EFFECT OF MANURE SOURCES ON SOIL PHOSPHORUS DYNAMICS

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ABSTRACT

This study evaluated the effects of different organic fertilization strategies on soil P pools across two sites in Ohio. Treatments included two manure-amended sites, one receiving dairy manure (Northwest) and the other receiving swine manure (Western), with a history of a hog farm at the site. Soil samples were collected from the 0-20 cm depth in summer 2024. Samples were analyzed for inorganic P pools using a sequential extraction procedure. Phosphorus saturation (P-sat), determined using acid ammonium oxalate extraction, remained below the environmental risk threshold (11.8%) under dairy manure, while swine manure increased P-sat above the threshold, indicating enhanced risk of P loss. Total phosphorus (TP), measured using EPA 3051A acid digestion, varied with treatments. Swine manure increased TP by 3 to 4 times as compared to controls, whereas dairy manure showed no significant effect on P pools. Inorganic P pool analysis revealed calcium (Ca-P) and iron-bound P (Fe-P) as dominant fractions. The results underscore that manure type, rate, and historical management could influence soil P dynamics differently. Understanding these interactions is key to balancing agronomic and environmental goals in nutrient management planning.

INTRODUCTION

Phosphorus (P) is vital for crop production, but also contributes to water quality issues when it enters water bodies through leaching or runoff. In Ohio, runoff and subsurface leaching of P from agricultural soils are major causes of nutrient enrichment in Lake Erie (Watson et al., 2016). While manure applications can improve soil fertility, repeated use may lead to P buildup and greater loss risk, depending on the manure source and management history. Understanding how different manure types affect soil P pools is essential for balancing productivity with environmental protection. This study evaluated the effects of dairy and swine manure on soil P distribution and P saturation across two field sites in Ohio to identify how manure source and site history influence soil P dynamics.

MATERIALS AND METHODS

Soil samples were collected from two locations in Ohio, USA: Northwest (Hoytville; 41°12'46"N, 83°45'50"W) and Western (Clark County; 39°51'39"N, 83°40'45"W), which had a history of hog farming. At the Northwest site, treatments included two dairy manure applications: 8,000 gallons acre^{-1} and 12,000 gallons acre^{-1}, and a control treatment receiving urea ammonium nitrate solution (UAN 28%) at 67 gallons acre^{-1}. At the Western site, two primary treatments were imposed: swine manure application and no-manure control. Each treatment was further subdivided into two nitrogen (N) rate levels. Plots receiving swine manure were fertilized at high (200 lb N acre^{-1}) and medium (150 lb N acre^{-1}) nitrogen rates, while no-manure plots received high (200 lb N acre^{-1}) and low (100 lb N acre^{-1}) nitrogen rates. UAN 28%

served as the N source for all treatments. Treatments started in 2013 and 2023 at Northwest and Western sites, respectively, with corn-soybean rotations.

Laboratory Analysis

Fractionation of inorganic soil phosphorus pools

Inorganic P sequential fractionation was performed according to Zhang & Kovar (2002). The procedure identified five P fractions: (i) soluble or loosely bound P (Sol-P), extracted with 1 mol L-1 NH_4Cl; (ii) Al-P associated with aluminum (hydr)oxide surfaces, extracted using 0.5 mol L-1 NH_4F; (iii) Fe-P associated with iron (hydr)oxide surfaces, extracted with 0.1 mol L-1 NaOH; (iv) Reductant or occluded P defined as P trapped within mineral matrices, extracted using a solution of 0.3 mol L-1 sodium citrate, 1 mol L-1 sodium bicarbonate, and sodium dithionite, and (v) Ca-P, extracted using 0.25 mol L-1 H_2SO_4. Between each extraction step, samples were washed and centrifuged twice with saturated NaCl to remove residual P from the previous fraction. The NaCl wash solutions were combined with their corresponding extracts to ensure complete recovery of P associated with each phase. All extracts were diluted 10 times using 3% HCl, except Sol-P, and analyzed for P using inductively coupled plasma-atomic emission spectrometry (ICP-OES; Agilent Technologies 700 Series, Santa Clara, CA, USA).

Oxalate Extractable Phosphorus

The soil samples were analyzed for oxalate phosphorus saturation (P-sat) as outlined by McKeague and Day (1966). The samples were extracted with 0.2 M ammonium oxalate solutions. The oxalate [(NH4)2C2O4] extractable fraction identifies P adsorbed to amorphous, non-crystalline, or poorly ordered Al and Fe oxides, unlike the inorganic P sequential fractionation method, which is assumed to primarily extract P bound to crystalline Al (hydr)oxide surfaces (Bayley et al., 2008). Following extraction, all solutions were centrifuged, decanted, diluted 10x using 3% HCl, and analyzed for P using ICP-OES. Phosphorus saturation was calculated using extractable P, Al, and Fe concentrations obtained from acid ammonium oxalate extraction (Equation 1):

$$[\text{Ox-P (mol)}/ (\text{Ox}(\text{Al(mol)} + \text{Fe(mol)}))] \times 100 = \text{P-sat}\% \quad (1)$$

Total phosphorus

Total phosphorus (TP) was determined using the microwave-assisted acid digestion procedure outlined in U.S. EPA Method 3051A (U.S. EPA, 2007). In this procedure, soils were digested using concentrated hydrochloric and nitric acids. The digestion process was conducted under controlled temperature conditions of 175 °C using a MARS 1600-watt microwave to complete the dissolution of phosphorus-bound mineral and organic matrices. After digestion, the resulting extracts were diluted to appropriate concentrations using deionized water. These liquid extracts containing the released phosphorus were then analyzed for TP content using ICP-OES.

Statistical Analysis

Statistical analyses were performed using R version 4.4.2 (R Core Team, 2024). Assumptions of parametric testing were evaluated using the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance. When these assumptions were violated, non-parametric Kruskal-Wallis tests were used. Significant treatment effects were followed by pairwise Wilcoxon rank-sum tests, with adjusted p-values using the Benjamini-Hochberg method.

RESULTS

Dairy manure

Dairy manure amendments did not affect TP concentrations. Despite the application of 12,000 gal acre^{-1} (D1) and 8,000 gal acre^{-1} (D2) of dairy manure, TP remained statistically similar to the inorganic fertilizer treatment of UAN 28% at 67 gal acre^{-1} (D3), which received no manure-derived P. Mean TP concentrations in D1 (711.05 mg kg^{-1}) and D2 (710.20 mg kg^{-1}) were statistically similar ($p > 0.05$) to those in the control treatment (D3; 741.50 mg kg^{-1}) (Figure 1A). Across all soil inorganic P pools, dairy manure treatment effects were not statistically significant, suggesting that manure inputs at the applied rates did not alter the distribution of soil P. Phosphorus saturation levels ranged from 6.5% to 11.15% across all treatments (Figure 1B), with all values remaining below the Ohio environmental threshold of 11.8%. This suggests a low potential risk of P loss via runoff or leaching under the dairy manure management evaluated in this study.

Swine Manure

Swine manure treatments resulted in significantly higher TP concentrations compared to the no-manure control plots at Western (Figure 1C). Mean TP values were 1161 mg kg^{-1} and 1411 mg kg^{-1} under swine manure with high and medium nitrogen application, respectively, while no-manure plots averaged 370 mg kg^{-1} (high N) and 379 mg kg^{-1} (low N). TP concentrations under swine manure treatments were approximately 3 to 4 times greater than those under no-manure treatments.

Similarly, P-sat levels were elevated with swine manure. Phosphorus saturation levels ranged from 16.64% up to 29.89% under both swine manure treatments; in contrast, no-manure treatments remained below the Ohio environmental threshold, ranging from 6.2% to 9.31% (Figure 1D).

Swine manure treatments significantly affected all soil P fractions (Figure 2). All P fractions showed higher concentrations under swine manure treatments compared to no-manure controls. The observed differences were primarily between the manure treatments (swine vs. no manure), while nitrogen rate within each major treatment had no significant effect.

DISCUSSION

The effects of dairy and swine manure on soil P dynamics were evaluated at two sites that differed in soil type and management conditions. As these sites contrasted in manure type, application history, rate, and intrinsic soil properties, the results were interpreted within each site. Therefore, no direct statistical comparisons were made between these two experiments or sites. Two different rates of dairy manure compared with control manure plots did not affect any of the soil P pools. Among all pools, Ca-P was the dominant fraction at the dairy manure site. As the dominant soil series at NW was Hoytville clay soils, these soils commonly contain residual limestone fragments that might create Ca-rich conditions within the 0-20 cm soil depth, favoring Ca-P accumulation (USDA-NRCS, 2025a).

In swine manure-treated plots, TP concentrations were approximately 3 to 4 times greater than those in control plots (Figure 1A). Moreover, P-sat percentages at the swine site exceeded the Ohio environmental threshold, whereas values at the dairy site remained below this limit (Figure 1B). The higher P content in swine treatments could be from the legacy effect of swine manure, as the area was used for raising hogs about 2 decades ago (J. Davlin, personal communication, 2025). The higher P accumulation under swine manure can be attributed primarily to the larger application rates used in the swine manure treatments and the inherently greater P content of swine manure (Rayne & Aula, 2020). Li et al. (2014) reported that P content in swine manure is approximately 4.4 times higher than in dairy manure. The primary factor responsible for this difference in P content is how P is supplied in their feed. In cereal grains, P occurs predominantly as phytic acid (Leytem et al., 2004), and swine generally have lower phytase activity than cattle, thus limiting their ability to hydrolyze phytic acid (Rayne & Aula, 2020). Thus, swine are often fed with supplemental phytase to improve the breakdown of phytate and increase P digestibility. Without adequate phytase, more phytate-bound P is excreted, contributing to higher manure-P loads.

Excessive P buildup in soils receiving manure applications is also linked to the inherently narrow nitrogen-to-phosphorus (N:P) ratio in manure compared with the N:P ratio in crop demand. To meet crop N requirements, manure is often applied at rates that far exceed the crop's P needs, resulting in P accumulation over time (Sharpley et al., 1993). Further, the timing of manure application might have influenced these outcomes. Soil samples at the swine manure site were collected roughly six months after the most recent application, whereas at the dairy manure site, samples were collected nearly twelve months after application. According to Kleinman and Sharpley (2003), P loss to runoff is greatest immediately after application and declines over time as applied P becomes more stabilized in the soil, suggesting that the shorter interval since application at the swine manure site could have contributed to the elevated P saturation observed. Overall, these findings highlight that manure type, nutrient composition, application rate, and timing interact to shape soil P dynamics. Future work should compare swine and dairy manures side by side at the same site, using matched application rates under both N-based and P-based regimes to minimize site effects.

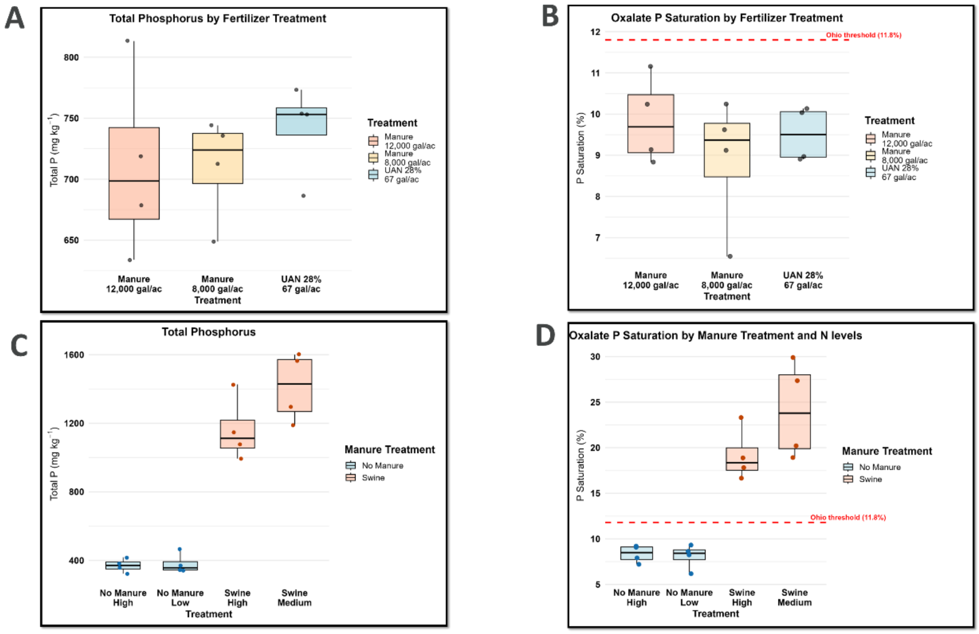

Figure 1. Effect of different manure amendments on total phosphorus (TP) and oxalate phosphorus saturation across the two sites in Ohio: Western (Clark County) and Northwest (Wood County). (A) and (B) represent the TP and P saturation under two dairy manure treatments and one no-manure treatment at the Wood County site. (C) and (D) shows TP and P saturation under swine manure and no-manure treatments with different nitrogen levels at the Clark County site. The red dashed lines in (B) and (D) represent the Ohio environmental threshold for P saturation (11.8%).

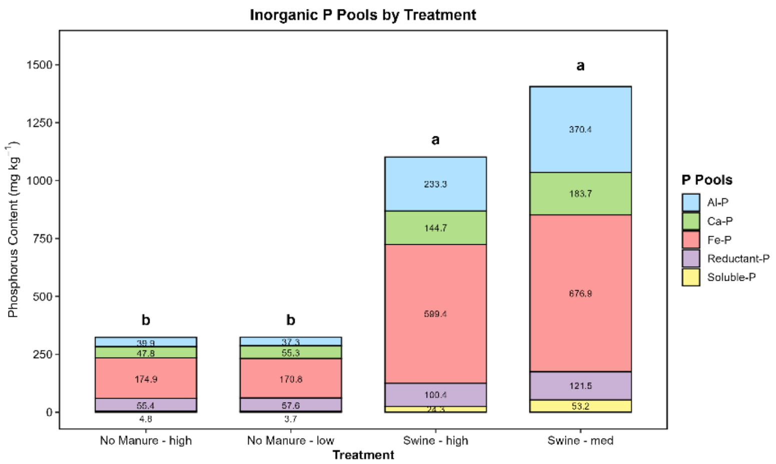

Figure 2. Five different soil phosphorus (P) fractions under different swine manure and no manure treatments. The distribution of inorganic P pools (Soluble-P, Reductant-P, Fe-P, Ca-P, and Al-P) under swine manure and no-manure treatments with varying N rates at the Clark County site. Different letters above bars indicate statistically significant differences among treatments (Tukey HSD, $p < 0.05$).

CONCLUSION

This study demonstrated that manure source plays a critical role in shaping soil P dynamics. Dairy manure applications did not significantly alter total or inorganic P pools and maintained P saturation below the environmental risk threshold, suggesting low potential for P loss. In contrast, higher P accumulation and saturation were observed under swine manure. However, these results should be interpreted with caution, as site-specific factors such as past management history and time since manure application may have contributed to the elevated P levels. Overall, the findings emphasize that differences in manure composition, rate, and site legacy can shape soil P behavior, underscoring the need for site-specific and P-based manure management strategies to sustain productivity while minimizing environmental risk.

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