rotational system of corn, small grain, and soybean has been studied rather extensively in the Eastern Coastal Plain. However, investigation of rotational systems that used cotton and conservation are limited. A two year rotation of corn, wheat, and cotton was grown on a Norfolk loamy sand with conservation and conventional tillage. Tillage systems were not significantly different for any of the crops, but cotton cultivars were significantly different. The rotation appears to be a viable production option, but research is continuing to asses the long term effects of tillage and the limitations of frost free days.

Conservation tillage has been viewed as a promising technology for conserving natural resources and optimizing crop productivity through controlled soil erosion, reduced soil compaction, increased water use efficiencies, and reduced energy costs since the early 1970's. Enthusiastic reports of success in hilly areas of the Southeast resulted in an 80% increase in conservation tillage usage in the southeastern USA between 1973 and 1983 (Christensen and Magleby, 1983). Corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), and soybean *[Glycine max* (L.) Merr.] were the first crops evaluated using conservation tillage in the Coastal Plain (Campbell et al., 1984; Karlen et a1.,1984, 1985, 1987; Hunt et al., 1985, 1987).

Initial conservation tillage experiences on the sandy soils of southeastern Coastal Plain revealed soil fertility and plant establishment problems that resulted in reservations concerning the utility of these practices. Sojka et al. (1985) concluded that differences in soil physical and chemical properties could affect conservation tillage in this region. Reduced crop yields associated with non-uniform plant establishment was often a significant problem with conservation tillage on sandy coastal plain soils. Karlen and Sojka (1985) reported that corn yield differences between conservation and conventional tillage systems were initiated by early season differences in plant growth and development. They observed that only 27 to 43% of the plants had emerged during the first week after planting when conservation tillage was used, but 64 to 77% of the plants had emerged when conventional tillage was used. Lower yields and dry matter production of wheat with conservation tillage has also been attributed to non-uniform plant establishment (Karlen and Gooden, 1987). Early research was conducted with less advanced conservation tillage equipment, and poor seed-soil contact was a major factor contributing to non-uniform plant establishment.

More recently, an eight-year evaluation by Karlen et aL(1989) showed that Coastal Plain soil fertility levels could be maintained by using current soil-test procedures and recommendations for lime and fertilizer application. Several improvements in planters and in-row subsoiling equipment for conservation tillage have made it possible to establish more uniform plant stands with conservation tillage. Corn, wheat, and soybean systems have been investigated rather extensively. However, conservation tillage research with cotton [*Gossypium hirsumtum* (L)] in the southeastern Coastal Plain has been limited (Roach, 1981; Roach and Culp, 1984; Baker. 1987). The present study was initiated to evaluate the influence of conservation tillage on productivity of a two-year, corn-wheat-cotton rotation.

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[2]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agr. or the S.C. Agr. Exp. Sta. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

Materials and Methods

Conventional and conservation tillage plots that were 75 feet wide and 200 feet long were established in 1979 on a Norfolk loamy sand soil (fine-loamy, silicious, thermic, Typic Paledult) at the Clemson University Pee Dee Research and Education Center near Florence, SC. Continuous corn was grown from 1979 through 1982. A two-year rotation consisting of a wheat-soybean double crop followed by corn was used between 1983 and 1986. The site was chemically fallowed in 1987 to control bermudagrass [*Cynodondactylon* (L.)] and Johnson grass [*Sorghum halepense* (L.)] infestations. In 1988, the two-year rotation was changed to acorn-wheat-cotton sequence. Sub-plots (10 feet wide by 7.5 feet long) were used for plant sampling to insure that sequential samples would be taken from the same area. Conventional tillage consisted of multiple diskings and cultivation. Surface tillage was eliminated for conservation tillage treatments. Corn and cotton were planted with Case-IH Series 800 Early-Riser planters, and in-row subsoiling was used with both tillage systems to fracture a root-restrictive E horizon. Wheat was planted with a Kelley Manufacturing (KMC) Uni-drill for conservation tillage and a John Deere Grain Drill for conventional tillage.

Prior to planting the corn, dolomitic lime and fertilizer (0-10-20) were applied at the rate of 2000 and 500 lbs/acre, respectively. Corn (Pioneer 3165) was planted on 30-inch rows at the rate of 25000 seeds/acre in April 1988. Liquid nitrogen (30% UAN) and 'Furadan' (carbofuran) were applied at the rate of 30 and 13.3 Ibs/acre, respectively, at planting. Immediately after planting, 'Atrazine' and 'Lasso' were applied to the conventional tillage plots; 'Atrazine', 'Lasso', and 'Gramoxone' were applied to the conservation tillage plots at recommended rates. Forty days after planting, additional liquid nitrogen (120 lbs/acre as 30% UAN) was applied to both tillage systems.

Following corn grain harvest, wheat (Coker 9227) was planted in November, 1988. Prior to planting, corn stover was disked into the soil surface. for conventional tillage; it was chopped but left on the soil surface for conservation tillage. Fertilizer (10-10-10) was applied at the rate of 450 Ibs/acre. Wheat was planted at the rate of 90 Ibs/acre. Immediately after planting, 'Roundup' was applied to the conservation tillage plots. In March, 1989, wheat was sidedressed with 60 Ibs/acre of nitrogen (30% UAN).

Following wheat grain harvest, cotton was planted in June, 1989. Six cotton cultivars (Delta Pine 20, Delta Pine 41, Delta Pine 50, Delta Pine 90, PD1, and PD3) were planted in 38-inch rows at the rate of 55000 seeds/acre. Nitrogen was applied at the rate of 25 Ibs/acre at planting and at 50 lbs/acre four weeks after planting. 'Temik' was applied at the rate of 2 Ibs/acre; 'Meturon' was applied to the conventional tillage plots; and 'Meturon' and 'Roundup' were applied to the conservation tillage plots immediately after planting. Seed cotton was harvested in November, 1989.

Yields for corn, soybean, and all six cultivars of cotton were taken from 200 feet of row in each main plot with a mechanical harvester. Corn, wheat, and seed cotton ('PD1') yield, number, and dry matter samples were obtained from the sub-plots prior to the main plot harvest. Analysis of variance. and least significant differences were calculated using a randomized complete block design with five replicates.

Results and Discussion

Tillage practices did not significantly affect corn or wheat or 'PD1' cotton yields (Table 1). Plant stand and dry matter were similar for both tillage systems. The equivalent yields with the two tillage systems were possible because of adequate plant stands. The improved yields with conservation tillage in this study relative to yields with conservation tillage in earlier studies may be partially due to the increased organic matter and nitrogen in the surface layer over the ten year period.

Table 1. Yield, plant populalion, and biomass of corn, wheal, and cotton plants in sub-plots at harvest as influenced by conservation and conventional tillage in a two-year rotation

Crop	Tillage	Yield	-----------Plant----------- Number	Weight
		-bu/ac-	-No./ac-	-tons/ac-
Corn	Conservation	91.8	18005	6.49
	Conventional	89.8	18179	5.84
	LSD $_{0.05}$	NS+	NS	NS
Wheat	Conservation	29.5	-----	1.97
	Conventional	30.7	-----	2.00
	LSD $_{0.05}$	NS		NS
Cotton	Conservation	1983++	26543	2.25
	Conventional	2027	26020	2.38
	LSD $_{0.05}$	NS	NS	NS

+The term 'NS' indicates that data between tillage systems were not statistically different.

++Seed cotton yields are reported in lbs/acre.

Seed cotton yields were significantly different among cultivars ($p < 0.01$) (Table 2). Cotton cultivars 'Delta Pine 50 and 20' had the highest yields with either tillage practices, and they both had significantly higher yields with conservation tillage. The cotton yields of the hand sampled subplots of 'PD1' cotton were higher than those of the main plots (Table 1 vs Table 2). However, the differences between tillage methods were small and nonsignificant in both cases. Thus, the data from the first cycle of the rotation system show conservation tillage to be equal to conventional tillage for yield.

Table 2. Seed cotton yields as influenced by cultivar and tillage.

	Cotton Cultivar					
Tillage	**DP2O**	**DP41**	**DP50**	**DP90**	**PD1**	**PD3**
	-------------------------lbs/ac------------------------					
Conservation	**1529**	**1061**	**1404**	**921**	**1235**	**1032**
Conventional	**1275**	**1095**	**1168**	**822**	**1126**	**1094**
Mean	**1402**	**1078**	**1286**	**872**	**1181**	**1063**
LSD $_{0.05}$	**235**					

Conclusions

These studies indicate that cotton grown in a two-year rotation with corn and wheat is a viable conservation tillage rotation for the southeastern Coastal Plain. However, selection of early maturing cultivars will be important for this crop rotation with any tillage system. Further studies are being conducted to better understand the long term effects of conservation tillage.

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Conservation Tillage Interseeding of Soybeans into Standing Wheat

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Introduction

Doublecropping soybeans after winter wheat has been a successful practice in South Carolina for many years. Currently, approximately 50 to 60% of the state's soybean acreage is doublecropped. Though popular, doublecropping has become economically risky due to high production costs, low commodity prices, and drought-induced low soybean yields. The risks associated with conventional methods plus the advent of better herbicides and equipment have stimulated interest in intercropping as an economically-viable double cropping method. The idea of intercropping wheat and soybeans in the southern U. S. involves planting soybeans between rows of standing wheat in early to mid-May during the heading stage. The advantages of intercropping over conventional doublecropping are: a) better potential for full-season or mono-crop soybean yield; b) better utilization of soil moisture; c) reduced soil erosion and compaction; d) early competition with weeds; and e) potential for lower costs, especially for fuel and equipment.

Interseeding requires the planting of wheat in 13 in rows in the fall with soybeans planted between wheat rows the following May. To accomplish this with minimum damage to wheat, Clemson University's Agricultural Engineering Department developed an inexpensive interseeder drill. For wheat, the drill has 11 Danish or s-tine furrow openers on 13 in centers with small spring-mounted fingers, for covering the seed with soil, behind the seed drop tubes (Khalilian et al., 1987). Eight double-disk openers and small press wheels are utilized for interseeding the soybean crop. Figure 1 shows the intercropping planting pattern for wheat and soybeans.

The concept of interseeding soybeans into standing wheat utilizes the benefits of deep tillage before wheat planting, since there is no tillage prior to soybean planting. The objectives of this study were to determine the residual effects of various conservation tillage systems and controlled traffic on soybean yield, crop responses and the formation of soil hardpan.

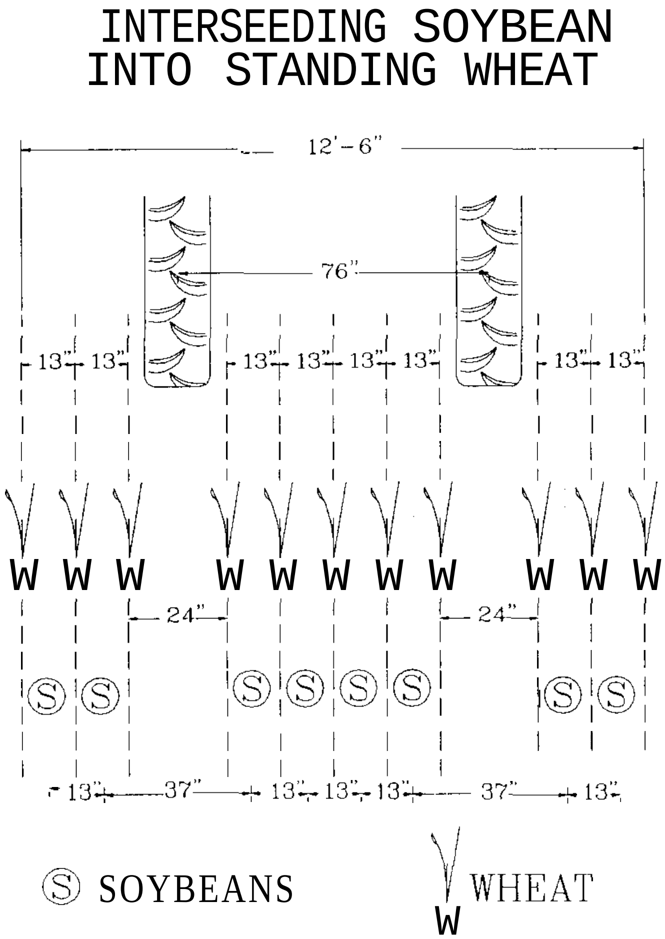

Figure 1. The intercropping planting pattern for wheal and soybean.

Procedures

Conservation tillage tests were conducted three years (1987-89) at the Edisto Research & Education Center at Blackville, S.C., to determine the proper tillage system for interseeding soybeans into standing wheat. Six treatments (Tablc 1) involving various tillage and planting comparisons were utilized on a Dothan sandy loam (irrigated location) and Varina loamy sand (non-irrigated location), both typical of productive soils in the southeastern Coastal Plains. A randomized complete block experimental design with six

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replications selected for evaluating the tillage/planting treatments.

Primary tillage equipment included a four-shank Paraplow with 22 in spacing, operating 12-13 in deep; an eleven-shank chiselplow , with 12 in spacing, operating at 11 in depth; and a four-shank 38-in spaced subsoiler operating at 12-13 in depth.

Wheat varieties 'Coker 983' (1987-88) and 'Coker 9766' (1989) were planted in late November each year immediately after tillage work at a seeding rate of 90 Ib/acre. The soybean variety 'Kirby' was interseeded at a rate of 60 Ib/acre between rows of standing wheat around mid-May. Only the plots in treatments one, three, and four (Table 1.) were interseeded with soybeans. Wheat from all plots was harvested around the first week in June, and soybeans planted in plots for treatments two, five, and six. Fertilizer, applied at rate based on soil analyses, was broadcast before any tillage in the fall. Postemergence herbicides were applied as needed.

Table 1. Tillage/Planting Trealmenl Combinations.

Treat. No.	Tillage Before Wheat			Wheat Planting Method		Tillage Before Soybean	Soybean Planting Method	
	Disk	Ch	Para	Clem	Drill	Para	Clem	KMC/Sub
1	x			x			1*	
2	x			x			2**	
3	x	x		x			1	
4	x		x	x			1	
5	x		x	x		X	2	
6***	x	x			x			2

* - Mid-May soybean interseeding date.
** - Soybean planted in june after wheal harvest.
*** - Conventional doublecropping method for wheat and soybeans in Coastal Plain soils.

Ch = chisel plow; Para = Paraplow; Clem = Clemson interseeder; Drill = conventional grain drill with 7 in rows; KMC/sub = KMC subsoiler-planter with 38 in rows.

To determine effects of deep tillage equipment, a tractor-mountcd recording penetrometer was used to quantify soil resistance to penetration. Soil compaction values were calculated from the measured force required to push a 0.5 in2base area cone into the soil. Penetrometer data were taken two months after wheat planting and one month after soybean planting. Two sets of penetromcter readings were taken from soybean plots, one from the soybean rows and the other from the tractor tire tracks.

Root weight and length were measured immediately after penetrometer data were taken. Core samples were taken at depths of 0-6, 6-12, and 12-18 in from the wheat plots. A steel tube, four inches in diameter with a hardened cutting edge, was used to take a minimum of nine cores from each plot. Thus a total of 54 cores were taken per treatment. Roots were separated from the soil by washing, samples were floated in shallow water in a clear glass tray, and root length measured with an area meter (Delta T Device) as described by Harris and Campbell (1987). *Also*, each sample was oven dried to determine root dry weight. Shoot growth was measured by clipping the wheat plant on the same date penetrometer data were taken.

Harvest data for both wheat and soybean were taken with a plot combine in 1987. Middle rows from each plot were harvested and weighed for yield determination. In 1988 and 1989, a conventional combine with 13 ft header was used to harvest the crops. An attachment was added to the combine for placing wheat straw in wheel tracks to aid in weed management.

Results and Discussion

Table 2 shows shoot growth, root growth at different soil depth nitrogen uptake by wheat, and cone index values averaged over the E-horizon (hardpan area) for tillage/planting equipment used in the test. The Paraplow significantly reduced soil compaction of the hardpan layer compared to chisel and disk plots. Cone index values in hardpan area for disk plots were not high enough to completely eliminate root penetration into the clay layer (cone index values above 290 psi generally stop root growth -- Taylor and Gardner 1963, and Carter and Tavernetti 1968). Also, there was a significant difference in soil compaction between chisel plots planted with Clemson interseeder and chisel plots planted with a conventional grain drill in 1987. This could be due to press wheels and double disk openers on the grain drill which tend to compact the soil. The grain drill used in 1988 did not have press wheels and used instead single disk openers. There were no differences in soil compaction between chisel plots planted with the grain drill and Clemson interseeder in 1988.

As shown in Table 2, two months after tillage a noticeable difference was observed in root length in the clay layer due to high resistance to penetration. There was a very good correlation between soil compaction in the hardpan and root length in the clay layer. Figure 2 shows the relationship between root distribution at different depths and shoot biomass for different tillage tools for 1987. A similar trend was observed in 1988. Shoot growth increased as root penetration of the clay layer increased. There was no significant difference in total root length of wheat plants in different tillage plots.

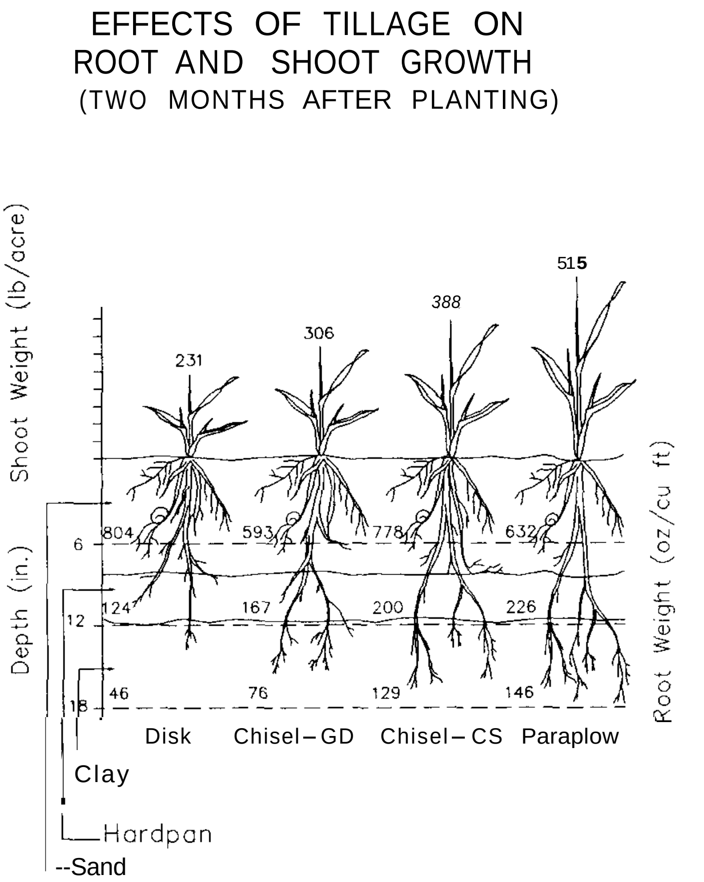


Figure 2. Correlation of root distribullon at different depths and shoot biomas (1987).

Deep tillage increased nitrogen uptake by the wheat plant. The plants in the Paraplow and chiselplow plots had the higher levels of nitrogen uptake compared to those in disk plots (Table 2). This would result in a higher protein forage for winter grazing.

A comparison of individual root dry weight measurements with root length data, measured by the Delta T Device area meter, showed a good relationship between root weight and length (Figure 3). The correlation coefficient was 0.978 (significant at the 95 percent level). Root length measurement requires excessive time expenditure and is not without error. Root weight is relatively easy to obtain and can be used to estimate root length from prediction equation developed for the 'Coker 983' wheat variety.

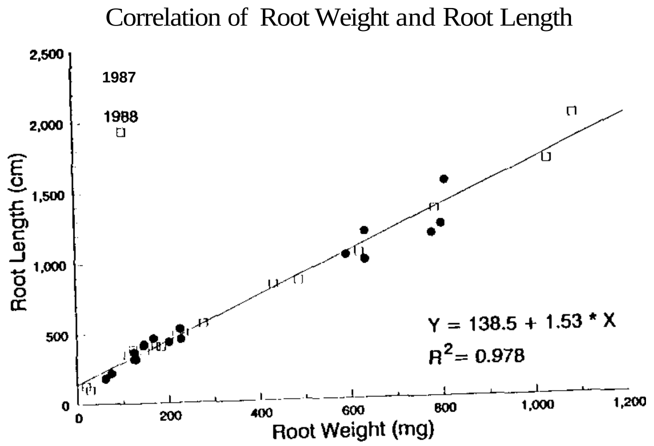


Figure 3. Correlation of root weight and root length for wheal (Coker 983).

The Paraplow plots produced significantly higher wheat yield per acre than any other tillage treatments at both locations (Figures 4 and 5). There was no significant difference in yield between chiselplow plots planted with Clemson interseeder (13-in rows) and those planted with conventional grain drill (7-in rows). Seeding rate per acre for both planters was the same (90 lb/acre). Interseeding soybeans between rows of standing wheat did not reduce wheat yields (Disk 'CS-IN' vs. Disk 'CS-AH' and Paraplow 'CS-IN' vs. Paraplow 'CS-AH', Figures 4 and 5). Disk plots produced significantly less yields compared to Paraplow and chiselplow plots in both locations.

Table 2 Average shoot weight, root length at different soil depth, nitrogen uptake and cone index values two months after wheat planting.

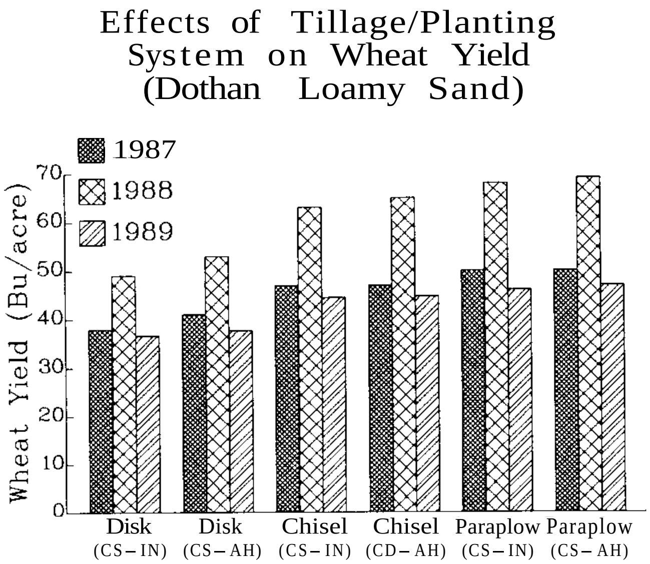
Tillage	Planter	Shoot Weight (lb/ac)	Root length (in/quart) 0-6"	6-12'	12-18"	Nitrogen Uptake (% DM)	Average* Cone index (Psi)
1987:							
Paraplow	Clem.	515 a**	405 a	184 a	156 a	3.83 a	96 a
Chisel	Clem.	388 b	434a	163a	117 ab	3.55 a	129a
Chisel	Drill	343 c	382 a	175 a	81 b	3.66 a	178 b
Disk	Clem.	259 c	514a	127a	68 b	2.93 b	200 b
1988							
Paraplow	Clem.	558 a	434 b	198 a	152 a	3.80	98 a
Chisel	Clem.	504a	317 c	182 a	131 a	3.70	137a
Chisel	Drill	508 a	308 c	193a	144 a	3.70	127a
Disk	Clem.	383 b	681 a	138 a	43 b	3.20	198 b

* Cone index values are averaged over E horizon (hardpan area), depth = 8 to 11 in.

** Values followed by the same letter are not significantly different (based on Duncan's Multiple Range lest).

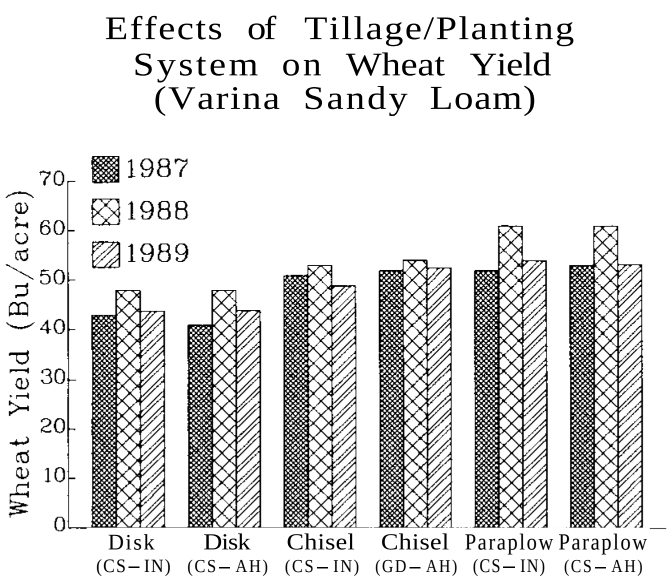
Traffic significantly increased soil compaction compared to penetrometer measurements within the soybean rows. The biggest difference in soil compaction was experienced in the hardpan area. Due to controlled traffic deep tillage benefits from Paraplowing before small grain planting carried over and benefitted soybeans. There was no significant difference in soil compaction between Paraplow plots tilled in fall with those of conventional doublecropped plots (chiselplowing in the fall followed with subsoiling prior to planting soybeans). Also, there was no significant difference in penetrometer measurements between plots Paraplowed only once in the fall with those which had an extra deep tillage operation with the Paraplow in next June. This indicates that, when interseeding is practiced behind deep tilling for wheat, there is no advantage to deep tillage for soybeans.

Interseeding soybeans into standing wheat produced higher soybean yield compared to those planted after wheat harvest for each tillage system ('IN vs. 'AH', Figures 6 and 7). Paraplowing before wheat significantly increased soybean yields compared to chiselplow and disk. Top interseeded soybean yields for both irrigated and non-irrigated locations were significantly better than conventional KMC row-subsoil planted yields of 'Kirby' soybeans after wheat harvest. Irrigation increased soybean yields about 15 bushels per acre in 1989 but increased only 2 bushels per acre in 1988 (irrigation decisions were not made with aid of tensiometers).



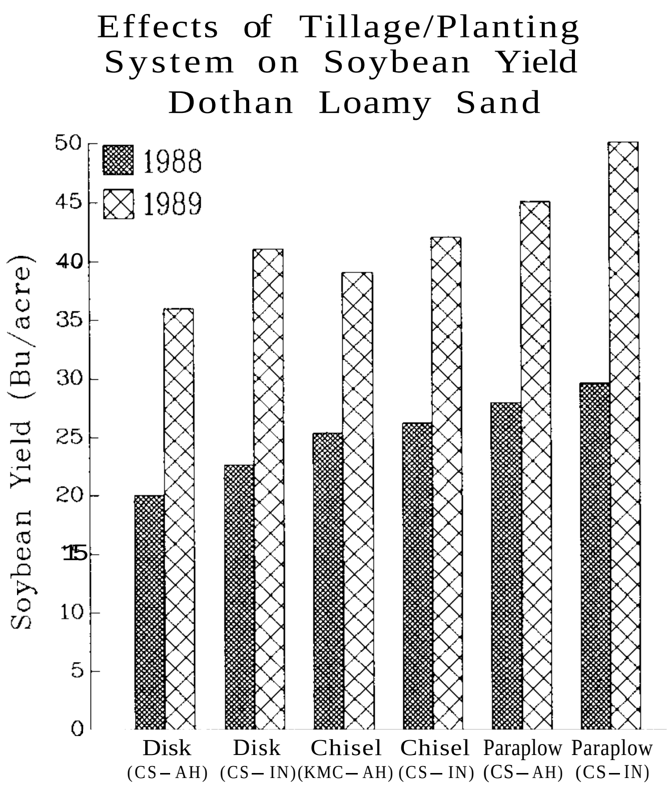
CS = Clemson Seeder; KMC = Subsoiler/planter
CI = Interseded into wheat; AH = After Harvest

Figure 4. Effects of tillage/planting system on wheat yield (Dothan loamy sand).



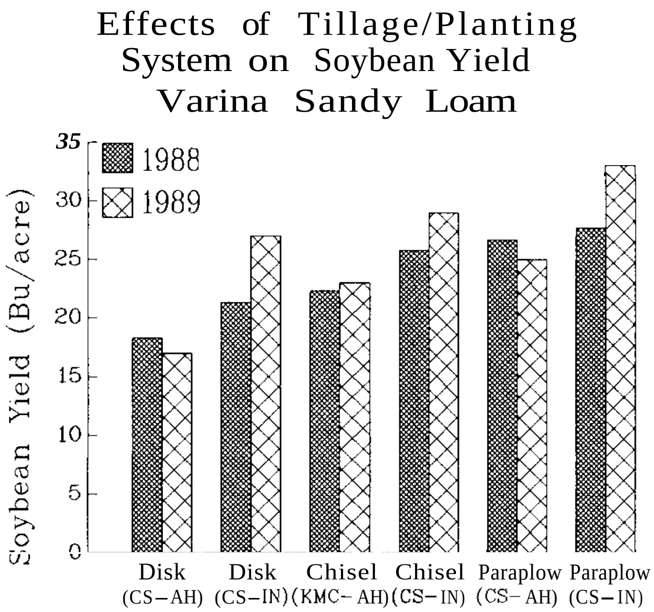
CS = Clemson Seeder; KMC = Subsoiler/planter
CI = Interseded into wheat; AH = After Harvest

Figure 5. Effect of tillage/planting system on wheal yield (Varina sandy loam).



CS = Clemson Seeder; KMC = Suhsoiledplanter
CI = Interseeded into wheat; AH = After Harvest

Figure 6. Effects of tillage/planting system on soybean yield (Dothan loamy sand).



CS = Clenison Seeder, KMC = Subsoiler/planter
CI = Interseeded into wheat; AH = After Harvest

Figure 7. Effects of tillage/planting system on soybean yield (Varina sandy loam).

Conclusions

a) Paraplowing significantly reduced soil compaction in the hardpan area compared to chiselplow and tandem disk.

b) Shoot biomass for wheat increased as root penetration of clay layer increased.

c) Wheat yields were not affected by row spacing at yield levels of 40 to 70 bushels per acre. Deep tillage significantly increased wheat yields. Interseeding soybeans into standing wheat did not reduce wheat yields.

d) Deep tillage benefits from Paraplowing before small grain planting carried over and benefitted soybeans due to controlled traffic patterns associated with the interseeding system.

e) Interseeded soybeans yielded significantly more than conventional double-cropped soybeans at both the irrigated and non-irrigated locations.

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No-Till and Reduced Tillage Production of Grain Sorghum Under Dryland Conditions

J.E. Matocha[1]

Introduction

Interest in conservation tillage has generally been on the increase in the last decade in the deep South and Southwest. However, this region has been considerably slower to convert to this alternative tillage system than the Midwest and Southeast. Some of the reasons for this lack of interest are generally given as being 1) the longer growing season due to warmer temperatures and therefore greater problem with weed control and 2) difficulty in overcoming traditional practices of low crop residue on the surface or "trashless farming".

Economic factors including rising input costs for fuel, labor, other variable costs and uncertain market prices are requiring crop producers to continually strive to reduce input costs and maximize profits. Additionally, U.S. farm policy mandating soil erosion control has stimulated interest in use of conservation tillage in production of major crops. Earlier reports have described a minimum tillage system that appeared suitable for Southern Texas and possibly other parts of the South (1,2).

Reduced crop yields due to plant water stress is a common problem in the sub-humid and semi-arid regions of the South and Southwest (5). Plant stress for water due to short term droughts can also severely limit crop yields in these regions. Other problems associated with conservation tillage may involve a greater dependency on soil insecticides since more crop residue may present greater dependency from insect pests. Research in the region has shown benefits of soil-applied insecticide on production of sorghum under conventional tillage (3,4). Little or no attention has been given in the past to studying the need for soil-applied insecticides in sorghum production under conservation tillage systems. This long-term research was established to develop alternative tillage practices to minimize the adverse effects of the weather and water deficiencies. Specific purposes of this tillage experiment were 1) compare alternative tillage systems including two forms of conservation tillage with conventional tillage, deep chisel and moldboard systems of primary tillage, 2) Ascertain the need for an in-row soil insecticide treatment as related to tillage systems and the effects on production of grain sorghum.

[1]**Professor, Texas Agricultural Experiment Station, Texas A&M University.**

Materials and Methods

The study was conducted on an Orelia sandy clay loam (Typic Ochraqualf) located at the Texas Agricultural Experiment Station research farm at Corpus Christi. A randomized complete block design with eight tillage treatments as major plots and three principal crops, grain sorghum, corn and cotton as sub or split-plots were each studied in four replications. Five of the eight tillage systems using grain sorghum as the indicator crop will be reported in this paper. They include 1) conventional, 2) minimum tillage, 3) no-till, 4) moldboard 12-inch depth and 5) chisel 12-inch depth. The conventional system included some 10-12 tillage operations including planting and cultivating.

Maximum tillage depth in the conventional system was 6 inches. The minimum or reduced tillage treatment consisted of a maximum tillage depth of 3 inches and used four to five tillage operations per year. A list of tillage treatments and description of the minimum till treatment are presented in Table 1.

Table 1. List of primary tillage treatments and description of minimum tillage.

1) **Conventional Tillage**
2) **Minimum Tillage**
3) **No-till**
4) **Moldboard at 30-cm depth**
5) **Chisel at 30-cm depth**

Minimum tillage treatment comprised the following: 1) disc-3 inch depth, 2) sweep plow low profile beds and root plow stalks, 3) spray herbicides for fall-winter weed control, 4) inject fertilizer, (3 inch depth), 5) plant and, 6) cultivate sorghum.

Atrazine, paraquat and sometimes glyphosate were used in weed control in the no-till and minimum till plots. Atrazine was also used in the conventional, moldboard and chisel tillage systems.

The experiment was initiated in 1981 and continued for nine years with tillage systems repeated each year on the same plots. The soil insecticide portion of the test was conducted on grain sorghum in 1983-87 and again in 1989 on all tillage treatments. Carbofuran (Furadan) was used in the initial five years while terbufos (Counter) was used in 1989. A single rate of 0.5 Ib a.i. A-1 of each insecticide was tested with 0 lb a.i. A-1 in a split-plot comparisons across all tillage treatments. A small grain combine was used to harvest the 80 feet long and 2 row wide research split plots.

Results and Discussion

Tillage and Rainfall Effects:

Grain sorghum yields were highly variable across the nine production years. Average yields ranged from 1566 for one of the dry years to *5066* lb A-1 for a wet season (1981). Highest average yields were measured in 1981 when April-May rainfall was highest (9.0 inches). Conversely, lowest yields were measured in 1989 when Counter was used as soil insecticide and 2.68 inches of rainfall were received during April-May. Correlation analyses of fall and/or spring rainfall with average grain yields over the nine year period were not statistically significant (data not shown).

The effects of various systems of primary tillage including the no-till system on relative yields are presented in Figure 1. With sorghum grown in a conventional tillage system using soil insecticide as a standard of comparison (set at 100%) the data show that minimum tillage produced less grain than conventional tillage in four of nine years while the no-till system fell short of the conventional in six of nine years. The poorest comparisons for both conservation tillage systems occurred in 1982, 1983 and 1987 when averaged yield dropped 34.8, 19.4 and 23.9% respectively, below those yields for the conventional system. These relative comparisons did not appear to follow any rainfall trends.

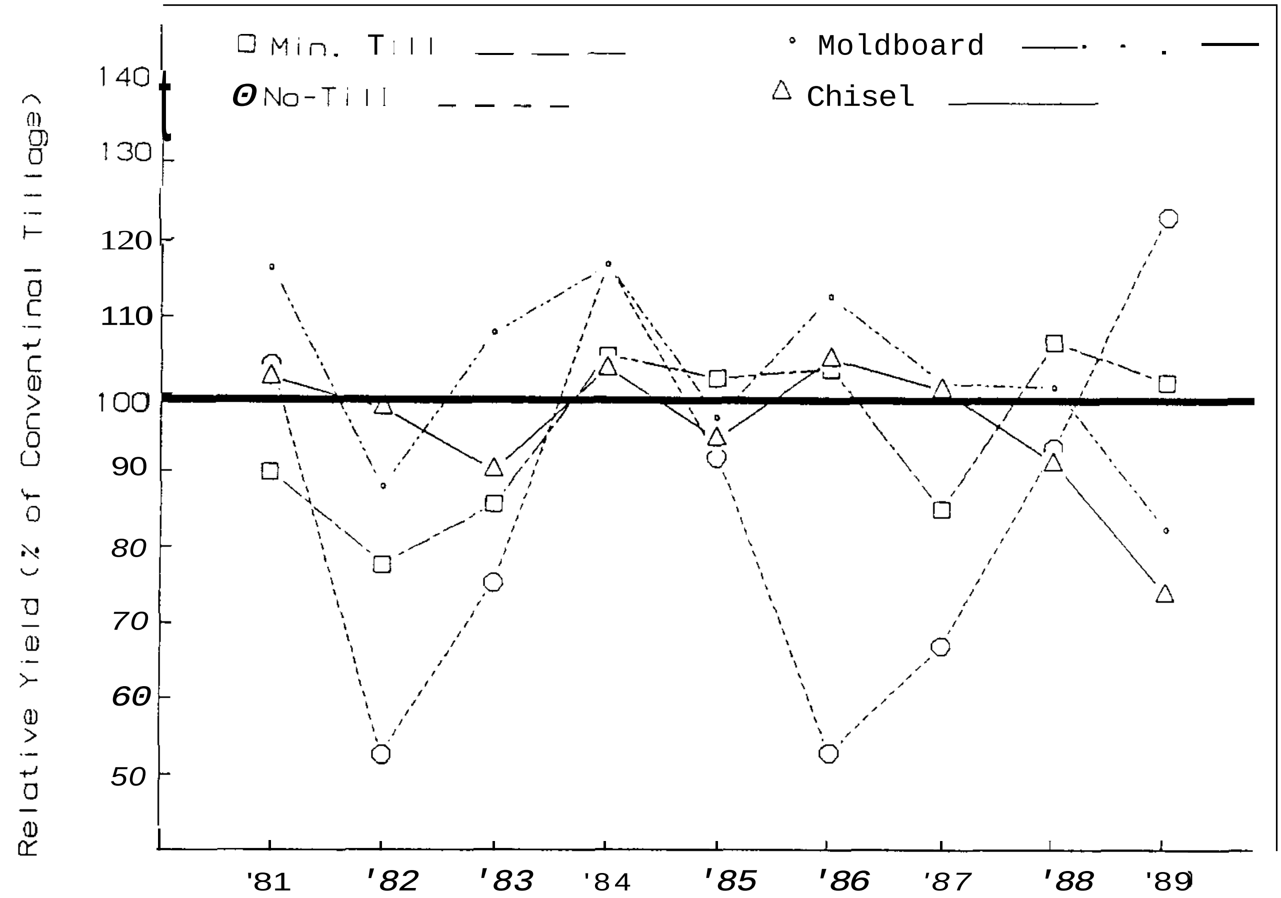

Figure 1. **Relative yield of grain sorghum grown under conservation tillage and two forms of primary tillage (1981-89)**

Further breakdown of tillage treatment response indicates that moldboard tillage at 30-cm depth resulted in sorghum becoming less productive in seasons with subnormal fall and spring rainfall. The chisel system of primary tillage (30-cm depth) disturbs soil aggregates considerably less than the moldboard system. However, sorghum responded to this system quite similarly to the moldboard in most seasons. The moldboard system appeared to improve sorghum yields above the conventional system in four of the nine seasons. Also, when moldboarding was used as a method of primary tillage, only three of nine years were less productive than the conventional system. Subnormal rainfall was recorded during two of those less productive seasons. At the same time, yields dropped in four of nine years when chiseling was the form of primary tillage. Lowest yields were experienced with no-till farming in years with above normal rainfall and this was usually associated with problems in weed control.

Soil Insecticide Effects:

Relative yields of grain sorghum as affected by placement of soil insecticide in the seedrow are presented for six years with the initial year in 1983 and the final year 1989 (Table 2). Soil insecticide comparisons were not made in 1988 due to a split-plot comparison of two sorghum hybrids.

Table 2. Relative response of grain sorghum to in-row soil insecticide as affected by conservation tillage and seedbed preparation. Percent increase *or* decrease in yield due to soil insecticide.

Tillage System	1983[1]	1984[1]	1985[1]	1986[1]	1987[1]	1989[2]	Avg.
	--------------------------------			%		-----------------------------	
Conventional	**116.1**	**113.0**	**132.9**	**90.7**	**98.3**	**68.9**	**103.3**
Min. Till	**107.7**	**112.8**	**118.0**	**113.6**	**113.9**	**86.2**	**108.7**
No-till	**79.0**	**127.2**	**114.9**	**84.8**	**137.5**	**91.5**	**105.8**
Moldboard	**114.0**	**127.7**	**104.4**	**109.0**	**135.9**	**61.7**	**108.8**
Chisel	**147.3**	**123.8**	**113.1**	**102.5**	**94.3**	**64.5**	**107.6**
$\bar{X}$	**1128**	**120.9**	**116.7**	**1W.1**	**116.0**	**74.6**	

[1]0.50 lb a.i. ac-1 of carbofuran in seedrow.
b.5 lb a.i. ac-1 of terbufos in seedrow.

As indicated earlier, grain yields fluctuated widely over the six production seasons. Yields averaged across tillage treatments and the six years were 3409 lb A-1 for the insecticide treated plots and 3076 Ib A-1 for the check plots. Relative yields averaged over tillage treatments for individual years ranged from a low of 74.6% (1989) to a high 120.9% (1984). Although treatment means averaged across years show only slight changes due to the type of primary tillage, treatment differences within season were quite substantial. The largest spread in relative yields as a function of insecticide and method of tillage occurred in 1983 and 1987 with the extend approximating 68 and 43%, respectively. The larger treatment variation was recorded during the droughty season in 1983.

There did not appear to be a consistent relationship between method of tillage and response to soil-applied insecticide. In seasons when the relative response to insecticides showed the greatest disparity due to tillage system, insecticide treatment produced a negative response (79%) in the no-till system while in the 30-cm chisel system the same treatment showed the highest response (147%). However, in the season with the second highest treatment response spread (1987) and less plant stress for water, no-till sorghum showed the highest response to insecticide (137.5%) while the chisel method produced no response (94.3%). The yield fluctuations were not associated with consistent changes in plant population in response to the soil-applied insecticide.

The relative yield for treated sorghum averaged across tillage systems for 1989 was less than 75% of yield for sorghum not receiving soil insecticide. This severe suppression of yields was not due to adverse effects on plant population but apparently a result of phytotoxic effects from terbufos on the plants. Visual observations indicated stunted growth and some chlorosis of sorghum foliage. Carbofuran used in the previous five years showed no phytotoxicity or stunted growth. Recent greenhouse experiments on a similar soil showed severe stunting and induced interveinal chlorosis of foliage in sorghum plants treated with terbufos while similar symptoms were not noted on sorghum treated with carbofuran.

Summary

Results of this long-term experiment indicate grain sorghum grown in a minimum reduced tillage system can produce as much or more grain in five of nine years as sorghum grown in a conventional tillage system. Based on relative yields averaged for the nine years, grain sorghum grown with minimum tillage can be 95% as productive as that grown under the conventional system.

The six-year evaluation of the need for a soil-applied system insecticide for control of sorghum pests indicated that sorghum response as measured by final grain yields will be highly variable with cropping season. Yield response averaged over seasons with minimum tillage showed an approximate nine percent increase in sorghum grain yield. This compared to six and three percent for no-till and conventional tillage, respectively.

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Planting Tropical Corn in Minimum Tillage Systems

D.L. Wright[1], D.P. Lilly, and I.D. Teare[2,3]

Introduction

Tropical corn is well suited to Central and South America and the southern United States because of its long growing season and tolerance to insects and diseases. Field studies were planted from 1985 to investigate the feasibility of growing tropical corn as a grain crop in Florida. Tropical corn fits well into current cropping systems in the Southeast and provides a much needed energy supply for dairy and livestock operations in Florida (Wright and Prichard, 1988). Many dairies prefer corn silage over sorghum silage because of better milk production even though yield is often not as high. Work has been done with the tropical hybrids in recent years at Quincy and Gainesville, with regard to management and evaluation of tropical hybrids for grain (Wright and Chambliss, 1989). However, there has been only one commercially available tropical hybrid for farmers to plant and that hybrid is known for its low grain yield but good tolerance to insects and diseases when planted late. Growers need improved hybrids that will produce higher grain yields and for increased energy content of silage. One such hybrid was evaluated in 1989 that doubled the grain yield of the currently used tropical hybrid. Research in Florida over the past several years with tropical corn has shown that it can be grown successfully after small grain, vegetables, or early corn for silage. Grain yields from these later plantings have been equal or better than the state average for temperate corn planted at the normal time and grain quality has been excellent.

Recent research and demonstration plots have excited farmers about growing tropical corn and acreage increased from *5,000* acres three years ago to almost 40,000 acres in 1989 in the southern U.S. (Teare et al., 1990). Reasons for the dramatic increase in acreage is that growers want a more consistent grain or silage crop that can be grown under natural rainfall conditions, a higher quality grain, a grass crop that can be grown after vegetables or small grains to increase profitability and cash flow, and a rotation crop for legumes (soybeans, and peanuts) (Teare et al., 1989). Since it is grown during the summer months when rainfall is most bountiful, it should perform more consistently. Because of these positive results grower interest has increased. However, more information on tropical corn growth, management, feed value and availability of new better yielding hybrids needs to be provided to answer questions for this expanding southern crop. Tropical corn has the potential to increase profitability of dairy, livestock and grain producer operations in the South while supplying a more consistent supply of feed.

Materials and Methods

These studies were conducted on a Norfolk sandy loam (fine, loamy siliceous, thermic Typic Kandiudults) located on the North Florida Research and Education Center. The soil has a compacted layer located 7 to 14 inches below the surface. These experiments were planted from early June to August 1 in 1988, and then at 3 dates in 1989. A Brown Ro-Till was used to plant all studies into standing wheat stubble. These studies were conducted using residual fertility from the wheat crop except for 120 Ibs N/A. Four row plots were 25 feet long planted at 20,000 plants/acre in each of four replications. The studies were not irrigated and depended on natural rainfall. A sidedress application of N was made to bring total N to 120 Ibs/acre when corn plants were 12 inches tall. Planting date studies were made comparing N rates of from 0 to 200 Ibs N/A.

Results and Discussion

The most common double cropping system in the south is wheat followed by soybeans (Teare and Wright, 1990). Dry weather normally keeps corn yields low in the Coastal Plain averaging from 60 to 80 bu/A in the southern states. Because of low yields and low prices, acreage of corn has dropped dramatically. Tropical corn has been shown to be much more insect and disease resistant than temperate corn and has been planted for several years on limited acreage for silage following an early corn silage crop. The need for rotation with peanuts and soybeans to help control pests that tend to build up from continuous cropping is one of the biggest advantages of tropical corn after

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[3]Acknowledgements: Our thanks to E. Brown, Agricultural Technician IV; B.Y. Kidd, Biological Scientist II; North Florida Res. and Educ. Ctr., Univ. of Florida, Quincy, FL; for plot preparation and management, data collection, and computer processing.

fitting into double cropping systems with wheat. Yields of three varieties of wheat grown during 1985 to 1988 prior to planting tropical corn are shown in Table *1*. These wheat varieties are normally harvested from May 20 to June 1.

Table 1. Wheal Yields' (bu/A) for Florida 301, 302, and 303 during 1985 to 1988 at Quincy, Florida.

Year	Varieties: Florida 301	Florida 302	Florida 303
	- - - - - - - - - - - - - - - - bu/A	- - - - - - - - - - - - - - - -	
1985	56	45	49
1986	60	48	60
1987[2]	57	55	64
1987[3]	43	65	62
1988[4]	65	63	70
1988[5]	58	62	70
Mean	56	56	62

[1]Agronomists of IFAS, Univ. of Fla., Florida Field and Forage Crop Variety Reports: AY86-10, AY87-2, AY88-02, AY89-07.
[2]State Variety Test
[3]Uniform Southern Test
[4]Early Planted State Test (12-1-87)
[5]Late Planted Stale Test (12-9-87)

Tropical corn grain yields from Pioneer Brand X304C are shown in Table 2. Yields were low in 1985 from a hurricane which passed through and caused severe lodging. Visual observations in 1985 indicated that the sidedress application of N was too late. Because of the corns fast growth in the summer time, N should probably be applied to the corn by the time it is 12 inches tall.

Table 2. Tropical corn in relation year, planting date, harvest date, applied N, water use (water mgt., ppt/irr), grain yield, and some problems in a low-energy-input system.

Year	Planting Date	Harvest Date	Applied N	Water Mgt.	ppV irr.	Grain Yield
			(lb/A)		(in.)	(bu/A)
1985	13 June	23 Oct	120	Dryland	16/0	64[1]
1986	16 June	21 Oct	120	Dryland	25/0	97
1987	24 June	27 Oct	120	Dryland	15/0	96
1988	15 June	27 Oct	120	Dtyland	23/0	88

[1]Problem: Sidedressed, late lodging

A study with 2 plant populations and 5 N rates was planted on August 4, 1988. Grain yields were low as well as plant heights and cool temperatures slowed growth. Ear fill was not finished before the first frost resulting in poor quality grain. Grain yields ranged mostly in the 20 to 30 bu/A range for most treatments.

In 1989 planting dates studies with 5 nitrogen rates were planted after wheat. Yield of no-till tropical corn was highest from the May planting and then decreased with successive later plantings (Table 3). Insect pressure from the fall armyworm (*Spodoptera frugiperda*, J. E. Smith) also increased as planting dates were delayed. Higher rates of nitrogen were beneficial from early planting dates as compared to later plantings. A nitrogen rate of 100 Ibs/A produced highest yields in May while 50 Ibs produced highest yields in June, and no nitrogen yields were as high as any rate of nitrogen in July. Growth of plants is often retarded from late plantings because of shorter days and cooler, drier weather during the ear fill period.

Table 3. Planting date and N rate influence on Pioneer 304C Yield (Quincy, 1989).

N Rate	Planting Date: May 29	June 15	July 14
lbs/A	-----------------------------	Bu/A-----------------------------	
0	70.9 a	39.2 a	40.9 a
50	96.0 b	69.1 b	44.0 a
100	113.3 c	67.6 b	40.0 a
150	111.6 c	81.4 b	42.1 a
200	115.2 c	72.3 b	43.0 a
Average	101.4	65.9	42.0

More research needs to be done on tropical corn in various systems to determine best management procedures. However, in Florida we have found that late plantings (late July-July) usually yield less than earlier plantings because of the severe armyworm pressure and the grain fill period is less favorable due to cool nights and normally drier conditions. Stalks of the corn plant have been noted to be smaller which could result in more lodging and less silage yield.

Tropical corn is a viable crop to plant after small grain for rotation with soybeans and peanuts and as new varieties and management techniques become available, its use in double crop systems will become widespread.

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Tillage Effects on Infiltration and Crop Yields

G. C. Naderman and M. G. Wagger[1]

Abstract

Four 1989 studies compared no-tillage with other conventional and conservational tillage practices for corn (*Zea mays*) production. Surface textures were sandy loam and loamy fine sand. A sprinkling infiltrometer was used to compare water intake during a 30 or 39 minute, simulated rain application at 2 in/hr.

In the finer textured soils tillage systems which left minimal surface residue resulted in 25-50 percent less water intake compared to conservation tillage treatments. In the soil with loamy fine sand surface texture no difference was found in water intake nor yields in response to conservation tillage. The paratill system improved infiltration only where no cover crop residue was present. Significantly higher soil bulk density was found in the NT treatment than in any other treatment compared. Greater yields (16-50%) were associated with the conservation tillage treatments which showed greater water intake, even though the season was unusually wet.

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Winter Annual Cover Crops

Strip-till Management of Crimson Clover for a Self-Reseeding, Year-Round Ground Cover in Piedmont, North Carolina Corn Production

C. R. Crozier and L. D. King[1,2]

Introduction

The winter annual growth habit of crimson clover (*Trifolium incarnatum* L.) allows for self-reseeding when grown with annual crops such as grain sorghum (*Sorghum bicolor* L. Moench), which have relatively late planting dates (Touchton, et al., 1982). For self-reseeding to occur with earlier planted crops such as corn (*Zea mays* L.), management methods involving herbicide strip-kill have been developed (Myers, 1989). This study describes an attempt to till rather than herbicide-kill strips of the clover into which corn is then planted. This method of crimson clover management was developed for an ongoing long-term study comparing conventional and reduced chemical input cropping systems (L.D. King, 1988). The strip-till method should reduce costs due to the self-reseeding, and should provide a year-round ground cover while avoiding the use of herbicides.

In addition, the increased period of time available for crimson clover growth in the row middles may play a significant role in increasing the amount of nitrogen accumulated, and in providing a more slowly mineralizing source of nitrogen to the subsequent corn crop (Wagger, 1987). There is some evidence that hairy vetch results in available nitrogen early in the season for corn, with recommendations for supplemental fertilizer nitrogen later in the growing season (Hubbard, 1986). Therefore the adoption of a method such as strip-till may affect recommendations dealing with the timing of supplemental applied nitrogen.

Materials and Methods

This study was carried out at North Carolina State University Research Unit Number Nine, Raleigh, NC. The soils belong to the Cecil and Appling series and are gravelly sandy loam classified as clayey, kaolinitic, thermic, Typic, Kanhapludults (Natl. Coop. Soil Survey, 1988). The slope ranges from 2-6% at the site, which was used for silage corn production for several years prior to September, 1985. The conventionally tilled and strip-tilled experimental plots are two of the forty treatments in a larger field experiment which was laid out in a completely randomized block design in fall, 1985. The four experimental blocks were delineated based on landscape position and a visual estimate of surface texture (King, 1988). The plots described in this study were managed with winter crimson c1over:summer corn using conventional cultivation and no fertilizers or pesticides from fall, 1985 through summer. 1988.

For each treatment, four replicate 25ft x 100 ft plots were chisel plowed, disked twice, and planted with Tibbee crimson clover (innoculated with Pelinoc) at a rate of 20 lbs/acre on October 2, 1988, immediately following corn harvest. The four plots of the conventionally tilled treatment were chisel plowed and disked twice on April 23,1989 and were planted on April 25 with 29,660 seeds/acre of Dekalb 789 corn using a two-row planter. The four plots of the strip-till treatment were planted on April 27 with the same seed and seeding rate by using a two-row no-till planter with 12 inch wide sweeps mounted immediately behind the coulters. The width of the strip of removed vegetation was measured one week after planting at four row positions within each plot.

Post emergence weed control consisted of two cultivations with a Hinnaker cultivator, These occurred on May 19 and June 12 in the conventionally tilled plots. For the strip-till plots, the row middle sweeps were removed during the first cultivation (May 30), so that only a 3 inch wide strip approximately 3 inches on each side of the crop row was cultivated. For the second cultivation (6/12/89), the row middle sweeps were left in place, however clover residues remained in clumps on the surface rather than being incorporated.

Soil temperatures were measured prior to planting and within the crop row during the germination period. A Digi-Sense Model 8523-00 Thermistor thermometer with YSI #418 probes was used to collect three or four readings at a depth of 2 inches in the center of each

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[2]This research was supported by USDA (LISA) Grant No. 88-COOP-3559, and the principal author is being supported by an assistantship provided by the Jessie Smith Noyes Foundation. Marc Buchanan and Mark Barnes assisted with field plot management operations. The soil thermometer and assistance in manuscript preparation were provided by Greg Hoyt. Marc Buchanan and Michael Wagger provided helpful suggestions for designing the Crimson clover management scheme.

plot on each sampling date. The mean of the individual readings was used as the temperature for statistical analysis.

Plant populations were determined by periodic counts of the center two rows of each plot. Grain yields were determined by harvesting the two center rows of each plot with a two-row combine on October 4-5, 1989. Moisture contents were determined using a portable Dickey-john grain moisture tester and yields were converted to bushels/acre at a 15.5% moisture level.

Statistical comparisons of means were made using two-tailed t tests (Steel and Torrie, 1980).

Results

The strip-till planting method appeared to place the corn seed at the desired depth of 1 inch in most cases. However in some row segments in rockier areas, the seed could be observed at the surface in the planting slit and was pressed into the ground by hand. The mean width of the clover strip removed by tillage with the 12 inch sweep was 8.50 inches (s.d.=1.73 in.).

Soil temperatures were lower within the crop row of the strip-till plots (Table 1). For the post-planting sampling dates the range of these temperature differences was 1-5 degrees F. These differences were statistically significant at the .10 or .05 level for three of the five post-planting sample dates.

Table 1. Soil temperatures at a deplh of 2 inches (degrees F).

Days Postplant	Conventional Till		Skip-till	
	mean	c.v.	mean	c.v.
-18	56	.036	55	.012
-13	65	,003	67	.047
2**	94	.026	89	.028
7	85	.040	84	.013
8*	84	.011	79	.046
14	81	.028	79	.034
16*	80	.028	77	.032

** treatment means differed at the .05 level at sampling date.
* treatment means differed at the .10 level at sampling date.

The strip-till method resulted in slightly delayed germination rates and lower plant population densities than did the conventionally tilled method (Figure 1). Stand densities were also more variable for the strip-till plots. Coefficients of variability ranged from .200-.600, compared with .015-.080 in the conventionally tilled plots. In the conventionally tilled plots, germination was almost complete one week after planting, while in the strip-till treatment most plants germinated between one and two weeks after planting, with some germinating between two and four weeks after planting. It should be noted that the strip-till treatment was planted two days after the conventionally tilled treatment and that cooler weather, including frost on May 5, 1989 (twelve days after the strip-till planting date) followed the warmer interval at planting time. Final plant population density was approximately 15% less in the strip-till managed plots.

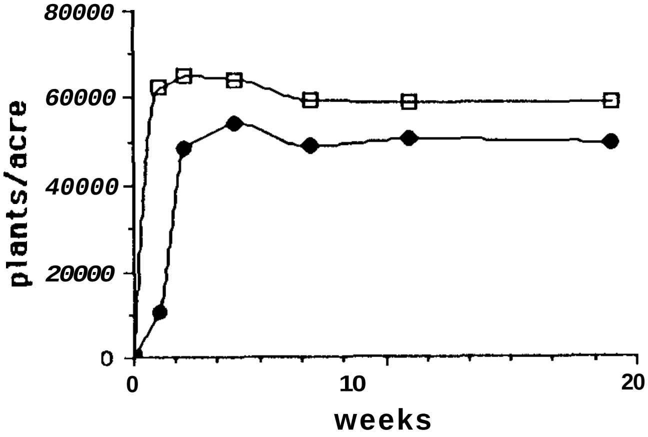

Figure 1. Corn plant population densities.

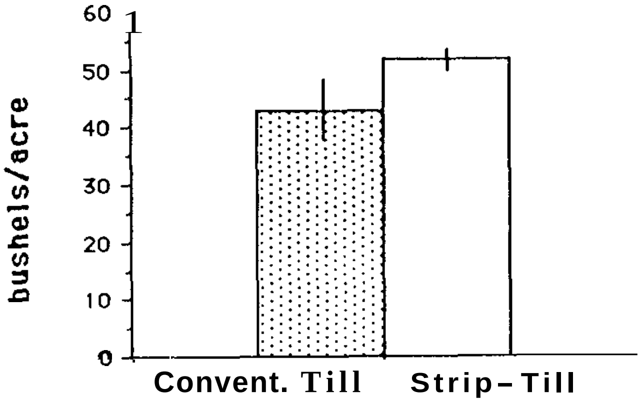

Figure 2. Corn grain yields (mean +/- s.d.)

Rodent activity was evident in some of the strip-till managed plots and seed prcdation presumably accounts for much of the reduction in population density as well as the increased variability (Figure 1). Rodent problems have previously been reported in legume management systems where dense surface residues occur (Shaw, 1988).

In spite of reduced plant populations, grain yields were approximately 20% greater in the strip-till treatment (Figure 2). This difference was significant at the .05 level.

Conclusions

Although some problems were noted with germination rates and stand establishment, grain yields indicate that strip-till management may be a feasible alternative in continuously cropped corn production systems. Potentially serious limitations to its use may include seed placement, rodent activity, delayed germination, stand variability, and soil desiccation if moisture is limiting. The delay in germination observed in this study was probably related to reduced temperatures, either associated with ground surface shading by the remaining clover or possibly to a combination of the two day delay in planting and a drop in temperature. The reduction in plant population and the increased stand variability were probably a result of seed predation by rodents which may have been attracted to the dense residue cover. The same plots will be monitored through the 1990 and 1991 growing seasons to determine if effective self-reseeding occurs and if the apparent feasibility for corn production is maintained.

Strip-till management would reduce the cost of utilizing crimson clover as the sole or as a supplemental nitrogen source for corn due to a reduced planting cost and to reduced pre-corn planting tillage costs. Strip-till management could provide an earlier establishing, more complete winter and early growing season ground cover, thereby reducing soil erosion. Finally, these potential benefits of strip-till management do not involve the use of synthetic chemicals, so it could be incorporated into reduced chemical input farming systems.

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Influence of Cover Crop, Perennial Sod, and Crop Rotation on Soybean Growth and Yield

J.H. Edwards[1] D. L. Thurlow[2], J. L. Holliman[3] ,and M. D. Pegues[3]

Abstract

Continuous cropping of Braxton soybean *(Glycine max.* (L.) Merr.] was compared with cropping systems that included various sequences of annual and perennial grass species. The study was conducted on a Sumter clay (fine-silty, carbonatic, thermic, Rendollic Eutrochrepts) soil. The grasses in the rotation were wheat ***(Triticum aestivum)*** for winter cover, grain sorghum (*Sorghum bicolor)* for one year, and tall fescue *(Festuca arundinacea* Schreb.) sod for three years. The six-year average yields of continuous soybean were increased by 23% when wheat was included as a winter cover crop. When soybean was rotated with grain sorghum and wheat was included as a winter cover crop, soybean yields were increased by 52%. After three years of fescue sod, yields of soybean were increased 68%. The rotation effects on soybean yields appear to be related to the reduction in soybean cyst nematode ***(Hererodera Glycine)*** populations after 2 to 4 years of grasses. The differences in early-season growth of Braxton soybean as measured by plant height were similar to yield but lower in magnitude.

Introduction

Soybean production in the Black Belt region of Alabama is limited by foliar diseases and parasitic nematodes. These diseases and nematodes become acute after land has been in continuous soybean production for more than three years (Curl and Rodriguez-Kabana, 1971). Some of the most successful soybean producers are cattleman who rotate their declining pastures into soybean production.

Some success in controlling or reducing disease and nematode damage in soybean bas been achieved by planting resistant or tolerant cultivars (Rodriguez-Kabana and Thurlow, 1980; Rodriguez-Kabana and Weaver, 1984); in rotation with corn ***(Zea mays*** L.) (Kinloch, 1983; Kinloch, 1986); by using conservation tillage cropping systems (Edwards et al., 1988a; Edwards et al., 1988b); in rotation with grain sorghum (Rodriguez-Kabana et. al, in press); and in rotation with bahiagrass (Rodriguez-Kabana et al., 1990). These studies were conducted for 2 to 3 years, but the long-term cropping sequence best suited for controlling soybean diseases or damage induced by nematodes could not be determined. Thus, the purpose of this study was to: (i) compare growth and yield of continuous cropping soybean with those in a 2-year rotation with grain sorghum; (ii) compare the affect of winter cover crop on growth and yield of soybean; (iii) determine the residual effects of a perennial grass sod (tall fescue 'Kentucky 31') on the growth and yield of soybean.

Materials and Methods

A field experiment was established in the Black Belt region of west central Alabama on Sumter clay (fine-silty, carbonatic, thermic, Rendollic Eutrochrepts) soil. Initial soil test levels are given in Table 1. Soil samples were collected each spring before planting to determine the required P and K fertilization for grain sorghum and soybean. Phosphorus and K fertilizers were applied broadcast, according to Auburn University soil test recommendations, each spring prior to the chiseling and disking tillage operation. The experiment is a seven-year rotation which includes 3 years of perennial sod crop ('Kentucky 31' tall fescue) and 4 years of row crops. The rotation treatments were: (i) continuous soybeans-no wheat cover; (ii) continuous soybean-wheat cover; (iii) soybean-no wheat cover-grain sorghum; (iv) soybean-wheat cover-grain sorghum.

Table 1. Initial soil test values for Ihe experimental site.

Soil test values	soil test Kg/ha		
	Sample depth (cm)		
	0-20	20-33	33-39
pH	8.1	8.1	8.1
P	63	15	15
K	232	183	1%
Mg	146	119	124

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The experimental design was a split-split plot in a randomized complete block with three replications. The main plot (22.9 m x 18.3 m) included the rotation treatments; the split-split plot was for nitrogen levels on grain sorghum, wheat, and tall fescue in the rotations. Row spacing was 36 in. for both soybean and grain sorghum. Plant height measurement were made at maturity for both soybean and grain sorghum.

Soybean (Braxton) and grain sorghum (Savannah 5) were planted in mid-May and mid-April of each year, respectively. The center two rows of soybean and grain sorghum were harvested to determine yield. All soybean yields were adjusted to 13% moisture.

Results and Discussion

Grain sorghum and wheat yields were determined each year, however, only the soybean data will be presented. The early- growth of soybean was influenced most by perennial sod crop; plant height was 38% taller when following three years of fescue (Table 2). In general, the early-growth pattern was the same as the final soybean yield, but was not as dramatic in effect as the yield.

The rotation was established in 1983; therefore, 1986 was the first year that soybean yields were measured after the full three years of fescue sod (Table 3). The soybean yield in the early years of the rotation appeared to be influenced by one or two years of fescue that interrupted the continuous-cropping sequence. The rotation effect on soybean yields appears to be related to the reduction in soybean cyst nematode (*Heterodera glycines)* population after two to three years of continuous grass crops (Edwards et. al, 1989).

Table 2. The effect of annual and perennial grass crops in the rotation of early soybean growth as measured by plant height of Braxton soybeans at Black Belt Substation.

		Plant Height of Braxton Soybean (Inches)							6 yr.	4 yr.	3 yr.
Cropping System	**Crop Rotation**	*1983*	**1984**	*1985*	*1986*	*1987*	*1988*	*1989*	**Avg. (84-89)**	**Avg. (86-89)**	**Avg. (87-89)**
No Winter Cover											
Continuous Row Cropping	Continuous Sovbeans	**29**	**31**	**26**	**10**	**22**	**27**	**20**	**23**	**20**	**23**
	Grain Sorghum-Soybean	GS[1]	**34**	GS	**17**	GS	**30**	GS	**26**	**23**	**25**
		---	GS	**31**	GS	**22**	GS	**24**			
Winter Cover											
Continuous Row Cropping	Continuous Soybean	30	**33**	27	**15**	**20**	28	**21**	**24**	**21**	**23**
	Grain Sorghum-Soybean	GS	36	GS	**24**	GS	**29**	**GS**	**28**	**25**	**26**
		---	GS	30	GS	**25**	GS	**23**			
3 yr. Perennial Sod											
Continuous Row Cropping	Soybean	FES[2]	FES	FES	**21**	**21**	**28**	**20**	**---**	***23***	**---**
	Soybean	---	FES	**FES**	FES	**29**	**32**	**24**	**---**	**---**	**28**
	Soybean		---	FES	FES	FES	**34**	**20**	**---**	---	---
	Soybean		---	**---**	FES	FES	FES	**25**	**---**	**---**	**27**
	Grain Sorghum-Soybean	FES	**FES**	FES	GS	**26**	GS	**26**	---	---	---
					SB[3]	GS	28	**GS**			
	Grain Sorghum-Soybean		FES	FES	FES	GS	28	GS	---	**---**	---
						SB	GS	**24**			
	Grain Sorghum-Soybean	**---**	---	FES	**FES**	FES	***GS***	26	---	---	**---**

[1]GS = Grain Sorghum; [2]FES = Fescue; [3]**SB =** Soybean.

Table 3. The effect of annual and perennial grass crops in the rotation on Braxton soybean yields.

Cropping System	Crop Rotation	Yield of Braxton Soybean (Bu/A) 1983	1984	1985	1986	1987	1988	1989	6 yr. Avg. (84-89)	4 yr. Avg. (86-89)	3 yr. Avg. (87-89)
No Winter Cover Continuous Row Cropping	Continuous Soybeans	20.6	22.3	13.5	3.0	9.8	18.2	7.7	12.4	9.7	11.9
	Grain Sorghum-Soybean	GS	26.8	GS	11.4	GS	21.9	GS	16.5	15.0	14.5
			GS	17.4	GS	8.5	GS	13.0			
Winter Cover Continuous Row Cropping	Continuous Soybean	22.3	29.0	16.6	7.4	8.9	24.2	5.6	15.3	11.5	10.2
	Grain Sorghum-Soybean	GS[1]	30.5	GS	23.7	GS	21.7	GS	18.9	15.8	13.1
			GS	19.8	GS	10.1	GS	7.6			
3 yr. Perennial Sod Continuous Row Cropping	Soybean	FES[2]	FES	FES	19.6	12.1	28.2	2.3	---	15.6	---
	Soybean	---	FES	FES	FES	9.8	31.1	8.8	---	---	16.6
	Soybean	---	---	FES	FES	FES	29.2	4.4	---	---	---
	Soybean	---	---	---	FES	FES	FES	6.5	---	---	---
	Grain Sorghum-Soybean	FES	FES	FES	GS	11.8	GS	12.1	---	---	19.4
					SB[3]	GS	34.4	GS			
	Grain Sorghum-Soybean	---	FES	FES	FES	GS	34.4	GS	---	---	---
						SB	GS	12.1			
	Grain Sorghum-Soybean	---	---	FES	FES	FES	GS	9.0	---	---	---

[1]GS= Grain Sorghum; [2]FES= Fescue; [3]SB= Soybean

In comparison to continuous soybean cropping for six years (1984-1989), soybean yields were 33% higher when grown in a 2-year rotation with grain sorghum. This relative increase in yield appears to be increasing with the duration of the experiment. There was a 23% increase in soybean yield for this period by using a winter cover crop of wheat, which is a slight decrease from early data from the test, and a 52% increase when comparing soybean yields following grain sorghum in a two-year rotation along with wheat as a winter cover.

During the four-year period 1986-1989, first-year soybean yields were 68% higher when following three years of fescue sod versus continuous cropping soybean. This is also a larger relative yield increase from early data when only one or two years of sod was used. The effect of three years of fescue sod carried into the second year of soybean yields, but started to drop off by the third and fourth years. The highest soybean yields were obtained when soybean followed grain sorghum after three years of fescue sod. This response was observed in the second year soybean.

Summary

Soybean yields were increased by winter cover and rotation with annual grass row crop. An additional benefit was obtained by incorporation of a perennial grass sod crop into the rotation sequence. The rotation affects on soybean yields and plant height appears to be related to the reduction in soybean cyst nematode population following the grass crops in rotation as compared to continuous cropping soybean.

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Choosing a Legume Cover Crop for No-Till Corn

Greg D. Hoyt[1]

Abstract

Winter annual legume cover crops were established to provide cover crop residue and a nitrogen source for no-till corn. Spring legume residue nitrogen was greatest in both species of vetch and peas. Greatest grain and silage yields also were produced from treatments of vetch and pea residue. No one selection of legume residue was found to be superior, but hairy vetch consistently survives the winter in Western N.C. and produces sufficient residue and N for good to excellent crop yields.

Introduction

The potential use of legume cover crops in the southeastern U.S. has been well documented in popular press and scientific literature (Hoyt and Hargrove, 1986). Legume residues have been shown to produce over 180 Ibs/acre of nitrogen during their growing season (Hoyt, 1987) and reduce fertilizer input by as much as 90 Ibs N/acre (Ebelhar et al., 1984; Hargrove, 1986; Touchton et al., 1982). This experiment was designed to determine which legume residue would contribute to greater grain and silage yields if no nitrogen was applied.

Methods

All legume cover crop treatments received no addition of nitrogen fertilizer. All legumes treatments were planted in early October the previous year of the experiment. Standard labeled herbicides were applied as well as phosphorus and potassium at soil test recommended rates. All four years of experiments were conducted at the Mtn. Hort. Crops Research Station (near Asheville, N. C.) on Typic Hapludult soils. Corn (Dekalb 689) was no-till planted in mid-May each year at 28,000 plants/acre. All bare soil plots had winter weeds killed in mid-April, with the legume cover crops killed 1 to 6 days after planting. All plots were harvested in late September or early October. All treatments received 4 replications in a randomized complete block arrangement. Legumes were planted at seeding rates of 30, 30, 40, 40, 20, 15, and I5 Ibs/acre for hairy vetch, bigflower vetch, caley peas, A. winter peas, crimson clover, sub. clover, and berseem clover, respectively. Rainfall was inconsistent throughout the four years of testing and probably did not influence yield reduction among the legume residue treatments (Table 1).

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Table 1. Rainfall during the summer growing season. 1985-1988.

Year	Month			
	May	June	July	August
	----------------inches/month----------------			
1985	2.0	1.6	6.3	9.5
1986	5.0	1.3	.7	6.6
1987	2.5	13.3	2.7	3.1
1988	1.6	.8	3.1	2.9

Results

Various legume cover crop treatments were planted each of four years to determine residue effect on corn grain and silage yields. Because no nitrogen was applied with the residue treatments, nitrogen became a key element for corn growth in these experiments. Corn grain and silage yield differences among the various legume residue trcatments thus were related to N relcase from the residue.

Nitrogen content of the legume cover crops at planting are listed in Table 2. All species of both peas and vetch produced greater quantities of N in the above-ground biomass than the clover legume species. Both subterranean and berseem clover produced lower amounts of N as compared to vetch or pea species, and generally lower N than crimson clover.

Hairy vetch was chosen to represent the legume of choice for Western N. C. for producing N and cover residue. For this rcason, all yields are in proportion to the hairy vetch residue treatment corn yield (176, %, 106, and 118 bu grain/acre and 25, 12, 15, and 15 tons silage/acre for the years 1985, 1986, 1987, and 1988, respectively).

Table 2. Nitrogen content of the legume cover crop.

Cover Crop	Nitrogen Content 1985	1986	1987	1988
	---------------	lbs N/acre	---------------	
Hairy Vetch	101	175	138	168
Bigflower Vetch	92	121	126	163
A. Winter Pea	106	131	143	232
caley Pea		203	151	86
Crimson Clover	102	119	115	68
Subterranean Clover		120	86	
Berseem Clover	81		67	

Grain yields measured in 1985 reflect the higher yield attained from the hairy vetch residue treatments and how the other vetch and pea residue contributed to a similar yield as hairy vetch residue (Figure 1). Even though crimson clover residue N content was similar to hairy vetch N content (101 and 102 Ibs N/acre for hairy vetch and crimson clover residue, respectively), vetch residue has a much lower C N ratio (not shown) and released more N than the crimson clover residue. Berseem clover produced the least amount of N in above-ground biomass and in corn grain yields.

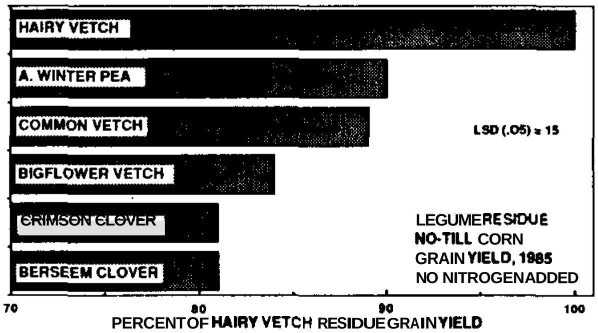

Figure 1. No-Till Corn Grain Yields as Influenced by Legume Cover Crop Residue, 1985.

Corn silage yields for 1985 produced similar trends as grain yie1ds;with vetch and peas producing greater yields than the various clover treatments (one exception to this was the lower silage yield from common vetch as compared to the grain yields) (Figure 2).

Greatest grain yields produced from the legume residue treatments in 1986 was again from the hairy vetch residue treatment (Figure 3). Bigflower vetch and caley pea residue treatments had similar yields (97 and 96 % of the yield attained by hairy vetch, respectively) as the hairy vetch residue treatment, with crimson clover grain yield at 89 % of the hairy vetch residue treatment yield. Although subterranean clover had similar residue N as crimson clover and bigflower vetch, grain yields were lower than those treatments and 24 % lower than the hairy vetch residue treatment yield. Bare soil with no N added produced grain yields similar to the subterranean clover residue treatment. Adding 90 Ibs N/acre to a bare soil treatment increased yields to those similar to hairy vetch residue treatment. Thus, the use of hairy vetch cover crop residue in 1986 was similar to adding 90 lbs N/acre to bare ground.

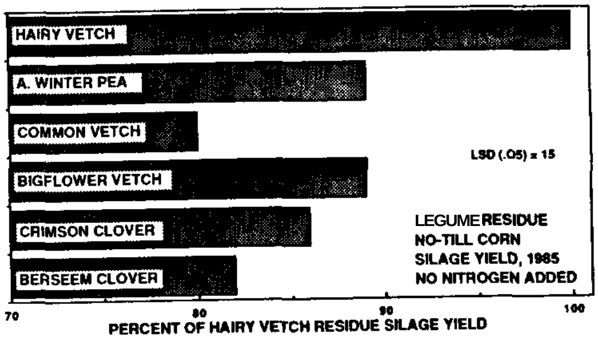

Figure 2. No-Till Corn Silage Yields as Influenced by Legume Cover Crop Residue, 1985

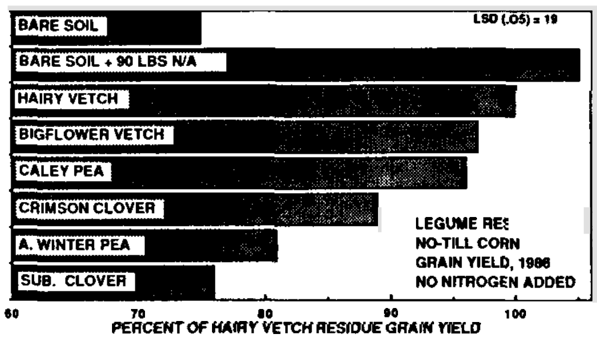

Figure 3. No-Till Corn Grain Yields as Influenced by Legume Cover Crop Residue, 1986.

Silage yields for 1986 showed a similar pattern for the legume residue treatments as in grain yields, but the bare soil treatment yield dropped to 65 % and the bare soil + 90 Ibs N/acre yield decreased to 88 % of that produced by the hairy vetch residue treatment (Figure 4).

Greatest grain yields in 1987 were produced in legume treatments that contained both A. winter and caley pea residues and bigflower vetch residue (114, 112, and 111 % of the hairy vetch residue treatment, respectively) (Figure 5). Crimson and berseem clover residue treatments produced grain yields similar to the hairy vetch residue treatment, while arrowleaf and subterranean clover produccd yields slightly lower (possibly due to the lower N content in the residue).

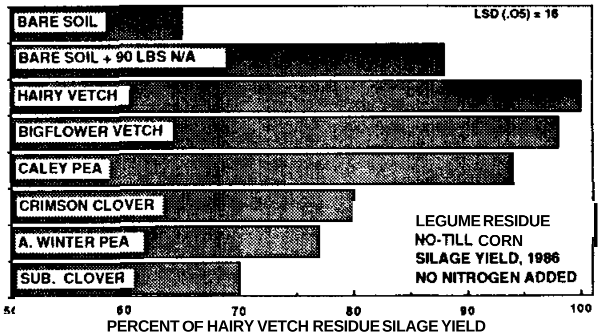

Figure 4. No-Till Corn Silage Yields as Influenced by Legume Cover Crop Residue, 1986.

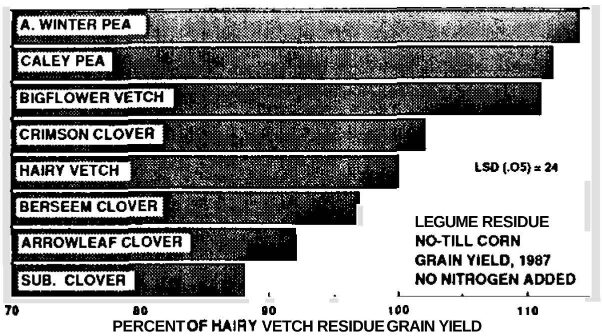

Figure 5. No-Till Corn Grain Yields as Influenced by Legume Cover Crop Residue, 1987.

Corn silage yields for 1987 show a different pattern of response to legume residue as compared to grain yields (Figure 6). Clearly, A. winter pea residue produced the greatest silage yield of all legume residue treatments. Next, a group of four legume residues were similar (caley pea, bigflower and hairy vetch, and crimson clover residue treatments). Lowest in silage yields were berseem, arrowleaf and subterranean clover residue treatments (these legumes are marginal for Western N.C. in winter survival and generally produce lower biomass and N content in the spring).

The fourth year of these experiments produced trends similar to the three previous years. A. winter peas, bigflower and hairy vetch, and caley pea residue all produced similar (statistically) grain yields (Figure 7). Crimson clover residue was lower and similar to bare soil + 0 N /acre, while bare soil + 90 lbs N/acre was similar to the highest legume residue and 14 % higher than the vetch residue in grain yields. The bare soil + 180 Ibs N/acre treatment increased yields 28 % higher than thc hairy vetch residue treatment.

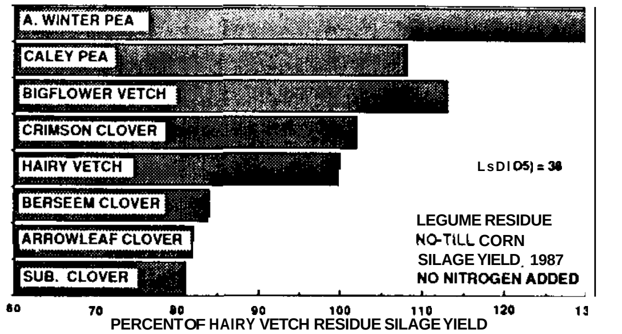

Figure 6. No-Till Corn Silage Yields as Influenced by Legume Cover Crop Residue, 1987.

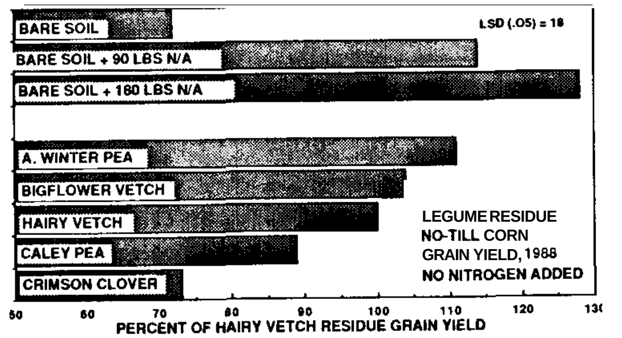

Figure 7. No-Till Corn Grain Yields as Influenced by Legume Cover Crop Residue, 1988.

Corn silage yields produced by the legume residue treatments showed a similar pattern as grain yields (Figure 8), with all legumes in the same order and the bare soil + the various N rates at similar percentages as in the grain yield (Figure 7).

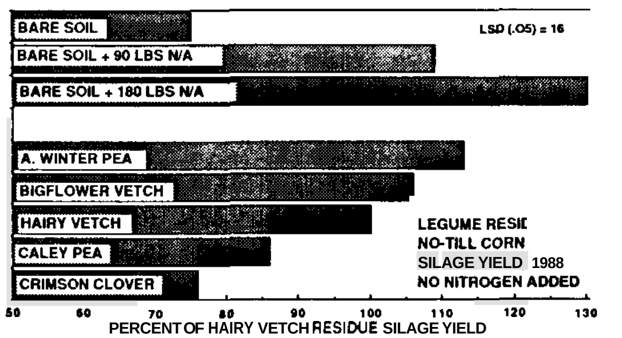

Figure 8. No-Till Corn Silage Yields as Influenced by Legume Cover Crop Residue, 1988.

Summary

Various legume residues were compared for grain and silage utilization in no-till corn. All pea or vetch residue treatments produced grain and silage yields that in one year or another proved as good or better than the rest. Although a clear superior choice was not obvious, any of the selected pea or vetch residue would be beneficial in producing no-till corn and would be dependent on which selection grew best at any one location. Hairy vetch has consistently survived the winter in Western N.C. and produced sufficient residue and N for good to excellent corn crop yields. Thus, if nitrogen contribution is a main factor for selecting a legume for no-till corn production, hairy vetch would be a top selection for this region.

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Residual Effects of Cover Crops and Fertilizer N in a No-Tillage Corn System

Kyaw Yee and Jac. J. Varco[1]

Introduction

Cover crops provide several advantages such as soil erosion control, improved soil water conservation and greater soil organic matter content (Mannering and Meyer 1963; Meyer, et al. 1970; Phillips 1984, and Hargrove 1986). Moreover, legume cover crops can supply a considerable amount of biologically fixed N to the summer row crops.

Estimates of N fertilizer equivalence of legume cover crops vary considerably (Smith et al. 1987). Ladd et al. (1981) concluded that the main benefit of legumes was in maintenance of soil organic N. McCracken et al. (1989) evaluated the residual effects of long-term cover cropping and fertilizer N addition on N availability in a no-tillage corn system. They observed that a history of hairy vetch increased N uptake by 25 Ib/acre, while the average residual effect of fertilizer N was 18 Ib/acre. Little effort has been put forth in determining the cumulative residual effects of cover crops and fertilizer N in no-tillage corn production. The objective of this study was to determine the cumulative residual effect of cover crops and fertilizer N on N uptake by no-tillage corn.

Materials and Methods

This experiment was conducted at the Northeast branch experiment station, Verona, Mississippi. The soil at this site was a Prentiss fine sandy loam (coarse-loamy, siliceous, thermic, glossic fragiudult) with 4% slope. A randomized complete block design with four replications was used in this study. Management practices prior to studying residual effects included broadcasted fertilizer N as NH_4NO_3 at rates of 0, 58, 116 and 174 Ib N/acre within a week of corn planting and cover cropping with hairy vetch *(Vicia villosa* Roth.) and ryegrass *(Lolium multiflorum* Lam.) in 1987 and hairy vetch and wheat *(Triticum sativum* L.) in 1988. Residual years are designated as residual year-1 and residual year-2. These terms describe the number of years that the factorial combinations of cover crop and fertilizer N treatments were imposed on those plots. For example, residual year-2 plots were studied the residual year after discontinuing treatments which were previously imposed on the plots for two growing seasons, while for residual year-1, treatments were imposed on plots only one growing season.

At physiological maturity, a 3.3 foot length of whole corn plants was harvested. Also, two rows, each 25 feet long, were harvested using a combine with corn headers. Grain yield was adjusted to 15.5% moisture content. Corn stover and grain samples were dried and ground separately in preparation for total N analysis. Plant samples were digested by the micro-Kjeldahl method described by Nelson and Sommers (1973). Ammonium-N in the digests was measured colorimetrically (Catalodo et al., 1974). Statistical analyses included ANOVA and regression using SAS (SAS/STAT 1988).

Results and Discussion

Corn Yield and N Uptake

There were no residual effects of cover crops on corn yield in residual year-I (Table 1). This is likely due to the extreme drought stress which occurred during tasseling and silking in 1988 (Table 5). Residual effects of cover crops on corn yield were observed in residual year-2. Averaged over N rates, hairy vetch increased corn stover yield by 1.6 ton/acre and corn grain yield by 0.5 ton/acre compared to a grass cover crop. Residual effects of fertilizer N on corn yield are shown in Table 2. In residual year-I, corn stover yield increased linearly as N rates increased. No effect of N rates on grain yield was observed. No residual effect of fertilizer N was observed for either stover or grain yield in residual year-2. This was probably due to NO; leaching as well as denitrification as a result of above normal precipitation received during the fallow period (Table 6).

The effects of cover crops on corn N uptake are presented in Table 3. When hairy vetch was used as a cover crop, corn stover and total N uptake were

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Table 1. Residual effect of cover crops on corn yield.

Residual Year	Cover Crop	Stover Yield	Grain+ Yield
		---- ton/acre ----	
Year-1	Grass	3.8	1.9
(1988)	Vetch	3.5	2.0
Year-2	Grass	5.2	1.9
(1989)	Vetch	6.8'	2.4'

+ Adjusted to 15.5% Moisture
• Means significantly different at p = 0.05

Table 2. Residual fertilizer N effects on corn yield

Fertilizer N lb./acre	Year-1 (1988) Stover Yield	Year-1 (1988) Grain' Yield	Year-2 (1989) Stover Yield	Year-2 (1989) Grain Yield
	------------ lb/acre ----------			
0	3.2	1.9	6.4	2.2
58	3.4	1.7	6.1	2.3
116	3.6	2.1	5.4	1.8
174	4.4	2.3	6.1	2.2
Effect of:				
Fertilizer N	•	NS	NS	NS

+ Adjusted lo 15.5% Moisture
• Linear effect significant p = 0.05
NS = Not significant

Table 3. Residual cover crop effects on N uptake by corn.

Cover Crop	Year-1 (1988) Stover	Year-1 (1988) Grain	Year-1 (1988) Total	Year-2 (1989) Stover	Year-2 (1989) Grain	Year-2 (1989) Total
	Corn N Content					
	------------------ lb/acre --------------					
Grass	53	42	95	62	29	91
Vetch	70*	45	115*	78*	34	112*

* Means significantly different at p = 0.05

Table 4. Residual effects of fertilizer N on corn N uptake.

Fertilizer N lb/acre	Year-1 (1988) Stover	Year-1 (1988) Grain	Year-1 (1988) Total	Year-2 (1989) Stover	Year-2 (1989) Grain	Year-2 (1989) Total
	Corn N Conient					
	------------------- lb/acre ------------					
0	41	41	82	71	33	104
58	60	37	97	74	31	105
116	69	44	113	64	28	92
174	76	51	127	72	33	105
Effect of:						
Fertilizer N	*	NS		NS	NS	NS

• Linear effect significant p = 0.05 NS = Not significant

Table 5. Precipitation each growing season at Verona

Duration	1988 Apr	1988 May	1988 Jun	1988 Jul	1988 Aug	1989 Apr	1989 May	1989 Jun	1989 Jul	1989 Aug
	Precipitation									
	---------- inch ----------									
1st half of the month	2.3	1.1	0.3	1.4	2.1	2.3	3.4	7.8	4.2	2.2
2nd half of the month	2.3	0.9	---	0.3	0.8	0.6	1.3	2.1	1.8	1.5
Total	4.6	2.0	0.3	1.7	2.9	2.9	5.0	9.9	6.0	3.7
30-year average	5.3	4.0	3.5	4.5	3.1	5.3	4.0	3.5	4.5	3.1

Table 6. Precipitation each fallow period at Verona

Year	1st half of the month	2nd half of the month	Total	30-Yr Average
	---------- inch ----------			
Year-1				
Sept. 87	2.05	0.12	2.17	3.39
Oct.	-- --	1.38	1.38	2.60
Nov.	0.04	3.39	3.43	4.49
Dec.	0.31	3.70	4.01	5.44
Jan. 88	4.02	1.62	5.64	5.44
Feb.	2.84	0.51	3.35	5.36
Mar.	2.09	1.69	3.78	6.34
Total	11.35	12.41	23.76	33.06
Year-2				
Sept. 88	0.75	8.43	9.18	3.39
Oct.	2.17	3.07	5.24	2.60
Nov.	1.77	3.31	5.08	4.49
Dec.	0.16	3.31	3.47	5.44
Jan. 89	6.93	0.55	7.48	5.44
Feb.	2.09	7.21	9.30	5.36
Mar.	3.82	1.62	5.44	6.34
Total	17.69	27.50	45.19	33.06

increased in both residual year-1 and year-2. Although stover and total corn N uptake were increased, no effect on grain N content was observed. The effect was consistent in that with vetch N in stover was 17 lb/acre year-1 and 16 lb/acre year-2 and total N was 20 lb/acre year-1 and 21 lb/acre year-2 more than with a grass cover. A residual effect of fertilizer N on corn N uptake was observed in residual year-1 (Table 4). Corn stover and total N uptake increased linearly with increasing N rates, although no effect on grain N uptake was observed in residual year-1. No residual effect of fertilizer N rates on corn N uptake was observed in residual year-2.

Summary

The residual effect of fertilizer N on no-tillage corn yield was not consistent. Although, stover yield and N content increased linearly with increasing N rates in residual year-I, fertilizer N did not influence corn stover yield or N content in year-2. No residual effects of fertilizer N on grain yield were observed either year. Grain and stover yield were not influenced by cover treatments in residual year-1 but were greatest with vetch in residual year-2. Hairy vetch increased stover N content both years compared to a grass cover crop.

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Effects of Legume Cover Crops and Tillage on Grain Sorghum Yield

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Introduction

Interest in utilizing winter legumes as a source of nitrogen (N) for non-legume summer crops is prompted by the search for alternate and renewable sources of energy and the need for reducing soil erosion and crop production costs. Residues of winter legumes can serve as a source of N and act as a mulch in a no tillage production systems. Mineralized N from decomposed winter legumes can supply some of the N fertilizer needs for the summer grain crops. The amount of N produced by winter legume cover crops depend on various factors, such as summer grain crop planting date, growth stage of legumes at killing, climatic conditions, and adaptability of the legume to a particular area. The objectives of this research were to evaluate (i) the N contribution of selected winter legumes on grain sorghum yield, (ii) grain sorghum response to cover crops and fertilizer N, and (iii) the effect of tillage on grain sorghum yield.

Materials and Methods

The experiment was established in the fall of 1984 on a Catalpa silty clay (fine, montmorillonitic, thermic Fluvaquentic Hapludoll). This is a deep moderately well drained soil, which has been formed from clayey alluvium and ranges in slope from 0 to 2%. The study was located on the Mississippi State University Northeast Branch Experiment Station, Verona, Mississippi.

The experimental design was a split plot with cover crops as main plots and N rates as subplots with 5 replications. Cover crop treatments included 'Hairy' common vetch, 'Tibbee' crimson clover, 'Meteora' subclover, wheat, and no-tillage (NT) winter fallow (WF). In addition, a conventional tillage (CT) no cover treatment was evaluated. Within each cover treatment, subplots were established by applying fertilizer N at rates of 0, 40, *80,* 120, and 200 Ib/acre.

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The study received a uniform broadcast application of 300 Ib/acre of 0-17-34 in the fall of 1984 and 1985 and 300 lb/acre of 0-20-20 in the fall of 1986 and 1987. A no-till drill was used to plant cover crops at seeding rates of 45, 30, 20, and 18 Ib/acre for wheat, vetch, crimson clover, and subclover, respectively. These cover crops were planted in a prepared seedbed in the fall of 1984 and no-till planted into grain sorghum residue each fall thereafter. Cover crops in all no-till grain sorghum plots were killed with appropriate burndown herbicides (Table 1) 2-3 weeks prior to planting grain sorghum. The CT plots were chiseled 6-8 inchcs deep and disked a month before planting, and harrowed just prior to planting. Grain sorghum was planted in May of each year (Table 1) at approximately 90,000 seeds/acre in 30-inch rows using a John Dcere 7000 planter equipped with a screw-type fertilizer spreader, trash whippers, and cast iron press wheels. Fertilizer N (urea) at appropriate rates was applied in-furrow, 3 inches to each side of each row, and 2 inchcs deep at grain sorghum planting. Weeds were controlled as needed with appropriate herbicides applied at labeled rates (Table 1).

Cover crop dry matter production was determined by clipping four randomly selected 1/4 square meter samples from all legume cover crop plots approximately 2 weeks prior to grain sorghum planting. The samples were oven-dried for at 150^0 F and thcn analyzed for total N by the Kjeldahl procedure. Grain sorghum yields were determined by harvesting the two center rows of each plot with a small plot combine. The seed samples were weighed and grain yield was adjusted to 13% moisture and expressed as lb/acre. The data were subjected to an analysis of variance procedure and means were separated using least significant differences (LSD) at the 5% level of probability.

Results and Discussion

Cover Crops

Yearly cover crop dry matter yields, nitrogen concentration and N content of cover crops are shown in Table 2. Dry matter production among cover crops was not significantly different in 1985, 1987, and 1988. All cover crops produced the most dry matter in 1985. Cover crop stands in most plots were severely reduced

Table 1. Grain sorghum varieties, planting dates. herbicides and method of application in a legume cover crop-grain sorghum cropping system study in 1985-88.

Year	Grain Sorghum Variety	Date	Planting Herbicides	lb ai/a	Method of Application*	Crop**
1985	'Funks G-522DR'	5/15/85	2,4-DB	1.0	POT	CC
			fluazifop	a 3	POT	CC
			paraquat	0.5	BD	CC+NT
			metolachlor	2.0	PRE	GS
			atrazine	2.0	E-POT	GS
1986	'Funks G-522DR'	5/16/86	2,4-DB	1.0	POT	CC
			fluazifop	0.3	POT	CC
			glyphosate	1.5	BD	CC+NT
			metolachlor	20	PRE	GS
			linuron	1.0	PD	GS
1987	'Funks G-1711'	5/19/87	2,4-DB	1.0	POT	CC
			paraquat	1.0	BD	CC
			metolachlor	2.0	PRE	GS
1988	'Savannah 5'	5/17/88	HO-39866	a75	BD	CC+NT
			glyphosate	1.5	BD	CC
			metolachlor	20	PRE	GS

* Method of application: POT = post over top. BD = burndown, PRE = pre-emergence, PD = post direct and E-POT = early post over-top.
**Crop: CC = cover crop, GS = grain sorghum.

in the fall of 1985, possibly due to atrazine carry-over from the grain sorghum crop. Crimson clover was the only cover crop that survived and produced dry matter residue for 1986 grain sorghum. However, yield and N content of crimson clover in 1986 was the lowest of the four years evaluated. The average N content for 1985, 1987, and 1988 of wheat, crimson clover, and vetch was 27, 69, and 92 Ib/acre, respectively. Although vetch did not produce more dry matter than other crops all of the years, the N content of vetch was the greatest. Subclover did well the first year of the study, but stands were poor in subsequent years and, therefore, it was not harvested.

Table 2 Dry matter production, nitrogen concentratino, and nitrogen content of cover crops in 1985-88.

Cover Crops	1985 lb/a	1985 % N	1985 lb N/a	1986 lb/a	1986 % N	1986 lb N/a	1987 lb/a	1987 % N	1987 lb N/a	1988 lb/a	1988 % N	1988 lb N/a
Wheat	4385	1.02	45	----	—	--	1679	1.13	19	2078	1.30	19
Crimson Clover	4385	226	96	1913	225	43	2837	207	59	2952	210	53
Vetch	3295	3.68	121	--	----	-	2099	3.19	67	2500	3.68	89
Sub. clover	5992	2.02	121	----	----	--	----	----	--	----	----	--
Mean	44%	224	96	1913	225	43	2536	213	48	2507	2.36	54

Grain Yield

The influence of cover crops, tillage, and nitrogen rates on grain sorghum yield for 1985-88 are shown in Table 3. In 1985, cropping systems had a significant effect on grain yield, with no differences in 1986, 1987, and 1988. In all years nitrogen rates had a significant effect on grain yield and there was no cropping system X N rate interaction.

In 1985, grain sorghum yield following vetch was greater than the other cropping systems, with no difference when grain sorghum followcd crimson clover, subclover, and CT. All cropping systems produced yields greater than following wheat. Averaged over cropping system grain sorghum yield with 120, and 200 lb/acre were not different and were higher than 0 and 40 lb N/acre. Vetch with no added N produced yields equal to 80 lb N/acre when compared with wheat, subclover, CT, and NT. Grain sorghum after crimson clover and subclover with no added N, was equal to wheat with 40 and 80 lb N/acre, respectively. CT and NT yields were equal across N rates and were great than with wheat.

Grain sorghum yields in 1986 were lower than 1985 with no differences in cropping systems. Cover crop failure in dry matter production and dry weather during the period of mid-June to mid-August attributed to the lower yields in 1986. Averaged over cropping systems grain yield with N rates of 120 and 200 lb/acre were equal and produced higher yield than 80, 40, and 0 Ib N/acre. Vetch with no added N, produced yiclds equal to 40 lb N/acre with crimson clover, CT, and NT/WF. Vetch and wheat yields were equal across N rates.

In 1987, grain sorghum yields were severely reduced due to maize dwarf mosaic virus infection and cropping system had no effect on yield. Vetch, however, with no added N produced grain yields equal to of 80 Ib N/acre with crimson clover and CT and were equal to 120 lb N/acre with wheat, subclover, and NT.

In 1988, grain sorghum yields were similar to 1985 but cropping system had no effect on yield. Vetch with no added N produced grain yields equal lo or greater than all other cropping systems at 200 Ib N/acre.

Table 3. Effect of cover crops, tillage, and nitrogen rates on grain sorghum yield in 1985-88.

Cover crop/ cropping systems	N rates (lb/acre)					
	0	40	80	120	200	Mean
			lb/acre			
1985						
Wheat/NT	1794	2861	3565	3605	4082	3181
Crimson clover/NT	3678	4487	4602	4281	3543	4118
Vetch/NT	4174	4793	4713	4488	4287	4491
Subclover/NT	4004	3591	3928	4448	4138	4022
CT	2977	3854	3871	4577	4602	3976
NTWF	2898	3334	3989	4093	4595	3782
Mean	3254	3820	4111	4249	4208	
LSD (0.05) Cropping system	311	LSD (0.05) N rates	305			
CV (%)	25	CV (%)	14			
1986						
Wheat/NT	23%	2985	3335	3965	4486	3433
Crimson clover/NT	2139	2589	3065	3486	3674	2991
Vetch/NT	2588	3144	3237	4247	4054	3454
Subclover/NT	2767	3044	3321	4095	4710	3587
CT	1646	2672	3655	3868	4593	3287
NTWF	1718	2488	2891	3611	4191	2980
Mean	2209	2820	3251	3879	4285	
LSD (0.05) Cropping system	NS	LSD (0.05) N rates	410			
CV (%)	39	CV (%)	24			
1987						
Wheat/NT	1327	1166	1356	1730	2286	1573
Crimson clover/NT	1369	1552	1920	2234	2258	1867
Vetch/NT	1904	1457	1654	2346	2898	2052
Subclover/NT	1556	1595	1505	2434	2482	1914
CT	1626	1429	1834	1768	2182	1768
NTWF	1313	1330	1460	2004	2021	1626
Mean	1516	1422	1622	2086	2355	
LSD (0.05) Cropping system	NS	LSD (0.05) N rates	217			
CV (%)	24	CV (%)	20			
1988						
Wheat/NT	3350	4123	4055	5159	5077	4353
Crimson clover/NT	3819	4348	4666	4704	5176	4543
Vetch/NT	5670	4921	5404	4388	5743	5225
Subclover/NT	3566	4284	4146	4718	5468	4436
CT	4022	4086	4695	4443	3790	4207
NTWF	3655	4807	5093	5284	5516	4871
Mean	4014	4428	4676	4783	5131	
LSD (0.05) Cropping system	NS	LSD (0.05) N rates	633			
CV (%)	26	CV (%)	25			

Conclusion

Within years there were no significant differences in dry matter production due to cover crops. Crimson clover and vetch cover crops seemed to be better adapted than subclover to the silty clay soil and climatic conditions of North Mississippi. Although vetch usually produced less dry matter than crimson clover, it had a higher N concentration, N content, and higher grain sorghum grain yield.

Poor cover crop stands, grain sorghum disease, and limited precipitation influenced grain sorghum grain yield in 1985-88. Cropping systems had a significant effect on grain yield one of four years, while N rates were significant over all years. Yield generally increased as N rates increased across cropping systems. Vetch with no added N produced yields equal to or greater than 80 lb/acre of added N with all cropping systems in 1985 and 1987-88. In 1985, crimson clover and subclover with no added N were equal to wheat with 120 and 200 lb N/acre, respectively. However, in 1986-88, crimson clover did not increase grain sorghum yield when compared to all cropping systems.

Managing Winter-Annual Legumes as Nitrogen Sources for No-Tillage Corn on Sandy Coastal Plain Soils

J.R. Anderson Jr., N.L. Hubbard, F.D. Shaw and F.W. Smith[1,2]

Cultural practices that reduce soil erosion and conserve soil moisture are priorities among southeastern corn producers. The planting of corn into a legume mulch reduces soil erosion and may conserve sufficient soil moisture to increase grain yields in dry seasons. No-tillage corn planting into a legume cover also lowers labor and fuel requirements while providing substantial amounts of nitrogen (N) for the crop. A cropping system involving winter annual legumes followed by no-tillage corn may be especially useful in the southeastern coastal plain where corn is grown on soils that are low in organic matter, low in water-holding capacity and subject to wind and water erosion.

Effect of pH and Planting Date on Legume Performance

Since both the quantity of mulch and N produced by winter legumes is directly related to the accumulation of root and top growth prior to corn planting, an excellent legume stand is essential. Corn grain yield will be reduced where legume stands are inadequate. Soil pH and planting date greatly influence the establishment of legume stands. Most winter annual legumes are sensitive to soil acidity (Table 1). If soil pH is less than 5.8, it is best to postpone legume seeding until lime can be incorporated.

Table 1. Management suggestions for various winler annual legumes.

Legume	Seeding Rale		Seeding	Optimum pH
	Broadcast	Drilled	Depth	
	-----bu/ac-----			
Hairy vetch	20-30	15-20	1/2 - 1 1/2	5.8 - 6.2
Cahaba White	20-30	15-20	1/2 - 1 1/2	5.8 - 6.2
A. winter pea	25-35	20-25	3/4 - 1 1/2	5.8 - 6.0
Crimson clover	20-25	15-20	1/4 - 1/2	

Optimum planting dates (Table 2) are equally important in the establishment of vigorous legume stands. Since late planting increases the sensitivity of winter annuals to low winter temperatures, it is important to plant legume cover crops in late summer or early fall when soil moisture is favorable. In North Carolina, optimum planting conditions are usually encountered around September 1. September-planted legumes produce more top growth in the spring that translates into extra pounds of N available for use by corn.

Table 2 Suggested planting dates for selected winter annual legumes in North Carolina

Legume	Coastal Plain		Piedmont	
	Best Dales	Possible Dales	Best Dates	Possible Dales
Hairy vetch	9/1-9/30	9/1-10/30	8/25-9/30	8/25-10/25
Cahaba white	9/1-9/30	9/1-10/30	Not Adapted	
A. winter pea	9/1-9/30	9/1-10/30	8/25-9/30	8/25-10/25
Crimson clover	9/1-9/30	9/1-10/25	8/25-9/15	8/25-10/25

It is unwise to encourage further legume growth by delaying corn planting into late April. It is preferable to stimulate legume growth with early seedling dates and good management of the cover crop. A special situation may arise when vigorous cover crop growth is accompanied by spring rainfall deficits. Cover crops may deplete soil moisture such that poor corn stands are obtained. If a dry spring appears to be forthcoming, it is advisable to destroy the cover crop one to two weeks ahead of corn planting (Wagger, 1989).

On-Farm Evaluation of Winter Annual Legumes

There are a number of legumes that may serve as N sources for corn. Several were evaluated in replicated, on-farm experiments in the coastal plain of North Carolina between 1982 and 1985. Legumes and legume management practices were examined in 4-row by 50 ft. plots arranged in split plot designs with at least four replications. Inoculated legumes were assigned to main plots and N fertilizer (ammonium nitrate) rates to subplots. Soil types were of the Norfolk or Wagram series.

After an initial screening, sweet clover *(Melilotus)*, red clover *(Trifolium pratense* L.) and subterranean clover *(Trifolium subterraneum* L.) were discarded. However, hairy vetch *(Vicia villosa* Roth), Cahaba White vetch *(Vicia sativa)*, crimson clover *(Trifolium*

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incarnatum L.; Tibbee variety) and Austrian winter pea *(Pisum sativum* subsp. *arvense* (L.) Poir.) all exhibited characteristics favoring their use as N sources.

Hairy and Cahaba white vetch The data (Tables 3 and 4) indicated that the greatest N production and highest grain yields were obtained with hairy vetch. Producers that grow small grains are often reluctant to use vetch in their rotations because of its reputation as a volunteer weed in wheat. An application of 2,4-D or dicamba effectively controls vetch in small grains. To date, producers using vetch as a winter cover have been able to chemically destroy it before seeds are produced. Volunteer vetch has not been a problem for those growers.

Table 3. Dry matter and nutrient content of legume top growth at corn planting..

Legume	Dry matter	% N	Total N	Total K
	(lb/ac)		(lb/ac)	(lb/ac)
Hairy vetch	3916	4.04	159	117
Cahaba white	3568	3.74	133	94
A. winter pea	2872	3.45	99	68
Crimson clover	5816	2.59	151	98

***Data represent the average of three experiments conducted during the 1983 and 1984 crop years. All legumes were planted in September following tobacco.**

Vetch is the easiest of the legumes to establish on sandy soils and, of the legumes tested, it was the best performer on poorly-drained soils. Hairy vetch was also the most winter hardy of the winter annuals tested. Cahaba White vetch was less winter hardy than hairy vetch; it also produced slightly lower corn yields and total above-ground nitrogen than hairy vetch (Tables 3 and 4). It was, however, easier to kill with paraquat and offered resistance to nematode diseases that are often a problem in eastern North Carolina.

Austrian winter pea: Austrian winter pea did not produce yields as high as the vetchs and generated the least amount of N among the legumes tested. Nevertheless, it was easy to establish on sandy soils, easy to kill with paraquat and, during the course of our studies, it was less expensive than vetch seed. Austrian winter pea also appeared to be more responsive to late seeding dates than Tibbee Clover and Cahaba White vetch. At one time, there were thousands of acres of Austrian winter pea in the coastal plain of North Carolina. They disappeared because Austrian winter pea was not resistant to common nematodes and were susceptible to troublesome peanut diseases like Southern stem rot. Nematode sampling of plots in 1983 and 1984 suggested that the legumes tested neither aggravated problem fields nor created new nematode infestations (data not shown). This observation probably resulted from the fact that the winter annual cover crops were present in fields when nematode populations were dormant.

Table 4. Effect of cover crop and nitrogen rate on corn yield.*

Legume	Nitrogen Rate 0	50	100	150
	(bu/ac)			
Hairy vetch	109	117	125	129
Cahaba while	89	109	106	115
A. winter pea	72	104	104	100
Crimson clover	73	88	96	105
No cover	12	43	68	85

***Data represent the average of three experiments conducted during the 1983 and 1984 crop years. All legumes were planted in September following tobacco.**

Crimson clover: Crimson clover produced large quantities of N and dry matter (Table 3). However, no-tillage planting into crimson was difficult in our tests because the thick vegetation hampered efforts to obtain consistent seeding depths. Moreover, the dense canopy of vegetation remained standing for several days after glyphosate was applied preemergence. The failure of the crimson clover to fall rapidly increased the incidence. of rodent damage to germinating seed. For this reason, it appeared advisable to use paraquat rather than glyphosate when chemically killing crimson clover.

Supplemental Nitrogen

The data from our on-farm tests suggested that vigorous, winter annual legumes provided corn with the equivalent of at least 100 lb/ac of fertilizer N (Table 3). It was still necessary to apply about 50 pounds of supplemental N (Table 4) although legumes provided all the necessary N when drought and pursuant low yields were encountered. Monitoring of soil inorganic N levels in 1984 and 1985 suggested that supplemental N should be applied in sidedressing applications 4- to 6-weeks after planting.

Managing Hairy Vetch as a Nitrogen Source

Collectively, our 1982-1983 data suggested that hairy vetch was the best legume alternative. Accordingly, additional studies were conducted in 1984-1985 to determine how to best utilize hairy vetch as a N source for corn. Two years of experimentation indicated that supplemental N was needed even when spring vetch growth averaged 3768 lb/ac (Table 5). Removal of vetch as a forage prior to corn planting reduced grain yield; however, the decrease in yield was overcome by the addition of 75 Ib/ac N. In-row subsoiling produced grain yield increases at all N rates even though vetch residues on the soil surface provided a thick mulch. Incorporation of the vetch by disking prior to in-row subsoiling did not reduce grain yield. When vetch was killed in a 10-inch band over the corn row at planting, and vetch in the row middles allowed to grow for 2- to 4-weeks after planting, corn yield was decreased. Thus, "strip-killing" of vetch was eliminated as a viable method for increasing the volume of vetch mulch and its N contribution after corn planting.

Table 5. Influence of vetch management and N fertilizer rate on grain yield. Avenge of 1984 and *1985* experiments

Management Treatment	Abbreviation	N fertilizer rate (lb/ac) 0	75	150
		Corn grain ykld (bu/ac)		
No cover	F	50	91	117
Cover removed	CR	71	143	138
Cover incorporated	INC	115	126	139
No-till with subsoiling	NT	125	132	134
No-till without subsoiling	NS	97	114	120
Strip-killed/2 weeks	S2	95	115	108
Strip-killed/4 weeks	s4	88	93	110
Strip-killed/maturity	SM	70	72	91

Planned Comparisons

Source	df	MS	Source	df	MS
Management treatment	7	41.24**	N rate X Mgmt.	14	7.98**
F vs NT, NS (C1)	1	91.70**	NL X (C1)	1	33.61**
NT vs NS (C2)	1	23.30*	NL X (C2)	1	1.81
INC vs CR (C3)	1	5.34	NL X (C3)	1	18.18**
INC,CR vs NT,NS(C4)	1	0.44	NL X (C4)	1	15.25**
S2,S4 vs SM (C5)	1	44.76**	NL X (C5)	1	0.12
S2 vs s4 (C6)	1	5.00	NL X (C6)	1	0.79
S2,S4,SM vs Otrs (C7)	1	93.44'	NL X (C7)	1	13.79**
Error (a)	28	3.94	NQ X (C1)	1	0.26
			NQ X (C2)	1	0.12
N rate	2	80.02**	NQ X (C3)	1	20.15*
N rate linear	1	151.45**	NQ X (C4)	1	5.80
N rate quadratic	1	8.58**	NQ X (C5)	1	2.80
			NQ X (C6)	1	5.17*
			NQ X (C7)	1	5.85**
CV (a) = 29.63					
CV (b) = 12.98			Error (b)	64	0.76

'denotes significance at the P = .05 probability level.
** denotes significance at the P = .01 probability level.

Chemical Control of Legumes

Among growers, there is concern about the most effective method for chemically destroying standing legumes. Our experience between 1982 and 1985 suggested that the non-selective herbicides, paraquat and glyphosate, were effective on the four legumes tested. Paraquat appeared to be the most consistent of the two herbicides, particularly when it was tank-mixed with atrazine and UAN solutions. In either case, an inexpensive, layby application of 2,4-D or dicamba eliminated concerns about legume plants that escaped non-selective herbicide treatments. Our general observations regarding chemical control of winter annual legumes were consistent with those of White and Worsham (1990) who studied the chemical control of legumes in detail.

Moisture and Nutrient Conservation by Legumes

Legumes intended for use as N sources for corn are generally evaluated in terms of their potential N production. Often overlooked is increasing evidence that mulches and crop residues may be managed to conserve soil moisture, thereby increasing corn yields. Although we were, in our 1984-1985 studies, unable to document soil moisture conservation by a hairy vetch mulch during corn grainfilling, hairy vetch mulches do appear to retain additional soil water for crop use early in the growing season (Frye, 1989). Often overlooked is the ability of the legume covers to take up and store nutrients such as potassium (Table 3). In effect, the legume mulches may serve as a reservoir of nutrients that are essentially "slow-released" as corn develops on sandy soils.

In conclusion, it appears reasonable to suggest that legume cover crops are generally more economical to establish than rye or wheat when the value of their N contribution is considered. Thus, winter annual legumes offer many opportunities to the corn producer who is willing to manage them with the same care that he gives other crops. However, legume planting dates appear to be the most critical component of a successful legume/corn cropping system. Among current rotational schemes, continuous corn and corn rotated with tobacco provide late summer or early fall planting "windows" that facilitate adequate spring growth of winter annuals and permit the effective use of winter annual legumes as N sources for no-tillage corn.

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