Phosphorus Dynamics in Two Poultry-Litter Amended Soils of Mississippi Under Three Management Systems

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ABSTRACT

An experiment arranged in a randomized complete block design with three replications was conducted on a Lexington soil (fine-silty, mixed, active, thermic, Ultic Hapludalfs) and a Loring soil (fine-silty, mixed, active, thermic, Oxyaquic Fragiaudalfs) in Mississippi from September 1997 to September 2000 on 18 runoff plots under natural rainfall condition to study the phosphorus (P) dynamics in poultry litter amended soils under three management systems combining tillage and planting date treatments to identify effective management practices in southern U.S.A. The management systems in the study were: 1) tillage in the fall prior to litter application followed by a delayed planting of fall forages (CT-DP); 2) tillage followed by immediate planting of the fall forage with subsequent litter application (CT-IP); and 3) no-till with planting prior to litter application (NT-IP). The results indicated that there was significant increase in soil P after 3 years of poultry litter application for both Lexington and Loring soils (P < 0.05). Based on P budget analysis, the majority of P from poultry litter application (> 90%), was accumulated in both soils. In Loring soil, soluble P mass in the runoff was significantly higher from NT-IP than from CT-DP and CT-IP over the entire study period (P < 0.01). For both soils, there were no significant differences in sediment P mass between management systems. For Loring soil, CT-DP and CT-IP were effective management practices to mitigate negative effects due to poultry litter application.

Key Words: conventional tillage, no-till, sediment phosphorus, soluble phosphorus


INTRODUCTION

The total value of U.S. broiler production in 2005 was approximately $20.87 billion (USDA, 2006). Mississippi ranked 4th based on the number of broilers produced following Georgia, Arkansas, and Alabama (USDA, 2006). Since 1995, poultry production has become the top agricultural income producer for Mississippi farmers (Morgan and Murray, 2002). Though economically successful, the large and geographically concentrated poultry industry creates several highly complex and challenging environmental issues, such as eutrophication of fresh waters (Edwards and Daniel, 1993; Sims and Wolf, 1994; Moore et al., 1995; Sims et al., 1998; Sharpley, 2003). Land application of poultry litter is the most common waste disposal method (Sauer et al., 1999). Due to transportation economics, poultry litter is used close to production facilities, where repeated applications over years have produced high phosphorus (P) levels in soils. Several studies have shown that repeated poultry litter applications have led to as much as 6 times more P in the top 30 cm of treated soils as compared with untreated soils (Sharpley et al., 1993; Kingery

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et al., 1994; Simard et al., 1995; Sims et al., 1998; Sharpley, 2003). Broiler production is concentrated in central Mississippi, where 7 counties produced more than 50 million broilers annually (Morgan and Murray, 2002). Results from the Mississippi State University Soil Testing Laboratory indicated that at least 46% of soil samples in pastureland during 2000 to 2004 from these 7 counties had high levels of P. In addition, poultry litter was generally applied at a rate based on crop nitrogen (N) requirement instead of the crop P requirement, which resulted in excessive P fertilization due to the lower N:P ratio in the poultry litter (Nichols et al., 1994; Moore et al., 1995; Robinson and Sharpley, 1996). High P concentrations in the surface soil can lead to increased P in runoff and sediment which potentially accelerate the eutrophication of lakes and streams (Kingery et al., 1994; Pote et al., 1996; Daniel et al., 1998; Sauer et al., 1999; Pierson et al., 2001). Sauer et al. (1999) found that P concentrations were significantly higher from poultry litter treated sites (13.5 mg L\(^{-1}\)) as compared with treatment with dairy feces and urine (0.79 mg L\(^{-1}\)). Pierson et al. (2001) found that P concentration in surface runoff from poultry litter amended grasslands was highest after litter addition and only decreased slowly with subsequent runoff events. Potential P loss from litter-amended soils has received significant scrutiny from environmental agencies. Poultry litter applications to these fields may be constrained or eliminated if the risk of P movement is assessed as high or very high (USDA and USEPA, 1999).

Adverse impacts resulting from poultry litter application can be mitigated by implementation of effective best management practices (Moore et al., 1995). Agricultural management practices, including fertilization timing, fertilization techniques, crop planting date, and tillage practices, have shown mixed effects on P loss via runoff or sediment movement depending on local climatic conditions, rainfall patterns, site-specific soils, and nutrient characteristics of poultry litter (Heathman et al., 1994; Andraski et al., 2003). Research has focused on the impacts of individual management practices on P loss associated with poultry litter application, centering on fertilization techniques or tillage practices. A tillage system that lightly incorporates the litter or fertilizer into the soil can lead to a reduction in sediment bound P lost in the runoff, due chiefly to minimal soil disturbance. However, heavier tillage could result in more nutrients being lost in the particulate form, as well as leading to more soil erosion. Gilley et al. (2000) reported that reduced and no-till systems may increase infiltration on some soils leading to less runoff. Sharpley (2003) indicated that plowing has the potential to decrease the risk of P enrichment in overland flow from these soils. For no-till, the P loads in runoff were reduced by an average of 57% compared with chisel plow based on 8 years of data (Andraski et al., 2003). Heathman et al. (1994) reported that there were slight differences in the mean concentrations of P in the surface runoff under no-till(15.4 mg L\(^{-1}\)) and tillage(16.7 mg L\(^{-1}\)). Compared with surface application, injection of liquid dairy manure significantly decreased P losses in runoff (Ross et al., 1979). Baker and Laflen (1982) reported that there were no significant differences in dissolved P concentrations in runoff between injection and surface broadcast applications. Nichols et al. (1994) indicated that there were no significant differences in P concentration in runoff and P mass losses between surface-broadcasted and incorporated treatments of poultry litter. They attributed the insignificance between fertilization techniques to the damage to the surface soil covering by rotary tillage, which decreased P retention in the soil.

A management system widely used in Mississippi is tillage of pasture soils in the fall followed by planting of winter forages along with poultry litter application. Often, there is a significant lag between the tillage operation and the establishment of the winter forage. This creates conditions where tilled high-P soils are left partially or fully exposed to rainfall, increasing the potential for P loss via runoff or sediment movement. Pierson et al. (2001) stated that the concentration of dissolved P in runoff depends, in part, on the time elapsed between litter application and the first runoff event. Therefore, management system options consisting of tillage practices and planting date combinations must be evaluated for their ability to minimize environmental impact while sustaining forage productivity. Information is needed on the effects of these combinations on P loss for best P management practices in the area of poultry litter application. The objectives of this study were to: 1) determine changes in soil P with poultry litter additions under three management systems; 2) measure soluble and sediment
P losses in runoff as influenced by management of litter-amended soils; and 3) determine the P mass balance in the systems.

MATERIALS AND METHODS

Study site description

This study was conducted from September 1997 to September 2000 at the North Mississippi Branch of the Mississippi Agriculture and Forestry Experiment Station (MAFES) in Holly Springs, Mississippi. The study site is located within the Southern Mississippi Valley Silty Uplands Major Land Resource Area which has a hilly terrain and a subtropical, generally uniform climate (Tyer et al., 1972). The average annual temperature is 16.7 °C and average annual rainfall is 141 cm. The general weather pattern consists of wet winters and springs, and dry summers and falls (Tyer et al., 1972). Annual rainfall during the study years were 143, 145, 130, and 95 cm, respectively. The first 3 study years were relatively normal in comparison, while the year 2000 had 32% less rainfall than the 3 previous years.

Experimental design

The experiment was laid out in a randomized complete block design with three replications and conducted on 18 existing runoff plots with 3.65 m in width and 10.64 m in length. Each plot had approximately 3% slope and was enclosed on 3 sides by polyvinyl chloride (PVC) pipe borders, and equipped with an FW1 water level recorder, a 0.3-m H-flume, and an N-1 Coshocton runoff sampling device (Carter and Parsons, 1967). Water discharge from the Coshocton wheels was routed to cisterns through buried PVC pipe. All the runoff from a given storm event was collected and runoff and sediment grab samples were collected within 24 hours of each storm event if enough sample was available. Digital rain gauges were used to measure rainfall. Over the study period, 151 precipitation events and 40 runoff events were measured and collected.

The runoff plots were evenly distributed across two soils, which were Lexington silt loam (fine-silty, mixed, active, thermic, Ultic Hapludalfs), and Loring silt loam (fine-silty, mixed, active, thermic, Oxyaquic Fragiudalfs) (Tyer et al., 1972). These soils are moderately fertile and highly erodible and contain large amounts of silt and little sand (McGregor et al., 1969). Lexington soils are well drained, have moderate to moderately rapid permeability, and runoff is slow to rapid (Tyer et al., 1972). Loring soils are moderately well drained, have moderate permeability above the fragipan and moderately slow permeability in the fragipan. Depth to the fragipan ranges from 35 to 89 cm (Tyer et al., 1972). Treatments consisted of three management systems: 1) rotary till on 1 September and undisturbed until planting on 1 October, which was referenced as conventional tillage with delayed planting (CT-DP); 2) rotary till on 1 September and immediate planting, which was referenced as conventional tillage with immediate planting (CT-IP); and 3) no till with planting on 1 September, which was referenced as no till with immediate planting (NT-IP).

Poultry litter was applied at a Natural Resources Conservation Service (NRCS) recommended rate of 8960 kg ha⁻¹ on all plots on 15 March and 15 September each year of the study. Based on the size of the plots, an equivalent of 35 kg of poultry litter was applied to each of the 18 plots. Marshall ryegrass (Lolium multiflorum Lam.) was planted at 45 kg ha⁻¹ each fall. For both management systems of CT-DP and CT-IP, soil was tilled on 1 September. The planting of ryegrass was immediately after tillage for CT-IP, but delayed 1 month for CT-DP. For NT-IP, ryegrass was planted on 1 September without tillage. Crabgrass (Digitaria sanguinalis) was planted in the spring of 1997 as a warm season annual (prior to the start of the study) at a rate of 6.7 kg ha⁻¹ and allowed to reseed itself the following years. Ryegrass was harvested with a sickle-bar and crabgrass was harvested with a rotary mower when either was about 25 cm tall to a 5-cm stubble. Crabgrass was harvested in June, July, August, and September of each year. Harvests in other months were ryegrass.
Sample analysis

Initial soil sampling was in September 1997 after tillage and before and after litter application to a depth of 15 cm. Subsequently, soils were sampled each spring and fall prior to litter application at depths of 0 to 5 cm and 5 to 15 cm. Soil samples were air-dried, then ground to pass a 10-mesh (2 mm) sieve (Jones, 2001). Soil pH was determined from a 1:1 soil/water slurry. Total P in soils, sediment, and poultry litter were determined using the methods described by Murphy and Riley (1962) and Bowman (1988).

Plant tissue analysis was done to characterize elemental presence and concentration. The harvested tissue samples were dried at a minimum temperature of 65 °C for forty-eight hours, weighed, and then ground to pass a 1-mm sieve. Tissue P concentrations were measured after dry-ashing by inductively coupled plasma spectroscopy (ICP).

Runoff analyses included volume, sediment content, pH, inorganic P, and total P. Runoff volume and sediment loss were recorded at each runoff plot following storm events if sample was available. Runoff samples were then analyzed after filtration through a 0.45-µm filter. Determination of inorganic P in runoff was analyzed by using ion chromatography (IC). The determination of total P in runoff was done by ICP. After sample analysis using the IC and ICP, data were examined to compare P fractionation. Quality control in all analysis included the use of check standards, sample spikes, and replicates.

Data analysis

Data analysis was as a randomized complete block design with soils as blocks and management systems as treatments. The impacts of management systems on runoff volume, sediment loads, solution P in runoff, and sediment P were compared at the following 4 poultry litter application periods: fall 1997 (September 15, 1997 to March 14, 1997), spring 1998 (March 15, 1998 to September 14, 1998), fall 1998 (September 16, 1998 to March 14, 1998), and spring 1999 (March 15, 1999 to September 14, 1999). Analyses were performed using Proc Mixed of SAS with fixed effects of management systems (SAS Institute Inc., 1999). Correlation between soluble inorganic P and soluble P in surface runoff was determined by computing a correlation coefficient. For both soils, correlations among rainfall amount, runoff volume, sediment loads, soluble P mass, and sediment P mass over application periods were also determined by computing correlation coefficients.

Phosphorus budget analysis was conducted for each soil to define the P accumulated in the soil by the difference between total input P and output P. Equation 1 was used to determine P gains and losses for each management system over the 3 years of the study.

\[ P_{\text{soil}} = P_i + P_p - P_t - P_r - P_s \]  

where \( P_{\text{soil}} \) is the P accumulated in the soil; \( P_i \) represents the total P input from the poultry litter application; \( P_p \) is the P input from precipitation; \( P_t \) represents the forage P uptake; \( P_r \) is the total soluble P loss via runoff; and \( P_s \) is the total P lost via sediment. The P input from poultry litter was calculated based on the application rate and P composition. The P input from precipitation was estimated using observed data from National Atmospheric Deposition Program/National Trends Network (NADP/NTN). The observed data from Station MS10 located at Hinds County, Station MS19 located at Newton County, and Station MS30 located at Yalobusha County were analyzed. The results indicated that P input from precipitation is negligible.

RESULTS AND DISCUSSION

Runoff volume and sediment load

The local rainfall pattern had strong impacts on surface runoff and sediment loads. The observed
precipitation data are shown in Fig. 1 for the 4 poultry litter application periods. There were large variations in the total amount of rainfall among the 4 poultry litter application periods. The total amount of rainfall was 71.7, 60.1, 70.3, and 51.7 cm, respectively for fall 1997 application, spring 1998 application, fall 1998 application, and spring 1999 application. There were two large storm events, one on September 23, 1997 with rainfall amount of 12.5 cm and another on March 12, 1998 with rainfall amount of 10.2 cm.

Fig. 1 Observed precipitation during 4 poultry litter application periods: fall 1997 (a), spring 1998 (b), fall 1998 (c), and spring 1999 (d).

Averaged across the treatments and replications, the runoff volumes in Lexington soil were 23.4, 16.5, 9.0, and 6.7 cm for the 4 application periods of fall 1997, spring 1998, fall 1998, and spring 1999, respectively; whereas those in Loring soil for the 4 application periods were 33.0, 16.0, 18.1, and 10.9 cm, respectively (Fig. 2). For the entire study period, total runoff volume from Loring soil (78.0 cm) was 40% higher than that from Lexington soil (55.7 cm) (Fig. 2). This increased amount of runoff may be attributed to the higher infiltration capacity in Lexington soil and a fragipan at 35 cm in Loring soil, which restricts infiltration and percolation through soil profile (McGregor et al., 1969). Runoff volume over each application period was linearly related to the amount of rainfall, with correlation coefficient

Fig. 2 Runoff from Lexington soil (a) and Loring soil (b) under different management systems for each poultry litter application period. CT-DP = conventional tillage with delayed planting; CT-IP = conventional tillage with immediate planting; NT-IP = no-till with immediate planting. Error bars represent standard error of the mean (n = 3).
r of 0.57 for Lexington soil and 0.80 for Loring soil. In the fall 1998 application period for Lexington soil, management system CT-DP contributed a significantly lower amount of runoff compared with CT-IP and NT-IP \((P = 0.05)\) (Fig. 2). However, there were no significant differences in runoff volume for other poultry litter application periods between management systems.

Averaged across the treatments and replications, the sediment loads from the Lexington soil were 5.77, 1.59, 0.73, and 1.15 kg plot\(^{-1}\) for the 4 application periods of fall 1997, spring 1998, fall 1998, and spring 1999, respectively; whereas those from Loring soil were 6.63, 2.87, 5.47, and 4.59 kg plot\(^{-1}\), respectively, for the 4 application periods (Fig. 3). Total sediment load from Loring soil (19.57 kg plot\(^{-1}\)) over the 4 application periods was 89% higher than that from Lexington soil (10.35 kg plot\(^{-1}\)), which was due to the higher runoff potential of Loring soil (McGregor et al., 1969). The sediment loads over each application period were linearly correlated with total runoff volume, with correlation coefficient \(r\) of 0.89 for Lexington soil and 0.72 for Loring soil. Over the 4 application periods, sediment loads from CT-DP, CT-IP, and NT-IP were 10.97, 9.0, and 7.72 kg plot\(^{-1}\) for Lexington soil, and 24.65, 20.12, and 13.92 kg plot\(^{-1}\) for Loring soil, respectively. The lowest sediment load trends for both soils were with NT-IP. However, there were no significant differences in sediment loads for each application period between management systems due to large variations within the management system. For example, in the fall 1998 application period for Loring soil, sediment loads from CT-DP, CT-IP, and NT-IP, were 7.48, 6.87, and 2.05 kg plot\(^{-1}\), respectively (Fig. 3). Statistically, NT-IP contributed slightly lower amounts of sediment than CT-DP \((P = 0.18)\) and CT-IP \((P = 0.22)\). Many of the reported effects of management practices on runoff and sediment, were conducted immediately after tillage practice with simulated rainfall for a single or discrete event. Andraski et al. (2003) conducted a rainfall simulation study immediately after spring disking and fall harvest when the soil was just disturbed and a large amount was eroded, and found that chisel plowing created much more sediment (2803–4833 kg ha\(^{-1}\)) than no-till practice (45–467 kg ha\(^{-1}\)). Our study was conducted under natural rainfall conditions, and there was a time lag between tillage practice and the first storm event. For example, in the fall 1997 application, the first storm event happened 8 days after tillage, and in fall 1998 application, the first storm event occurred 5 days after tillage. In addition, the rainfall intensity applied by Andraski et al. (2003) was extremely high, 75 mm h\(^{-1}\), corresponding to a return period of 50 years for southern and southwestern Wisconsin. There were normal amount of rainfall during the study period, with typical rainfall intensities ranging from 0.1–30.0 mm h\(^{-1}\). The above factors may have contributed to the statistically insignificant differences in sediment loss between management systems.

**Fig. 3** Sediment loads for Lexington soil (a) and Loring soil (b) under different management systems for each poultry litter application period. CT-DP = conventional tillage with delayed planting; CT-IP = conventional tillage with immediate planting; NT-IP = no-till with immediate planting. Error bars represent standard error of the mean \((n = 3)\).

**Phosphorus budget analysis**

Budget analysis is an effective approach for tracking the amount of P entering and exiting an
ecosystem of interest. Over the 2-years study, each plot received 2,603 g P in total (Table I). Phosphorus outputs from the system consisted of sediment P, solution P in runoff, and plant uptake P. The P accumulated in the soil is equal to the difference between the total input and output P. The relative percentages of P in each component for Lexington and Loring soils are shown in Table II. The majority of P from poultry litter application accumulated in the soil with 92.9% in Lexington soil and 92.6% in Loring soil (Table II). Phosphorus over-supplied crop requirements with only 3.8% used by forage in Lexington soil and 3.2% in Loring soil (Table II). Approximately 2.3% and 3.7% of total P was removed by surface runoff in Lexington soil and Loring soil, respectively (Table II). The sediment P loss was 1.0% and 0.6% in Lexington and Loring soils, respectively (Table II).

### TABLE I

<table>
<thead>
<tr>
<th>Year</th>
<th>Application time</th>
<th>Rate of litter application</th>
<th>P content in the poultry litter</th>
<th>Total P applied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg plot^{-1}</td>
<td>g kg^{-1}</td>
<td>g plot^{-1}</td>
</tr>
<tr>
<td>1997</td>
<td>September 15</td>
<td>35</td>
<td>18.3</td>
<td>639</td>
</tr>
<tr>
<td>1998</td>
<td>March 15</td>
<td>35</td>
<td>21.8</td>
<td>761</td>
</tr>
<tr>
<td>1998</td>
<td>September 15</td>
<td>35</td>
<td>17.8</td>
<td>622</td>
</tr>
<tr>
<td>1999</td>
<td>March 15</td>
<td>35</td>
<td>16.6</td>
<td>580</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>2,603</td>
</tr>
</tbody>
</table>

### TABLE II

Phosphorus budget\(^a\) of three management systems used on two soils

<table>
<thead>
<tr>
<th>System(^b)</th>
<th>(P_i)</th>
<th>(P_t)</th>
<th>(P_s)</th>
<th>(P_r)</th>
<th>(P_{soil})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{Lexington soil})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT-DP</td>
<td>2603</td>
<td>116</td>
<td>47</td>
<td>53</td>
<td>2,387</td>
</tr>
<tr>
<td>CT-IP</td>
<td>2603</td>
<td>91</td>
<td>16</td>
<td>57</td>
<td>2,440</td>
</tr>
<tr>
<td>NT-IP</td>
<td>2603</td>
<td>92</td>
<td>17</td>
<td>67</td>
<td>2,426</td>
</tr>
<tr>
<td>(\text{Loring soil})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT-DP</td>
<td>2603</td>
<td>83</td>
<td>71</td>
<td>53</td>
<td>2,396</td>
</tr>
<tr>
<td>CT-IP</td>
<td>2603</td>
<td>90</td>
<td>24</td>
<td>66</td>
<td>2,423</td>
</tr>
<tr>
<td>NT-IP</td>
<td>2603</td>
<td>82</td>
<td>16</td>
<td>96</td>
<td>2,410</td>
</tr>
</tbody>
</table>

\(^a\)\(P_i\) = total P input from the poultry litter application; \(P_t\) = forage P uptake; \(P_s\) = total P lost via sediment; \(P_r\) = total soluble P loss via runoff; \(P_{soil}\) = P accumulated in the soil; \(^b\)CT-DP = conventional tillage with delayed planting; CT-IP = conventional tillage with immediate planting; NT-IP = no-till with immediate planting.

In this study, poultry litter was applied at commonly used rates in Mississippi, which were intended to meet the N requirement of the forage. This practice often results in excessive P fertilization, due to the generally lower ratio of N:P added in poultry litter than that required by crops (Moore et al., 1995). Hence, poultry litter applications based on plant N needs, as in this study, would provide an excess of P. The results from soil sample data analysis also strongly indicated the buildup of P in the surface soil (0–15 cm) due to poultry litter application over time. In both soils, total soil P increases from 1997 to 2000 were significant (\(P = 0.05\)) within management systems (Fig. 4).

**Solution P in runoff**

Phosphorus in runoff from plots amended with poultry litter was primarily in the inorganic form (Fig. 5). Inorganic P accounted for 94% of total phosphorus in runoff, indicating that dissolved organic P was not important. This is, in part, due to a major proportion of inorganic P in poultry wastes (Leinweber, 1997) and dissolution and desorption of inorganic P from surface soil during interaction processes of soil with runoff. The results were in agreement with those by Heckrath et al. (1997) that 65%–85% of P in drainage was inorganic P and by Heathwaite (1997) in which initial storm runoff in early autumn
Fig. 4  Accumulation of P in Lexington soil (a) and Loring soil (b) under different management systems due to poultry litter application over time. CT-DP = conventional tillage with delayed planting; CT-IP = conventional tillage with immediate planting; NT-IP = no-till with immediate planting. Error bars represent standard error of the mean (n = 3).

Fig. 5  Correlation between dissolved inorganic P and total P in runoff.

were dominated by the soluble inorganic fraction (87%–99% of dissolved P). However, Chardon (1997) found that more than 90% of the P leached in a cattle-manured sandy soil column was an organic form.

Fig. 6 shows the P concentrations in surface runoff over the fall 1997 application period for Lexington and Loring soils. The first rainfall event happened 8 days after the poultry litter application at a rate of 12.5 cm d\(^{-1}\). In general, inorganic P concentrations decreased with time after poultry litter application for both soils. The P concentration in runoff was highest in the first rainfall event immediately following

Fig. 6  Soluble P dynamics in the runoff from Lexington soil (a) and Loring soil (b) after first poultry litter application under different management systems. CT-DP = conventional tillage with delayed planting; CT-IP = conventional tillage with immediate planting; NT-IP = no-till with immediate planting.
poultry litter application, ranging from 8 to 14 mg L$^{-1}$ (Fig. 6). With subsequent storm events, P concentrations in surface runoff significantly decreased, and ranged from 0 to 3.9 mg L$^{-1}$. Schroeder et al. (2004) also found that greater P concentrations were measured for the first runoff event when runoff-producing rainfall occurred immediately after litter application. The first storm event caused the majority of soluble P mass loss. The loss of soluble P mass from this single storm event accounted for 79%, 83%, and 71% of total P mass over fall 1997 application period for CT-DP, CT-IP, and NT-IP in Lexington soil and 68%, 65%, and 72% in Loring soil, respectively.

![Fig. 7 Soluble P in Lexington soil (a) and Loring soil (b) under different management systems for each poultry litter application period. CT-DP = conventional tillage with delayed planting; CT-IP = conventional tillage with immediate planting; NT-IP = no-till with immediate planting. Error bars represent standard error of the mean ($n$ = 3).](image)

The mass of soluble P from CT-DP, CT-IP, and NT-IP for Lexington and Loring soils is shown in Fig. 7. Averaged across the treatments and replications, the mass of soluble P from Lexington soil was 29.3, 19.1, 5.4 and 5.2 g plot$^{-1}$ in fall 1997, spring 1998, fall 1998, and spring 1999 applications, respectively; whereas that from Loring soil for the 4 application periods was 36.5, 18.2, 10.8, and 6.3 g plot$^{-1}$, respectively (Fig. 7). The mass of soluble P over an application period was linearly related to total runoff volume with correlation coefficient $r$ of 0.94 for Lexington soil and 0.84 for Loring soil. In Lexington soil, there were no significant differences in total soluble P mass over the entire study period between management systems. However, there were significant differences in total soluble P mass for specific poultry litter application periods. The $P$ values for comparison of effects of management systems on soluble P mass for the 4 application periods are shown in Table III. For fall 1998 application, CT-DP contributed a significantly lower amount of soluble P mass than NT-IP ($P = 0.042$) and CT-IP ($P = 0.039$) (Table III). In spring 1999 application, there was significantly higher amount of soluble P mass from NT-IP than CT-IP ($P = 0.039$). In Loring soil, there were significant differences in total soluble P mass over the entire study period between management systems ($P < 0.01$). NT-IP contributed a significantly higher amount of soluble P mass than CT-DP and CT-IP (Fig. 7). The $P$ values of comparison of effects of management systems on soluble P mass are also given by Table III. Other studies have also shown that dissolved P in runoff was greater from no-till than from conventional till practices, since accumulation of crop residues and added P at the soil surface provide a source of P to runoff that would be reduced by incorporation of tillage (Barisas et al., 1978; Sharpley et al., 1994).

**Sediment P**

Application of poultry wastes significantly increased P concentrations in sediments (Table IV). Average sediment P concentrations increased from 2784 mg PO$_4$ kg$^{-1}$ before application to 7271 mg PO$_4$ kg$^{-1}$ after the first year of application. Phosphorus concentration in sediment after the second year was similar to those following the first year of application.

The mass of sediment P from CT-DP, CT-IP, and NT-IP for Lexington and Loring soils is shown
TABLE III
P values for comparison of effects of management systems on soluble P mass in Lexington and Loring soils

<table>
<thead>
<tr>
<th>Systema)</th>
<th>Lexington soil</th>
<th>Loring soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT-DP</td>
<td>CT-IP</td>
</tr>
<tr>
<td><strong>Fall 1997</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT-DP</td>
<td>-</td>
<td>0.869</td>
</tr>
<tr>
<td>CT-IP</td>
<td>0.869</td>
<td>-</td>
</tr>
<tr>
<td>NT-IP</td>
<td>0.178</td>
<td>0.225</td>
</tr>
<tr>
<td><strong>Spring 1998</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT-DP</td>
<td>-</td>
<td>0.805</td>
</tr>
<tr>
<td>CT-IP</td>
<td>0.805</td>
<td>-</td>
</tr>
<tr>
<td>NT-IP</td>
<td>0.231</td>
<td>0.163</td>
</tr>
<tr>
<td><strong>Fall 1998</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT-DP</td>
<td>-</td>
<td>0.039</td>
</tr>
<tr>
<td>CT-IP</td>
<td>0.039</td>
<td>-</td>
</tr>
<tr>
<td>NT-IP</td>
<td>0.042</td>
<td>0.955</td>
</tr>
<tr>
<td><strong>Spring 1999</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT-DP</td>
<td>-</td>
<td>0.263</td>
</tr>
<tr>
<td>CT-IP</td>
<td>0.263</td>
<td>-</td>
</tr>
<tr>
<td>NT-IP</td>
<td>0.039</td>
<td>0.213</td>
</tr>
</tbody>
</table>

a)CT-DP = conventional tillage with delayed planting; CT-IP = conventional tillage with immediate planting; NT-IP = no-till with immediate planting.

TABLE IV
Changes in PO₄ concentrations in runoff sediments

<table>
<thead>
<tr>
<th></th>
<th>Before application</th>
<th>After application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averagea)</td>
<td>2784a</td>
<td>7271b</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1263</td>
<td>3567</td>
</tr>
<tr>
<td>Maximum</td>
<td>6673</td>
<td>28354</td>
</tr>
<tr>
<td>Minimum</td>
<td>1259</td>
<td>1365</td>
</tr>
</tbody>
</table>

a)Means followed by the same letter are not significantly different at the 0.05 probability level.

in Fig. 8. Averaged across the treatments and replications, the mass of sediment P from Lexington soil was 18.1, 5.1, 2.2 and 1.3 g plot⁻¹ in fall 1997, spring 1998, fall 1998, and spring 1999 applications, re-

![Fig. 8 Sediment P from Lexington soil (a) and Loring soil (b) under different management systems for each poultry litter application period. CT-DP = conventional tillage with delayed planting; CT-IP = conventional tillage with immediate planting; and NT-IP = no-till with immediate planting. Error bars represent standard error of the mean (n = 3).](image-url)
spectively; whereas that from Loring soil was 18.6, 9.0, 8.4, and 0.8 g plot\(^{-1}\), respectively, for the 4 application periods (Fig. 8). The mass of sediment P over an application period was linearly related to the total sediment load with a correlation coefficient \(r\) of 0.80 for Lexington soil and 0.68 for Loring soil. For both soils, there were no significant differences in mass of sediment P between management systems for the entire study period. Also, for both soils there were no significant differences in mass of sediment P between management systems for each individual application period. The results were consistent with the insignificant differences in sediment loads between management systems.

CONCLUSIONS

There was significant increase of soil P after 3 years of poultry litter application for both soils \((P = 0.05)\). The majority of P from poultry litter application was accumulated in both soils. Less than 10% of P from poultry litter application was removed by surface runoff and sediment. For Loring soil, CT-DP and CT-IP were effective management practices to mitigate negative effects due to poultry litter application. NT-IP contributed a significantly higher amount of soluble P mass than CT-DP and CT-IP over the entire study period. However, there were no significant differences in mass of sediment P between the management systems. For Lexington soil, none of the 3 management systems significantly reduce the P mass from the surface runoff and sediment over the entire study period. However, there were significant differences in soluble P mass between management systems for some specific poultry litter application periods. The insignificance in soluble P mass and sediment P mass between the management systems CT-DP and CT-IP and the management system CT-DP might be due to the complexity in conditions over the study period, such as the time lag between tillage and first storm event, and the intensity of the first storm event following poultry litter application.

REFERENCES


