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Long-term effects of poultry litter and conservation tillage on crop yields and soil phosphorus in cotton–cotton–corn rotation

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ABSTRACT

Long-term field experiments are needed to fully realize positive and negative impacts of conservation tillage and poultry litter application. A study was initiated on a Decatur silt loam soil at the Tennessee Valley Research and Extension Center, Belle Mina, AL, USA in 1996 to evaluate cotton (*Gossypium hirsutum* L.) performance with long-term poultry litter (PL) application under different tillages and to study the build up of phosphorus (P) with application of PL. Treatments include incomplete factorial combinations of three tillage systems [conventional till (CT), mulch till (MT), and no-till (NT)], two cropping systems [cotton-fallow and cotton-winter rye (*Secale cereale* L.)], and two nitrogen sources and rates [100 kg N ha^{-1} from ammonium nitrate (AN), and 100 and 200 kg N ha^{-1} from poultry litter (PL)]. Cotton was rotated with corn (*Zea mays* L.) every third year. Results from 2003 to 2008 showed that all tillages gave similar cotton lint yields with AN at 100 kg N ha^{-1}. Application of PL at 100 kg N ha^{-1} in NT plots resulted in 12 and 11% yield reductions compared to that of CT and MT, respectively. However, NT plots with higher quantity of PL (200 kg N ha^{-1}) gave similar yields to CT and MT at 100 kg N ha^{-1}. During corn years, higher residual fertility of PL, in terms of grain yields, was observed in NT plots compared to CT and MT. Long-term PL application (100 kg N ha^{-1} $year^{-1}$) helped to maintain original soil pH in CT and MT while AN application decreased soil pH. In NT plots, PL at 100 kg N ha^{-1} was not sufficient to maintain original soil pH, but 200 kg N ha^{-1} maintained original pH. Although not-significant, elevated P levels were observed in all tillages compared to original P levels which indicates possibility of P build up in future with further application of PL. Application of PL at double rate (200 kg N ha^{-1}) in NT plots resulted in significant build up of P. Results indicate that NT gives similar yields to CT when received AN, but needs higher rate of PL application to achieve similar yields to CT.

1. Introduction

No-tillage concept has started in 1950s, but its adoption began widely in 1980s in the United States and then in Australia, South America, and Canada (Triplett and Dick, 2008). Improved planters and herbicides helped for rapid expansion of area under no-tillage. Area of cropland under no-tillage, in the USA, increased form 5% (5.7 million ha) in 1989 to 23% (25 million ha) in 2004 (CTIC, 2006). Major crops that are grown under no-tillage, in the USA, are soybean, corn, cotton and sorghum. No-tillage gained popularity for its benefits over conventional tillage. Major benefits of no-tillage, compared to conventional tillage, include reduced soil erosion (Nyakatawa et al., 2001a), decreased input, labor and equipment cost (Duiker, 2004), and improved soil quality (Raper et al., 1994; Kabir et al., 1997; Wander and Bollero, 1999; Mozafar et al., 2000; McVay et al., 2006).

Cotton is one of the major crops grown in southeastern USA. Field studies have reported both significant increases and decreases in cotton yields due to no-tillage (Ishaq et al., 2001; Nyakatawa et al., 2000; Pettigrew and Jones, 2001; Raper et al., 2000; Schwab et al., 2002). Major problems associated with no-tillage include poor seedling emergence, root penetration problems, less vigorous seedlings and poor crop growth due to soil compaction, resulting in reduced cotton yields (Schertz and Kemper, 1994; Raper et al., 2000; Schwab et al., 2002). In some cases, conservation tillage has been found to lower soil temperature, which may reduce seedling emergence and growth of cotton (Stevens et al., 1992; Norfleet et al., 1997). Hence, many farmers were reluctant to adopt no-tillage on a large scale, as a result only 17.5% of cotton area is currently under no-till in the USA (CTIC,

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2006). It is therefore imperative to build soil organic matter and to reduce soil compaction to have good cotton germination and seedling establishment in no-tillage. It may take 3 years for the no-till system to become fully functional when changing from tilled to NT culture (Triplett and Dick, 2008). Therefore, long-term use of NT should be encouraged to realize its potential agronomic and environmental benefits over tilled system (Grandy et al., 2006). To make cotton production more sustainable under a conservation tillage system, inclusion of winter cover crop has been reported to be essential (Bauer and Busscher, 1996; Boquet et al., 2004; Keeling et al., 1989; Langdale et al., 1990; Reddy et al., 2004; Schwenke et al., 2001). Cover crops can increase soil organic matter, improve soil water retention, and reduce soil erosion (Khanh et al., 2005; Nyakatawa et al., 2001b). Cover crops also help in reducing the potential leaching of nutrients and contamination of surface and ground water by assimilating them into plant biomass (Meisinger et al., 1991; Brandi-Dohrn et al., 1997). Rye is an effective winter cover crop in the southeastern USA region because it establishes rapidly, provide good winter ground cover and produce consistent amounts of biomass (Sustainable Agriculture Network, 1998).

The poultry industry in southern states of USA, such as Alabama, Arkansas, Georgia, Mississippi and North Carolina accounts for over 60% of the 8.6 billion broilers raised in the USA (USDA-National Agricultural Statistics Service, 2007) and generates 6 billion kg of poultry litter (PL) out of total 10 billion kg of PL produced in the country every year. In an effort to dispose of the PL, poultry growers usually over apply the litter to pastures and hayfields in close proximity to poultry house areas, thus overloading soils with nutrient rich PL (Cabrera and Sims, 2000; Ritter, 2000). This indiscriminate PL disposal practice, coupled with the rapid growth of poultry industry, is leading to major environmental problems like ground water contamination and eutrophication (Carpenter et al., 1998; Sharpley, 1995; Staver and Brinsfield, 1995). Thus safe disposal of this byproduct without detrimental effects on the immediate environment is of national concern.

Utilizing PL as a nutrient source provides an environmentally friendly way of disposing of the large quantities of PL produced on poultry farms in several southeastern states (Reddy et al., 2004). Poultry litter is also an economical alternative to increasingly expensive fertilizers. Bosch and Napit (1992) studied the economic viability of transporting broiler litter from areas of surplus to areas of deficit supply. The results of the study showed that the value of litter as a fertilizer was higher than the costs associated with the transfer of litter even to a distance of 50 miles. Many studies showed beneficial effects of PL on cotton yields (Mitchell and Tu, 2005; Nyakatawa et al., 2000; Reddy et al., 2007). At the same time many other studies documented potential problems with continuous application of PL for crop production (Adeli et al., 2007; Gascho and Hubbard, 2006; Mitchell and Tu, 2006; Tewolde et al., 2005; Wood et al., 1996). Usually PL is applied based on the N requirement of the crop. Continuous application of PL over years, based on N requirement, may result in excessive application of P and its build up in surface soil, which is prone to surface runoff and consequent eutrophication (Daniel et al., 1998; Mitchell and Tu, 2006; Moore et al., 1995; Novak et al., 2002). Eutrophication has been linked to a variety of ecological and human health problems (Boesch et al., 2001).

It has been hypothesized that once in few years crop rotation with an exhaustive crop without any fertilization may help in removal of residual fertility such as excessive phosphorus by acting as a scavenger, and prevents nutrient loss into runoff. Further, crop rotations help to improve soil fertility (Bagayoko et al., 1992), reduce erosion (Wang et al., 2002), and reduce buildup of pests (Baird and Bernard, 1984; Long and Todd, 2001; Young et al., 1986). Corn, one of the major crops in southeastern USA, can be considered to rotate with cotton. It can be assumed that tap root and fibrous root systems in cotton and corn, respectively, help in uniform excavation of nutrients from soil layers. Further, corn supplies plant residues which help to increase soil organic matter in conservation tillage cotton production systems (Reeves, 1997).

Large-scale adoption of no-tillage can be achieved by demonstrating competitive yields and improved soil quality relative to conventional tillage. To fully realize the benefits or deficits of poultry litter application and conservation tillage on cotton production, a long-term study was initiated with the following objectives (I) to evaluate the effect of long-term application of PL, conservation tillage and cover crop on cotton lint yields and (II) to study the P status in the soil after long-term PL application under conventional and conservation tillage systems with corn rotation and winter rye as a cover crop. Data on growth and yield components from 1997 to 2001 were reported earlier (Reddy et al., 2004). Results on lint yields for remaining years and status of pH and available P 12 years after initiation of the study are discussed in this paper.

2. Materials and methods

2.1. Treatments and experimental design

A long-term field study was initiated in 1996 at the Tennessee Valley Research and Extension Center in Belle Mina, Alabama (34°41′N, 86°52′W) on a Decatur silt loam (clayey, kaolinitic thermic, Typic Paleudults) soil. Table 1 describes the 11 treatments evaluated in this study consisting of tillage, cropping system and N sources and rates of application. The treatments included three tillage systems: conventional tillage (CT), mulch tillage (MT), and no-tillage (NT); two cropping systems: cotton-fallow (C-F; cotton

Table 1
List of treatments used in the long-term study, Belle Mina, AL.

Treatment	Tillage	Cropping system		Nitrogen source	Nitrogen rate (kg ha^{-1})
		Summer	Winter		
1	Conventional till	Cotton	Rye	None	0
2	Conventional till	Cotton	Fallow	Ammonium nitrate	100
3	No-till	Cotton	Fallow	Ammonium nitrate	100
4	Conventional till	Cotton	Rye	Ammonium nitrate	100
5	Conventional till	Cotton	Rye	Poultry litter	100
6	Mulch till	Cotton	Rye	Ammonium nitrate	100
7	Mulch till	Cotton	Rye	Poultry litter	100
8	No-till	Cotton	Rye	Ammonium nitrate	100
9	No-till	Cotton	Rye	Poultry litter	100
10	No-till	Cotton	Fallow	None	0
11	No-till	Cotton	Rye	Poultry litter	200

in summer and fallow in winter), and cotton-rye (C-R; cotton in summer and cereal rye cover crop in winter); two sources of nitrogen: ammonium nitrate at 100 kg N ha^{-1} and poultry litter at 100 and 200 kg N ha^{-1}. The experimental design was a randomized complete block with an incomplete factorial treatment arrangement. Due to constraints on land availability, out of all combinations, only 11 important treatments were selected and replicated four times.

Poultry litter was applied based on the N content of it. Each year, prior to land application, litter was analyzed with the LECO CN 2000 (LECO Corporation, St. Joseph, MI) to determine the total N content. The PL used in the study contained nitrogen on average 30 g kg^{-1}. Poultry litter application rates were adjusted to a 60% of N availability for the crop during the first year (Keeling et al., 1995).

The total amounts of AN and PL were applied to the plots by hand on the day of planting. Ammonium nitrate was applied at a rate of 100 kg N ha^{-1}, the extension recommendation for cotton in the region (Adams et al., 1994), but two rates of PL were used in the no-tillage treatments (100 and 200 kg N ha^{-1}) due to variability in N release associated with PL and to determine if higher rates of PL could be safely and sustainably utilized. The 200 kg N ha^{-1} litter treatment was only applied in the no-tillage system since no-tillage with a cereal crop has become the standard in the region. Prior to planting, the experimental plots received a blanket application of a 336 kg ha^{-1} of a 0–20–20 fertilizer each year from 1996 to 1999 and 112 kg ha^{-1} of a 0–0–60 fertilizer in 2000, and 224 kg ha^{-1} of 5–20–20 fertilizer in 2001 and 2002 to nullify the effects of P and K applied through poultry litter. This practice was abandoned after 2002 since levels of P and K reached critical levels for cotton production.

After application of PL and AN to respective plots, tillage operations were carried out. Conventional tillage included moldboard plowing in November to a depth of 15 cm and chisel plowing in April to a depth of 15 cm followed by disking to a depth of 10–15 cm before cotton seeding. Mulch till included only chisel plowing to partially incorporate crop residues into soil before planting. Smooth seed beds were prepared in both CT and MT plots using a roterra. In no-till plots, soil was disturbed only to the extent of opening furrows for seeding purpose. While tilling, PL and AN were incorporated into soil in conventional and mulch tillage plots, and left unincorporated in no-tillage plots.

After tillage, cotton was planted using a planter in all tillages. Plot size was 8-m wide and 9-m long, which resulted in eight rows of cotton spaced 1-m apart. Irrigation was applied based on crop moisture requirement. During the experiment 100, 43, 109, 204, 257 and 170 mm of irrigation water was applied in 2003, 2004, 2005, 2006, 2007 and 2008, respectively. Weed control, cotton defoliation, and other cultural practices were carried out as per the recommendation of the local extension service.

Table 2
Cropping sequence followed in the long-term experiment, Belle Mina, AL, 1997–2008.

Season	Year	Crop	
		In treatments 1, 4–9 and 11	In treatments 2, 3 and 10
Summer	1997	Cotton	Cotton
Winter/spring	1997/1998	Rye	Fallow
Summer	1998	Cotton	Cotton
Winter/spring	1998/1999	Fallow	Fallow
Summer	1999	Corn	Corn
Winter/spring	1999/2000	Rye	Fallow
Summer	2000	Cotton	Cotton
Winter/spring	2000/2001	Rye	Fallow
Summer	2001	Cotton	Cotton
Winter/spring	2001/2002	Fallow	Fallow
Summer	2002	Corn	Corn
Winter/spring	2002/2003	Rye	Fallow
Summer	2003	Cotton	Cotton
Winter/spring	2003/2004	Rye	Fallow
Summer	2004	Cotton	Cotton
Winter/spring	2004/2005	Fallow	Fallow
Summer	2005	Corn	Corn
Winter/spring	2005/2006	Rye	Fallow
Summer	2006	Cotton	Cotton
Winter/spring	2006/2007	Rye	Fallow
Summer	2007	Cotton	Cotton
Winter/spring	2007/2008	Fallow	Fallow
Summer	2008	Corn	Corn

2.2. Crop rotation and cover cropping

Corn was planted every third year as a rotation crop after two continuous cotton years in a cotton–cotton–corn cropping sequence. Table 2 explains the history of cropping sequence followed from 1997 through 2008. Corn was planted in all plots uniformly without applying any tillage treatment/fertilizers. The winter rye cover crop was planted in fall of each year after cotton with a no-till drill in selected plots according to the treatment plan (Table 1). Rye cover crop was killed with 1.12 kg a.i. ha^{-1} glyphosate [*N*-(phosphonomethyl) glycine] herbicide about 7 d after flowering in the spring. Similar to cotton, row spacing given for corn was 1 m and row spacing given for rye was 20 cm. Table 3 gives more details on varieties, seed rate, planting and harvesting times for corn and rye during 2003–2008. Since corn generally adds sufficient crop residue, winter rye was not planted in corn planting years (Table 2). The time between killing of winter rye and cotton planting was about 4 week each year to allow for total drying of residues. No fertilizer was applied to the cover crop.

Table 3
Cropping scheme, varieties, planting and harvest dates of cotton, winter rye and corn crops, Belle Mina, AL, 2003–2008.

Season	Year	Crop	Variety	Seeding rate	Planting date	Harvest date
Summer	2003	Cotton	SG 215 BR	16 kg ha^{-1}	May 27, 2003	October 23, 2003
Fall/spring	2003/2004	Winter rye	Elbon	60 kg ha^{-1}	November 11, 2003	April 10, 2004
Summer	2004	Cotton	STN 4892 BR	16 kg ha^{-1}	May 18, 2004	October 25, 2004
Fall/spring	2004/2005	Fallow	–	–	–	–
Summer	2005	Corn	Pioneer 31G98	75,000 plants ha^{-1}	April 5, 2005	September 21, 2005
Fall/spring	2005/2006	Winter rye	Elbon	60 kg ha^{-1}	October 11, 2005	April 12, 2006
Summer	2006	Cotton	DPL 445 BR	16 kg ha^{-1}	May 17, 2006	October 2, 2006
Fall/spring	2006/2007	Winter rye	Elbon	60 kg ha^{-1}	October 25, 2006	April 13, 2007
Summer	2007	Cotton	DPL 445 BR	16 kg ha^{-1}	May 4, 2007	September 20, 2007
Fall/spring	2007/2008	Fallow	–	–	–	–
Summer	2008	Corn	NK Brand N70-C7 GT/CB/LL	75,000 plants ha^{-1}	March 26, 2008	September 3, 2008

2.3. Data collection

In this long-term study, from 2003 through 2008, cotton was planted four times (2003, 2004, 2006 and 2007) and corn was planted two times (2005 and 2008) in cotton–cotton–corn rotation (Table 2). At maturity, seed cotton was picked twice in the central four rows of each plot and lint yield was calculated by using a ginning percentage of 39%. Corn ears were harvested 4–6 weeks after physiological maturity in the central four rows in each plot. The ears were shelled using a small plot combine and yields were calculated. Seed weights were adjusted for a moisture content of 15.5%. Cotton and corn residue were left in the field. Soil samples were collected from the experimental plots in fall 1996 to determine soil chemical status before imposing the treatments. Twenty-four soil cores were randomly collected from each of the four replications using a tractor powered hydraulic probe. The soils were composited by replication and by depths of 0–15, 15–30, 30–60, and 60–90 cm. Again in fall 2008, two cores of soil samples were collected from each plot at same depths. Soil samples were analyzed for available P concentrations. The double acid (Mehlich-1 extractant) method was used to extract available P (Mehlich, 1953). Available P was determined using ascorbic acid method (Murphy and Riley, 1962); P concentration was read with a spectrophotometer Spectronic 601 (Milton Roy, Rochester, NY) set at 880 nm. Soil pH was measured using a glass electrode connected to the Orion A290 pH meter in a 1:2 soil: water suspension.

2.4. Data analysis

Study design was a randomized complete block with an incomplete factorial treatment arrangement. Cotton lint yield data for the years 2003, 2004, 2006 and 2007, corn grain yields for the years 2005 and 2008, and available soil P and pH for the year 2008 were analyzed using GLM procedures of the Statistical Analysis System (SAS Institute, 2004). Year × treatment interactions were found significant and hence data were presented for individual years. Since the treatments were laid out in an incomplete factorial arrangement, treatments 2, 3, 4 and 8 (Table 1) containing complete combination of tillage and cropping systems were used to determine the effect of tillage × cropping system interaction. Similarly, treatments 4–9 containing complete combinations of tillage and N source were used to determine the effect of tillage × N source interaction. Since poultry litter was applied at 200 kg N ha^{-1} only in no-tillage (treatment 11), contrast analysis was done separately to compare the effect of 100 kg N ha^{-1} vs. 200 kg N ha^{-1}. Treatment means were compared using the LSD procedure at alpha level 0.05 within these sets of analyses. Available P and pH at different depths in 2008 soil samples were compared with the initial P and pH values in 1996 at the beginning of the experiment.

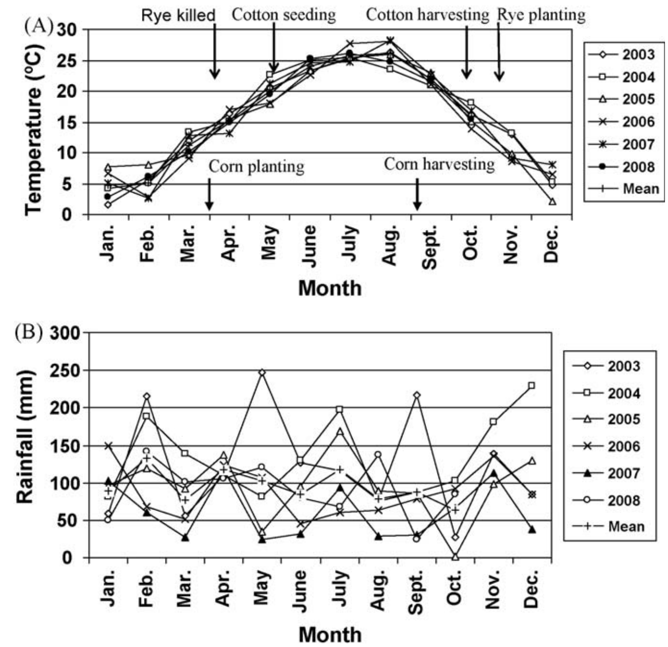

Fig. 1. Mean temperature and total monthly rainfall during the experiment, Belle Mina, AL, 2003–2008.

3. Results and discussion

3.1. Weather data

Monthly mean temperature and total rainfall data at experimental site during 2003–2008 are presented in Fig. 1. All years showed similar trends in air temperatures with highest temperatures in June, July and August and lowest in December, January and February. Years 2006, 2007 and 2008 had received less than average rainfall. However, it did not reflect on the yields since the crops were supplemented with irrigation water.

3.2. Cotton lint yields

Cotton lint yields were affected by tillage and N source interactions in years 2003, 2006 and 2007 (Table 4). Lint yields were higher in 2006 and 2007 compared to 2003. This might be attributed to varietal difference (Table 2). In 2003, application of ammonium nitrate (AN) at 100 kg N ha^{-1} gave similar lint yields in conventional (1468 kg ha^{-1}), mulch (1517 kg ha^{-1}) and no-tillage (1554 kg ha^{-1}) plots. Similar trend was also observed in 2006 and 2007. Application of poultry litter (PL) at 100 kg N ha^{-1} gave significantly higher lint yields in conventional till plots (1427 kg ha^{-1}) compared to that of no-tillage (1271 kg ha^{-1}) in 2003. Similar trend was also observed in 2006 and 2007. Mulch

Table 4
Cotton lint yields as influenced by N sources in different tillage systems, Belle Mina, AL, 2003–2007.

Tillage	N source					
	2003		2006		2007	
	100ANN[a] (kg ha^{-1})	100PLN (kg ha^{-1})	100ANN[a] (kg ha^{-1})	100PLN (kg ha^{-1})	100ANN[a] (kg ha^{-1})	100PLN (kg ha^{-1})
CT	1468 a	1427 a	1981 ab	1996 ab	2021 a	2012 a
MT	1517 a	1300 b	1879 ab	2016 a	1904 ab	2028 a
NT	1554 a	1271 b	1862 b	1701 c	1944 ab	1789 b

In each year, treatment means followed by the same lowercase letter are not significantly different from each other at $p \leq 0.05$.
[a] CT = conventional tillage, MT = mulch tillage, NT = no-tillage, 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter.

Table 5
Cotton lint yields with poultry litter at 200 kg N ha^{-1} in no-tillage in relation to poultry litter or ammonium nitrate at 100 kg N ha^{-1} in different tillages.

	2003 (kg ha^{-1})	2006 (kg ha^{-1})	2007 (kg ha^{-1})
CT-100ANN vs. NT-200PLN	1468 vs. 1561 (NS)	1980 vs. 1829 (NS)	2021 vs. 2053 (NS)
CT-100PLN vs. NT-200PLN	1427 vs. 1561 (NS)	1996 vs. 1829*	2012 vs. 2053 (NS)
MT-100ANN vs. NT-200PLN	1517 vs. 1561 (NS)	1878 vs. 1829 (NS)	1904 vs. 2053 (NS)
MT-100PLN vs. NT-200PLN	1300 vs. 1561***	2016 vs. 1829*	2028 vs. 2053 (NS)
NT-100ANN vs. NT-200PLN	1514 vs. 1561 (NS)	1862 vs. 1829 (NS)	1944 vs. 2053 (NS)
NT-100PLN vs. NT-200PLN	1271 vs. 1561***	1701 vs. 1829 (NS)	1789 vs. 2053*

CT = conventional tillage, MT = mulch tillage, NT = no-tillage, 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter, 200PLN = 200 kg N ha^{-1} as poultry litter.
* Significant at $p \leq 0.05$.
*** Significant at $p \leq 0.001$.

Table 6
Cotton lint yields as influenced by cropping system in conventional and no-tillage systems, Belle Mina, AL, 2004.

Tillage	Cropping system	
	Cotton-fallow (kg ha^{-1})	Cotton-rye (kg ha^{-1})
Conventional tillage	1045 b	1180 a
No-tillage	1151 ab	1267 a

Treatment means followed by the same lowercase letter are not significantly different from each other at $p \leq 0.05$.

tillage also gave significantly higher lint yields with PL at 100 kg N ha^{-1} compared to no-tillage in 2006 and 2007. On average, application of PL at 100 kg N ha^{-1} in no-tillage plots resulted in 12 and 11% reduction in lint yields compared to conventional and mulch tillages, respectively. Tewolde et al. (2008) observed similar yield reductions in no-tillage system and suggested that litter left on surface in no-tillage soils was subjected to nutrient loss through volatilization and runoff. In the present study, both the N sources were surface applied in no-tillage plots, but yield reductions were observed only with PL application. In the same experiment, Roberson et al. (2008) measured CO_2 emissions for 3 years and reported that conventional and mulch tillage plots with PL at 100 kg N ha^{-1} released 27 and 25% higher CO_2, respectively into the atmosphere compared to no-tillage with the same N source. It seems reasonable to assume that slow mineralization of PL along with nutrient loss through volatilization and runoff could be the reasons for yield reductions in no-tillage plots. Further study would be required to confirm that. However, application of PL at a double rate (200 kg N ha^{-1}) in no-tillage plots resulted in similar lint yields compared to conventional and mulch till plots receiving either AN or PL at 100 kg N ha^{-1} (Table 5). Lint yields in no-tillage plots with PL at 200 kg N ha^{-1} ranged between 1561 and 2053 kg ha^{-1} with an average of 1814 kg ha^{-1}. It was evident that application of AN at 100 kg N ha^{-1} in a no-tillage system is sufficient to meet the yields of conventional and mulch tillages, but it needs more than 100 kg N ha^{-1} when it received N in the form of PL. Mulch tillage gave similar lint yields to conventional tillage with application of PL at 100 kg N ha^{-1} except in 2003.

Interaction effect of tillage × cropping system on lint yields was found significant only in 2004 (Table 6). Conventional tillage with winter rye cover crop gave significantly higher lint yields (1180 kg ha^{-1}) compared to winter fallow (1045 kg ha^{-1}). However, no-tillage gave similar yields with and without winter rye cover crop. No-tillage with cotton-rye cropping system gave significantly higher lint yields compared to that of conventional tillage under cotton-fallow cropping system. Apart from yield gains, multiple benefits such as reduced soil erosion (Nyakatawa et al., 2001b), reduced nitrate leaching into ground water (Brandi-Dohrn et al., 1997; Kessavalou and Walters, 1997), increased soil organic matter (Tisdall and Oades, 1982; Oades, 1984), soil moisture conservation by providing mulch (Nyakatawa and Reddy, 2000; Steiner, 1994) and weed control (Reddy, 2003) have been reported due to rye cover crop. This offers great promise for the use of rye as a winter cover crop in southeastern USA.

3.3. Corn grain yields

In 2005 and 2008, corn was grown as a rotation crop in cotton–cotton–corn cropping sequence. Corn did not receive tillage or N source treatments and was grown on residual fertility. In both the years 2005 and 2008, tillage and N source interactions on corn grain yields were significant (Table 7). Application of PL at 100 kg N ha^{-1} in conventional till plots gave similar or higher corn grain yields compared to AN at the same rate. In mulch tillage plots, application of PL at 100 kg N ha^{-1} recorded similar grain yields to that of AN at the same rate. However, PL at 100 kg N ha^{-1} in no-tillage plots recorded significantly higher grain yields (37 and 36%) compared to AN at the same rate in 2005 and 2008, respectively. This was attributed to higher residual effect of PL in no-tillage plots compared to conventional and mulch till plots. Surface application of PL in no-tillage plots during cotton years might be responsible for its slow mineralization in the year of application and higher residual fertility in the following year. It was evidenced with lower cotton lint yields in no-tillage plots in current years of PL application compared to conventional and mulch tillages. Evers (1999) estimated that about 60% of N in PL would be available in the first year and rest adds to residual fertility. In a long-term study, Mitchell and Tu (2005) found that the residual effect of PL in

Table 7
Corn grain yields as influenced by N sources in different tillage systems, Belle Mina, AL, 2005 and 2008.

Tillage	N source			
	2005		2008	
	100ANN[a] (kg ha^{-1})	100PLN (kg ha^{-1})	100ANN (kg ha^{-1})	100PLN (kg ha^{-1})
Conventional tillage	3505 b	4419 ab	4714 b	5831 a
Mulch tillage	4319 ab	3834 b	4859 b	5434 ab
No-tillage	3832 b	5242 a	4540 b	6192 a

In each year, treatment means followed by the same lowercase letter are not significantly different from each other at $p \leq 0.05$.
[a] CT = conventional tillage, MT = mulch tillage, NT = no-tillage, 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter.

Table 8
Corn grain yields with poultry litter at 200 kg N ha^{-1} in no-tillage in relation to poultry litter or ammonium nitrate at 100 kg N ha^{-1} in different tillages.

	2005 (kg ha^{-1})	2008 (kg ha^{-1})
CT-100ANN vs. NT-200PLN	3505 vs. 6668***	4714 vs. 8580***
CT-100PLN vs. NT-200PLN	4419 vs. 6668***	5831 vs. 8580***
MT-100ANN vs. NT-200PLN	4318 vs. 6668***	4859 vs. 8580***
MT-100PLN vs. NT-200PLN	3834 vs. 6668***	5434 vs. 8580***
NT-100ANN vs. NT-200PLN	3832 vs. 6668***	4540 vs. 8580***
NT-100PLN vs. NT-200PLN	5242 vs. 6668**	6192 vs. 8580***

CT = conventional tillage, MT = mulch tillage, NT = no-tillage, 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter, 200PLN = 200 kg N ha^{-1} as poultry litter.
** Significant at $p \leq 0.01$.
*** Significant at $p \leq 0.001$.

Table 9
Soil pH (0–15 cm) as influenced by N sources in different tillage systems, Belle Mina, AL, 2008.

Tillage	N source	
	100ANN[a]	100PLN
Conventional tillage	5.52 c	6.00 ab
Mulch tillage	5.53 c	6.10 a
No-tillage	5.58 bc	5.89 abc

Treatment means followed by the same lowercase letter are not significantly different from each other at $p \leq 0.05$.
[a] 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter.

the second year after application resulted in 30–50% of the cotton lint yield and 25–65% of the corn grain yield that resulted from a standard N fertilization rate. In the present study, unlike in no-tillage, residual effect of PL was not observed in conventional and mulch tillages. This was attributed to soil incorporation of PL and consequent faster mineralization in the year of application. As expected, no-tillage plots that received 200 kg N ha^{-1} in the form of PL (in cotton years) recorded significantly higher corn grain yields in 2005 (6668 kg ha^{-1}) and 2008 (8580 kg ha^{-1}) compared to all other interactions (Table 8). Corn grain yields were not significantly influenced by winter rye cover crop.

3.4. Soil pH

Soil pH in the surface 0–15 cm was significantly influenced by tillage and N source interactions in 2008 (Table 9). Conventional and mulch till plots that received long-term PL application at

Table 10
Soil pH and P with poultry litter at 200 kg N ha^{-1} in no-tillage in relation to poultry litter or ammonium nitrate at 100 kg N ha^{-1} in different tillages.

	Soil pH (0–15 cm)	Soil P (0–15 cm) (mg kg^{-1})
CT-100ANN vs. NT-200PLN	5.52 vs. 6.20***	20.81 vs. 95.91***
CT-100PLN vs. NT-200PLN	6.00 vs. 6.20 (NS)	54.26 vs. 95.91**
MT-100ANN vs. NT-200PLN	5.53 vs. 6.20***	24.71 vs. 95.91***
MT-100PLN vs. NT-200PLN	6.10 vs. 6.20 (NS)	50.00 vs. 95.91**
NT-100ANN vs. NT-200PLN	5.58 vs. 6.20***	19.32 vs. 95.91***
NT-100PLN vs. NT-200PLN	5.89 vs. 6.20 (NS)	57.71 vs. 95.91*

CT = conventional tillage, MT = mulch tillage, NT = no-tillage, 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter, 200PLN = 200 kg N ha^{-1} as poultry litter.
* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.
*** Significant at $p \leq 0.001$.

100 kg N ha^{-1} recorded significantly higher pH compared to application of AN at the same rate. Although not-significant, decrease in soil pH was observed in no-tillage plots with AN compared to PL. Application of PL at 200 kg N ha^{-1} maintained highest pH value (6.20) (Table 10). All three tillage practices with PL at 100 kg N ha^{-1} had similar pH compared to the no-tillage plots that received PL at 200 kg N ha^{-1}. Long-term application of AN caused the soil pH to decline at 0–15 cm depth from 6.2 in 1996 (before starting the experiment) to 5.52, 5.53 and 5.58 in conventional, mulch, and no-tillage, respectively in 2008 (Table 11). Similar trends were observed up to 30 cm in mulch and no-tillage, and up to 60 cm in conventional tillage. When AN is applied to soil, nitrification of ammonium takes place and releases hydrogen ions (H^+) that cause acidity. Moore and Edwards (2005) found a linear decrease in soil pH with the application of AN as a function of application rate. Unlike soil pH trends with AN application, continuous application of PL helped in maintaining original soil pH in conventional and mulch tillages. However, effect of PL in maintaining soil pH was observed only up to 15 cm depth. Poultry litter contains large quantity of bases such as calcium carbonate and these bases neutralize the acidity produced by nitrification. Mitchell and Tu (2006) found similar results with broiler litter in similar kind of soils. Hue (1992) found that PL is as effective as $Ca(OH)_2$ in raising the pH of acidic soils. However, application of PL at 100 kg N ha^{-1} in no-tillage plots was not sufficient to maintain the original soil pH, but application of the double rate (200 kg N ha^{-1}) helped in maintaining the original pH. Soil pH was not influenced by winter cover crop.

Table 11
Soil pH in different tillage systems with different N sources in 2008 and their comparison with initial pH in 1996.

Tillage	Soil depth			
	0–15 cm	15–30 cm	30–60 cm	60–90 cm
CT				
1996 vs. 100ANN	6.20 vs. 5.52*	6.20 vs. 5.51*	5.70 vs. 5.19*	5.30 vs. 4.82 (NS)
1996 vs. 100PLN	6.20 vs. 6.00 (NS)	6.20 vs. 5.52**	5.70 vs. 5.20*	5.30 vs. 4.71**
MT				
1996 vs. 100ANN	6.20 vs. 5.53**	6.20 vs. 5.33**	5.70 vs. 5.04 (NS)	5.30 vs. 4.99 (NS)
1996 vs. 100PLN	6.20 vs. 6.10 (NS)	6.20 vs. 5.55*	5.70 vs. 5.12 (NS)	5.30 vs. 4.85 (NS)
NT				
1996 vs. 100ANN	6.20 vs. 5.58**	6.20 vs. 5.37*	5.70 vs. 5.21 (NS)	5.30 vs. 5.03 (NS)
1996 vs. 100PLN	6.20 vs. 5.89**	6.20 vs. 5.69***	5.70 vs. 5.18 (NS)	5.30 vs. 4.79 (NS)
1996 vs. 200PLN	6.20 vs. 6.23 (NS)	6.20 vs. 5.68*	5.70 vs. 5.43 (NS)	5.30 vs. 5.15*

CT = conventional tillage, MT = mulch tillage, NT = no-tillage, 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter, 200PLN = 200 kg N ha^{-1} as poultry litter.
* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.
*** Significant at $p \leq 0.001$.

Table 12
Influence of N sources on available soil P (0–15 cm) in different tillage systems, Belle Mina, AL, 2008.

Tillage	N source	
	100ANN[a] (mg kg^{-1})	100PLN (mg kg^{-1})
Conventional tillage	20.81 bc	54.26 ab
Mulch tillage	24.71 abc	50.00 abc
No-tillage	19.32 c	57.71 a

Treatment means followed by the same lowercase letter are not significantly different from each other at $p \leq 0.05$.
[a] 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter.

3.5. Available soil phosphorus

Available P concentration at surface soil (0–15 cm) in 2008 was significantly influenced by tillage and nitrogen source interaction (Table 12) and was not influenced by winter cover crop. In all tillages application of PL at 100 kg N ha^{-1} resulted in higher available P compared to AN at the same rate. Conventional, mulch and no-tillage plots recorded approximately 3, 2 and 3 times, respectively higher available P with application of PL at 100 kg N ha^{-1} compared to AN at the same rate. In no-tillage plots, PL application at a double rate (200 kg N ha^{-1}) resulted in significantly higher available P (96 mg kg^{-1}) compared to all tillages with application of either AN or PL at 100 kg N ha^{-1} (Table 10).

At the beginning of the experiment in 1996, initial available soil P concentrations at depths 0–15, 15–30, 30–60 and 60–90 cm were 44, 38, 8 and 3 mg kg^{-1}, respectively. Soil chemical properties in 1996, before starting the experiment, were reported earlier (Nyakatawa et al., 2001b). In fall 2008, after eight PL applications (100 kg N ha^{-1} $year^{-1}$), available soil P concentrations were compared with initial P levels in 1996. All three tillage practices receiving PL did not differ significantly in surface soil (0–15 cm) P concentration from initial P (Table 13). Previous studies have reported that to produce 100 kg of seed cotton, approximately 2.6 kg P is required (PPI and PPIC, 2003). In the present study with over 8 cotton years, average seed cotton yields in conventional, mulch and no-tillage plots were 3385, 3695 and 3521 kg ha^{-1}, respectively and to produce this approximately 88, 96 and 92 kg P ha^{-1}, respectively would be required. The average phosphorus concentration in broiler litter in Alabama on dry weight basis is 1.5% (Mitchell et al., 2007). Application of PL at 100 kg N ha^{-1} can supply approximately 85 kg P ha^{-1} and plant available P would be much lower than the applied total P. Hence, it can be concluded that P application rates through PL did not exceed the crop P requirements in this experiment. This could be the reason for maintaining available P with in the range of initial P levels (1996) in all tillage systems with application of PL at 100 kg N ha^{-1}. Reddy et al. (2008) also observed no P build up in similar kind of soils with continuous application of fresh PL at 120 kg N ha^{-1} for 5 years. However, they observed P build up with composted PL where on average, 23% extra quantity of PL was applied every year to meet same N rate.

Further, inclusion of corn as a rotation crop without P fertilization helped in scavenging on residual fertility. Corn was planted without any fertilizer application in every third year after 2 continuous cotton years in the cotton–cotton–corn sequence (Table 2). On average, conventional and no-tillage plots with PL at 100 kg N ha^{-1} gave significantly higher corn grain yields (25 and 37%, respectively) compared to AN at 100 kg N ha^{-1} (Table 7) and was attributed to higher residual fertility associated with PL. On average 1 kg of corn grain removes 3.8 g of P from soil (Heckman et al., 2003). Calculated data showed that in conventional and no-tillage plots which received PL, corn extracted approximately 19 and 21 kg ha^{-1} P, respectively. It can be understood that corn extracted considerable amount of residual P from soil and that helped in preventing P buildup due to PL application. However, although not-significant, elevated levels of P in all tillages with application of PL at 100 kg N ha^{-1} compared to 1996 levels indicate that there is possibility of significant build up of P in future with further application of PL.

Application of PL at a double rate (200 kg N ha^{-1}) in no-tillage system resulted in build up of available P in the surface soil (0–15 cm). In no-tillage plots which received PL at 200 kg N ha^{-1}, available P concentration increased by two folds (96 mg kg^{-1}) when compared to initial available P in 1996 (44 mg kg^{-1}) (Table 13). On average, 5.5 and 11 Mg ha^{-1} $year^{-1}$ of PL was applied to supply 100 and 200 kg N ha^{-1}, respectively. It can be inferred from the results that although higher cotton yields can be achieved with higher quantity of PL (200 kg N ha^{-1}), from an environmental perspective, using PL at 100 kg N ha^{-1} is advantageous because no significant P build up in soil was observed with it. Continuous application of AN resulted in a significant decline in available P compared to initial P (1996) in all tillages in the top soil (0–15 cm) (Table 13). Reduction in available P concentration in AN plots might be attributed to a decline in soil pH (Table 11) and no addition of P for many years. Moore and Edwards (2005) observed that long-term application of AN increased the exchangeable Al levels in the soil whereas exchangeable Al levels remained the

Table 13
Available soil P in different tillage systems with different N sources in 2008 and their comparison with initial P in 1996.

Tillage	Soil depth			
	0–15 cm (mg kg^{-1})	15–30 cm (mg kg^{-1})	30–60 cm (mg kg^{-1})	60–90 cm (mg kg^{-1})
CT				
1996 vs. 100ANN	44 vs. 21*	38 vs. 12**	8 vs. 10 (NS)	3 vs. 10***
1996 vs. 100PLN	44 vs. 54 (NS)	38 vs. 15***	8 vs. 10 (NS)	3 vs. 10*
MT				
1996 vs. 100ANN	44 vs. 25**	38 vs. 15***	8 vs. 9 (NS)	3 vs. 9 (NS)
1996 vs. 100PLN	44 vs. 50 (NS)	38 vs. 19**	8 vs. 19 (NS)	3 vs. 16 (NS)
NT				
1996 vs. 100ANN	44 vs. 19**	38 vs. 12***	8 vs. 16 (NS)	3 vs. 7 (NS)
1996 vs. 100PLN	44 vs. 58 (NS)	38 vs. 16***	8 vs. 5 (NS)	3 vs. 5 (NS)
1996 vs. 200PLN	44 vs. 96**	38 vs. 17**	8 vs. 6 (NS)	3 vs. 7 (NS)

CT = conventional tillage, MT = mulch tillage, NT = no-tillage, 100ANN = 100 kg N ha^{-1} as ammonium nitrate, 100PLN = 100 kg N ha^{-1} as poultry litter 200PLN = 200 kg N ha^{-1} as poultry litter.
* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.
*** Significant at $p \leq 0.001$.

same with application of PL. Increased exchangeable AL levels may result in P fixation. Depending on soil type and extractant used, previously reported critical levels of soil P for cotton were 6–12 mg kg^{-1} with Mehlich-1 extractant (Bingham, 1966; Cope, 1984), 12 mg kg^{-1} with Mehlich-3 extractant (Cox and Barnes, 2002), and 14–32 mg kg^{-1} with a bicarbonate extractant (Duggan et al., 2003). In the present study, available P levels in AN plots were still within range of the above critical levels and signs of yield reductions due to P limitation were not observed. At the 15–30 cm depth, in all tillage systems irrespective of N source available P concentration decreased (Table 13). It might be attributed to the fact that cotton has deep root system and has the ability to extract nutrients from deeper layers. Increased concentration of P was observed in deeper layer (60–90 cm) which indicates downward movement of P.

4. Summary and conclusions

To fully realize the benefits and deficiencies of conservation tillage and poultry litter application on cotton production, a long-term field study was initiated in 1996. Results from 2003 to 2008 were discussed in this paper. All three tillage practices; conventional tillage (CT), mulch tillage (MT) and no-tillage (NT) had similar cotton lint yields with application of ammonium nitrate (AN) at 100 kg N ha^{-1}. On average, 12 and 11% yield reductions were observed in NT when receiving PL at 100 kg N ha^{-1} compared to CT and MT, respectively. However, NT plots with PL application at a double rate (200 kg N ha^{-1}) gave similar yields to that of CT and MT either with PL or AN at 100 kg N ha^{-1}. Winter rye cover crop increased lint yields significantly in CT plots. During corn years, where corn was grown as a rotational crop, highest residual fertility of PL was observed in NT plots in terms of corn grain yields. Status of soil pH and available P were studied 12 years after initiation of the experiment (after 8 PL applications) and were compared with initial values in 1996. Results showed that PL application at 100 kg N ha^{-1} helped in maintaining original pH in CT and MT plots, but it was not sufficient to maintain pH in NT plots. Application of PL at 100 kg N ha^{-1} helped in maintaining original available P levels in all tillage practices while use of AN decreased available P. Quantity of P applied through PL was with in the range of crop requirements and it helped in preventing build up of soil P. Further, the corn crop rotation served as a scavenger on the residual fertility. However, although non-significant, elevated levels of P in all tillages with application of PL at 100 kg N ha^{-1} compared to 1996 levels indicate that there is possibility of significant build up of P with further application of PL at the same rate. Application of a higher rate of PL (200 kg N ha^{-1}) in NT plots resulted in build up of P.

It can be concluded that NT gives similar yields to CT when received AN at a similar rate, but needs higher rates of PL to achieve similar yields to CT. No-tillage with winter rye cover crop gave similar yields to CT. Considering the fact that higher rate of PL (200 kg N ha^{-1}) leads to P build up in soil, the no-tillage with PL application at 100 kg N ha^{-1} combined with a winter cover crop and corn rotation can be recommended for a sustainable cotton production in south eastern USA. Further studies are needed to find out suitable PL application rates between 100 and 200 kg N ha^{-1} for a NT system that gives comparable yields to CT without affecting soil quality.

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