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Phosphorus availability in two soils amended with poultry litter

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Abstract——Understanding P transformation in soils amended with poultry litter is important if water quality is to be protected. Our objectives were to determine the influence of method of litter application and temperature on P availability. Poultry litter containing 20.8 g P/kg (dry weight) was either surface-applied or incorporated into Captina (fine-silty, siliceous, mesic Typic Fragiudult) and Nixa (loamy-skeletal, siliceous, Glossic Fragiudult) silt loams at rates of 0 or 10 g/kg and incubated at 20℃ or 35℃ at a water potential of −40 kpa. Water soluble and available P (0.03 mol/L NH_4F + 0.025 mol/L HCl extraction) were determined during a 60d laboratory study. Results indicated that water soluble and available P levels in the soils initially decreased, then rapidly increased, and approached a steady state phase after approximately 20d. After 60d, water soluble P levels were significantly higher when litter was surface applied than when litter was incorporated. When the incubation was terminated, the net increase in available P in both soils was > 100 mg P/kg. For efficient recycling of P and protection of water quality, application method and temperature should be considered when amending soils with poultry litter.

Keywords: nutrient cycling; phosphorus availability; poultry litter; water quality.

1 Introduction

Commercial poultry production is usually accompanied by generation of large quantities of waste. The mixture of manure plus bedding material such as straw or wood chips is commonly known as poultry litter and is used as an organic fertilizer in agriculture in many places of the world. Runoff from agricultural lands has the potential to contribute substantial amounts of P to lakes and streams. Addition of bioavailable P to many freshwater systems can result in eutrophication since algal growth is generally limited by low P levels (Caraco, 1989; Dorich, 1984). To protect water quality and ensure efficient use of poultry litter as a nutrient source for plants, it is necessary to evaluate the influence of application methods and soil conditions on amounts and forms of P present in soils amended with poultry litter.

The objectives of this study were to determine the influence of temperature and method of application on water soluble and available P in two soils amended with poultry litter.

2 Materials and methods

2.1 Soils

The silt loam soils used in the study were Captina, a fine-silty, siliceous, mesic Typic Fragiudult, and Nixa, a loamy-skeletal, siliceous, mesic Glossic Fradiudult (Table 1).

Table 1 Selected properties of the two silt loam soils studied

Soil	pH (H_2O)	Organic matter, %	CEC, cmol/kg	Phosphorus, mg P/kg	
				Water solule P	Availale P
Captina	5.8	1.0	10.0	0	14
Nixa	5.8	2.3	15.5	4	256

Soils, collected at field moist conditions from Arkansas State, the United States of America, were crushed to pass a 2 mm sieve, and 100g was weighed into 250 ml polypropylene containers. The soils were adjusted to a moisture potential of −40 kpa and sealed with plastic film to maintain a constant moisture while allowing gaseous exchange.

Poultry litter used in this study was collected from a broiler house following five flock cycles. The bedding material used was hardwood sawdust. The litter was grounded to pass a 2 mm sieve and either applied to the soil surface or incorporated at rates of 0 and 1 g/100g soil. Prior to addition to the soil, the litter contained 0.4, 8.7, and 20.8 g/kg (dry weight) of water soluble, available, and total P, respectively. The percentage solids and pH of the litter were 70% and 8.7, respectively.

2.2 Incubation

The samples were incubated at 20℃ or 35℃ and sampled at 0, 1, 3, 6, 9, 12, 15, 20, 30, 45, and 60 days. Phosphorus extractions and determinations were conducted according to the procedure described by Olsen and Sommers (Olsen, 1982). To determine water soluble P, soil was extracted with 0.01 mol/L $CaCl_2$ at a ratio 1:10. To evaluate available P, soil was extracted with 0.3 mol/L NH_4F + 0.025 mol/L HCl at a ratio of 1:7. The P concentrations were determined colorimetrically with a Model 21 Bausch & Lomb Spectrophotometer. The pH values were determined in 1:1 distilled water to soil suspensions.

2.3 Statistical analysis

A randomized complete block experimental design with three replicates was used. Analysis of variance was conducted and means separated at $p<0.05$.

3 Results and discussion

3.1 Water soluble P

The dynamics of water soluble P in both soils amended with poultry litter followed a similar pattern (Fig. 1). Initially, the water soluble P levels decreased for 3d to 9d. Then a stage of rapid increase in soluble P occurred that lasted until day 12 to 20 of the incubation. The third stage was a steady state phase that lasted until the incubation was terminated at 60d and generally showed a slight increase in soluble P levels in the soils amended with litter.

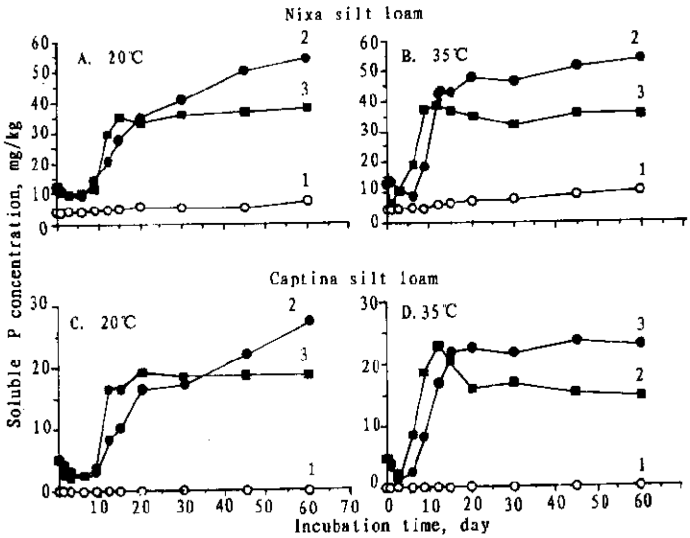

Fig. 1 Water soluble P concentration in two silt loamy soils amended with poultry litter during 60 day incubation in control (1), surface-applied (2), and incorporated (3) treatments

The initial decrease in soluble P lasted for 9d in both soils incubated at 20℃, but at 35℃, it lasted only 3d when the litter was incorporated and 6d when the litter was applied to the soil surface. The data suggest that the soluble P initially present in the litter rapidly formed insoluble compounds in both soils. At the higher temperature, rapid mineralization of organic P apparently counterbalanced the initial water soluble P removal.

In both soils, the rapid increase in water soluble P occurred until 20d and 12d for the 20℃ and 35℃ incubations, respectively. The rapid increase is likely due to mineralization of large quantity of readily decomposable P compounds in the litter. There is little information on P mineralization in poultry litter, however, Gale and Gilmour (Gale, 1986) reported that C and N mineralization in litter occurred in three phases they designated rapid, intermediate, and slow. In their study conducted at 25℃, the rapid and intermediate phases lasted 14d. Bitzer and Sims (Bitzer, 1988) also reported N mineralization in soil amended with poultry manure and noted substantial inorganic N production within 14d. Our results appear to be consistent with the observations reported by both research groups.

Following the phase of rapid increase in water soluble P, the soils amended with poultry litter exhibited a slow but steady increase in soluble P until the end of the 60d incubation. At the termination of the study, water soluble P levels were significantly higher when the poultry litter was incorporated. The lower P concentration when the litter was incorporated was apparently due to greater surface area contact between the soils and the litter and a consequent increase in P adsorption. During the phase of rapid increase in water soluble P, however, P levels were generally higher when the litter was incorporated than when the litter was applied to the soil surface. The rapid mineralization of the incorporated litter may have resulted in the microbial production of organic acids that can substantially reduce P fixation (Lee, 1990; Han, 1995).

Water soluble P levels in the unamended Captina soil were negligible during the incubation (Fig. 1c, d). The unamended Nixa soil had a water soluble P level of 4 mg/kg (Fig. 1a, b) when the experiment was initiated. The high value reflects a history of litter applications in the field where the soil was collected.

We wanted to calculate the P that was released from poultry litter. To do that, we quantified the water soluble P released from litter using the following equation:

Water soluble $P_{released} = P_{trt} - P_{ck} - P_{litter}$,

where P_{trt} was the water soluble P concentration at the sampling time; P_{ck} was the P concentration in the control that did not receive poultry litter; P_{litter} was the amount of water soluble P added in the litter, respectively. Fig. 2 demonstrates the net amounts of water soluble P released from litter in different treatments. The pattern was very similar to the total water soluble P concentrations (Fig. 1). After 60d, the net water soluble P released from litter were about 40, and 23 mg/kg for surface applied and incorporated treatments in a Nixa soil, and 20 and 12 mg/kg for surface-applied and incorporated treatment in the Captina soil, respectively. The negative soluble P released during the initial phase indicates that water soluble P present in the litter was adsorbed by soil and transformed more insoluble fractions. Fig. 2 also indicates that there is a trend of gradual decrease in P released form litter for the incorporated treatment at 35℃. This may illustrate that water soluble P is gradually moving to more non-labile forms, or the slow release of P from litter could not compensate for P moving into other fractions.

3.2 Available P

Available P, or Bray extractable P, exhibited a pattern similar to that for water soluble P in that three phases were evident (Fig. 3). The phase of decreasing available P lasted 9d to 12d and was followed by a stage of rapid increase in available P levels until 12 to 20d of incubation. When the study was terminated after 60d, available P levels were not significantly different between incorporated and surface-applied treatments and between the 20℃ and 35℃ incubations.

The net available P increase after 60d in the litter-amended Nixa and Captina soils were 123 and 108 mg P/kg, respectively. Because the P extracted with dilute NH_4F + HCl includes part of the P sorbed by Al- and Fe-oxides (Olsen, 1982), it would appear that a portion of the strong P-sorbing sites in the Nixa soil was no longer available for P removal. Reddy *et al.* (Reddy, 1980) also reported that manure addition reduced the P-sorption capacity of soil. The history of litter application to the Nixa soil is indicated by the 256 mg P/kg and the higher organic matter content (Fig. 1, Table 1). The Captina soil did not have a history

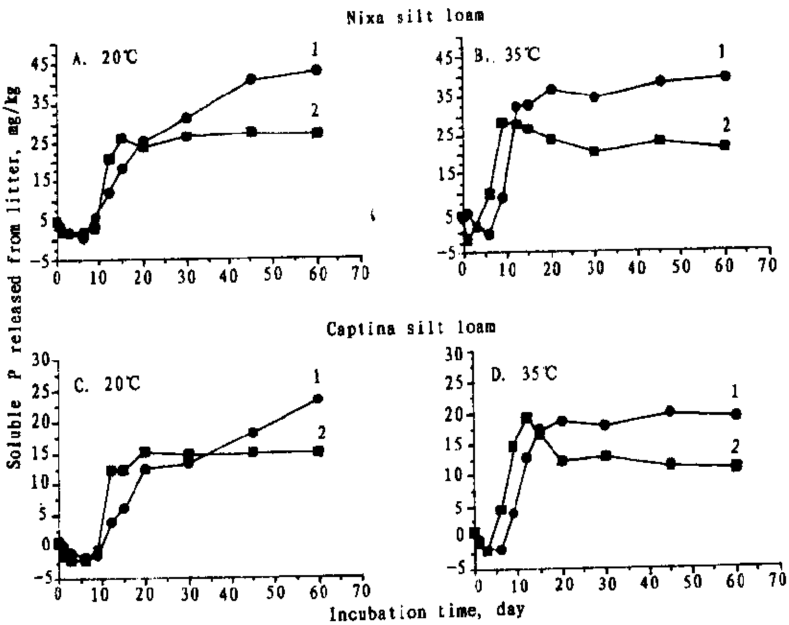

Fig. 2 Water soluble P released from poultry litter in two silt loamy soils amended with poultry litter in surface- applied (1) and incorporated (2) treatments

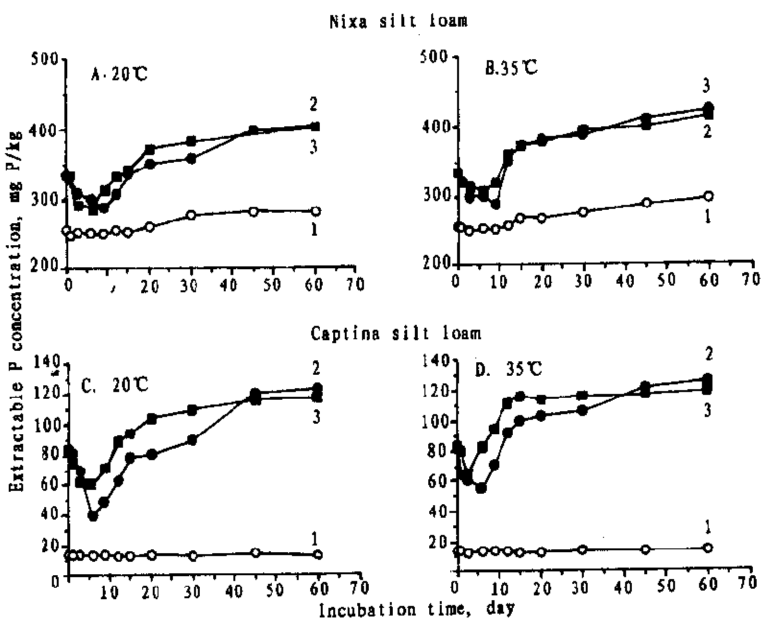

Fig. 3 Extractable (Bray extractable) P concentration in two silt loamy soils amended with poultry litter in control (1), surface-applied (2), and incorporated (3) treatments

of litter addition, and apparently more P-removal sites were present which resulted in lower available P levels. Field *et al.* (Field, 1985) developed linear regression equations to show that addition of 1g anaerobically digested poultry litter/100g soil would increase double acid extractable P approximately 40 mg P/kg following a 30d incubation. Using poultry litter and the Bray extraction solution, we found available P increases in excess of 100 mg/kg.

During the initial 30d of incubation, available P levels were greater in soils incubated at 35℃ compared to 20℃. The increased available P levels could be due to increased decomposition of the organic P in the poultry litter. Sims (Sims, 1986) reported that increasing incubation temperature from 25℃ to 40℃ resulted in increased N mineralization in poultry-litter-amended Evesboro loamy soil.

We also calculated the net amount of extractable P released from the decomposition of litter using the same equation as for the water soluble P. It can be seen from Fig. 4 that during the initial stage, about 50 mg P/kg soil was adsorbed by clay and microbial immobilization, as indicated by the negative values. After 60d of incubation, the net amount of extractable P released from the poultry litter were about 35 and 20 mg/kg for Nixa soil and Captina soil, respectively.

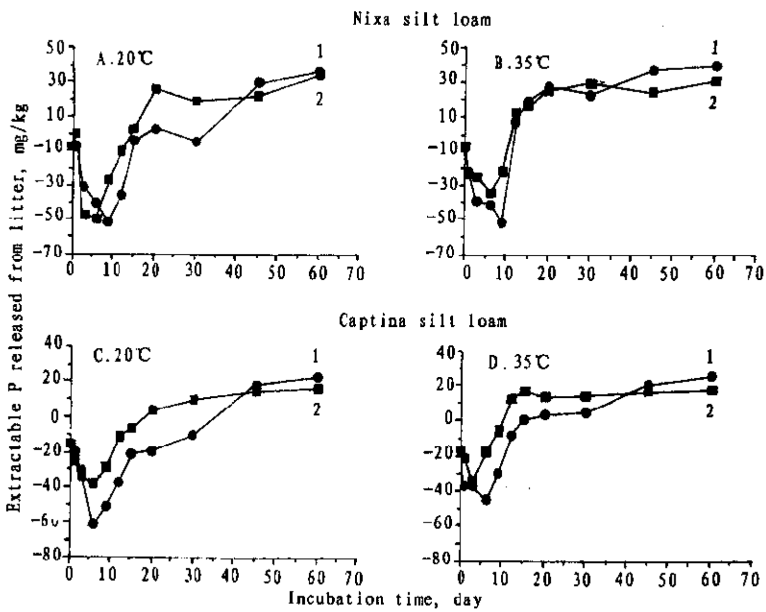

Fig. 4 Extractable P released from poultry litter in two silt loamy soils amended with poultry litter in surface- applied (1) and incorporated (2) treatments

In comparison to the net amount of water soluble P released from poultry litter decomposition (Fig. 2), the pattern of extractable P that was released from poultry litter (Fig. 4) could imply two major important points. First, the P released from poultry litter decomposition mainly exists in water soluble forms because the net amount of P released from the decomposing litter was similar in these two fractions. Second, greater difference can be found between the two application methods for water soluble P compared to extractable P, indicating that more water soluble P might have entered into less soluble P pools when poultry litter was incorporated into the soil. The extractable P is generally considered to be less readily available for plant uptake than water soluble P even thought this fraction is still labile (Mattingly, 1975).

3.3 Soil pH

Table 2 Soil pH following a 60d incubation at 20℃ and 35℃

Soil	Treatment	pH	
		20℃	35℃
Captina*	Check	5.0b**	4.6e
	Litter surface	4.5f	4.3h
	Litter incorporated	4.7d	4.4g
Nixa	Check	5.1a	4.6e
	Litter surface	4.7d	4.3h
	Litter incorporated	4.8c	4.4g

* Initial pH = 5.8

* * Values followed by the same letter are not significantly different ($\alpha=0.05$)

Both soils exhibited pH decreases during the incubation (Table 2). As incubation temperature increased, there was a significantly pH decrease, and surface-applied litter resulted in significantly lower pH values than incorporated litter. The largest pH decrease of 1.5 units occurred when the litter was surface-applied and incubated at 35℃. The unamended soils incubated at 20℃ showed the smallest pH reduction of only 0.7 units. It is likely that the levels of water soluble and available P would have been even larger if litter decomposition and nitrification had not resulted in significant pH reductions.

4 Summary

Application of poultry litter as an organic fertilizer is an important method for recycling nutrients. Data from this study indicated that soluble and available P levels initially decreased, then rapidly increased, and approached a steady state phase after approximately 20d. Water soluble P levels were significantly higher when litter was surface applied than when litter was incorporated. Organic P in poultry litter was rapidly mineralized for a net increase of >100 mg P/kg after the 60d incubation. Litter decomposition and nitrification resulted in significant pH decreases during the study. Method of litter application and temperature should be considered if environmentally safe and agriculturally effective waste application practices are to be developed and implemented.

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