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Nitrogen and Phosphorus Accumulation in Pasture Soil from Repeated Poultry Litter Application

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Abstract: Poultry litter (PL) is a traditionally inexpensive and effective fertilizer to improve soil quality and agricultural productivity. However, over application to soil has raised concern because excess nutrients in runoff could accelerate the eutrophication of fresh water. In this work, we determined the contents of total phosphorus (P), Mehlich 3 extracted P, total nitrogen (N), ammonium (NH_4)-N, and nitrate (NO_3)-N, in pasture soils receiving annual poultry litter applications of 0, 2.27, 2.27, 3.63, and 1.36 Mg/ha/ yr, respectively, for 0, 5, 10, 15, and 20 years. Samples were collected from three soil depths (0–20, 20–40, and 40–60 cm) of the Hartsells series (fine-loamy, siliceous, subactive, thermic, Typic Hapludults) on a 3–8% slope in the Sand Mountain region of north Alabama. PL application increased levels of total P, Mehlich-3 extractable P, and total N significantly. However, the change in NH_4-N and NO_3-N contents by the PL application was not statistically significant. Correlation analysis indicated that the contents of total P, Mehlich 3 extracted P, and total N were more related to cumulative amounts of poultry litter applied than the years of application or annual application rates alone. This observation suggested that N and P from poultry litter accumulated in soil. Predicting the build-up based on the cumulative amounts of PL application, rather than isolated factors (i.e., application year or

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rate), would improve the accuracy of evaluating long-term impacts of poultry litter application on soil nutrient levels.

INTRODUCTION

Poultry litter (PL, a mixture of manure and other external materials, such as bedding material) is traditionally inexpensive and used as fertilizer to improve soil quality and agricultural productivity (Franzluebbers and Stuedemann 2003, 2005, Franzluebbers et al. 2004, Jackson et al. 1977, Kingery et al. 1993, Mitchell and Tu 2006). For example, most of the 1.5 million Mg of broiler litter generated in Alabama during 1999 was used for fertilizing pastures (Kpomblekou et al. 2002). But over-application of PL to soil may lead to detrimental environmental effects, such as pollution of ground and surface waters due to leaching and runoff of nutrients and soil accumulation of heavy metals (Franzluebbers et al. 2002, He et al. 2008, Kingery et al. 1994, Tazisong et al. 2005).

Nitrogen (N) and phosphorus (P) are two major nutrients in PL (He et al. 2006). Whereas the two elements are required for profitable agricultural practices, N- and P-driven eutrophication of water ecosystems is a serious environmental concern (Tilman et al. 2001). Thus, a best management practice for poultry litter application would maintain adequate N and P for plant growth while minimizing adverse environmental impacts of PL. Soils in the Sand Mountain region of Alabama are sloping, permeable to water and dissolved constituents, and shallow to bedrock, thus constituting a system with a high potential for escape of nutrients to ground and surface (Kingery et al. 1994). For evaluating the long-term impact of PL application, a field experiment of land applied litter to pasture soils has been maintained for two decades at the Sand Mountain region of north Alabama, USA (He et al. 2008, Tazisong et al. 2005). The objectives of this study were to evaluate the impact of PL application history (0, 5, 10, 15, and 20 years) on accumulation and distribution of total P, Mehlich 3 extracted P, total N, ammonium (NH_4)-N, and nitrate (NO_3)-N through soil profiles (0–60 cm). The impacts on trace elements and macro cations have been reported elsewhere (He et al. 2008, Tazisong et al. 2005).

MATERIALS AND METHODS

Soils

Soils were collected from slope positions (3 to 8% slope) of the Hartselle (fine sandy loam, siliceous, thermic, Typic Hapludults) soil series in the

Sand Mountain region of north Alabama, USA. Samples were collected randomly at three locations in each field at depth increments of 0–20, 20–40, and 40–60 cm. Soil samples in five fields had received poultry litter continuously for the past 0 (control), 5, 10, 15, and 20 years at rates of 0 (control), 2.27, 2.27, 3.63, and 1.36 $Mg\,ha^{-1}\,yr^{-1}$, respectively. These fields were hayed and fertilized with litter only and were being managed for pasture without supplemental inorganic N, P, or potassium (K) fertilizers. The soil samples were air-dried, ground to pass a 2-mm stainless steel sieve, and stored in plastic bags at room temperature. Subsamples were also ground to pass a 100 mesh screen for total metal determinations.

Chemical Analyses

To determine total P content, 1.0 g of each soil sample (100 mesh) was placed in 100-mL Teflon beakers to which 5 mL concentrated nitric acid (HNO_3) was added (Kpomblekou and Tabatabai 1994). The beakers were covered with watch glasses after which they were heated to dryness and allowed to cool, after which 6 mL of perchloric acid ($HClO_4$) was slowly added to the contents and reheated at 203°C until a colorless residue was obtained. Total P in the digest was determined with inductively coupled atomic emission spectroscopy (ICP-AES, Perkin-Elmer Plasma 400 Emission Spectrophotometer, Norwalk, CT). For Mehlich-3 extractable P content, soils (2.5 g) were extracted with Mehlich-III [0.2 M acetic acid (CH_3COOH) + 0.25 M ammonium nitrate (NH_4NO_3) + 0.015 M ammonium fluoride (NH_4F) + 0.13 M HNO_3 + 0.001 M ethylenediaminetetraacetate (EDTA)] extractant (25 mL) at pH 2.5 for 5 min prior to ICP-AES analysis (Mehlich 1984). Total N was determined by dry combustion at 1350°C (Elementar Americas, Inc). Soil NO3-N and NH4-N were determined colorimetrically after extraction with 2 M potassium chloride (KCl) using 1:5 soil/solution ratio (Keeney and Nelson 1982).

Statistical Analysis

All data are presented as the average of triplicate samples collected from different locations of each field. The ANOVA-single factor analysis was used to evaluate the differences in soil N and P contents impacted by PL application history. The Correlation Analysis Tool of Microsoft Excel was used to analyze correlation coefficients of N and P levels impacted by the rate, year and cumulative amount of PL application. As there were no field replicates for each PL application, these statistical treatments only

reflected the variables or inhomogeneity of these field soils, and should not be considered as the estimates of field variability of PL application managements.

RESULTS AND DISCUSSION

Mehlich-3 Extractable P

In the top soil (0–20 cm) without PL application, the level of Mehlich-3 P was 30 mg kg^{-1} of dry soil (Figure 1), below the critical value of 50 mg kg^{-1} for plant growth (Sims 2000). Thus, plant growth responded positively to PL application, shown by increased hay yield with increasing PL application (Table 1). In fact, Mehlich-3 P content increased to 107 mg kg^{-1} in soil with 5-year PL application and 326 mg kg^{-1} in soil with 15-year PL application. PL application also

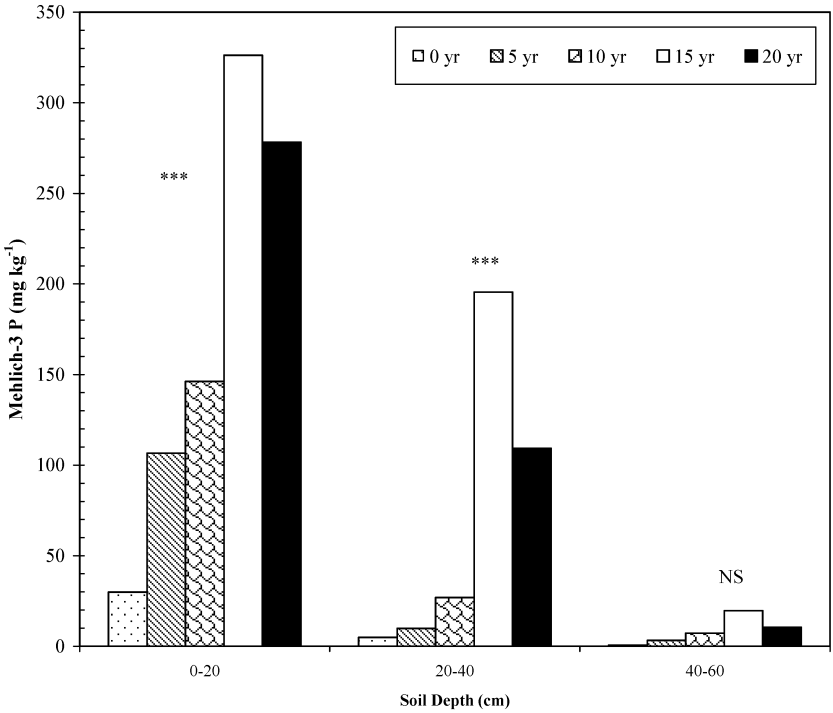

Figure 1. Changes of Mehilich-3 extracted P impacted by repeated poultry litter application. ***, significance at α= 0.001; ns, no significance at α=0.05, based on the data of triplicate sampling soils collected from each of the five fields with different PL application histories.

Table 1. History of poultry litter application and hay yield at the five sampling fields †

Year	Annual rate	Cumulative amount	Hay yield
	($Mg\,ha^{-1}\,yr^{-1}$)	($Mg\,ha^{-1}$)	($Mg\,ha^{-1}\,yr^{-1}$)
0	0	0	6.6
5	2.27	11.4	7.3
10	2.27	22.7	8.8
15	3.63	54.5	10.4
20	1.36	27.2	12.9

† Data are derived from (He et al. 2008).

increased the Mehlich-3 P content in soil at 20–40 cm. The increase was greater in soils with 15- and 20-year PL application than those with 5- and 10-year PL application (Figure 1).

The five fields had received PL continuously at different application rates. Thus, the cumulative amounts applied did not increase with increasing years of application (Table 1). The highest cumulative amount was 54.5 $Mg\,ha^{-1}$ in the plot with 15-y application. The increase of Mehlich-3 P was less relevant to the annual rate or the years of application, but rather more related to the cumulative amount of PL applied as shown by the correlation coefficients of 0.93 and 0.94 with the Mehlich-3 P data in the 0–20 and 20–40 cm depths (Table 2). This observation indicated that not all nutrients in PL applied to soils immediately became available for plant uptake, as residual effects of manure or composition application on crop production and soil

Table 2. Correlation coefficients between PL application parameters and soil nutrient (P or N) contents calculated base on the five averages of the triplicate sampling data which were significantly different at $\alpha \leqslant 0.05$

	Annual applied rate	Year of application	Cumulative applied amount
Total P			
0–20 cm	0.75	0.91	0.92
20–40 cm	0.74	0.75	0.98
40–60 cm	0.85	0.74	0.93
Mechlich-3 P			
0–20 cm	0.68	0.92	0.93
20–40 cm	0.64	0.76	0.94
Total N			
0–20 cm	0.69	0.81	0.86
20–40 cm	0.66	0.84	0.89

Table 3. Linear regression relationship between soil nutrient contents (P or N in $mg\,kg^{-1}$) and the cumulative amounts (X in $Mg\,ha^{-1}$) of PL applied calculated base on the five averages of the triplicate sampling data which were significantly different at $\alpha \leqslant 0.05$

	Linear regression	R^2
Total P		
0–20 cm	P=12.6X + 259	0.84
20–40 cm	P=9.9X + 76	0.96
40–60 cm	P=3.3X + 109	0.87
Mechlich-3 P		
0–20 cm	P=5.6X + 48	0.87
20–40 cm	P= 3.8X − 18	0.89
Total N		
0–20 cm	N=18.4X + 428	0.74
20–40 cm	N=4.4X + 237	0.80

properties can last for years (Eghball et al. 2004). Linear regression analysis further revealed strong, positive correlations between the buildup of Mehlich-3 P and the cumulative amount of PL applied (Table 3). This relationship could be used as a rapid method to estimate the long-term impacts of repeated PL application on soil P (i.e., Mehlich-3 P level), provided the correlations in Table 3 are confirmed by future studies.

Previous studies have investigated Mehlich-1 or dilute double-acid-extractable P contents of Alabama and Georgia soils impacted by long-term PL application (Franzluebbers et al. 2002, Gascho and Hubbard 2006, Kingery et al. 1994, Mitchell and Tu 2006). These studies have found extractable P to accumulate is mainly in the surface 20 cm of both pasture and cropped soils. Mitchell and Tu (2006) report that Mehlich-1 P in the upper 0–5 and 5–20 cm is significantly related to the rate of PL application for the last year it was applied. However, some downward movement of extractable P has been observed mainly to a depth of 40 cm with a minor P increase at 60 cm, demonstrating the mobility of P in some soils when surface concentrations are high (Gascho and Hubbard 2006). These observations are consistent with our observation reported here.

Total Soil P

In the soil without PL application, the total P content was 156, 109, and 90 $mg\,kg^{-1}$ of dry soil, at the 0–20, 20–40, and 40–60 cm depths, respectively (Figure 2). Repeated PL application significantly increased total soil P in all three soil depths, although most P from PL generally

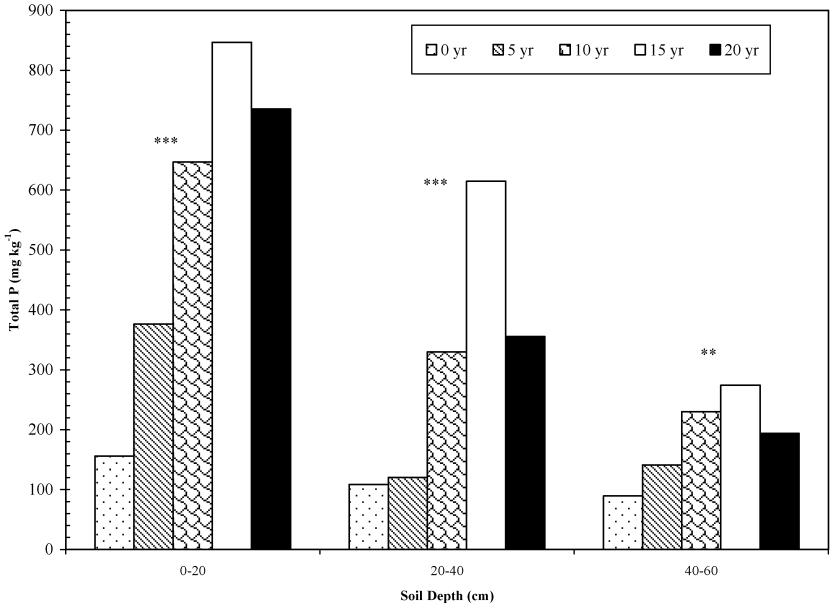

Figure 2. Changes of total P impacted by repeated poultry litter application. **, and ***, significance at $\alpha = 0.01$, and 0.001, respectively, based on the data of triplicate sampling soils collected from each of the five fields with different PL application histories.

accumulated in the surface 20 cm (Figure 2). For instance, total P was 847, 615, and 274 mg kg^{-1} of dry soil, at 0–20, 20–40, and 40–60 cm, respectively, after 15-year PL application. Even so, a significant increase in total P by repeated PL application was observed at both 20–40 and 40–60 cm depths. This increase was greater than observed for Mehlich-3 P, indicating the P was less mobile and less plant available. Similar to Mehlich-3 P, total P was most strongly correlated with cumulative amount of PL, rather than application rates or years (Table 2). These results indicate P in PL was not fully harvested by the hay crop, leached or lost by runoff and most P in PL accumulated in the soil.

Few studies have investigated soil accumulation of total P from long-term PL application. In an earlier study, Sharpley et al. (1993) found 2-13 fold increases in total P in the surface 30 cm of 12 Oklahoma grassland soils receiving PL for 12–35 years. However, below 30 cm, no increase in P content was evident. Linear regression analysis showed that total P increased by 12.6, 9.9, and 3.3 mg kg^{-1} in the 0–20, 20–40, and 40–60 cm depths for every Mg PL ha^{-1} applied (Table 3). In other words, for every four parts of litter P that accumulated in the top soil (0–20 cm), another three parts of litter P accumulated in the 20–40 cm depth, and one part litter P accumulated at 40–60 cm.

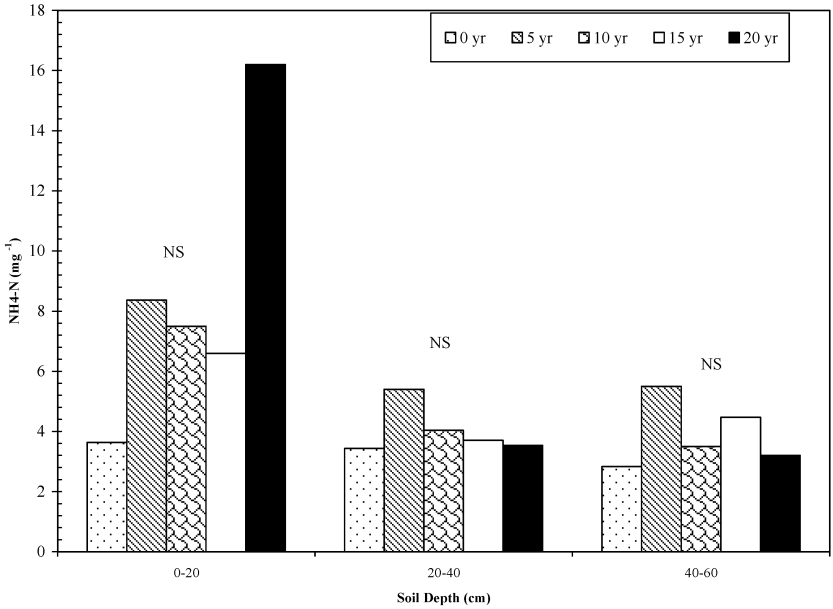

Figure 3. Changes of NO3-N impacted by repeated poultry litter application. * ns, no significance at α=0.05, based on the data of triplicate sampling soils collected from each of the five fields with different PL application histories.

Soil Inorganic N

Soil NH4-N and NO3-N were not significantly affected by PL application (Figures 3 and 4). This statistical insignificance apparently reflects the substantial variance in NO_3-N and NH_4-N concentrations among the three replicate samples. For instance, the concentrations of NO_3-N were 2.3, 12.4 and 3.8 mg kg^{-1} for top soil receiving 5-year PL application, and 21.3, 11.4, and 7.7 mg kg^{-1} for top soil receiving 20-year PL application. Others have also reported inconsistent observations in inorganic N as affected by PL application (Gascho and Hubbard 2006, Kingery et al. 1994, Mitchell and Tu 2006, Sharpley et al. 1993). Sharpley et al. (1993) reported that NO_3-N and NH_4-N concentrations increased only in the surface 20 cm. Kingery et al. (1994) demonstrated that even though the littered pastures had higher NO_3-N concentrations than nonlittered pastures at the depths of 0–60 cm, the differences were not considered to be of practical significance. They did however find a significant accumulation of NO_3-N in soils at or near bedrock (3 m) where PL had been applied. Gascho and Hubbard (2006) observed that NO_3-N was related to soil depth but not to PL application rate or its interaction with soil depth after 7-year PL application to a southern Coastal Plain cropland soil. Mitchell and Tu (2006) found that

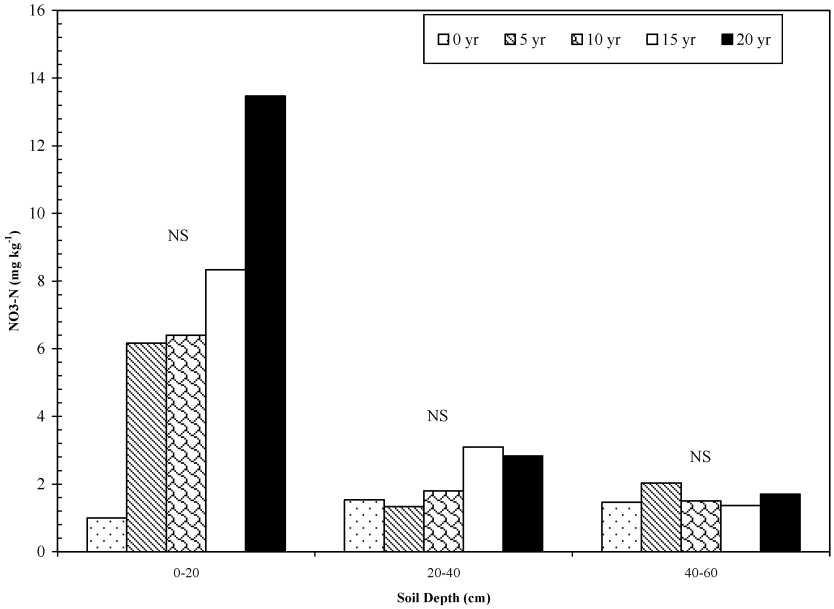

Figure 4. Changes of NH4-N impacted by repeated poultry litter application. * ns, no significance at α=0.05, based on the data of triplicate sampling soils collected from each of the five fields with different PL application histories.

application of PL in an Alabama Coastal Plain soil over a 10-year period did not always result in significant change in NH_4-N, but they found a significant linear relationship between soil NO_3-N and N rates of PL application.

Total N Accumulation

Long-term application of PL increased total N at 0–20 and 20–40 cm but not at 40–60 cm (Figure 5). In the surface 20 cm, total N ranged from 320 mg kg^{-1} in the soil without PL to 1273 mg kg^{-1} in the soil receiving 15-y PL. In the 20–40 cm depth, total N increased from 227 to 443 mg kg^{-1} following 15-y PL application. Like total P, the change in total N was also related to the cumulative amount of PL applied (Tables 2 and 3). Soil total N in 0–20 and 20–40 cm depths increased by 18.4 and 4.3 mg N kg^{-1} soil for each Mg of PL ha^{-1} added.

The levels of soil total N were 40–220 times higher than those of soil NO_3-N and NH_4-N. The lower levels of inorganic P were consistent with previous observations reported to reflect rapid leaching and plant uptake (Gascho and Hubbard 2006, Kingery et al. 1994, Mitchell and Tu 2006). Therefore, the high levels of total soil N implied most of the soil N was in

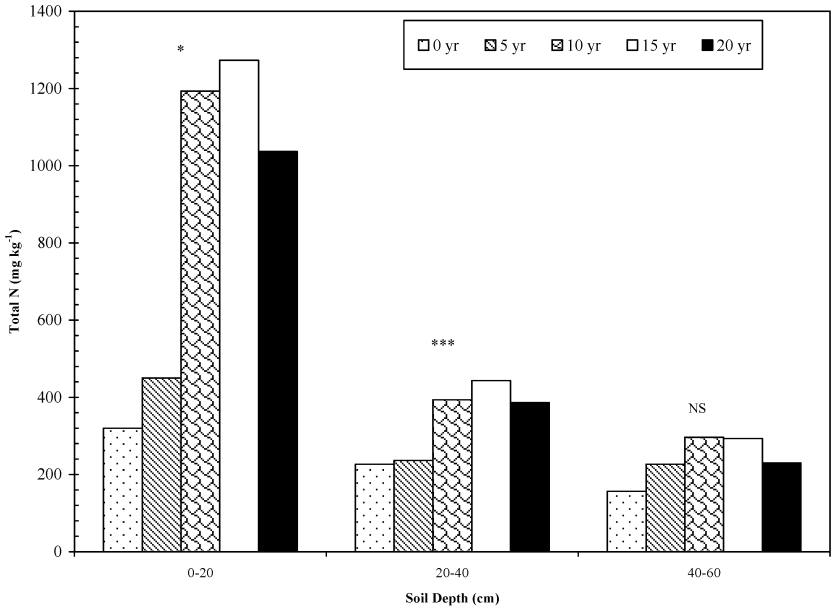

Figure 5. Changes of total N impacted by repeated poultry litter application. *, and ***, significance at $\alpha = 0.05$, and 0.001, respectively; * ns, no significance at $\alpha = 0.05$, based on the data of triplicate sampling soils collected from each of the five fields with different PL application histories.

the organic form. This organic N would become bioavailable in time through mineralization (Kingery et al., 1994). Gascho and Hubbard (2006) proposed that the accumulation of total N (i.e., organic N) associated with PL application provided a continuous source of NO_3 in the surface soil through mineralization and nitrification. These N transformation processes have been successfully predicted for a range of organic N sources, as demonstrated by Honeycutt et al. (1991; 2005).

CONCLUSIONS

Long-term PL application affected the status of soil P and N. We examined the effects of applied litter at multiple rates and years, thus revealing their dynamic impacts. Total and Mehlich-3 extractable P concentrations increased with increasing cumulative PL applied, but the extent of these impacts decreased with soil depth. Our data indicate that the build-up of total N in soils was significant with long-term PL application, but not for soil NO_3 or NH_4. Predicting the build-up based on the cumulative amounts of PL application, rather than isolated factors

(i.e., application year or rate), would improve the accuracy of evaluating long-term impacts of poultry litter application on soil nutrient levels.

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