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Influence of Tillage and Crop Rotation on Yields of Corn, Soybean, and Wheat

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ABSTRACT

Cropping systems for minimum or no tillage have been developed to produce corn (*Zea mays* L.) yields equal to or higher than yields obtained in conventional tillage systems, but limited research has been conducted with tillage systems involving corn and soybean [*Glycine max* (L.) Merr.] rotations. The objective of this study was to compare different cropping sequences of corn, soybean, and wheat (*Triticum aestivum* L.) in conventional, strip, and no tillage. A field experiment was conducted on a Hartsell fine sandy loam (fine-loamy, siliceous, thermic Typic Hapludults). In 1981, corn yields with no tillage were 30% lower than those from conventional tillage systems. No corn yield differences were observed in 1982 and 1984 due to tillage or crop rotation; however, in 1983, strip and no tillage in conjunction with soybean in the rotation increased corn grain yields by 12%. Soybean yields in strip and no tillage decreased 16% compared to conventional tillage yields in 1981, but in subsequent years, soybean yields increased with those systems. A significant tillage × rotation interaction in 1981, 1982, and 1983 was caused primarily by a buildup of soybean cyst nematode (*Heterodera glycines* Ichinohe) (SCN) population with conventional tillage and continuous soybean. Rainfall affected soybean yields more with conventional tillage than with strip or no tillage. The conservation tillage systems (strip or no-tillage system) in combination with corn-soybean rotation for both full-season or double-cropped soybean gave the most consistent yield increase for the 4 yr.

Additional index words: Double-cropping, Strip tillage, *Zea mays* L., *Glycine max* (L.) Merr., No tillage, *Heterodera glycines*, *Triticum aestivum* L.

CONSERVATION tillage is a system of managing crop residue on the soil surface with minimum or no tillage (Unger and McCalla, 1980). A shift from conventional row crop to conservation tillage systems has increased in corn and soybean production gradually in the United States, from about 17.8% in the early seventies to 34.5% in the mid-eighties (Lessiter, 1983). This represents an increase from 16.4 million hectares in 1973 to 45.3 million hectares in 1982. The reason for the shift in tillage systems is the increased availability of subsoil water (Weatherly and Dane, 1979) and reduced water runoff, soil erosion, and energy requirements (Gallaher, 1977; Langdale et al., 1978; Tyler and Overton, 1982; Vaughan et al., 1977) in minimum tillage systems.

One of the many problems associated with conservation tillage systems is the change with time in the soil chemical and physical properties in the top 4 to 6 cm. Soil bulk density in the 0- to 15-cm layer was not affected after 10 yr of continuous no-till and conventionally tilled corn production on a Maury silt loam (Typic Paleudalfs) soil (Blevins et al., 1983a,b). However, when high rates of acidic N fertilizers were used along with no tillage and no addition of lime, rapid acidification of the soil surface occurred in the Maury silt loam soil.

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Most conservation tillage research in the Southeast has dealt with the application of starter fertilizers in conjunction with monocultures. Yields of grain sorghum (*Sorghum bicolor* L.) (Touchton and Hargrove, 1983), corn (Touchton and Karim, 1986; Reeves et al., 1986; Touchton and Hargrove, 1982), cotton (*Gossypium hirsutum* L.) (Brown et al., 1985; Touchton et al., 1986), and soybean (Bharati et al., 1986; Touchton and Rickerl, 1986; Touchton, 1984; Touchton and Johnson, 1982) were increased with the application of starter fertilizers in conjunction with some form of conservation tillage. Most of these studies were conducted on soils that may have had traffic or tillage pans restricting rooting to the soil volume above the traffic pan.

Problems associated with conservation tillage systems are cold and wet soil conditions in the spring (Gauer et al., 1982; Karlen and Sojka, 1985), higher soil bulk density (Douglas et al., 1980), and lower soil O_2 levels. Soybean nodulation, N_2 fixation as measured by C_2H_4 reduction, and soybean seed yields decreased with conservation tillage systems. In the Midwest, soybean yields are often not affected by tillage systems ranging from complete residue incorporation to no tillage (Erbach, 1982; Richey et al., 1977). Weed control in no-tillage soybean in the Midwest had the greatest effect on yields in 2 out of 3 yr (Burnside et al., 1980; Kapusta, 1979). In a 3-yr study in the Midwest, soybean yields were not affected by tillage systems (Elmore, 1987).

In a 10-yr study in the Midwest, yields of corn, soybean, and oat (*Avena sativa* L.) were affected more by soil type than by tillage system (Dick and Van Doren, 1985); corn grain yields were insensitive to tillage over a wide range of soil types, cropping systems, and climates so long as equal plant densities and adequate weed control were maintained (Van Doren et al., 1976). Most studies in the Southeast concerning conservation tillage were conducted for 2 to 3 yr without any concern about the previous crop. The purpose of this study, therefore, was to compare (i) different cropping systems utilizing various combinations or successions of soybean, corn, and wheat and (ii) different conservation tillage systems within the cropping systems.

MATERIALS AND METHODS

A field experiment was established at the Sand Mountain Substation in the Appalachian Plateau region of Northeast Alabama on a Hartsell fine sandy loam soil where row crops had been planted for many years. Lime was applied to adjust soil pH to 6.0. Because the experiment was initiated in the spring of 1980, wheat was not planted the first year, but it was planted in the fall in subsequent years. Soil samples were collected each fall to determine the required P and K fertilizer for corn and soybean. Lime and P and K fertilizers were applied broadcast, according to Auburn University Soil Test recommendation, each fall prior to disking the experimental area and planting wheat as a cover crop to all plots.

Three tillage treatments were established in the spring of 1980. They were conventional tillage (moldboard plowing the wheat cover in the spring, disking in herbicide, and planting conventionally on the surface), strip tillage (killing the wheat winter cover with herbicides, planting behind a chisel tilled to a 30-cm depth, pulling soil over the chisel area), and no tillage (planting in the killed crop residue with a double disk-opener planter).

Rotation treatments were: continuous soybean-wheat cover; continuous corn-wheat cover; soybean-wheat cover-corn-wheat cover; soybean-wheat cover-corn-wheat grain; corn-wheat cover-soybean-wheat cover; and corn-wheat grain-soybean-wheat cover. The first rotation of crops was completed in 1982.

The experimental design was a split plot in a randomized complete block with four replications. Whole plots were tillage (32.9 by 15.25 m) and subplots were rotation treatments (5.49 by 15.25 m). Row spacing was 0.92 m for corn and 0.69 m for soybean.

Corn (cv. Pioneer 3369A) was planted in mid-April, 10 d after the wheat cover was desiccated by a broadcast application of paraquat (1,1′-dimethy-4,4′-bipyridinium) at 1.1 kg a.i. ha^{-1}. Full-season soybean (cv. Essex) was planted in early May following wheat as a winter cover crop, or mid-June for double-cropped soybean and wheat following wheat harvested for grain. No-tillage, double-cropped soybean was planted in the wheat stubble following grain harvest.

At planting in the fall, 56 kg N ha^{-1} as NH_4NO_3 was applied to wheat. Corn received 56 kg N ha^{-1} at planting and an additional 168 kg N ha^{-1} as NH_4NO_3 2 to 3 wk after emergence. No additional fertilizers were applied to the soybean plots. Atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] was applied preemergence at a rate of 2.2 kg a.i. ha^{-1} followed by 2,4-D [(2,4-dichlorophenoxy)acetic acid] applied postemergence at 0.6 kg a.i. ha^{-1} to control weeds in corn. One row of corn (0.92 by 15.25 m) was harvested for grain yield with moisture adjusted to 150 g kg^{-1}. Stand counts of corn were determined at grain harvest.

Linuron [*N*′-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea] at a rate of 0.7 kg a.i. ha^{-1} and 2,4-DB [4-(2,4-dichlorophenoxy)butyric acid] at 0.2 kg a.i. ha^{-1} were tank mixed and applied post-directed to soybean for weed control. On the conventional plots, trifluralin [2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine] at a rate of 0.6 kg a.i. ha^{-1} was applied preplant-incorporated. Additional weed control was achieved by cultivation as needed. Two rows of soybean, 0.69 by 15.25 m, were harvested for seed yield. Stand counts of soybean were determined at harvest and soybean yields were adjusted to 130 g kg^{-1}.

Soil samples were taken 12 to 14 cm deep, under the rows of each plot in the last week of August 1983. Cyst nematode counts were determined by the flotation method on a 50-cm^3 subsample of soil. Nematode analysis was also determined on March, July, and August 1984 soil samples. The July and August samples were taken 58 and 59 d after planting full-season and double-cropped soybean, respectively.

RESULTS AND DISCUSSION

Rainfall

Rainfall during April 1981 through August 1984 was adequate to insure good growth of corn. Above-average rainfall occurred in the 1984 corn growing season; however, precipitation was below average in 1981 during the soybean growing season (Fig. 1). In 1982 through 1984, poor rainfall distribution resulted in periods of drought stress on soybean of 14 d or more. In late July through 3 Sept. 1983, a 10-mm rainfall resulted in water stress during soybean pod development and pod fill.

Soybean Yields

The highest soybean yields in 1981 (2886 kg ha^{-1}) were measured for double-cropped soybean with conventional tillage (Table 1). In 1982, 1983, and 1984, the conservation tillage systems, when rotated with corn, resulted in the highest yields. The average yields for tillage treatments in a soybean-corn rotation were 2295, 2999, 2069, and 2634 kg ha^{-1} in 1981, 1982, 1983, and 1984, respectively. Yield averages for 4 yr for full-season soybean rotated with corn were 2215, 2625, and 2659 kg ha^{-1} for conventional, strip, and no-tillage systems.

During 1981 through 1984, yields of continuous soybean grown with conventional tillage ranged from 29 to 92%, as high as the no-tillage soybean rotated with corn. Yield averages for continuous full-season soybean were 1642, 2034, and 2385 kg ha^{-1} for conventional, strip, and no tillage. Yields for double-cropped soybean (soybean-wheat cover-corn-wheat grain; Table 1) were lower each year than those for full-season soybean (soybean-wheat cover-corn-wheat cover). Yield averages for the 4 yr for double-cropped soybean were 2406, 2445, and 2163 kg ha^{-1} for conventional, strip, and no tillage.

Soybean yields in 1983 followed trends established

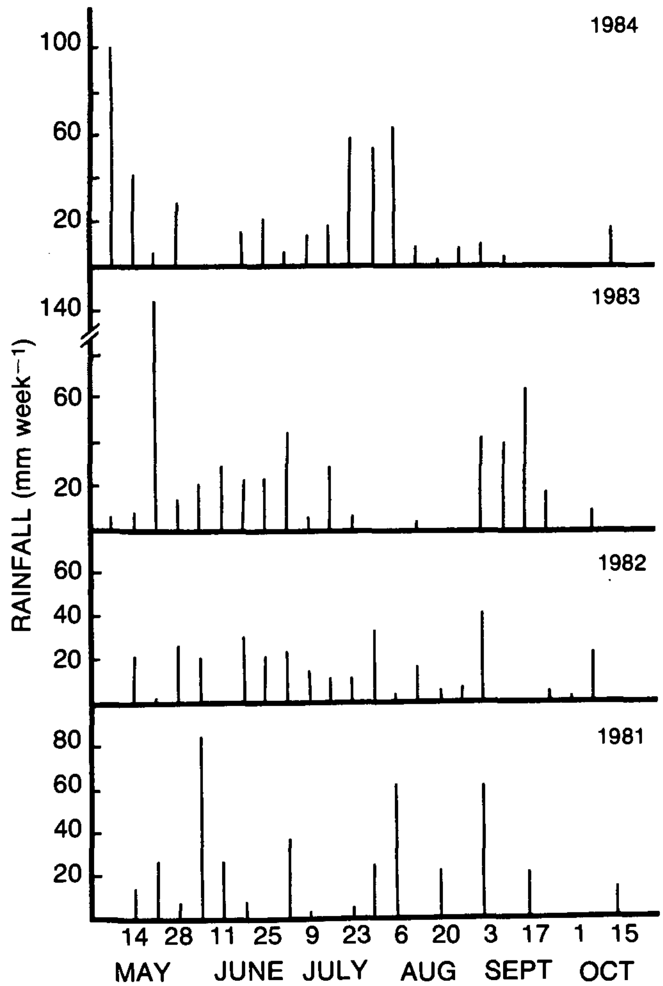

Fig. 1. Rainfall in millimeters per week at Sand Mountain substation for 1981 through 1984 for the soybean growing season.

Table 1. Effects of tillage and crop rotation on soybean yields for 1981 through 1984.

Tillage system	Yield of soybean				
	1981	1982	1983	1984	4 yr mean
	kg ha⁻¹				
	Continuous soybean				
Conventional	1988	2026	690	1867	1642
Strip tillage	1837	2770	1557	1972	2034
No tillage	2187	2783	2210	2360	2385
Rotation means	2004	2526	1485	2066	
	Soybean-corn†				
Conventional	2589	2799	1605	1870	2215
Strip tillage	2142	3067	2223	3070	2625
No tillage	2154	3133	2380	2970	2659
Rotation means	2295	2999	2069	2634	
	Wheat-soybean-corn				
Conventional	2886	2851	1930	1960	2406
Strip tillage	2284	2895	1880	2720	2445
No tillage	1609	2763	1833	2450	2163
Rotation means	2260	2836	1880	2377	
Tillage means					
Conventional	2488	2558	1408	1899	
Strip tillage	2088	2910	1887	2588	
No tillage	1984	2893	2141	2590	
LSD (0.05) Tillage (T)	NS	257	171	199	
LSD (0.05) Rotation (R)	NS	210	227	384	
LSD (0.05) T × R	305	283***	398	NS	

*** Significant at the 0.10 level of probability. NS = not significant.
† These means are pooled across treatments that include the same crops.
‡ Used to test tillage means with rotation systems.

in previous years: lower yields were observed with continuous soybean than with soybean in rotation with corn, and lower yields were observed with conventional tillage than with conservation tillage (Table 1). The lowest yields were obtained from continuous soybean grown in the conventional tillage system (690 kg ha^{-1}). Low yields with this system were probably due to a high nematode population found in August of 1983 (Table 2). Nematodes caused stunting and reduced the vigor of soybean plants in the conventional tillage treatment that had been in continuous soybean for 4 yr (Table 1). The high SCN population found in the conventional tillage treatment under continuous soybean and full-season soybean in rotation with corn were probably part of the reason that the double-cropped soybean yields were higher than those of full-season soybean in 1981.

Soybean yields in 1984 were lowest with the conventional tillage treatment when averaged across all cropping sequences (Table 1). Highest soybean yields

Table 2. Soybean cyst nematode larve counts found in soybean grown in 1983 and 1984 with different tillage and crop rotation systems.

Tillage treatment	SCN counts by sampling dates†			
	August 1983	March 1984	July‡ 1984	August 1984
	Continuous soybean			
Conventional	433	9	586	108
Strip tillage	767	53	779	694
No tillage	476	87	797	576
Rotation means	558	49	721	459
	Soybean-corn§			
Conventional	1037	65	712	275
Strip tillage	130	26	632	751
No tillage	17	4	216	126
Rotation means	394	42	620	384
	Wheat-soybean-corn			
Conventional	230	17	197	512
Strip tillage	12	14	164	174
No tillage	1	0	29	28
Rotation means	88	16	127	257
Tillage means				
Conventional	566	27	498	298
Strip tillage	303	36	550	540
No tillage	179	70	391	263
LSD (0.05) Tillage (T)	155	NS	NS	NS
LSD (0.05) Rotation (R)	345	NS	220	NS
LSD (0.05) T × R#	566	56	NS	483

† SCN counts in 50-cm³ sample of soil.
‡ July and August samples were taken 58 and 59 d after planting full-season and double-cropped soybean.
§ These means are pooled across treatments that include the same crops.
# Used to test tillage means with rotation systems.

occurred with full-season soybean grown in rotation with corn and using strip tillage. Double-cropped soybean yields were approximately 300 kg ha^{-1} lower than those of full-season soybean; however, wheat yields ahead of the double-cropped soybean were 3670 kg ha^{-1} in 1984.

Seed size was correlated with soybean yield; i.e., the highest yielding treatments had the largest soybean seeds (Table 1 and Table 3). Full-season soybean rotated with corn resulted in larger soybean seeds than did continuous full-season or double-cropped soybean. Both conservation tillage treatments (strip and no tillage) resulted in larger soybean seed size than did the conventional tillage system. Seed size of double-cropped soybean was affected more by reduced rainfall in late August and September (Table 3 and Fig. 1) than full-season soybean. Rainfall was only 4 mm for September, and 20 mm or less during the last 10 d of August and the first 10 d of October. Soybean seed size and yields showed a higher correlation with the SCN population that occurred 58 d after planting rather than SCN population determined prior to soybean planting in the spring (Table 2).

Table 3. Soybean seed size at harvest as affected by tillage and cropping systems for the 1984 crop year.

Tillage treatment	Continuous soybean	Soybean-corn	Wheat-soybean	Tillage means
	g 100⁻¹ seeds			
Conventional	9.8	11.8	10.5	10.7
Strip tillage	11.0	14.8	11.8	12.5
No tillage	12.8	14.8	11.3	12.9
Rotation means	11.6	13.7	11.2	
LSD (0.05) Tillage (T)	0.34			
LSD (0.05) Rotation (R)	0.83			
LSD (0.05) T × R	1.55			

Nematode Populations

In 1984, the number of SCN in continuous soybean was very high in July and August for strip and no tillage, but the SCN counts in conventional tillage dropped in August. Reduced SCN counts in the conventional tillage plots were similar to those observed in 1983, and were probably due to plants and roots dying in the conventional tillage treatments (Table 2).

The SCN counts increased throughout the growing season with full-season soybean in rotation with corn for strip and no tillage. Increased rate of SCN with no tillage appears to be 1 to 2 yr behind strip tillage with full-season soybean. Delaying planting to accommodate double cropping soybean behind wheat resulted in reduced SCN counts when compared to full-season soybean. By August of 1984, the SCN counts under double-cropped soybean with conventional tillage were at a very high population. The no-tillage system with double-cropped soybean had the lowest SCN count, and the SCN population did not appear to have an effect on soybean yields.

Corn Yields

Corn grain yields were influenced by rotation in 1981 and both tillage and rotation in 1983 (Table 4). No effects of tillage or crop rotation were observed in 1982 or 1984 on corn yields. The corn-wheat grain-soybean-wheat cover and soybean-wheat cover-corn-wheat cover rotations gave higher grain yields than did continuous corn in 1981. The same trend was observed in 1983 with rotation; however, corn grain yields were greater with strip and no tillage than with conventional tillage. This represents a 14% higher corn yield when rotated with soybean than when grown continuously. Corn grain yields were 10% higher with strip and no tillage than with conventional tillage. The tillage × rotation interaction was not significant during 1981 through 1984 for corn yields.

Corn yields were very high for all years for dryland conditions in the southeastern United States. Crop rotation affected corn yields only 2 out of 4 yr, and tillage systems affected yields only 1 out of 4 yr. The population of stunt nematodes (*Tylenchorahynchus* spp.) with continuous corn in conventional tillage was significantly higher than with strip or no tillage (data not shown). The rotation treatments may have reduced the buildup of stunt nematodes when compared to continuous corn. In all years, rainfall distribution was adequate for maximum corn yields.

Table 4. Effects of tillage and crop rotation on corn grain yield for 1981 through 1984.

Tillage system	1981	1982	1983	1984	4-yr Mean
	Yield of corn				
	kg ha^{-1}				
	Continuous corn				
Conventional	6 616	9 332	7 064	10 974	8 496
Strip tillage	6 758	7 794	7 288	10 272	8 028
No tillage	5 405	9 093	6 801	11 085	8 096
Rotation means	6 260	8 740	7 051	10 777	
	Soybean-corn				
Conventional	6 700	7 913	7 317	10 832	8 191
Strip tillage	7 257	9 392	8 507	10 715	8 968
No tillage	6 344	8 861	8 229	10 863	8 574
Rotation means	6 767	8 722	8 017	10 804	
	Wheat-soybean-corn				
Conventional	6 985	8 344	7 142	10 297	8 192
Strip tillage	7 632	9 299	8 161	10 863	8 989
No tillage	7 691	8 132	8 467	10 574	8 716
Rotation means	7 436	8 592	7 923	10 578	
Tillage means					
Conventional	6 767	8 530	7 174	10 701	
Strip tillage	7 216	8 828	7 985	10 617	
No tillage	6 480	8 696	7 832	10 841	
LSD (0.05) Tillage (T)	NS	NS	551	NS	
LSD (0.05) Rotation (R)	1 037	NS	710	NS	
LSD (0.05) T × R†	NS	NS	NS	NS	

† Used to test tillage means with rotation systems.

SUMMARY

Corn grain yields were less affected by rotation treatments and tillage treatments than soybean yields. Corn grain yields were high in all years and very high in 1984, due to a large amount of rainfall in the last 10 d of July and the first 7 d of August. The most significant contribution of corn in the rotation was in delaying the SCN population buildup in the conservation systems.

In 1982 and 1984, water stress occurred during late pod fill, which was not as critical on soybean yields. Soybean yields in strip or no tillage did not appear to be affected as much as soybean yields in conventional tillage. The moisture conserving advantage of the mulch in conservation tillage was presumably responsible for higher soybean yields.

Soybean yields were increased by strip and no tillage, and crop rotation when compared to conventional tillage. In all years, soybean yields consistently increased with conservation tillage practices because of water conservation and reduced SCN population. Soybean cyst nematode populations were extremely high for conventional tillage systems; however, the SCN population increased more slowly with conservation tillage than with conventional turning and disking. Yields were higher from soybean in a 2-yr rotation with corn than from continuous soybean. Increased yields of soybean in rotation with corn were even more evident when grown with conservation rather than conventional tillage. The SCN population increased in the conservation tillage systems, but the buildup appeared to be 2 yr behind that of the conventional tillage systems. Rainfall distribution in 1983 affected soybean yields more than either crop rotation or tillage.

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