Title: The impact of phosphorus soil test level differences on crop response, phosphorus leaching, and phosphorus runoff under long-term no-till management in South Dakota

PI: Dr. Jose Guzman, Assistant Professor, Department of Agronomy, Horticulture and Plant Science, South Dakota State University. Email. Jose.Guzman@sdstate.edu Ph. 605-773-8120.

Co-PI(s): Dr. Dwayne Beck, Professor/Manager, South Dakota State University and Dakota Lakes Research Farm. **Dr. Michael Lehman**, Microbiologist, Agriculture Research Service (ARS)

Fund Title: Guzman-NREC-P Use Efficiency-18-2

Fund Amount: $63,000

Project Start and End Date: 1/1/2018 – 4/31/2019

Summary

We hypothesize that under management systems which promote mycorrhizal populations and healthy root systems along with fertilization practices that increase phosphorus (P) crop use efficiency; that soil test P levels can be intentionally maintained at levels below current recommend levels without experiencing yield losses due to P deficiency. The project was established in November of 2017 at the Dakota Lakes Research Farm. The experiment was in a replicated strip plots. The treatments were P application method (surface and soil placed) and fertilization rates of 0, 100, and 200 lbs of MAP (monoammonium phosphate per acre. Potential of P transport in water and sediment was measured and analyzed using a simulated rainfall event. Results show that the lowering of soil P (Olsen test 0-6 inch) levels to approximately 6 ppm, did not significantly reduce soybean yields using hand harvested techniques. Additionally, no P deficiencies observed as evidenced by mid-season leaf tissue testing. This was likely due to the much higher mycorrhizal populations where no MAP was applied, increasing P uptake efficiency compared to when 100 and 200 lbs of MAP per acre applied. The potential for P transported in water run-off was 4 times higher when MAP was surface applied compared to that placed into the soil. However, 91 to 99% of the total P transport was from sediment loss, which was greater when the soil was disturbed during soil placement application of MAP. Total P loss tended to increase with addition of MAP, and ranged from 4 to 7 and 4 to 11 lbs of P/acre when MAP was surface applied and placed into the soil, respectively. The highest return over direct cost occurred when 200 lbs/acre MAP was soil placed, followed by when no MAP was applied and 200 lbs of MAP per acre was applied in the surface. The lowest return over direct cost occurred when 100 lbs of MAP per acre was soil placed or surface applied. Findings from one year show that under long-term healthy soils under low soil disturbances and high mycorrhizal populations, that soil P levels can be reduced without negativity affecting crop yields, in order to reduce the potential for P runoff to aquatic ecosystems.

Introduction

Current recommended P fertilization rates from Soil Testing Laboratories are based on an estimation of the P supplying ability of the soil and the projected need of the crop at the stated yield goal. Recommendations assume P fertilization is done by surface broadcast applications and that conventional tillage practices are used. Some state that banding of P near the seed increases the efficiency of P crop uptake, subsequently rates can be reduced by 1/3. However, these P recommendations do not take into account differences in tillage, crop rotations, or mycorrhizal populations. We hypothesize that under management systems which promote mycorrhizal populations and healthy root systems (i.e. no-tillage, diverse rotations, high crop residue) and fertilization practices that increase P crop use efficiency (banding); soil test P levels (solubility) can be intentionally driven (below 10 ppm Olsen P or very low) without experiencing yield losses due to enhance P use efficiency. The total P in the soil will not be reduced significantly but the potential for transport of P to aquatic ecosystems will be reduced.

Goal and Objectives: The main goal of this project is to provide South Dakota producers information on optimum application methods and rates of P fertilizer to increase crop yields while reducing risks of P transport to aquatic ecosystems. Specific objectives of the project are to:

1. Assess the impacts of different soil test P levels and P fertilizer application methods on crop yields and P use efficiency.
2. Quantifying P movement associated with soil test level and fertilization practices.
3. Documenting the relationship between mycorrhizal populations and crop P use efficiency.
4. Performing cost/return analysis under different P fertilizer application methods.

Work Plan

The project was conducted at the Dakota Lakes Research Farm (18 miles southeast of Pierre) on an irrigated field in a no-till, Corn-Corn-Soybean-Wheat-Soybean rotation since 1990. In 2018, the total annual precipitation was 10.9 inches, and mean annual temperature was 47^{o}F. There was a hail storm in early July that caused severe tissue and leaf damage in the field. Replicated strips with differing soil test P levels were established in 2014 by applying zero, 100, and 200 lbs of MAP (monoammonium phosphate) per acre on soils where the Olsen P soil levels had been lowered to approximately 5 ppm. The experiment was in a randomized complete block design with 5 replications. Dimensions for each plot at the site were 20 ft by 50 ft.

MAP was placed into the soil and surface broadcasted in late fall (11/5/2017). Shortly after P fertilizer application, Cornell Infiltrometers were used to simulate a major rainfall event to measure infiltration, runoff, and transport of PO_4^{3-} and total P in water and sediment (Ogden et al., 1997). A rainfall rate of 0.2 inches min^{-1} was used and runoff was collected for the first 15 minutes after initial runoff. Soybeans were planted in May 17, 2018. Tissue sampling (sampled 7/10/2018) and grain yield (sampled 10/22/2018) was done to assess P recovery-efficiency (% = P uptake in fertilized – check P uptake/ P applied) and agronomic use-efficiency (yield increase/amount of P applied). P use efficiency will also be calculated using grain P at maturity. Additionally, soil bulk density, moisture, organic carbon, total nitrogen, P (Olsen test), total P, nitrate, pH, and aggregate stability was measured at 0-6, 6-12, 12-24, and 24-36 inches soil depths in fall of 2018 (after harvest). AMF (mycorrizal fungi) populations (sampled 6/10/2018) was measured in Dr. Lehman's ARS lab in Brookings (Lehman and Taheri, 2017).

Results and Impacts

Objective 1: Crop yields and P use efficiency

Assessment of P use efficiency can provide insight on optimum levels of nourishment to the crop, while minimizing P loss from the field. Before MAP was re-applied in fall of 2017, second year corn yields did not significantly vary across application rates and averaged 197 bu/acre. In 2018, soybean yields did not significantly vary between 0 and 100 lbs of MAP per acre, and averaged 54.1 bu/acre. However, when 200 lbs of MAP per acre was applied, soybean yields were on average 6.6 bu/acre higher when compared to 0 and 100 lbs/acre rates (Table 1). Soybean yields did not significantly vary between surface and soil placement applications of MAP. Yields might have been even higher, if not for a hail storm that caused severe leaf damage early in July. P recovery efficiency (% = P uptake in fertilized – check P uptake/ P applied) in soybean under 100 and 200lbs of MAP per acre was 1.7 and 5.0% of P applied, respectively during mid-season. Both of these values are below average, largely due to the relatively small yield increases with P application. P recovery efficiency values from other studies in the Mid-west typically range from less than 10% during the first year and increase to 15 to 25% as years increase. P use efficiency using grain P at maturity still needs to be assessed.

Objective 2: Soil P and P from water runoff and sediment

One way to reduce the risks of P transport to aquatic ecosystems is by reducing soil P. Although MAP was applied in fall of 2017, Soil P (Olsen test) in fall of 2018 did not significantly vary across 0, 100, and 200 lbs/acre rates and averaged 6.1 ppm across rates in the top 6 inches. This could be due to the high pH (avg. 7.9) in this soil quickly fixing P applied. However, the threat of P transport is highest during the first intense runoff event following P application. Simulating this runoff event situation, most of the total P runoff originated from the sediment (ranging from 91 to 99%) instead of the water runoff. Thus, management practices that disturbed the soil, such as placement of fertilizer into the soil, resulted in higher sediment erosion and total P runoff (Fig. 1). P concentrations in the water runoff increased from 0.02 when no P was applied to 0.63 ppm when MAP was applied. Surface applied MAP had higher concentrations of P (0.68 ppm) in the runoff compared to when it was placed into the soil (0.17 ppm). It is important to consider that the critical P concentration level for eutrophication to occur is 0.2 ppm in body of waters. Figure 1 shows total lbs/acre of P loss by application rate and placement. The greatest potential for P loss was observed when the P was placed into the soil and under high rates of P. Since most of the total P runoff is derived from the sediment, it is critical to reduce soil disturbances and lower soil P levels as low as possible without negativity affecting crop yields, in order to reduce the potential for P runoff to aquatic ecosystems.

Objective 3: Mycorrhizal populations and crop P use efficiency

Phosphorus (P) is often an important limiting factor for crop yields, however, high P application levels in agriculture have led to environmental problems. One of the ways to tackle this issue simultaneously is improving P use efficiency of crops through increasing P uptake via mycorrhizal fungi.

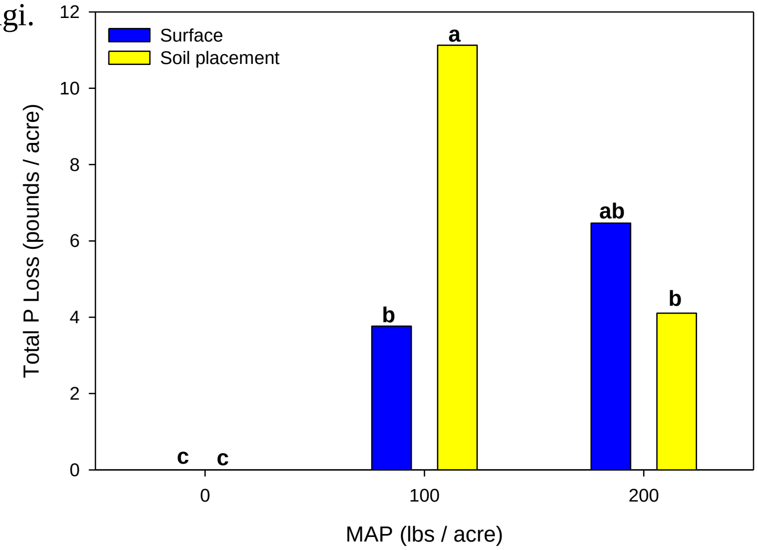

Figure 1. Total P loss (lbs/acre) by application rate and placement. Different letters indicate significant differences.

Soybean P uptake did not significantly vary between application rates nor placement method as measured by P concentration in plant tissue, which on average was 0.45%. Lack of difference is likely due to the higher mycorrhizal populations observed when no MAP was applied compared to 100 and 200 lbs of MAP per acre (Fig. 2). To put into context, in conventional tilled systems under corn-soybean rotation, AM fungal propagules per gram of soil on average range from 0.5 to 2. Additionally, overall soil health (soil physical, chemical, biological) in general was high in regardless of how much MAP was applied or placement.

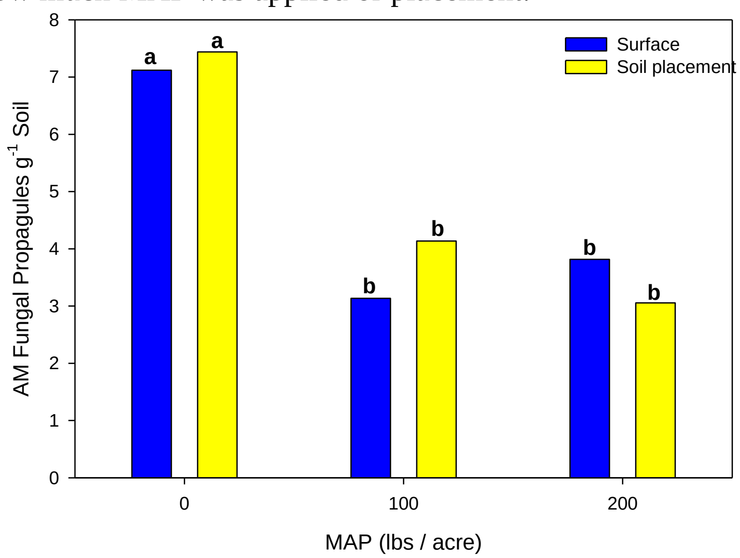

Figure 2. AM fungal propagules by application rate and placement. Different letters indicate significant differences.

Objective 4: Economics

Efficient use of P in crop production is important for economic and environmental reasons (Table 1). Under 100 lbs/acre of MAP, the agronomic use-efficiency (yield increase/amount of P applied) was negative compared to when no MAP was applied. When 200 lbs of MAP per acre was applied, the agronomic use-efficiency increases, but was still relatively low considering the higher risk of P runoff and higher cost of production. The highest return over direct cost occurred when 200 lbs of MAP per acre was placed into the soil, followed by when no MAP was applied and 200 lbs of MAP per acre was applied in the surface.

	0 lb/acre MAP		100 lb/acre MAP		200 lb/acre MAP	
Per acre	Soil placement	Surface	Soil placement	Surface	Soil placement	Surface
Yld (bu)	55.6	53.7	54.6	52.6	61.0	60.3
Gross Rev. ($)	456	440	448	431	500	494
MAP cost/acre ($)	0	0	25.5	25.5	51	51
Direct Cost* ($)	149	149	174	180	185	191
Total direct cost per bu	2.68	2.77	3.19	3.43	3.03	3.17
Return over direct cost ($)	**307**	**291**	**274**	**251**	**315**	**303**

*includes machinery, pesticide applications, other fertilization, seed, fuel and oil, drying, other variable costs.

Changes in Project or Personnel

No changes to project personnel. Application of MAP was completed in November, 2017 to mimic more what a farmer would do instead of spring application when planting soybean. No collection of leaching samples was collected due to the lysimeters not arriving until mid-September 2018. The lysimeters will be installed once the soil thaws in 2019. Additional MAP will be applied again to raise soil P to desired levels. A no-cost extension was granted to finish publications by May of 2019.

Products (publications, presentations, disclosures/patents)

Simulated rainfall field demonstrations have been presented at the experiment plots showing the potential of mono-ammonium phosphate (MAP) runoff under no-till with surface and soil placement applications, and tillage (simulated). Demonstrations were given for the Soil Health Field Tour on 6/13/2018 (≈ 80 attendance) and the Central South Dakota Field School on 6/19/2018 (≈ 30 attendance). Poster presentation on soil health, P use efficiency, and P transport in runoff and sediment was presented at the American Society of Agronomy Annual meeting in Baltimore on 11/8/2018, and oral presentation at the Dakota Lakes Research Farm annual meeting on 2/12/2019 with attendance of approximately 50.

Budget Table

This fund has a remaining of $33,775.63. This amount is based on all claims processed through the accounting system to January 31, 2018 and may have outstanding charges not yet processed. Please see the table below for the budget and expenses, and available balance by category.

	Budget	Cumulative Expenses through December 31, 2018	Available Balance	Available %
Salaries	19,935.00	12,068.02	7,866.98	39%
Benefits	1,473.00	1,229.30	243.70	17%
Travel	800.00	853.64	-53.64	-7%
Contractual	23,960.00	4,953.97	19,006.03	79%
Supplies	16,832.00	10,119.44	6,712.56	40%
Total	63,000	29,224.37	33,775.63	54%

Title: The impact of phosphorus soil test level differences on crop response, phosphorus leaching, and phosphorus runoff under long-term no-till management in South Dakota

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Co-PI(s): Dr. Dwayne Beck, Professor/Manager, South Dakota State University and Dakota Lakes Research Farm e-mail (dwayne.beck@sdstate.edu 605-224-6114. **Dr. Michael Lehman**, Microbiologist, Agriculture Research Service (ARS)

Fund Title: Beck-NREC-P Use Efficiency

Fund Amount: $36,496

Project Start and End Date: 1/1/2020 – 4/30/2021

Summary

Phosphorus, the plant nutrient, is receiving intense scrutiny at the present time due to its potential impact on the degradation of aquatic ecosystems. This requires that everyone involved carefully examine all aspects of phosphorus use in agriculture to assure that every possible effort is made to prevent environmental damage while at the same time optimizing its value as a plant nutrient. Scientific knowledge increasingly indicates that under management systems that promote enhanced biological activity, specifically that associated with mycorrhizal fungi activity, behave differently as compared to traditional systems. There is also evidence that promoting healthy root systems and using fertilizer placement techniques can increase phosphorus (P) crop use efficiency. If all these steps are combined it is probable that soil test P levels (P solubility) can be intentionally maintained at levels lower than those currently recommended without experiencing yield losses due to P deficiency. The net result should be a reduction in the potential for movement of phosphorus to aquatic ecosystems and more efficient use of P fertilizers.

The project was established in November of 2017 at the Dakota Lakes Research Farm. A Corn-Corn-Soybean-Wheat Soybean rotation is being used. The crop in 2020 is the soybeans grown in wheat stubble (seeded to a cover-crop). Two factors are being examined. One is a differential in P soil test level and the other is phosphorus fertilizer placement (soil placed vs surface applied). The soil test differential experiment was in a randomized complete block design with 5 replications. Soil tests that had been drawn to approximately 5 ppm Olsen, received treatments where P soil test level differences were created by applying MAP fertilizer to replicated strips at rates of 0, 100, and 200 lbs of MAP (mono-ammonium phosphate)/acre in 2014 and again in 2017 and 2019. Fertilizer placement impacts are tested in a separate field, with the same crop rotation, and similarly low soil test P levels. Replicated strips of soybeans received 53 lbs of a blend of MAP (90%) and KCl (10%) per/acre placed 3 inches to the side of the seed in the soil test level experiment. The same procedure was used on the placement experiment with the broadcast treatments receiving the same fertilizer applied on the soil surface during the seeding process. Potential of P transport in water and sediment was measured and analyzed using a simulated rainfall event using a Cornell infiltrometer applying approximately 9 to 12 inches of

water in 1 hour, Water samples were collected from the runoff that occurred and from the soil solution extracted by vacuum 30 inches immediately below the infiltration instrument. The water was analyzed for nitrate, sulfate, ortho P and total P. The water sample analysis from the first infiltration run on the soil test portion of the experiment have been completed. Water samples from the placement experiment are in process.

Mid-year results indicate that soil test P values have increased in the treatments that have received an additional 300 and 600 lbs of MAP/acre since 2014 (100 and 200 lbs of MAP/acre three times). The Check has values of 7.7, 5.2, and 3.6 ppm Olsen at the 0-3, 3-6, and 6-12 inch depths. The intermediate rate has 11.2, 5.2, and 3.6 ppm. Olsen. The highest addition produced values of 16.8, 4.9, and 3.7 ppm Olsen. The shallower sampling depth accentuated difference. Normal testing is done to 6 inches. Runoff data from applications of 9 to 12 inches in an hour indicate that the highest runoff of Ortho P was 0.12 lbs/acre and the highest total P runoff was 0.15 lbs of P/acre. Most values were less than .05 lbs of P/acre. The values from the placement study are not complete. We expect some of them to be higher.

Introduction: Phosphorus management in agriculture is receiving substantial scrutiny at the present time due to the role this nutrient can play in degrading aquatic ecosystems. Addressing these concerns requires all involved to examine every aspect of present practice. There is currently an effort to promote the 4 R's of nutrient management. This entails applying the right amount of nutrient, in the right form, in the right place, at the right time. In many cases soil testing is used as a tool in determining the correct amount of nutrient to use. Current recommended P fertilization rates from Soil Testing Laboratories are based on an estimation of the P supplying ability of the soil and the projected need of the crop at the stated yield goal. Recommendations assume P fertilization is done by surface broadcast applications 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, subsequently rates can be reduced. However, these P recommendations do not take into account differences in tillage, crop rotations, or mycorrhizal activity. It is probable that under management systems that promote mycorrhizal activity and healthy root systems (i.e. no-tillage, diverse rotations, high crop residue) and fertilization practices that increase P crop use efficiency (banding); soil test P levels (solubility) can be intentionally managed at solubility levels lower than is now common without experiencing yield losses. The total P in the soil will not be reduced significantly since the lower solubility level will be maintained, but the potential for transport of P to aquatic ecosystems should be reduced.

Goals and Objectives: The main goal of this project is to provide South Dakota producers with information on optimum application methods and rates of P fertilizer to increase crop yields while reducing risks of P transport to aquatic ecosystems. Specific objectives of the project are to:

1. Assess the impacts of different soil test P levels on crop yields and P use efficiency.
2. Document the impact of nutrient placement in improving P use efficiency and reducing potential off-site movement.

3. Quantifying P movement associated with soil test level and fertilization practices.
4. Document the relationship between arbuscular mycorrhizal (AMF) fungi activity and crop P use efficiency.
5. Perform cost/return analysis related to these factors.

Work Plan

The project is being conducted at the Dakota Lakes Research Farm (18 miles southeast of Pierre) on an irrigated field in a no-till, Corn-Corn-Soybean-Wheat/cover crop-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 zero, 100, and 200 lbs of MAP (mono-ammonium phosphate)/acre on soils where the Olsen P soil levels had been lowered to approximately 5 ppm. The experiment was in a randomized complete block design with 5 replications. Dimensions for each plot at the site were 20 ft by 450 ft. A crop of soybeans and two crops of corn were grown on this area during the 2015, 2016, and 2017 years respectively.

In the fall of 2017 and the fall of 2019 (after wheat harvest) applications of MAP were again made at rates of 0, 100, and 200 lbs of MAP/acre to the same replicated strips that were treated in 2014. A no-till drill was used to place the nutrient 1.5 inches deep in 7.5-inch rows.

In the soil test field, a cover-crop of winter wheat was seeded following fertilizer applications. Small portions of this cover-crop were terminated before frost to allow testing P runoff as impacted by cover crops that freeze. These data have been collected but more analysis is required.

The P placement portion of the study is conducted in a separate field that has been in the same rotation and has similarly low P soil test values. In this area a cover-crop of oats, barley, and German millet was seeded immediately after wheat harvest. The cover-crop was swathed when the oats was in the milk stage. These swathes were grazed during the winter and spring by beef cattle. A cover-crop of oats was seeded early in the spring on this field.

Both fields were seeded to soybeans using a row-crop seeder with 20-inch spacing. Fertilizer (MAP 90% and KCl 10%) at 53 lbs/acre was applied at seeding either placed 3 inches to the side of the seed or on the surface depending on the protocol. The cover crop was terminated after seeding.

Mid-season Results and Impacts

Objective 1: Crop yields and P use efficiency
Early season leaf samples have been collected and submitted for analysis. Whole plant samples will be collected and analyzed to determine total P uptake before the crop is harvested.

Objective 2: Impact of phosphorus placement on P use efficiency, P uptake and yield

It is too early to assess this factor. Leaf samples have been collected and are being analyzed.

Objective 3: Soil P and P from water runoff and sediment

Cornell infiltrometers were used to quantify potential P transport in water and sediment as impacted by soil test P levels and placement differences. Long-term no-till history made it necessary to apply water at very high rates on 9 to 12 inches/hour for 1 hour to produce sufficient runoff to allow analysis. Water samples were collected from the runoff that occurred and from the soil solution extracted by vacuum 30 inches immediately below the infiltration instrument. The water was analyzed for nitrate, sulfate, ortho P and total P. The water sample analysis from the first infiltration run on the soil test portion of the experiment have been completed. Water samples from the placement experiment are in process.

Mid-year results indicate that soil test P values have increased in the treatments that have received an additional 300 and 600 lbs of MAP/acre since 2014 (100 and 200 lbs of MAP/acre three times). The Check has values of 7.7, 5.2, and 3.6 ppm Olsen at the 0-3, 3-6, and 6-12 inch depths. The intermediate rate has 11.2, 5.2, and 3.6 ppm. Olsen. The highest addition produced values of 16.8, 4.9, and 3.7 ppm Olsen. The shallower sampling depth accentuated difference. Normal testing is done to 6 inches. Runoff data from applications of 9 to 12 inches in an hour indicate that the highest runoff of Ortho P was 0.12 lbs/acre and the highest total P runoff was 0.15 lbs of P/acre. Most values were less than .05 lbs of P/acre. The values from the placement study are not complete. We expect some of them to be higher.

Objective 4: Mycorrhizal activity and crop P use efficiency

Samples for determination of AMF populations will be collected and used by Dr. Lehman to conduct greenhouse/laboratory studies to determine most probably numbers. We will also subject these samples to Phospholipid Fatty Acid analysis and DNA evaluation. These samples need to be collected when plants are actively growing. Results from last year's AMF sampling have been prepared but need to be "read" when the USDA center reopens. Samples form 2018 indicated the most probably number was over twice as high where no MAP was applied in 2014 or 2017 as compared to were 100 and 200 lbs of MAP/acre were each of these years (200 and 400 lbs of total product).

Objective 5: Economics

Efficient use of P in crop production is important for economic and environmental reasons. Obviously obtaining comparable yields with less total nutrient applied is beneficial. Yields need to be obtained before economics can be calculated.

Changes in Project or Personnel

Brennan Lewis was hired in May to be a MS student working on this project. The open soil scientist position has been open since May 2019. It is hoped that will be filled before fall. Dr. Dwayne Beck has taken over primary duties for directing field activities for this research until a replacement is hired.

Products (publications, presentations, disclosures/patents)
This study was a featured stop on the June 25, 2020 DLRF Virtual Field Day Videos are online.

Budget

This fund has a remaining balance of $36,496 as of June 30, 2020. That is the entire budget for this year. Brennan is being paid by DLRF until his assistantship begins. Most of the soil design and analysis work has not been processed. The Covid issue resulted in our secretary working from home part-time. This will continue through the summer.

Title: The Impact of Phosphorus Soil Test Level Differences on Crop Response, Phosphorus Leaching, and Phosphorus Runoff Under Long-Term No-Till Management in South Dakota

Co-PI(s): Dr. Dwayne Beck, Professor/Manager, South Dakota State University and Dakota Lakes Research Farm, e-mail (dwayne.beck@sdstate.edu), 605-224-6114.

Dr. Michael Lehman, Microbiologist, Agriculture Research Service (ARS), email (michael.lehman@usda.gov), 605-693-5205

Dr. Sutie Xu, Assistant Professor, Department of Agronomy, Horticulture, and Plant Science, South Dakota State University, email (sutie.xu@sdstate.edu), 605-733-8125

Fund Title: Beck-NREC-P Use Efficiency

Fund Amount: $49,752

Project Start and End Date: 1/1/2020 – 6/30/2021

Summary

Blue-green algal blooms are of major concern in South Dakota lakes and in aquatic ecosystems world-wide. Phosphorus has been determined to be the primary growth limiting nutrient in algal bloom formation. The phosphorus that causes the algal blooms comes from both point and non-point sources. Included in non-point pollution sources are farming operations. Utilizing management systems that minimize the potential for movement of phosphorus to aquatic ecosystems are key. One such approach is to lower phosphorus soil test levels (P solubility) while utilizing management techniques that minimize sediment movement, strategically place fertilizer nutrients, and promote biological activity that aids in the uptake of phosphorus by plants. In the case of this study mycorrhizal fungi are seed as being important. The goal is to reduce the potential for phosphorus movement from the soil into aquatic ecosystems and to gain efficiency in the use of phosphorus fertilizers so crop yields are not adversely impacted.

Goals and Objectives: The main goal of this project is to provide South Dakota producers with information on optimum application methods and rates of P fertilizer to sustain yields while reducing risks of P transport to aquatic ecosystems. Specific objectives of the project are to:

1. Assess the impacts of different soil test P levels on crop yields and P use efficiency.
2. Document the impact of nutrient placement in improving P use efficiency and reducing potential off-site movement.
3. Quantifying P movement associated with soil test level and fertilization practices.
4. Document the relationship between arbuscular mycorrhizal (AMF) fungi activity and crop P use efficiency.
5. Perform cost/return analysis related to these factors.

Work Plan:

The project is being conducted at the Dakota Lakes Research Farm (18 miles southeast of Pierre) on two irrigated fields in a Corn-Corn-Soybean-Wheat/cover crop-Soybean rotation. This site has been strictly no-till since 1990. In the soil test P level field replicated strips with differing soil test P levels were established in 2014 by applying zero, 100, and 200 lbs of MAP (mono-ammonium phosphate)/acre on soils where the Olsen P soil levels had been lowered to approximately 5 ppm. The experiment was in a randomized complete block design with 5 replications. Dimensions for each plot at the site were 20 ft by 450 ft. Before the initiation of this study crop of soybeans and two crops of corn were grown on this area during the 2015, 2016, and 2017 years respectively. In the fall of 2017 and the fall of 2019 (after wheat harvest) applications of MAP were again made at rates of 0, 100, and 200 lbs of MAP/acre to the same replicated strips that were treated in 2014. A no-till drill was used to place the nutrient 1.5 inches deep in 7.5-inch rows.

In the soil test portion of the study soybeans (P29A 85L) were seeded 1.5 inches deep at 175,000 pls in 20-inch rows at 180,000 pls/acre on May 14, 2020. A blend of 90% MAP and 10% KCl at 38 lbs/ace was placed 3 inches to the side of the seed row and at the same depth as the seed. In the placement study the same variety and seeding rate were used on May 12, 2020 for the treatments that had fertilizer banded. The surface application treatments were accomplished by moving the fertilizer hose from the side-band opener on each row to a deflection plate that caused the material to be distributed on the surface during the seeding process.

Simulated rainfall events were conducted in both the soil-test P level study and the fertilizer placement study fields using the Cornell infiltrometer to measure the potential P transport in water and sediment. Nine to twelve inches of water were applied in a 1-hour period where runoff from the soil surface was collected. Additionally, water samples were collected from soil solution by extracting the water by vacuum approximately 30 inches directly below where infiltration equipment was placed. The water samples were analyzed for nitrate, sulfate, ortho P, and total P. Soil samples to the depth of 0-3, 3-6, and 6-12, 12-24, and 24-36 inches were collected in the spring prior to seeding.

Whole plant samples were collected at V6 and analyzed for nutrient content. Whole plant samples were collected at physiological maturity and analyzed for total biomass and nutrient content. Plots were harvested with a field scale combine and flex header. Weights were obtained with a weigh wagon. Grain samples were collected for analysis.

Results and Impacts

Objective 1: Impacts of different soil test P levels on Crop yields and P use efficiency

The results from physiological maturity plant samples indicate that the average % P found in the plants, as well as the pounds of P removal from plant tissues, were not significantly different between treatments under different P fertilizer application (Table 1). The grain P concentration, however, was significantly higher under 200 lbs of MAP/ acre application (0.487%) than that receiving no fertilizer (0.429%) ($P < 0.05$). The difference between these two treatments was also found in pounds of P removed in the grain. The soybean yield was not influenced by P application rate, which was ranged from 60.6 to 61.6 bushel / acre for the three treatments.

Table 1 Plant and Grain P in Fall 2020 under different P fertilizer application (bold numbers within each column mean statistically different at $P \leq 0.05$)**.**

	Plant			Grain			Yield
	P (%)	P (lbs/acre)	P_2O_5 (lbs/acre)	P (%)	P (lbs/acre)	P_2O_5 (lbs/acre)	(bushel /acre)
Check	0.110	34	77	**0.429**	**16**	36	61.1
100MAP	0.108	35	80	0.459	17	38	60.6
200Map	0.127	36	83	**0.487**	**18**	41	61.6
Significant	NS	NS	NS	0.02	0.03	NS	NS

Our data show a slightly increase in grain P concentration when the plots received the highest fertilizer rate than those without fertilizer, while little difference was found in plant P concentration, soil P concentration, and soybean yield under different soil test level management.

Objective 2: Impact of phosphorus placement on P use efficiency, P uptake and yield

Both grain P concentration and removal as pounds of P per acre and the yield in 2020 fall was not influenced by placement methods (Table 2). Similarly the V6 plant P concentration was not influenced by placement method (average 0.41, *P* = 0.9)

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Table 2 Grain P and yield in Fall 2020 under different P placement methods.

	Grain			Yield
	P (%)	P (lbs/acre)	P_2O_5 (lbs/acre)	(bushel / acre)
Banded	0.433	20	45	75.3
Surface	0.449	20	46	74.0
Significance	NS	NS	NS	NS

Fertilizer placement was not important in terms of yields and plant concentrations in soybeans. It was important in wheat in 2019. Having the material in the soil is valuable from an environmental services standpoint.

Objective 3A: Soil test P (extractible or available) and total P

Soil extractable P (soil test level) level in spring 2020 was increased in plots receiving higher P fertilizer rates at 0-3” depth (Table 3). Total MAP applied since 2014 differed by 600 lbs of MAP/acre.

Table 3 Soil test P levels and total P (ppm) in the P rate experiment plots in Spring 2020

(bold numbers within each column and depth mean statistically different at $P \leq 0.05$)**.**

	Bray P	Olsen	Mehlich P	Total P
0-3"		PPM		
Check	6	**8**	**8**	661
100MAP	10	**11**	**13**	643
200MAP	17	**17**	**22**	699
Significance	0.002	0.002	<0.0001	NS
3-6"				
Check	3	5	6	594
100MAP	4	5	6	615
200MAP	5	5	6	605
Significance	NS	NS	NS	NS
6-12"				
Check	2	4	4	579
100MAP	2	4	4	614
200MAP	2	4	4	555
Significance	NS	NS	NS	NS
12-24"				
Check	2	3	4	610
100MAP	1	3	4	605
200MAP	2	4	4	633
Significance	NS	NS	NS	NS

Soil test P levels and total P were not influenced by placement method according to the data from Spring 2020 (Table 4).

Table 4 Soil active and total P (ppm) in the placement experiment plots in Spring 2020.

	Bray P	Olsen P	Mehlich P	Total P
0-3"		PPM		
Banded	9	12	15	700
Surface	8	11	12	659
Significance	NS	NS	NS	NS
3-6"				
Banded	2	4	5	609
Surface	11	11	19	656
Significance	NS	NS	NS	NS
6-12"				
Banded	2	4	4	603
Surface	5	7	8	737
P value	NS	NS	NS	NS
12-24"				
Banded	0.1	3	3	560
Surface	1	4	4	614
Significance	NS	NS	NS	NS

This study was conducted on soils that are neutral in pH to slightly basic. Consequently, the appropriate soil test to use in most cases would be the Olsen P test. The extractant in the Bray test is neutralized by the soil and would give low values. The addition of 600 lbs/acre of MAP over several years has slightly raised soil test levels. Treatments will be repeated again this coming spring.

Objective 3B: Surface runoff and percolation losses of P

Cornell infiltrometers were used to quantify potential P transport in water and sediment as impacted by soil test P levels and placement differences. Long-term no-till history made it necessary to apply water at very high rates of 9 to 12 inches/hour for 1 hour to produce sufficient runoff to allow analysis. Water samples were collected from the runoff that occurred and from the soil solution extracted by vacuum 30 inches immediately below the infiltration instrument. The water was analyzed for nitrate, sulfate, ortho P and total P. The water sample analysis from the first infiltration run on the soil test portion of the experiment have been completed. Water samples from the placement experiment are in process.

At the mid-year report, we had runoff results for the rate study. The results indicated that soil test P values have increased in the treatments that have received an additional 300 and 600 lbs of MAP/acre since 2014 (100 and 200 lbs of MAP/acre three times). The Check has values of 7.7, 5.2, and 3.6 ppm Olsen at the 0-3, 3-6, and 6-12 inch depths. The intermediate rate has 11.2, 5.2, and 3.6 ppm. Olsen. The highest addition produced values of 16.8, 4.9, and 3.7 ppm Olsen. The shallower sampling depth accentuated difference. Normal testing is done to 6 inches. Runoff data from applications of 9 to 12 inches in an hour indicate that the highest runoff of Ortho P was 0.12 lbs/acre and the highest total P runoff was 0.15 lbs of P/acre. Most values were less than .05 lbs of P/acre.

We received the test reports for the placement trials and were able to find the averages for the tested depths. In this field we sampled at the 0-3", 3-6", 6-12", and 12-24" depths. The surface application method had values of 10.5, 11.5, 6.9, and 4.4 ppm, in order of ascending depth, in each category of depth. The banded treatment saw values of 12.1, 4.5, 3.8, and 3.2 ppm at the 0-3", 3-6", 6-12", and 12-24" depths respectively. We tested at the shallower depth to accentuate the differences here as we did in the rate study.

When testing for runoff we applied 27.5 to 28 inches of water per hour. In the placement study we found that the runoff Ortho P was on average 0.17 lbs/acre in the surface applied phosphorus and the average runoff ortho P for the banded application method was .24 lbs/acre. It was also interesting to note that the measurement of water from the soil solution access tube showed that in the surface application of fertilizer had a higher rate of Ortho P than the banded application method with the measurements being 0.06 lbs/acre and 0.02 lbs/acre respectively. This is likely due to macropore flow in the surface applied treatments (water taking P from the surface down the macropore). In the case of the banded treatment the fertilizer P is in the soil in a band and does not come in contact with water moving over the surface and down through a macropore. This is one of the primary advantages of banding fertilizer (both N and P) in no-till systems.

Objective 4: Mycorrhizal activity and crop P use efficiency

Soil samples for determination of AMF populations were collected and have been processed by Dr. Lehman. The process of reading this year's samples and those from last year to estimate Most Probable Number of AMF remains to be done. The USDA facility is still highly locked down. These same samples were also subjected to Ward Laboratories for Phospholipid Fatty Acid analysis and for DNA evaluation by Trace Genomics. The available data show that bacterial proportion from the microbial community was higher in plots receiving P fertilizer than those without fertilizer application (53.8 and 52.6 vs. 46.4%) (Table 5), while the total microbial biomass, gram positive and negative bacteria proportion, and the fungi proportion was not influenced by treatment. These samples were collected when plants were actively growing. Samples from 2018 indicated the most probable AMF number was over twice as high where no MAP was applied in 2014 or 2017 as compared to were 100 and 200 lbs of MAP/acre were each of these years (200 and 400 lbs of total product).

Table 5 The PLFA results from summer 2020 in P rate study (bold numbers within each column are statistically different at $P < 0.05$).

	biomass	**Bacteria (%)**	**Gram positive bacteria (%)**	**Gram negative bacteria (%)**	**Fungi (%)**
Check	8704	**46.4**	19.9	1704	14.6
100MAP	7767	**53.8**	20.8	1597	13.1
200MAP	8177	**52.6**	21.5	1708	12.7
Significance	NS	0.04	NS	NS	NS

Objective 5: Economics

The economic analysis of these results is straightforward at this point. There is no difference between treatments that differed in total application of MAP fertilizer that differed by 300 and 600 lbs of MAP/acre. This presents significant savings.

Changes in Project or Personal

Brennan Lewis was hired in May 2019 to be a MS student working on this project. Dr. Dwayne Beck has taken over primary duties for directing field activities for this research. Dr. Sutie Xu, the new soil scientist, has started at SDSU and will work together with Dr. Beck on finishing this project and publish the results.

Products (publications, presentations, disclosures/patents)

The results for this study has been reported at field days and the DLRF virtual field day in June. They will be published in peer reviewed journals in the future.

Budget

The project budget will be expended prior to the end of the 6 month no-cost extension. It is being spend on Brennan Lewis's stipend until April and for testing procedures that are still in process.

Title: The impact of phosphorus soil test level differences on crop response, phosphorus leaching, and phosphorus runoff under long-term no-till management in South Dakota

Co-PI(s): Dr. Dwayne Beck, Professor/Manager, South Dakota State University and Dakota Lakes Research Farm e-mail (dwayne.beck@sdstate.edu 605-224-6114.

Dr. Michael Lehman, Microbiologist, Agriculture Research Service (ARS)

Brennan Lewis, GRA AHPS-SDSU email (brennan.lewis@sdstate.edu)

Fund Title: Beck-NREC-P Use Efficiency

Fund Amount:

Project Start and End Date: 1/1/2021 – 6/30/2022

Summary:

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. These 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. Addressing this issue begins with the 4-R's of nutrient management. This project deals with evaluating the right rate of phosphorus (specifically soil test level) needed under long-term no-till management and the best placement method for supplying this phosphorus.

The project was established in November of 2017 at Dakota Lakes Research Farm. The rotation utilized is Soybean-Wheat-Soybean-Corn-Corn. Both fields used in this project originally had soil test P levels drawn down to less than 5 ppm Olsen P. The soil-test calibration area has 5 replicated field-length strips in each of three treatments. These treatments were 0, 100, and 200 lbs of MAP (11-52-0) per acre applied in the falls of 2014, 2017, and 2019 using a no-till drill to place it into the soil. All of the stirps were seeded to corn with a side-band of fertilizer (51-29-4) placed 3 inches to the side of the seed row and at seed depth. The phosphorus placement portion of the experiment is being conducted on a separate field that has received no large applications of phosphorus over the years and has similar soil type and soil test level (Olsen P of 5 ppm). Replicated strips of corn were seeded with the P source placed in the side-band with the nitrogen fertilizer or broadcast on the surface or banded in the seed row above the seed and below the surface. The "pop-up" fertilize source was 10-34-0. The phosphate and N rate is the same in all treatments.

Soil sampling and water sampling protocols were similar as in the past with one significant change. It has been difficult to produce consistent simulated runoff events using the Cornell infiltrometers used in the past. This year a rainfall simulator was constructed that is similar to those used by the NRCS and by some other scientists. This machine has an oscillating spray head directing simulated rainfall directly on the soil. This would more directly mimic natural rainfall in terms of soil splash and sealing. This machine has an application intensity of 20 inches/hour. This intensity is necessary to produce runoff. A 30 inch by 20 inch metal frame is

used to direct any runoff into a catchment vessel. Runoff volume and potential nutrient movement from the field can be calculated with these data. Soil solution sampler are inserted diagonally under the infiltration frames to extract soil solution from each test area. This allows evaluation of potential leaching of N, P, and S.

There was no significant response in corn yield in the P rate portion of the study. There were differences in the placement experiment. Little ortho-P or P was lost through runoff even under very high application intensities.

Introduction: The management of phosphorus fertilizers is a serious issue due to its role in the degradation in 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) and fertilization practices that increase P crop use efficiency (banding or pop-up). Utilizing the aforementioned practices, the soil test P levels (solubility) can be managed at intentionally low levels, 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.

Goals and Objectives: The main goal of this project is to provide South Dakota producers with information on optimum application methods and rates of P fertilizer to increase crop yields while reducing risks of P transport to aquatic ecosystems. Specific objectives of the project are to:

1. Assess the impacts of different soil test P levels on crop yields and P use efficiency.
2. Document the impact of nutrient placement in improving P use efficiency and reducing potential off-site movement.
3. Quantifying P movement associated with soil test level and fertilization practices.
4. Document the relationship between arbuscular mycorrhizal (AMF) fungi activity and crop P use efficiency.
5. Perform cost/return analysis related to these factors.

Work Plan:

The project was conducted at the Dakota Lakes Research Farm (18 miles southeast of Pierre) on two irrigated fields in a no-till, Corn-Corn-Soybean-Wheat/cover crop-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 zero, 100, and 200 lbs of MAP (mono-ammonium phosphate)/acre on soils where the Olsen P soil levels had been lowered to approximately 5 ppm. The experiment was in a randomized complete block design with 5 replications. Dimensions for each plot at the site were 20 ft by 450 ft. A crop of soybeans and two crops of corn were grown on this area during the 2015, 2016, and 2017 years respectively.

In the fall of 2017 and the fall of 2019 (after wheat harvest) applications of MAP were again made at rates of 0, 100, and 200 lbs of MAP/acre to the same replicated strips that were treated in 2014. A no-till drill was used to place the nutrient 1.5 inches deep in 7.5-inch rows.

In the soil test field corn was seeded using a row-crop seeder with 20-inch spacing. Fertilizer (MAP 90% and KCl 10%) at 63 lbs/acre was applied at seeding. The placement portion of the study takes place in a separate field with similarly low P soil test values and in the same rotation as the soil test portion. The fertilizer (MAP 90% and KCl 10%) for the placement study was also applied at 63 lbs/a, in the banded treatment the fertilizer was applied 3 inches to the side of the seed, the surface applied treatment fertilizer was broadcast across the soil surface at planting, and in the pop-up treatment the fertilizer (10-34-0 liquid fertilizer) was placed in the seed trench (above the seed and below the surface) at a rate of 7.3 gallons per acre. The 7.3 gallons per acre of the 10-34-0 has the equivalent amount of phosphorus as the 63 lbs of MAP +KCl blend. Urea Ammonium Nitrate (UAN) was side banded in all areas at a rate producing an application rate of 45 lbs of N/acre.

Plant samples were collected at V3, V7, VT, and at maturity. The V3 samples were weighed to determine early season total uptake of nutrients. The whole plant samples at maturity were collected by harvesting the corn ears and the stalks separately. The 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 tests do indicate that soil test P values have increased in the treatment that have received an additional 300 and 600 lbs of MAP/acre since 2014 (100 and 200 lbs of MAP/acre applied a total of three times). The check treatment has Olsen values of 6.0, 6.3, 5.4, and 5.3 at the 0-3", 3-6", 6-12", and 12-24" depths respectively. The 100 lbs of MAP/acre treatment had values of 5.9, 5.7, 5.3, and 5.4. The 200 lbs of MAP/acre treatment had values of 7.6, 7.2, 5.4, and 6.5. By sampling at shallower depths, the differences between treatments are accentuated, this is different from the standard sampling procedure where samples are taken to 6 inches

Results and Impacts

The results are contained in a separate table for each field. The

The following table outlines the status of the work at this time. Brennan Lewis is the graduate student on the project and will use these data in his MS thesis and his defense in May.

Table of Activities: Dakota Lakes NREC Phosphorus calibration study 2021

Activity	Collected	Submitted	Results	Statistics
Soil Samples	x	x	x	x
V-3 Plants	x	x	x	x
V-7 Leaves	x	x	x	x
R-1 Leaves	x	x	x	x
Machine Harv	x	x	x	x
Hand Harv Grain	x	x	x	x
Hand Harv Plant	x	x	x	x
Soil Sample	x	x	x	x
Rainfall/Runoff	x	x	x	x

Objective 1: Crop yields and P use efficiency

There were no significant differences among the three soil test level treatments in 2022. Whole plant samples were collected at V3 and maturity. Leaf samples were also collected at V7 and at tasseling (VT). All biomass samples were analyzed for nutrient content. The V3 and maturity samples were dried and weighed to allow biomass and total nutrient uptake calculations.

Table 1 Plant and Grain P in Fall 2021 under different P fertilizer application

	Plant				Grain			Yield
	Biomass	P (%)	P (lbs/acre)	P_2O_5 (lbs/acre)	P (%)	P (lbs/acre)	P_2O_5 (lbs/acre)	(bushel /acre)
Check	9900	0.073	7.3	17	0.294	29	67	208
100MAP	10500	0.071	7.4	17	0.323	32	73	209
200Map	10700	0.113	12.3	28	0.323	32	74	212
Significant	NS	NS	NS	NS	NS	NS	NS	NS

Our data show a slightly increase in grain P concentration when the plots received the highest fertilizer rate than those without fertilizer, while little difference was found in plant P concentration, soil P concentration, and corn yield under different soil test level management.

Table 2 shows the nutrient P concentrations over the life of the plant in 2021. It also has the calculation of the biomass present at V3. None of these differences were significant. The biomass P percentage would have shown a difference at a 0.1 confidence level.

Table 2: Phosphorus Rate Study-Impact of Application Treatments on Tissue Concentrations

Treatment	V3 %P	V3 %N	V7 %P	V7 %N	VT %P	VT %N	Harvest Tissue %P	Harvest Tissue %N	Harvest Grain %P	Harvest Grain %N	Dry Bimass V3 (lb/a)	Biomass At Harvest
Check	0.50	4.89	0.33	3.79	0.28	3.06	0.07	0.634	0.30	1.479	242	9922
P at 100 lbs MAP	0.52	4.84	0.34	3.76	0.28	3.02	0.07	0.593	0.32	1.467	251	10469
P at 200 lbs MAP	0.56	5.05	0.37	3.62	0.31	3.09	0.11	0.650	0.32	1.492	245	10719

The fertilizer treatments were applied again in the fall of 2021 and the same 0, 100, and 200 lbs of MAP/acre rates. This field will be in second year corn next year.

Objective 2: Impact of phosphorus placement on P use efficiency, P uptake and yield

The side-band and broadcast treatments were made as planned. There were some equipment difficulties experienced during the pop-up treatment seeding operations. Attempts were made to not sample in areas where problems occurred. This experiment is being repeated in 2022.

Table 3 Plant and Grain P in Fall 2021 under different P fertilizer placement scenarios

	Plant				Grain			Yield
	Biomass	P (%)	P (lbs/acre)	P_2O_5 (lbs/acre)	P (%)	P (lbs/acre)	P_2O_5 (lbs/acre)	(bushel /acre)
Side-band	9525	0.064	6	14	0.281	29	67	**220**
Broadcast	9377	0.073	7	16	0.272	28	65	**221**
Pop-up	9248	0.081	7	17	0.271	25	58	197
Significant	NS	NS	NS	NS	NS	NS	NS	0.001

The highly significant response associated with the pop-up fertilizer is a bit surprising. It may be due to the mechanical problems so it should be viewed with caution. The seeding time nitrogen fertilizer application was placed in the side-band on all treatments. The side-band nitrogen applications have consistently been an advantage in our past studies as compared to broadcast treatments.

Table 4: Placement Study P Content in Plant Tissue %

Treatment	V3 P%	V3 %N	V7 %P	V7 %N	VT %P	VT %P	Harvest %P	Harvest %N	Harvest Grain %P	Harvest Grain %N	Dry Biomass V3 (lbs/a)	Dry Biomass at Harvest (lbs/a)
Surface	0.49	4.75	0.32	3.14	0.25	2.90	0.07	0.566	0.28	1.37	248	9387
Banded	0.52	5.00	0.33	3.19	0.28	3.02	0.06	0.486	0.28	1.32	266	9535
Pop-up	0.47	4.91	0.35	3.41	0.27	2.97	0.08	0.529	0.27	1.33	263	9258

There was not a trend for higher concentrations of phosphorus in the plants on any of the treatments. The V3 content of phosphorus was slightly lower with the pop-up program than the other treatments. I am not sure that can be explained either. This experiment will be repeated in 2022 with better equipment to monitor the pop-up application.

Objective 3: Soil P and P from water runoff and sediment

A version of the NRCS rainfall simulator was constructed at Dakota Lakes research farm to conduct rainfall simulation. The rainfall simulator was used to quantify potential P transport in water and sediment as impacted by soil test P levels and placement differences. Due to the ability of the soil to infiltrate intense rainfall and irrigation events the water was applied at the equivalent of 20 inches of water per hour. This high rate of application was necessary to ensure runoff would occur. During the runoff trials the machine was operated until 4 inches of total water was applied. A metal frame was placed into the soil to contain all runoff. This was directed toward a tube that emptied into a large beaker The time used to do this averaged approximately 9 minutes. Water samples collected from the runoff produced by the rainfall simulation were submitted to Ward Labs for analysis of ortho P and the total P. Nitrates and Sulfate content was also measured. Calculations to determine how much phosphorus was lost due to runoff indicate that for all treatments in both fields the loss of ortho P and total P were both less than 0.1 lbs/acre. This is the lower limit of what can be considered accurate.

Soil solution was extracted from the soil using soil solution access tubes under vacuum. These tubes are placed approximately 20 inches below the infiltration instrument. The water samples collected from the soil solution were analyzed for ortho P, total P, Nitrate, and Sulfate. These concentrations along with the average volume extracted are list in the table below.

Rate Study Soil Solution Access Tube Data

	Volume ml	Nitrate -N ppm	Sulfate -S ppm	Ortho P ppm	Total P ppm
Check	95	8.2	138	0.02	0.07
100 MAP	110	13.8	168	0.01	0.05
200 MAP	85	18.2	165	0.01	0.07

Placement Study Soil Solution Access Tube Data

	Volume ml	Nitrate-N ppm	Sulfate-S ppm	Ortho P ppm	Total P ppm
Pop-up	73	7.2	133	0.02	0.11
Surface	63	9.6	152	0.01	0.20
Banded	98	10.1	132	0.02	0.13

The nutrients in the soil solutions are those associated with soil water. These nutrients should not move to aquatic ecosystems if the water does not move from the soils. In many environments this would be a rare occurrence. If drain tile is present the movement would be more likely. Sulfate-S is in highest concentrations. Nitrate-N is also common. These measurements were taken not long after N and S had been applied to the crop. It is not likely that the P will move from this field unless drain tile are present.

Objective 4: Mycorrhizal activity and crop P use efficiency

Soil samples for determination of AMF populations have been collected and delivered to be used by Dr. Lehman to conduct greenhouse/laboratory studies to determine most probable numbers. These samples have also been sent for analysis for Phospholipid Fatty Acid. The samples have to be collected when plants are actively growing. Results have been prepared for the past two years and have now been read by Dr. Lehman. Samples from 2018 indicated the most probable number was over twice as high where no MAP was applied in 2014 or 2017 as compared to the treatments where 100 and 200 lbs of MAP. In 2019 the check averaged around 7 VAM propagules/g, while the fertilizer treatments averaged between 3 and 4. The 2020 check samples were between 4 and 5 AMF propagules/g while the fertilized area samples were less than one. The 2021 soil samples are still in progress. The samples sent for genetic analysis were not delivered to the correct place because the company moved. They will be resent this spring to the new address. This service does not measure quantity at this time but does measure organisms present.

Objective 5: Economics

Efficient use of P in crop production is important for economic and environmental reasons. Obtaining comparable yields with less total nutrient applied is beneficial to the economics of the operation. There was not a response again this year. Yields were appreciably over 200 bu/a across the three rate treatments and were not statistically significant. The economic difference between applying 600 lbs of MAP/acre and not using it will be significant. Another addition of fertilizer will be present in 2022. There seemed to be a trend toward higher plant nutrient concentration at the higher rate.

Changes in Project or Personnel

Brennan Lewis was the primary individual on this project in the summer of 2020 through all of 2021.

Products (publications, presentations, disclosures/patents)

This study was a featured stop on the June 25, 2020 DLRF Virtual Field Day videos online. The rainfall simulator used for the runoff experiment was also featured June 24, 2021 during the DLRF Field Day. Data from this study has been presented in at least 10 meetings this year. It is a popular topic.

Budget

The remaining budget will be expended prior to the 6/30/2022 end date. It is being used to support Brennan Lewis' GRA stipend and tuition remission.

Title: The impact of phosphorus soil test level differences on crop response, phosphorus leaching, and phosphorus runoff under long-term no-till management in South Dakota

Co-PI(s): Sam Ireland, Manager, Dakota Lakes Research Farm (South Dakota State University) e-mail (sam.ireland@sdstate.edu) 605-224-6114.

Dr. Jason Clark, Assistant Professor & Extension Soil Fertility Specialist, South Dakota State University

Dr. Michael Lehman, Microbiologist, Agriculture Research Service (ARS)

Brennan Lewis, GRA AHPS-SDSU email (brennan.lewis@sdstate.edu)

Clarence Winter, GRA AHPS-SDSU email (clarence.winter@sdstate.edu)

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3. Quantifying P movement differences associated with soil test level and fertilization practices.
4. Document the relationship between arbuscular mycorrhizal (AMF) fungi activity.
5. Perform cost/return analysis related to these factors.

Work Plan:

The project was conducted at the Dakota Lakes Research Farm (18 miles southeast of Pierre, SD) on two irrigated fields in a no-till, Soybean-Wheat-Soybean-Corn-Corn 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, 100, and 200 lbs of MAP (mono-ammonium phosphate)/acre (equivalent to 0, 52, and 104 lbs P205 and/or 0, 23, and 46 lbs P/acre) using a JD 750 drill to place the material on soils where the Olsen P soil levels had been lowered to approximately 5 ppm. The experiment was in a randomized complete block design with 5 replications. Dimensions for each plot at the site were 20 ft by 450 ft. A crop of soybeans and two crops of corn were grown on 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, 100, and 200 lbs of MAP/acre to the same replicated strips that were treated in 2014. A no-till drill was used to place the nutrient 1.5 inches deep in 7.5-inch rows. Total additions on top of a maintenance side-band application were 0, 400, and 800 lbs of MAP (0, 92, and 184 lbs of P/acre) on this part of the experiment.

In the soil test field corn was seeded using a row-crop seeder with 20-inch spacing. Fertilizer (MAP 90% and KCl 10%) at 63 lbs/acre was applied at seeding in a side-band 3 inches to the side of the seed row and at seed depth. The placement portion of the study takes place in a separate field with similarly low P soil test values and in the same rotation as the soil test portion. The fertilizer (MAP 90% and KCl 10%) for the placement study was also applied at 63 lbs/a, in the banded treatment the fertilizer was applied 3 inches to the side of the seed, the surface applied treatment fertilizer was broadcast across the soil surface at planting, and in the pop-up treatment the fertilizer (10-34-0 liquid fertilizer) was placed in the seed trench (above the seed and below the surface) at a rate of 7.3 gallons per acre. The 7.3 gallons per acre of the 10-34-0 has the equivalent amount of phosphorus as the 63 lbs of MAP +,KCl blend. Urea Ammonium Nitrate (UAN) + Ammonium Thiosulfate (ATS) was side banded in all areas at a rate producing an application rate of 45 lbs of N/acre.

Plant samples were collected at V3, V7, and VT, and at maturity. The V3 samples were weighed to determine early season total uptake of nutrients. The whole plant samples at maturity were collected by harvesting the corn ears and the stalks separately. The 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 tests do indicate that soil test P values have increased in the treatment that have received an additional 400 and 800 lbs of MAP/acre since 2014 (100 and 200 lbs of MAP/acre applied a total of four times). The amount of this difference is small when using the standard 6-inch sampling depth (See Chart A). Taking samples soon after applications or at shallower depths (3-inch) accentuates differences. Soil test P values on Chart A are an example were higher than expected Olsen-P values occurred in the spring after a fall application. The soil test P in the fall returned to historic levels.

Results and Impacts

The results are contained in a separate table for each part of the experiment. The following table outlines the status of the work completed.

Table of Activities: Dakota Lakes NREC Phosphorus calibration study 2022

Activity	Collected	Submitted	Results	Statistics
Soil Samples	x	x	x	x
V-3 Plants	x	x	x	x
V-7 Leaves	x	x	x	x
R-1 Leaves	x	x	x	x
Machine Harv	x	x	x	x
Hand Harv Grain	x	x	x	x
Hand Harv Plant	x	x	x	x
Soil Sample	x	x	x	x
Rainfall/Runoff	x	x	x	x

Objective 1: Phosphorus application history impact on yield and nutrient uptake

Chart A: Olsen-P Soil -Test P Levels for 6-inch dept at Different Times on the Application History Portion of the Study.

		0-6" Olsen P (ppm)	
	May 5 2018	May 10, 2022	November 2, 2022
Treatment	Start of Study	Fall Fertilizer	After Harvest
Check	5.8	12	4.6
100 MAP	6.1	20	6.9
200 MAP	5.8	24	9.8

Chart A presents some interesting contrasts. The first column shows the initial soil tests values from 2018. In the course of this experiment a total of 400 and 800 lbs of MAP/a have been added to the two treatments. Spring (May) soil samples indicate a significant difference in the 0-6 inch samples and produced higher than expected numbers. This is probably due to the fact there had been little activity since the fall fertilizer application. This was more accentuated at a 0-3" inch depth with the Check treatment (15.6 ppm) being lower than the 100 lbs of MAP/acre (31.5 ppm) and 200 lbs of MAP/acre (39.8 ppm). These data reinforce the need for the RIGHT TIME in fertilizer application. Even when the P was placed in the soil, high solubility remained through spring. Surface applications would have been prone to runoff losses. The soil test in the fall indicated a more normal pattern.

Corn grain yields were determined using a standard combine. There was some livestock damage on the ends of the field. The rows were trimmed with the combine to produce a uniform length of undamaged material. This was harvested with the combine, samples were collected for analysis and the grain weighed in a grain cart. The results are in Table 1.

Table 1. Corn yield in Fall 2022 under different P fertilizer application histories

Treatment	Grain Yield (bu./ac)
Check	196
100 MAP	202
200 MAP	203
P Value	NS 0.33

Table 1 shows the grain yield, measured in bushels per acre, gathered from machine harvest (combine). Despite a slight increase in grain yield for the 100 MAP and 200 MAP treatments as compared to the Check, the values were not significantly different at a 95% confidence interval. A numeric difference was present indicating that the 100 MAP and 200 MAP treatments yielded slightly higher (6-7 bu/ac) than the check.

Whole plant samples were collected at V3 and maturity. Leaf samples were also collected at V7 and at tasseling (VT). All biomass samples were analyzed for nutrient content. The V3 and maturity samples were dried and weighed to allow biomass and total nutrient uptake calculations.

Table 2. Corn tissue nutrient concentration under different P fertilizer application histories

	V3		V7		VT	
Treatment	% P	% N	% P	% N	% P	% N
Check	0.47	5.2	0.42	3.7	0.40	3.1
100 MAP	0.52	5.2	0.48	3.7	0.49	3.2
200 MAP	0.54	5.2	0.49	3.4	0.52	3.2
P value	<0.001	0.99 NS	0.11 NS	0.47 NS	<0.001	0.06 NS

Table 2 contains tissue nutrient concentration of phosphorus (% P) and nitrogen (% N) at the V3, V7, and VT corn stages. The % P concentration was significantly different amongst the treatments at V3 and VT stages. The trend at the V3 stage has been documented in previous years of this study. A plant's specific uptake of phosphorus is highest at the early growth stages. Limiting the available phosphorus should be apparent at these early growth stages. If a difference in plant phosphorus content is going to be observed, it is most likely that this will be observed early in the plant's growth. The difference at tasseling (VT) was more surprising. Amongst all treatments, each growth stage had sufficient concentration according to Ward Laboratories Plant Tissue Testing Guide.

Table 3 contains nutrient concentration and uptake information at growth stage V3. Uptake is determined by multiplying nutrient content by whole plant above ground biomass. Even though the lowest P soil test level produced lower P content at V3 the total uptake of P at this stage was not different from the other treatments. This has occurred in several previous years as well.

Table 3. Phosphorus and Nitrogen Uptake from whole plant sampling at V3 under different P fertilization histories

	Stage V3 Nutrient Content			Stage V3 Uptake (lbs/acre)	
Treatment	P %	N %	Total Biomass lbs/a	P lbs/acre	N lbs/acre
Check	0.47	5.2	47	0.22	2.4
100 MAP	0.52	5.2	39	0.20	2.0
200 MAP	0.54	5.2	48	0.26	2.5
P value	<0.001	0.1 NS	0.3 NS	0.16 NS	0.002

Table 4. Phosphorus Uptake from whole plant sampling at R6 (maturity) under different P fertilization histories. Grain and Stover weights are at 0% moisture. The Stover weight is Stover plus Cobs

	Stage R6 Nutrient Content				Stage R6 Uptake (lbs/acre)		
Treatment	Stover P %	Grain P %	Stover lbs/a	Grain lbs/a	Stover P Uptake	Grain P Uptake	P Uptake in lbs/a
Check	0.06	0.31	9300	9330	6	28	34
100 MAP	0.09	0.34	9940	9620	9	33	42
200 MAP	0.11	0.38	10008	9660	11	38	49
P value	<0.001	0.001	0.3 NS	0.3 NS	<0.0001	0.002	<0.001

Table 4 presents tissue phosphorus concentrations for the stover (plus the cob) and grain at maturity. There were significant differences in nutrient concentrations but not in the yield of either the stover or grain. Total nutrient removal for harvesting only the grain is the majority of the nutrient removal that would occur. If the stover was also harvested removal would increase about 20%. All residues have been maintained on the study area.

Objective 2: Impact of phosphorus placement on yield and nutrient uptake

This section deals specifically with the placement of phosphorus products at seeding. Broadcast would be spreading on the surface. Banded is placing the phosphorus in the side-band with the N and S products. This is located 3 inches to the side of the seed row and at seed depth. The Pop-up treatment is placed in the seed trench but above the seed. This is above the seed because placement takes place behind the seed pressing wheel but before closing wheels.

Table 5. Corn yield in 2022 under different P fertilizer placement treatments

Treatment	Grain Yield (bu./ac)
Pop-up	187
Broadcast	191
Banded	194
P Value	0.26 NS

Table 5 contains 2022 machine harvested corn yield in the phosphorus placement portion of the study. No statistical difference was observed amongst the placement methods. This is not surprising for row crops. Placing the N and S products in the side band has proven very beneficial but response to P placement has not been as consistent with row crops.

Table 6. Corn tissue nutrient concentration under different P placement methods

	V3		V7		VT	
Treatment	% P	% N	% P	% N	% P	% N
Pop-up	0.47	4.9	0.42	4.0	0.36	3.3
Broadcast	0.44	5.1	0.43	4.1	0.37	3.3
Banded	0.44	5.0	0.42	4.0	0.43	3.5
P value	0.31 NS	0.39 NS	0.96 NS	0.40 NS	0.32 NS	0.06 NS

Table 6. contains 2022 corn tissue nutrient concentrations for three plant growth stages of the corn crop (V3, V7, VT). These data show no significant differences to phosphorus placement methods. All of these treatments were on soils testing very low in P. Broadcast applications would not be recommended due to environmental concerns.

Objective 3: Nitrate-N and Phosphorus Losses During Rainfall Simulation

Table 7. Water quality collected from runoff caused by rainfall simulator under different P fertilizer application histories

Treatment	Nitrate N (ppm)	Ortho-P (ppm)	Total P (ppm)
Check	2.1	0.27	0.33
100 MAP	1.4	0.50	0.56
200 MAP	5.3	0.44	0.52
P value	0.52 NS	0.06 NS	0.09 NS

Table 7 contains the water quality data collected from runoff water during the rainfall simulator experiment. None of these data are significantly different from one another, however the Ortho-P and Total P are numerically lower in the Check treatments. This suggests that maintaining a lower soil test P level may reduce the amount of Ortho-P and Total P lost in runoff. All of the values are very low.

Table 8. Total Nutrient load (loss) collected from runoff caused by simulated intense rainfall for different P fertilization histories

Treatment	Nitrate-N Load (lbs/ac)	Ortho-P Load (lbs/ac)	Total P (lbs/ac)
Check	0.086	0.009	0.012
100 MAP	0.039	0.012	0.014
200 MAP	0.064	0.018	0.020
P-value	0.68 NS	0.50 NS	0.57 NS

Table 8 contains nutrient load information collected from runoff using the rainfall simulator. The nutrient load was calculated by multiplying the concentration of nitrate-N, ortho-P, and total P by the runoff totals and converting to lbs/ac. There was no statistical differences between nutrient load in nitrate-N, ortho-P, or total P. These are incredibly low numbers and probably below accurate detection level. They should be reported as LESS THAN 0.1 lbs/acre. The high soil test category (200 MAP) did show numerically higher Ortho-P and Total-P values.

Table 9. Water quality collected from runoff caused by rainfall simulator under different P fertilizer placement options

Treatment	Nitrate-N (ppm)	Ortho-P (ppm)	Total P (ppm)
Pop-up	0.4	0.21	0.29
Broadcast	0.4	0.16	0.19
Banded	0.5	0.18	0.24
P value	0.77 NS	0.75 NS	0.44 NS

Data in table 9 does not contain statistical differences. This would be unexpected if the rainfall simulation was the first event after application in tilled systems where surface applications increase P movement. Rainfall had occurred between application and this test. In no-till systems runoff enters the soil by macropores limiting movement as runoff. It is expected that the fertilizer placed by surface broadcasting is more likely to be lost in runoff. Since runoff was also very low under simulated rainfall the total nutrient loss is very low (less than 0.1 lbs/acre).

Table 10. Water quality collected from soil solution access tubes under different P fertilizer application histories

Treatment	Nitrate-N (ppm)	Ortho-P (ppm)	Total P (ppm)
Check	1.1	0.04	0.46
100 MAP	1.4	0.23	0.35
200 MAP	2.6	0.03	0.53
P value	0.54 NS	0.38 NS	0.37 NS

Table 10 contains water quality data collected from the soil solution access tubes under different P fertilizer application histories. No significant differences were found. Values are very low.

Table 11. Water quality collected from soil solution access tubes after a simulated rainfall event as impacted by P fertilizer placement

Treatment	Nitrate-N (ppm)	Ortho-P (ppm)	Total P (ppm)
Pop-up	0.7	0.02	0.37
Broadcast	0.6	0.07	0.05
Banded	1.9	0.05	0.36
P value	0.11 NS	0.52 NS	0.49 NS

Table 11 contains water quality data collected from the soil solution access tubes under different phosphorus placement strategies. No significant differences were identified.

Objective 4: Mycorrhizal activity and crop P use efficiency

Phosphorus fertilization is much more complex than what is experienced with many of the other nutrient elements. Much of this stems from the fact that a large majority of the phosphorus exists in low-solubility minerals in the soil. Some is in organic compounds. Very little exists in soluble (available) forms that can readily taken up by plant roots. The highly soluble phosphorus contained in inorganic fertilizers can be converted to low-solubility minerals in the soil in a relatively short period of time. Attaining adequate P nutrition requires that there is soil moisture, available nutrient, and active roots at the same place in the soil. Most fertility programs seek to increase the available nutrient through fertilizer additions. Other programs use fertilizer placement schemes to increase the probability that the root will contact fertilizer. This project investigates both approaches, but it is also trying to determine if factors such as the presence of VAM (vesicular arbuscular mycorrhizal fungi) or other biological components can improve the plant’s ability to obtain adequate nutrition in locations where phosphorus solubility is low. Many of the tests that were performed this year are designed to provide some insight into this part of the system. The Most Probable Number analysis to determine VAM populations has been performed by Dr. Lehman over the life of this study. This has consistently demonstrated that much higher number occur in the treatments that have received only minimal additions of phosphorus. Unfortunately, this procedure is not suitable for routine use. One or more of the tests that are being evaluated will hopefully allow a producer to know if it is possible for them to attain yields while also maintaining the soil at lower levels of soluble P (lower soil test levels). Not all of these results have been attained at this time.

Table 12. Most probable number of arbuscular mycorrhizal fungi/ gram of soil

Treatment	2018	2019	2020	2021	4-year Average
Check	7.2	3.8	4.4	5.2	5.2
100 MAP	3.5	0.5	0.6	1.0	1.4
200 MAP	3.3	1.4	2.0	1.0	1.8

Table 12 contains consolidated averages of the most probable number of arbuscular mycorrhizal fungi per gram of soil. These data suggest that the presence of AMF is encouraged by maintaining low solubility phosphorus levels in the soils. The differences are dramatic, highly significant, and not surprising.

Dr. Mike Lehman has performed the analysis to obtain these data. It takes over 6 months to conduct this analysis, therefore the results from 2022 will not be available until next year.

Table 13. 2022 PLFA soil samples under different P fertilizer application histories

Treatment	Total Fungi %	Total Fungi Biomass (ng/g)	Arbuscular Mycorrhizal %	Arbuscular Mycorrhizal Biomass (ng/g)
Check	9.4	155	3.3	55
100 MAP	8.1	137	2.8	48
200 MAP	9.7	192	3.5	68
P-value	0.16	0.22	0.16	0.19

Table 13 contains a portion of the PLFA (phospho-lipid fatty acid) analysis with focus on soil fungi. No significant differences were detected using this chemical analysis scheme. This is contrary to the data obtained in the most probable number analysis for VAM. Over several years there has been no consistent correlation between MPN and the PLFA test. These warrants investigating other biological testing protocols in an attempt to identify when there is adequate biological activity in the soil to allow using different critical P levels for the fertilizer program.

Objective 5: Economics

It is evident that additional MAP fertilizer (on top of the starter fertilizer application) is not contributing to yield increases. With ever increasing fertilizer prices, a yield response is needed to justify the fertilizer programs. Cutting costs on inputs is one way a farmer can improve his bottom line. Without considering external costs to the environment (water quality impacts), phosphorus fertilizer placement techniques have minor impact on economics to a no-till farmer on corn and soybeans. Tillage based systems are more likely to see response to P placement. Economic response to N fertilizer placement is much more beneficial to a no-till farmer.

Changes in Project or Personnel

Dwayne Beck retired as the manager at Dakota Lakes Research Farm in January of this year. Sam Ireland became the new manager at that same time. Sam Ireland replaced Dwayne Beck as a CO-PI on this project. Brennan Lewis finished his term as a graduate research assistant (GRA) in June and graduated. Clarence Winter started as a GRA in August.

Products (publications, presentations, disclosures/patents)

The impact of phosphorus fertilization history (different applications of MAP) to AMF is in the process of being published in a scientific journal. Dr. Michael Lehman and Dr. Sutie Xu are the lead authors on this publication. The study was discussed in depth at the Dakota Lakes Research Farm annual field day. Graduate Research Assistant, Clarence Winter (MS student at SDSU), presented findings at the North Central Fertility Conference in Des Moines, IA. Dr. Dwayne Beck (previous manager at Dakota Lakes Research Farm) presented aspects of this study at a conference called Groundswell in the United Kingdom. The talk was recorded and has over 11,000 views. The link to this talk can be found below.
https://www.youtube.com/watch?v=d61oEzVx3k0

It is likely that the results generated by this 5 year study will be compiled into a journal article published by the lead authors. Further research on identifying ways to test for biological activity will most likely continue. Work on P calibration on farmer fields is underway.

Budget

The remaining budget will be expended prior to the 6/30/2023 end date. It is being used to support Clarence Winter's GRA stipend and tuition remission. Grain content and post-harvest soil samples will be sent off for analysis before the 2022 calendar year's end.

An additional analysis will be conducted on crop residue and fall soil samples. This analysis will test for the presence of ergothioneine. This compound is an amino acid that is produced by mycorrhizal fungi. Current methods for accurately determining the mycorrhizal fungi (AMF) activity in soils are very time consuming. It is hopeful that this analysis will prove useful in predicting the functionality of AMF in soils.