TOTAL SOIL PHOSPHORUS, ZINC AND COPPER CONCENTRATIONS AS AFFECTED BY LONG-TERM TILLAGE AND FERTILIZATION CHOICES IN CECIL SOIL

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ABSTRACT

Adoption of conservation tillage and use of animal waste as an alternative fertilizer source is increasing. The environmental consequences of these farm management choices need to be thoroughly evaluated. Poultry litter (PL) for example, while being an inexpensive and effective source of plant nutrients, could result in the buildup of phosphorus and heavy metals in soils with over application. Changes in total soil P, Zn and Cu in a Cecil soil (fine, kaolinitic, thermic Typic Kanhapludults) were assessed after 2, 5, 10 and 11 yrs of PL application under two tillage treatments, conventional tillage (CT) and no-till (NT) and two fertilizer sources, conventional fertilizer (CF) and PL in a cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) production experiment at the USDA-ARS, J. Phil Campbell, Sr. Natural Resource Conservation Center in Watkinsville, Georgia. At the end of 5 years of the cotton phase, under an annual PL application rate of 2 tons acre^{-1}, concentrations of total soil P, Zn, and Cu did not increase. In Yr 10 (end of the corn phase), soil P, Zn and Cu concentrations in the 0- to 6-in depth increased approximately 1.5 to 3 times to 846, 50 and 42 lb acre^{-1}, respectively, in NT, and 1116, 64, 54 lb acre^{-1}, respectively, in PL treatments. Total P and Cu also increased in the 6- to 12-in depth with concentrations being approximately 1/2 times those in the in the 0- to 6- in depth. The increase was due to a 2 to 4 times greater input of P, Zn and Cu from PL fertilizer to meet the corn N requirement. The PL effect continued one year after the last PL application. In Yr 11, total P, Zn and Cu concentrations were much greater in the 0- to 1-in depth for NT and in the 0- to 1- and 1- to 2-in depths for PL. Changes with depth exhibited both linear and non-linear patterns based on treatment effects. The relationship between extractable and total P and Zn changed at a threshold value beyond which extractable P and Zn increased at more than double the initial rate. These results highlight the need to reevaluate the practice of PL application based on crop N requirement.

Keywords: No-till, Conservation tillage, Poultry litter, Soil nutrients, Environmental risk

INTRODUCTION

Tillage and fertilizer source choices are important management variables with agronomic and environmental consequences in cropping systems. Adoption of conservation tillage and the use of animal waste as an alternative fertilizer source are increasing. Approximately 42% of U.S. cropland is in conservation tillage, of which approximately 24% is in no-till (CTIC, 2009). In the Southeast about 36% of all cropland is in no-till. The southern states of Alabama, Arkansas, Georgia, Mississippi and North Carolina account for over 60% of the 8.6 billion broilers ***(****Gallus*

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gallus domesticus) raised annually in the U.S, and consequently produce approximately 10 million tons of poultry litter (a mixture of bedding material and manure) (National Agricultural Statistics Service, 2007). Poultry litter provides a wide range of nutrients and organic matter (Moore et al., 1995) and is often an economical alternative to inorganic fertilizers.

The increased adoption of conservation tillage and use of animal waste as an alternative fertilizer source have raised environmental concerns related to soil and water resources, particularly from phosphorus (P). Manure application rates have historically been based on the nitrogen (N) requirement of crops and forages which has led to application of P greater than plant utilization (Kingery et al., 1994; Sharpley et al., 1993; Wood et al., 1996). Over time, this rate of application results in an accumulation of P and other elements in the soil (Kingery et al. 1994; Mitchell and Tu, 2006; Gascho and Hubbard, 2006; Adeli et al. 2007). In addition, high soil P decreases very slowly after P fertilization has stopped (Sharpley et al., 2003). State soil test results for the Southeast in 2000 indicated that, except for Alabama, 40 to 70% of the agriculture soil samples had high or very high soil test P levels (Sharpley et al., 2003). Schomberg et al. (2009) found that for a Cecil soil in the Southern Piedmont, Mehilich-1 extractable nutrients after a 10-yr PL application were predominantly in the 0- to 6-in. depth and that Mehilich-1 extractable P and Zn had increased more than 200%. Extractable nutrients represent only the acid soluble portion of P and metals in the soil. On the other hand, environmental risk assessments are generally based on total rather than extractable concentrations (Franklin et al. 2006; USEPA 1994, 1999). These reports suggest that the use of PL must be managed carefully to avoid negative environmental effects and the need for more research to quantify relationships between PL inputs and accumulation of nutrients in different tillage systems.

We evaluated the change in total P, Zn and Cu in the same Cecil soil used by Schomberg et al. (2009), a study of five years of cotton followed by five years of corn under combinations of tillage (conventional tillage and no-till) and fertilizer source (PL and conventional inorganic fertilizer). Our objectives were to quantify any buildup in the soil of these nutrients and to ascertain any definable relationships between extractable and total nutrients that might help identify environmental risks associated with long-term PL use.

MATERIALS AND METHODS

Experimental Site and Managements

The study was conducted from 1995 to 2005 at the USDA-ARS, J. Phil Campbell, Sr. Natural Resource Conservation Center, Watkinsville, GA (83^{o}24' W and 33^{o}54' N). The research facility is described in detail by Endale et al. (2002, 2008) and Schomberg et al. (2009). Briefly, the facility consists of 12 large (30 ft x 100 ft) tile-drained plots, located on nearly level (<2% slope) Cecil sandy loam soil. Cecil and closely related soils occupy greater than 50% the area of the approximately 42 million acres Southern Piedmont (Radcliffe and West, 2000). These soils are deep, well drained and moderately permeable. The pH decreases with depth. The clay subsurface (~ 10 in. from the surface where not eroded) is overlain by sandy clay loam to clay loam texture (Bruce et al., 1983). Long-term average daily air temperature in summer ranges from 75 to 80 ^{o}F at the site. Mean annual rainfall is 48.9 inches evenly distributed across months but with greatest amount occurring in March and the least in October. Short-term summer droughts are frequent in spring and summer.

Main plot treatments are conventional tillage (CT) and no-till (NT) while subplots treatments are conventional fertilizer (CF - either NH_4NO_3 or $(NH_4)_2SO_4$ for N) and PL. This arrangement results in a factorial combination of treatments: CT-CF, CT-PL, NT-CF, and NT-PL (Table 1). The experimental design is a randomized complete block with three replications of each treatment. The CT consisted of a 12-in deep chisel plowing, to break possible hard pans, followed by one to two diskings to an 8-in depth, and a subsequent disking to 3 in to smooth the seed bed. The only soil disturbance in NT occurs during planting with a four-row no-till planter equipped with fluted coulters to cut through surface residue, followed by double-disk openers to make a narrow slit for the seed, and press wheels to firmly cover the seed. No-till treatments were begun in the fall of 1991.

Cotton (cv. Stoneville 474) with a cereal rye (*Secale cereale* L.; cv. Hy Gainer) cover crop was grown from fall 1994 to fall 2000 (cotton phase). The cotton fertilization need of 60 lb N acre^{-1} was provided as NH_4NO_3 in the CF treatment while in the PL treatment, starting in spring 1995 (Year zero), an equivalent amount of N was added by applying 2 tons PL acre^{-1} (fresh weight basis) on the assumption that mineralization of N in PL was 50% during the main cropping season (Ritz and Merka, 2004). In both the CT and NT treatments, the cover crop was chemically killed two to three weeks before planting of cotton. Corn (cv. Pioneer 3223), again with cereal rye as the winter cover crop, was grown beginning in spring 2001. Nitrogen fertilization increased to 150 lb acre^{-1} based on recommendations for corn and was applied as $(NH_4)_2SO_4$ in the CF treatment. The PL treatment received 5 ton PL acre^{-1} in 2001, 2002, 2004 and 2005 providing an equivalent amount of plant available N. In 2003 the N application rate was doubled (to 300 lb N acre^{-1} in CF and 10 ton PL acre^{-1} in PL) to investigate hormone concentrations in soil, runoff and drainage from poultry litter use. The rye cover crop in the PL treatment was fertilized with 3.0, 1.8, and 1.8 ton PL acre^{-1} during 2001, 2002 and 2003 and with $(NH_4)_2SO_4$ (60 lb N acre^{-1}) in 2004 and 2005 of the corn cropping phase in contrast to the use of commercial fertilizer during the entire cotton phase. Rye in the CF treatment was fertilized with $(NH_4)_2SO_4$ (60 lb N acre^{-1}) from 2001 through 2005. In CF treatments P and K fertilization rates were based on soil test where triple super phosphate and potash, respectively, were used as fertilizer sources. Corn and rye residues were shredded with a rotary mower in both the CT and NT treatments but were only incorporated in the CT treatment. No additional PL was added to these fields after the spring of 2005 (Yr-10) but conventional fertilizer continued to be used for fall and spring N fertilization as needed.

Soil Sampling and Analysis

In the fall of 1997 (Yr 2), 2000 (Yr 5) and 2005 (Yr 10), soil samples (0 to 12 in.) were collected with a tractor mounted hydraulic soil coring device from three locations in each plot. Soil cores (1-in diameter) were partitioned into 0- to 6-, and 6- to 12-in depths and the samples from each depth group from each plot were combined by plot. In addition, in December 2006 (Yr 11), we took 0- to 1, 1- to 2, and 2- to 6-in samples from each plot using the same procedure. All samples were dried at 55 to 60 °C for 3 to 5 d and kept at room temperature until analyzed. For analysis, soil samples were digested in concentrated HNO_3 in a CEM MDS-2100 microwave system (Matthews, NC). The resulting solution was analyzed using a TJA Model IRIS 1000 dual-view inductively coupled plasma emission spectrometer (ICP-ES) for total P (TP) and other metals (USEPA, 1986).

Table 1. Cumulative amounts of P, Zn, and Cu added to the experimental fields.

Year†	Treatment‡	P	Zn	Cu
			lb acre^{-1}	
1997 (Yr 2)	CT-PL	178.6	3.7	3.3
	CT-CF	66.1	0.0	0.0
	NT-PL	178.6	3.7	3.3
	NT-CF	66.1	0.0	0.0
2000 (Yr 5)	CT-PL	378.6	6.9	8.5
	CT-CF	132.2	0.0	0.0
	NT-PL	378.6	6.9	8.5
	NT-CF	132.2	0.0	0.0
2005/2006 (Yr 10/11)	CT-PL	1537.7	34.0	54.3
	CT-CF	219.7	0.0	0.0
	NT-PL	1537.7	34.0	54.3
	NT-CF	219.7	0.0	0.0

† Yr 2, 5, 10, 11 represent year since start of PL application in spring 1995

‡ CT, Conventional tillage; NT, no-till; PL, poultry litter; CF, commercial fertilizer.

Statistical Analysis

The MIXED procedure of SAS (Littell et al., 2000; SAS Inst. 2003) was used to analyze the data as a randomized complete block experiment with repeated measures. Tillage, fertilizer, year and their interactions were considered as fixed main effects while bock was considered a random effect. Means were estimated as least square means and contrast statements were used to compare means. Because plots of extractable P and Zn versus total P and Zn concentrations exhibited patterns of abrupt slope change, we used piecewise regression to estimate a break-point and regression parameters for the two line segments. Unless otherwise indicated, all significant differences are expressed at the level of $P \leq 0.05$.

RESULTS AND DISCUSSION

In the discussion, Yr 2, Yr 5, Yr 10 and Yr 11 refer to years after poultry litter application which began in spring 1995. For example the 1997 poultry litter application is also referred to as Yr 2. Depth and depth interactions with tillage or fertilizer source effects were generally significant including for the data collected in 2006 where we analyzed soils at finer depth increments in the top 6 in. Results are therefore presented by depth.

Total P

0- to 6-in Depth

During the cotton phase (Yr ≤ 5), mean total P concentrations were 426 to 620 lb acre^{-1} and there was no increase with either CF or PL (Fig. 1a-1). During the corn phase, total P in PL plots increased from near 600 to more than 1100 lb acre^{-1}, in part reflecting the increased P input from PL during the corn phase (from 63 to 261 lb acre^{-1} yr^{-1}). In CF plots total P was greater in Yr 10 (~600 lb acre^{-1}) than in Yr 5 (440 lb acre^{-1}) but not Yr 2 (510 lb acre^{-1}). Input of P from CF (as triple super phosphate based on soil test results) was approximately 20 lb acre^{-1} yr^{-1} during both the cotton and corn phases. Total soil P concentration remained essentially the same in Yr 11 (2006) one year after the last application of PL. Tillage and the tillage by year interaction effects were not significant (P>0.18) and the three way interaction with tillage, fertilizer, and year was not significant (P =0.1).

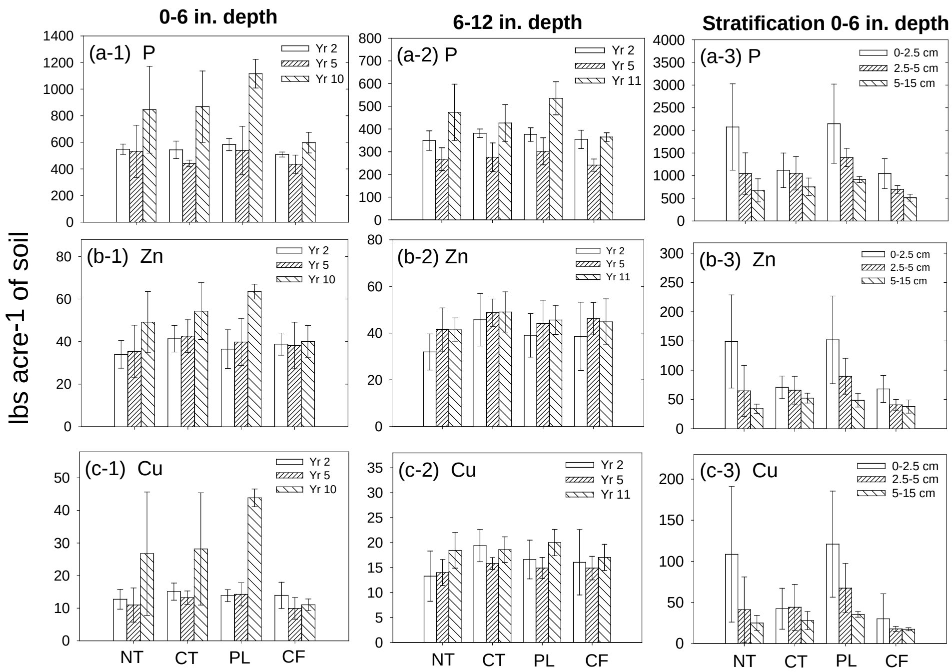


Fig. 1. Total P, Zn and Cu concentration in the 0- to 6-in depth for Yrs 2, 5 and 10, and in the 6- to 12-in depth for Yrs 2, 5 and 11, and in the 0- to 1-, 1- to 2-, and 2- to 6-in depths for Yr 11 by tillage (NT- No-till or CT- conventional tillage) or fertilizer (PL- poultry litter or CF- commercial fertilizer). Data are the average of 6 field triplicates. Error bars represent standard deviations.

6- to 12-in Depth

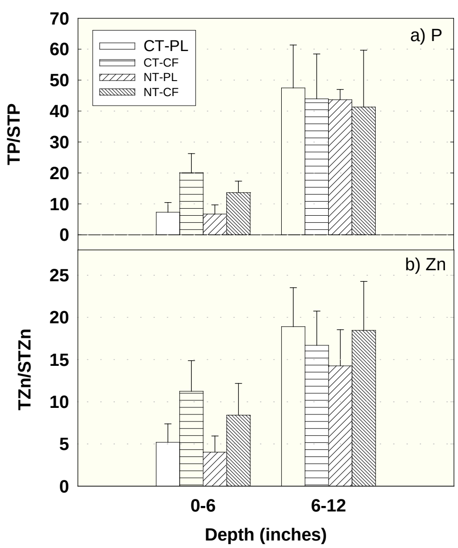
Soils collected in Yr 11 were used to compare concentrations in the 6- to 12-in subsurface soil (Fig. 1 a-2) (there were no soil samples for this depth in Yr 10). Year, fertilizer, and fertilizer by year interaction significantly influenced total P concentration (P<0.001). The interaction of tillage, tillage by fertilizer and tillage by fertilizer by year were not significant for total P (P

>0.17). Total P concentrations in the 6- to 12-in depth were essentially similar between CT-CF and NT-PL during the cotton phase (240 to 380 lb acre^{-1}) but by Yr 11 (2006) total P in the NT-PL soil was approximately 1.6 times greater than in the CT-CF soil with that for CT-CF showing no significant change from the cotton phase. In 1997 (Yr 2) total P was approximately 1.4 times greater in the 0- to 6-in than in the 6- to 12-in depth in both PL and CF treatments. By 2006 total P had increased to 2.2 and 1.7 times greater in the PL and CF treatments, respectively.

Stratification of P within the top 6 in. Soil Depth in Yr 11

As shown in Fig. 1 a-3, there were significant tillage by depth and fertilizer by depth interactions in total P distribution in the 0- to 1-, 1- to 2-, and 2- to 6-in depths of the Yr 11 soils. The tillage effect was limited to the 0- to 1-in depth, whereas that of fertilizer source was apparent in the 0- to 1-, 1- to 2- and 2- to 6-in depths. In the 0- to 1-in depth, total P was approximately 1.8 times greater in NT than in CT (2074 versus 1118 lb acre^{-1}), and approximately 2 times greater in PL than in CF treatments (2146 versus 1046 lb acre^{-1}). Total P in NT-PL was 3.6, 2.0 and 1.5 times greater compared to CT-CF, in the 0- to 1-, 1- to 2-, and 2- to 6-in depths, respectively.

When the total P data from all depths were pooled, a power relation best described change in total P concentration with depth in NT soils while both linear and exponential equations fit the CT data equally (data not shown). For fertilizer type, the distribution of P indicated slower or lesser movement from CF than from PL perhaps due to inorganic P in CF being more susceptible to immobilization by soil components and also due to greater organic P content and mobility with PL (He et al., 2009; Hunt et al., 2007).



Relationship between Total and Extractable P

The relationship between total versus extractable P was examined using total P data from this study and extractable P data reported in Schomberg et al. (2009) for these plots and time period of this study (Fig. 2a). Mean total P was approximately 7 times that of extractable P in the 0- to 6-in depths in the PL plots of either tillage treatment. The equivalent ratio was approximately 14 times that of extractable P in NT-CF and 20 times in CT-CF. The greater ratio for the CF plots indicates less extractable P than in PL. The ratio was much greater in the 6- to 12-in depth, but varied in a narrow range of 41 to 48 across the four treatments, again indicating less extractable P in the 6- to 12- than the 0- to 6-in depth.

Fig. 2. The ratio of total P to extractable P (a) and total Zn to extractable Zn (b) in conventional tillage (CT) and no-till (NT) fields with poultry litter (PL) or commercial fertilizer (CF) application. Data are the average of 3 field triplicates. Error bars represent standard deviations.

Plots of extractable P versus total P concentration showed patterns of abrupt slope change. We used piecewise regression to estimate a break-point and regression parameters for the two line segments (data not shown). The solution converged for all treatments except CF and CT-CF. Where piecewise regression estimated a break point, 86 to 97% of the variation in extractable soil P could be explained by variation in total P. The 95% confidence limit lines for the two-line model for P based on pooled data are shown in Fig. 3a. For data pooled across treatments, the break point for total P was approximately at 600 lb acre^{-1}. The slope after the break point was approximately 7 to 8 times that of the slope before the break point for PL associated with either CT or NT. While we cannot make definitive comparisons across treatments due to the non-convergence for CF and CT-CF, some general observations are: 1) a greater break point with PL compared to CF, 2) a smaller break points with NT compared to CT, and 3) a greater change in extractable P with PL than with CF.

The smaller break point for NT compared to CT probably reflects the greater stratification of nutrients in the NT treatment. Stratification could result in saturation of exchange sites in the surface soil and increase extractable P concentration at a lower total P concentration. In the NT plots the amount of P needed to saturate the available sorption sites is smaller because there is no soil mixing. Our results indicate that the available P fraction response to the cumulative amount applied may be confounded because once a saturation point is reached availability changes substantially.

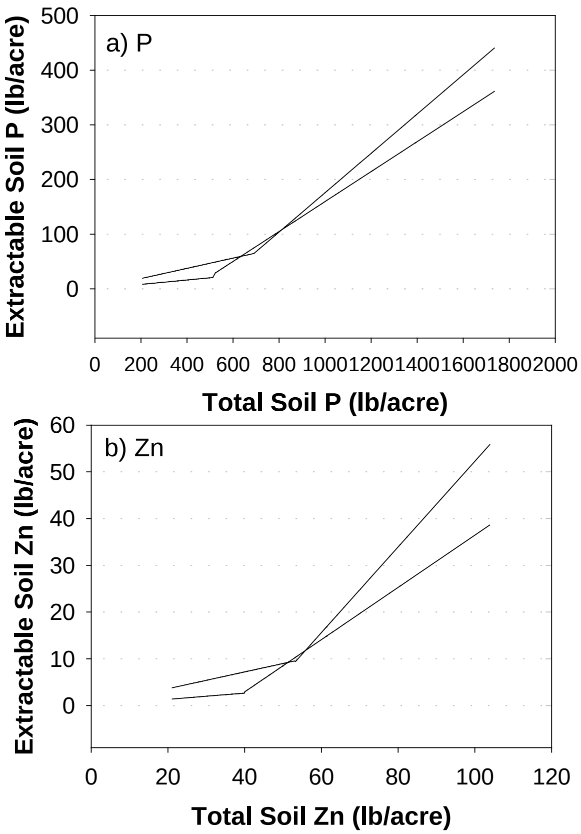


Fig. 3. 95 percent confidence limit lines for a two-line linear model for extractable soil P versus total P (a) and extractable soil Zn versus total Zn (b) based on data pooled across all treatments.

Total Zn

The three-way interaction for tillage, fertilizer and year significantly influenced the concentration of total Zn in the 0- to 6-in depth (P=0.04). No soil build up of Zn due to PL was observed during the cotton phase (Fig. 1 b-1). Total Zn concentration remained in the narrow range of 42 to 46 lb acre^{-1} in CT-CF for the 10-yr period while in the NT-PL it increased 1.4 times this amount by Yr 10 (62 versus 42 lb acre^{-1} for PL and CF treatments, respectively). Input of Zn increased from 1 lb acre^{-1} yr^{-1} during the cotton phase to 6 lb acre^{-1} yr^{-1} during the corn phase (Table 1). The long-term PL application effect remained a year after application of PL was stopped (2006). Changes in total Zn in the 6-12-in depth were much less than in the 0- to 6-in depth (Fig. 1 b-2). There were significant changes over time (P=0.01) but changes due to fertilizer or tillage (and their interactions) were too small to be significant. Total Zn concentrations in CT-CF and NT-PL were essentially similar in the 6- to 12-in depth.

Combinations of tillage and fertilizer influenced the distribution of total Zn in the top 6 in. soil in 2006 (P<0.007; Fig. 1 b-3). The tillage effect was most obvious in the 0- to 1-in depth while fertilizer source effects were obvious in the 0- to 1-, and 1- to 2-in depths. In the 0- to 1-in depth, total Zn was approximately 2 times more in NT and PL than in CT and CF, respectively.

Total Zn in NT-PL was approximately 4 and 2 times greater than in CT-CF in the 0- to 1-, and 1- to 2-in depths, respectively. Total Zn concentrations were similar between CT-CF and NT-PL in the 2- to 6-in depth.

As shown in Fig 2b, total Zn was up to 5 times greater than extractable Zn in the 0- to 6-in depths in PL soils, whereas in the CF plots it was 4 to 12 times greater. In the 6- to 12- in depth total Zn was approximately 14 to 19 times that of extractable Zn. Where piecewise regression (similar to total P) estimated a break point (between 40 and 44 lb acre^{-1}; Fig. 3), 73 to 91% of the variation in extractable Zn could be explained by variation in total Zn. Piecewise regression solutions could not be determined for CF, CT-CF and NT-CF. The slope of the second line segment is approximately 5 times greater than the slope of the line segment before the break point for PL associated with either CT or NT.

Total Cu

Tillage and fertilizer treatments influenced total Cu in the 0- to 6-in depth **(**Fig. 1 c-1). The fertilizer and year by fertilizer interaction effects were significant (P<0.0001), as was the tillage by fertilizer interaction (P=0.03). Total Cu concentration in 1997 and 2000 was less than total Cu concentration in 2005 and 2006 (P<0.0001). In CT and NT plots, total Cu concentration remained in the range 10 to 16 lb acre^{-1} during the cotton phase but rose to approximately 28 lb acre^{-1} at the end of Yr 10 (Fig. 1 c-1). Inputs of Cu from PL were approximately 1.5 lb acre^{-1} yr^{-1} and 10.3 lb acre^{-1} yr^{-1} during the cotton and corn phases, respectively. The absence of inputs of Cu in the CF treatment is reflected in the difference in total Cu concentration between the PL and CF treatments (44 lb acre^{-1} versus 12 lb acre^{-1}, respectively). The concentration of Cu was approximately 3.4 times greater in NT-PL than in CT-CF at Yr 10 and 11. In the 6- to 12-in depth the concentration of total Cu showed a significant response only to year (P=0.002). Tillage and fertilizer did not affect the concentration of total Cu at the 6- to 12-in depth (no significant interactions or main effects). At this depth, total Cu concentration was essentially similar between CT-CF and NT-PL through out the study (Fig. 1 c-2).

There was significant stratification of Cu in the 0- to 6-in depth in Yr 11. Combinations of fertilizer and tillage influenced differences by depth (P=0.05). Tillage differences were most apparent in the 0- to 1-in depth with total Cu concentration being approximately 2 times greater in the NT versus CT soils (Fig. 1 c-3). Fertilizer source effects were apparent in both the 0- to 1- and 1- to 2-in depths with PL having approximately 4 times more total Cu than CF in both depths. Compared to CT-CF, total Cu in NT-PL was approximately 8.5, 3.3 and 1.8 times more in the 0- to 1-, 1- to 2- and 2- to 6-in depths, respectively.

CONCLUSIONS

Application of 5 years of poultry litter at 2 tons acre^{-1} annually based on crop N requirement in a no-till and conventional tillage cotton-rye cover cropping system did not increase total soil P, Zn or Cu. While this is encouraging, the effect on even longer term application has not been established. A similar crop N requirement-based application of PL for corn (four years at 5 and one year at 10 tons acre^{-1} year^{-1}), however, lead to substantial increases within the 0- to 6-in soil depth potentially increasing environmental risks from these nutrients. These results support the need for P-based application of PL in vulnerable soils and calls for continued longer term research to determine critical threshold values under combinations of different tillage and fertilization sources across regions.

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