Long-Term Tillage and Poultry Litter Impacts on Soybean and Corn Grain Yield

Dexter B. Watts* and H. Allen Torbert

ABSTRACT

Reduced tillage, poultry litter applications, crop rotations, and winter cover cropping are management practices that could be used with conservation tillage systems to increase yields compared to conventional monoculture systems. This study evaluated cropping sequences of corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and corn–soybean rotations with wheat (*Triticum aestivum* L.) covers in conventional, strip, and no-tillage (no-till) systems, following poultry litter additions to wheat cover. The study was conducted from 1991 to 2001 on a Hartsells fine sandy loam (fine-loamy, siliceous, subactive, thermic Typic Hapludults). Poultry litter (112 kg N ha^{-1}) was applied to wheat each year in fall. Wheat not receiving poultry litter received equivalent inorganic N. Corn was fertilized with inorganic fertilizer in spring with 56 kg N ha^{-1} at planting followed by 168 kg N ha^{-1} 3 wk after emergence; soybean received no fertilizer. Corn yields were influenced by tillage in 1991, 1992, 1993, 1994, 1996, 1997, 1998, and 2001 with conventional tillage producing greater yields, except in 1993 (strip tillage) and 2001 (no-till). Poultry litter increased corn yield in 1991, 1997, and 1998. Crop rotations increased corn yield for all years, except 2001. Soybean yields were not impacted by differences in tillage. Crop rotations significantly impacted soybean yield in 1992, 1995, and 1998, with higher yields observed in 1992, and 1995, and lower yields in 1998. Poultry litter significantly increased soybean yield 8 of the 9 yr evaluated. This study suggests that poultry litter use for these crop rotations in conservation tillage systems could increase sustainable yield production.

No-tillage (no-till) using mechanized agricultural equipment has been encouraged in the southeastern United States since the 1960s (Phillips and Young, 1973), following the development of broadleaf herbicides 2,4-D and atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5,-triazine-2,4-diamine] (Derpsch, 2004). Interest in no-till was primarily driven by the need to reduce soil erosion and fuel consumption (Larson, 1981; Campbell et al., 1984). Since that time, considerable effort has been spent on developing better technology for weed control and planting equipment to increase the success and productivity of no-till. In the southeastern United States, achieving benefits from the implementation of strict no-till was extremely challenging due to the hot, humid climate that promotes rapid surface residue decomposition and easily compacted soil types. This facilitated implementation of conservation systems that integrate practices such as reduced tillage (strict no-till, para-till, or strip-till), maintaining 30% crop residue on the soil surface, increasing soil surface coverage by growing winter cover crops, and use of crop rotations.

Soils in the southeastern United States are characteristically sandy in nature, low in organic matter, have low water holding capacities, and are easily compacted by rainfall and machine traffic (Carreker et al., 1977). These soil conditions often limit water availability and restrict root growth, decreasing crop production. This has hindered the adoption of strict no-till. Use of deep tillage (turning the soil over) or in-row subsoiling has generally been recommended to alleviate root restriction and allow more vigorous growth for water and nutrient exploration (Vepraskas and Guthrie, 1992; Raper et. al., 1994; Torbert and Reeves, 1994; Reeves and Mullins, 1995; Torbert and Reeves, 1995; Mullins et al., 1997; Zou et al., 2001; Rosolem et al., 2002) and to increase yield potentials (Threadgill, 1982; Busscher et al., 1995; Frederick et al., 1998; Busscher et al., 2000; Schomberg et al., 2006). Specifically, the use of strip tillage to alleviate soil compaction zones has increased in recent years. This practice disturbs only a small zone, leaving the inter-row soil surface area undisturbed, which allows greater residue retention on the soil surface compared to conventional moldboard tillage and disking operations.

Implementing crop rotations in a conservation tillage system also has the potential to increase yields for the Southeast. For instance, crop rotations can provide better weed control, interrupt insect and disease cycles, and improve crop nutrient use efficiency (Karlen et al., 1994). When grown in rotation, corn grain yields were 10 to 17% greater than under continuous corn (Higgs et al., 1990). Significant yield increases for corn grown in rotation also have been observed in experiments where N, P, and K soil test levels were high and pest populations were managed (Copeland and Crookston, 1992). The greatest impact of crop rotations on yield has been reported in the Corn Belt. However, use of crop rotations in the southeastern United States has been mixed. For example, rotating dryland cotton (*Gossypium hirsutum* L.) with other crops increased yield only 3% compared with continuous cotton in Alabama (Mitchell, 1996), whereas cotton rotated with corn produced 12% higher yield than monoculture cotton in Arkansas (Paxton et al.,

USDA-ARS, National Soil Dynamics Lab., 411 S. Donahue Dr., Auburn, AL 36832. Received 9 Mar. 2011. *Corresponding author (Dexter.Watts@ars.usda.gov).

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1995). Cotton yields ranged from 5% decrease to 28% increase following 1 yr of corn and from 10% decrease to 20% increase following 2 yr of corn in Mississippi under irrigated conditions (Ebelhar and Welch, 1989). Thus, more information is needed on how crop rotations used with different conservation tillage system approaches impact yields.

Addition of poultry litter to a conservation tillage system can increase soil organic matter (Watts et al., 2010), thereby potentially providing yield benefits. The Southeast is home to the largest poultry producers in the United States, generating significant amounts of litter. Historically, the most common use for this poultry litter has been land application to pastures. However, poultry litter can serve as a relatively inexpensive nutrient source for crop production (Nyakatawa and Reddy, 2002; Moss et al., 2001). Research has shown that poultry litter use with cropping systems under conservation tillage can increase soil organic matter content of eroded southeastern soils (Edwards et al., 1992; Watts et al., 2010). Thus, the addition of poultry litter to a conservation tillage system managed with cover cropping and crop rotations may provide yield increases for crops grown in the southeastern United States.

Most of the research on conservation tillage systems in the southeastern United States has focused on cotton production. However, corn is by far the largest row crop produced and exported in the United States, followed by soybean (USEPA, 2009). While the majority of this production occurs in the Midwest, corn and soybean land area in the Southeast is predicted to increase in coming years. Historically, these crops have been a source of food for human and animal consumption (feed). Interest in renewable bioenergy production has substantially increased the price and demand for these crops within recent years. Responding to the Energy Policy Act of 2005 (U.S. Government, 2005), which established a new Renewable Fuels Standard mandating the use of 28.4 million L (7.5 billion gallons) of renewable fuel in the United States by 2012 (from 15.1 million L, or 4 billion gallons, in 2006), the corn-based ethanol and soybean–biodiesel industry is expanding at an unprecedented rate (Endale et al., 2008). In the southeastern United States, changes in production of corn and soybean have already started to experience an increase to respond to the expanding ethanol and biodiesel industry. Thus, to achieve the greatest yield potential for corn and soybean production in the southeastern United States, an area that historically has been dominated by cotton production, producers need regionally specific information on how cropping systems managed under different conservation systems interact together to develop best management practices for their farming conditions.

There is a paucity of information on how different agricultural practices integrated in a conservation tillage system influence corn and soybean grain yield in the southeastern United States. Multiple-year evaluations are needed to examine the sustainability of these cropping systems due to year-to-year variability of environmental conditions. The objectives of this study were to determine the impact that tillage, poultry litter application, and crop rotations have on corn and soybean grain yield during nine growing seasons.

MATERIALS AND METHODS

Site Description

A long-term study was initiated in spring of 1980 at the Sand Mountain Research and Extension Center in the Appalachian Plateau region of northeast Alabama near Crossville (34°18′ N, 86°01′ W). The soil was a Hartsells fine sandy loam. The Hartsells series consists of moderately deep, well-drained, moderately permeable soils that formed in loamy residuum weathered from acid sandstone containing thin strata of shale or siltstone. Climate in this region is subtropical with no dry season; mean annual rainfall is 1325 mm, and mean annual temperature is 16°C (Shaw, 1982). Before field study initiation in 1980, the site had been under intensive row crop production for more than 50 yr.

Experimental Design and Treatments

An evaluation of grain yield for corn and soybean was conducted from 1991 through 2001. The experiment was a split-split plot design with a randomized complete block arrangement of three tillage treatments (initiated in 1980), four crop rotations (initiated in 1980), and two fertilization treatments (initiated in 1991) for which there were four blocks. The main plots were tillage, the split plots were rotations, and the split-split plots were fertilization. The cropping systems consisted of corn and soybean. Each plot consisted of four rows. Row spacings for the four row plots were 0.92 m for corn and 0.69 m for soybean. Main plots (tillage) were 32.9 by 15.25 m, split plots (rotations) were 5.49 by 15.25 m, and split-split plots (fertilization) were 5.49 by 7.62 m with a 1.82-m buffer separating the plots. The tillage treatments (main plots) consisted of conventional tillage (CT; moldboard plowing and disking followed by rototiller in the spring), no-tillage (NT; planting into crop residue with a double disk-opener planter), and strip tillage (planting behind a strip-till shank to a 35- to 40-cm depth). Strip tillage consisted of using a four-row KMC strip tillage unit equipped with a coulter, shank, and rolling baskets. This created a 30-cm-wide clean tilled strip in each row. Rotation treatments were continuous corn–wheat cover, continuous soybean–wheat cover, corn–wheat cover–soybean–wheat cover, and soybean–wheat cover–corn–wheat cover. The rotational corn–wheat cover–soybean–wheat cover and soybean–wheat cover–corn–wheat cover treatments alternated yearly to evaluate the impact crop rotations had on corn or soybean grain yield each year.

Cultural Practices

Wheat cover crops were established the preceding fall of each year and seeded at a rate of 100 kg ha^{-1}. After wheat emergence, 112 kg N ha^{-1} as NH_4NO_3 and poultry litter were applied to the wheat cover of the corn and soybean crops. Desiccation of wheat cover occurred 2 wk before the anticipated planting of cash crops. Approximately 1 wk after cover crop desiccation, strip tillage and conventional tillage operations were administered to the appropriate plots. A day or two after tillage operations occurred, the subsequent corn and soybean crops were planted at a rate of 57,000 seed ha^{-1} and 32 seed m^{-1}, respectively. Corn was planted in mid-April, and soybean was planted in early June of each year. Corn received 56 kg N ha^{-1} at planting and an additional 168 kg N ha^{-1} as NH_4NO_3 (no poultry litter was applied to corn) 2 to 3 wk after emergence. No fertilizer was applied to the soybean crop. Both poultry litter and NH_4NO_3 were surface-broadcasted by hand. The average poultry litter nutrients applied each year from 1991 to 2001 was 112 kg N ha^{-1}, 6.5 kg P ha^{-1}, 96 kg K ha^{-1}, 86 kg Ca ha^{-1}, and 6 kg Mg ha^{-1} to the wheat cover crop. Dolomitic lime, KCl (0–0–60) ,and P were applied in the fall according to Auburn University soil test recommendations. Phosphorus was not applied to plots receiving poultry litter to prevent P buildup. Lime and K application rates varied across years, but all plots received the same amount when applied. No additional micronutrients other than those contained in the poultry litter were applied during the 10-yr study period.

Weed control initially consisted of atrazine followed by glyphosate [*N*-(phosphonomethyl) glycine] applied post-emergence for the corn plots. Weed control in soybean plots was accomplished by applying Imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinoline-carboxylic acid} at planting; Linuron [(*N*′-3,4-dichlorophenyl)-*N*-methoxy-*N*-methyl-urea] and 2,4-DB (4-(2,4-dichlorophenoxy)butanoic acid) were tank-mixed and applied post-directed to soybean for weed control. Additional weed control was achieved by hand weeding and cultivation as needed in the NT and CT, respectively, for corn and soybean plots.

Corn was harvested in mid-September of each year using a mechanical combine. The center two rows of each plot were used for grain yield. Yield was determined by weighing the freshly harvested grains in the field and adjusting weight based on the subsample collected to 150 g kg^{-1}. Similar to corn, soybean was harvested in mid-October of each year using a mechanical combine. The center two rows of each plot were harvested for seed yield, and weights were adjusted to 130 g kg^{-1}.

Statistics

The experimental design was a split-split plot with four replications. For each cropping system, tillage was the main plot, rotation was the split plot, and poultry litter vs. no poultry litter was the split-split plot. Corn and soybean grain yield analyses were performed separately using the MIXED procedure of SAS (Littell et al., 1996). Cropping systems, fertilization regimes, and tillage treatments were analyzed as fixed effects, whereas replication and years were random effects. Interaction effects were entered into the model as fixed or random effects as appropriate. Means were compared using the LSmeans statement (diff and pdiff) in PROC MIXED. Means were separated using a significance level of $\alpha = 0.10$, which was established a priori.

RESULTS AND DISCUSSION

In general, evaluation of corn and soybean yields indicated that the use of poultry litter and crop rotations can impact yields in the Southeast. Historically poultry litter has been applied to actively growing hayfield or pastures, regardless of season, following removal from poultry production facilities. This study focuses on the effects that poultry litter application to an actively growing cover crop has on succeeding soybean and corn crops. Thus, although numerous studies have evaluated the impact poultry litter application to the cash crop, few experiments have evaluated the application to cover crops. The following discussion is an in-depth look at how corn and soybean management practices impact crop yields in the southeastern region.

Weather Conditions

Temperature conditions for each growing season are shown in Table 1. Generally, monthly temperatures between seasons were normal and did not deviate much (more than 2–3°) from the 30-yr average during the course of this study. However, precipitation varied markedly between years and within months (Table 2). The wettest growing seasons (from April to September) were observed during 1994, 1995, 1996, and 1997, with precipitation totals within these years above the 30-yr average. The lowest rainfall amounts were observed during 1991, 1993, 1998, and 2001, with precipitation totals falling below the 30-yr average for rainfall. Difference in rainfall percentages between the driest and wettest growing seasons ranged from 33% below the 30-yr average in 1993 to 62% above the 30-yr average in 1997.

Weather Variability Effects on Corn and Soybean Yield

Weather conditions were exceptional for evaluating the year-to-year variability of grain yield response for a dryland production system. The contrasting weather conditions from year to year produced drastically different growing conditions for the corn and soybean crops. Although differences in weather conditions were observed, rainfall and soil moisture was sufficient enough to produce crop yields each year. Mean grain yields averaged across treatments for each year are presented in Table 2. Grain yield varied from year to year. The mean corn grain yield harvested from 1991 to 2001 ranged from 4.3 to 11.0 Mg ha^{-1} (SE = 0.69), resulting in a 155% total difference during 9 yr. Similarly, mean soybean grain yield from 1991 to 2001 ranged from 1.8 to 3.4 Mg ha^{-1} (SE = 0.20), resulting in 85% difference. Variations in precipitation amounts and patterns, impacting water availability during the hot, summer months between seasons, is most likely the greatest cause for observed differences in grain yield response during the 9-yr study. In general, the highest corn and soybean grain yields were observed during years when rainfall was close to or above the 30-yr average. Normal or better corn grain yield was observed in 1992, 1994, 1996, 1997, and 2001, with the greatest yield in 2001. Similarly, soybean produced normal or

Table 1. Average monthly temperature from 1991 to 2001 growing seasons.

Season	Temperature							
	April	May	June	July	Aug	Sept	Oct	Avg.
	°C							
1991	16.4	20.9	23.1	25.7	24.8	21.9	16.2	21.3
1992	14.6	17.7	21.7	24.9	22.5	21.2	14.4	19.6
1993	12.9	18.7	23.6	26.8	25.3	21.4	15.2	20.6
1994	16.3	17.4	23.8	23.9	23.2	20.3	15.7	20.1
1995	15.6	19.9	22.4	25.9	26.4	20.9	15.6	21.0
1996	13.3	20.7	23.4	24.8	24.1	19.9	15.1	20.2
1997	12.6	17.2	21.3	25.4	23.4	21.9	15.3	19.6
1998†	14.1	21.3	25.2	26.3	25.3	24.3	18.1	22.1
2001	16.1	19.8	23.2	25.1	24.5	20.5	14.2	20.5
30-yr avg.‡	14.9	19.1	22.9	24.6	24.3	21.2	15.1	

† Yield data for 1999 and 2000 are missing.

‡ Means for the 30-yr avg. were calculated from temperature data collected at the Sand Mountain Research and Extension Center.

Table 2. Total monthly rainfall from 1991 to 2001 growing seasons and mean grain for corn and soybean.

Season	Rainfall							Grain yield 9-yr Mean	
	April	May	June	July	August	September	Totals	Soybean	Corn
	mm							kg ha^{-1}	
1991	157.23	125.22	139.19	72.90	79.50	84.15	658.19	2551.22	5891.91
1992	56.64	52.83	144.53	123.44	111.00	113.41	679.58	1678.18	9298.39
1993	100.33	111.25	21.34	59.44	107.95	45.47	498.35	1814.65	4310.74
1994	110.24	97.28	180.34	148.84	40.64	160.78	872.74	3099.94	7744.3
1995	107.70	37.59	87.12	66.55	197.87	103.38	800.61	3372.95	6081.58
1996	106.93	72.14	57.91	143.00	168.40	159.26	747.52	2428.36	7403.06
1997	137.92	217.93	211.07	84.58	59.69	190.25	1075.18	2713.4	7142.15
1998†	227.33	41.15	90.93	89.66	64.01	12.45	533.15	1816.81	5206.56
2001	70.10	132.33	24.13	118.87	114.55	93.98	617.22	2950.48	11031.3
9-yr mean	119.38	98.64	106.28	100.81	104.85	107.01	636.97		
30-yr mean‡	129.54	119.38	96.52	119.38	119.38	114.3	662.94		

† Yield data for 1999 and 2000 are missing.

‡ Means for the 30-yr average were calculated from temperature data collected at the Sand Mountain Research and Extension Center.

better grain yield in 1991, 1994, 1995, 1997, and 2001, with greatest yield in 1995. Although the greatest seasonal rainfall occurred in 1997, the greatest grain yield was not observed during this year for corn or soybean. This was because most of the rainfall occurred during early growth of the corn and soybean crops during the 1997 growing season. Most likely, excess rainfall during this time of the season resulted in delayed plant development, as well as loss of fertilizer nutrients through leaching or surface-water transport, thereby reducing grain yield. Lower-than-average rainfall observed during the growing season in this study most likely resulted in periods of drought stress to the crop, thereby decreasing grain yield. The lowest corn grain yield was observed in 1993, when rainfall percentages were approximately 33% below the average 30-cm rainfall. Similar to the corn grain yield observed in 1993, soybean grain yield also was adversely affected by drought conditions. Even though the lowest soybean yield was observed in 1992, this was most likely caused by delayed planting due to excess rainfall during the early portion of June.

Corn Grain Yield Response to Treatments

Mean corn grain yield as affected by tillage, fertilizer, and crop rotations are shown for each year in Table 3. Corn grain yield was significantly affected by interactions between tillage and fertilization in 1992 (Table 4). The highest grain yield was observed in the conventional tillage with poultry litter. Although conventional tillage with poultry litter produced the highest yield in 1992, no differences were observed for grain yield between the strip tillage and conventional tillage treatment. A rotation and fertilization interaction was observed in 1992 and 1998. In both years, grain yield averaged across tillage was significantly higher for the corn–soybean rotation with poultry litter compared with the corn–soybean rotation with commercial fertilizer and continuous corn with poultry litter or commercial fertilizer. No-tillage and rotation interaction effects were observed for grain yield.

Significant differences were observed for the main effects of tillage, rotation, and fertilization when evaluating grain yield by years. Tillage significantly influenced corn yield in 1991, 1992, 1993, 1994, 1996, 1997, 1998, and 2001. In the 8 yr that tillage was significantly different, conventional tillage produced the highest yields for 6 out of 8 yr, while no-till and strip-till each produced the highest yield for 1 yr. Corn grain yields were significantly increased by rotation in all years except 2001. Although no significant differences were observed in 2001, rotating the crops increased grain yields compared with yields without a rotation. The significant corn grain yield increases observed in 8 out of the 9 yr evaluated suggests that crop rotations in corn production systems may increase and maintain sustainable yields. One reason for increased yields probably results from growing corn in rotation with a legume. Soybean planted the previous year probably supplied some additional N to the subsequent corn crop. Previous research has also reported increased grain yield when growing corn in rotation with soybean compared with continuous corn in the midwestern Corn Belt (Crookston et al., 1991; Meese et al., 1991; Porter et al., 1997; Pedersen and Lauer, 2002, 2003; Stanger et al., 2008). Residual N from the previous soybean crop was probably not the only benefit from the rotation (Torbert et al., 1996). For instance, research has shown that corn grown in rotation had higher yields compared with corn grown in monoculture systems, even when the presence of N, P, and K were not limited (Stanger and Lauer, 2008). Thus, increasing the N rate will not produce the same benefits as crop rotations in a production system. Most studies evaluating the impact of corn and soybean rotations have been conducted in the northern Corn Belt. Historically in the South, crop rotations have been used in cotton, tobacco (*Nicotiana tabacum* L.), and peanut (*Arachis hypogaea* L.) systems. Similar to the northern Corn Belt, these results show that long-term management of corn in rotation with soybean will increase yields relative to a monocultural cropping system in southeastern U.S. soils.

Addition of poultry litter to the wheat cover crop significantly influenced corn yields in 1991, 1997, and 1998. Although not significant in all years, poultry litter addition consistently increased grain yields in 8 of the 9 yr studied. These results show that poultry litter addition to the soil can increase corn grain yields. The addition of the poultry litter, relative to commercial fertilizers, increases the amount of macro- and micronutrients in soil, thus increasing the grain yield potential. In addition, some residual N from the poultry litter most likely supplied the corn with increased N. Similar results

Table 3. Effects of tillage, poultry litter application, and crop rotation on corn grain yields for 1991–2001.

Tillage system	Fertilization practice	Yield of corn									
		1991	1992	1993	1994	1995	1996	1997	1998†	2001	9-yr mean
		kg ha^{-1}									
Continuous corn											
No tillage	litter	6627.4	7780.15	3638.24	7528.47	4492.27	5250.91	6565.45	1968.05	12690.25	6282.354
	inorganic	4974.00	9142.28	2997.23	7837.59	5090.97	5114.76	5038.33	2200.03	10894	5921.021
Strip tillage	litter	5039.63	9154.06	4582.75	5946.82	6078.27	6078.27	6519.03	2980.19	10004.76	6264.864
	inorganic	4492.17	8308.68	4099.67	6433.32	5651.45	5618.18	5573.15	3071.77	9046.6	5810.554
Conventional tillage	litter	6847.42	9677.79	3354.24	8131.68	6038.03	8148.10	8383.38	6235.43	10749.86	7507.326
	inorganic	5558.20	8370.98	3750.81	8104.13	5920.41	8472.99	6750.74	5741.17	11508.44	7130.874
Corn–soybean rotation											
No tillage	litter	5971.86	6258.57	4701.07	7573.29	6675.01	7880.33	6748.05	6744.79	13152.32	7300.588
	inorganic	5639.00	8833.8	4520.83	7956.37	6560.66	7390.11	6874.99	5877.01	11646.74	7255.168
Strip tillage	litter	6400.72	10894.39	6414.62	8400.26	6788.94	8179.66	8451.15	6867.21	12190.77	8287.524
	inorganic	5661.97	11196.80	4884.10	7596.98	7158.51	7358.00	8511.61	5241.28	10687.86	7588.568
Conventional tillage	litter	7019.04	11082.01	4544.82	9194.6	6407.52	9509.98	8776.90	7594.77	10409.21	8282.094
	inorganic	6474.46	10881.15	4240.54	8228.12	6116.94	9317.62	7512.95	7009.61	9393.89	7686.142
Rotation means											
Continuous soybean		5589.8 b‡	8739.0 b	3737.2 b	7330.3 b	5545.2 b	6533.5 b	6471.7 b	3774.7 b	10816.0 a	6504.2 b
Soybean–corn rotation		6194.0 a	9857.8 a	4884.3 a	8158.3 a	6617.9 a	8272.6 a	7812.6 a	6555.8 a	11246.6 a	7733.3 a
Tillage means											
No tillage		5802.0 ab	8003.7 b	3964.3 b	7723.9 ab	5704.7 a	6409 b	6306.7 b	4434.3 b	12096 a	7555.5 b
Strip tillage		5398.6 n	9888.5 a	4995.3 a	7094.3 b	6419.3 a	6938 b	7263.7 a	4540.1 b	10515.4 b	7881.6 b
Conventional tillage		6474.8 a	10003.0 a	3972.6 b	8414.6 a	6120.7 a	8862.2 a	7856.0 a	6645.2 a	10482.5 b	8603.9 a
Fertilization means											
Litter		6317.7 a	9141.2 a	4539.3 a	7795.9 a	6083.0 a	7594.2 a	7574.0 a	5555.3 a	11532.9 a	7751.1 a
Inorganic		5466.1 b	9455.6 a	4082.5 a	7692.8 a	6080.0 a	7211.9 a	6710.3 b	4856.8 b	10509.7 a	7075.3 b

† Yield data for 1999 and 2000 are missing.
‡ Means without a letter in common differ significantly at the 0.10% probability level.

Table 4. Analysis of variance results for corn grain yield from 1991 through 2001.

Source	P = F (0.10)								
	1991	1992	1993	1994	1995	1996	1997	1998†	2001
Tillage (T)	0.0651	0.0050	0.0745	0.0350	ns	<0.0001	0.0218	<0.0001	0.1085
Rotation (R)	0.1007	0.0116	0.0082	0.0413	0.1090	<0.0001	0.0041	<0.0001	ns
Fertilizer (F)	0.0255	ns	ns	ns	ns	ns	0.0560	0.1037	0.0156
R × T	ns	ns	ns	ns	ns	ns	ns	ns	ns
R × F	ns	0.0060	ns	ns	ns	ns	ns	0.1000	ns
T × F	ns	0.0275	ns	ns	ns	ns	ns	ns	ns
R × T × F	ns	ns	ns	ns	ns	ns	ns	ns	ns†

† Yield data for 1999 and 2000 are missing.

have been reported by Mitchell and Tu (2005) and Sistani et al. (2008). They attributed increased corn grain yield from poultry litter additions to an increase in micronutrient concentrations supplied to the soil, particularly Zn found in the litter.

Overall, the findings from this study show that crop rotations had the greatest impact on corn grain yields as evidenced by a more consistent impact on yield compared with tillage and poultry litter application. There was no tillage × rotation × fertilization interaction effect observed for corn grain yield in this study.

Soybean Grain Yield Response to Treatments

Mean soybean grain yields for each year are shown in Table 5. Tillage, crop rotations, and fertilization influenced grain yield. This was evidenced by tillage, rotations, and fertilization main effects (Table 6). However, no tillage × rotation × fertilizer interaction or any combination of the effects was observed between treatments. Tillage significantly impacted yield in 1992, 1994, 1997, and 2001. Conventional tillage produced the greatest yields in 1992 and 1994, while no-tillage produced the greatest yields in 1997 and 2001. These results suggest that, unlike the corn systems evaluated, tillage was less effective at impacting soybean grain yield compared with corn. Wilhelm and Wortmann (2004) found similar results in a rain-fed 16-yr corn and soybean production system in southeastern Nebraska. Deep tillage increased corn yield, whereas no differences were observed between tillage in the soybean system. Lueschen et al. (1992) reported that soybean grain yield differences between tillage (moldboard, chisel, spring disking) were small and inconsistent, making it nearly impossible to single out any tillage system. This suggests that a similar level of soybean grain production can be achieved with no-till or strip-till compared with conventional tillage.

Rotating soybean with a corn crop significantly impacted yield in 1991, 1992, 1995, and 1998, with the soybean–corn rotation treatment increasing yield in 1991, 1992, and 1995 and decreasing yields in 1998. Although not significant in all years, soybean–corn rotation produced higher yields 6 out of

Table 5. Effects of tillage, poultry litter application, and crop rotation on soybean grain yields for 1991 through 2001.

Tillage system	Fertilization practice	Yield of soybean									
		1991	1992	1993	1994	1995	1996	1997	1998†	2001	9-yr mean
		kg ha^{-1}									
Continuous soybean											
No tillage	litter	2525.19	1251.74	2018.23	3134.44	3429.05	2487.90	3117.80	1962.03	2869.21	2532.838
	inorganic	2084.63	1050.55	1669.37	2703.18	3447.64	2464.90	2719.01	1750.34	3469.65	2373.252
Strip tillage	litter	2770.72	1633.82	2028.18	3108.29	3331.48	2517.55	2883.37	2253.43	3058.61	2620.606
	inorganic	2223.23	1109.92	1766.49	2893.00	2827.21	2060.97	2442.94	1881.23	3163.39	2263.153
Conventional tillage	litter	2815.16	2045.86	1983.19	3701.96	3327.51	2630.14	2877.32	1911.85	2752.35	2671.704
	inorganic	2281.48	1675.60	1730.06	2680.43	3104.33	2175.72	2255.94	1628.24	2583.10	2234.989
Soybean–corn rotation											
No tillage	litter	2829.50	1930.50	1850.31	3020.51	3688.59	2620.96	3102.97	1618.38	2832.94	2610.518
	inorganic	2633.62	1782.94	1630.22	2755.85	3164.12	2350.14	2641.67	1646.26	3102.94	2411.973
Strip tillage	litter	2732.82	1777.89	1772.89	3160.85	3625.65	2588.83	2977.84	1804.16	2571.01	2556.882
	inorganic	2424.84	1472.54	1590.19	2716.34	3250.88	2189.49	2008.01	1637.46	3477.71	2307.496
Conventional tillage	litter	2715.16	2045.86	1983.19	3701.96	3327.51	2630.14	2877.32	1911.85	2752.35	2660.593
	inorganic	2281.48	1675.60	1730.06	2680.43	3104.33	2175.72	2255.94	1628.24	2583.10	2234.989
Rotation means											
Continuous soybean		2450.1 b‡	1461.3 b	1865.9 a	3036.9 a	3244.5 b	2389.5 a	2710.7 a	1897.9 a	2982.7 a	2449.43
Soybean–corn rotation		2652.4 a	1895.1 a	1767.7 a	3163.0 a	3501.4 a	2467.2 a	2716.1 a	1731.5 a	2918.2 a	2534.13
Tillage means											
No tillage		2518.2 a	1504.0 b	1792.0 a	2903.5 b	3432.3 a	2480.9 a	2895.4 a	1744.3 a	3068.7 a	2482.14
Strip tillage		2537.9 a	1498.5 b	1789.4 a	2969.6 b	3258.8 a	2339.2 a	2578.0 b	1894.1 a	3067.7 a	2437.02
Conventional tillage		2597.5 a	2033.0 a	1869.0 a	3426.7 a	3427.8 a	2464.1 a	2666.8 b	1805.6 a	2715.1 b	2556.17
Fertilization means											
Litter		2742.5 a	1851.7 a	1920.7 a	3331.5 a	3513.4 a	2602.9 a	2967.6 a	1916.1 a	2817.5 b	2629.322
Inorganic		2360.0 b	1504.6 b	1712.9 b	2868.3 b	3232.5 b	2253.7 b	2459.2 b	1713.2 b	3083.5 a	3254.211

† Yield data for 1999 and 2000 are missing.
‡ Means without a letter in common differ significantly at the 0.10% probability level.

Table 6. Analysis of variance results for soybean grain yield from 1991 through 2001.

Source	$P = F$ (0.10)								
	1991	1992	1993	1994	1995	1996	1997	1998†	2001
Tillage (T)	ns	<0.0001	ns	0.0110	ns	ns	ns	ns	0.0829
Rotation (R)	0.0879	<0.0001	ns	ns	0.0503	ns	ns	0.0530	ns
Fertilizer (F)	0.0021	0.0012	0.0333	0.0030	0.0331	<0.0001	<0.0001	0.0198	0.0731
T × R	ns	ns	ns	ns	ns	ns	ns	ns	ns
R × F	ns	ns	ns	ns	ns	ns	ns	ns	ns
T × F	ns	ns	ns	ns	ns	ns	ns	ns	ns
T × R × L	ns	ns	ns	ns	ns	ns	ns	ns	ns†

† Yield data for 1999 and 2000 are missing.

9 yr compared with continuous soybean. In 1993 and 1998, when continuous soybean produced higher grain yields than soybean following a corn rotation, the driest growing seasons were observed, thereby producing soil conditions that were conducive for normal yields. On the other hand, although the 2001 growing season as a whole experienced higher than the normal 30-yr average rainfall, June was an extremely dry month, which most likely negatively impacted soybean production. Similar results have been reported by others, showing that soybean grown in rotation produced consistently higher yields compared with monoculture (Dabney et al., 1988; Edwards et al., 1988; Pedersen and Lauer, 2003).

Fertilization treatments had the greatest impact on soybean yield. Addition of poultry litter to the wheat cover crop increased soybean yield in all years evaluated between 1991 and 2001, except 2001. Poultry litter addition to the soybean cropping system had the greatest impact on grain yield compared with tillage and crop rotations. This is in agreement with Adeli et al. (2005), who observed that applying poultry litter to soybean at planting increased grain yield compared with commercial fertilizer. Adeli et al. (2005) reported that the increased grain yield was attributed to macro- and micronutrients from the applied poultry. In their study, the same amount of available P and N that was in the poultry litter was applied to plots not receiving poultry litter using commercial fertilizer. Regardless of these supplements, the poultry litter treatments produced higher grain yield than the plots that received no poultry litter. In our study, poultry litter was applied each fall (November) to the wheat cover crop. Commercial fertilizer was applied at the same rate as poultry litter based on total N and P content (not available N and P content). The plots that received poultry litter produced higher yields than the commercial fertilizer plots. Thus, these results indicate that the addition of poultry litter to winter cover crops can effectively increase grain yield production of the succeeding soybean crop.

CONCLUSIONS

Improving the integration of conservation agricultural practices is important to enhance conservation tillage in the Southeast. This study demonstrated the influence that tillage, poultry litter application, and crop rotations can have on grain production of corn and soybean managed under conservation tillage systems for other types of soils and climates than in the northern Corn Belt soil. Grain yield measurements were evaluated from 1991 to 2001. Results from this study show that crop rotations are very important in corn production systems in the Southeast. Corn rotated with soybean had the most consistent increase in yield compared with continuous corn. Soybean gain yield also was increased with crop rotation. This was most evident in years where rainfall total was close to the 30-yr average or above. Addition of poultry litter also increased grain yield of corn and soybean. An increase in grain yield resulting from poultry litter application was most likely caused by addition of micronutrients to the soil. No-till, strip tillage, and conventional tillage all produced similar levels of soybean grain production, whereas conventional tillage was favored with corn production. This study shows that the use of poultry litter and crop rotations in a conservation tillage system could increase grain yield production of corn and soybean in the southeastern United States.

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