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AGRONOMY & SOILS

Utilization of Poultry Litter, Tillage, and Cover Crops for Cotton Production on Highly Degraded Soils in Northeast Louisiana

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) has been the main agronomic crop in northeast Louisiana for many years. However, intensive agricultural production paired with mono-cropping has resulted in decreased productivity and declining soil quality. The implementation of best management practices has the potential to alleviate many of these problems. Information is limited on the benefit of these conservation practices on these highly degraded soils. Therefore, a field trial to evaluate the effect of poultry-litter applications on cotton production and the environment was established. Trials were conducted at the Macon Ridge Research Station in Winnsboro, LA from 2008 to 2011. Poultry litter was applied at the rate of 0, 3.3, and 6.7 mg ha^{-1}. The effect of litter applications was evaluated over both conservation and conventional tillage systems with and without a winter cover crop. Additionally, to simulate traditional production practices, an inorganic fertilizer treatment was included. Cotton lint yields of the poultry-litter treatments were significantly (P < 0.05) higher than those that received inorganic fertilizers, yielding 231, 175, 392, and 330 kg lint ha^{-1} more for poultry-litter applied plots compared to inorganic fertilizers in 2009, 2010, 2011, and 2012, respectively. However, the application of 6.7 mg ha^{-1} did not significantly improve yields over the 3.3 mg ha^{-1} rate. A significant buildup of Mehlich-3 extractable, soil test P level was found when poultry litter was applied compared to inorganic fertilizers, with increased soil test P levels of 26 mg P kg^{-1} by the end of the trial. Overall, poultry litter can be used as a soil amendment in northeast Louisiana; nonetheless, management that enhances yield benefits while minimizing soil accumulation needs to be emphasized to minimize increased soil P buildup.

Historically cotton (*Gossypium hirsutum* L.) has been and will continue to be one of the most important row crops in Louisiana. However, after years of an intensely managed mono-cropped system, soil quality parameters have begun to decline rapidly. This is illustrated by the upland loess soils of the Macon Ridge. Selim et al. (1983) described these soils as highly degraded with low inherent nutrient content and often low soil organic matter (SOM). Although these fields continue to be in production, the highly degraded conditions often have resulted in decreased agronomic productivity. However, it has been indicated that the implementation of conservation production practices, especially integration of organic amendment applications, not only have potential to enhance soil quality but also improve crop productivity (Hornick and Parr, 1987; Pretty et al., 2006). Poultry litter (PL) is one of the most promising organic amendment sources for northern Louisiana due to its relative availability in the region, as well as its high nutrient content and ease of application, compared to other organic amendments (Edwards and Daniel, 1992).

The utilization of PL as an effective alternate fertilizer source for agricultural production systems has been documented previously (Reddy et al., 2007; Tewolde et al., 2010). Reddy et al. (2007) indicated that application of PL improved cotton lint yields compared to inorganic fertilizers over a 5-yr period. They further indicated that the use of fresh PL improved yields compared to inorganic fertilizers; however, composted PL did not show that same benefit, and yields were similar to inorganic fertilizers. Tewolde et al. (2010) reported a similar benefit of PL application on cotton lint yields compared to inorganic fertilizers. Although they indicated that cotton fertilized with PL had

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less tissue N, chlorophyll index, and leaf area index, it produced more lint than that fertilized with ammonium nitrate. They concluded that the benefit of PL applications on cotton production far exceed the value of nutrient concentrations. Although the benefits of PL applications to cotton production are apparent, the benefits of PL applications on degraded soils have the potential to be highly beneficial. Diacono and Montemurro (2010) reported the benefit of these amendments on highly degraded soils. They documented a 250% increase in crop yield when comparing organic amendments to inorganic fertilizer additions. Hornick and Parr (1987) emphasized that the application of organic amendments, such as PL, has the potential to improve crop productivity in highly degraded soils, especially when amendment applications and other management practices are optimized. Although these reports suggest benefits of PL applications on cotton production systems, little work has been conducted to determine the direct benefit of PL on cotton production in highly degraded soils such as those on the Macon Ridge.

Although the use of PL has the potential to be a beneficial soil amendment to improve cotton production, especially in highly degraded soils, it is essential to understand how PL applications influence other properties of the production system. One property is soil nutrient concentrations, especially soil P levels. As a result of the high nutrient content of this amendment, proper management is essential to ensure limited soil nutrient buildup. Hooda et al. (2001) indicated soil P buildup occurred when fertilizer applications were excessive. This is often the case for PL, because N and P levels have similar concentrations in PL, but crop N requirements are often higher. Sharpley et al. (2007) noted that the increase in soil P values with PL applications is due to the N:P ratios. Typically, these ratios for PL are approximately 3:1, which is much narrower than what crops typically need (Sharpley et al., 2007). They further noted that as a result of this ratio, short- and long-term effects of PL applications based on N demand will greatly increase soil P values.

In addition to the direct effect of PL, the integration of PL into conservation-based systems can have an effect on not only the productivity of the system but also the influence of PL applications. Two major conservation systems throughout the Mid-South have been conservation tillage and integration of winter cover crops. Boquet et al. (1997) reported that cotton lint yield following conservation tillage increased by 16% over ridge tillage and 9% over conventional tillage on similar Macon Ridge upland loess soils. Nyakatawa et al. (2000) reported similar results. They indicated a 24% and 18% greater yield for no-till compared to conventional and mulch tillage, respectively. It was hypothesized that increased soil moisture during early season was responsible for the increased yield. Reddy et al. (2009) demonstrated the interaction between PL applications and soil tillage. They found that when PL was applied at a similar rate, no-till plots yields were lower than both conventional or mulch tillage. However, when the PL application rate was doubled for no-till plots but not for mulch or conventional tillage, yields were similar. They theorized that due to surface application without incorporation on no-till plots, increased volatilization and runoff were the primary nutrient loss pathways. Although the effects of tillage within cotton systems, as well as how PL applications are influenced by tillage are well documented within the current literature, cover crops are still a novel concept across the Mid-South and therefore information is scarcer. Adeli et al. (2011) noted that the use of a winter rye cover crop had no significant influence on cotton yield. In addition, they noted that there was a greater benefit of spring-applied PL when cover crops were absent. Although there was no evident yield benefit to winter cover crops, they did indicate NO_3-N leaching was reduced under treatments with cover crops compared to fallow treatments.

For production agriculture to be sustainable, the implementation of conservation production practices will become essential, especially on highly degraded soils. Although there are numerous publications on the benefits of PL applications on crop production, little is currently known on how beneficial these applications can be on highly degraded soils; likewise, little is known on how long-term PL applications affect soil P buildup. Additionally, the interaction between PL applications and other conservation practices is still limited. Therefore, the objectives of the study were to: 1) Determine the effects of yearly PL applications on cotton production systems of highly degraded loessial soils of the southern Mid-South when paired with other conservation practices, and 2) evaluate how continuous PL applications influenced the buildup of soil P levels.

MATERIALS AND METHODS

Field sites were established in 2009 and continued through 2011 at the Macon Ridge Research Station in Winnsboro, LA (32°09'48"N, 91°43'24"W) under furrow irrigation. The dominant soil series for the experiment was Gigger silt loam (fine silty, mixed, thermic Typic Fragiudalf). These upland soils had less than 1% soil organic matter and possessed a shallow impenetrable clay pan with an underlying moderately to very acidic sub-soil.

Treatments and Experimental Design. Detailed descriptions of all agronomic practices are given in Table 1. The three fertilization schemes evaluated were: PL applied at the recommended N rate (PL-N), PL applied at the recommended P rate plus supplemental inorganic N (PL-P+N), and inorganic fertilizer with no PL applications (NPL). The application rate of PL varied by year, but was applied to meet the N or P demand based on composition and nutrient availability estimations. The composition of the PL for each year is presented in Table 2. To determine application rates of PL each year, nutrient availability was assumed at 50% for N, 80% for P, and 100% for K (Eghball and Power, 1999; Eghball et al., 2002). Furthermore, PL applications were evaluated at two levels of cover crops and two levels of tillage. Cover crop levels were with or without winter wheat (*Triticum aestivum* L.) cover. Tillage levels were conservation tillage or conventional tillage. Treatments were arranged in a randomized complete block design with four replications, with a complete three-way factorial design between PL, cover crops, and tillage resulting in 12 total treatments.

Table 1. Agronomic practices from 2009 to 2012

Year	Planting date	Variety	Harvest date	Poultry litter application	Soil sample collection[z]
2009	April 30th	Deltapine 0912B2RF	September 22nd	March 2nd	October 13th
2010	April 29th	Deltapine 0912B2RF	September 19th	March 1st	October 19th
2011	April 20th	Deltapine 0912B2RF	September 10th	Feburary 21st	October 7th
2012	April 17th	Deltapine 0912B2RF	September 7th	Feburary 29th	October 1st

[z] Baseline soil samples were collected prior to trial establishment (October 27th, 2008).

Table 2. Poultry litter analysis for 2009 to 2012

Nutrient[z]		Year			
		2009	2010	2011	2012
Boron	mg kg^{-1}	114	89	NA[y]	93
Copper	mg kg^{-1}	550	447	NA	482
Manganese	mg kg^{-1}	870	771	NA	807
Zinc	mg kg^{-1}	1051	803	NA	1011
Aluminum	%	0.3	0.3	NA	0.3
Calcium	%	1.0	1.0	NA	0.9
Iron	%	0.8	1.0	NA	1
Potassium	%	5.1	3.3	2.6	3.7
Magnesium	%	10.4	8.8	NA	9.9
Sodium	%	0.3	0.2	0.2	0.2
Phosphorus	%	2.4	3.0	1.9	2.2
Sulfur	%	2.5	1.4	0.7	1.5
Nitrogen	%	2.2	3.3	2.3	2.9
Moisture[x]	%	22	27	24	23

[z] Nutrient analysis conducted using ICP-AES total digestion analysis

[y] Nutrient analysis was not conducted for the given nutrient on the given year

[x] Moisture determined through gravimetric method

Trial Management. The study was initiated in 2008 with the site being disked down flat. Beds were then established on 102-cm wide spacing. Plot sizes were four rows by 30.5 m in length. For the conservation tillage treatments, annual reshaping of the beds was the only tillage event. This is the most common conservation tillage practice of the region as annual bed reshaping is needed for furrow irrigation systems. The winter wheat cover crop was planted annually in the late fall with a grain drill (Model No. 14, Marliss Industries, Inc. Jonesboro, AR) with initial cover establishment occurring in November 2008 and every successive fall. For non-cover crop treatments, fields lay fallow and natural winter vegetation was allowed to grow. Early spring termination of the winter wheat cover crop as well as green winter vegetation, particularly in the fallow plots, was accomplished through the use of dicamba (3,6-dichloro-2-methoxybenzoic acid) and glyphosate (N-(phosphonomethyl)glycine). Following cover crop and weed burn-down, conventional tillage treatment beds were disked flat. Following tillage treatment applications, fertilizer applications were made. The PL treatments were applied with a calibrated small-plot spreader equipped with a controlled application system.

Prior to annual fertilizer applications, soil samples were collected from each plot (i.e., soil samples from 2008 were taken after harvest but prior to 2009 treatment application) (Fig. 1). Soil samples were taken in the spring to account for any nutrient uptake by the winter cover crop or fallow season plants. Samples were collected using a standard soil probe to the depth of 15 cm. Following collection, soils were dried at 50° C for 48 hr. Dried soils were ground to pass through a 2-mm sieve. Samples were then extracted with Mehlich-3 solution and analyzed for plant-available nutrients using inductively coupled plasma spectroscopy (SPECTRO Analytical Instruments, Kleve, Germany). Inorganic fertilizers were applied as liquid urea ammonium nitrate with thiosulfate (30-0-0-2) knifed into the beds, triple superphosphate (0-45-0), muriate of potash (0-0-60), and zinc sulfate (36% Zn). Following fertilizer applications, conventional tillage treatments were bedded with a bedding hipper (AMCO Manufacturing, Inc., Yazoo City, MS) implement.

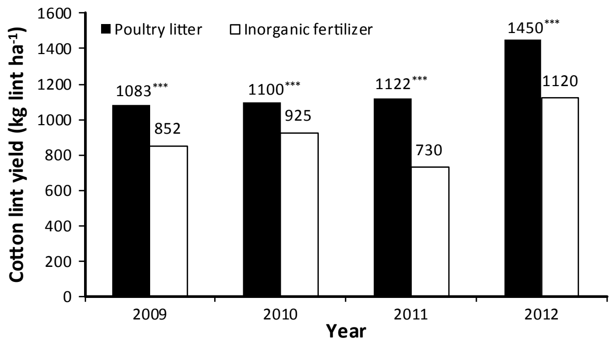

Figure 1. The effect of fertilizer scheme on cotton lint yields on highly degraded soils in Winnsboro, LA from 2009 to 2012. Poultry litter application was for the PL-P+N treatments at the rate of 3.3 mg litter ha^{-1}. (Symbols *, **, * represent *P* < 0.05, 0.01, and 0.001, respectfully).**

Plots were planted on 30 April 2009, 29 April 2010, 20 April 2011, and 17 April 2012 with ‘DP 0912B2RF’ each year. Cotton was planted at an appropriate rate to achieve 114,000 live plants per hectare. All insect, weed, and disease management was carried out according to LSU AgCenter recommendations. Irrigation was applied throughout the season through furrow irrigation management. Irrigation applications were based on soil moisture collected throughout the trial field. Soil moisture was determined using placed soil moisture sensors (Spectrum Technologies, Aurora, IL) placed at the end of the field at 15-cm depths and readings were averaged to determine irrigation events. These sensors were not placed within specific treatments. Therefore, no treatment specifically determined irrigation events. At maturity, all plots received an application of Def® (S, S, S-tributyl phosphorotrithioate), Dropp® (1-phenyl-3-(thiadiazol-5-y) urea), and Prep® (sodium (Z)-3-chloroprop-2-enoate) as a cotton defoliant. Cotton defoliant was applied twice annually at a 10-d interval to achieve adequate leaf removal for harvest operations (Table 1). Cotton plots were mechanically harvested using a small-plot cotton picker with an attached load weigh scale. Seedcotton samples were collected and processed with a custom built table top gin to determine percentage gin turnout and lint yield.

Statistical Analysis. Statistical analysis of all data collected was conducted using SAS 9.2. Analysis of variance was utilized to determine if there were significant differences among treatments using MIXED procedure. Within these models, the variables cover crop, tillage, and poultry litter were considered fixed variables, whereas year and replication were considered random variables. Contrasts were utilized to determine differences between treatments. This allows for comparison between treatment groups, i.e., determining the differences between PL and inorganic applications or differences between cover crops and non-cover crops when PL was applied. These tests determined the differences between PL applications, cover crops, and tillage regime on cotton lint yield, cotton fiber characteristics, and soil nutrient concentrations.

RESULTS AND DISCUSSIONS

Overall, cotton yields were found to be highly variable across years ($P < 0.01$) with significant year by treatment effect ($P < 0.05$). As a result, both cotton lint yields and soil nutrient concentrations were analyzed separately across years. The highest cotton lint yields were achieved in 2012, with cotton lint yields ranging from 1067 to 1676 kg lint ha^{-1} and averaged 1355 kg lint ha^{-1} across all treatments. Cotton lint yields during the 2011 growing season were found to have the lowest yields, which ranged from 629 to 1292 kg lint ha^{-1} and averaged 901 kg lint ha^{-1}. Additionally, no significant interaction was found between cover crops, tillage, or fertilizer scheme.

Cotton lint yields. Significance levels for main effect contrasts for lint yields are in Table 3. The use of a winter cover crop did not demonstrate a consistent nor significant influence on cotton lint yields across all years averaged across both fertilizer schemes and tillage programs. Furthermore, although not significant, use of a cover crop resulted in averaged lint yields to be from 112 to 224 kg lint ha^{-1} higher than winter fallow. The decreased or non-affected cotton lint yields with winter cover crops followed similar trends in the current literature (Delaney, 1991; Nyakatawa et al., 2000; Ward et al., 2006). Ward et al. (2006) found that the use of a rye cover crop negatively influenced cotton lint yields. They theorized that this decreased cotton lint yield was a result of potentially decreased N availability in the soil systems due to short-term immobilization. Delaney (1991) reported similar findings through on-farm demonstrations. However, Delaney (1991) attributed the decreased yield to poor early season growth and increased weed pressures. Nyakatawa et al. (2000) observed no response of cotton lint yields to the use of a rye winter cover crop. They further documented that these similar yields were achieved even though the cover crop treatments achieved increased number of bolls per plant and increased root biomass.

Tillage significantly affected cotton lint yields only in 2011 ($P < 0.001$) and 2012 ($P < 0.05$) (Table 3) with cotton grown using conservation tillage yielding 337 and 254 kg lint ha^{-1} higher than cotton grown with conventional tillage, respectively. Similar trends were found for the 2009 and 2010 production systems; however, these differences were not significant. Nyakatawa et al. (2000) reported that although yield components varied between years, no-tillage consistently produced higher cotton lint yields compared to both mulch tillage and conventional tillage. They indicated that the yield increase from no-tillage potentially can be attributed to improved soil moisture dynamics. Improved soil moisture conditions are potentially the cause of higher yields with conservation tillage in the present study because the soil possesses low moisture retention and holding capacity. Even though the trial was irrigated, irrigation events were not controlled by a single treatment, as mentioned previously. Therefore, some plots or treatments could have become water deficient, whereas other treatments remained at adequate soil moisture levels. Boquet et al. (2004) emphasized this concept, theorizing that no-tillage and optimum N management are critical to cotton productivity in these highly degraded silt loam soils.

Table 3. Contrast analysis on the main treatment effects influence on cotton lint yield from 2009 to 2011 on highly degraded soils

Contrasts	2009	2010	2011	2012
poultry litter^z vs. inorganic fertilizer	***	***	***	***
poultry litter N rate vs. poultry litter P rate+supplimental N^y	NS	NS	NS	**
cover crop vs. native fallow	NS	NS	NS	NS
conventional tillage vs conservation tillage	NS	NS	***	*

***, **, *** represent $P < 0.05$, 0.01, and 0.001, respectfully**

NS represents nonsignificant effect

^{z} Poultry litter applied at P rate with supplemental N

^{y} Poultry litter N rate 6.7 mg ha^{-1}; poultry litter P rate 3.3 mg ha^{-1}

Fertilizer scheme demonstrated the most consistent and largest influence on cotton lint yields. Application of PL increased cotton yields over inorganic fertilizer in every year of the study (Table 1). These results slightly differed from that found by both Nyakatawa et al. (2000) and Reddy et al. (2009). Both reported that when PL was applied at 100 kg N ha^{-1} rates, yields between ammonium nitrate and PL were similar. However, when PL application rates were increased to 200 kg N ha^{-1} yields achieved were higher than both ammonium nitrate and poultry litter at 100 kg N ha^{-1}. They theorized that the N in the PL was too slowly mineralized and, therefore, was potentially limiting crop growth; however, when N application was doubled, the PL supplied a non-limiting N level. These results slightly differ from the current experiment as a result of the supplemental inorganic N application associated with the PL-P+N treatment. In the current study, only in the 2012 growing season did the PL-N treatments significantly out yield the PL-P+N treatments (Table 3 and Fig. 2). Furthermore, inorganic applied treatments received equivalent amounts of available nutrients compared to the PL-P+N, with additional available nutrients with the PL-N treatments compared to the PL-P+N and organic. This might give an indication that PL applications benefit the production system beyond simply a source of N, P, K, and S nutrition. Tewolde et al. (2010, 2011) reported increased levels of Mn, K, and B uptake associated with PL applications. They indicated that this increased uptake potentially could be associated with a more favorable and stable pH associated with PL applications (Reddy et al., 2004; Tewolde et al., 2010, 2011).

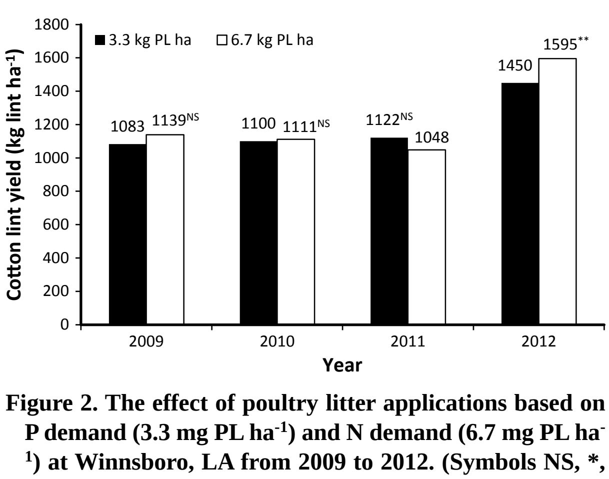

Figure 2. The effect of poultry litter applications based on P demand (3.3 mg PL ha^{-1}) and N demand (6.7 mg PL ha^{-1}) at Winnsboro, LA from 2009 to 2012. (Symbols NS, *, **, * represent nonsignificant $P < 0.05$, 0.01, and 0.001, respectfully).**

Soil nutrient buildup. As an organic amendment, PL applications have the potential to be agronomically beneficial; however, improper management of these inputs can be detrimental, especially to soil P accumulation. Detrimental impacts to the surrounding environment have been well documented, particularly soil nutrient buildup (Bitzer and Sims, 1988; Hooda et al., 2001; Jaja et al., 2013; Kingery et al., 1994; Sharpley et al., 2007). One plant essential nutrient that increased its concentration in soil with PL applications is P. As a result of P being immobile in the soil system, high or continual P applications, especially those from continually high PL applications, can lead to increased P concentrations in the soil (Sharpley et al., 2007).

Both cover crop and tillage showed no significant effect on plant-available (or Mehlich-3 extractable) soil P concentrations. These results differ from those found by Nyakatawa et al. (2001), which found that a rye cover crop generally could be used to limit the buildup of plant-available P levels when PL was applied. In the current study, these trends were present; however, no significant differentiation was found between the treatments. The effect of fertilizer scheme showed a significant influence on plant-available P concentrations; however, this effect was not seen until the third and fourth years of continual applications (Table 4). Plant-available P concentrations for the PL and inorganic fertilizer scheme applications are shown in Table 5. No significant or numerical differences of plant-available P concentrations were observed between the inorganic fertilizer treatments and those applied to meet P demand (PL-P+N) within the first two growing seasons. Furthermore, plant-available P concentrations for the first season of application varied little from initial baseline plant-available P concentrations, which were found to be 19.8 mg kg^{-1}. However, following the initial year's application, a nearly linear increase in plant-available P concentrations were found with the PL applied treatments, whereas the increases in the inorganic fertilizer treatments were limited in the final two growing seasons. Similarly, Kingery et al. (1994) reported a buildup of plant-available P levels to the depth of 60 cm as a result of long-term PL applications.

Table 4. Contrast analysis on the main treatment effects influence on soil test P levels from 2009 to 2012 at Winnsboro, Louisiana

Contrast	2009	2010	2011	2012
poultry litter[z] vs. inorganic fertilizer	NS	NS	*	***
poultry litter N rate vs. poultry litter P rate+supplemental N[y]	NS	*	*	***
cover crop vs fallow	NS	NS	NS	NS
conventional tillage vs. conservation tillage	NS	NS	NS	NS

*, **, *** represent $P < 0.05$, 0.01, and 0.001 respectfully

NS represents nonsignificant effect

[z] Poultry litter applied at P rate with supplemental N

[y] Poultry litter N rate 6.7 mg ha^{-1}; poultry litter P rate 3.3 mg ha^{-1}

Table 5. The effects of fertilizer scheme on soil test P levels from 2009 to 2012 at Winnsboro, LA. Baseline soil test P levels for the study location were 19.8 mg kg^{-1}

Treatment	2009	2010	2011	2012
Poultry litter	26.1a[z]	46.47a	74.43a	83.7a
Inorganic fertilizer	23.6a	44.67a	54.77b	57.7b
PL-P+N	26.1a	46.47a	74.43a	83.7a
PL-N	32.1a	57.7b	133.51b	159.75b

[z] Letters indicate significant differences within each column by treatment block

Significant differences were more evident when comparing PL application based on P demand (PL-P+N) and N demand (PL-N) (Table 4). In 2009, an increase in soil test P levels were found between the PL-N and PL-P+N treatments as well as a greater than 10 mg kg^{-1} increase in plant-available P levels for the PL-N compared to baseline soil P levels, but neither were found to be significant (Table 5). A significant increase in soil test P levels was found between the two application rates from the 2010 season until the completion of the trial in 2012. Additionally, the differences between the two application levels following the 2011 and 2012 growing season continued to increase, with 59 and 76 mg P kg^{-1} differences between the two rates for the 2011 and 2012 seasons, respectively. Similar results were found by Kingery et al. (1994) from their long-term study. They reported that when PL was applied to meet N demands, plant-available P levels could increase by six to eight fold. Gilfillen et al. (2010) reported similar results to Kingery and the current study. They indicated that soil P levels increased when PL was applied to meet N demand, whereas the application of PL to meet P demand as well as inorganic application resulted in no significant differences from baseline treatments.

CONCLUSIONS

This study along with that recorded by Boquet et al. (2004) found similar findings, in that highly degraded silt loam soils require more conservation-based production practices to increase the productivity of intensive agricultural systems. The results from this study indicated the conversion from a conventional to conservation tillage system increased cotton lint yield. However, these yield increases were not seen until two years into the project, indicating that tillage systems have more long-term benefits compared to immediate returns. Additionally, the application of PL has the potential to increase cotton productivity across many production seasons. It was found that the benefit of applying PL was beyond providing inorganic nutrition. It has been hypothesized that the increased yield benefit from PL applications can be potentially attributed to increased nutrient cycling and that supply of basic micronutrients could be contributing to this yield increase (Kingery et al., 1993). However, management that attempts to minimize high nutrient buildup or runoff is critical. It was noted that four continuous years of applying PL resulted in a steady increase in plant-available P concentrations. This plant-available P buildup was exacerbated when PL was applied at a rate to meet the N demand of the cotton crop, in lieu of applying PL to meet P demand with supplemental inorganic N fertilizers. Also, the marginal increase in cotton lint yields is indicative that the value of a PL application diminishes with higher application rates. Furthermore, because plant-available P concentrations increased even under the lower application rates, the authors believe further studies investigating various PL application management practices would be critical in not only improving the benefit of this input but also guarding against detrimental environmental impacts.

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