IMPACT OF PHOSPHORUS SOIL TEST LEVEL DIFFERENCES ON CROP RESPONSE IN NO-TILL SOILS IN CENTRAL SOUTH DAKOTA

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ABSTRACT

Water and nutrient dynamics in no-till soils vary significantly from conventionally tilled soils. It is evident that soil structure, chemical parameters, and biological profiles influence the functionality of these different management systems. University soil fertility programs have been developed and calibrated for conventionally tilled management. Dakota Lakes Research Farm (Pierre, SD) conducted three years of research (2019-2021) to investigate the impact of phosphorus soil test levels in long term no-till. Three levels of phosphorus solubility (Low, Medium, High) were established by applying Monoammonium phosphate (MAP) fertilizer over the course of four applications. The long-term crop rotation of this plot is Corn-Corn-Soybean-Wheat-Soybean. No yield response was observed during the experiment's three-year span. Soils were sampled during the growing season to evaluate the effect of soil test phosphorus levels on the presence of arbuscular mycorrhizal fungi (AMF). AMF form relationships with plants and assist in nutrient and water uptake. A method was established to count the most probable number of fungal propagules present in the soil. From 2019 through 2021, the Low level of soil test phosphorus contained 4.5 propagules/g soil compared to 0.7 propagules/g soil in the Medium level and 1.5 propagules/g soil in the High level. It is reasonable to assume that elevated levels of AMF compensated for lower available soil phosphorus. This likely enhances a plant's ability to uptake the nutrient and furthermore maintain crop yield. These data indicate that higher levels of soluble phosphorus may discourage AMF. Increasing fertilizer costs and concerns of fertilizer availability and reserves highlight the importance of responsible phosphorus fertilizer management. In addition, nutrient movement from agricultural land to water bodies has created water quality concerns. These data indicate a low soluble test phosphorus management system in no-till soils is beneficial to an agricultural producer's bottom line and is environmentally responsible.

INTRODUCTION

Phosphorus, the plant nutrient, is vital for growing a healthy crop capable of producing economic grain yield. Phosphorus is also the most limiting factor for blue-green algae in freshwater bodies. Blue-green algae are aquatic organisms responsible for eutrophication of aquatic ecosystems world-wide. Phosphorus enters aquatic ecosystems from both point and non-point sources. In many cases farming operations are the largest producers of non-point source pollution of phosphorus (Withers et. al, 2014). This study evaluates soil test phosphorus rate (specifically soil test level) required under long-term no-till management to maintain crop yields.

The management of phosphorus fertilizers is a serious issue due to its role in the degradation of aquatic ecosystems. There are steps that can be taken to help in the reduction of phosphorus pollution into water bodies. The 4 R's of nutrient management are currently being promoted in an effort to help reduce phosphorus pollution. The 4 R's stand for applying the right amount of a nutrient, in the right form, in the right place, and at the right time. A common tool used in determining the correct amount of a nutrient to use is the soil test. The current recommendations for P fertilization rates from Soil Testing Laboratories are based on the estimation of the P supplying ability of the soil (P solubility) and projected needs of the crop to achieve the stated yield goal. Currently P recommendations assume the application method of the fertilizer is surface broadcast application and that conventional tillage practices are used. There is substantial evidence that banding of P near or with the seed increases the efficiency of P crop uptake, this in turn would allow for rates to be reduced. The P recommendations currently used do not account for the differences in tillage, crop rotations, or mycorrhizal activity. With the promotion of mycorrhizal activity and healthy root systems (i.e. no-tillage, diverse rotations, high crop residue), the soil test P levels (solubility) can be managed at intentionally low levels. These soil test P levels may be lower than the currently recommended levels, without experiencing yield losses. By maintaining lower P soil test levels, the potential for transport of phosphorus to aquatic ecosystems should be reduced. The total P in the soil will not be reduced significantly since lower solubility levels will be maintained with fertilizer applications.

MATERIALS AND METHODS

The project was conducted at the Dakota Lakes Research Farm (29 kilometers southeast of Pierre, SD) under irrigation in a no-till, Corn-Corn-Soybean-Wheat-Soybean rotation. This site has been strictly no-till since 1990. Replicated strips with differing soil test P levels were established in 2014 by applying 0, 112, and 224 kg of MAP (mono-ammonium phosphate) ha^{-1} (equivalent to 0, 58, and 116 kg P205 ha^{-1} or 0, 26, and 52 kg P ha^{-1}) using a JD 750 drill to place the fertilizer on soils where the Olsen P soil levels had been lowered to approximately 5 ppm. The experiment was set up in a randomized complete block design with five replications. Dimensions for each treatment were 6 m by 137 m. A crop of soybeans and two crops of corn were grown in this area during the 2015, 2016, and 2017 years respectively.

In the fall of 2017, the fall of 2019 (after wheat harvest), and the fall of 2021 (after corn harvest) applications of MAP were again made at rates of 0 kg, 112 kg, and 224 kg of MAP ha^{-1} to the same replicated strips that were treated in 2014. A no-till drill was used to place the nutrient at a 3.8 cm depth and 19 cm spacing. Total additions on top of a maintenance side-band application were 0 kg MAP ha^{-1}, 448 kg MAP ha^{-1}, and 896 kg MAP ha^{-1}. This study evaluates crop response under different established levels of soil test phosphorus. The treatments will be referred to as Low P (0 kg MAP ha^{-1} applied), Medium P (448 kg MAP ha^{-1} applied) and High P (896 kg MAP ha^{-1} applied).

Soil tests do indicate that soil test P values have increased in the treatments that have received an additional 448 kg MAP ha^{-1} and 896 kg MAP ha^{-1} since 2014 (112 kg MAP ha^{-1} and 224 kg MAP ha^{-1} respectively applied a total of four times). The soil test difference is small when using the standard 15 cm sampling depth. Taking samples soon after applications or at shallower depths (7.5 cm) accentuates differences.

Winter wheat (WB4462) was grown in 2019. The crop was seeded at a rate of 915,000 pure live seed ha^{-1} on 2018-10-24 using a 6 m JD 750 no-till drill with row spacings of 19 cm. Fertilizer was placed in furrow with the wheat seed at rates of 42 kg MAP ha^{-1} and 5 kg KCL ha^{-1}. Tissue samples were obtained at V6. Yield data was obtained from the combine at harvest.

Soybeans (P28A25L) were grown in 2020. The crop was seeded at a population of 71,000 pure live seed ha^{-1} on 2020-05-14 using a row-crop seeder with 50 cm spacing. Fertilizer was applied at seeding in a sideband 7.5 cm to the side of the seed row and at seed depth. Fertilizer rates applied were 38 kg MAP ha^{-1} and 4 kg KCL ha^{-1}. Tissue samples were obtained at the V3 growth stage. Yield data was obtained from the combine at harvest.

Field corn (P0220AM) was grown in 2021. Corn was seeded at a population of 15,000 seeds ha^{-1} using a row-crop seeder with 50 cm spacing. Fertilizer was applied at seeding in a sideband 7.5 cm to the side of the seed row and at seed depth. Fertilizer rates applied were 63 kg MAP ha^{-1}, 7 kg KCL ha^{-1}, 73 kg UAN (urea ammonium nitrate) ha^{-1}, 9 kg ATS (ammonium thiosulfate) ha^{-1}. Plant samples were collected at V3. The V3 samples were weighed to determine early season total uptake of nutrients. Corn was hand harvested and ears were dried and shelled to determine hand-harvested grain yields. The grain was analyzed for nutrient analysis. The stalks were dried and weighed. A subsample of this material was submitted for nutrient analysis.

Soil samples were obtained during the growing season for each cropping year (2019, 2020, and 2021). Dr. Mike Lehman (USDA-ARS Brookings, SD) conducted an analysis to estimate the colonization of arbuscular mycorrhizal fungi in each treatment. This analysis entails a serial dilution of the soils followed by growing Bahai grass in the diluted soil pots in a greenhouse setting. After four weeks of growth, the plants were harvested and roots were stained and scored for presence of arbuscular mycorrhizal fungi (Lehman et. al, 2012).

Statistical analysis (ANOVA) was performed using R 4.3.2. An ANOVA single factor with replication test was used. For post-hoc analysis, a Fischer's LSD test at a significance level of 0.1 was performed.

RESULTS AND DISCUSSION

Soil test levels have been elevated in the treatments that have received additional phosphorus fertilizer applications as shown in Table 1.

Table 1 Olsen phosphorus soil test levels in Spring 2020

	Olsen Soil Test Levels (ppm)		
Treatment	0-7.5 cm	7.5-15 cm	15-30 cm
Low P	7.7 b	5.2	3.6
Medium P	11.2 b	5.2	3.7
High P	16.8 a	4.9	3.7
P Value	0.004	NS	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

These data indicate that the soluble phosphorus levels have been elevated in the Medium P (numerically) and High P (statistically significant) treatments. Differences in soil test exist in the 0-7.5 cm soil depth.

In 2019, winter wheat was grown in this study. Plant samples were harvested at V6 and grain samples were obtained at harvest (Table 2).

Table 2 Wheat Plant and Grain P in Summer 2019 under different P soil test levels

	Plant @ V6			Grain		
	Biomass	P Concentration	P Uptake	P Concentration	P Uptake	Yield
Treatment	kg ha^{-1}	P (%)	kg ha^{-1}	P (%)	kg ha^{-1}	kg ha^{-1}
Low P	700 a	0.39	2.7	0.40	15	3,830
Medium P	560 b	0.40	2.2	0.41	16	3,820
High P	590 b	0.45	2.7	0.44	17	3,840
P Value	0.05	NS	NS	NS	NS	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

Biomass yield at V6 was higher in the Low P treatment, however this did not carry through the growing season to increased grain yield. Phosphorus concentration was numerically higher in the plant tissue at V6 and in the grain at harvest for the High P treatment, however these values were not statistically significant. The winter wheat grain yield was not impacted by phosphorus soil test level.

In 2020, soybeans were grown in this study. Plants were sampled at V3 and grain samples were obtained at harvest (Table 3).

Table 3 Soybean Plant and Grain P in Fall 2020 under different P soil test levels

	Plant @ V3		Grain		
	P Concentration	P Uptake	P Concentration	P Uptake	Yield
Treatment	P (%)	kg ha^{-1}	P (%)	kg ha^{-1}	kg ha^{-1}
Low P	0.11	38	0.43 b	18 b	4,110
Medium P	0.11	39	0.46 ab	19 ab	4,080
High P	0.13	40	0.49 a	20 a	4,140
P Value	NS	NS	0.02	0.03	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

No differences were found in the plant sample data. For grain content, phosphorus concentration increased as phosphorus soil test levels increased. This led to higher levels of phosphorus uptake in the Medium P and High P treatments.

In 2021, corn was grown in this study. Plants were sampled at V3 and grain samples were obtained at harvest (Table 4).

Table 4 Corn Plant and Grain P in Fall 2021 under different P soil test levels

	Plant @ V3			Grain		
	Biomass	P Concentration	P Uptake	P Concentration	P Uptake	Yield
	kg ha^{-1}	P (%)	kg ha^{-1}	P (%)	kg ha^{-1}	kg ha^{-1}
Low P	11,100 b	0.07 b	8.2 b	0.29	33	13,060
Medium P	11,800 b	0.07 b	8.3 b	0.32	36	13,120
High P	12,000 a	0.11 a	14.0 a	0.32	36	13,300
P Value	0.04	0.06	0.06	NS	NS	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

At V3, corn plants contained both a higher biomass and phosphorus concentration in the High P treatment. Higher levels of soluble phosphorus likely contributed to this additional biomass and phosphorus concentration. This led to a higher phosphorus uptake value at V3. The early advantage of additional phosphorus did not carry through to statistically higher grain yields.

Table 5 contains grain yield data for all three years of this study. All three years showed no grain yield advantage to higher levels of soil phosphorus.

Table 5 Grain Yields for 2019 (Wheat), 2020 (Soybeans), and 2021 (Corn)

		Low P	Medium P	High P	P-value
Year	Crop		kg ha^{-1}		
2019	Wheat	3,830	3,820	3,840	NS
2020	Soybean	4,110	4,080	4,140	NS
2021	Corn	13,060	13,120	13,300	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

Table 6 Most probable number of arbuscular mycorrhizal fungi propagules per gram of soil

Year	Crop	Low P	Medium P	High P	
		AMF Propagules per gram of soil			P Value
2019	Wheat	3.8 a	0.5 b	1.4 b	0.01
2020	Soybean	4.4 a	0.6 c	2.0 b	0.002
2021	Corn	5.2 a	1.0 b	1.0 b	0.003
Cumulative Average		4.5	0.7	1.5	

*P values over the 0.1 significance value are shown as NS (Not Significant).

These data indicate that higher soluble soil phosphorus levels discourage the colonization of arbuscular mycorrhizal fungi. The higher levels of AMF in the lower soluble phosphorus treatments might be compensating for the lower levels of the phosphorus nutrient.

The phosphorus concentration was numerically higher at V6 in winter wheat, and statistically higher at V3 in corn and soybeans. Higher levels of soluble phosphorus gave the crop an early advantage and in the case of corn, raised biomass levels at V3. Grain yields, however, showed no significant differences in any of the three years/crops. The increased levels of arbuscular mycorrhizal fungi in the treatments with less soluble phosphorus may have played a role in maintaining yield. Arbuscular mycorrhizal fungi may play a key role in allowing farmers to maintain lower soluble phosphorus test levels while maintaining high yields.

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