CONSERVATION PRACTICES LOWER SOIL TEST PHOSPHORUS REQUIREMENTS AND OPTMIZE CROP YIELD

Clarence Winter, Jason Clark, Michael Lehman, Sutie Xu, Sam Ireland
South Dakota State University-Brookings, SD
Clarence.winter@jacks.sdstate.edu

ABSTRACT

Sustainable P management in cropping systems is a challenge in modern agriculture. The implementation of conservation practices of no-till, retaining high levels of residue in the field, and diverse crop rotations may create a more suitable environment for arbuscular mycorrhizal fungi (AMF) to accumulate. A greater AMF population may subsequently increase the P available to crops, lowering the soil test P amount needed to optimize crop yield. At the Dakota Lakes Research Farm in Pierre, South Dakota a five-year crop rotation was established in the 1990's (soybean-wheat/cover crop-soybean-corn-corn). Soil test levels were drawn down to 5 ppm Olsen P in 2014 and P fertilizer was applied to strips across the field to create low, medium, and high soil test P levels. This study evaluated the effect of these soil test P levels on soil test P, AMF, and crop yield. In 2023, the mean soil test P value of the low, medium, and high areas at 0-3 inches were 6.5, 7.8, and 12.1 ppm, respectively. From 2019-2021, the AMF most probable number values were three times higher in the low treatment (4.5/g) compared to the high P treatment (1.5/g). After five years, regardless of the soil test P level there was no difference in yield response to P fertilization. These results indicate that soil test P levels may be intentionally left at low levels in these conservation management systems, resulting in higher AMF values, and limited yield decline.

INTRODUCTION

Crop fertility is one of the most critical objectives of producers during the growing season. The fertility amendments that are commonly applied are nitrogen, phosphorus (P), and potassium, all of which have important physiological benefits to plants. However, unlike nitrogen fertilizers that are synthesized in labs, P fertilizers are mined from the ground as phosphate rock (PR). Therefore, this resource is nonrenewable, creating a sustainability problem. In fact, on a global scale, peak phosphate rock production is estimated to be reached as early as 2050 (Beardsley, 2011). The limited availability of this element in the future, and the rising prices of agricultural inputs in general have the potential to create significant problems in food scarcity and agricultural production. However, pools of P are present in most agricultural soils, held as insoluble complexes (S. B. Sharma et al., 2013). The release of P from these complexes has the potential to reduce the need for P fertilizer application.

The use of tillage equipment to prepare the seed bed for sowing seed and removing weed pressure has been around in agriculture for millenniums. However, tilling the soil has devastating effects on soil fungi populations, and leads to greater losses of soil through wind and water erosion (Sharma-Poudyal et al., 2017).

Alternatively, soil conservation practices such as no-till exist that protect the soil from water and wind erosive forces, while also building the soil biology, including soil fungi. The buildup of soil fungi is significant because soil-borne fungi dissolve insoluble phosphates in the soil. These organisms increase the bioavailability of soil P for plants to use by dissolving insoluble mineral P that becomes bound to other cations in the soil (Ca^{2+}, Fe^{3+}, or Al^{3+}) (Timofeeva et al., 2022). These relationships work through symbiotic relationships between the fungi and plants, where the plants supply the soil fungi with carbohydrates, and the fungi provide the plants with previously insoluble P (Lehman & Taheri, 2017). When looking at total P in the soil, only 20% of that soil P is available to plants in an average agronomic ecosystem. With this information at hand, it becomes evident that microbes that facilitate the solubilization of phosphate are an important aspect to consider when discussing P sustainability (S. B. Sharma et al., 2013). However, what is not known is the impact of synthetic P in the soil on the abundance and functionality of soil fungi, specifically arbuscular mycorrhizal fungi (AMF), and what the implications of this are in a low soil test P category. Therefore, the objectives of this study are studying the use of management systems like no-till, diverse cropping rotations, and high residue deposit to see if soil test P levels can be intentionally left at low levels without experiencing a yield decline, and if symbiotic relationships in the soil between AMF and plants can provide soluble P to the plant.

MATERIALS AND METHODS

This study has been continuously conducted at Dakota Lakes Research Farm in Pierre, South Dakota since 2014. At the start of the experiment, soluble P concentrations were drawn down to five ppm Olsen P. The study was arranged as a randomized complete block design with 15 strips and five replications. Since the initial depletion of soluble P, three distinct rates were applied in the field to create areas of low, medium, and high concentrations of soluble P measurements. P fertilizer was applied at rates of 0, 52, and 104 lbs P_2O_5 in 2014, and again applied to the same treatment areas in 2017, 2019, and 2021. A five-year crop rotation was initiated in 2014 as well, planted in succession as soybean-wheat/cover crop-soybean-corn-corn. The addition of grass crops of wheat, cover crops, and corn were done to maximize the amount of residue in the field.

Soil samples were collected in the spring and fall periods of the year. The spring samples were collected prior to planting and fertilization and the fall samples were collected after harvest. The samples were collected as two depths, the first being from 0-3 inches and the second at 3-6 inches. The 0–3-inch composite sample was collected using a spade in a cross-section pattern four times throughout the plot to include the banded area of P. During the spring sampling period, the 3–6-inch composite sample was collected using a 0.75-inch diameter soil core at four locations throughout the plot. In the fall sampling period, the 3-6-inch composite sample was collected using a 1.25-inch diameter Giddings hydraulic probe at two locations in the plot, while also collecting two additional cores using a standard 0.75-inch diameter probe. These soil samples were analyzed for soluble P (Olsen, Mehlich-III, and Bray) and total P concentrations. Additionally, biological soil samples were collected from each soil test category treatment using a 0.75-inch diameter soil core and sent to the USDA-ARS building in

Brookings, South Dakota to determine AMF abundance using the most probable numbers method (Porter, 1979). During the 2023 growing season, 400 grams of soil were collected using a 1.25-inch diameter JMC soil sampler across all treatments to obtain an NLFA analysis. NLFA analysis methods have been studied on root and soil samples extensively, and have shown a strong affinity for fungal organisms, and have shown promise in approximating fungal biomass, which could play a role in P availability. (M. P. Sharma & Buyer, 2015).

Whole plant samples were collected at various stages of growth. For soybeans, samples were collected at the V3, R1, R3, and R6 growth stages. The V3 and R1 sampling period involved collecting four five-foot sections of soybean biomass in each strip of the experiment. The R3 and R6 sampling period reduced the sampling amount to two half-meter sections of soybean biomass in each strip of the experiment. This change was done to reduce the amount of plant biomass being collected from the experimental area. All the plant samples were dried and sent to Ward Labs for analysis for N, P, and K concentrations.

Water samples were collected to determine run-off and leaching risk under high rainfall conditions by testing these runoff samples for nitrate, orthophosphate (ortho P), and sulfur. This sampling procedure was accomplished through a constructed rainfall simulator that applied water at ~20 inches an hour. The rainfall simulator contained an oscillating spray nozzle mounted on a ladder directly above the sampling area. Below the oscillating spray nozzle was a metal square that was inserted into the ground with an opening at the surface of the soil. The resulting water shed, or runoff, was collected and sent to Ward Labs for analysis, testing for ortho P and nitrates. The sample collection process involved three total samples per strip in the field. These samples were indicated as initial, after 10 minutes, and after 20 minutes. This was done to obtain more accurate runoff results, where the initial runoff is higher than continued runoff after a prolonged rainfall event. After 30 minutes, the simulated runoff was terminated, and total runoff was recorded in mL. Additionally, after the runoff simulator was conducted, a soil solution tube was inserted behind the sampling area, and a vacuum was applied. This was done to capture water movement through the profile. The solution tubes that contained solution after a week were removed and sent to Ward Labs for analysis.

RESULTS AND DISCUSSION

Soil testing

The soil test P results from this experiment show the varying levels of soluble P between soil test category treatments (Table 1). At the 0–3-inch level, which is sampled with a spade and a bucket across the crop row, there was a larger difference in STP than the 3–6-inch depth, which was sampled with a standard 0.75-inch sampling probe randomly within each plot. These results indicate how sampling the banded layer of P in no-till systems is difficult to quantify. The exact method for determining soluble P in these conditions has not been fully developed (James & Topper, n.d.).

Soil pH values were included in the soil test results to see if there was a change in alkalinity or acidity at these varying levels. The relative abundance of hydrogen ions influences the solubility of P; in this scenario, a higher pH value indicates a higher level of calcium ions, which can be subsequently bound to P in the soil solution (Mallarino, 1997). The pH levels of these two soil sampling depths are classified as alkaline, however, there were limited differences in pH values between the surface depths collected.

Table 1. Soil test P and pH at three depths along with yield as affected by three soil test P categories.

	Soil depth			
Soil Test P Level	**0-3 in.**	**3-6 in.**	**0-6 in.**	**Yield, bu/ac**
Olsen-P, ppm				
Low	6.5	4.8	5.7	73.3
Medium	7.8	5.3	6.6	76.4
High	12.1	5.3	8.7	77.3
pH				
Low	7.5	7.6	7.6	
Medium	7.6	7.6	7.6	
High	7.6	7.6	7.6	

A neutral lipid fatty acid (NLFA) analysis on soil and root samples that were collected in the spring of 2023. Total fungi biomass was affected by the low, medium, and high soil test categories, decreasing from 219007, 203032, and 174,300 µg/g respectively (Figure 1).

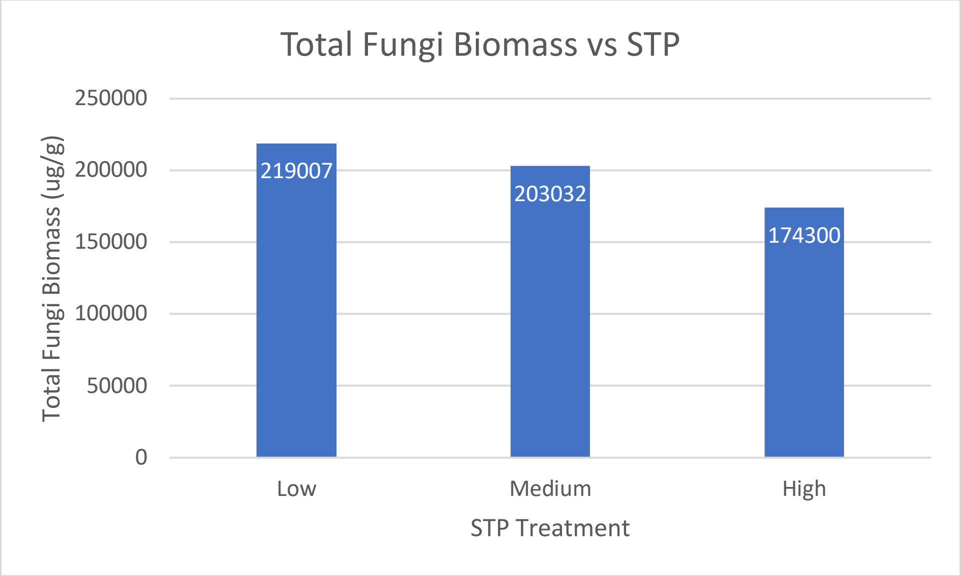

Figure 1. Total fungi biomass as calculated through NLFA processing as affected by the low, medium, and high soil test P category treatment areas.

P Uptake- Plant Samples

At the V3 sampling period, there was a difference in P uptake between treatments, as the high soil test P category treatment areas had more P in the vegetation (Table 2). One explanation for this occurrence may be that the study area had a distribution of varying types of AMF species. Some of these AMF species may lead to plants having a poorer provision of P in the plant tissue (Smith & Read, 2008). Another explanation for this result may be that low soluble P environments, without the presence of AMF species at all, would be markedly worse than the observed result. Ultimately, the P uptake and AMF concentration interaction between treatments is classified as dynamic, and the fungal influence on P concentration in plant tissue is still unknown (Kobae, 2019).

Table 2. Phosphorus uptake in soybean tissue at four different growth stages as affected by three soil test P categories.

	Soybean Phenology			
Soil Test Category	**V3**	**R1**	**R3**	**R6**
P uptake, lbs/ac				
Low	0.96	3.6	8.2	14.3
Medium	1.04	4.9	14.1	22.1
High	1.06	5.4	16.3	28.9
p-value	0.54	0.0007	0.0045	0.0017

Water testing

Generally, ortho P values in runoff solutions decreased over time as illustrated in the medium soil test P category treatment where ortho P went from 0.11 to 0.09 to 0.08 ppm over time. Soil test P category similarly influenced ortho P values at all sampling intervals where ortho P increased as soil test category increased. For example, in the initial runoff samples ortho P were 0.04, 0.11, and 0.15 ppm in the low, medium, and high soil test P category treatments, respectively. In other studies, increased levels of synthetic P fertilizers and manure applied on the surface of no-till ag fields also increased ortho P runoff in intense rainfall events (Bertol et al., 2010).

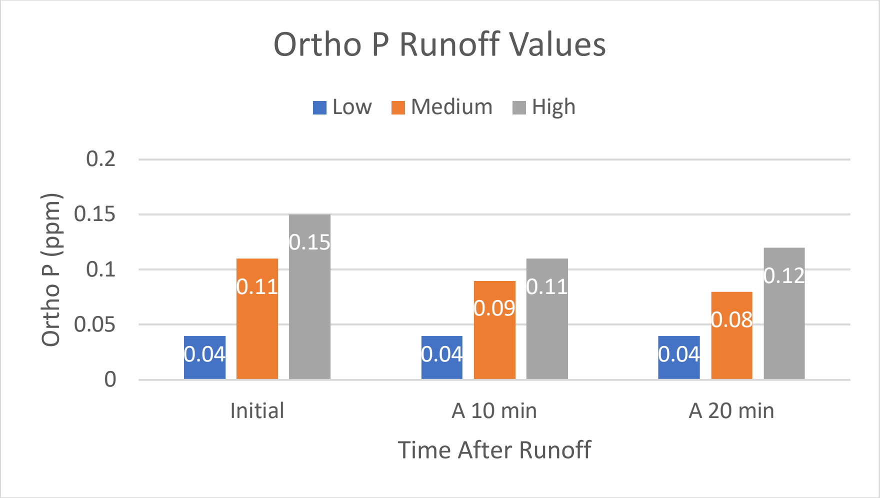

Figure 2. Average ortho P runoff values for low, medium, and high P treatment categories.

REFERENCES

Beardsley, T. M. (2011). Peak Phosphorus. *BioScience*, *61*(2), 91–91. https://doi.org/10.1525/bio.2011.61.2.1

Bertol, O. J., Rizzi, N. E., Favaretto, N., & Lana, M. do C. (2010). Phosphorus loss by surface runoff in no-till system under mineral and organic fertilization. *Scientia Agricola*, *67*(1), 71–77. https://doi.org/10.1590/S0103-90162010000100010

James, D. W., & Topper, K. F. (n.d.). *Chapter 2 Soil Sampling*.

Kobae, Y. (2019). Dynamic phosphate uptake in arbuscular mycorrhizal roots under field conditions. In *Frontiers in Environmental Science* (Vol. 6, Issue JAN). Frontiers Media S.A. https://doi.org/10.3389/fenvs.2018.00159

Lehman, R. M., & Taheri, W. I. (2017). *Soil Microorganisms Can Reduce P Loss from Cropping Systems* (pp. 15–36). https://doi.org/10.1007/978-3-319-48006-0_2

Mallarino, A. P. (1997). Interpretation of soil phosphorus tests for corn in soils with varying pH and calcium carbonate content. *Journal of Production Agriculture*, *10*(1), 163–167. https://doi.org/10.2134/jpa1997.0163

Porter, W. (1979). The “most probable number” method for enumerating infective propagules of vesicular arbuscular mycorrhizal fungi in soil. *Soil Research*, *17*(3), 515. https://doi.org/10.1071/SR9790515

Sharma, M. P., & Buyer, J. S. (2015). Comparison of biochemical and microscopic methods for quantification of arbuscular mycorrhizal fungi in soil and roots. *Applied Soil Ecology*, *95*, 86–89. https://doi.org/10.1016/j.apsoil.2015.06.001

Sharma, S. B., Sayyed, R. Z., Trivedi, M. H., & Gobi, T. A. (2013). Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. *SpringerPlus*, *2*(1), 587. https://doi.org/10.1186/2193-1801-2-587

Sharma-Poudyal, D., Schlatter, D., Yin, C., Hulbert, S., & Paulitz, T. (2017). Long-term no-till: A major driver of fungal communities in dryland wheat cropping systems. *PLOS ONE*, *12*(9), e0184611. https://doi.org/10.1371/journal.pone.0184611

Smith, S. E., & Read, D. (2008). Phosphorus and base cation nutrition, heavy metal accumulation and water relations of ectomycorrhizal plants. *Mycorrhizal Symbiosis*, 349–385. https://doi.org/10.1016/B978-012370526-6.50012-X

Timofeeva, A., Galyamova, M., & Sedykh, S. (2022). Prospects for Using Phosphate-Solubilizing Microorganisms as Natural Fertilizers in Agriculture. *Plants*, *11*(16), 2119. https://doi.org/10.3390/plants11162119