53rd Annual

NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

15-16 November
2023

PROCEEDINGS

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ORAL PROCEEDINGS

OVERVIEW OF BIOSTIMULANT CLASSIFICATION AND INDUSTRY PERSPECTIVE

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There are many, but what is the definition of biostimulant? How are these products categorized? We will start off with definitions of commonly used terms around biostimulant products used in agriculture. The current categories in which biostimulant products fit, or do not fit into, are continually evolving as industry and regulatory work towards fine-toning definitions. As more products become commercially available, producers need to be aware of their advantages, as well as challenges, to maximize their effectiveness.

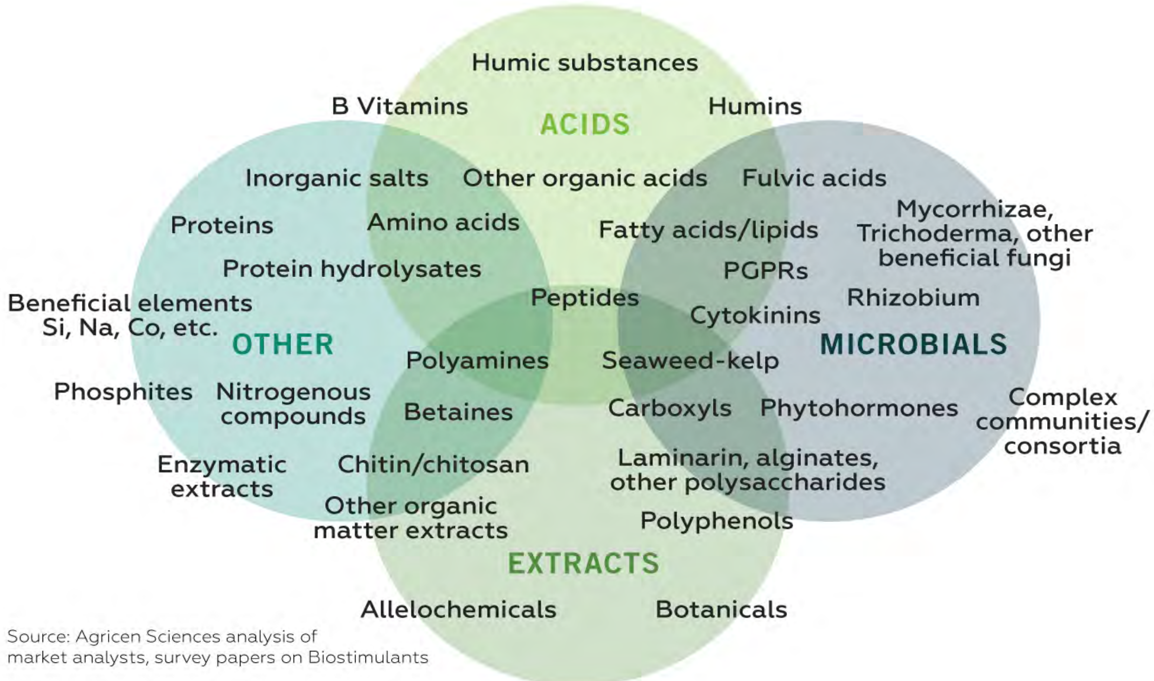
In 2018, the biostimulant market was valued at $2.19 billion and at that time, the projected growth rate into 2024 was expected to be 12.5% (Albrecht, 2019). However, in 2022 the market was valued at 2.6 billion, with an anticipated compound annual growth rate of 7.4% from 2023 to 2030. Market value increase is attributed to adoption of seaweed extracts, microbials, and acids.

What are biostimulants?

The overall classification of these products are biologicals. From there, biologicals can be broken into two major categories: biostimulants and biopesticides. Biopesticides are products that protect against or directly control fungal and bacterial pathogens, insects, or weeds. Biopesticides are heavily regulated by the Environmental Protection Agency (EPA). In general, biostimulants are substances that enhance plant growth, health, and productivity or provide direct/indirect benefits to a plant's development and are not regulated by EPA.

In 2018, the farm bill included some of the first definitions of biostimulants as "a substance or microorganism that, when applied to seeds, plants, or the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield." Since then, the definition has been modified to "plant biostimulant means a product stimulating plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following characteristics of the plant: (a) nutrient use efficiency, (b) tolerance to abiotic stress; and (c) crop quality traits."

However, biostimulants can have any of the following affects on the plant; the water use efficiency, root structure and growth, nutrient use efficiency, reduce stress tolerance, induced systemic resistance, and disease tolerance. The most popular ingredients include humic substances (humic and fulvic acids), seaweed extracts, beneficial bacteria, and beneficial fungi. Other ingredients can include chitosans, protein hydrolysates, and inorganic compounds such as silicon. Of the different forms of biostimulants, acid-based materials account for the largest in the market, followed by seaweed (Albrecht, 2019).



Source: Agricen Sciences analysis of market analysts, survey papers on Biostimulants

The possibilities of these types of products are endless. Many new products contain various combinations of different biostimulant substances. Producers should pay close attention to the active ingredients in products is needed to ensure the maximum effectiveness in production systems.

SUMMARY OF REGIONAL STUDIES IN CORN ON SELECTED COMMERCIAL ASYMBIOTIC N-FIXING ORGANISMS AND SUGGESTIONS FOR COMPANIES DEVELOPING SIMILAR PRODUCTS

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ABSTRACT

This is a summary of N rate studies from the North Central region which include treatments with selected commercial asymbiotic N-fixation organism products. Farmers are encouraged to remain curious of new products, but also skeptical; testing the products of interest through replicated strip trials their farms to determine whether the products have value to their operation. In conversations over the past several months with companies interested in developing asymbiotic N-fixation products, the following are frequent topics of concern:

- The organisms need to be kept alive through transportation and storage intervals between manufacturer, shipper, warehouses, distributor, dealer, and finally on farm storage before use.
- There should be a method of analysis developed to determine whether the organism is alive and functioning in the soil/plant after application.
- The organism should be able to ‘win a war’ with native microorganisms in order to survive and perform its function.
- The organism should be adapted to variable moisture, soil pH and soil salts in order to perform its function.

INTRODUCTION

The source of N for crops in this region is N from mineralized organic matter and residue decomposition, release of N from ‘fixed’ non-exchangeable ammonium in the interlattices of smectitic clay minerals, fertilizer N, N from atmospheric deposition and N released from the activities of N-fixing organisms. Most agronomists are aware of the contribution of symbiotic N-fixing bacteria to soybean and other legumes. However, it is common for agronomists to be unaware, or at least dismissive of the N contribution of asymbiotic, or non-symbiotic, free-living N fixing organisms. A more detailed description of the activities of these organisms is provided in Franzen et al., 2022 https://www.ndsu.edu/agriculture/extension/publications/performance-selected-commercially-available-asymbiotic-n-fixing-products ; however, the following is an abridged version.

Asymbiotic N-fixing organisms, primarily accepted to be bacteria at present, are active in most soils. It is one reason among others why when a fertilizer applicator ‘skips’ an area in an intended corn field, the yield is not zero. The limitation to their activity is food and housing. In a conventionally-tilled field (fall chiseled, once or more, and one to two field prep trips in the spring with a field cultivator or other finishing tool) the housing for the bacteria is serious disrupted and even destroyed several times a year. Some bacteria survive, but many die. Also, in a conventionally-tilled soil, residue is exposed to oxygen resulting in a fast decomposition by a limited number of organisms. The resulting decomposed material is a less desirable food source compared to leaving residue alone in a more anaerobic environment.

In a long-term, continuous no-till field, the tiny nooks where bacteria produce a microenvironment hosts many organisms, including evidence shows asymbiotic N-fixing organisms. The food in a long-term no-till soil is much more diverse and therefore supports a greater array of organisms at a higher biomass compared to a frequently tilled system. A paired-sample study in North Dakota, with one sample at each paired location from a long-term no-till soil, compared to a sample directly across the fence or road in a similar soil series showed that asymbiotic N-fixing organism activity was much higher in long-term no-till soil compared to the conventionally-tilled relative (Franzen et al., 2019). The higher activity of the asymbiotic N-fixing organisms may contribute up to about one-third of the long-term no-till N credit provided in the N calculators for corn, spring wheat/durum, sunflower and 2-row malting barley in North Dakota (https://www.ndsu.edu/pubweb/soils/N_calculators/).

Asymbiotic N-fixing organisms are very sensitive to the soil environment. They function best when the soil is warm and moist. Dry soils support very low active and activity in saturated soils was near zero in a recent study (Franzen et al., 2023). Activity is low during spring thaw in North Dakota, and increases as the soil warms. Activity thereafter is a function of soil moisture.

THE COMPILATION DOCUMENT OF NCERA-103 RESEARCHER EXPERIMENTS THROUGH 2022

In November, 2021, the Agricultural Experiment Station North Central Committee on Specialized Soil Amendments and Products, Growth Stimulants, and Soil Fertility Management Programs met after the North Central Extension-Industry Soil Fertility Conference in Des Moines, as it has met for decades. The discussion was largely centered on the new asymbiotic N-fixing products on the market and the intention of most around the room to conduct some work with them in 2022. A few researchers already had a little experience with one of more of the products. It was resolved for each researcher to contribute their methods/results at the 2022 committee meeting and compile the results in a single document. There was general hope around the room that the products would have value, enabling reduction of farmer-applied N rates, which despite the efforts of many researchers and extension soil fertility people in the region tend to be greater than published recommendation in print or in N calculators.

In November 2022, the committee met again, and results and experimental details were provided before mid-December 2022 by all members of the committee. The document was prepared sent out to the committee for edits and the final version was published April 2023. NDSU Extension Circular SF2080. Performance of Selected Commercially Available Asymbiotic N-fixing Products. D. Franzen, J. Camberato, E. Nafziger, D. Kaiser, K. Nelson, G. Singh, D. Ruiz-Diaz, E. Lentz, K. Steinke, J. Grove,

E. Ritchey, L. Bortolon, C. Rosen, B. Maharjan, and L. Thompson https://www.ndsu.edu/agriculture/extension/publications/performance-selected-commercially-available-asymbiotic-n-fixing-products . The authors represented all of the North Central States with the exception of Iowa and South Dakota. Out of 51 trials of products on corn, using label rates and company instructions, 2 produced a statistical yield advantage over the N rate used alone, while 49 did not provide a yield improvement nor did it provide evidence that N rate might be reduced due to its use.

Summary table of results from corn trials on corn yield with N rate alone vs addition of amendment to N rate.

State	Envita IF	Utrisha	ProveN	ProveN 40 IF	ProveN 40 ST
	Number of site-years of product testing				
ND	4 No	4 No	--------	---------------	----------------
MN	1 No	--------	3 No/ 1 Yes	----------------	-----------------
IL	2 No	--------	4 No	5 No	2 No
IN	1 No	--------	--------------	---------------	---------------
MO	2 No / 1 Yes	3 No	2 No	1 No	---------------
MI	1 No	1 No	-------------	1 No	---------------
KS	---------------	--------	1 No	--------------	---------------
KY	-------------	2 No	--------------	--------------	-------------
NE	-------------	--------	5 No	6 No	--------------
OH	-------------	1 No	----------------	----------------	--------------
Total	8 No / 1 Yes	11 No	15 No / 1 Yes	13 No	2 No

TAKE-HOME MESSAGES FROM THE NCERA-103 EXPERIMENTS

There are two important messages that should come from these results. One is that it is OK that farmers are curious about new products; the NCERA-103 committee members were certainly curious about these N-fixing products or they would have had no interest in examining them. However, farmers should also be skeptical about new products. A better way to learn about new products is to test them on their farms. Note that the Nebraska data in the table as explained in the circular are all farmer replicated test strips. This is the way that farmers should test products or management techniques. Applying a product on thousands of acres based on claims, then thinking the product performed well or not well due to overall yields compared to those in the past is not helpful or informative. Neither is using it on one field compared to another. Each field has a different 'personality' and one field compared to another is likewise not helpful in indicating future performance of a product. Also, splitting a field is not helpful. If I three a rock towards the west half of a field and didn't throw a rock into the other, the half I threw the rock on would yield more than the one without the additional rock about half the time. Not helpful. The only way to truly have confidence on product or management difference performance is through replicated strip trials.

At the 2022 NC Extension-Industry Conference, the paper Thompson et al. (2022), was particularly helpful in guiding farmers onto a path towards better product testing. Using replicated N-rate strips within a field, the field had grower N-rate alone compared to strips of grower N-rate with addition of a product. Figure 1 represents a possible farmer strip-trial with use of biological product against N rate alone.

Figure 1. A possible field arrangement of replicated strips to test biological product against N rate alone.
(From Thompson et al., 2022, reproduced with permission.)

Thought should go into what treatments should be compared. Is it best to compare a farmer-rate of 200 pounds N per acre to 200 pounds N per acre with amendment, when the state recommendations are 160 pounds N per acre? Probably not. A better comparison might be 120 pounds N per acre with amendment compared to the state recommendations. That way if the amendment produced N, the yields of the treatments when compared would justify reduction of N rate when the amendment was used, and still achieve similar yield to a higher rate from the state recommendations.

There are many accessible papers regarding on-farm replications. Kyveryga et al. (2018) recommendations making sure that the field chosen for the experiments will not include areas in which treatments might be confounded special areas of natural or manmade interference. The treatments should be randomized. The paper also includes strategies for blocking and even split-plot designs, all of which can easily be statistically analyzed. At the simplest, replicated strips analyzed with a simple t-test in Excel is a great improvement over something like splitting a field, which is a poor observation at best.

One of the results of publishing the NCERA-103 authored compilation of research trials has been an opening of communication with other startups of N-fixing organisms in the US and in Europe. I have visited in person, on the phone and on web-meetings with representatives and scientists from several industries and I have discussed with them what might be done to improve their chances in the marketplace when they decide the product is ready to sell. The discussions always settled on four points:

- The organisms need to be kept alive through transportation and storage intervals between manufacturer, shipper, warehouses, distributor, dealer, and finally on farm storage before use.

- There should be a method of analysis developed to determine whether the organism is alive and functioning in the soil/plant after application.
- The organism should be able to ‘win a war’ with other native microorganisms in order to survive and perform its function.
- The organism should be adapted to variable moisture, variable soil pH and variable soil salts in order to perform its function.

The asymbiotic N-fixing bacteria are living organisms. Although the firms were convinced that when the product left the point of manufacture, they all were concerned that they might not be viable by the time they reached the point of field application. If the product is produced overseas, what will be the conditions if air-freight instead of by ship. In a cargo-hold of a jet liner, the temperature can be adjusted between about 40 degrees F and 70 degrees F. Some bacteria have narrow temperature storage requirements. One product that was used in the North Dakota experiments recommended 42 degrees F. The flight from overseas can be 6 to 20 hours depending on where it originates, so the bacteria needs to be shipped at a temperature at which survival is assured; similarly, on a ship. Transport in a shipping container is subject to temperatures at the dock, on the ship, then again on the dock for an extended period of time. Will the bacteria survive?

If produced in the USA, shipment is still an issue. Will it be shipped to a distributor on a climate-controlled truck? Once it is dropped off at the distributor, are they equipped with a large fork-lift accessible climate-controlled storeroom? Then a distributor to a retailer, again is the transporting truck climate controlled, or subject to 100-degree temperatures in a hot spring? At the retailer, do they have a climate-controlled storeroom capable of handling the volumes anticipated. Finally, delivery to the farm. Does the farmer have climate-controlled storage capable of holding the bacteria live for 2-3 weeks in case planting is delayed due to rain or breakdowns? The logistics of delivery to the end-user is not a trivial exercise and some manufacturers are now aware of the issues that need to be overcome.

Presently, according to industry people I have visited with, there are no quick assays or analyses available to determine whether the organisms in the container, in the soil or plant are alive and functioning in the manner they need to function to benefit the end-user. These tests need to be developed to support the product and provide confidence to the farmer that the product is performing.

The organism needs to be able to compete with other organisms in the soil. The soil is alive with all kinds of macro- and micro-organisms all ‘thinking’ the same thought- ‘What’s for dinner today?’ If the ‘*Spéciale du jour*’ is the newly applied asymbiotic bacteria, the application was for naught. It is possible that one of the reasons that in controlled experiments newly released Rhizobium for soybean with claims of greatly improved N-fixation seldom result in more than a bushel if that of soybean yield improvement, is the lack of competitiveness of the new release. Regardless, competitiveness of any organism applied to the soil is important for its degree of benefit to the end-user.

Finally, conditions in soils across the North Central Region in terms of soil pH, temperature through the growing season, soil moisture conditions, and presence of soluble salts. Just in North Dakota, soil temperature when seeding spring wheat is often

35 degrees F at the beginning. Soil pH may vary in the same field from the high 4's to over 8. Soil moisture varies all over the region from very dry to very wet at times. Throwing bacterium into such an environment that has specific environmental demands for its performance without the screening successes through the possible extreme conditions would not be a successful venture unless luck was on its side.

CONCLUSIONS

To date, researchers associated with the NCERA-103 Committee of Specialized Soil Amendments and Products, Growth Stimulants, and Soil Fertility Management Programs have found a low frequency of N fertilizer rate replacement from the application of commercial asymbiotic bacterial products to corn. It is possible that future related products might be beneficial if manufacturers consider ways to maintain viability of the organisms from point of production to point of field application, are able to assay organism activity in the field, and screen organisms for their ability to compete with other soil organisms and remain active in a wide range of possible soil environments. Farmers should strive to be curious regarding new products, but also to be skeptical; testing products of interest in replicated trials on their farms.

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ASSESSING SULFUR RESPONSE, UTILIZATION EFFICIENCY, AND DIAGNOSTIC TOOLS FOR CORN IN KANSAS

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ABSTRACT

Efficient sulfur (S) utilization is crucial for crops' productivity and the sustainability of agricultural systems. This study aims to evaluate the effect of sulfur application on corn production across various Kansas sites and determine how sulfur fertilization affects different growth parameters and diagnostic tools for corn. The study was conducted over the 2021-2022 growing seasons across 26 sites in Kansas. Two different sulfur fertilizer treatment rates were applied. Soil samples were collected and analyzed for pH, organic matter, sulfate content, and soil texture. Plant tissue samples were obtained at different growth stages, and diagnostic tools such as NDVI and SPAD measurements were recorded. A strong positive correlation was found between the total sulfur uptake and yield, indicating the critical role of sulfur in determining crop productivity. The SUE analysis revealed that the mean agronomic efficiency across all sites was 22 lb. lb., indicating the yield achieved for each sulfur unit applied. The average recovery efficiency in the year of application was 6%, the proportion of applied sulfur that the crop successfully utilized. The recovery efficiency value was was high as 20% at some locations. This study highlights the importance of sulfur in corn production in Kansas and its direct influence on crop yield. The positive correlation between total sulfur uptake and yield suggests that optimizing sulfur application can increase productivity.

INTRODUCTION

Sulfur, often referred to as the "fourth major nutrient," plays a crucial role in the growth and yield of corn crops. Its efficient utilization is essential to the sustainability of agricultural systems. The significance of sulfur in agriculture cannot be overstated. It is a constituent of essential amino acids, vitamins, and enzymes crucial to plant growth. Like any nutrient, sulfur's efficient utilization is vital to maximize crop yield while minimizing environmental impacts. Effective use of sulfur directly impacts crop productivity and influences the overall sustainability of agricultural systems. Corn cultivation is a vital part of the Kansas agriculture system, and it's essential to understand the relationship between sulfur application and corn production. This study explores the dynamics between sulfur application and corn production across different sites in the state. By studying soil properties and analyzing plant tissue samples using diagnostic tools such as the Normalized Difference Vegetative Index (NDVI) and Soil Plant Analysis Development (SPAD), this research aims to evaluate sulfur response, utilization efficiency, and diagnostic tool application.

MATERIALS AND METHODS

The study was conducted from 2021-2022; field experiments were carried out in 26 sites throughout Kansas (Table 1). Two different rates were used for the fertilizer treatments - one with sulfur fertilizer (40 lb. of S ac^{-1}) and one without (lb. of S ac^{-1}). Ammonium sulfate (21-0-0-24S) was used as a sulfur fertilizer source. Additionally, a uniform application of phosphorus fertilizer was applied at a rate of 90 lb. of P_2O_5 ac^{-1} using mono-ammonium phosphate (11-52-0). Nitrogen was balanced using urea (46-0-0). All the fertilizer was applied once by broadcast pre-plant. Soil samples were collected by block at 0-6 in depth and 0-24 in depth. Soil samples were analyzed for pH 1:1 (soil:water) (Peters, Nathan, and Laboski 2012), organic matter by loss on ignition (Combs and Nathan 1998), sulfate by the monocalcium phosphate extraction (Franzen 2015) and soil texture (particle size distribution) using a hydrometer. In early season, tissue samples were taken from whole plants in the V6 growth stage (V5-V7). At the same time NDVI using a RapidSCAN CS-45 handheld crop sensor. In the middle season, tissue sampling was done on the ear leaf in the R1 growth stage (range between VT-R2). Additionally, SPAD was also collected using the handheld chlorophyll meter SPAD-502. During the late season, a whole plant at the R6 stage was sampled. The tissue samples were dried and ground. The concentration of sulfur was determined using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The uptake was calculated based on the concentration of sulfur and biomass. The two center rows were harvested to determine grain yield, and grain yield was calculated and adjusted to 15.5% moisture. Sulfur use efficiency (SUE) components were calculated using the agronomic use efficiency (AE) and apparent sulfur recovery efficiency (RE) described by (Fixen et al. 2015). All statistical analyses were performed in R version 4.2 using RStudio version 2022.12.0+353.

RESULTS AND DISCUSSIONS

Correlation for Different Parameters

The correlation analysis conducted in this study has revealed valuable insights into the complex relationship between various parameters and their impact on corn production. One of the findings of this study was that there was no significant correlation between NDVI at V6 and corn yield. This indicates that while NDVI can be a useful tool for monitoring plant health and growth, it may not be able to directly predict corn yield. On the other hand, the correlation between SPAD measurements and corn yield was found to be relatively modest with a coefficient of 0.21. Although the correlation is not strong, it suggests that chlorophyll content, as measured by SPAD, can be used to indicate corn yield to some extent. However, it is important to remember many other factors influence that yield, and NDVI and SPAD readings should only be considered as one part of a broader assessment. The most significant correlation within this study was between corn yield and total sulfur uptake, with a strong and positive relationship with a correlation coefficient of 0.85. This finding is of utmost importance as it highlights the crucial role of sulfur in determining crop productivity. The strong correlation between total sulfur uptake and yield confirms that the efficient application and uptake of sulfur in corn plants significantly contributes to higher grain yields.

Sulfur use efficiency

The agronomic efficiency value calculated from the study stands at 22 lb/lb as an average across 25 sites. This means that for every unit of sulfur applied, an average of 22 pounds of corn is produced. The high agronomic efficiency value indicates that sulfur application significantly impacts corn yield in the study sites. The elevated value reflects the crop's ability to convert the applied sulfur into increased grain yield, highlighting the importance of sulfur in agricultural systems. The average apparent recovery efficiency value was found to be 6% on average across all the sites. The recovery efficiency metric quantifies the proportion of the applied sulfur the crop utilized successfully. A recovery efficiency value of 6% indicates that only a small fraction of the sulfur applied was recovered and utilized by the corn plants the year of application. The low recovery efficiency value suggests the need for further investigation into methods for improving sulfur recovery during the year of application. A significant portion of applied sulfur may be taken up by plants during multiple years (cycling/accumulating in the organic fraction). Strategies for enhancing sulfur utilization, such as optimizing application rates and timing, can be explored to maximize the benefits of sulfur fertilization. Additionally, understanding the factors that affect sulfur uptake by corn plants, such as soil pH and organic matter, can aid in devising more effective sulfur management practices. These findings provide practical insights for farmers and agricultural practitioners to refine nutrient management strategies, boost corn yields, and minimize resource wastage.

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Table 1: Soil test information from samples collected before fertilizer application. Sampling depth of 0-15 cm for pH, organic matter (OM), Sand, and Clay; and 0-60 cm for SO_4^{-2}.

Site	**Year**	**County**	**pH**	**OM** %	**SO_4^{-2}** ppm	**Sand** %	**Clay** %
1	2021	Riley	6.2	2.0	2	36	10
2	2021	Shawnee	7.5	1.9	3	46	12
3	2021	Republic	6.0	2.7	4	20	19
4	2021	Republic	6.5	3.3	8	28	15
5	2021	Brown	6.2	3.1	4	18	16
6	2021	Gove	6.6	2.7	4	21	25
7	2021	Gove	7.1	2.5	3	20	21
8	2021	Franklin	5.8	3.4	4	14	24
9	2021	Gove	6.0	3.1	5	21	21
10	2021	Logan	6.4	2.8	4	20	24
11	2021	Dickinson	6.0	3.5	4	22	26
12	2021	Salina	5.3	2.9	5	30	24
13	2022	Jewell	6.8	3.7	3	11	24
14	2022	Jewell	7.1	5.5	3	10	32
15	2022	Jewell	5.2	3.4	3	12	26
16	2022	Shawnee	7.0	2.1	2	46	11
17	2022	Franklin	6.1	3.6	4	12	24
18	2022	Franklin	5.7	3.6	4	11	27
19	2022	Reno	7.4	2.8	14	42	26
20	2022	Reno	6.8	3.2	18	31	28
21	2022	Jefferson	7.2	3.8	4	40	22
22	2022	Republic	6.3	3.5	11	14	20
23	2022	Republic	6.2	3.0	9	14	18
24	2022	Riley	6.4	2.8	4	14	28
25	2022	Smith	6.2	2.9	2	14	34
26	2022	Smith	5.3	3.0	3	8	29

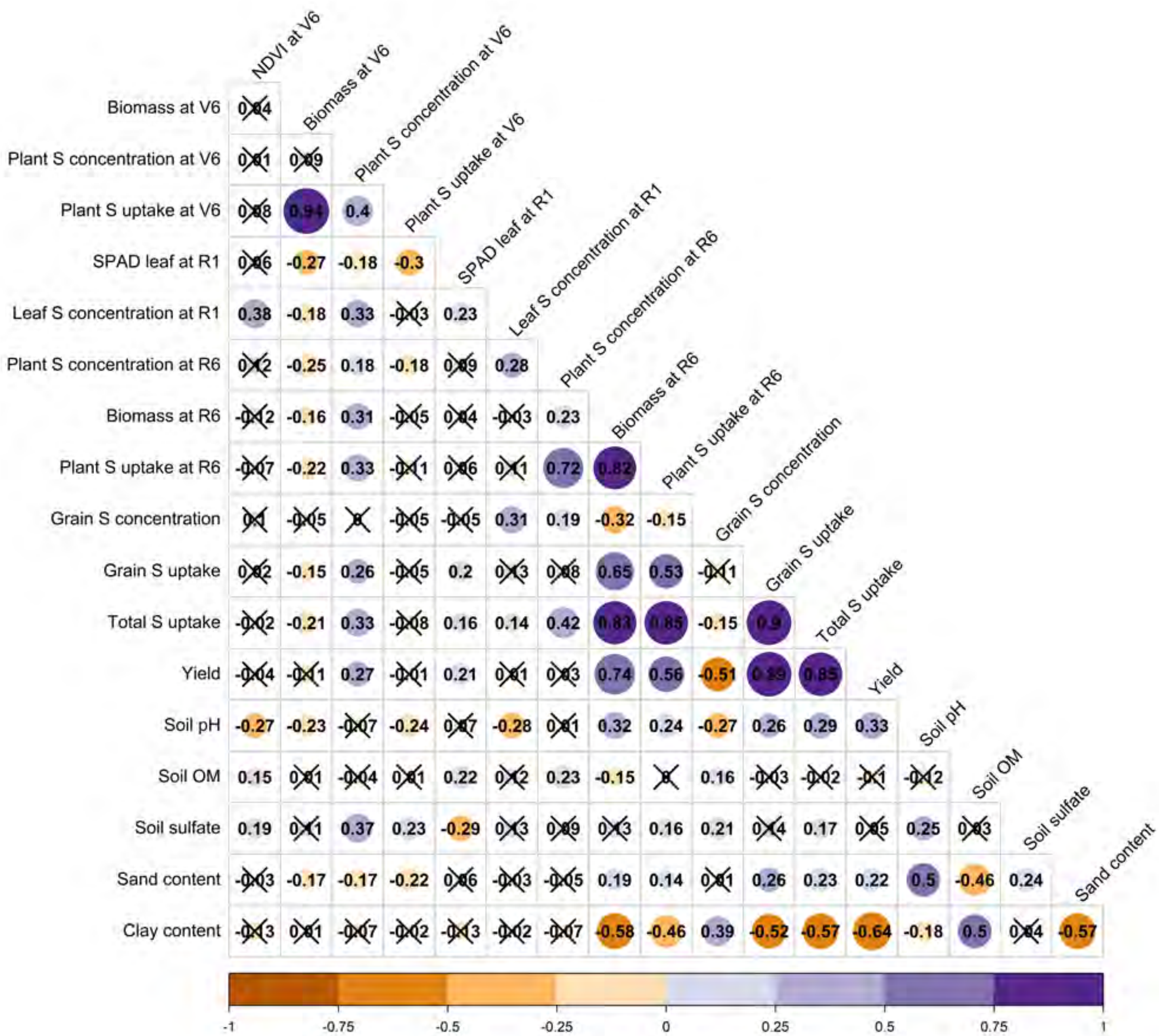

Figure 1. Pearson correlation matrix for different tissue, yield, and soil parameters (p<0.05). Darker colors indicate a higher (positive or negative) correlation coefficient; non-significant correlations are indicated by an “X”.

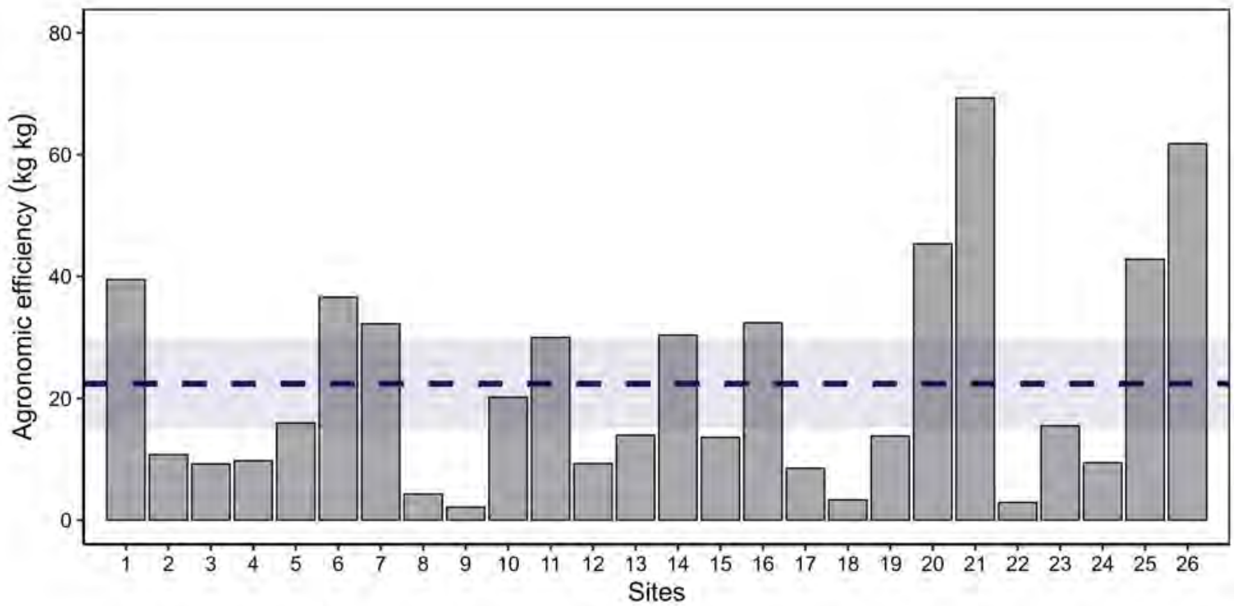

Figure 2. Agronomic sulfur efficiency (lb. of grain per lb. of sulfur applied), the dashed line represents the average across all sites, and the shaded area indicates a 95% CI of the mean.

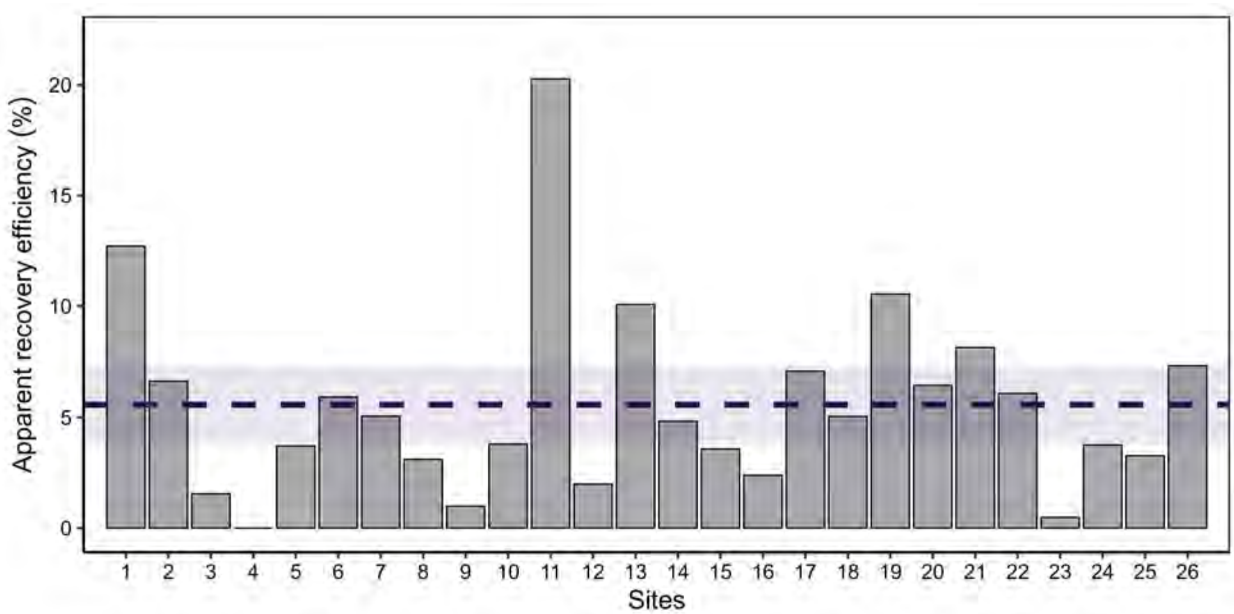

Figure 3. Apparent sulfur recovery efficiency (percent), the dashed line represents the average across all sites, and the shaded area indicates a 95% CI of the mean.

IS THERE AN OPTIMAL SOURCE OF SULFUR FOR CORN?

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ABSTRACT

Sulfur has become a common nutrient applied to corn in the Corn Belt. While research has demonstrated that sulfur can greatly increase yield, the source of sulfur offered to farmers by retailers can vary. Sulfur is only taken up by corn in the sulfate form while sulfur fertilizer source can contain sulfate that is readily available to plants or elemental sulfur which needs to be oxidized to sulfate before it is taken up by a crop. Four long-term research sites were established in Minnesota using a continuous corn rotation. Sulfur was applied at four rates (5, 10, and 20 lbs of S per acre) as four sources including a no-S control, sulfate-S applied as K-sulfate, elemental S as Tiger 90®, and elemental S as potash MST®. Treatments were applied and incorporated into the soil annually in the spring within 1 week of planting. Corn grain yield was significantly impacted by S application at three of the four locations. The only location where S did not increase yield was on a clay loam soil near Morris, MN that was heavy textured with soil organic matter concentration above 5%. For the remaining three sites, corn grain yield responded to sulfur rate (10 lbs S per acre) but not source at Becker, MN on an irrigated loamy sand soil. The remaining two locations corn grain yield responded to sulfur source and rate. For a silt loam soil near Rosemount, MN, 20 lbs of S per acre were needed to maximize yield across four years. In contrast for a clay loam soil at Waseca, MN, corn grain yield was maximized by 10 lbs of S per acre. The increase in sulfur requirement at Rosemount may be a result of a lower soil organic matter concentration (4% versus 6% at Waseca). At both locations, K sulfate and K-MST produced the greatest yield potential. Tiger 90 resulted in similar yield potential at Becker and Rosemount but yielded less at Waseca. It is possible that the Tiger 90 could not fully disperse the elemental S when incorporated into the soil and that coarser soils may help increase the potential for oxidation when a product like Tiger 90 is incorporated prior to planting. The data shows that sulfur application can be highly beneficial to corn, and that soil texture may play an important role in whether incorporated elemental S can oxidize to plant available forms.

INTRODUCTION

The response of corn grain yield to sulfur fertilization has been one of the major factors for increased productivity and profitability in some cropping rotations. Current projects on sulfur timing, rate, and placement have clearly demonstrated the need for sulfur. While a soil test is available for sulfur, differences in sulfate due to S application are difficult to detect with the soil test and soil test concentration of sulfate-S can be high even in soils where S responses occur. This highlights our limited understanding of how sulfur cycles among forms in the soil. Sulfate-S can be reduced in low oxygen situations but a complete reduction of sulfate to hydrogen sulfide which can be lost to the atmospheric via volatilization is unlikely. Basic research on forms of sulfur in the soil is needed to better understand availability in soils across Minnesota.

Elemental sulfur is a low-cost option for supplying S to plants but must be oxidized to sulfate prior to plant uptake. Oxidation is mediated by bacteria, *Thiobacillus thiobacteria*. From previous work, we know that the activity of *Thiobacillus* sp.tends to be low when soils remain cool. In fact, the optimum temperature for Thiobacillus activity is above 80^{o}F and even at these temperatures the oxidation of elemental sulfur can take 30 days. With more sources of S fertilizer containing elemental S due to a lower cost, research needs to identify whether any elemental S containing fertilizers can supply enough S for crops in situations where S is needed.

Research in Minnesota has demonstrated the need for sulfur to be applied to corn. However, the source of sulfur available to farmers can vary. The objective of this study is to compare sulfur release and availability of a sulfate source of S versus two sources of elemental S in a continuous corn rotation

MATERIALS AND METHODS

Table 1. Soil series information, planted crop at each location, and initial potassium soil test data from phosphorus studies conducted in 2019. Soil test data was collected in the Fall at trial establishment from each main plot.

	Soil Test				SO_4-S			
Location	Bray-P1	K	pH	OM	0-6	6-12	12-24	Soil Series
	ppm			%	ppm			
Becker	127	164	6.8	1.6	8.8	8.8	8.3	Hubbard
Morris	37	198	7.9	5.8	12.4	14.2	13.2	McIntosh
Rosemount	29	171	5.4	4.2	11.5	10.5	8.3	Tallula
Waseca	17	170	5.7	4.7	10.1	9.4	7.1	Clarion-Webster

† K, Soil test potassium (K-ammonium acetate); CCE, calcium carbonate equivalency.

Long term S research trials were established at four locations in 2019 (Table 1) Continuous corn trials were established at each location. Treatments were arranged in a split plot design. Main blocks consisted of 5, 10, or 20 lbs of S. Each main block was split into four sub-plots which were sulfur sources. Sulfur source treatments included a no sulfur control and three sources of S as potassium sulfate (0-0-50-17), Tiger 90 (60-800 micron elemental S and bentonite mixture), and a co-granulated S source. Co-granulated S materials, similar to what is contained in the micro-essentials line of products, are becoming more available and allow for a more even distribution of elemental S as each fertilizer granule contains S along with N and P unlike Tiger 90 which is 90% S therefore the amount of total product applied per acre is small reducing the distribution of sulfur over the landscape. The co-granulated product used for this study is a potash-based material consisting of 49% K_2O and 13.6% S manufactured by Sulvaris LTD (Calgary, AB) where the S is micronized to a smaller particle size (<40 microns). The use of a potash source eliminates the use of phosphate materials such as MAP, DAP, or TSP which can contain from 1-2% total S and can affect the ability to detect a response to S in a field study.

High P testing sites were selected, and additional P fertilizer was applied as a combination of in-furrow and 2x2 application of 6-24-6. Starter rate varied by site and typically were 5 gallons 6-24-6 in furrow at medium to fine textured sites plus 10 gallons 2x2. The in-furrow application rate was reduced to 3 GPA at Becker where the soil is a loamy sand. The 6-24-6 product was tested by ICP and averaged 667 mg S L^{-1}. Additional K as 0-0-60 will be applied to balance K across plots and N will be applied at non-limiting rates. Plots are 20' in width (except for Waseca which was 15' in width) , and were 40-55 feet in length. All sites were rain-fed except for Becker which was irrigated. The total irrigation applied at Becker in 2019 was 8.05 inches of water, 10.6 inches were applied in 2020, 14.3 inches in 2021, and 13.05 inches in 2022. Well water samples indicated an average of 29.8 mg SO4-S L^{-1} water at Becker in 2019, 31.0 in 2020, 27.1 in 2021, and 26.2 in 2022 which equates to 6.7, 7.0, 6.1, and 5.9 lb SO_4-S per inch of water applied, respectively. A total of 53.9, 74.3, 87.2, and 76.9 lbs SO_4-S was applied over 2019, 2020, 2021, and 2022 growing season through the irrigation water, respectively. The amount of S in rainfall was not determined at any of the locations.

Corn grain yield response (adjusted to 15.5% moisture) to S was measured in all plots. Corn leaf tissue samples were collected at V10 by sampling the uppermost fully developed leaf and at R1 sampling the ear leaf (leaf opposite and below the ear) and the 2nd leaf from the top of the plant. A subsample of grain will be saved from each plot, ground, and analyzed for total S concentration. All samples will be analyzed for total S concentration using combustion analysis. Soil test S will be measured from each main block at the beginning of the trial at the 0-6, 6-12, and 12-24" depth. Plant root simulator (PRS) probes, sold by Western Ag Innovations (Saskatoon, SK) were installed in the 10 lb S rate main blocks in all fertilizer sources and were sampled over a period of 8 sampling dates. A total of four anion probes were installed between the center two corn rows in an area 5' in each direction from the center of each plot. The PRS probes were installed in the soil to a depth of roughly 4-5 inches. At each sampling date the probes were removed from the soil, washed with deionized water, and new probes were re-installed into the slots created by the old probes. A garden knife was used to apply back pressure on the probes to ensure good contact between the soil and ion exchange membranes. Probes were sent to Western Ag. Innovations to be extracted and analyzed for sulfate-S sorbed. Soil samples (0-6 and 6-12") were collected prior to the initial PRS instillation and each time PRS probes are installed and removed. A total of three cores were sampled from between the rows where PRS probes were installed and were analyzed for sulfate-S using the mono-calcium phosphate procedure.

RESULTS AND DISCUSSION

Results of selected variable are summarized in Table 2. Corn grain yield was affected by sulfur sources at two of four locations while rate affected corn grain yield at three locations. Becker, the only irrigated location, saw corn grain yield increased by sulfur rate regardless of source. Sulfur source and rate both impacted corn grain yield at Rosemount and Waseca. At both these locations, K sulfate produced the greatest yield. The K-MST also produced maximum yield at both locations. However, Tiger 90 produced less yield at Waseca compared to K-sulfate and K-MST. Tiger 90 application did result in greater yield over the control, but the yield increase was only 60% that of K-sulfate and K-MST. What is interesting is that the sources, even the no-S control, did not affect grain yield at Becker even though statistically there was a difference between the 5 versus the 10 and 20 lb S application rates. There also was no significant interaction between source and rate at Becker. At Rosemount, 20 lbs of S was required to maximize corn grain yield over the 4 years while 10 lbs was sufficient at Waseca.

Table 2. Source and rate main effect means across four years 2019, 2020, 2021, and 2022 at four Minnesota locations. Within each main effect, within rows, numbers followed by the same letter are not significantly different at $P \leq 0.10$.

	Source Rate Effect				Rate Main Effect		
Location	Control	K-Sulfate	K-MST	Tiger 90	5	10	20
			Bushels per acre at 15.5% moisture				
Becker	197	200	196	197	189b	200a	202a
Morris	200	199	199	203	201	200	200
Rosemount	186b	207a	207a	201a	197b	195b	209a
Waseca	119c	177a	174a	153b	147b	158a	162a
				V10 Upper Leaf %S			
Becker	0.27b	0.29a	0.28ab	0.29a	0.28b	0.29a	0.29a
Morris	0.24	0.25	0.25	0.25	0.23b	0.25a	0.25a
Rosemount	0.20c	0.24a	0.24a	0.21b	0.21b	0.21b	0.24a
Waseca	0.17c	0.22a	0.22a	0.19b	0.19b	0.20b	0.21a
				R1 Ear Leaf %S			
Becker	0.26c	0.28a	0.27ab	0.27b	0.26b	0.27a	0.27a
Morris	0.23	0.23	0.23	0.22	0.22b	0.23ab	0.23a
Rosemount	0.18c	0.21a	0.21a	0.20b	0.19b	0.19b	0.21a
Waseca	0.14c	0.19a	0.18a	0.16b	0.16c	0.17b	0.18a
				R1 Upper Leaf %S			
Becker	0.25	0.25	0.25	0.24	0.24	0.25	0.25
Morris	0.23	0.23	0.22	0.23	0.22b	0.23a	0.23a
Rosemount	0.20d	0.24a	0.23b	0.21c	0.21b	0.21b	0.23a
Waseca	0.16c	0.21a	0.21a	0.18b	0.18c	0.19b	0.20c
				Grain %S			
Becker	0.095	0.096	0.097	0.099	0.096	0.098	0.096
Morris	0.094	0.096	0.096	0.096	0.095	0.095	0.096
Rosemount	0.088b	0.094a	0.093a	0.089b	0.089b	0.088b	0.096a
Waseca	0.070c	0.082a	0.081a	0.074b	0.072c	0.077b	0.082a

Corn leaf tissue and grain S concentration data are summarized in Table 2. Sulfur source and rate affected tissue S concentration more often than corn grain yield. Effects on leaf tissue S concentration were present even at Morris where corn grain yield was not impacted by S. Sulfur application rate almost always affected leaf tissue S concentration while source more commonly impacted leaf S concentration for the sites where grain yield were increased. Corn grain S concentration was only impacted by S source or rate at Rosemount and Waseca where both also impacted corn grain yield. Tissue S concentration was not regressed with yield to determine optimal leaf tissue S concentration. It is not surprising that S concentration was increased without an increase in corn grain yield occurring at a location as luxury uptake of S is expected by corn. It was surprising that leaf S concentration was impacted at Becker due to the large quantity of S contained in the irrigation water that was applied annually. Leaf S concentration did tend to be higher at Becker than the other locations. While not stated in the methodology, the same corn hybrid was planted across all locations each year so hybrid alone would not explain differences in leaf tissue S concentration.

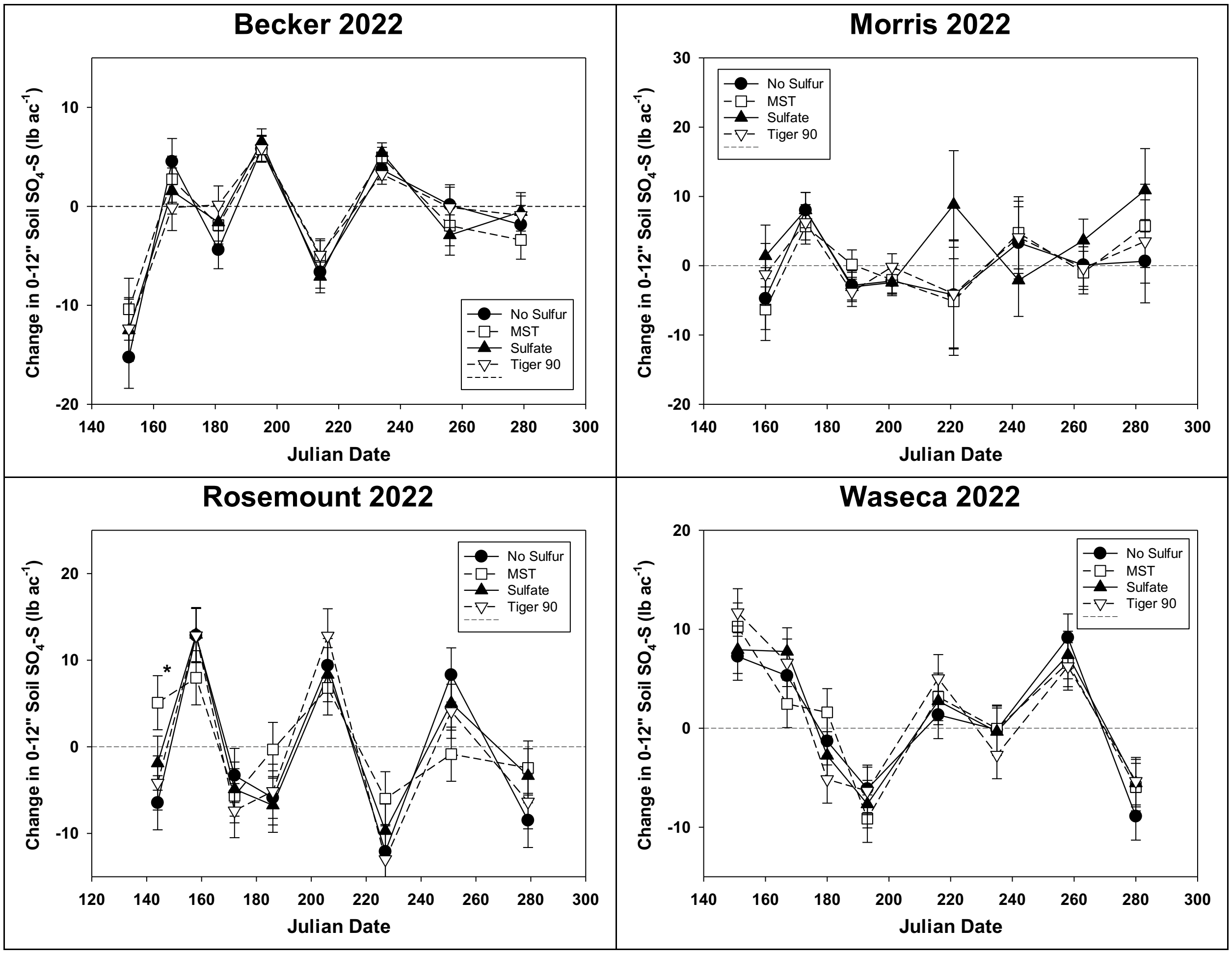

Figure 1. Summary of change in soil sulfate-S content at eight sampling dates from the initial soil sampling collected when the PRS probes were installed following the application of three sulfur sources at 10 lbs S/ac and a no-S control.

Plant root simulator (PRS) probes and soil samples were taken throughout the growing season in all four years of the study. Figures 1, 2, and 3 summarize only the 2022 results as the data were similar across years. Soil samples were collected from 0-6 and 6-12" depths when the PRS probes were installed and removed only in the main blocks receiving 10 lbs of S. Changes in the amount of S between samplings are summarized in Figure 1. Overall, there was no clear increasing or decreasing trend in the amount off extractable SO_4-S in soil measured to a 0-to-12-inch sampling depth. Increases or decreases were seen over time which could not be explained using soil temperature or moisture. The soil test for S is not that sensitive to applications of fertilizer and is not the best for indicating when S applied in fertilizer would become available as there was almost never a significant difference among the four sources at any individual sampling time.

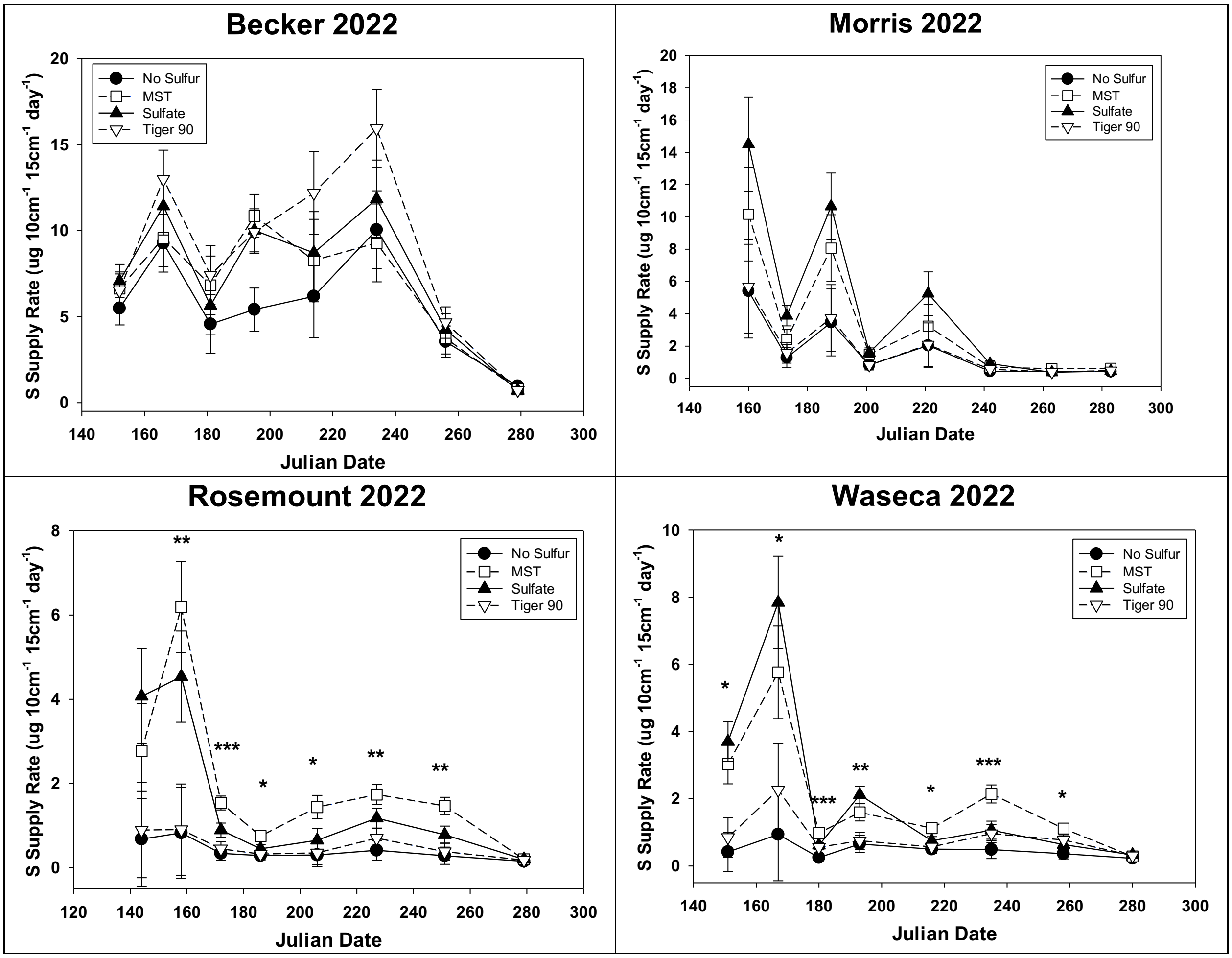

Figure 2. Summary of soil sulfate-S supply rate measured as daily sulfate-S flux by the PRS probes following application of three sulfur sources at 10 lbs S/ac and a no-S control.

Plant root simulator (PRS) probes were used as a proxy for plant roots to determine the amount of SO_4-S potentially available over time. The PRS data are summarized based on daily supply rate (Figure 2) as well as total SO_4-S sorbed over time (Figure 3). The units obtained from the PRS probes are presented in terms of a flux which is the amount of SO_4-S sorbed per unit surface area per unit time. The data are not intended to determine the total amount of sulfate released from the fertilizer. Rather we are interested to know when the different fertilizer sources may be providing available S to the plant. Asterisks in Figures 2 and 3 denote instances where where was variation among the sources at each site. Differences in daily sulfate flux could only be measured at Rosemount and Waseca in 2022. The availability of S from K-sulfate could be seen at the initial sampling and dropped off considerably by the third sampling at each location. Initial availability of S from K-MST was lower than K-sulfate for the first one or two samplings, but available S tended to be greater with K-MST compared to K-sulfate for the mid- to late sampling dates. Tiger 90 did not exhibit any significant availability of S over the growing season compared to the other two sources. However, Tiger 90 did increase corn grain yield at both Rosemount and Waseca therefore the PRS data wasn't fully reflective of the amount of S becoming available to the crop.

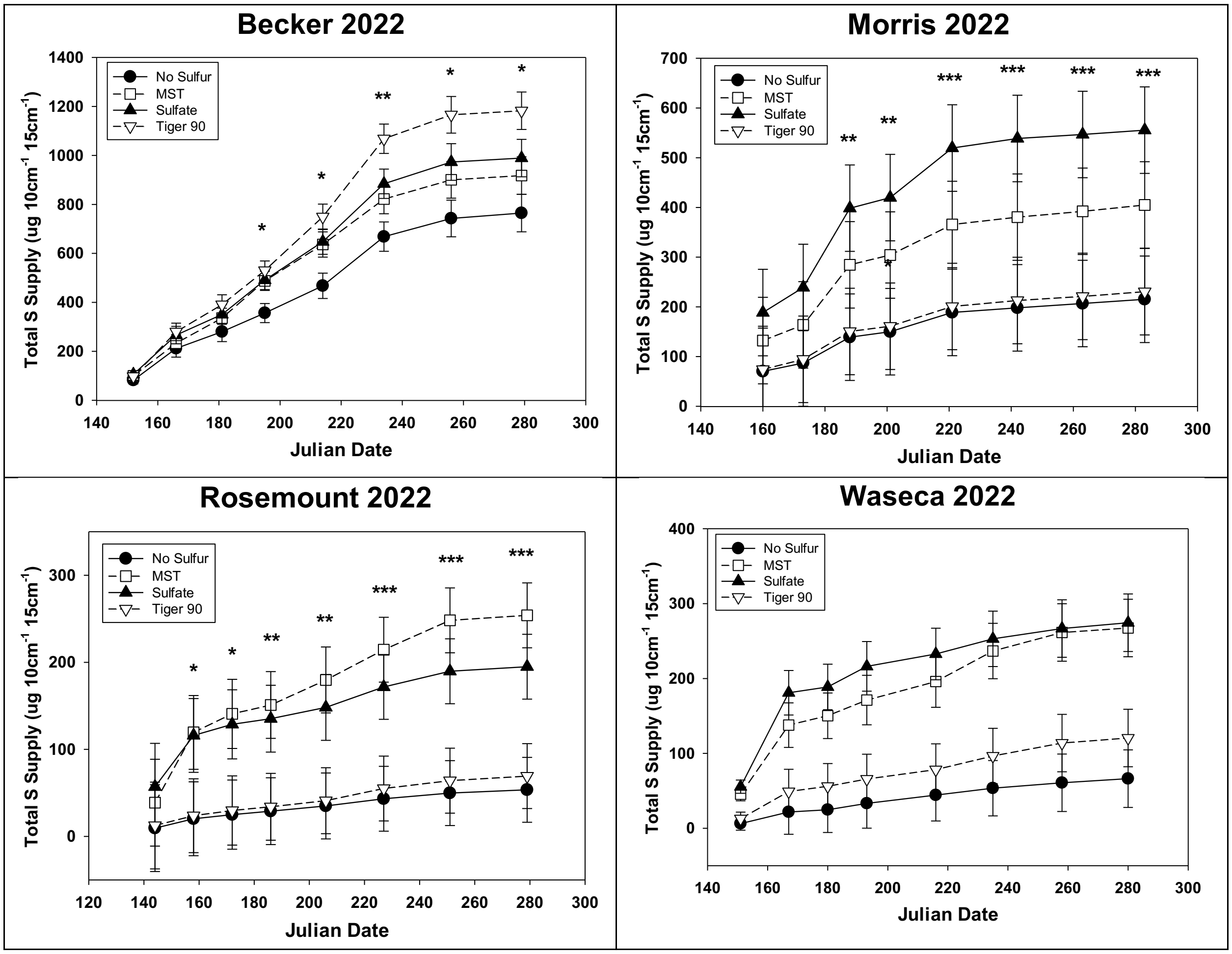

Figure 3. Summary of cumulative sulfate-S adsorption by the PRS probes following application of three sulfur sources at 10 lbs S/ac and a no-S control.

The total S supply shown in Figure 3 shows more difference in S availability from the individual sources across the four locations compared to the daily flux data shown in Figure 2. In fact, total S supply varied among S sources at all four locations. Asterisks are not presented for Waseca in Figure 3. However, that was due to no source by sampling date interaction. In fact, the total S supply data matched better with corn grain yield at Waseca where K-sulfate and K-MST yielded more than Tiger 90. One thing to note is that for Becker and Morris the scale on the Y axis is much larger than the other two locations indicating a generally larger supply of sulfur coming from the soil due to organic matter mineralization at Morris, and through the contribution of sulfate in the irrigation water at Becker. Even though the sources did vary, the additional supply of S by S fertilizer at Becker and Morris was not likely needed. Again, Becker did respond to rate but not to source. At Rosemount, the K-MST did supply more total sulfur over time than K sulfate.

The PRS data does give some indication of when S is becoming available for the crop. In the case of K-MST, available S is lower than K-sulfate initially, but the K-MST appears to supply more S at mid- to late growth stages. Across the four years, the elemental S in K-MST seemed to start to become more available about four to six weeks into the growing season. What is interesting though is that the Tiger 90 did not show to be any more affective compared to the no S control at Rosemount even though statistically is provided the same yield at the end of the season. The only site were Tiger 90 appeared to be better at supplying S was at Becker where the total S supply was greatest with Tiger 90 at the end of the 2022 growing season.

The fact that the Tiger 90 did not produce similar yield compared to K-sulfate and K-MST is not surprising for Waseca. The larger particle size of the elemental sulfur combined with the bentonite likely slows the oxidation in soils such as Waseca and Morris that are high in clay. Elemental sulfur is not water soluble and burying large particles in the soil would slow oxidation. Also, the bentonite clay in the Tiger 90 would not be able to disperse the elemental S if buried in soils with smaller pore spaces. The potash matrix in the K-MST would likely dissolve leaving more space for the elemental S in the K-MST to avoid all the elemental S clumping together which would increase the overall diameter of S particles and slow oxidation. Coarse textured soils such as that at Becker would leave more space for the bentonite to expand and potentially disperse the elemental S particles.

CONCLUSIONS

The data provided indicates that elemental S can be an effective source of S fertilizers for crops. Elemental S needs to be managed differently than other S sources. Co-granulated materials such as the K-MST may have a greater chance of supplying available S to crops due to a smaller particle size and better dispersion of the sulfur across the landscape. For fine textured soils, a project like Tiger 90 is not as effective when incorporated into the soil and the rate of S needed to result in maximum yield may be at least two times greater than that which would be required using a sulfate source of fertilizer. The data does indicate that no more than 20 lbs of S are required annually for corn grown in a continuous corn cropping system which optimal rates as low as 10 lbs of S per acre in some circumstances.

ACKNOWLEDGEMENTS

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THE AG FORECAST GOING INTO 2024

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USDA's World Agricultural Supply and Demand Estimates (WASDE) report outlines the current view for agricultural markets over the next 12–18 months. In general, extreme weather events and domestic and international economic concerns have shaped the agricultural projections for the near future. While US meat demand remains resilient, cattle numbers have continued to decline due to drought and high production costs. Meanwhile, USDA projects the pork and poultry industries will grow. Livestock prices have a mixed outlook for 2024, with beef and pork prices expected to increase, while prices for broilers and turkeys fall. This year's acreage shifts seem to have bigger impacts on crop production than the ongoing drought, with corn acreage and production jumping higher, while soybean area and production fell. Crop usage eroded from sustained higher prices; however, the forecast shows a rebound in crop usage for the 2023 crops, with the exception of soybean exports.

For the livestock sector, the 2023 calendar year has been another challenging year. Drought continued to be a problem across a sizable chunk of the country, limiting pasture use and constraining herd size. Meat demand has been mixed. For beef, domestic consumption has been solid, but international consumption has retreated. Meanwhile, for pork, it is the opposite, as international consumption has increased, while domestic consumption is weaker. While prices are relatively strong (with the exception of pork), producers continue to face higher costs, limiting profitability. Table 1 shows the current projections for the 2023 and 2024 calendar years in the livestock sector. Overall, meat production in 2023 is set to be just slightly above 107 billion pounds. Compared to 2022, beef production declined, while pork, broiler, and turkey production increased. However, the overall total is slightly lower. Meat prices exhibit the opposite pattern, with higher beef prices and lower pork, broiler, and turkey prices. The outlook for 2024 points to lower beef production and increased pork, broiler, and turkey production. USDA expects beef prices to remain strong and projects pork prices will recover a bit. However, the forecast shows broiler and turkey prices will continue their decline. Total meat supplies will be lower, but there will be greater availability of pork and poultry. International meat trade is projected to rise slightly in 2024, as beef exports are projected to fall by 189 million pounds, but pork exports are expected to rebound by 189 million pounds, along with roughly 100 million pounds of poultry export expansion.

Table 1. USDA Livestock Projections

	2023		2024		
	Forecast	Change from September	Forecast	Change from September	Change from 2023 to 2024
Production			(Billion Pounds)		
Beef	26.98	0.04	25.28	0.11	-1.70
Pork	27.29	0.13	27.90	0.56	0.61
Broilers	46.69	-0.20	47.11	-0.20	0.62
Turkey	5.55	-0.03	5.64	-0.01	0.09
Total	107.06	-0.07	106.66	0.46	-0.40
Meat Prices			($ per Cwt.)		
Steers	177.30	-1.18	185.00	-0.50	7.70
Hogs	59.70	-0.18	61.25	-3.50	1.55
			(Cents per Pound)		
Broilers	124.00	0.80	122.30	1.00	-1.80
Turkey	144.90	-4.60	137.80	-8.80	-7.10

Source: USDA-WAOB.

For the corn and soybean markets, the September USDA report incorporates new acreage information from the Farm Service Agency and new survey data from NASS's farmer and objective yield queries. For both crops, USDA's new estimates indicate more acreage and less yield. The October report carried the acreage changes forward, but updated yield and production estimates. The national corn planted area estimate was increased by 800,000 acres to a total of 94.9 million acres; however, the national average corn yield estimate dropped to 173 bushels per acre. Putting together the acreage and yield updates, USDA finds evidence to keep supplies above 15 billion bushels for the year, which puts this year's production 1.35 billion bushels above the 2022 total and nearly equal to 2021 production.

USDA also updated corn usage. Given recent corn processing data, 18 million bushels were removed from the corn grind out of the 2022 crop. Corn export sales out of the 2022 crop were lowered by 4 million bushels and corn usage for sweeteners fell by 28 million bushels. However, corn feed and residual usage increased by 124 million bushels. Combining all of the changes, the projections show the 2022/23 corn ending stocks at 1.361 billion bushels. Normally, a reduction in stocks translates to an increase in prices, but USDA lowered its 2022/23 season-average price estimate by a penny to $6.54 per bushel. For the new (2023) crop, USDA reduced its estimates for feed and exports by 25 million bushels each, with feed and residual use at 5.6 billion bushels, ethanol at 5.3 billion bushels, food, seed, and other use at 1.415 billion bushels, and exports at 2.025 billion bushels. Overall corn usage is projected to be nearly 600 million bushels higher for the new corn marketing year—2023/24 ending stocks are now set at 2.111 billion bushels, down 110 million from last month, but up 749 million from last year. With plenty of corn available to the market, USDA estimates the 2023/24 season-average price at $4.95 per bushel.

Table 2. Corn Supply and Use

Marketing Year		2022		2023		
		Estimate	Change from September	Forecast	Change from September	Change from 2022 to 2023
Area Planted	(mil. acres)	88.6	0.0	94.9	0.0	6.3
Yield	(bu./acre)	173.4	0.0	173.0	-0.8	-0.4
Production	(mil. bu.)	13,715	-15	15,064	-69	1,350
Beg. Stocks	(mil. bu.)	1,377	0	1,361	-90	-16
Imports	(mil. bu.)	39	-1	25	0	-14
Total Supply	(mil. bu.)	15,130	-16	16,451	-160	1,320
Feed & Residual	(mil. bu.)	5,549	124	5,600	-25	51
Ethanol	(mil. bu.)	5,177	-18	5,300	0	123
Food, Seed, & Other	(mil. bu.)	1,382	-28	1,415	0	33
Exports	(mil. bu.)	1,661	-4	2,025	-25	364
Total Use	(mil. bu.)	13,769	74	14,340	-50	571
Ending Stocks	(mil. bu.)	1,361	-90	2,111	-110	749
Season-Average Price	($/bu.)	6.54	-0.01	4.95	0.05	-1.59

Source: USDA-WAOB.

Note: Marketing year 2022 = 9/1/2022 to 8/31/2023

Nationally, total planted area for soybeans increased from August's estimate by just under 100,000 acres, to 83.6 million acres. The national average soybean yield estimate came in at 49.6 bushels per acre, down 0.5 bushels. Overall, national soybean production is projected at 4.104 billion bushels. Soybean usage adjustments changed both domestic and international consumption. For the 2022 crop, exports were raised by 2 million bushels, reflecting slightly better sales at the end of the marketing year. On the other hand, domestic crush was reduced 8 million bushels and seed and residual usage fell by 23 million bushels. Those changes increased the 2022/23 ending stocks to 268 million bushels, maintaining already low stock levels. The 2022/23 season-average price estimate held steady at $14.20 per bushel. For the 2023 crop, the usage changes were mixed. The domestic crush expectation increased by 10 million bushels. The larger decline hit in exports, with 35 million bushels removed there, based on greater global supplies. Despite the reductions in usage, USDA projected 2023/24 ending stocks at 220 million bushels, down 48 million from last year. Thus, US soybean stocks are projected to get even tighter. Given the large global soybean supplies, it’s not surprising that soybean prices are lower year-over-year. USDA has its 2023/24 season-average price estimate at $12.90 per bushel, $1.30 below last year.

Table 3. Soybean Supply and Use

Marketing Year		2022		2023		
		Estimate	Change from September	Forecast	Change from September	Change from 2022 to 2023
Area Planted	(mil. acres)	87.5	0.0	83.6	0.0	-3.9
Yield	(bu./acre)	49.6	0.0	49.6	-0.5	0.0
Production	(mil. bu.)	4,270	-6	4,104	-42	-166
Beg. Stocks	(mil. bu.)	274	0	268	18	-6
Imports	(mil. bu.)	25	-5	30	0	5
Total Supply	(mil. bu.)	4,569	-11	4,403	-24	-167
Crush	(mil. bu.)	2,212	-8	2,300	10	88
Seed & Residual	(mil. bu.)	97	-23	128	2	31
Exports	(mil. bu.)	1,992	2	1,755	-35	-237
Total Use	(mil. bu.)	4,301	-29	4,183	-23	-118
Ending Stocks	(mil. bu.)	268	18	220	0	-48
Season-Average Price	($/bu.)	14.20	0.00	12.90	0.00	-1.30

Source: USDA-WAOB.

Note: Marketing year 2022 = 9/1/2022 to 8/31/2023.

Over the past couple years, US agriculture, for the most part, has enjoyed strong production, prices, exports, and incomes. The outlook going into 2024 shows reductions in most agricultural prices, a mixed picture in exports and production, and a decline in income. While incomes are retreating, the health of the overall agricultural economy is still good, it’s just not quite as rosy as it used to be.

OPTIMIZING NITROGEN MANAGEMENT FOR SUSTAINABLE PRODUCTION OF FURROW-IRRIGATED CORN IN NEBRASKA PANHANDLE

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ABSTRACT

Losses of nitrogen (N) via leaching to groundwater and greenhouse gas emissions pose an environmental and human health threat. The risk for environmental N losses, particularly nitrate leaching loss, is greater in furrow-irrigated fields than those under drip or sprinkler irrigation. Furrow irrigation accounts for 30% of total irrigated acres in Nebraska and approximately 36% in the US. However, much of the efforts for N management improvement are concentrated on sprinkler or drip systems. The two-year experiment was conducted to evaluate the effects of urea, polymer-coated urea (PCU), and urea with urease and nitrification inhibitors (UI) on grain yield, nitrate leaching, and nitrous oxide emission in furrow-irrigated corn at the UNL Panhandle Research, Extension, and Education Center in Scottsbluff, NE. The main treatment included three N sources at four N rates (50%, 75%, 100%, and 125% of recommended rate). Corn grain yield differed by applied N rates in 2021 but not in 2022, when yield was overall low due to drought and irrigation issues. When averaged across N rates, grain yield was in the order SuperU>PCU=urea>control in 2021. In 2022, nitrate concentrations in potential drainage water were lower than in 2021. Given full irrigation, N management in furrow-irrigated corn can be optimized with the use of UI.

INTRODUCTION

Optimization of fertilizer N application is critical to simultaneously ensure increased grain yield and reduced environmental risk. Irrigated fields are prone to nitrate leaching, with a greater risk in furrow-irrigated croplands than fields under drip or sprinkler irrigation (Siyal and Siyal, 2013). Although there has been a substantial shift in irrigation systems from gravity/furrow to potentially more efficient sprinkler and drip irrigation systems, the gravity flow method accounted for approximately 36 % of irrigation systems in the U.S. in 2018 (USDA-NASS, 2018). In Nebraska, furrow irrigation accounts for around 30% of total irrigation, and almost 38% of the area with furrow irrigation systems falls under areas of high nitrate concentrations (≥10 mg NO_3-N/L) (Juntakut, 2018).

Optimal rates and the right source of fertilizer N can help reduce nitrate leaching. The use of available advanced fertilizer technologies has been reported to reduce nitrate leaching from irrigated corn fields in several instances (Rui et al., 2019; Peng et al., 2015; Motavalli et al., 2008; Ferguson, 2015; Delgado & Bausch, 2005; Li et al., 2016) and this may potentially benefit furrow irrigation system as well. These products are designed to release N more gradually over the course of the season compared with conventional fertilizers to minimize N losses and improve synchrony between soil N availability and crop N demand. Several field experiments have reported the use of such products to optimize N management in corn (Hatfield & Parkin, 2014; DeBruin et al., 2020), but most of them are solely focused on agronomic output and under sprinkler irrigation. Halvorson and Bartolo (2014) reported the potential benefits of such advanced fertilizer technologies on crop yield and N-use efficiency in furrow-irrigated corn fields but did not study their effects on nitrate leaching. Other studies that reported the effects of such fertilizers on nitrate leaching and water quality are under sprinkler irrigation systems (Maharjan et al., 2014; Wilson et al., 2010; Venterea et al., 2011).

The use of advanced fertilizer technologies such as controlled- or slow-release N has shown the potential to mitigate nitrate leaching loss under sprinkler irrigation systems (Venterea et al., 2011), but their potential has not been evaluated under furrow irrigation yet. It is also important to quantify the emission of nitrous oxide (N_2O), one of the potent greenhouse gases, resulting from fertilizer N in agricultural soils and optimize fertilizer N rates and sources to reduce N_2O emissions. The objective of this experiment is to evaluate the effects of different sources and rates of fertilizer N for improved crop grain yield and reduced nitrate leaching and nitrous oxide (N_2O) emissions from corn fields under the furrow irrigation system.

MATERIALS AND METHODS

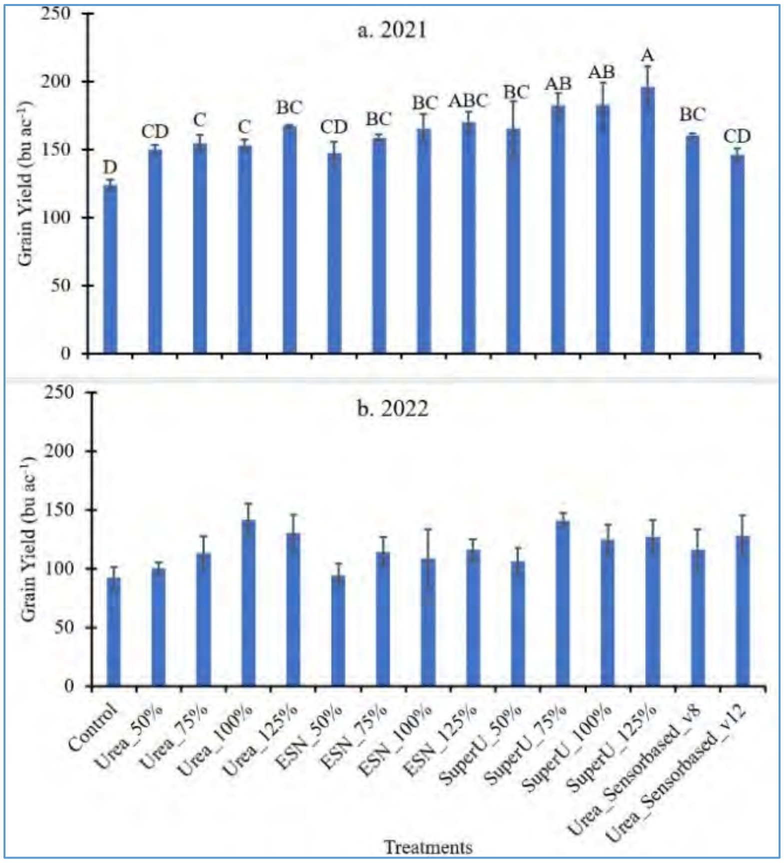
A three-year field experiment was started in a furrow-irrigated corn at the UNL Panhandle Research, Extension, and Education Center in Scottsbluff, NE, in 2021. The experiment was laid out in a randomized complete block design with four replications. The treatments included three fertilizer N sources at four rates (50%, 75%, 100%, and 125% of the recommended N rate based on soil test and yield goal) plus a crop sensor-based N rate applied at V8 and V12 growth stages. The N sources included urea, polymer-coated urea (ESN®), and urea with urease and nitrification inhibitors (SUPERU®). Corn was planted on May 14 in 2021, and May 19 in 2022. All fertilizers were applied at corn emergence except for the sensor-based treatments, where only 30% was applied at emergence and the rest at respective growth stages based on the crop sensing data.

After corn planting, a suction-cup lysimeter was installed at 120 cm depth in selected treatment plots. Lysimeters were left under a vacuum and sampled every week (following irrigation or rainfall events) for water analyzed for nitrate-N. The field was irrigated with the gated-pipe system to provide full irrigation matching the crop water demand. Nitrous oxide fluxes from selected plots were measured weekly using an N_2O analyzer (Li-COR Biosciences, NE). At crop maturity, corn grain was harvested with a plot combine. Postharvest soil samples were collected in all treatment plots and analyzed for nitrate-N.

RESULTS AND DISCUSSION

Corn Grain Yield

In 2021, corn grain yield significantly increased with fertilization compared to control, except for urea and ESN applied at 50% of recommended rate and sensor-based urea application at the V12 growth stage (Figure 1). When averaged across the N rates, grain yield was in order urea with inhibitors (SUPERU) > polymer-coated urea (ESN) = urea >



Control (Figure 2). Grain yield had significant quadratic responses across N ramps for each fertilizer source (Figure 3).

For the second year, there were no significant differences among fertilized treatments which might be due to severe drought conditions early in the season. In addition, the irrigation well was short of water, and we could not irrigate until an alternative source was arranged later in the season. When averaged across the N rates, only urea with inhibitor (SUPERU®) had significantly greater grain yield than the control. Across N ramps for each fertilizer source, grain yield had a significant quadratic response as in 2021, but with a much smaller slope (Figure 3).

Figure 1. Mean corn grain yields (with standard deviation) for different N treatments in (a) 2021 and (b) 2022. Different uppercase letters refer to the significant treatment differences in grain yield at $p < 0.05$. In treatment labels, the number followed by the fertilizer source indicates the applied percentage of recommended N rates.

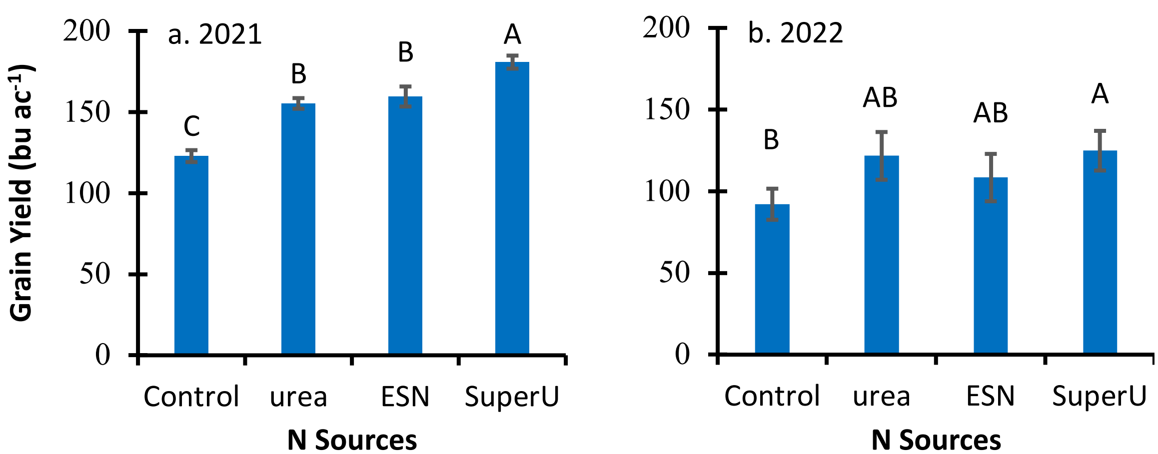


Figure 2. Mean corn grain yield (with standard deviation) averaged across N rates for different N sources in (a) 2021 and (b) 2022. Different uppercase letters refer to the significant treatment differences in grain yield at $p < 0.05$.

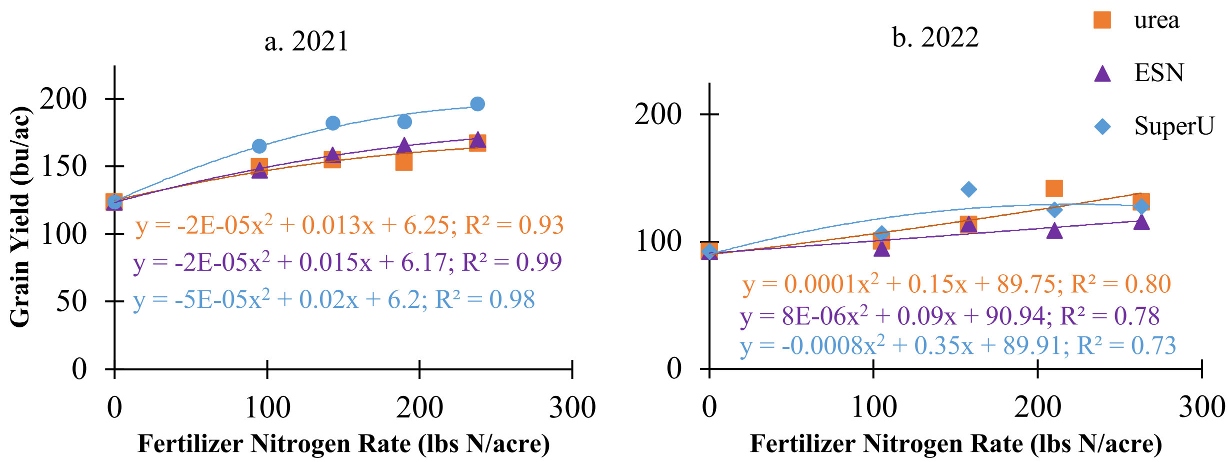


Figure 3. Regression of grain yield against N rates for different N sources in (a) 2021 and (b) 2022. All regression relationships are significant at $p \leq 0.05$.

Nitrate Concentrations in Soil Water

The trends for nitrate concentrations in water samples from lysimeters in 2021 showed an inconsistent pattern across urea-N rates. There were instances where the highest urea-N rate treatment had greater nitrate concentrations than the others, as anticipated. But there were other cases where lower-N rate treatments had greater nitrate concentrations. All urea-N treatments had nitrate concentrations > 10 ppm in more than 1 sampling event. In 2022, nitrate concentrations in water samples were lower than in 2021, which could be potentially due to drought and lower than optimal irrigation. At two sampling events, the highest N rate treatment had nitrate concentration > 10 ppm.

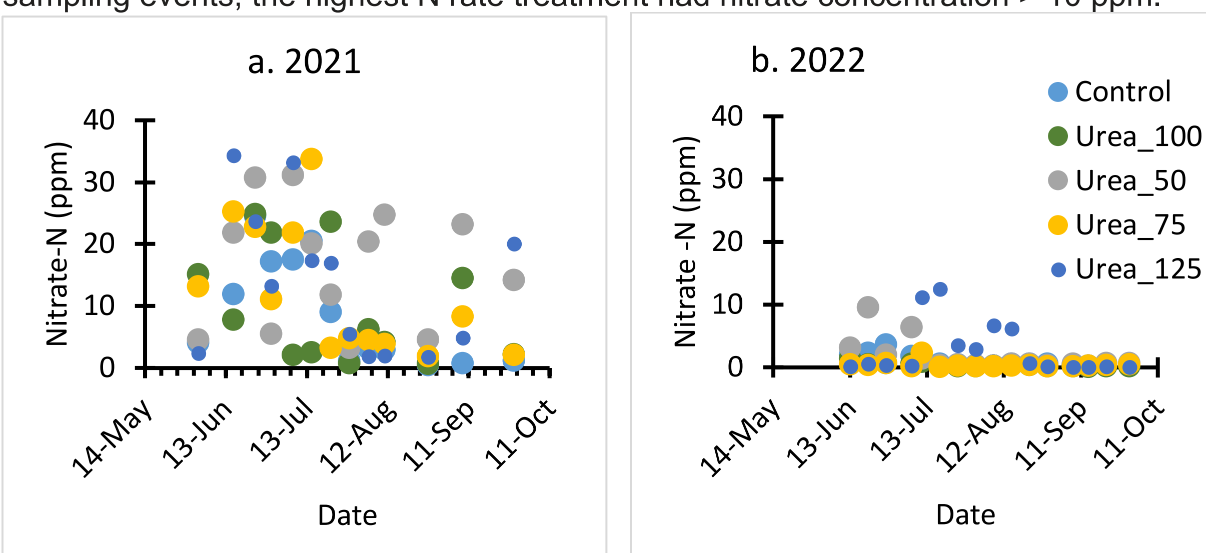


Figure 4. Nitrate-N concentration (ppm) in water samples throughout the growing season under different urea-N rate treatments in (a) 2021 and (b) 2022

Nitrous Oxide Emissions

Nitrous oxide fluxes peaked a month after fertilization. The higher the urea-N rate, the greater the flux was observed. The SuperU and ESN treatments had lower fluxes compared to urea treatments. The ESN treatment had higher fluxes than other treatments later in the season (late July – early August). Overall, the split N application based on sensor data had minimal fluxes throughout the season. Only after mid-September (3 months after fertilizations), the fluxes for all treatments reduced to <20 μgN/m^2/hr.

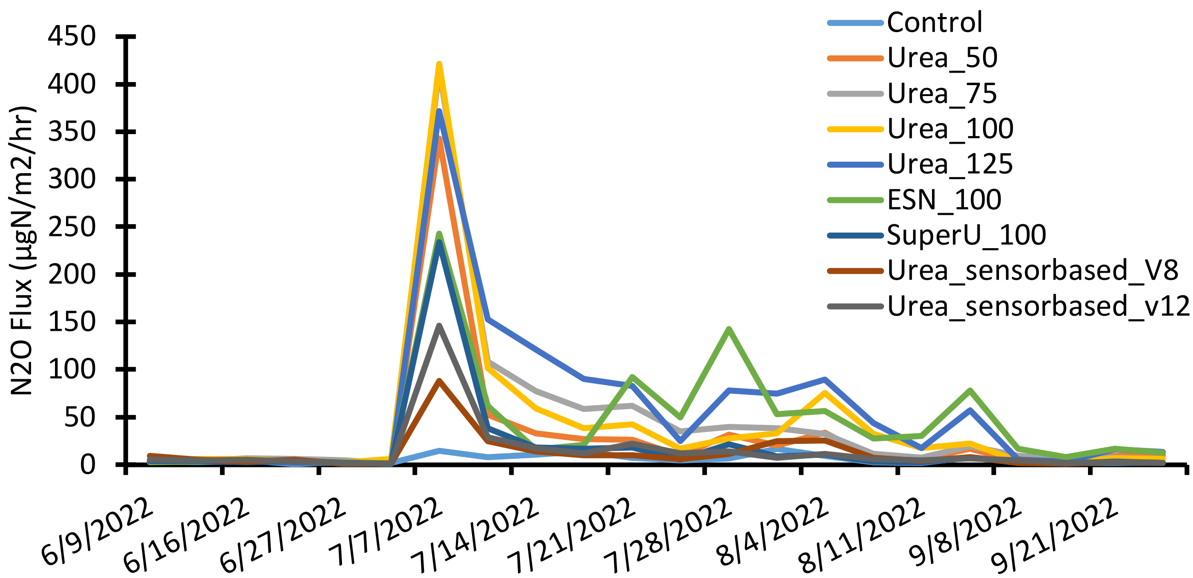


Figure 5. Nitrous oxide fluxes during the growing season of year 2022 for different N treatments. Fertilizers were applied on 06/07/2022 except for crop sensing treatments which received N at V8 (on 07/11/2022) and V12 (on 07/18/2022).

Conclusions

Urea with chemical inhibitors demonstrated yield benefits compared to urea with or without polymer coating. Since irrigation water was applied at full or sub-optimal amounts, drainage water sampling was not always successful. Still, urea rates or use of advantage fertilizer technology needs to further be evaluated to reduce potential leaching losses. Chemical inhibitors tend to reduce N_2O emission loss compared to urea with or without polymer coating. The N treatment based on crop sensing is also a potential tool to reduce N_2O emission and needs further evaluation.

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EVALUATION OF INSTINCT II AND RADIATE ON SOFT RED WINTER WHEAT IN NORTHWEST OHIO

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ABSTRACT

Producers in Northwest Ohio are encouraged to purchase various additives for urea-ammonium nitrate (UAN) with the expectation to increase grain yields; however, they have limited information on the benefits of these products except what was provided by the selling company. Two products that were commonly promoted were Instinct II, a nitrification inhibitor, and Radiate, a growth regulator. A three-year study was completed at the OARDC Northwest Agricultural Research Station near Custar, Ohio to see the benefits of using these products in soft red winter wheat in northwestern Ohio. AGI 217B, a medium-maturity variety, was established in the fall of 2018, 2019, and 2020 in late September or early October. There were three treatments in the study: 90 lb A^{-1} of UAN-N, 90 lb A^{-1} of UAN-N plus 37 oz Instinct II, and 90 lb A^{-1} of UAN-N plus 4 oz Radiate. Treatments were applied at greenup (Feekes 3.0). Experimental design was randomized block replicated four times. Measurements included grain yield, harvest test weight, flag leaf N concentration, and spikes per foot-row. There was no difference among treatments in 2019 for yield, but the Instinct II and Radiate had significantly lower yields than the UAN alone in 2020 and 2021 ($p < 0.10$). There were no differences among the treatments for the other measurements in any year. This study found no benefit adding Instinct II or Radiate to UAN in wheat. These two additives did not increase yields compared to UAN alone, and in some years, yields were reduced.

INTRODUCTION

Most of Ohio's wheat production occurs in the northwestern part of the state. Agricultural fields are relatively flat with poor internal drainage. As a result, most of the land is systematically tiled. Because of the poor drainage, nitrogen loss is a concern. Companies promote various products to limit N loss or to enhance plant growth. Producers are encouraged to purchase these additives to mix in UAN solution with the expectation to increase grain yields, but they have limited information on the benefits of these products except what was provided by the selling company. Two commonly promoted products in the region are Instinct II, a nitrification inhibitor (Corteva), and Radiate, a growth regulator containing IBA and kinetin (Loveland). The objective of this study was to evaluate Instinct II and Radiate for yield and other agronomic traits in soft red winter wheat under Northwest Ohio field conditions.

MATERIALS AND METHODS

To investigate the potential benefits of additives to UAN (28-0-0) in wheat, a three-year field experiment was completed at the Ohio Agricultural and Research Development Center's Northwest Agriculture Research Station near Custar, OH. Soft red winter wheat variety AGI 217B was established in the fall of 2018, 2019, and 2020 in late September or early October. Tillage was conventional and 300 lb A^{-1} of 10-26-26 was added prior to planting. Previous crop was soybean. Seeding rate was 1.4 to 1.8 million seeds A^{-1} drilled in 7.5-inch row spacing. Soil type was a Hoytville silty clay. Experimental design was a randomized complete block with three treatments replicated four times. Treatments consisted of 90 lb UAN-N A^{-1}, 90 lb UAN-N A^{-1} plus 37 oz of Instinct II, and 90 lb UAN-N A^{-1} plus 4 oz of Radiate applied at Greenup (Feekes 3.0). Nitrogen was applied as a broadcast. Seven ounces of Prosaro fungicide was applied at Feekes 10 in 2020 and 2021; no fungicide was applied in 2019. Forty to fifty flag leaves were collected at flowering (Feekes 10) for N analysis. Spikes were counted from a one-foot section of a row from two areas in each plot during early grain fill. Grain harvest occurred in early July. Plots were 10 feet wide and 60 - 80 feet long. The center 11 rows were measured for grain yield. A combine scale estimated grain weight and a sensor estimated grain moisture and test weight. Yields were adjusted to 13.5% moisture. Statistical analysis was ANOVA.

RESULTS AND DISCUSSION

Results are given for each year rather than a three-year summary since weather for a given year has a large impact on N utilization. Table 1 shows that 2019 was an abnormally wet year and 2020 and 2021 were slightly drier than normal.

Table 1. Total rainfall averages (inches) from April 10 to June 10 for years 2019-2021, historical average rainfall for April 10 to June 10, and the difference for rainfall between a given time compared to the historical average.

Year	2019	2020	2021
Recorded rainfall	11.9	6.0	6.7
Historical rainfall average	6.9	6.9	6.9
Difference	+5	-0.9	-0.2

Results for grain yields and agronomic traits for Instinct II and Radiate are given in Table 2. Year 2019 would be characterized as an abnormally low yielding year, year 2020 as an average yielding year, and year 2021 as an abnormally high yielding year. Disease was not factor for any of the years. To limit the potential for head scab disease a fungicide was sprayed at flowering in 2020 and 2021. Rainfall at flowering in 2019 prevented the timely application of fungicide; however, disease was not a problem that year (Table 2).

In 2019, there was no benefit adding Instinct II or Radiate to UAN for grain yield, test weight, and spike count. The overall mean for yield was 48.9 bu A^{-1} and the range was 37.8 to 65.9. Test weight overall mean was 50.8 lb bu^{-1} and the range 47.7 to 55.5. test weight. With the excessive rainfall, test weights would be expected to be low. However, Variety AGI 217B is known for large yields but not large test weights. The overall mean for spike counts (spike ft-row $^{-1}$) was 44.5and the range 35.5 to 56.5. Leaf N analysis was not completed.

There were significant differences for yield among treatments in 2020. Yields were 10.6% and 10.9% lower for Instinct II and Radiate, respectively, compared to UAN alone. Differences were not significant among treatments for test weight, leaf N content, and spikes. The overall mean for test weight was 56.9 with a range of 52.6 to 58.9. Leaf N levels were in the nutrient sufficiency range for all three treatments (2.59 - 4.00). The overall mean was 3.45 with a range of 2.84 to 4.18. The overall mean for spikes was 44.0 with a range of 35.0 to 56.0.

Table 2. Grain yields, harvest test weights, blade leaf N, and spike number means for soft red winter wheat with and without Instinct II and Radiate.

Year	Treatment	Yield bu A^{-1}	Test Weight lb bu^{-1}	Leaf N %	Spikes ft-row^{-1}
2019	None	47.7	49.3	---	43.8
	Instinct II	51.8	52.0	---	44.1
	Radiate	47.5	51.1	---	45.6
	$lsd_{0.10}$	ns	ns	---	ns
2020	None	84.3^{a}	57.5	3.57	45.1
	Instinct II	75.4^{b}	55.5	3.38	41.5
	Radiate	75.1^{b}	57.6	3.39	45.4
	$lsd_{0.10}$	3.3	ns	ns	ns
2021	None	121.8^{a}	57.3	3.71	49.5
	Instinct II	117.6^{b}	57.1	3.79	45.9
	Radiate	116.4^{b}	57.0	3.55	42.0
	$lsd_{0.10}$	1.2	ns	ns	ns

means with different letters are significant; ns = no significance ($p < 0.10$)

For 2021, there were significant differences for yield among treatments. Yields were 3.4% and 4.4% lower for Instinct II and Radiate, respectively, compared to UAN alone. Differences were not significant among treatments for test weight, leaf N content, and spikes. The overall mean for test weight was 57.1 with a range of 56.3 to 57.9. Leaf N levels were in the nutrient sufficiency range. The overall mean for leaf N was 3.68 with a range of 3.33 to 3.91. The overall mean for spikes was 45.8 with a range of 30.5 to 60.5.

The potential for N loss was the largest in 2019 where rainfall was five inches over the long-term average. Excessive rainfall during the 2019 spring growing season resulted in below average yields compared to other years (Table 1). Nitrogen loss may have been the main factor for lower yields, though other factors may have contributed to the low yields. However, diseases were not an observed problem. Instinct II would only be effective on NH_4-N portion of UAN, and not the NO_3-N portion. The NO_3-N portion is about 25% of UAN. The loss of 25% of the N from excessive rainfall may have attributed to the lower yields across the treatments. Still, the Instinct II treatment, a nitrification inhibitor only had similar yields to UAN alone in 2019. Nitrogen loss was not an issue in 2020 and 2021 as evident by the leaf N content. Thus, a benefit would not be expected from a nitrification inhibitor for those years. However, yields were significantly lower for Instinct II compared to UAN alone. These yield differences could not be explained by test weight, leaf N content, or spike number.

Growth regulators are often utilized by producers with the expectation that additional plant hormones will increase yields. However, the increase was not observed in this study. Yields and other agronomic traits were similar between Radiate and urea alone in 2019. However, yields were significantly lower for Radiate compared to urea alone in 2020 and 2021 (4.4 – 10.9%). The yield reduction could not be explained by test weight, leaf N content, or spike number.

SUMMARY AND CONCLUSION

In summary, Instinct II and Radiate were evaluated during three distinctly different growing seasons: abnormal wet with low yields, slightly dry with average yields, and slightly dry with high yields (Table 1). Instinct II did not increase yields in the three years of this study (Table 2). In two of the three years, observed yields were statistical lower than urea alone. Agronomic characteristics were similar between Instinct II and urea alone for test weight, leaf N content, and spike number for each year. Similar results were observed for Radiate (Table 2). Yields were similar to urea alone in 2019, but significant yield decreases were observed in the other two years. Agronomic measurements were similar between Radiate and urea alone for test weight, leaf N content, and spike number. The results of this study would suggest little benefit from the addition of Instinct II and Radiate to UAN in wheat on northwestern Ohio soils.

RE-EVALUATING PHOSPHORUS AND POTASSIUM MANAGEMENT FOR CORN, SOYBEAN, AND WHEAT IN ONTARIO

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ABSTRACT

In Ontario, long term trends show decreasing soil test P and K levels as high crop yields in corn, soybeans, and wheat remove more nutrients than are being replaced through nutrient application. Deficiencies or insufficient available P and K from either the soil, fertilizer applications, or both, could mean that modern yields of these crops are not fully reaching their potential. A long-term project was established between 2010 and 2012 on 4 field sites in Ontario to compare two different fertilizer strategies: the sufficiency approach (current OMAFRA recommendations), and the build-and-maintain approach. This project used various starters on fields varying in background soil test P and K. In Phase I, the "Build Phase" (completed in 2017), the regime of built P+K levels produced the highest yields of all 3 crops: corn, soybean, and wheat yields using starters at approximate replacement rates were 10.0, 3.0, and 11.4 bu/ac higher, respectively, than in the no-build regime using the same starter rates.

Phase II, the "Drawdown Phase", started in 2018 and was designed to validate the crop responses to both the sufficiency and build-and-maintain fertilization strategies. In the Drawdown Phase, only starter fertilizer treatments were used, the background levels of P and K had been carried on from the Build Phase. Yield responses in the Drawdown Phase were lower compared to those in the Build Phase, identifying that higher crop yield response was due to increased applied P and K fertilizer used to build P and K levels in the soil, instead of the replacement rates of starter fertilizer alone. In the Drawdown Phase, corn, soybean, and wheat yields were 5.9, 0.8, and 6.7 bu/ac higher, respectively, in the built P+K regime using starters at approximate replacement rates compared to the no-build regime using the same starter rates.

INTRODUCTION

Current recommendations from the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) for phosphorus and potassium application in corn, soybeans, and wheat are based on research data from the 1960s-1970s. Since these recommendations were developed, crop yields, crop nutrient uptake, and nutrient removal have increased significantly, and P and K soil tests have been decreasing. There is appetite within Ontario's agriculture industry to identify the best P and K fertility strategy for use with current yield trends: does a build-and-maintain approach provide improved long-term productivity than current recommendations based on the sufficiency approach?

This project is Phase II of a two-part study. Phase I's primary objective was to initiate trials in 4 locations across southwestern Ontario in a corn-soybean-wheat rotation, and establish plots of various P and K build strategies and P and K starter treatments. The outcome of Phase I was: in plots that were built to moderate P and K levels, crop yields were significantly higher compared to the strategy where P and K were applied at rates similar to current OMAFRA recommendations (sufficiency approach). However, these responses were generated with a “build” strategy rather than a “build and maintain” strategy, and so Phase II was initiated to identify whether the crop responsed to increased rates, or higher P and K background fertility.

Phase II compares the economic yield response of corn, soybean, and wheat in various P and K soil testing scenarios: no P&K build, built P, built K, and built P&K. Maintenance P and K will be applied to the built areas to keep soil test levels adequate. The study will also test various strategies of starter fertilizers within each management approach (build and maintain vs sufficiency), and test whether current OMAFRA P and K recommendations apply to high yield environments.

MATERIALS AND METHODS

Sites were introduced in 2011, 2012, and 2013 that identified as relatively low in soil test P (P <12 ppm Olsen) and K (K <80 ppm Ammonium Acetate). In Phase I, four levels of P and K fertility were established in a randomized strip-plot design, replicated four times, with the same fertility randomizations used each year across the corn-soybean-wheat rotation. The four “build regimes” were established in 4 strips per rep at each site by broadcasting 0-46-0 and/or 0-0-60 plus a no build control: 1. Control, 2. P_2O_5 only, 3. K_2O only, and 4. soil test P+K build. Fertilizer was broadcast and incorporated in the fall of every year at relatively high rates until the end of Phase I. The final crop year of Phase I ended in 2017.

Phase II started in 2018 at all sites. No more P and K fertilizer was broadcast-applied, starter treatments were maintained. The number and rates of starter varied slightly with each field site. Common across all corn and soybean sites were a control, liquid 6-24-6 applied at 3-5 US gal/ac in furrow, MAP applied at 100 lb/ac in a 2x2 band, potash applied at 80 lb/ac in a 2x2 band, and a 6-28-28 blend applied between 90-180 lb/ac (soybean) and 270 lb/ac (corn). Wheat starters were all applied in-furrow, including a control, liquid 6-24-6 applied at 3-5 US gal/ac, MAP at 80-100 lb/ac, potash at 70-80 lb/ac, and a blend of 6-28-28 applied at 90-225 lb/ac.

The highest starter treatment rates were approximately 50 lbs P2O5/ac and 50 lbs K2O/ac per cropping season. These rates were chosen at the onset of the experiment in 2011 to approximate rates (or exceed) the recommended P and K fertilizer rates under the “sufficiency approach” across a 3-crop rotation, assuming crop yields of corn, soybean and wheat were 180, 50 and 80 bu/ac.

Every plot was tested at startup for soil test P and K, as well as 4-5 times depending on the site during the study.

RESULTS AND DISCUSSION

Phase I of the study had an objective to build soil test P, K, or both to medium testing levels from the starting levels of the individual sites. This was called the “Build Phase”. Phase II of the study was called the “Drawdown Phase” because rates of P and K application across all sites were at or below crop removal rates. The Drawdown Phase will give the best comparison of the "sufficiency" approach to the "build and maintain" approach of fertilization.

Corn

Table 1. Grain corn yield responses to starters by P and K build regimes during the build and drawdown phases at 4 Ontario locations (2012-2021).

Build or drawdown phase	Build regime								Average across all regimes	
Starter regime	No build		P build only		K build only		P+K build			
Build phase (to 2017)	----------bu/ac----------									
No starter	156.9	d[1]	163.9	c	173.9	bc	188.9	c	170.9	d
6-24-6 @ 3-5 gal IF	167.0	c	176.8	b	177.8	b	191.7	bc	178.3	c
MAP @ 100 lb (2x2)	171.3	bc	175.0	b	187.3	a	195.3	ab	182.2	b
0-0-60 @ 80 lb (2x2)	174.7	b	190.5	a	172.6	c	193.0	bc	182.7	b
6-28-28@ 90-270 lb (2x2)	185.1	a	192.4	a	188.7	a	198.0	a	191.0	a
Drawdown phase (2018-2021)										
No starter	142.4	d	142.9	c	170.6	c	183.3	b	159.8	d
6-24-6 @ 3-5 gal IF	153.5	c	159.4	b	174.5	bc	185.2	ab	168.2	c
MAP @ 100 lb (2x2)	150.8	c	148.1	c	183.0	b	188.7	ab	167.7	c
0-0-60 @ 80 lb (2x2)	173.0	b	185.7	a	172.6	c	185.5	b	179.2	b
6-28-28@ 90-270 lb (2x2)	184.3	a	185.6	a	190.6	a	193.0	a	188.4	a

[1]Means within column of each build and drawdown phase followed by the same letter are not statistically different at P=0.05.

Table 2. Grain corn yield responses to P and K build regimes with and without high-rate starter during the build and drawdown phases across 4 Ontario locations (2012-2021).

Build or drawdown phase[3]	Build regime[2]								P>F across regime
Starter regime	No build		P build only		K build only		P+K build		
Build phase (to 2017)	----------bu/ac----------								
No starter	156.9	d[1]	163.9	c	173.9	b	188.9	a	<0.0001
P+K starter only	187.5	c	195.0	b	189.7	bc	197.5	a	0.0014
Drawdown phase (2018-2021)									
No starter	142.4	c	143.0	c	170.6	b	183.3	a	<0.0001
P+K starter only	188.0	a	189.3	a	191.6	a	193.9	a	0.5377

[1]Means within row followed by the same letter are not statistically different at P=0.05.
[2]No build=starter only; P+K build=broadcast 0-46-0 and/or 0-0-60 during the fall up to and including 2016.
[3]P+K starter only=highest rate of 6-28-28 applied as a starter at each location (up to 270 lb/ac).

During the Build Phase, the highest corn yields were produced where soil test values were built up in both P and K. Corn yields responded to a starter blend of P and K in the "no build" plots by 28 bu/ac across 21 site-years of this study. As expected, corn response to starter fertilizers was lower in the higher soil test P and/or K built strips. None of the starter rates applied in the non-built plots could produce yields as high as those in P+K built plots with the starter. The high corn yields in the P+K built soils may be partially due to responses to P and K fertilizers broadcast to build the soil test levels in this treatment, hence the need to assess corn responses when soils are not being built (i.e., just maintained) in the Drawdown Phase (2018-2021).

In the Drawdown Phase, no P or K fertilizer was broadcast. Only the high-rate starter fertilizer treatments approximated a "P+K maintain" scenario; other stater treatments resulted in higher P and K removals in the grain than was applied. The highest corn yields were produced in the P+K built soils, but the yield response between the no-build regime and the P+K built regime was slightly less than the Build Phase. Based on a trend that occurred at all 4 site-years, it may be argued that the average +5.9 bu/ac response to built P+K levels (compared to not built) is real despite the lack of statistical significance across 4 sites.

Soybean

Table 3. Soybean yield responses to starters by P and K build regimes during the build phase and drawdown phases at 4 Ontario locations (2012-2021).

Build or drawdown phase	Build regime								Average across all regimes	
Starter regime	No build		P build only		K build only		P+K build			
Build phase (to 2017)	----------------------------------bu/ac----------------------------------									
No starter	51.9	c[1]	53.5	c	54.5	b	58.6	b	54.6	c
6-24-6 @ 3-5 gal IF	53.5	b	54.9	b	55.1	b	58.8	ab	55.5	b
MAP @ 100 lb (2x2)	54.6	b	55.3	b	57.5	a	59.8	a	56.8	a
0-0-60 @ 80 lb (2x2)	53.5	b	56.7	a	52.4	c	58.4	b	55.2	bc
6-28-28@ 90-270 lb (2x2)	56.0	a	57.3	a	57.3	a	59.4	ab	57.5	a
Drawdown phase (2018-2021)										
No starter	53.6	c	55.7	c	58.4	b	61.9	ab	57.4	c
6-24-6 @ 3-5 gal IF	55.4	bc	56.9	bc	59.1	b	60.6	bc	58.0	c
MAP @ 100 lb (2x2)	57.2	b	57.3	bc	62.5	a	62.9	a	60.0	b
0-0-60 @ 80 lb (2x2)	55.6	b	59.1	b	55.9	c	59.7	c	57.6	c
6-28-28@ 90-270 lb (2x2)	61.0	a	61.9	a	61.4	a	62.2	ab	61.6	a

[1]Means within column of each build and drawdown phase followed by the same letter are not statistically different at P=0.05.

Table 4. Soybean yield responses to P and K build regimes with and without high-rate starter during the build and drawdown phases across 4 Ontario locations (2012-2021).

Build or drawdown phase[3]	Build regime[2]								P>F across regime
Starter regime	No build		P build only		K build only		P+K build		
Build phase (to 2017)	----------------------------------bu/ac----------------------------------								
No starter	51.9	c[1]	53.5	b	54.5	b	58.6	a	<0.0001
P+K starter only	56.7	b	58.1	ab	57.8	b	59.7	a	0.0043
Drawdown phase (2018-2021)									
No starter	54.2	c	55.7	c	58.4	ab	61.9	a	<0.0001
P+K starter only	62.0	a	62.7	a	61.4	a	62.7	a	0.6472

[1]Means within row followed by the same letter are not statistically different at P=0.05.
[2]No build=starter only; P+K build=broadcast 0-46-0 and/or 0-0-60 during the fall up to and including 2016.
[3]P+K starter only=highest rate of 6-28-28 applied as a starter at each location (up to 270 lb/ac).

During the Build Phase, soybeans responded to a starter blend of P and K in the no-build regime by 4.1 bu/ac across 21 site-years of the study, compared to a response of less than 1 bu/ac in the P+K built plots. This study supports existing work that soybeans respond to starter fertilizers when soil test levels are low; response to starter fertilizer becomes less as soil test values increase. This study has shown P nutrition is critical for the highest soybean yield; potash by itself was not sufficient to maximize soybean yield.

In the Drawdown Phase, soybean yields were similar in both the no-build and P+K built regimes where a high-rate starter was applied; the lack of response contrasts with the Build Phase, which showed 3 bu/ac higher soybean yields in the P+K built regime compared to the no-build regime. Based on this outcome, it may be argued that soybean yields did not respond to built P+K where starter was applied at removal rates.

Wheat

Table 5. Wheat yield responses to starters by P and K build regimes during the build phase and drawdown phases at 4 Ontario locations (2012-2021).

Build or drawdown phase	Build regime								Average across all regimes	
Starter regime	No build		P build only		K build only		P+K build			
Build phase (to 2017)	----------------------------------bu/ac----------------------------------									
No starter	66.7	c[1]	85.7	c	68.7	c	91.6	ab	78.2	c
6-24-6 @ 3-5 gal IF	73.8	b	87.5	bc	76.3	b	91.3	b	82.2	b
MAP @ 100 lb IF	82.1	a	89.2	ab	87.2	a	94.2	a	88.2	a
0-0-60 @ 80 lb IF	68.6	c	90.1	ab	69.9	c	88.5	c	79.3	c
6-28-28@ 90-270 lb IF	82.2	a	91.6	a	85.6	a	93.2	ab	88.1	a
Drawdown phase (2018-2021)										
No starter	70.7	c	86.4	c	76.5	c	93.2	ab	81.7	c
6-24-6 @ 3-5 gal IF	81.1	b	89.1	bc	84.7	b	93.8	ab	87.2	b
MAP @ 100 lb IF	88.9	a	90.4	b	93.1	a	95.8	a	92.0	a
0-0-60 @ 80 lb IF	71.3	c	91.2	b	74.6	c	91.5	b	82.1	c
6-28-28@ 90-270 lb IF	88.8	a	94.9	a	92.0	a	95.9	a	92.9	a

[1]Means within column of each build and drawdown phase followed by the same letter are not statistically different at P=0.05.

Table 6. Wheat yield responses to P and K build regimes with and without high-rate starter during the build and drawdown phases across 4 Ontario locations (2012-2021).

Build or drawdown phase[3]	Build regime[2]								P>F across regime
Starter regime	No build		P build only		K build only		P+K build		
Build phase (to 2017)	----------------------------------bu/ac----------------------------------								
No starter	66.7	c[1]	85.7	b	68.7	c	91.5	a	<0.0001
P+K starter only	82.3	c	92.5	a	86.7	b	93.7	a	<0.0001
Drawdown phase (2018-2021)									
No starter	70.6	d	86.3	b	76.4	c	93.1	a	<0.0001
P+K starter only	90.7	c	94.9	ab	92.9	bc	97.4	a	0.0094

[1]Means within row followed by the same letter are not statistically different at P=0.05.
[2]No build=starter only; P+K build=broadcast 0-46-0 and/or 0-0-60 during the fall up to and including 2016.
[3]P+K starter only=highest rate of 6-28-28 applied as a starter at each location (up to 270 lb/ac).

Winter wheat yields responded to MAP placed in-furrow in the no-build regime by 15.4 bu/ac; the addition of potash to the MAP did not increase yield in the Build Phase. On soils with built P+K, wheat showed less than 3 bu/ac response to any starter fertilizer compared to no starter. This study found that wheat is responsive to starter fertilizers especially when soil test levels are low, and that winter wheat is highly responsive to starter P. Results from the Build Phase of this study demonstrate that the sufficiency approach yielded significantly less (11.4 bu/ac) than soils that have been built with higher P and K; however, Phase II is necessary to identify whether the response was due to higher amounts of P and K that were broadcast to build soil test levels.

In the Drawdown Phase, 6.7 bu/ac higher wheat yields were produced in the P+K built regime using a high-rate starter compared to the no-build regime. Again, significant response was shown to starters including higher rates of P in-furrow in when soil test P was low, whereas starters low in P performed adequately when soil test P was built.

SUMMARY

This long-term project was established to compare various starters on various background P and K levels to compare two fertilizer strategies: the sufficiency approach (current OMAFRA) vs. a build-and-maintain approach. The highest grain yields of all 3 crops were produced with moderate soil test levels of P and K.

Soils low in both P and K did not respond to P fertilizer unless potash was applied. This was particulary evident at the Elora site.

During the Build Phase, it was determined that corn, soybean, and wheat yields using high-rate starter (at approx. replacement rates) were 10, 3, and 11 bu/ac higher, respectively, in the P+K build regime, compared to the no-build regime. The Drawdown Phase was initiated to determine whether these yield increases were the result of increased fertilization rates for the built regimes, compared to maintenance levels once soil test P and K are built. Corn, soybean, and wheat yields were 5.9, 0.8, and 6.7 bu/ac higher, respectively, in the P+K built regime with replacement rate starter compared to the same rate starter that was applied in the no-build regime during the Drawdown Phase.

In addition to this study, an M.Sc. thesis was produced by Mr. Harpreet Hanza at the University of Guelph, which analyzes the effects of the various build regimes in both phases of this study on P+K concentration in the grain, nutrient removal from the soil, and changes in soil test P+K.

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CARRYOVER EFFECTS OF SULFUR FERTILIZATION FROM ONE CROPPING SEASON TO THE NEXT

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ABSTRACT

Corn and soybean grain yield increases with S fertilization are not uncommon in Indiana. Low rates of S fertilizer (<15-20 lb S/acre) are needed to maximize grain yield response. We found that sulfate-S fertilizer applied to silt loam or heavier textured soils in one cropping season provided S to the crop grown the next season more often than not. At some S responsive locations, S applied the prior season at 10 to 20 lb S/acre produced yields of the second crop equivalent to crop yields with in-season fertilization. Continued research is needed to determine the soil, weather, and management factors that affect the magnitude of carryover and to ascertain the predictability of S carryover from one crop to the next.

COMPARING YIELD GOAL AND MAXIMUM RETURN TO N BASED METHODS IN PREDICTING CORN ECONOMIC OPTIMAL NITROGEN RATES

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INTRODUCTION

Nitrogen (N) is an essential plant nutrient commonly applied to South Dakota (SD) corn crops and is critical for optimizing corn yield. For commercial agriculture, there are two main sources of N for corn—N from decomposing manure, residue, and soil organic matter (mineralization) and synthetic N fertilizers. Each year, corn plants take up 98 to 250 lbs N/ac (average = 150 lbs N/ac) (Sierra, 1992; Kuzyakova et al., 2006; Blagodatskaya and Kuzyakov, 2008; Wu et al., 2008). Nitrogen derived from decomposing organic matter (i.e., mineralization) can provide 20 to 100% of the N required to optimize yield depending on factors like weather, soil type, previous crop, and management practices (Khan et al., 2001; Ros et al., 2011; Yost et al., 2012). The crop N need that is not supplied through mineralization is most often supplied by N fertilizer. However, excessive N fertilizer applications can reduce fertilizer efficiency, create environmental contamination issues, and reduce grower profits (Ribaudo et al., 2011; Cavigelli et al., 2012; Helmers et al., 2012; Struffert et al., 2016; USEPA, 2018). Thus, it is imperative to continually improve the accuracy of our corn N rate recommendations. At this time, there are two main N rate recommendation systems used in the U.S.–Yield goal and maximum return to N (MRTN) (Morris et al., 2018).

The yield goal approach was developed in the 1970s and was the main system for creating corn N recommendations until the maximum return to N approach was developed in 2005 (Sawyer et al., 2006; Morris et al., 2018). One of the greatest strengths of the yield goal approach is its simplicity, but that simplicity is likely not able to account for some of the challenges in using the yield goal approach, including being able to estimate yield, internal N efficiency (i.e., lbs N/bu corn) and other fertilizer use efficiency factors at the beginning of the season (Morris et al., 2018). The MRTN approach was developed to determine N rate recommendations based on N response data from each state or region. For more details see Sawyer et al. (2006). Data that initially went into creating the MRTN database did not include data from SD. Additionally, the current yield goal based system in SD has not been reevaluated for accuracy since 2013 (Kim et al., 2013). Therefore, the objective of this project was to 1) evaluate the accuracy of the current yield goal-based equation used in SD, which includes yield potential (goal), 1.2 lbs N/bu corn multiplier (coefficient), pre-plant soil test N (0 to 24 inches), previous crop, manure application, and tillage type and 2) create a database of N response trials for SD and evaluate the accuracy of using the MRTN approach for predicting N requirements.

MATERIALS AND METHODS

Forty-five corn N rate response trials were conducted at field locations across central and eastern SD from 2018-2022. Site locations varied in tillage practice, crop rotation, and soil type. Specifically, 32 in conventional till and 13 in no-till fields. The previous crop was soybean at 35 locations, and wheat, corn, or sunflower at 10 locations. Nitrogen fertilizer was applied before planting at rates from 0 to 200 lbs N ac^{-1} in 40 lb increments. Nitrogen fertilizer as urea (46-0-0) with a urease and nitrification inhibitor to minimize N loss potential was broadcast on the soil surface. Fertilizer was incorporated if conventional tillage practices were used or remained on the soil surface when no tillage was used. Soil samples were collected before planting and fertilizer application from the 0-6 and 6-24 in. depth increments and analyzed for nitrate-N (Nathan et al., 2015). Corn grain yield was determined by harvesting the center two rows of each plot and adjusting grain weight to 15.5% moisture.

Economic optimal N rates were determined by modeling the relationship between corn yield and N fertilizer rate by averaging the results from both the linear-plateau and quadratic-plateau models using a N fertilizer price to corn price ratio of 0.1 (Miguez and Poffenbarger, 2022). If no plateau was reached within the N rates used in the study, the economic optimal N rate was set to the maximum N rate used at that location. The lbs N/bu corn multiplier (coefficient) was calculated for each site by adding the amount of N fertilizer needed to optimize corn yield and the nitrate-N in the soil from 0 to 24 in. and dividing it by the optimal corn yield (e.g., (soil test N + economic optimal N fertilizer rate) / optimal grain yield). Four of the 45 sites were not included due to extreme drought conditions. For the yield goal approach, the N rate recommendation for each of the remaining 41 locations was calculated using three multipliers (1.2, 1.0, and 0.8). The 41 site-years of response trials were input into a database developed by John Sawyer at Iowa State University (Sawyer et al., 2006, personal communication). This spreadsheet was used to calculate an MRTN for all of SD as well as divided into a central and eastern region. The accuracy of the N recommendation for the yield goal and MRTN approaches was calculated by subtracting the actual EONR from the predicted EONR. The closer these numbers were to 0, the more accurate the recommendation. If numbers were positive, it meant an over application of N was recommended while negative numbers meant an under application of N was recommended. The mean, median, lower 25th quartile, upper 75th quartile and root mean square error (RMSE) of these calculations was completed to help in comparing the accuracy of each N recommendation approach.

RESULTS AND DISCUSSION

Yield Goal Approach

Across the 41 locations, corn yields ranged from 75 to 255 bu/ac with an average of 185 bu/ac while the optimal N rate ranged from 0 to 200 lbs N/ac with an average of 96 lbs N/ac (Figure 1a). The lbs N/bu corn multiplier (coefficient) ranged between 0.4 and 1.8 lbs N/bu corn with an average near 1.0 lbs N/bu corn (Figure 1b). These results demonstrate that the average amount of N to produce a bushel of corn has decreased from the previous 1.2 value. The reduction of this value is not new. In 1975, the multiplier (coefficient) was 1.45 and was reduced to 1.3 in 1982, to 1.2 in 1991, and in

2023 our research supports it being reduced to 1.0.

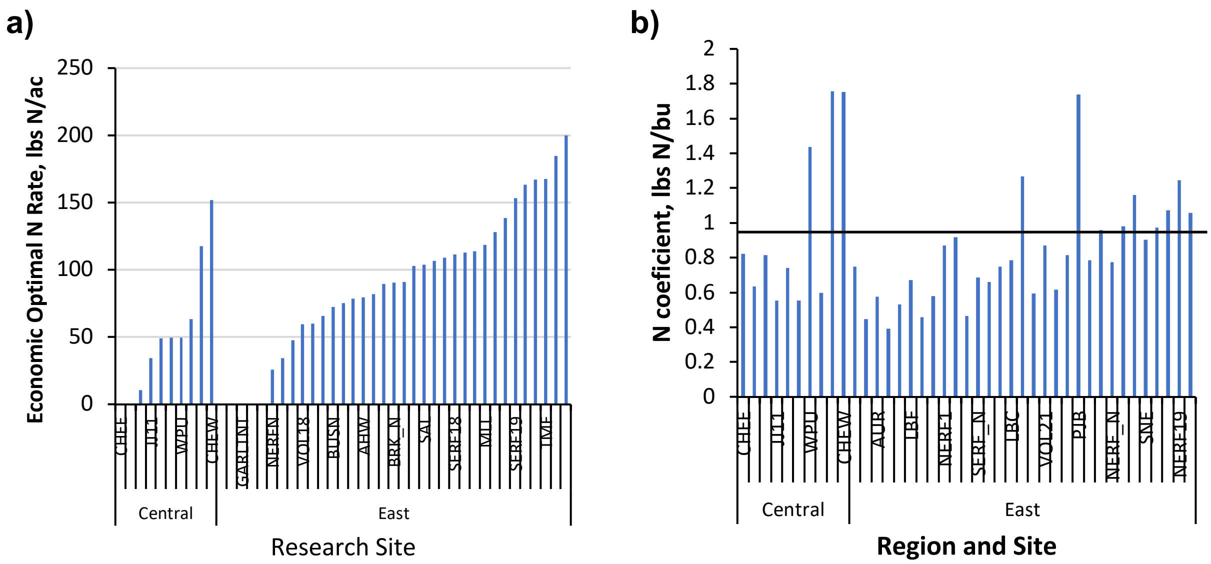

Figure 1. The a) corn economic optimal N rate (EONR) and b) amount of N fertilizer needed to produce one bushel of corn at research sites across South Dakota from 2018 to 2022. Black line represents the mean lbs N/bu corn multiplier value.

The N fertilizer rate equation accuracy was assessed using three different multipliers—the previously used 1.2 lbs N/bu corn, the new average of 1.0 lbs N/bu corn and a multiplier of 0.8 lbs N/bu corn. We calculated the N rate recommendation for each of the 41 locations using the three multipliers (1.2, 1.0, and 0.8). The recommended N rate was then subtracted from the actual rate determined at each location. The closer these numbers were to 0, the more accurate the recommendation. If numbers were positive, it meant an over application of N was recommended while negative numbers meant an under application of N was recommended. On average across all locations, using a multiplier of 1.2 resulted in an over application of 48 lbs N/ac, a multiplier of 1.0 an over application of 13 lbs N/ac, and a multiplier of 0.8 an under application of 22 lbs N/ac. These results demonstrate that reducing the multiplier from 1.2 to 1.0 or 0.8 improved the accuracy of N rate recommendations by 35 and 26 lbs N/ac, respectively. However, using the 1.0 multiplier compared to the 1.2 and 0.8 multipliers more evenly distributed the accuracy results around the 0-difference value (Figure 3). This result is demonstrated as using the 1.2 multiplier overestimated 78% and underestimated 22% of the time, the 0.8 multiplier overestimated 34% and underestimated 66% of the time, and the 1.0 multiplier overestimated 63% and underestimated 37% of the time. Thus, the 1.2 multiplier most frequently overestimated, while the 0.8 multiplier underestimated, and the 1.0 multiplier most evenly split whether it over- or underestimated N fertilizer requirement. Therefore, the multiplier (coefficient) of 1.0 instead of 1.2 or 0.8 provides the most accurate N fertilizer rate recommendations. Economically, the 35 lbs N/ac improvement in N rate recommendations by changing from a multiplier of 1.2 to 1.0 can save SD farmers $36/ac.

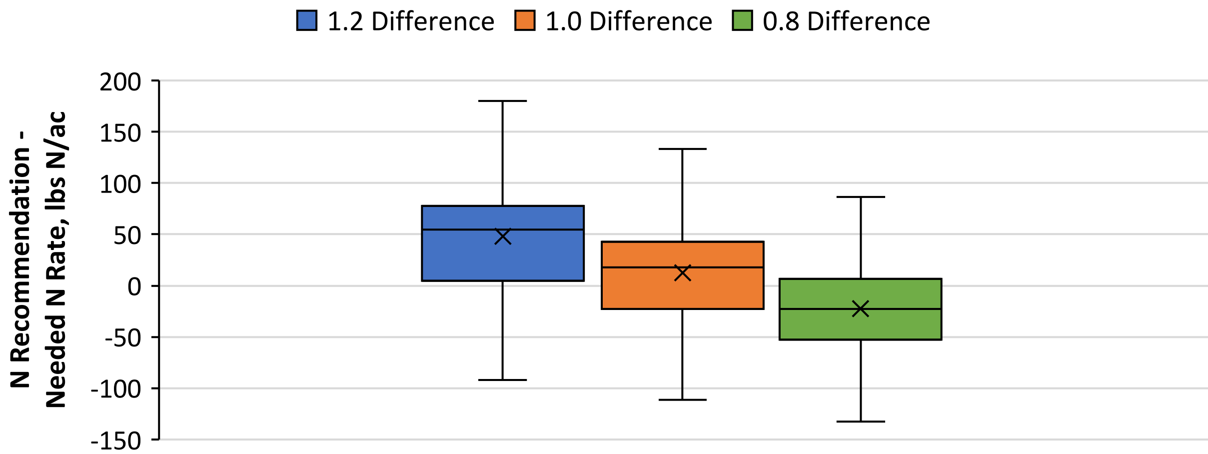

Figure 2. The accuracy of N fertilizer recommendations using three different lbs N/bu corn multipliers (1.2, 1.0, and 0.8) across 45 locations from 2018 to 2022. Accuracy as shown by the Y axis is determined by taking the N recommendation calculated using each of the multipliers and subtracting it from the N fertilizer rate needed at each location. Values closest to 0 are most accurate. Values above 0 are over applications and values below 0 are under applications. The box midline represents the median, the 'x' marks the mean, the upper and lower edges of the box represent the 25th to 75th percentiles, and the whiskers represent the range of data.

MRTN Approach

The MRTN for the state of SD at a N price to corn price ratio of 0.15 was 97 lbs. N/ac and when divided into regions it was 60 lbs. N/ac for central and 102 lbs. N/ac for eastern SD. On average across all locations using the MRTN for all of SD, the accuracy ranged between -103 and +97 lbs N/ac (Figure 3 and Table 1). For only the eastern region the accuracy ranged between -98 and +102 lbs N/ac while the central region ranged between -92 and +60 lbs N/ac. Averaged across all sites, there was a mean over application of 8 lbs N/ac, and when divided into eastern and central regions a mean overapplication of 1 and 7 lbs N/ac, respectively. The RMSE also decreased from ±51 lbs N/ac when using an MRTN for the entire state to ±46 and ±47 lbs N/ac when divided into eastern and central regions, respectively. These results indicate that the MRTN approach is most accurate when dividing SD into central and eastern regions, most likely due to the greater chance of moisture limiting corn yields in central compared to eastern SD.

In comparing the MRTN and yield goal results, the mean accuracy improved by 4 to 12 lbs N/ac and the RMSE improved by ±4 to ±9 lbs N/ac (Table 1). Further, the MRTN compared to the yield goal approach is slightly more accurate using the current dataset from 2018-2022. However, the results between the yield goal and MRTN approach are not large enough to say one approach is definitively better than the other. Nitrogen response trials will continue to be conducted and added to the yield goal and MRTN databases to see how these approaches differ over time and with an increased number of sites in the database.

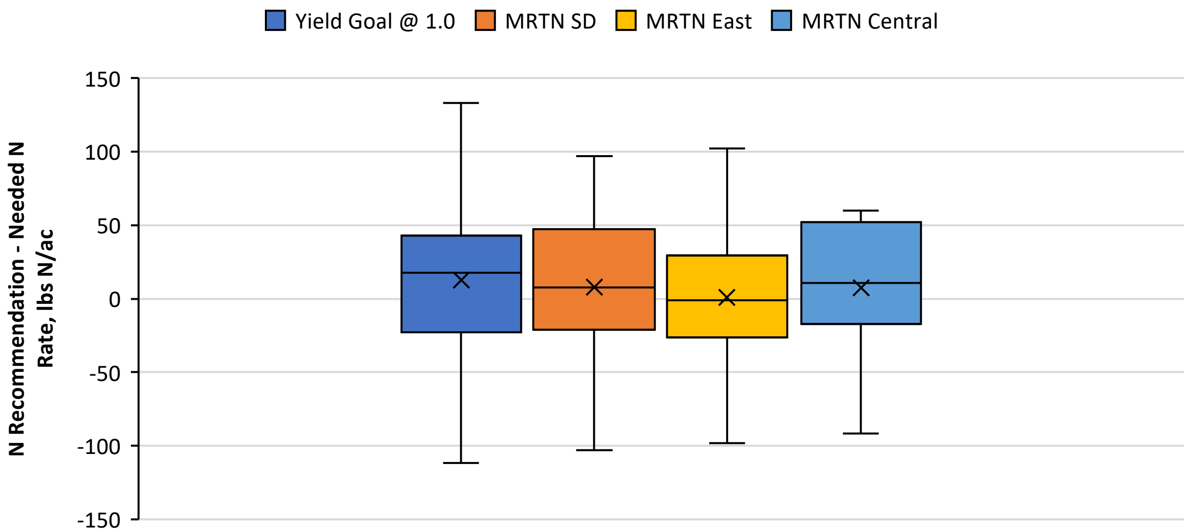

Figure 3. The accuracy of N fertilizer recommendations using yield goal approach with the 1.0 lbs N/bu corn multiplier and three maximum return to N methods across all sites or divided into eastern and central regions. Accuracy as shown by the Y axis is determined by taking the N recommendation calculated using each method and subtracting it from the N fertilizer rate needed at each location. Values closest to 0 are most accurate. Values above 0 are over applications and values below 0 are under applications. The box midline represents the median, the 'x' marks the mean, the upper and lower edges of the box represent the 25th to 75th percentiles, and the whiskers represent the range of data.

Table 1. Descriptive statistics regarding the accuracy of N rate recommendations using yield goal approaches with three different lbs N/bu corn multipliers and the maximum return to N (MRTN) approach with the state as one region and divided into east and central regions.

Statistic	Yield Goal @ 1.2	Yield Goal @ 0.8	Yield Goal @ 1.0	MRTN SD	MRTN East	MRTN Central
	lbs N/ac					
Min	-92	-133	-112	-103	-98	-92
Max	180	86	133	97	102	60
Mean	47	-23	13	8	1	7
Median	55	-23	18	8	-1	11
Upper 75th quartile	76	6	42	47	28	43
Lower 25th quartile	9	-52	-17	-20	-21	-0.12
RMSE, ±	76	55	55	51	46	47

ACKNOWLEDGEMENT

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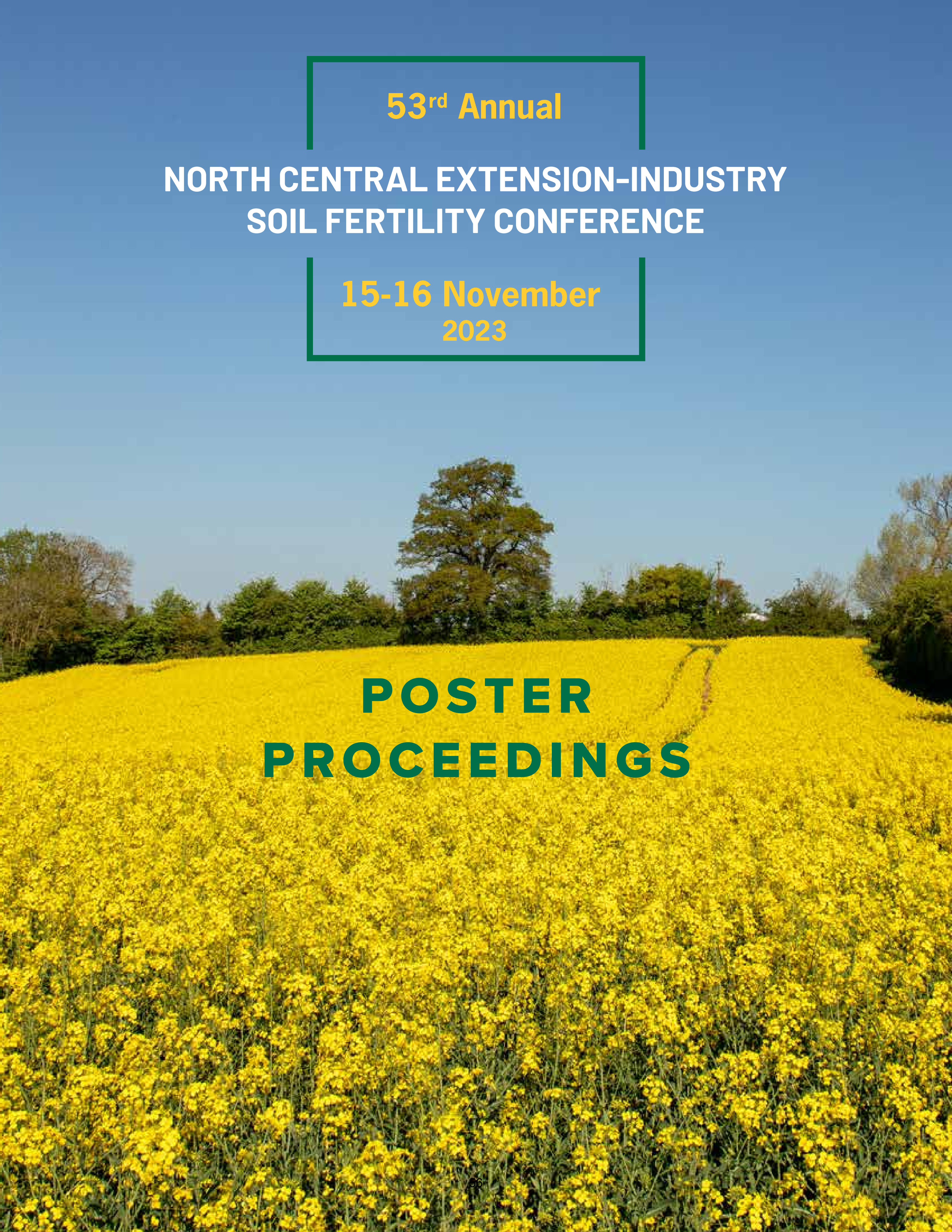

EFFECTS OF VARIABLE NITROGEN FERTILIZER RATES ON CORN GRAIN YIELD, PROFITABILITY, AND NITROGEN LOSSES IN SOUTHWESTERN MINNESOTA

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ABSTRACT

Global corn (*Zea mays L.)* production heavily relies on the application of nitrogen (N) fertilizers, which unfortunately comes with environmental concerns. The primary pathways N is lost to the environment are through nitrate leaching into groundwater, ammonia volatilization, and nitrous oxide emissions to the atmosphere. This ongoing study started in 2021 at the University of Minnesota Southwest Research and Outreach Center in Lamberton, MN, to comprehensively assess the effects of varying N fertilizer rates (0 to 320 lbs N ac^{-1} in 80 lbs N ac^{-1} increments) on corn grain yield, profitability, and N loss (nitrate, nitrous oxide, and ammonia). The N rates were split applied with 80 lbs N ac^{-1} as ESN pre-plant and the rest of the N was applied as Agrotain (urea + N-(n-Butyl) thiophosphoric triamide) at V6 development stage. The economic optimum N rate (EONR) was calculated at a fertilizer to corn price ratio of 0.1 US\$0.5 lb^{-1} N and \$5 bushel^{-1} of corn. The EONR in 2021 was 116 lb N acre^{-1} and the grain yield at the EONR was 106 bu acre^{-1} while in 2022, the EONR was 158 lb N acre^{-1} and the grain yield at the EONR was 111 bu acre^{-1}. The low yield and EONR reflected drought conditions in 2021 since there was minimal nitrate leaching (1.6 lbs NO_3-N ac^{-1}), minimal nitrous oxide emissions (0.48 lbs N_2O-N ac^{-1}) with the only significant emissions occurring after rainfall events, and ammonia volatilization was relatively low (1.4 lbs NH_3-N ac^{-1}) and similar between treatments. Compared to 2021, in 2022, early-season precipitation caused three times more N loss as nitrate leaching and two times more nitrous oxide emissions on average but slightly less ammonia volatilization and likely contributed to a higher EONR. However, dry conditions for the remainder of the growing season along with corn rootworm damage resulted in low grain yield. The 2023 season contrasted the previous seasons with more rainfall and ammonia volatilization being five times less on average than 2022 but preliminary analysis showed greater NO_3-N and N_2O-N emissions, indicating weather has a profound influence on N management.

INTRODUCTION

Minnesota plays a major role in corn production, being one of the largest corn producers in the US. Corn production relies on N fertilizer, but excessive use harms farmers profits and the environment. Nitrate leaching impacts surface and groundwater quality and nitrogenous gas losses to the atmosphere result in climate change and ecosystem degradation. All these environmental impacts also cause human health concerns, loss of diversity to ecosystems, and economic costs.

Studies that concurrently evaluate the various N loss processes are limited, especially studies that evaluate various loss pathways at the same location and time due to infrastructure and cost limitations. In addition, older studies are outdated due to changes in agriculture, technology, and climate. There is an imperative need to research systematically the effects of N rate on corn grain production and N losses via nitrate leaching from drain tiles, and nitrogenous gas losses as ammonia and nitrous oxide emissions. This research, conducted with an adequate number of N rates, allows us to define the point of intersection (optimum N rate) between profitable corn production and N loss to the environment. Having this information can allow us to generate data-driven scenarios to better determine the possible environmental and agronomic outcomes when the N rate departs from the optimum.

MATERIALS AND METHODS

Field experiments were conducted at the Southwest Research and Outreach Center (SWROC) in Lamberton, Minnesota in existing tile-drain plots that were established in 1994. Each of the 15 individual drainage plots has a tile line and is isolated by a plastic barrier to prevent lateral water flow from adjacent plots. Before this project, the site was under continuous corn production since 2014 with an annual application of 180 lb N ac^{-1}.

Starting in the 2021 growing season, five N rates in 80 lb N ac^{-1} increments (0, 80, 160, 240, 320 lb N ac-1) were applied in a randomized complete block design with three replications in a continuous corn cropping system. The N rates were applied as 80 lb N ac^{-1} at pre-plant using the polymer coated urea ESN (44-0-0, N-P-K), which was broadcast and incorporated with tillage. The remainder N was applied at the V6 corn growth development stage using urea (46-0-0, N-P-K) with the urease inhibitor Agrotain: N-(n-Butyl) thiophosphoric triamide (NBPT) to minimize volatilization losses, as the fertilizer was broadcast and left on the soil surface.

The site received primary tillage in the fall. Before planting every season samples were collected to determine general soil fertility parameters and to determine if adjustments were necessary. In the spring pre-plant N treatments were applied, incorporated with secondary tillage for seedbed preparation, planted with DKC 49-44 at 35,000 seeds ac^{-1}, and ammonia traps, nitrous oxide chamber emission bases, and moisture and temperature sensors were installed. The split nitrogen application was done at V6 development stage as well as the final plant population.

Agronomic responses were measured in several ways. Soil N (NH_4^+-N and NO_3-N) samples were collected from the 0-12-, 12-24-, and 24–36-inch depth increments before planting and after grain harvest and from the first two depth increments only at the V10 development stage. Canopy sensing data (NDVI and NDRE) was collected with a RapidScan at V8, V10, and V12 development stages. Plant biomass and nitrogen content was measured at V10 and R6 development stage. Lower stalk samples for nitrate-N analysis were also collected at R6 development stage. Grain yield and grain N content were measured at harvest. Plant N content and biomass were used to calculate crop N use efficiency parameters.

Nitrate leaching was measured continuously from each plot with automated sampling equipment. The sampling began each field season as soon as the frost was off the soil profile. Flow-proportionate water samples were collected and analyzed for nitrate concentrations and along with flow data, were used to calculate total nitrate loads and flow-weighted concentrations of nitrate. Nitrous oxide emissions were collected approximately two to three times per week from April through July, two times per week during August and September, and weekly thereafter until grain harvest. Measurements were done with a novel portable high-accuracy nitrous oxide and carbon monoxide gas analyzer and flux calculations were done using R studio. Ammonia emissions were measured with semi-static chambers following an acid trap methodology. Ammonia emissions were captured in traps that were sampled 1, 4, 7, 14, 21, and 28 days after each fertilizer application.

Regression analysis was used to develop response curves to N rate. This analysis was used to determine the EONR and grain yield at the EONR and to calculate the points of intersection between the EONR curve and the curves for the nitrogen loss parameters in the study. This analysis allowed us to evaluate the relationship that exists between agronomic and environmental parameters at different N rates and to determine the cost benefit relationship between these variables.

RESULTS AND DISCUSSION

Preliminary results indicate a positive response to N rate. This finding suggests that manipulating N levels can potentially enhance crop performance. However, it is essential to note that grain yields were consistently low for 2021 and 2022. Despite 2022 being drier overall compared to 2021, the observation of a greater EONR in 2022 (158 lbs N ac^{-1}) in comparison to 2021 (116 lbs N ac^{-1}) is intriguing. This shift in EONR is likely a result of increased NO_3-N leaching and N_2O-N losses, triggered by episodic rain events during 2022. Low yields and EONRs highlight that moisture was the most limiting factor rather than N for the 2021 and 2022 growing seasons (Fig. 1 and 2, Table 1).

Throughout the growing season, N_2O fluxes remained relatively low, except for the higher N rates following precipitation events (Fig. 3 and 4). This suggests that N_2O emissions are particularly sensitive to N application timing and rates. Precipitation, particularly in relation to the timing of fertilizer application, had a substantial and contrasting impact on N losses. Precipitation increased N_2O and NO_3 losses, whereas NH_3 losses decreased under similar conditions. Notably, NH_3 emissions surged shortly after fertilization, regardless of timing or rate of fertilization, with drier conditions post-fertilization intensifying these emissions. These variations in emission levels were evident when comparing 2021, the driest year, with 2023, the wettest year (Fig. 5).

A general trend of increased N losses with higher N application rates was apparent, although the differences were relatively small. At the highest N rates, grain yields also decreased. This is unusual in corn but could be attributed to larger biomass development early in the season that might have resulted in more evapotranspiration, and ultimately resulting in water stress during the dry growing seasons. This further reinforces the importance of managing N rates and timing to optimize yields. In conclusion, these findings shed light on the complex interplay of N management, moisture availability, and precipitation patterns in shaping crop performance and environmental outcomes. Managing N effectively, considering both rate and timing in the context of local weather conditions, is crucial for optimizing yields while minimizing environmental impacts.

Table 1. Cumulative NO_3-N load, flow weighted NO_3-N concentration, cumulative N_2O-N emissions, cumulative NH_3 emissions, and grain yield for 2021 and 2022. Within column and year, means followed by the same letter are not significantly different from one another (P<0.10)

Treatment	Cumulative NO_3 Load	Average Flow Weighted NO_3	Cumulative N_2O Emissions	Cumulative 56 day NH_3 Emissions	Grain Yield
lbs ac^{-1}	lbs ac^{-1}	mg L^{-1}	lbs ac^{-1}	lbs ac^{-1}	bu ac^{-1}
			2021		
0	0.8A	5.2B	0.05A	1.40A	82B
80	1.5A	7.1AB	0.16A	1.31A	100AB
160	2.3A	7.0AB	0.52A	1.45A	113A
240	1.2A	8.5A	0.73A	1.39A	100AB
320	2.0A	7.9AB	0.96A	1.32A	91AB
			2022		
0	0.7B	2.8A	0.08C	1.11A	67B
80	3.1AB	3.9A	0.12C	1.25A	99AB
160	11.3A	9.8A	0.54BC	1.20A	110A
240	5.9AB	7.8A	2.06AB	1.04A	111A
320	6.3AB	11.6A	3.23A	1.12A	100AB

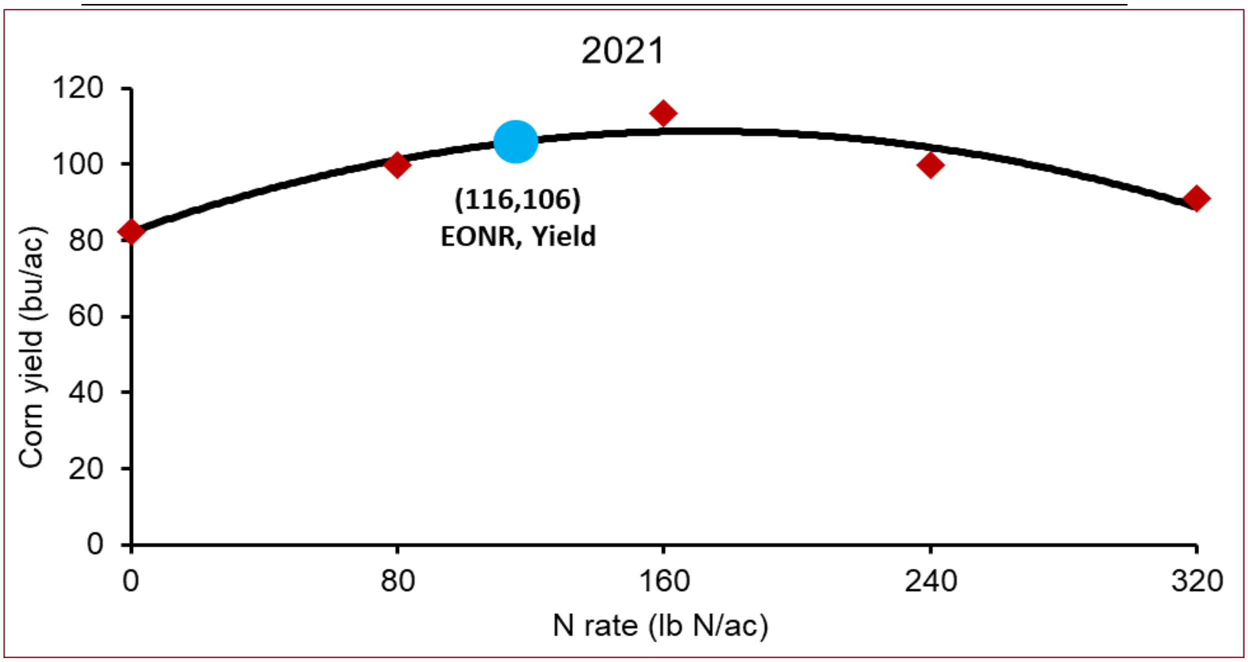

Figure 1. Agronomic trends in 2021 corn yields: quadratic regression analysis and EONR

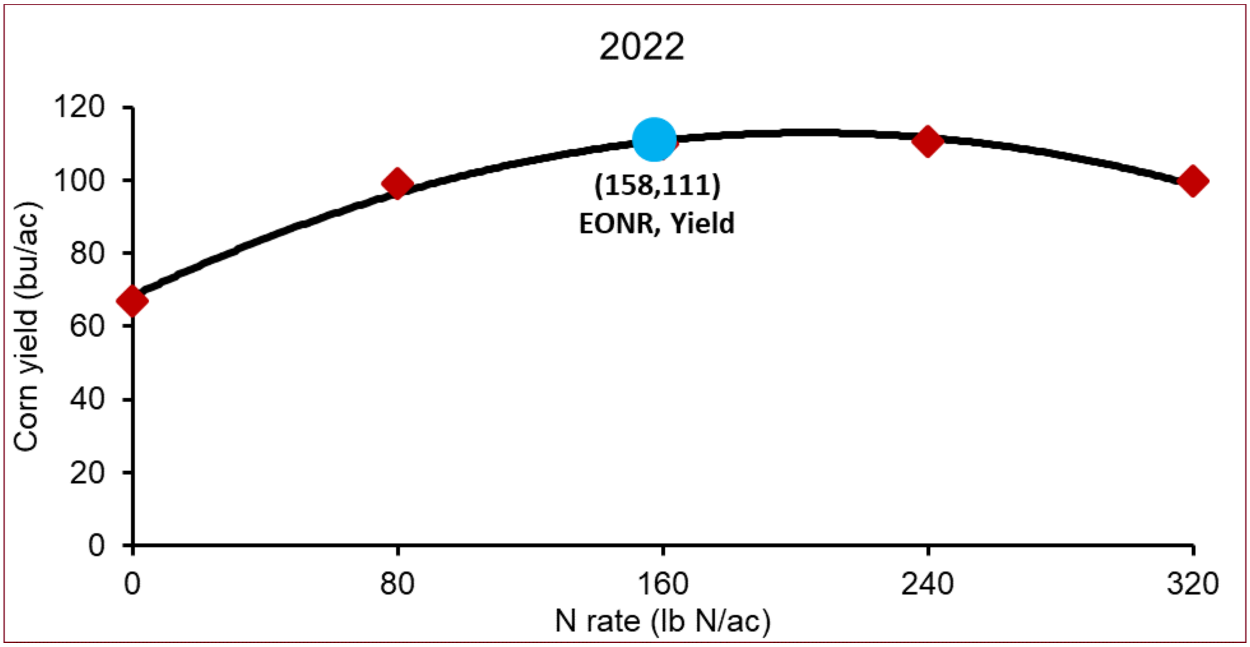

Figure 2. Agronomic trends in 2022 corn yields: quadratic regression analysis and EONR

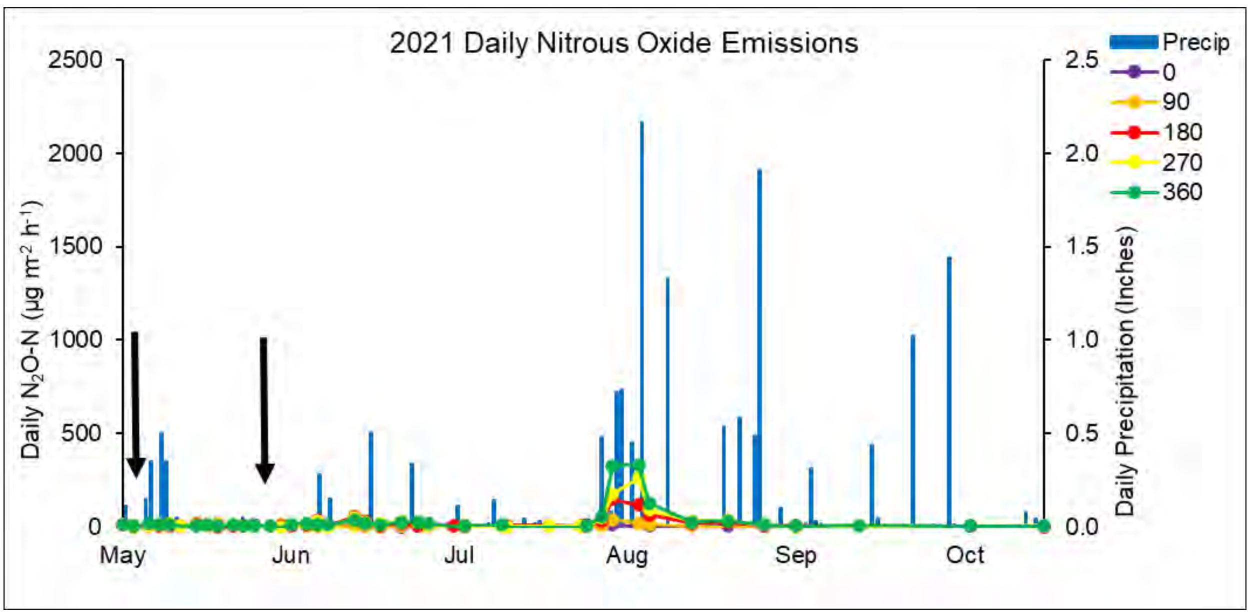

Figure 3. Daily N_2O-N emissions in response to N rate (lbs/ac) and daily precipitation in 2021. Downward pointing arrows indicate pre-plant and split fertilizer application dates.

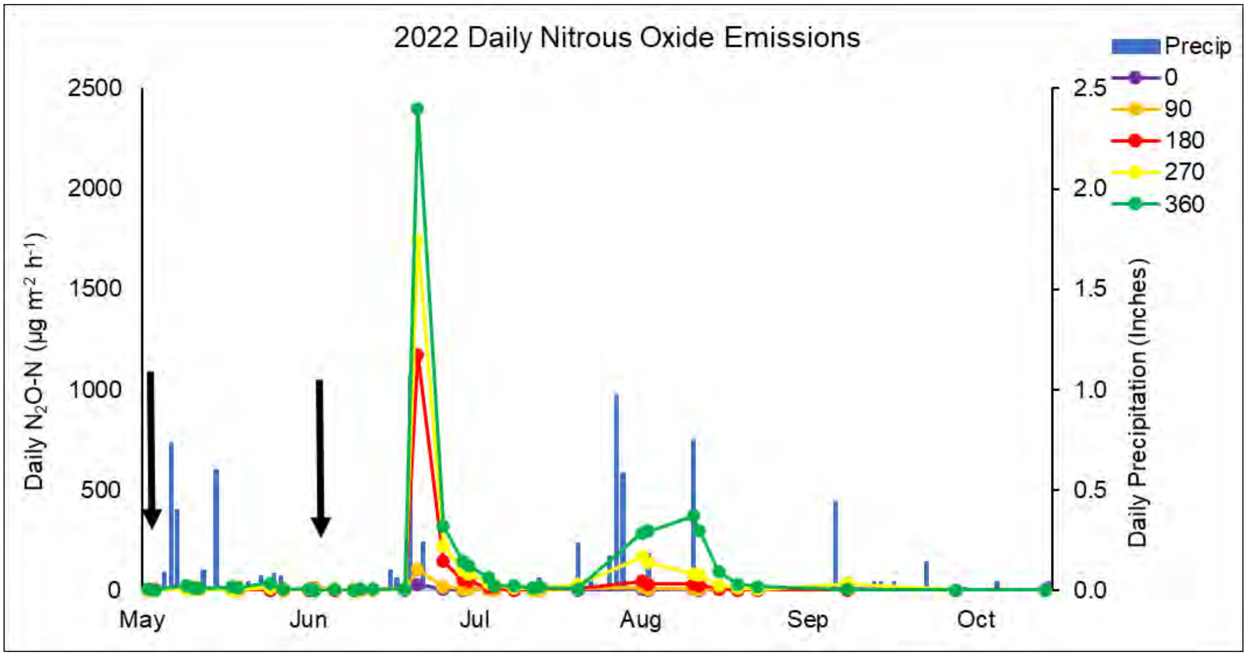

Figure 4. Daily N_2O-N emissions in response to N rate (lbs/ac) and daily precipitation in 2022. Downward pointing arrows indicate pre-plant and split fertilizer application dates.

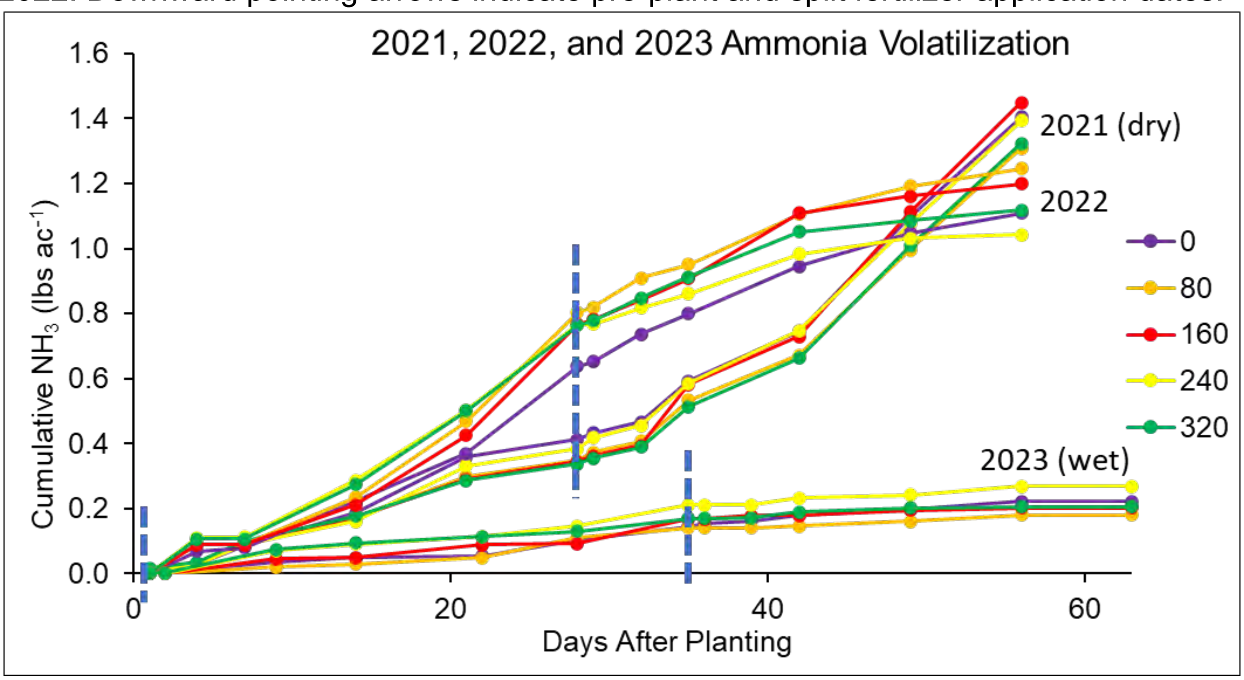

Figure 5. Cumulative NH_3-N volatilization loss as influenced by treatment over a 56-day period for 2021 and 2022 and a 63-day period for 2023 starting at pre-plant fertilizer application. Dashed blue lines indicate the split fertilizer application.

CEREAL RYE COVER CROPS MITIGATE SOIL PHOSPHORUS STRATIFICATION FROM LONG-TERM NO-TILLAGE

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ABSTRACT

Minimal or no-tillage is a widely adopted soil conservation practice and has been documented to reduce soil erosion, increase soil organic matter, and even reduce nutrient losses. Without tillage cultivation, however, phosphorus (P) can become stratified in surface soil layers and this may limit availability to crops or even increase bioavailable-P losses. Our primary objective was to measure the long-term (12-year) effects of long-term no-tillage (NT), cereal rye cover crops (CC), and their interaction on soil P stratification (SPS). We hypothesized: 1) NT would increase the stratification of bioavailable-P forms, and 2) CC would increase stratification compared to no cover crop under both conventional chisel plow tillage (CP) and NT via increased aboveground residue P inputs. There is not enough evidence in the literature to hypothesize about the NT × CC interaction. We sampled soils from a long-term, north central Iowa experiment with NT and cereal rye CC crossed factorially in place for 12 years resulting in the following treatments: 1) conventional CP tillage and no CC (CPWF), 2) NT also without CC (NTWF), 3) conventional CP tillage with a CC (CPCC), and 4) NT with the CC (NTCC). Soils were sampled to a depth of 10 in with increments at 0-1, 1-2, 2-4, 4-6, 6-8, and 8-10 in depths following both maize and soybean phases of the four treatments. These soils were analyzed for microbial biomass P (MB-P), anion exchange resin-P (AER-P), water extractable-P (WE-P), $NaHCO_3$ extractable-P ($NaHCO_3$-P), Mehlich 3 (M3-P), Olsen (Olsen-P), and Total-P. Soil P stratification varied across the soil P pools; but NT significantly stratified bioavailable-P pools such as WE-P, M3-P, and Olsen-P but not Total-P. Water extractable-P was most stratified with an average P stratification index (PSI) of 22.8. NTWF increased WE-P stratification by 584% compared to CPWF ($p < 0.001$). Although when NT was combined with CC (NTCC), it reduced this WE-P stratification by 88% ($p = 0.004$). Our findings confirm the plethora of previous work showing NT stratifies soil P, however, we show not equally for all forms of bioavailable-P and not for total-P. More importantly, we also show that cereal rye CCs can be a tool for 'destratification' of soil P, likely owing to cereal rye roots greater root uptake and re-distribution of surface P to lower depths during the shoulder seasons. This adds yet one more benefit of cereal cover crops, namely mitigating no-till SPS, when used in maize-soybean cropping systems in the Midwest US.

INTRODUCTION

Despite the many environmental and soil health benefits, no-tillage (NT) has some potential challenges, and one such challenge is that it redistributes or stratifies organic matter and non-mobile nutrients (Franzluebbers, 2002; Kay and VandenBygaart, 2002; Franzluebbers et al., 2007; Sá and Lal, 2009). One of the elements of most concern for stratification is the essential plant macronutrient phosphorus (P) – mostly because it is highly immobile and P fertilizer is applied as surface broadcast. In the long-term, annually deposited P —either from residues or fertilizers—tend to accumulate on the soil surface in conservation and reduced tillage systems as repeatedly observed in the literature (Zibilske et al., 2002; Bertol et al., 2007; Wright et al., 2007; Cade-Menun et al., 2015; Dang et al., 2015; Obour et al., 2017; Rahman et al., 2021). Two likely repercussions of soil P stratification (SPS) in soils are: 1) increased risk of higher runoff losses as dissolved reactive P and 2) crops may be P-limited if lateral roots cannot grow to access stratified bioavailable-P. In other studies, increased SPS was linked to increased bioactive-P losses in runoff (Smith et al., 2017; Daryanto et al., 2017a; Baker et al., 2017; Liu et al., 2019a). The majority of current SPS papers in the literature are related to the re-eutrophication of Lake Erie after a period of increased BMP implementation in the Lake Erie Basin.

MATERIALS AND METHODS

Site History and Treatments

In 2010 a long-term tillage and cover crop comparison experiment was established at the Agricultural Drainage Water Quality Research and Demonstration Site (ADWQDS) in Northwest Iowa by Gilmore City. The experiment has treatments represented in both maize (*Zea mays*) and soybean (*Glycine max L.*) phases of a maize-soybean rotation each year. The experiment uses a 2 × 2 factorial design with two factors – tillage and cover crops (CC). The factorial combination making four treatments: 1) conventional tillage with chisel plow and no cereal rye cover crop or winter fallow (CPWF), 2) no-tillage also without cover crop (NTWF), 3) conventional tillage with cereal rye (*Secale cereale.*) cover crop (CPCC), and 4) no-tillage with the cover crop (NTCC). The dominant soil types are Nicolet (Fine-loamy, mixed, superactive, mesic Aquic Hapludolls), Webster (Fine-loamy, mixed, superactive, mesic Typic Endoaquolls), and Canisteo (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) clay loams.

Soil Sampling and Soil Physical Properties

Plots were sampled on April 21, 2022 when the average daily temperature was 50 °F and soils were thawing if not recently thawed. Soil sampling took place before any field activities that would have disturbed the soil. For each plot six soil core samples were taken in a zig-zagging diagonal pattern within the plant rows and interrows to avoid sampling over the buried subsurface drainage. The soil cores were transferred to plastic soil sampling sleeves 2.5 cm in diameter and 30 cm long to preserve the core's shape and length. The soil tubes and soil were cut into six depth increments; 0-1, 1-2, 2-4, 4-6, 6-8, and 8-10 in, composited by depth, mixed, and passed through a 4 mm sieve field moist. Soil samples were then stored in a walk-in cooler (at ~ 39 °F) until extractions.

Soil Phosphorous Measurements and PSI

Microbial biomass phosphorous (MB-P) was determined using a chloroform fumigation method described in Jeannotte et al. (2004). The unfumigated portion used to determine MB-P were also analyzed ($NaHCO_3$-P). Plant available phosphates (AER-P) were determined using anion exchange membrane method described in Kovar et al. (2009) modified by measuring concentration using the malachite green method.

Deionized, water extractable-P (WE-P) was also performed to determine water-soluble orthophosphate, also described in Kovar et al. (2009), and modified to use the malachite green method. In addition, Mehlich-3-P (M3-P), Olsen-P, and total-P tests were performed by the Kansas State University Soil Testing Laboratory in Manhattan, KS.

Stratification indices were calculated for each plot to illustrate the severity of stratification for each phosphorous test. Phosphorous stratification indices (PSI) were calculated for each plot as

$$Phosphorus\ Stratification\ Index\ (PSI) = \frac{Concentration\ Average\ (0{-}5cm)}{Concentration\ Average\ (5{-}25cm)}.$$

RESULTS AND DISCUSSION

The crop phase had a significant effect on PSI, with soybean phase having 36% greater PSI on average compared to corn phase of the rotation. However, in partial support of our first hypothesis, 12 years of NT did increase SPS, measured as PSI, but only for some bioavailable-P pools and depended on if there was a CC or not. For example, NT only had a prominent effect on increasing the stratification of bioavailable-P (M3-P,Olsen-P, and WE-P) compared to chisel plow tillage (and in treatments without a CC – NTWF vs CPWF; Table 1). The NT soils had mean PSIs of 21.0 (range: 8.23 to 46.3) that were 28 to 584% greater than chisel plow across M3-P, Olsen-P, and WE-P tests and crop phases. This confirms previous literature showing NT and reduced tillage can more broadly stratify soil P.

Table 1. Average treatment PSIs with LSD values for significant results within each crop year.

Crop/Source	MB-P†	$NaHCO_3$-P	AER-P†	WE-P†	M3-P†	Olsen-P	Total-P
Soybean Year							
CPWF	1.78	18.02	1.44	7.80c	6.45c	5.88b	1.51
CPCC	3.27	14.92	2.92	28.95b	8.80a	9.03ab	1.63
NTWF	4.70	21.54	3.35	66.12a	9.25a	9.69a	1.61
NTCC	4.26	11.48	2.94	18.53b	7.75b	7.23ab	1.61
Maize Year							
CPWF	2.22	5.91	1.90	5.73d	6.91	6.94	1.40
CPCC	3.15	16.15	2.08	20.97b	7.57	7.72	1.52
NTWF	2.98	9.35	2.53	26.41a	7.94	6.79	1.53
NTCC	2.68	8.02	2.54	7.73c	5.39	5.23	1.47

†:MB-P = Microbial Biomass-P, $NaHCO_3$-P = sodium bicarbonate extractable P, AER-P = Anion Exchange Resin-P, WE-P = Water Extractable-P, M3-P = Mehlich-3 P.

In support of our second hypothesis, CCs had some minor effects on SPS. Although significant effects were infrequent, across crop phases and P tests, PSIs were 67% greater in chisel-plow soils with a CC than without (CPCC vs CPWF) (Table 1. and Figure 1.). In addition, WE-P, M3-P, and Olsen-P, CPCC was either significantly or marginally greater (only WE-P in maize) than conventional tillage without a CC by 107% on average (Table 1.). This is likely due to freeze-thaw processes acting upon the living biomass, leaching inorganic and organic bioactive-P into the soil. It could also be due to the annual deposition of P from terminated aboveground biomass. This aligns with

Bechmann et al. (2005) that found cereal rye CC increased bioavailable-P on the soil surface compared to bare and manured soils. Increased leaching of bioactive-P released from CC in temperate regions has been observed in other studies as well (Miller et al., 1994; Cober et al., 2018; Liu et al., 2019b; Sun et al., 2019). Assuming leached P is not mobile and accumulates in surface soils, then surface CC residues in CP may increase PSIs.

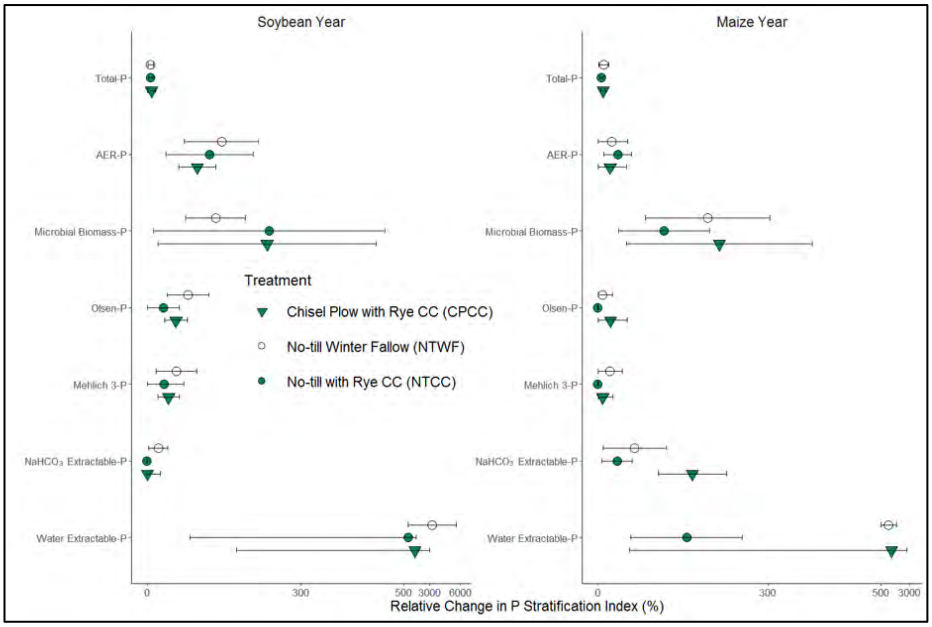

Figure 1. Relative change in soil phosphorus stratification index (PSI) in both soybean (left panel) and maize (right panel) phases of the rotation. Relative change was calculated as PSI of three treatments relative to the 'business-as-usual' treatment or Chisel Plow Winter Fallow (CPWF). AER-P = Anion exchange resin P.

Adding cereal rye CC to NT did decrease PSI for select soil P pools (Table 1.). For example, adding cereal rye CC to NT (NTCC) decreased PSIs for WE-P and M3-P by 72 and 24% respectively compared to NT without a CC (NTWF). This reduction in SPS was likely due to uptake and redistribution into the CC and microbial biomass (Rahman et al., 2021). Living roots in alkaline soils (which these are, mean pH = 7.5) could also modify pH of the rhizosphere and exude H^+, acidifying this surrounding soil and releasing Ca-bound phosphate (Gahoonia et al., 1992). This would mobilize and increase the amount of bioactive-P in the rhizosphere, perhaps redistributing it with depth as CC roots grew deeper into the soil.

Based on our findings, conservation practices of both NT and CC alone can stratify bioavailable-P but not total P. Moreover, and what is even more interesting is that when NT and CC are combined in an interaction, there is a negative effect on bioavailable-P stratification for some P pools (Table 1). In other words, by combining the two conservation practices you can alleviate P stratification issues. Further work is needed to link stratification of bioavailable-P to water quality issues and plant P uptake in order to further fine-tune conservation management and P use efficiency.

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DEVELOPING A SUSTAINABLE SUFFICIENCY PARADIGM

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ABSTRACT

Agronomic productivity and environmental protection goals of conservation practices must align for sustainable, widespread adoption on-farm. Phosphorus (P) fertilizer management is a critical control point for reducing consequences of P loss from agricultural fields to the environment. Reduced P fertilizer inputs are recognized as an effective and necessary control measure to limit P loss; however, current P fertilizer recommendation systems do not support this agronomically. Phosphorus fertilizer recommendations follow either a sufficiency (SF) or a build and maintain (BM) approach. Although SF is a low input recommendation system, it is viewed as unsustainable by producers as consecutive years of SF management will lead to a drawdown in soil test P (STP). To promote adoption conservation-minded P fertilizer management, and reduce P loss, a new paradigm for low input P management that aligns production and conservation goals is required.

To develop the sustainable sufficiency (SSF) P fertilizer management paradigm, historical P response data will be analyzed with a new approach to determining critical soil test P threshold for maintenance. Additionally, novel field studies will validate the theoretical optimum STP threshold for maintenance P fertilization developed from historical data, and investigate the effect of STP on yield response of corn and soybean to maintenance rates of P fertilizer. Preliminary findings from historical data analysis and the 2023 growing season will be presented.

INTRODUCTION

A hallmark challenge of P management is balancing crop response to P fertility and P fertilizer, while limiting P loss from agricultural fields to the environment. Phosphorus fertilizer management typically follows one of two contrasting philosophies: build and maintain (BM) or sufficiency (SF). A build and maintain approach typically increases soil test P (STP) above the critical threshold for yield response, and maintains it there, with regular P fertilizer applications. Sufficiency relies on annual P fertilizer applications based on the likelihood of crop response in that year. Unlike BM which generally raises STP and sustains higher levels in the system, SF can draw down STP overtime, as SF P fertilizer rates are often not enough to replace crop P removal. Optimizing P fertility plans with an alternate management strategy to better balance crop response to P fertility and P fertilizer in the year of application, while maintaining lower STP in the system, could reduce the environmental threat of P loss from agricultural fields, and optimize farm economics.

Historically, long-term research in Nebraska showed no benefit of a BM strategy, compared to SF, over 11 or 12 years for corn yield (Olson et al., 1987). In that study, the cost of build and maintain fertilization was almost double the cost of sufficiency management. Additionally, under a BM plan, STP increased to almost three times the STP of the sufficiency treatment. More recently, data from Minnesota showed no corn yield benefit to a BM approach, compared to a SF strategy, where P fertilizer rate decisions were made based on soil test P and the critical threshold for crop response (Fabrizzi et al., 2017). Similarly, Wortmann et al. (2018) found build rates of P fertilizer did not increase corn yield, compared to plots with P fertilization according to crop removal rates. From these studies, we see that an increase in STP as a result of BM management does not consistently translate to an increase in crop yield.

Along with agronomic and economic considerations there are potential environmental consequences of a BM strategy. Build and maintain systems, with higher P inputs, will lead to higher STP compared to a SF approach (Pierzynski & Logan, 1982). Higher STP concentrations are related to increased risk of P loss from the system (Osmond et al., 2019; Sharpley, 1995). Because of its role in P loss, managing P inputs and fertility to sustain lower concentrations of STP can be an important control measure to reduce P loss (Osmond et al., 2019). A BM system does typically represent a larger risk to the environment, and the work of Olson et al. (1987), Fabrizzi et al. (2017), and Wortmann et al. (2018) indicates a lack of consistent productivity benefits to offset the increased environmental risk.

A BM strategy may not be necessary to maximize yields, and can present a substantial economic investment, and environmental risk. However, the lower input SF approach may pose too great of a production risk to farmers, perceived or real, given the variability in P response even at high STP levels. Evidently, an alternate strategy to better balance crop response to P fertility and P fertilizer could be useful to reduce STP values maintained in fields, reduce P fertilizer inputs, and provide better mitigation of yield loss risk compared to a traditional SF strategy. As such, we will define a sustainable sufficiency (SSF) strategy to bring together the benefits of lower inputs and lower STP maintained in a traditional SF system, with the risk mitigation of maintaining a target STP level of a traditional BM strategy. Our objectives are to: i) investigate corn and soybean yield response to a maintenance rate of P fertilizer across a range of STP concentrations, using novel field studies and ii) determine the theoretical optimum STP for maintenance P fertilizer management, using historical data.

MATERIALS AND METHODS

Field Study

To investigate the effect of maintenance P fertilizer applications across a range of STP concentrations, our sites require a gradient of STP across plots. To achieve this, maintenance rate studies will be directly imposed over P fertilizer rate studies conducted in the previous growing season. In 2023, four site trial locations were selected in Riley, Reno, Franklin, and Republic counties in KS. The Riley and Reno sites are included in these results. Both of these locations had hosted a traditional P rate response study in 2022, with P rate treatments of 0, 30, 60, 90, and 120 lbs P_2O_5 ac^{-1} applied to four replicates. Post-harvest soil samples were collected from each plot following the 2022 season. The Riley and Reno sites were planted to soybean in 2023 and received a maintenance rate of 48 and 52 lbs P_2O_5 ac^{-1}, respectively, based on yield goals of 60 and 65 bu ac^{-1}. Maintenance rates were determined using expected removals for each yield goal, using standard removal estimates of 0.33 lbs P_2O_5 bu^{-1} for corn and 0.8 lbs P_2O_5 bu^{-1} for soybean. Maintenance rates were applied to each plot immediately following planting in the spring, using MAP. Yield data was collected by harvesting the center two rows of each plot and correcting grain moisture to 13%. Harvest data was analyzed by ANOVA using PROC GLIMMIX in SAS. There will be an additional 18 maintenance sites in 2024.

Historical Data Analysis

Soil test and yield data from traditional P rate response studies from KS, from 1980 to present, were compiled. The preliminary dataset includes 20 corn and 9 soybean response trials. Crop yield response to P fertilizer was ascertained from published results, or determined using ANOVA for studies with available raw data. PROC NLMIXED in SAS was used to fit a linear-plateau model to determine optimum P fertilizer rate (P_O) for each site with yield response to P fertilizer; P_O was set to zero for unresponsive site-years. Once P_O was established for each site-year, P removal by the crop at P_O (P_R) was determined based on yield at P_O and standard P removals of 0.33 lbs P_2O_5 bu^{-1} for corn and 0.8 lbs P_2O_5 bu^{-1} for soybean. Delta P_2O_5 (ΔP_2O_5) was then calculated for each site-year, using the following equation:

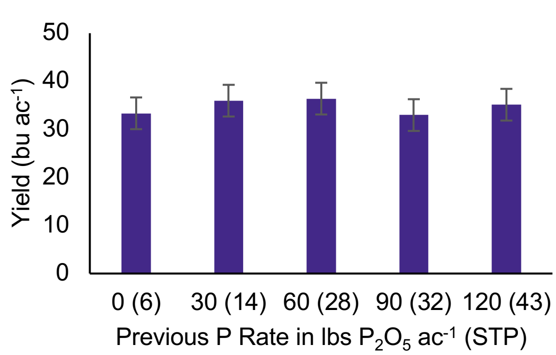
$$\Delta P_2O_5 = P_O - P_R$$

Calculated ΔP_2O_5 values were plotted against STP for each site-year. Once the dataset is complete, a model will be fit to the ΔP_2O_5 data to determine the relationship between ΔP_2O_5 and STP; theoretically, the optimum STP for maintenance would be the STP at which $\Delta P_2O_5 = 0$, as this is where $P_O = P_R$.

RESULTS AND DISCUSSION

Field Study

Preliminary results from two of the soybean maintenance studies from 2023 indicate a maintenance rate of P fertilizer was enough to meet crop demand, even when STP was <10 ppm. Neither site had a significant yield response to increased STP with a maintenance application of P fertilizer (Figure 1). Therefore, STP >20 ppm, the current critical threshold for yield response in KS, was not required to achieve yield with a maintenance rate of P fertilizer applied.



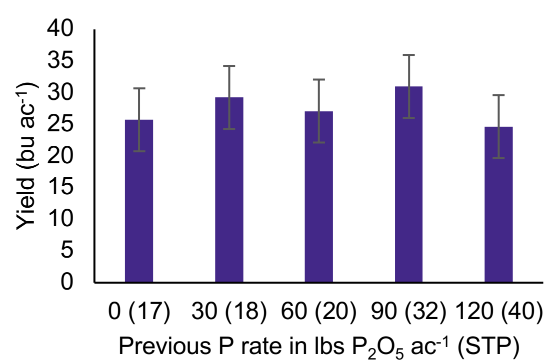


Figure 1. Soybean yield from Reno Co. (L) and Riley Co. (R) with a maintenance rate of P fertilizer applied as a spring broadcast application of MAP (n.s.)

Historical Data Analysis

For corn, only 5/20 site-years responded to P fertilizer and only one site-year required more P fertilizer than a maintenance rate to achieve optimum yield (Figure 2). At 19/20 site-years, a maintenance rate of P fertilizer would have sufficed to satisfy crop requirements for optimum yield. There were far more sites with $P_O < P_R$ than anticipated, particularly for site-years where STP was <20 ppm. Given the large spread in the data, and the number of site-years with STP >20 ppm, we have not yet attempted to fit a model to determine optimum STP for maintenance. Model fitting will take place once additional site-years in the low to very low STP range are added to the dataset.

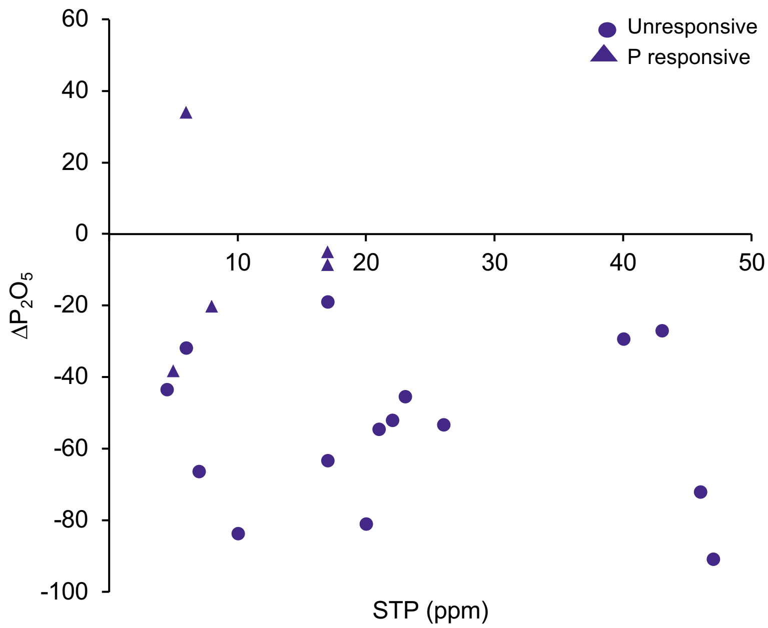


Figure 2. Preliminary ΔP_2O_5 results for corn (n = 20), where ΔP_2O_5 is the difference between optimum P fertilizer rate, P_O, and P removal at optimum yield, P_R.

For soybean, none of the nine site-years included in the preliminary analysis responded to P fertilization (Figure 3). Thereby, at all of these site-years, a maintenance rate of P fertilizer would have been enough to meet P demands at optimum yield. Similar to the corn site-years, there were more site-years with $P_O < P_R$ than anticipated. Model fitting to determine theoretical optimum STP for maintenance will take place in 2024, once the dataset is complete.

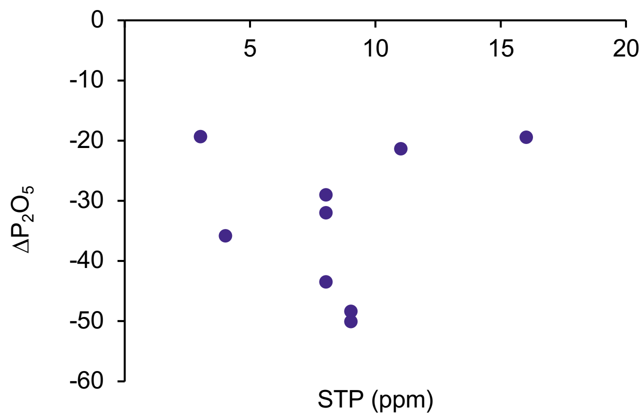


Figure 3. Preliminary ΔP_2O_5 results for soybean (n = 9), where ΔP_2O_5 is the difference between optimum P fertilizer rate, P_O, and P removal at optimum yield, P_R.

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DOES NITROGEN FERTILIZATION WITH MANURE INJECTION VERSUS SURFACE APPLICATION INFLUENCE CORN FOR SILAGE AND WINTER RYE YIELD, PHOSPHORUS BALANCE AND SOIL TEST PHOSPHORUS OVER THREE YEARS?

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ABSTRACT

Switching from nitrogen (N)-based to phosphorus (P)-based manure management can decrease P loss to the environment, allowing for sustainable P management in dairy farms. At high P soils, dairy farmers often surface apply the liquid manure to corn (*Zea mays* L.) for silage at the P-based rates and supplement the limited N to corn with N fertilizers to ensure optimum crop production. With high fertilizer prices, one solution to reducing the N requirement of corn could be to inject manure, conserve the ammonium-N fraction of the manure, and decrease the N need for corn. An experiment was conducted on a dairy farm located in Breese, IL from October 2019 to April 2022 with two main treatments including (i) surface application of manure at a P-based rate with 110 lbs ac^{-1} (to match 180 lbs N ac^{-1}) requirement for corn and (ii) injection manure at P-based rate plus 15 lbs N ac^{-1} to match 180 lbs N ac^{-1} requirement for corn. Our objectives were to evaluate whether injecting manure with lower N fertilizer need can produce similar corn silage yield and quality and if the manure application method influences the following winter rye (*Secale cereale* L.) as a forage crop in rotation. Our results indicated that injecting manure could produce a similar corn silage yield to surface application. This practice resulted in no quality loss but could save up to $150 of N fertilization. Winter rye in rotation also had similar biomass yield, nutrient accumulation, forage quality, and carbon input (shoots and roots) indicating that a shift from surface application to injection offers similar benefits, could reduce odor issues with surface application, and can save N fertilizer costs. Injecting manure effect on soil test P (STP) was similar to the surface application and did not increase STP over a three-year period. Future research should evaluate N- versus P-based manure management in intensified corn for silage with winter cereals in double cropping systems for eliminating N use, reducing the potential for P buildup in the soil, and increasing soil health.

INTRODUCTION

In Illinois, corn is a major cash crop, and corn grown for silage is particularly an important source of feed in the dairy farms. Dairy farmers often apply liquid dairy manure to meet the N requirement of a corn crop (N-based management) and also to enhance soil quality. However, the relatively high ratios of P to N in manure, when compared to the nutrient needs of a corn crop, can lead to an increase in soil test phosphorus (STP) levels over time (Sadeghpour et al., 2017). Elevated STP levels can result in greater phosphorus loss into surface and groundwater (Kleinman et al., 2002; Jahanzad et al., 2019).

Transitioning from an N-based approach to a P-based approach in managing manure for corn has been suggested to help regulate STP levels (Sadeghpour et al., 2017). However, such a shift necessitates a reduction in the manure application rate, which may impact the availability of N for the corn crop. Fertilization for N to supplement the N need for a corn crop has been proposed in soils that have high STP (Battaglia et al., 2021). In no-till systems, manure incorporation is not practiced, and thus, surface application of manure often results in loss of ammonium-N fraction through ammonia volatilization (Duncan et al., 2017). An effective approach that not only increases the N utilization of manure through reduction in ammonium-N loss but also addresses odor concerns linked to surface application is injection (Battaglia et al., 2021). Phosphorus-based manure management even with incorporation might result in a corn yield penalty (Sadeghpour et al., 2016), and adding fertilizer could eliminate that influence (Maguire et al., 2008). Literature is scant on evaluating P-based manure application methods (injection versus surface application) effects on both corn for silage and the following winter rye in rotation. Therefore, the primary objective of our research was to assess the consequences of switching from a surface application of P-based liquid dairy manure and supplementing it with N (110 lbs N ac^{-1}) to injection of manure at the P-based rate with low N requirement (15 lbs N ac^{-1}) on corn and winter rye performance in rotation. We hypothesized that a transition from P-based rate surface application to injection could produce similar corn yield at lower fertilizer N requirement and therefore, benefit the growers by saving N fertilizer and also by benefiting the environment through reduction in P runoff and odor concerns associated with the surface management practices.

MATERIALS AND METHODS

In 2019, a field experiment was initiated in Breese, IL (36º69'51'' N, 89º53'61'' W). According to the IL Agronomy Handbook, both STP and soil test K (STK) concentrations in 2019 were classified as very high and high, respectively. An experiment was conducted employing a randomized complete block design replicated four times. The two main treatments of this study were (i) surface application of manure at a P-based rate (12,900 gal ac^{-1}) with 110 lbs N ac^{-1} (to match 180 lbs N ac^{-1}) requirement for corn and (ii) injection manure at P-based rate (12,900 gal ac^{-1}) plus 15 lbs N ac^{-1} fertilizer to match 180 lbs N ac^{-1} requirement for corn.

Corn was planted on 30-inch row space using a no-till drill at 32000 ac^{-1} population. Winter rye was planted on 7.5-inch row spacing at 90 lbs ac^{-1} seeding rate. Corn planting dates were early-mid May and winter rye harvesting dates were late April to early May. Corn was machine-harvested from the middle rows of each plot after removing the edge effects. After weighing the harvested area, a subsample was collected and weighed again and then placed in an air-forced oven until it reach constant weight to measure dry matter yield for silage corn. Biomass sub-samples were then ground until they could pass through a 1 mm sieve, facilitating silage quality and nutrient analysis. The analysis was done by Ward Laboratories according to their analysis guideline (https://www.wardlab.com/services/feed-nirs-analysis/).

Winter rye's aboveground biomass was collected using grass shears (GS model 700; Black and Decker Inc., Towson, MD) during the late-April or early-May period. The harvesting area was 7.25 ft^2, which was done by avoiding edge effects. Subsequently, all biomass samples underwent a 72-hour oven-drying process at 118 f to determine their dry matter (DM) yield. Biomass sub-samples were then ground until they could pass through a 1 mm sieve, facilitating forage quality analysis. Forage quality indices evaluated in this study included CP, ADF, NDF, NDFD, ash, and lignin which were measured using near-infrared reflectance spectroscopy (NIRS). Guidelines for sample analysis and methodology can be found on the Ward Laboratory website (https://www.wardlab.com/services/feed-nirs-analysis/). Phosphorus balance was calculated as P applied – P removed by crops. Soil test P was analyzed using Bray-1 P extraction and ranges of P in the soil were determined based on Illinois Agronomy Handbook Guidelines (http://extension.cropsciences.illinois.edu/handbook/pdfs/chapter08.pdf). Data were evaluated for normality of the residuals and then analyzed with SAS statistical software at $p<0.05$, considered significant.

RESULTS AND DISUCSSIONS

Corn Silage Yield, Winter Rye Yield, and Total Yield

Corn silage yield was affected by year but not treatment (manure application method) or the interaction of year by treatment. Corn silage yield was higher in 2019 (14,730 lbs DM ac^{-1}) and 2021 (16,336 lbs DM ac^{-1}) than 2020 (8,616 lbs DM ac^{-1}) reflecting weather conditions and weed management issues in 2020 (Fig. 1).

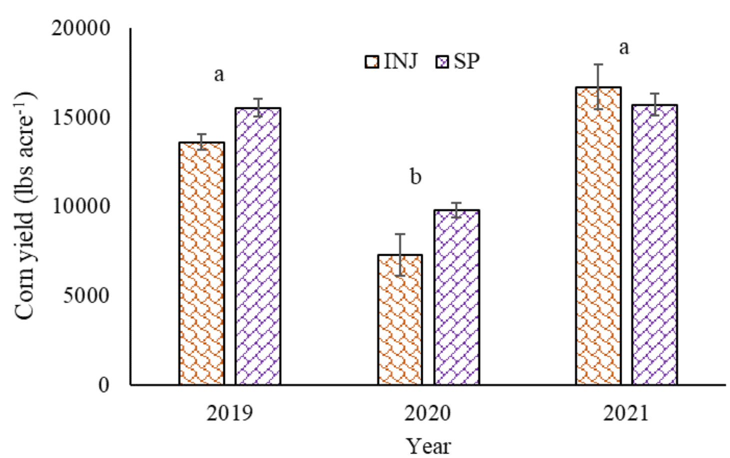

Fig 1. Effect of manure application method on corn silage yield in different years. The bars indicated standard error. INJ: inject manure, SP: spread manure. Year comparison means with the same letter are not significantly different (Tukey ≤ 0.05).

Corn silage yield (averaged over years) was 13,733 lbs DM ac^{-1} for surface application and 13,104 lbs DM ac^{-1} for manure injection. Rye forage yield (aboveground biomass) was similar between INJ and SP in all years. Rye forage yield ranged from 1732 lbs DM ac^{-1} in 2022 to 2854 lbs DM ac^{-1} in 2021 mainly reflecting harvesting time (Fig. 2).

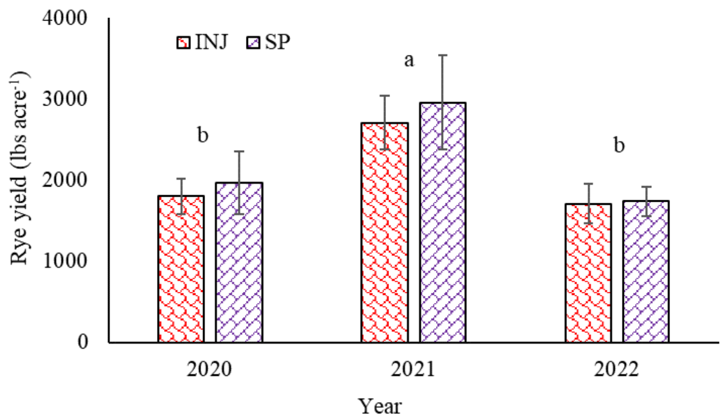

Fig. 2. Effect of manure application method on winter rye yield in different years. The bars indicated as standard error. INJ: inject manure, SP: spread manure. Year comparison means with the same letter are not significantly different (Tukey ≤ 0.05).

Total forage yield (corn DM yield plus winter rye DM yield) was only influenced by year. It was similar between the two manure application methods. Total forage yield was higher in 2020 (16,587 lbs DM ac^{-1}) and 2022 (18,077 lbs DM ac^{-1}) than in 2021 (11, 085 lbs DM ac^{-1}) mainly due to low yields in corn in 2021 (Fig. 3).

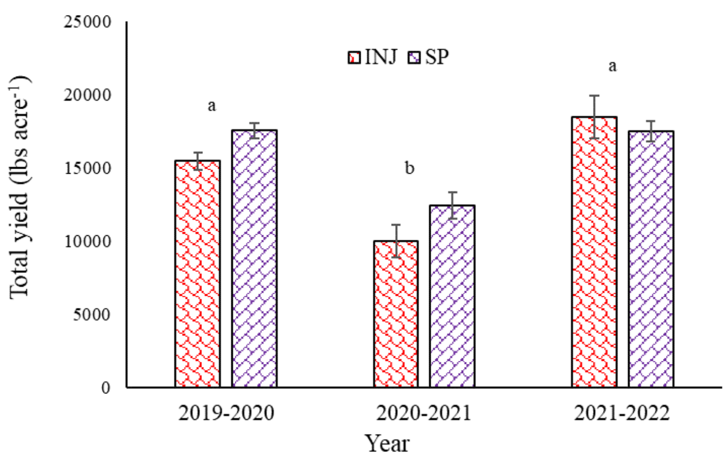

Fig. 3. Effect of manure application method on total forage yield (corn for silage plus winter rye) in different years. The bars indicated as standard error. INJ: inject manure, SP: spread manure. Year comparison means with the same letter are not significantly different (Tukey ≤ 0.05).

Phosphorus Removal, Balance, and Soil Test Phosphorus

Corn P removal was only influenced by year, and both INJ and SP had similar P removal within each year. Corn P removal was higher in 2019 (36.11 lbs ac^{-1}) and 2021 (44.80 lbs ac^{-1}) than in 2020 (23.46 lbs ac^{-1}) (data not shown). Phosphorus removal was influenced by year but not treatment or year-by-treatment interaction. Phosphorus removal was higher in 2021 (7.22 lbs ac^{-1}) than in 2020 (4.25 lbs ac^{-1}) and 2022 (4.42 lbs ac^{-1}) (data not shown). Total P removal was similar between the two application methods within each year. However, total P removal was lowest in INJ in the 2020-2021 season (26.03 lbs ac^{-1}) and highest in INJ and SP in 2021-2022 (49.23 lbs ac^{-1}) (data not shown). Phosphorus balance was negative in two of the three years and was highest in INJ in 2020-2021 (12.65 lbs ac^{-1}). Bray-1 STP concentrations were 78.5 mg kg^{-1} for INJ and 76.7 mg kg^{-1} for SP in spring 2019. After three years of P-based rate manure management, in spring 2022, STP levels remained unchanged, and INJ had an STP level of 79.0 mg kg^{-1} while SP had an STP level of 78.5 mg kg^{-1} (data not shown).

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INFLUENCE OF BIOLOGICAL SEED TREATMENT ON SOYBEAN GRAIN YIELD IN THE U.S.

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ABSTRACT

Biological seed treatment in soybean (*Glycine max* (L.) Merr.) is a growing market in the U.S., with multiple microbially active ingredients and several proposed benefits. Some of the claimed benefits include improving nitrogen fixation, stimulation of root growth, increasing phosphorus, sulfur, and other nutrient absorption, and control of diseases, with the aim to increase soybean grain yield. Farmers are often bombarded with marketing claims about biological seed treatments. In many cases, there is little or no third-party evidence of quantitative assessment regarding these biological seed treatments' ability to improve soybean yield. Therefore, this project's objective was to evaluate if biological seed treatments improved soybean yield across the U.S. Field experiments were established using a common protocol during the 2022 growing season at 49 locations across 17 U.S. states, examining the effectiveness of nine commercial biological seed treatments to increase soybean yield. The experimental design was a randomized complete block with six replications. Treatments included microbes from the genera *Bradyrhizobium, Bacillus, Azospirillum, Pseudomonas, Pantoea, Delftia, Trichoderma*, and *Glomus*. Some of the products had multiple active ingredients (microbes). Results showed that the effects of treatments were not significant (P=0.4229) nor varied among the examined locations (P=0.0985). Also, Bayesian analysis indicated that a high probability (>80%) of the yield difference (each treatment minus untreated control) being higher than zero was mainly found in the treatment products that contained *Trichoderma* only, *Bradyrhizobium* only, and the arbuscular mycorrhizal fungi *Glomus* mostly in Southern U.S. states. In these locations, the yield difference ranged between 1.2 to 2.3 bu/acre; however, none was significant (95% credible intervals included zero). Overall results suggest that the biological seed treatments tested in this study in a wide range of environments rarely increased soybean grain yield.

INTRODUCTION

Today's soybean industry faces many challenges, such as high input prices (e.g., fertilizers and pesticides) and an increasing need to produce high-yielding soybeans in an environmentally sustainable manner. Due to these challenges, some products, strategies, or management practices are becoming more available in the market. For example, biological seed treatment for soybean is one of the management practices available; however, the efficacy and use of these products to increase soybean yield need to be better studied.

The benefits of the interaction between microorganisms and plants can be several. For example, the bacteria genus *Azospirillum* has the ability to fix atmospheric nitrogen

(Day and Döbereiner 1976) and can secrete phytohormones (Reynders and Vlassak 1979). Other plant growth-promoting bacteria are from the genera *Bacillus* and *Pseudomonas*. Some *Bacillus* species can improve nutrient supply, secrete phytohormones (Radhakrishnan et al., 2017), and suppress diseases (Hu et al. 2014). Similar to *Bacillus*, the *Pseudomonas* bacteria can promote plant growth by suppressing pathogenic microorganisms and synthesizing phytohormones (Preston, 2004).

Many commercial biological seed treatments contain *Bradyrhizobium* spp., an important bacteria genus known for its ability to fix nitrogen and providing 50 to 60% of soybean N requirement (Salvagiotti et al., 2008). Plants also have a mutualistic relationship with some fungi species such as the fungus genus *Glomus* that promotes phosphorus uptake (Thioub et al., 2019). *Trichoderma*, another fungi genus, showed biocontrol effects against *Macrophomina phaseolina*, fungal causal agent of soybean charcoal rot (Khaledi and Taheri, 2016) and white mold (Macena et al., 2020).

Biological soybean seed treatment is a growing market worldwide. The global market is expecting that the biological market (biopesticides and biostimulants) will grow from $6.9 billion in 2019 to $13.6 billion by 2024 (BCC Research, 2020). Although the soybean seed treatment market is growing, there are limited studies on the efficacy of microorganisms in soybean production in the U.S. Therefore, the objective of this project was to evaluate if biological seed treatments improved soybean yield across the U.S.

MATERIALS AND METHODS

A small plot trial was established at 49 locations across 17 states in the USA (Alabama, Arkansas, Iowa, Indiana, Illinois, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, North Carolina, North Dakota, Ohio, South Carolina, South Dakota, Virginia, and Wisconsin) during the 2022 growing season. The experimental design used was a randomized complete block with six replications. Nine commercially available biological seed treatments were evaluated and compared to the non-treated control (Table 1).

Table 1. List of treatments (products) and active ingredients in each biological product.

Treatment (product)	Active ingredients
1	*Azospirillum brasilense, Bacillus licheniformis, Bacillus amyloliquefaciens, Bacillus subtillis, Pseudomonas fluorescens, Rhizobium*
2	*Trichoderma virens*
3	*Bradyrhizobium spp.*
4	*Bacillus subtillis, Bacillus amyloliquefaciens, Bradyrhizobium japonicum*
5	*Pantoea agglomerans**
6	*Pseudomonas brassicacearum**
7	*Bradyrhizobium elkanii, Delftia acidovorans + Bacillus velezensis*
8	*Bacillus velezensis*
9	*Glomus intraradices, Glomus mosseae, Glomus aggregatum, G. etunicatum*
10	Untreated Control

* Products 5 and 6 were applied only at locations in Illinois, Indiana, Michigan, Minnesota, North Dakota, Ohio, South Dakota, and Wisconsin.

The soybean variety and management practices (e.g., row spacing, seeding rate, soybean relative maturity, cropping history, etc.) were representative of each region. Also, seeds were treated with the same commercial fungicide + insecticide seed treatment to be representative of farmer practices. Biological seed treatments in this experiment were compatible with fungicide and insecticide seed treatments according to each company. Also, the application of biological on soybean seeds was followed by using the guidelines and rates provided by each company. Soybean yield was adjusted to 13% moisture concentration prior to data analysis.

Data were analyzed in SAS 9.4 using frequentist (PROC MIXED) and Bayesian (PROC BGLIMM) analysis approaches. In the first approach, location, treatment and their interaction were treated as fixed effects. Replication nested within locations was a random effect, and means were adjusted for multiple comparisons. In the second approach, the Bayesian analysis was modeled within each state.

RESULTS AND DISCUSSION

Grain yield

The main effect of location showed significant results because the trials were conducted in different regions under different environmental conditions, and under low or high yielding areas. The main factor treatment nor the interaction between location and treatment showed significant results ($\alpha = 0.05$) (Table 2). When the grain yield from each treatment was plotted against the untreated control, most of the points were close to the x=y line, showing that there were no substantial differences on grain yield when applying products (Figure 1).

Table 2. Analysis of variance (ANOVA) for location, treatment, and location x treatment.

Source of variation	F Value	Prob > F
Location	109.46	<.0001
Treatment	1.02	0.4229
Location*Treatment	1.10	0.0985

In the Bayesian analysis, high probabilities (>70%) of the yield difference (each treatment minus the untreated control) being higher than zero was mainly found in the treatments that contained *Trichoderma* only, *Bradyrhizobium* only, and the arbuscular mycorrhizal fungi *Glomus* mostly in Southern states (Table 3). Although the yield differences between each treatment minus the untreated control ranged from -6.1 to 4.2 bu/acre, none was significant (95% credible intervals included zero). Similar studies in the USA have been showing inconsistent results. For example, in a study conducted in 13 states in the U.S., Leggett et al. (2017) found a yield difference of 0.9 bu/acre between inoculated soybean seeds with *Bradyrhizobium japonicum* and non-inoculated seeds. Differently, Carciochi et al. (2019) did not find significant yield gain after inoculating seed with *B. japonicum* in any of the environments where the trial was conducted in four USA states. A recently published study in the USA found that the average response to applying *Azospirillum brasilense* in soybean was 1.8 bu/acre, with a probability chance of only 5.3% (de Borja Reis et al. 2022).

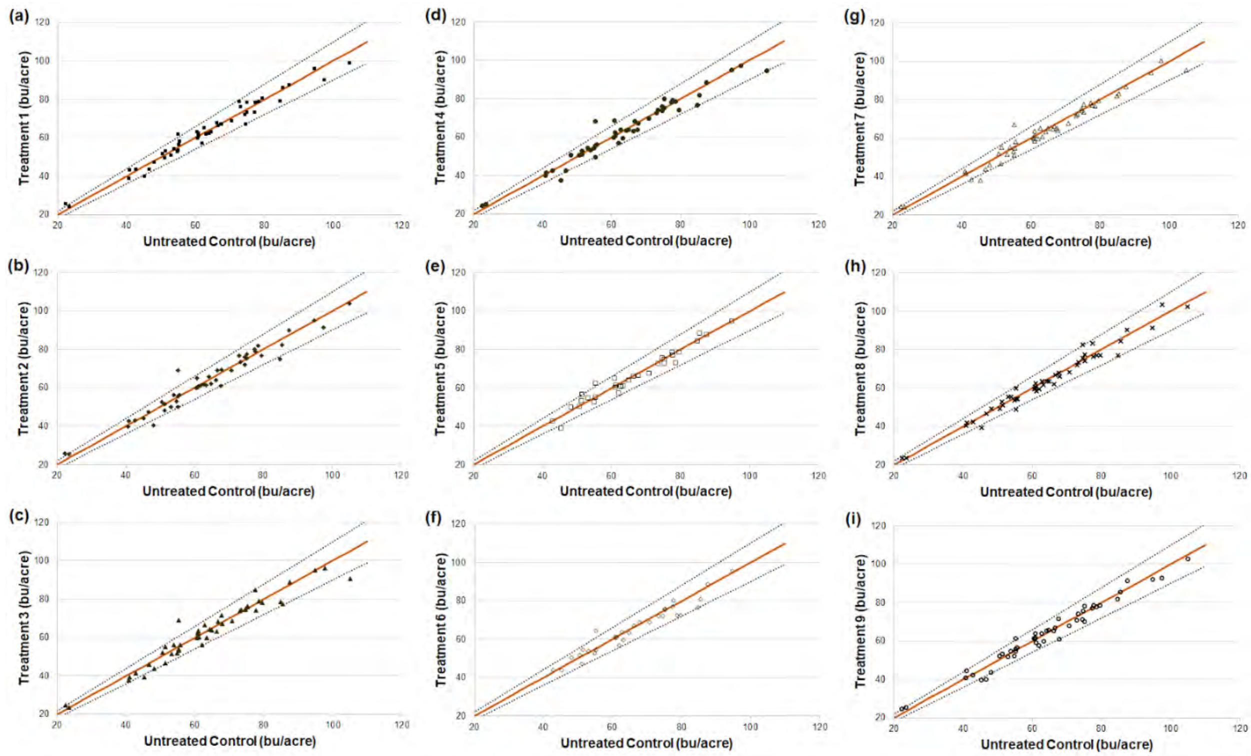

Figure 1. Average grain yield (kg/ha) at each site for each treatment (product) plotted against the average grain yield (kg/ha) of the untreated control (treatment 10) at the same site. Each symbol within a graph represents one site. Solid red lines represent x = y, and the dashed lines represent ±10% of the yield.

IMPLICATIONS

The effects of treatments were not significant (*P*=0.4229), nor were the location x treatment interaction (*P*=0.0985). The Bayesian analysis indicated that a high probability (>70%) of the yield difference (each treatment minus untreated control) being higher than zero was mainly found in the treatment products that contained *Trichoderma* only, *Bradyrhizobium* only, and the arbuscular mycorrhizal fungi *Glomus* mostly in Southern U.S. states. The yield difference ranged from -6.1 to 4.2 bu/acre; however, none was significant. In general, results suggest that the biological seed treatments tested in this study in various environments rarely increased soybean grain yield. These results are preliminary, and the project was repeated in 2023.

Table 3. Summary of the mean yield differences (Yd, in bu/acre) for each treatment minus untreated control, and probabilities for a difference>0 (P, in %) analyzed using Bayesian procedure for each U.S. participant state in 2022.

State	Trt 1		Trt 2		Trt 3		Trt 4		Trt 5		Trt 6		Trt 7		Trt 8		Trt 9	
	Yd	P	Yd	P	Yd	P	Yd	P	Yd	P	Yd	P	Yd	P	Yd	P	Yd	P
	bu/acre	%	bu/acre	%	bu/acre	%	bu/acre	%	bu/acre	%	bu/acre	%	bu/acre	%	bu/acre	%	bu/acre	%
Alabama	-1	33	0.3	55	-1.4	27	0.3	55	-	-	-	-	1.2	71	-0.1	48	0.7	62
Arkansas	1.9	86	0.5	62	-1.3	22	-0.3	43	-	-	-	-	0	50	-0.3	44	2	87
Illinois	0.6	62	-0.9	34	-2.3	15	-2	19	-0.7	38	-2.3	16	-0.3	44	-1.9	20	-0.1	47
Indiana	-0.5	35	-1.2	17	-1.1	19	-0.5	35	-0.5	34	-1	21	-0.1	46	-1.1	18	0.6	69
Iowa	-2	34	-5.3	15	-1.9	36	-5.5	13	-	-	-	-	-4	21	-6.3	11	-0.5	46
Kentucky	0.8	62	-1.2	32	-2.3	18	-2.8	13	-	-	-	-	-3.2	10	-2.5	17	-1	34
Louisiana	0.1	52	2.1	92	2.1	91	1.4	83	-	-	-	-	1	74	0.8	70	2.2	93
Michigan	-0.2	47	-3.6	8	-2.6	16	1.6	73	1	65	-1	35	-2.6	16	0.8	61	-0.8	37
Minnesota	0.7	61	0.4	56	1.6	71	0.4	55	-1.8	26	1.1	66	-3.5	10	-0.6	42	-3.1	13
Mississippi	0.3	59	2.3	94	1.2	79	0.5	64	-	-	-	-	0.5	64	0.3	59	1.4	83
North Carolina	-6.1	3	-3.1	17	-2.6	21	-3.7	13	-	-	-	-	-1.6	31	4.2	91	-0.5	43
North Dakota	-0.7	29	-0.5	34	-1	22	0.4	63	0.5	66	0.2	56	-2.5	3	-2.8	2	-2	7
Ohio	-0.7	33	-1.5	15	-1.4	17	-1.9	9	0.2	56	-1.4	16	-0.4	38	-1	25	-0.1	46
South Carolina	1.2	75	1.4	78	1.4	78	-1	28	-	-	-	-	0.7	65	0.3	57	0.7	65
South Dakota	-1.2	9	-0.8	17	-0.2	41	-0.1	47	-0.4	30	-0.2	42	-0.9	16	-0.7	21	-0.7	20
Virginia	-0.8	38	2.1	81	0	49	-2.5	16	-	-	-	-	-3.2	9	-0.8	37	-5	2
Wisconsin	-1.8	3	1.5	93	0.4	65	0.4	64	-0.8	20	-1.3	9	-0.8	20	-0.9	19	-2.1	2

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SOIL CARBON ADDITIONS IMPROVE SOIL NUTRIENT CYCLING AND YIELD OF CORN

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ABSTRACT

Increasing soil organic matter and the associated soil carbon is known to positively influence nutrient cycling, and agronomic practices such as conservation tillage and cover crops can facilitate soil carbon increases in the long term. Alternatively, the direct addition of carbon amendments to the soil may serve as an alternative solution for enhancing nutrient cycling in the short-term, which was the basis for this research. Our objective was to assess the potential of granular carbon amendments to increase corn (*Zea mays*) yield by either enhancing nutrient cycling and the release of soil nutrients or by improving the efficiency of fertilizer use. Field experiments were conducted in 2022 and 2023 at Champaign, IL and included two carbon amendments (biochar or humic acid) applied at three rates of carbon (90, 180, or 360 lbs carbon/acre), either with or without phosphorous (P) plus potassium (K) fertilization. The fertilizer treatment included MAP (11-52-0) and MOP (0-0-60) at rates of 60 lbs of P_2O_5/acre and 60 lbs of K_2O/acre, respectively. All treatment applications were broadcast-applied just prior to planting and lightly incorporated, with soybean [*Glycine max* (L.) Merr.] as the previous crop and with all plots receiving 180 lbs N/acre. Without the carbon amendments, fertilization with P and K significantly increased grain yield by 12.4 bushels/acre. Averaged over the carbon rates, both carbon amendments increased yield when applied without fertilizer (7.3 and 3.3 bushels/acre for biochar and humic acid, respectively), but not when applied with fertilizer. Although somewhat variable depending on the carbon source and the fertilization level, the lowest carbon rate (90 lbs carbon/acre) generally resulted in the highest yield. These data indicate that granular carbon additions can improve corn yield by enhancing soil nutrient cycling, without negatively affecting the availability of P or K from fertilization.

INTRODUCTION

As atmospheric carbon (C) levels continue to rise, new avenues for C sequestration are being explored in an attempt to mitigate the greenhouse gas effects of these elevated C levels. Carbon dioxide (CO_2) has recently become a gas of interest in the agricultural sector due to the annual C cycling that occurs in farmland soils, and increasing sequestration or reducing emission processes have been proposed as greenhouse gas mitigation strategies. The challenge proposed to farmers is to implement management practices that maintain or increase yields and simultaneously capture CO_2 via plant biomass production while sequestering that C in their soils for a net positive C balance to help offset emissions from the agricultural sector and reduce agriculture's contribution to climate change.

Replacing current agricultural management practices with ones that increase soil C sequestration, or that reduce C losses is considered a cost-effective mitigation strategy and is possible due to the active management of agricultural soils (Lal, 2013). Practices such as reducing tillage, switching to no-till, or implementing cover crops have been shown to increase soil C sequestration (Lal, 2013; Marks, 2020; Oldfield et al., 2021; Paustian et al., 2016; Smith et al., 2008). However, farmers can be resistant to changing their management practices as it can involve risk, have applicability limitations, and require the purchase of costly new equipment. Therefore, adding organic amendments that contain high levels of C may be a more feasible and immediately-implementable way to tandemly-increase nutrient availability, soil organic carbon levels, and soil health in a cost-effective manner. Additionally, combining carbon sources such as humic acids with fertilizers may potentially increase fertilizer use efficiency and crop yield.

Simultaneously enhancing fertilizer use efficiency, increasing plant productivity, sequestering C, and improving soil health would help to alleviate global concerns of environmental health and food insecurity. The question this research seeks to answer is if there is potential to simultaneously enhance the efficiency of fertilization and increase corn crop yields with application of organic amendments with or without phosphorus (P) and potassium (K) fertilizers. Previous studies have evaluated the effect of organic amendments on C fluxes and grain yield; however, their results have varied (Allohverdi et al., 2021; Yeboah et al., 2018), and little research has been conducted regarding the effect of these additions when paired with traditional fertilizers. The objective of this research project was to assess the effect of the application of two carbon amendments, biochar and humic acid, on nutrient use efficiency and corn grain yield.

MATERIALS AND METHODS

Site Description

Field experiments were conducted in 2022 and 2023 at two different fields at the Crop Sciences Research and Education Center at Champaign, IL. The soil in both fields were classified as Flanagan silt loam, (Fine, smectitic, mesic Aquic Argiudolls). In 2022, the site had a soil organic matter (SOM) content of 3%, pH of 6.7, a CEC of 15.7 meq/100g, and Mehlich III extractable P and K levels of 29 and 103 ppm, respectively. In 2023, the site had 3.2% SOM, 6.4 pH, a CEC of 20.6, and Mehlich III-extractable P and K levels of 24 and 114 ppm, respectively. Both sites followed a traditional corn-soybean rotation with soybean as the previous crop.

Experimental Design and Agronomic Management

For both years, six replications of treatments were arranged in a randomized complete block design. Each experimental unit (plot) comprised of four rows, each measuring 37.5 feet in length and spaced 30 inches apart, with a 30-inch walkway separating adjacent ranges of plots. Rows one and four of each plot served as border rows while rows two and three were considered yield rows. Corn hybrid DKC65-84 (Bayer Crop Science, Research Triangle Park, NC) was planted at a population of 36,000 plants/acre on 11 May 2022 in the first year of the study, and 26 April 2023 on the second year of the study using a SeedPro 360 research plot planter (ALMACO, Nevada, IA). To ensure optimal seedling-insect pest control, an in-furrow application of Force 6.5G [Tefluthrin: (2,3,5,6-tetrafluoro-4-methylphenyl)methyl-(1α,3α)-(Z)-(±)-3-(2-chloro-3,3,3-tri-fluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate; Syngenta Crop Protection LLC., Greensboro, NC] was applied at a rate of 2.3 oz/1000 ft at planting. In-season foliar protection was achieved using Miravis Neo fungicide (7.0% Pydiflumetofen + 9.3% Azoxystrobin + 11.6% Propiconazole; 13.7 fl oz/acre; Syngenta Crop Protection, LLC.) and Warrior II insecticide [22.8% Lambda-cyhalothrin (synthetic pyrethroid); 1.6 fl oz/acre; Syngenta Crop Protection, LLC.), which was applied at the VT/R1 (tasseling-to-silking) growth stage using a pressurized-CO_2 back-pack sprayer at a total volume of 20 gal/acre.

Treatment Applications

All treatments were broadcast-applied at pre-plant and lightly incorporated (2 inches deep) with a harrow. Each plot, including the untreated control (UTC), received an application of 180 lbs N/acre as urea ammonium nitrate (UAN-32) at preplant. Carbon amendments biochar or humic acid (Novihum; 78% organic matter sourced from lignite + 21% Bentonite clay), were applied at three rates (90, 180, or 360 lbs of C/acre) with or without P plus K fertilizer. Consequently, the C rate of 90 lb/acre corresponded to an applied carbon-to-nitrogen ratio of 1:2 (90C:180N), the 180 lb/acre rate corresponded to a ratio of 1:1, and the 360 lb/acre rate corresponded to a ratio of 2:1. Due to differences in carbon concentration between the two products (Biochar 90% C; Humic acid 42% C), the product application rate was balanced for the C concentration in each product, which resulted in product rates of 100, 200 or 300 lbs of biochar/acre and 210, 420, or 840 lbs of humic acid/acre, respective to the C rates of 90, 180, and 360 lbs/acre. Fertilization treatments of P plus K (P + K) were broadcast-applied as monoammonium phosphate (MAP; 11-52-0) and muriate of potash (MOP; 0-0-60) at rates of 60 lbs P_2O_5/acre and 60 lbs K_2O/acre.

Measured Parameters

Corn biomass nutrient concentrations were measured by collecting the entire above-ground portion of four plants from the center two plot rows (two plants from each row) of each plot at the VT growth stage. Samples were then dried to 0% moisture in a forced air oven at 75°C and weighed to determine shoot biomass per plant. Once weighed, samples were ground to pass through a 2 mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) and analyzed for nutrient concentrations of K, calcium (Ca), and magnesium (Mg) by A & L Great Lakes Laboratories (Fort Wayne, IN).

Following crop dry down, the two center rows of each plot were mechanically harvested for determination of crop grain weight and moisture using an R1 rotary combine (ALMACO, Nevada, IA). Grain yield data was standardized to 15.5% moisture. Statistical analysis was performed using a linear mixed model approach in PROC MIXED of SAS

(SAS 9.4) (SAS Institute Inc., Cary, NC), and means were separated using Fisher's protected LSD test. Assessment of normality of residuals and detection of potential outliers was conducted with PROC UNIVARIATE. Additionally, the Brown-Forsythe modification of the Levene test was performed using PROC GLM to ensure homogeneity of variance. The assumptions of homogeneity of variance and normality were confirmed, and the data from two years were combined and analyzed as a single dataset.

RESULTS AND DISCUSSION

All treatments containing carbon amendments significantly decreased Mg concentration in corn biomass at the VT growth stage (Table 1). However, plant K concentration significantly increased with biochar at 90 and 180 lbs C/acre with fertility, and humic acid at 90 lbs C/acre without fertility, and 180 and 360 lbs C/acre with fertility. All treatments containing carbon amendments numerically increased K concentration in corn biomass at the VT growth stage, while Ca and Mg concentrations tended to decrease (Table 1).

Even without additional P and K fertility, there tended to be more grain yield as a result of carbon amendment applications (Table 2). Notably, none of the carbon amendment treatments in the study decreased yield compared to the UTC. The application of biochar at 90, 180, and 360 lbs C/acre without fertility significantly increased yield over the UTC by 9.5, 6.8, and 5.8 bushels/acre, respectively, averaging a 7.3 bushel/acre yield increase (Table 2). Conversely, humic acid applications without fertility increased yield numerically, but not significantly, regardless of the rate applied. (Table 2).

Fertilization with P + K alone increased yield by 12.4 bushels/acre over the UTC, indicating that the research sites were deficient in P and K, limiting yield potential. Although non-significant, adding carbon amendments to P + K fertilizer numerically increased grain yield at the biochar rates of 90 and 180 lbs C/acre, and at the humic acid rate of 90 lbs C/acre, while the 360 lbs C/acre rate tended to decrease grain yield compared to P + K only, regardless of the carbon source. When averaged across fertility and carbon sources, as the rate of applied carbon increased, corn grain yield tended to decrease (Table 3).

When averaged across carbon rates and fertility, application of biochar resulted in greater corn grain yield than when humic acid was applied (Table 4). Due to the higher product application rate of humic acid when compared to biochar to achieve the same carbon application rate (100, 200, and 300 lbs biochar/acre vs. 210, 420, and 840 lbs humic acid/acre), biochar applications are potentially a more economical and feasible approach to adding carbon to soils than humic acid applications.

The results of this study demonstrate the potential of granular carbon amendments, with or without P and K fertilization, to increase corn grain yield, which may be related to the effect of carbon amendments on corn cation uptake. Therefore, granular carbon amendments may positively influence soil functions and soil carbon levels, while maintaining or increasing corn grain yield.

Table 1. Nutrient concentrations in corn plant tissue at the VT growth stage as affected by carbon amendment, rate, and fertilizer treatments at Champaign, IL in 2022. Data from 2023 was not available at the time of this publication.

Carbon Amendment	Rate	K		Ca		Mg	
		Fertility†					
		-	+	-	+	-	+
	lbs C/acre			%			
None		1.07	1.16	0.52	0.55	0.55	0.54
Biochar	90	1.16	1.22	0.52	0.50	0.50	0.48
	180	1.14	1.33	0.52	0.48	0.50	0.46
	360	1.12	1.19	0.49	0.52	0.48	0.49
Humic Acid	90	1.21	1.17	0.48	0.49	0.47	0.50
	180	1.09	1.28	0.48	0.49	0.46	0.48
	360	1.19	1.25	0.45	0.47	0.46	0.48
LSD(0.10)		0.13		0.04		0.05	

†Fertility applied as MAP at 60 lbs of P_2O_5/acre plus MOP at 60 lbs of K_2O/acre.

Table 2. Corn grain yield as influenced by fertility and biochar or humic acid treatments applied at three different rates at Champaign, IL.

Carbon Amendment	Rate	Fertility†	
		-	+
	lbs C/acre	bushels/acre	
None		238.9	251.3
Biochar	90	248.4	251.8
	180	245.7	253.5
	360	244.7	249.4
Humic Acid	90	242.3	254.4
	180	241.2	250.7
	360	243.3	247.8
LSD(0.05)		5.1	

†Fertility applied as MAP at 60 lbs of P_2O_5/acre plus MOP at 60 lbs of K_2O/acre. Grain yield data is averaged across two years and is presented at 15.5% moisture.

Table 3. Effect of carbon rate on corn grain yield at Champaign, IL.

Carbon Rate	Grain Yield
lbs C/acre	bushels/acre
90	249.0
180	247.8
360	246.3
LSD(0.05)	NS

Data was averaged across carbon source and fertility over two years.

Table 4. Effect of carbon source on corn grain yield at Champaign, IL.

Carbon Source	Grain Yield
	bushels/acre
Biochar	248.9
Humic Acid	246.5
LSD(0.05)	2.0

Data was averaged across years, carbon rates, and fertility.

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INVESTIGATING SOYBEAN RESPONSE TO PHOSPHORUS WITH A COVER CROP AND FERTILIZER COMBINATION IN KANSAS

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ABSTRACT

The soybean crop provides one of the best opportunities to include a cool season cover crop (CC) ahead of planting. This study aims to maximize the soybean crop's phosphorus (P) use efficiency by using CC planting as a window of opportunity for better P fertilizer placement and timing. Specifically, combining P fertilizer with cereal CC seeds will place the fertilizer below the soil surface and combine two operations (CC planting and fertilizer application) in one pass. Other benefits include eliminating the environmental risk of P fertilizer runoff and potentially creating a synergistic benefit of the CC and fertilizer combination on P availability to the soybean crop. The overall objective of this study was to improve phosphorus management for soybean production in Kansas, increasing yields using improved diagnostic tools and fertilization strategies and leveraging opportunities for application placement with a CC in the rotation. Nine sites were established, with five locations under supplemental irrigation and four rainfed locations. Phosphorus treatments included a control with no P application and three P rates of 45, 90, and 135 Kg P2O5/ha, using mono-ammonium phosphate (MAP). CC treatments included oat and triticale with no P application and with P application of 45 Kg P2O5/ha. CC samples were collected before soybean planting to measure biomass and P uptake. Soybean whole plant samples were collected at the V3-V4 stage for P Uptake analysis. At harvest, grain yield was recorded for each plot. The results obtained with this research showed that there was no significant response to CC treatments in locations that are non-responsive to P fertilization. In responsive locations to P fertilization, there was a penalty in soybean growth and yields when adding CC to the system. Excessive CC biomass seems to negatively affect soybean growth and yield, highlighting the need for timely termination of the CC.

INTRODUCTION

Phosphorus is an essential nutrient for plant development and can be scarce in some ecosystems, in addition to being an important cost for agricultural production and being a non-renewable resource. Phosphorus management can alter plant use efficiency, just as tillage and fertilizer placement can alter nutrient availability and stratification in the soil (Mallarino and Borges 2006).

The creation of many agricultural best management practices have been proposed to reduce fertilizer P losses, and their implementation is important since most fertilizer recommendation systems for agricultural crops were developed based on maximizing yields and not on avoiding possible environmental impacts (Withers et al. 2014).

Keeping the soil exposed, in the period without crops growing, can cause soil disaggregation by the impact of rain, and consequently runoff of soil and nutrients by water or even losses by wind (Havlin et al. 2005). Cover crops have been encouraged to be used before crops such as corn and soybeans, seeking the principles of a more conservationist agriculture. Cover crops can decrease sediment losses as they cover the soil surface during the time when there are no crops growing in the field, reducing the energy of raindrops and the speed of water runoff, increasing water infiltration into the soil and avoiding nutrient losses (Blanco-Canqui et al. 2011).

The soybean crop provides one of the best opportunities to include a cool season cover crop before planting. Combining P fertilizer with cereal cover crop seeds will place the fertilizer below the soil surface and combine two operations (cover crop planting and fertilizer application). This study aims to maximize phosphorus use efficiency by the soybean crop by using cover crop planting as a window of opportunity for better P fertilizer placement and timing. The hypothesis of this study was that, in locations responsive to P application (low P levels in the soil), CC would be beneficial for soybeans as it would act as a slow-release source of P into the soil.

MATERIALS AND METHODS

This study was conducted in 2022 and 2023 at nine locations across Kansas. Among the nine locations, five were established under supplemental irrigation and four rainfed locations. Before fertilizer application, soil samples were collected at a depth of 0 to 15 centimeters using a hand probe. The average soil test P (Mehlich 3 and Bray 1), pH, and organic matter (OM) are presented in Table 1.

Phosphorus treatments included a control with no P application and three P rates of 45, 90, and 135 Kg P2O5/ha, using mono-ammonium phosphate (MAP). CC treatments included triticale (planted in fall) and oat (planted in spring) with no P application and with P application of 45 Kg P2O5/ha. P rates and CC were arranged in a factorial combination of treatments.

Table 1: Average soil test P, pH, and organic matter (OM) by location.

		Soil test values			
Site	Year	STP-M3	STP-B1	pH	OM
		- - - - mg kg^{-1} - - - -			g kg-1
1	2022	79	84	5.3	33
2	2022	17	19	5.7	27
3	2022	3	6	5.8	37
4	2023	10	18	6.5	16
* 5	2023	5	13	6.0	31
6	2023	9	14	7.1	22
* 7	2023	3	8	6.1	33
* 8	2023	7	14	5.9	25
9	2023	18	30	6.8	19

* Yield was not included for this analysis.

CC samples were collected before soybean planting to measure biomass and P uptake. Soybean whole plant samples were collected at the V3-4 growth stage to be analyzed for P uptake. The plant tissue samples were digested using nitric-perchloric acid digestion and analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). At harvest, grain yield was recorded for each plot.

Data was analyzed by location and combined using lmer4 package in R 4.3.1, using RStudio (Version 2023.06.1+524), assuming block as a random factor in the model. When locations were combined, it was also considered as a random effect.

RESULTS AND DISCUSSION

The biomass of CC showed a significant difference comparing oat and triticale, with higher values when P fertilizer was applied (Figure 1). The difference between the CC was mainly due to the longer time given for triticale to grow, as it was planted in the fall of the year before soybean planting, while oat was planted in the spring.

Early-season phosphorus uptake (V3-V4) showed no significant difference between CC treatments with or without fertilizer P application I non-responsive locations (Figure 2 – Non-Responsive). In locations responsive to the application of P fertilizer (Figure 2 - Responsive), there was a penalty in P uptake when a CC was added, showing a tendency to reduce even further when the CC was triticale.

The CC undergoes a decomposition process that lasts several days, during which the nutrients they contain are gradually released into the soil. In scenarios where soil P availability is limited (Figure 2 – Responsive), delayed decomposition of cover crops can result in slower release of P. Consequently, this delay can negatively affect soybean crops, particularly during the early season, as the slow release of phosphorus from cover crop residues may not readily satisfy soybean nutrient demand. This delay can potentially interfere with the development of soybean plants and their P uptake (Varela et al. 2017).

In locations where the crop was non-responsive to P fertilization, the treatments with or without cover crops did not exhibit a significant difference in grain yield (Figure 3 – Non-Responsive). However, the scenario changes in areas with low P levels (Figure 3 – Responsive). The decomposition of cover crops may not occur timely or completely by the time the main crops need to uptake this nutrient for optimal growth, resulting in a penalty by using CC (Poudel et al. 2023). The disparity in grain yields in these cases can also be attributed to the disadvantage faced during the soybean early season, where nutrient demand is high but supply from cover crop decomposition was slow.

In summary, there was no significant response to CC treatments in non-responsive locations. In locations responsive to P fertilization, there was a penalty in soybean growth and yields when adding CC to the system, rejecting our hypothesis that CC treatments would act as a slow-release source of P into the soil for the next cash crop.

The situation where cover crops were at a disadvantage could also result from the dryer Kansas environment, which might have impacted the rate of decomposition and/or the availability of water to the main crop. However, in scenarios where no significant differences in grain yield were observed, employing CC may still present benefits as they can enhance soil health and protection, contributing to a better soil structure or playing as a weed suppressor.

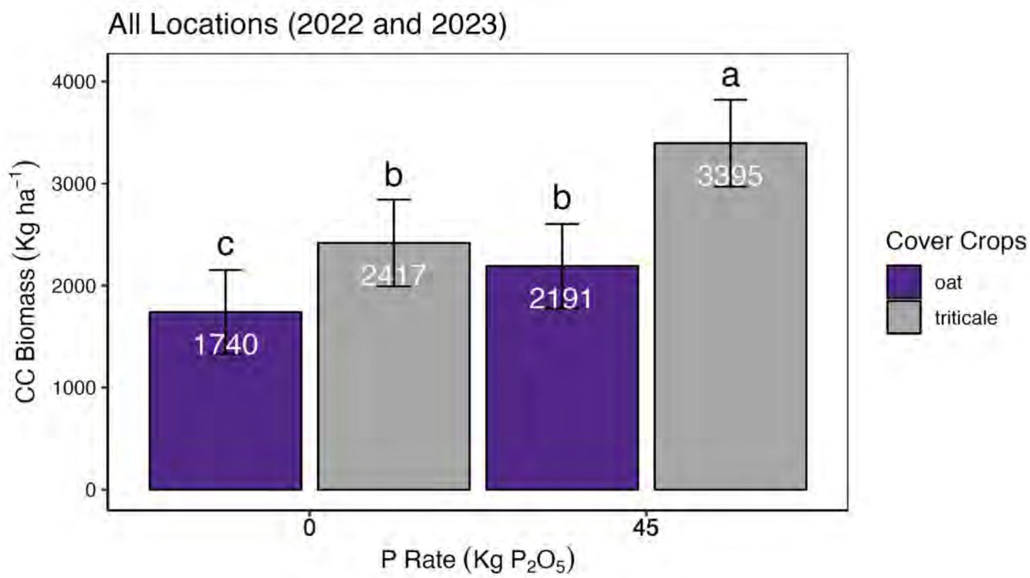

Figure 1: Cover crop biomass (Kg ha-1) as affected by different P rates and cover crop species across 9 locations.

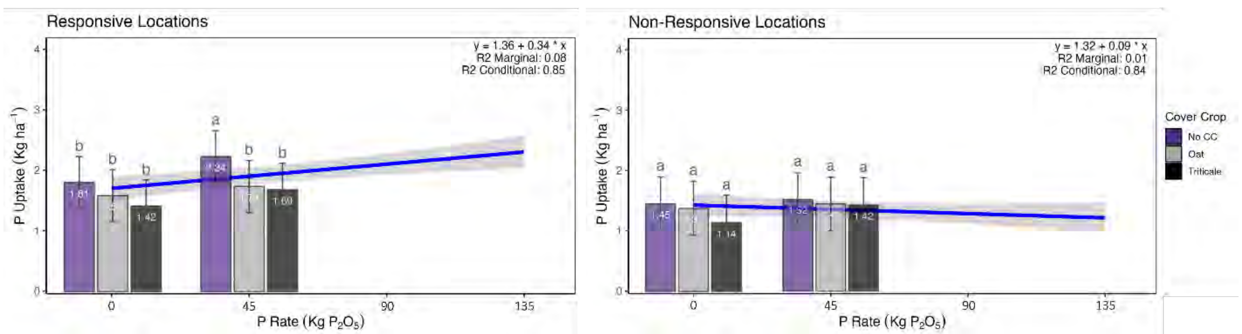

Figure 2: Phosphorus uptake (Kg ha-1) as affected by different P rates (regression line) and Phosphorus uptake (Kg ha-1) as affected by different P rates and cover crop species (bars) in <u>responsive</u> and <u>non-responsive</u> locations to P fertilizer.

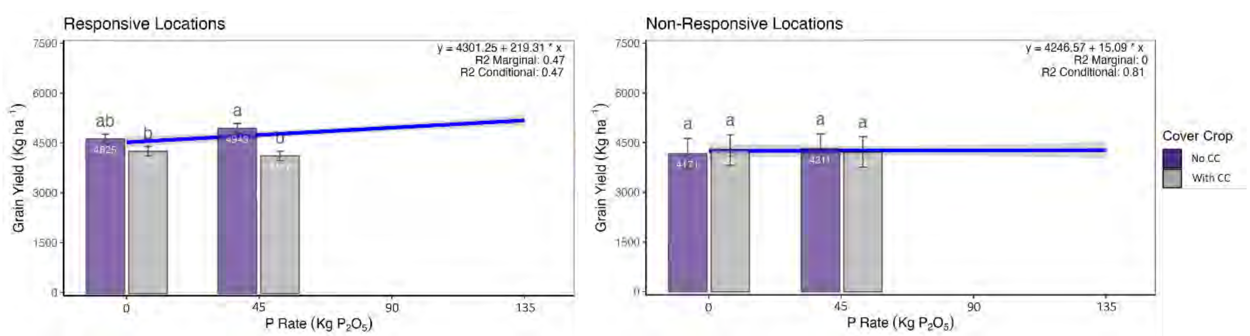

Figure 3: Grain yield (Kg ha-1) as affected by different P rates (regression line) and grain yield (Kg ha-1) as affected by different P rates and cover crop species (bars) in <u>responsive</u> and <u>non-responsive</u> locations to P fertilizer.

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EFFECTS OF FERTILIZER NITROGEN MANAGEMENT ON BIOMASS, OIL, AND NITROUS OXIDE EMISSIONS IN PEPPERMINT IN NEBRASKA PANHANDLE

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ABSTRACT

Peppermint (*Mentha pipperita*) is an aromatic perennial herb that contains aromatic oil, primarily menthol. Irrigated peppermint production requires large nitrogen (N) input, which is often higher than for irrigated corn. Therefore, if not managed properly, mint production has a high potential for N losses, including nitrous oxide (N_2O) emissions. Nitrous oxide is a major greenhouse gas and also the single most important ozone-depleting emission. Increasing N_2O emissions from agriculture are linked to soil management and the application of N fertilizers. The objective of this research is to assess the effects of different N fertilizer sources and rates on peppermint biomass, oil (menthol and carvone) concentration, and N_2O emission. The experiment was conducted in 2022-2023 at the University of Nebraska Research Station in Scottsbluff, NE. The experimental design is a randomized complete block with four replicates. The main factor is N treatment, which included the control, urea, and polymer-coated urea (Duration®, Allied Nutrients, Ohio) surface applied at different rates. Biomass yield ranged 3.33-3.98 Mg ha^{-1} and 7.56-14.11 Mg ha^{-1} in 2022 and 2023, respectively. The 2022 biomass yield was lower than in 2023 due to lower soil available N (spring soil test N + applied N) and crop establishment issues in the first year. In 2022, there was no significant difference in dry biomass across the N source and soil available N. In 2023, there was an increment of biomass with increasing soil available N and the biomass was similar for both urea and Duration, except at the applied rate of 120 kg N ha^{-1}, where Duration had a higher yield than urea. In both years, menthol content (>90% of total oil) was significantly higher than carvone (<10%). The greater the soil N, the higher the oil concentrations were. In both years, the urea treatments had higher N_2O emissions than Duration across all N levels, except for the lowest N rate in 2022 and 2023. Nitrous oxide emission differed by soil N levels in the urea treatments but not in Duration. These results show that fertilizer N can be optimized for sustainable peppermint production in NE using advanced fertilizer technology such as polymer-coated N.

INTRODUCTION

Peppermint is used in the food, pharmaceutical, and perfume industries for various purposes. Peppermint oil is the end product and primarily consists of menthol (Zheljazkov et al., 2009). The US is the world's largest producer of peppermint oil. Most peppermint is grown in the Northwest Pacific region (Idaho, Oregon, Washington), which accounts for 91% of US peppermint production (Brown et al., 2003). The Peppermint oil market shows steady growth, and Western NE has peppermint growing conditions, such as long days (>15 hours) and cool nights during the summer, like in the Northwest Pacific region

(Okwany, 2012). A few local farmers have started growing peppermint in Western NE and found it profitable. Those farmers have been using the fertilizer nitrogen (N) recommendation from other peppermint growing states, especially from Idaho. Based on Idaho N recommendation, peppermint requires more N (280-325 kg ha-1) (Brown et al., 2003) than irrigated corn (224-280 kg ha-1) for optimal yield (Gumz, 2007). Therefore, in such a high N-input system, a considerable amount of applied N can be lost to the environment, including emission of nitrous oxide (N2O) if managed improperly. N2O is a significant greenhouse gas (GHG) and the most important ozone-depleting emission. Increasing N2O emissions from agriculture are linked to soil management and the application of N fertilizers (Maharjan et al., 2014). Therefore, proper N management practice is required for commercial peppermint production in Western NE. However there hasn't been any published report on N2O emission in peppermint, which is essential for inventorying GHG emissions from agriculture and informing our mitigation efforts.

The objective of this study was to assess the effects of different N fertilizer sources and rates on peppermint yield, oil quality, and N2O emission in the Western NE.

MATERIALS AND METHODS

Field experiment was conducted at the Panhandle Research Extension and Education Center (PREEC) in Scottsbluff, NE (41°03'39" N, 103°40'54" W; elevation 1198 m), in 2022 and 2023. The experiment was in a randomized complete block design with four replicates. The N sources used were conventional Urea (46-0-0) and controlled-release fertilizer, Duration (43-0-0), with application rates of 140, 210, 280, and 350 kg N ha-1), which corresponded to 50, 75, 100, and 125% of the recommended N rate for commercially grown mint in the pacific northwest region. Peppermint biomass was collected at fully flowering stage and reported as dry matter. Oil concentration in leaves was measured using a Chromatography-Mass Spectrometer (GCMS). N2O Gas fluxes were measured twice a week using LI-COR 7820 N2O/H2O trace gas analyzer (LI-COR Biosciences, Lincoln, NE, U.S.). Cumulative N2O emission from flux was calculated using trapezoidal integration of flux over time. The treatment effects on measured variables were determined by the ANOVA test in SAS.

Table 1. Treatments used in the field experiment.

Treatment*	Spring test N (kg N ha^{-1}) (2022/2023)	Applied N (kg N ha^{-1}) (2022/2023)	Soil Available N (kg N ha^{-1}) (2022/2023)
Control	96/18	0/0	96/18
1	96/18	30/102	126/120
2	96/18	45/146	141/164
3	96/18	60/189	156/207
4	96/18	75/230	171/248

*Treatment included N applied as urea or Duration at different rates.

RESULTS AND DISCUSSION

Peppermint Dry Matter Biomass

Year 1 (2022) received less than half of N in year 2 (2023) and had plant establishment issues. Therefore, peppermint yield was greater in Year 2 (2023) than in Year 1 (2022). In Year 1, peppermint yield did not vary by N source or rate. In Year 2, fertilized plots had higher yields than the control in the cases of both urea and Duration. The lowest N rate treatment yielded less than the two highest N rates in the case of urea and the highest N rate in Duration. In 2023, between N sources, Duration had a greater yield than urea at the lowest applied N rate. The results of the year 2 (2023) related to N rates of urea treatments were similar with Alsafar & Al-Hassan, (2009) and Shormin et al. (1970) who reported fertilized plots had yield increment trend with increasing N rates. Year 2 (2023) results related to the N source (urea and controlled release fertilizer, Duration®) aligned with Kiran and Patra (2003) who reported significant yield increment of mint in the controlled release fertilizer than urea.

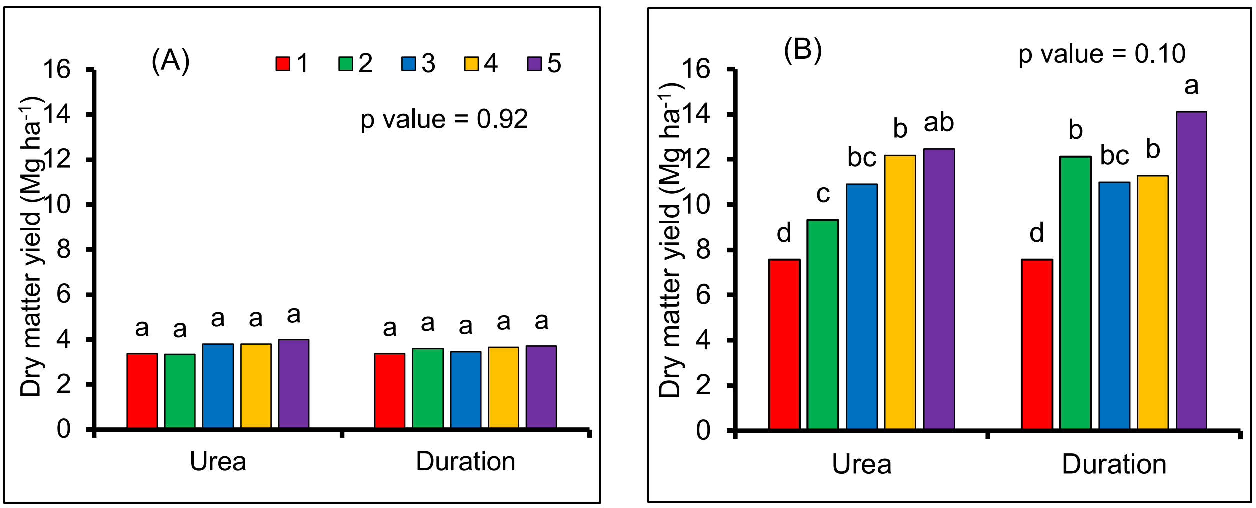

Figure 1. Interaction effect of N source and N rates on peppermint dry matter yield in 2022 (A) and 2023 (B). Different small case letters above bars indicate significant treatment differences at the given p values.

Cumulative Nitrous Oxide (N_2O) Emission

In Year 1, among urea treatments, emissions were in the order of treatments 4=3=2>1=control. In Year 2, they were in the order 4=3>2>1>control. All Duration treatments had similar emissions as the control in both years. Nitrous oxide emissions were greater in urea than in Duration in both years, except for the lowest applied N rate in Year 1 (2022).

It's well-established in previous studies that applying fertilizer N leads to increased N_2O emissions from agricultural systems, and this increase is directly proportional to the N application rates (Dusenbury et al., 2008; Hoben et al., 2011). Nitrous oxide emissions in Duration did not increase with N rates. Several studies have shown that the N source can affect soil N_2O emission (Drury et al., 2012). Polymer-coated urea such as Duration® reduces N_2O emission since durable polymer coated technology releases nutrients gradually and efficiently (the nutrient's releasing process is diffusion), thereby improving N use efficiency and reducing environmental N losses. Halvorson et al. (2010), and Sistani et al. (2011) also reported reduced N_2O emissions with polymer coated urea compared to urea in different cropping systems (corn and potato), as was the case in this experiment.

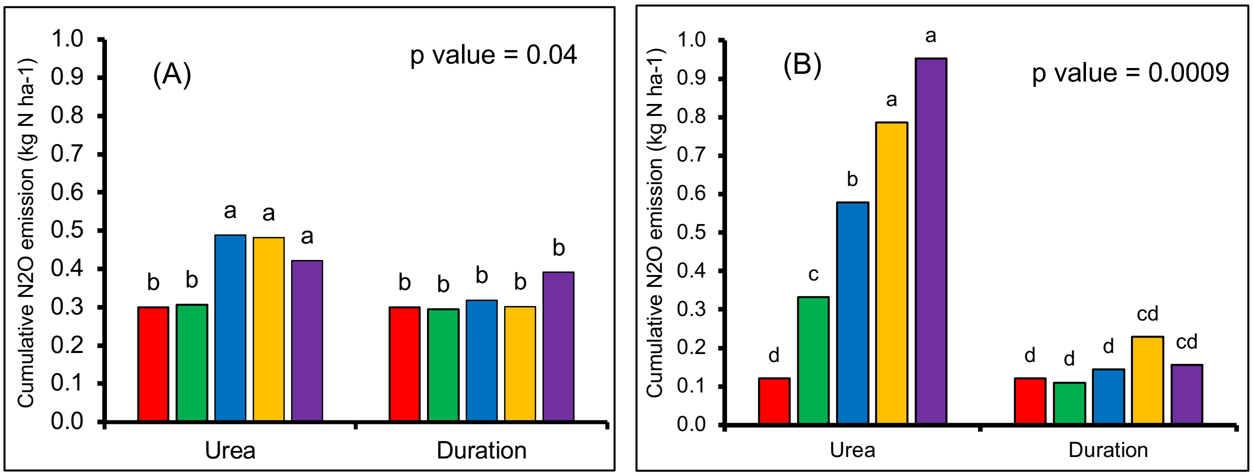

Figure 2. Interaction effect of N source and N rates on cumulative N_2O emission in 2022 (A) and 2023 (B). Different small case letters above bars indicate significant treatment differences at the given p values.

Peppermint oil

The menthol and carvone concentrations in peppermint leaves were significantly affected by N rates irrespective of N sources in both years. Fertilizer application increased the menthol and carvone concentrations in leaves. Our results aligned with Marotti et al. (1994), who also found that fertilizer N increased menthol concentration compared to control. In contrast, Kothari et al. (1987) and Poshtdar et al. (2016) reported reduced oil concentrations with higher N levels due to dilution effect as higher N increased biomass production.

Table 1. Menthol and carvone concentrations in peppermint leaves affected by N sources and N rates in year 1 (2022).

Factors	Menthol (mg g^{-1})	Carvone (mg g^{-1})
N source (N)		
Urea	6.51	0.91
Duration	7.14	1.01
Significance level (p value)	0.50	0.69
Applied N (R) (kg ha^{-1})		
0	4.07 **b**	0.22 **b**
30	7.73 **a**	1.17 **a**
45	6.34 **ab**	1.26 **a**
60	7.31 **a**	1.12 **a**
75	8.67 **a**	1.03 **ab**
Significance level (p value)	0.05	0.09
Interaction effect (N X R)		
Significance level (p value)	0.78	0.78

*Different small case letters behind mean values indicate significant treatment differences at given p values.

CONCLUSIONS

There were no significant yield differences by N rates or sources due to the establishment issue in year 1. Across N rates, Duration increased peppermint dry matter yield and reduced emissions compared to urea in year 2. Fertilizer application increased menthol and carvone concentrations. Fertilizer N can be optimized for sustainable peppermint production in NE using advanced fertilizer technology such as polymer-coated N (here, Duration). Maximum yield was obtained at 280 kg N ha^{-1} rate among Duration treatments. More site-year data would be necessary to determine the optimum N rates.

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NITROGEN FERTILIZER AND IRRIGATION EFFECTS ON SOIL AND PLANT NITROGEN DYNAMICS

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ABSTRACT

Cropping systems can be exposed to different nitrogen (N) and water availabilities for a variety of reasons. Both N and water have been shown to have both positive and negative; direct and indirect effects on soil and plant N dynamics. Given that agronomic crops require large amounts of N to achieve high yields and often acquire a majority of their N from soil nitrogen mineralization (N min), it is important to understand how nitrogen and water interactions alter soil and plant N dynamics. Our study was conducted on continuous no till corn at the USDA-ARS Central Great Plains site in Akron, CO during the 2021 and 2022 growing season. We utilized two irrigation treatments of 100% ET and 70% ET representing full water and near dryland conditions for the region, and three N fertilizer treatments ranging from 2 – 245 lbs / ac capturing low, optimal, and excess N. We used an in-situ undisturbed soil core with ion exchange resin beads to measure net N min and found that there was an N fertilizer by irrigation interaction. N-acquiring soil enzyme activity increased with N fertilizer and was not affected by irrigation regime. Plants in the water limited environment were still able to acquire large amounts of N, though that did not translate to large yield gains due to water limitations especially during reproductive growth stages. A follow up ^{15}N tracer study is being conducted to better understand what sources of N plants are utilizing under different resource availabilities.

EXPLORING THE IMPACT OF TEMPORAL VARIABILITY IN EMERGENCE ON CORN GRAIN YIELD AND DEVELOPMENT PATTERNS

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ABSTRACT

The objective of this study was to investigate the impact of starter fertilizer placement on the seedlings emergence and uniformity and assess whether the timing of seedling emergence influences the developmental stages and eventual single-plant grain yield. An early planting date was compared with a normal planting date with different starter fertilizer combination and placement. Liquid Starter fertilizers were placed in-furrow low and high rate, 2 x 2 normal rate, and a combination of in-furrow low rate and 2 x 2 placement, and provided 9, 14, 23, and 32 lbs. P2O5 a^{-1} respectively. These placements were compared to a control treatment without starter fertilizer application. Final emergence percentage was calculated based on the number of seedlings emerged as a percentage of seeds planted. Starter fertilizer placement did not influence daily seedlings emergence in either planting dates ($p > 0.05$). Delayed seedlings emergence highly correlated with shorter plant height, delayed silk and tassel emergence, lower ears weight, and single-plant grain yield ($p<0.01$) regardless of the planting dates. Early seedling emergence demonstrated a clear association with early silk and tassel emergence across both planting dates. Plant height decreased as a function of delayed seedlings emergence at all growth stages. The findings highlighted that uniform seedling emergence is critical in optimizing crop productivity.

INTRODUCTION

Concerns have been raised among farmers in the Midwest regarding the impacts of uneven emergence of corn (Zea mays L.) seedlings. They believe that even a minor delay in emergence of a few hours could have a substantial influence on plant performance (Kimmelshue et al., 2022). According to Liu et al., 2004, corn emergence delay decreases plant height, leaf area index, dry matter accumulation, and grain yield compared to early emerging plant. This suggests that if plants within a crop have consistent growth and emergence patterns, it can positively impact overall yield, indicating that plant emergence variability plays a crucial role single plant grain yield potential.

One of the contributing factors to uneven seedling emergence in corn is the application of starter fertilizer. Research has shown that placing fertilizer in the seed furrow during planting or seeding is an efficient method for cultivating small grains in low temperature soils. This approach, particularly crucial for ensuring an early nutrient supply for initial crop growth and development; however, if applied in close proximity to the seed in excessive amount, the fertilizers tend to increase the salt concentration surrounding the seed and as a result, delays seedling emergence, reduces crop stand and grain yield (Qian et al., 2010). Therefore, the objectives of these study were to Investigate the impact of starter fertilizer placement on seedlings emergence and uniformity as well as assess whether the timing of seedling emergence influences corn developmental stages and eventual single-plant grain yield.

MATERIALS AND METHODS

This experiment was conducted in Brookings, South Dakota in 2022 (44.3114° N, 96.7984° W). Soil in this area is a Fine-silty, mixed, superactive, frigid Pachic Hapludolls, which are well-drained and have a slope of 2%. The tillage practice of the field was conventional on a corn soybean [Glycine max (Merr) L.] rotation. The plot dimensions were 10 feet wide and 50 feet long and 34 000 seeds ac^{-1} were planted on a 4’30-inch row.

An early planting date was compared with a normal planting date with different starter fertilizer combination and placement. The first planting date was on October 23rd and the second was on June 3rd, 2022. Liquid Starter fertilizer (10-34-0, 10-34-0 + Zn, 8-21-5, 8-21-5 + Zn, were placed in-furrow low (IFL) and high rate (IFH), 2 x 2 normal rate, and a combination of in-furrow low rate and 2 x 2 placement (Both), and provide 9, 14, 23, and 32 lbs. P_2O_5 a^{-1} respectively. These placements were compared to a control treatment without starter fertilizer application (UTC). The field experiment was a split plot design with 4 replications where the main was the planting dates and the subplots were the starter fertilizer types and placements. Urea was applied to balance the nitrogen requirements of the corn plants regardless of the starter treatment at a rate of 150 lbs. a^{-1}.

Emerged seedlings from the central 10 feet of the second row of each plot were marked on a 12-hour basis and the emergence date was recorded. Colored stakes were used to facilitate visual identification of emergence date throughout the experiment. After 10 observations following the first emergence date recorded for each plot, emergence was considered complete. Final emergence percentage was calculated based on the number of seedlings emerged as a percentage of seeds planted. Total days to emergence were identified as accumulated growing degree units. Individual plant height was measured throughout the growing season (V4, V10 and R6). Silk and tassel emergence were recorded. Individual ears were hand harvested, tagged, and processed for yield and yield components analysis, and the weight was adjusted to 15.5% moisture.

RESULTS AND DISCUSSION

Starter fertilizer placement did not influence emergence regardless of the planting dates (Figures 1,2). The 2*2 normal rate placement increased seedling emergence in the first observations and the control treatments ended up with the lowest percent of emerged seedlings for the first planting; however, the differences were not significant (Figure 1). The patterns observed in the second planting date were similar for all the treatments (Figure 2), indicating that the placement of starter fertilizer did not result in a significant difference in uniformity of corn seedling emergence. This finding suggests that, in the specific conditions or context of the study, the application of starter fertilizer in the seed furrow did not provide a obvious advantage in promoting early seedling emergence.

Delayed seedlings emergence was highly correlated with shorter plant height (*p*<0.01) regardless of the planting dates throughout of the season (Figures 3,4). Plant height decreased as a function of delayed seedlings emergence at all growth stages. Late-emerging corn did not grow as tall as earlier-emerging corn when plant emergence is delayed. Our study corroborates the findings of previous research, specifically Liu et al., 2004, which reported decreased plant height are associated with delayed emergence, which could be attributed to the intensified competition late emerging plants face for incoming solar radiation, moisture, and nutrients.

Delayed seedlings emergence highly correlated with delayed silk and tassel emergence (*p*<0.01) regardless of the planting dates (Figure 5). There is a linear relationship between both silk and tassel and seedlings emergence timings. The early emerging corn were able to emerge silk and tassel earlier compared to the late emerging plants. The clear association that early seedling emergence demonstrated with early tassel and silk emergence across both planting dates (Figure 5), underlining the importance of synchronized developmental stages.

Single plant grain yield decreased with delayed emergence for both planting dates (Figure 6). This yield loss could be attributed to the drought conditions recorded in the 2022 growing season which caused more stress on the late emerging corn compared to the early emerging corn.

The findings highlighted that uniform seedling emergence is critical in optimizing crop productivity and emphasizing the importance of synchronized developmental stages for minimizing plant competition.

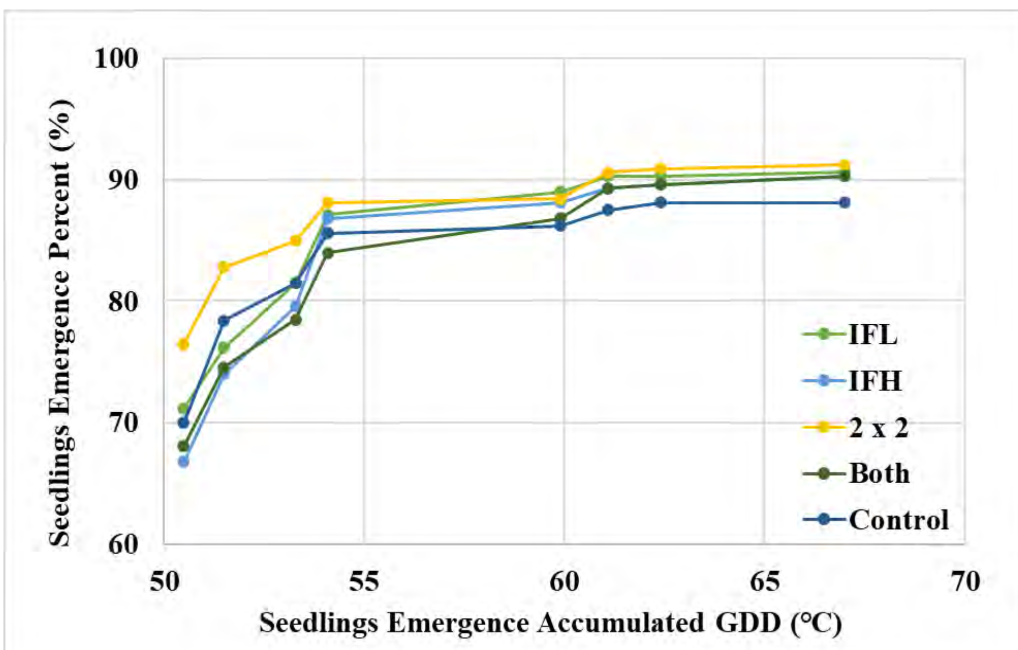


Figure 1: Cumulative seedlings emergence progress to starter fertilizer placement in corn planted on May 23rd, 2022 (first planting date). Seedlings emergence means are averaged for each observation.

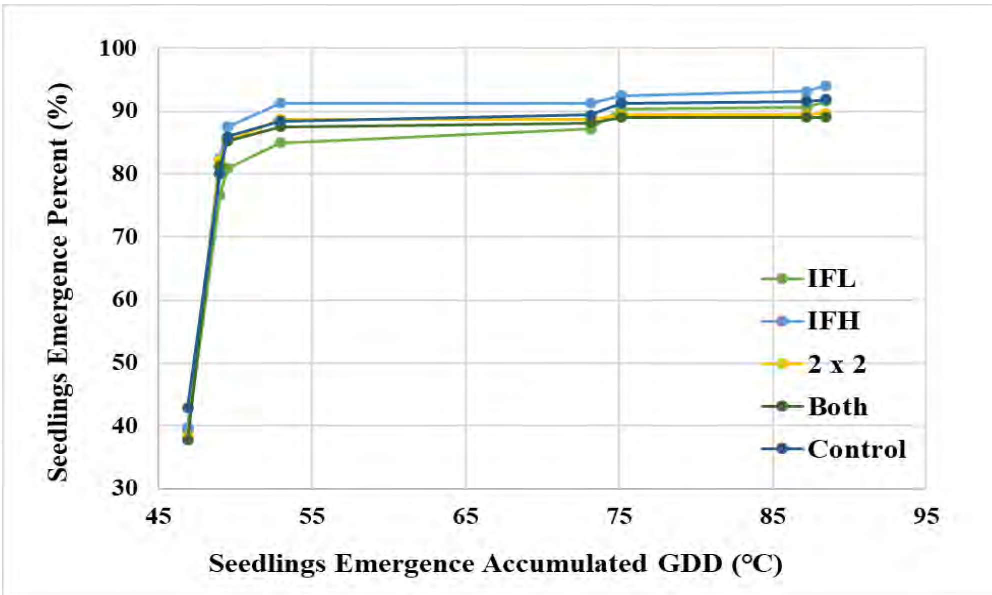
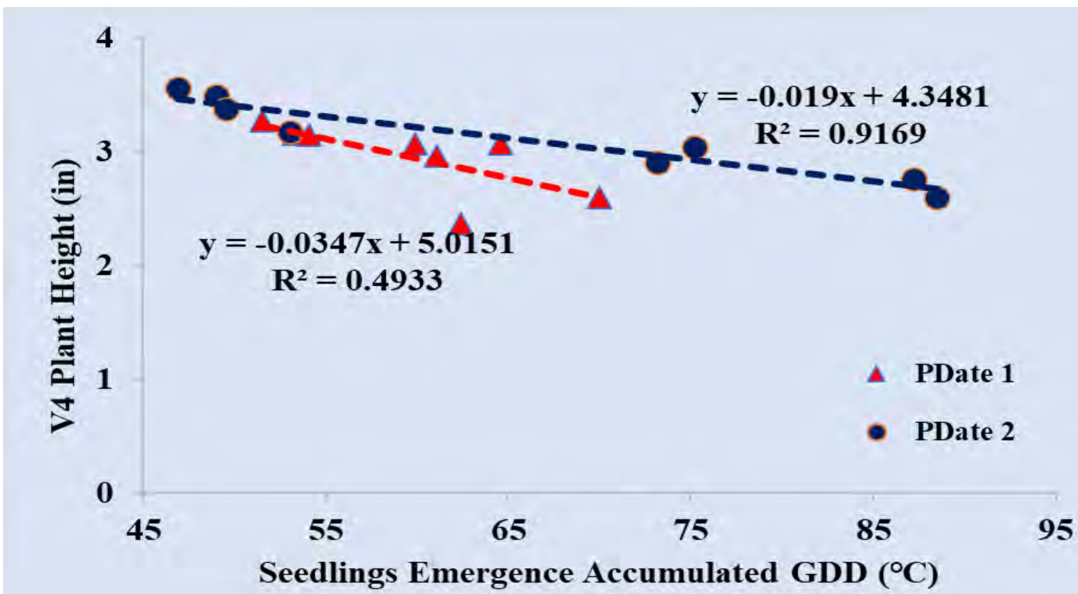


Figure 2: Cumulative seedlings emergence progress to starter fertilizer placement in corn planted on June 3rd, 2022 (second planting date). Seedlings emergence means are averaged for each observation.



Figures 3: Correlation between seedlings emergence accumulated GDD and early season (V4) plant height across both planting dates. Seedlings emergence means are averaged across each starter fertilizer placement for each observation.

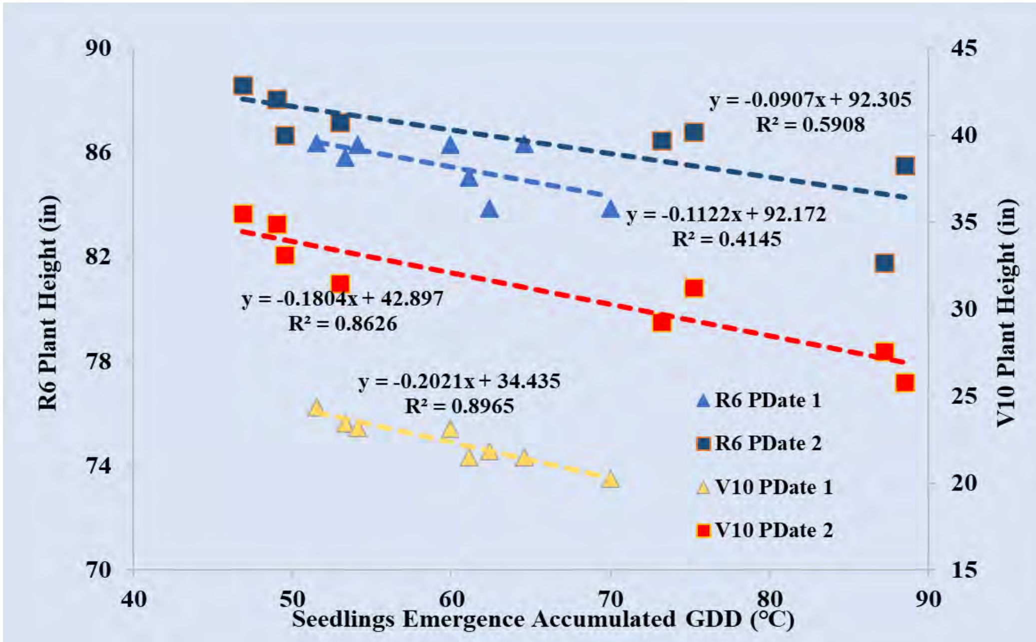


Figure 4: Correlation between seedlings emergence accumulated GDD, mid-season (V10, secondary axis) and whole-season (R6 physiological maturity, primary axis) plant height across both planting dates. Seedlings emergence means are averaged across each starter fertilizer placement for each observation.

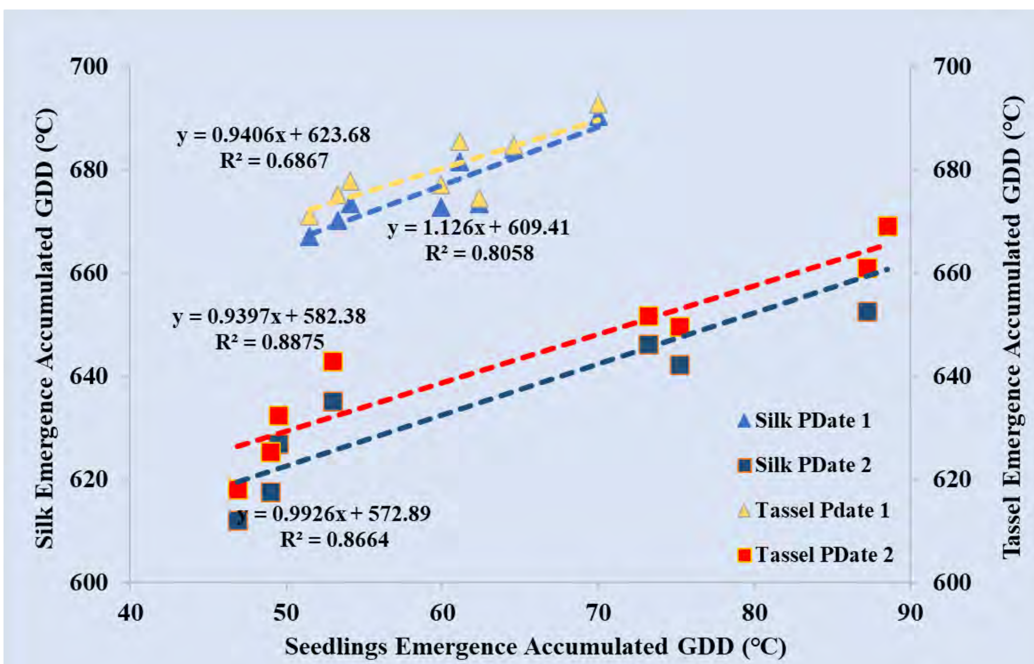


Figure 5: Correlation between seedlings emergence accumulated GDD, tassel (secondary axis) and silk (primary axis) plant height across both planting dates. Seedlings emergence means are averaged across each starter fertilizer placement for each observation.

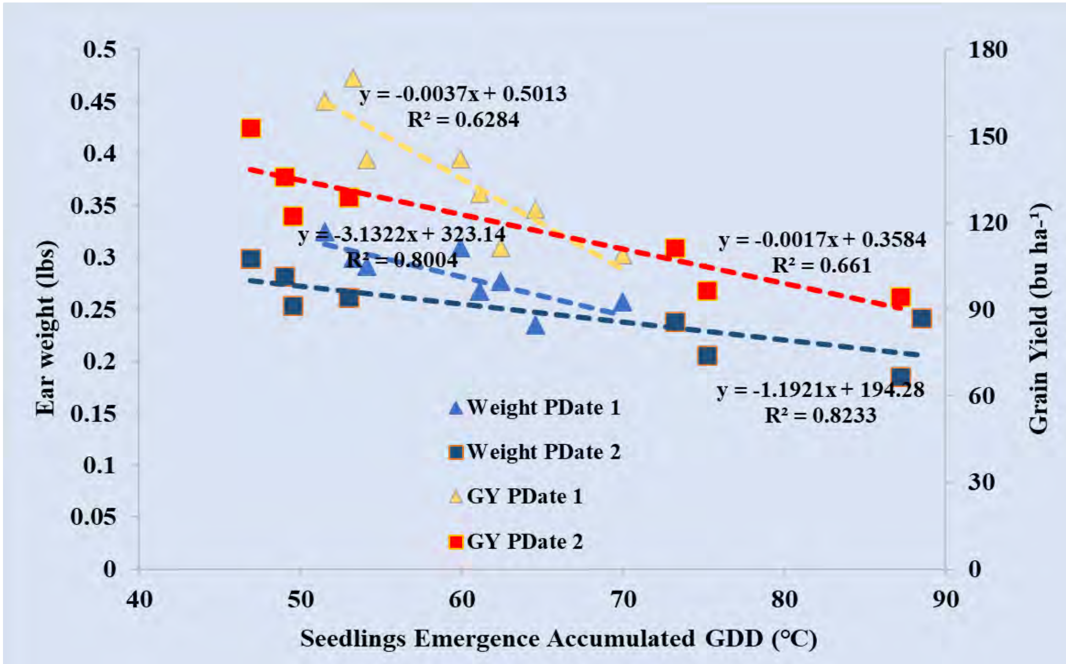


Figure 6: Correlation between seedlings emergence accumulated GDD, single plant grain yield (secondary axis) and ear weight (primary axis) plant height across both planting dates. Seedlings emergence means are averaged across each starter fertilizer placement for each observation.

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THE ALFALFA YIELD PLEATEAU: IS SOIL FERTILITY THE CAUSE?

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Alfalfa is a perennial forage legume known for its ability to produce high quality hay, earning it the title the “Queen of Forages.” It is produced across the United States as feed for the beef, dairy, and equine industries. During the 1950s, alfalfa yields rose exponentially due to advances in technologies such as improved varieties, synthetic fertilizers, and pesticides. However, yields plateaued at approximately 3.3 tons per acre in the 1980s for reasons not fully understood and remain there today. This study was initiated as part of a larger study that includes Oregon and Wisconsin and was funded by the USDA-ARS. The objective of this study is to determine soil fertility’s role in Kentucky’s alfalfa yield plateau. Fifty-three and 61 fields were sampled in 2022 and 2023, respectively. Only 2022 data is presented. Soil samples were collected to depths of 4-, 6-, and 12- inches and analyzed for plant available nutrients. Tissue samples were collected and analyzed for nutrient concentrations and feed nutritive value. Soil analysis revealed that approximately 5% of sampled stands were low in phosphorus and 35% of stands were low in potassium. Soil pH was below the ideal range in 40% of sampled stands. However, tissue analysis indicated that phosphorus was not limiting, and potassium was below the sufficiency range in only approximately 25% of stands. Tissue analysis also reported sulfur, magnesium and boron were below sufficiency ranges in 15%, 25%, and 5% of stands, respectively. In conclusion, soil fertility is likely contributing to the yield plateau observed in Kentucky but is not the sole cause.

INTRODUCTION

Alfalfa (*Medicago sativa* L.) is a perennial forage legume commonly referred to as the “Queen of Forages” because of its ability to produce high quality feed. In 2023, approximately 15.6 million acres were harvested across the United States with 100,000 of those acres being in Kentucky (USDA-NASS, 2023). Hay or Haylage for dairy cattle is the dominant use of alfalfa nationwide, however it is also commonly used as feed for equine and other livestock (USDA-ARS, 2020). Alfalfa yields in the United States increased exponentially from 2.1 tons per acre to 3.3 tons per acre between the 1950s and the 1980s but plateaued and remained there ever since (USDA-NASS, 2022). Yield increases during this time are attributed to advances in new technologies, such as improved yield potential, cultivars with increased pest resistance, and improved management practices (Barnes et al., 1988). This study is part of a much larger study to determine soil fertility’s role in the observed yield plateau across three states in different regions of the United States. However, only data from stands sampled in Kentucky during the 2022 growing season will be presented.

MATERIALS AND METHODS

Samples were collected during the 2022 growing season. In total 53 stands were collected from 31 different alfalfa producers across Kentucky. Producers were selected based on their geographical distribution across the state and ability to obtain fertilizer and other management records. Stands in this survey were between 1 and 5 years of age and sampling occurred between the late bud to early flower stage. Samples were only collected in cuttings 1 through 3. All data was collected from a representative 20 ft by 20 ft area of each stand.

Composite soil samples were collected using a handheld soil probe at 4-, 6-, and 12-inch depths. The 4- and 6-inch composite soil samples were split to be analyzed at the University of Kentucky Soil Testing Laboratory and Kansas State University Soil Testing Laboratory. Composite 12-inch samples were only analyzed at the Kansas State University Soil Testing Laboratory. Before being sent off for analysis, soil samples were dried at 151 °F. Mehlich 3 extraction was used for the analysis of P, K, S, Ca, Mg, Mn, Cu, Fe, and Zn. Boron content was analyzed using hot water extraction. Soil pH is determined in a 1 M KCl solution, converted, and reported as a water pH. The Sikora 2 buffer pH was used to determine reserve acidity for all soil samples.

Tissue nutrient content was obtained by collecting the top 6 inches of 30 stems. After drying for 72 hours at 151°F, stem samples were ground to pass a 0.08 and 0.04 in (2 and 1 mm) screens using Wiley (Thomas Scientific, Swedesboro, NJ) and Cyclone (Udy Corp., Fort Collins, Co) mills, respectfully. Ground tissue samples were then packaged in Whirl-Pak bags and sent to Kansas State University for analysis of N, P, K, S, Ca, Mg, Mn, Cu, Fe, Zn, and B.

A representative yield sample was collected from 6 quadrats measuring 40 in^2 at each site. Alfalfa from each quadrat was combined in a large trash can and weighed for yield estimation. After weighing, a subsample was collected to determine harvest moisture content, dried and ground using the protocol above to determine feed quality metrics using Near Infrared Spectroscopy (NIRS). Stem counts were also collected by returning to 3 of the 6 quadrats used for the yield analysis and counting all the stems in a 12 in by 12 in quadrat. Further, the number of plants within the 1 ft^2 area were also counted. Stand height was measured in six places randomly throughout the stand.

RESULTS AND DISCUSSION

Metric	Stand Height (Ft)	Stem Counts	Number of Plants	Yield (lbs. DM/acre)
Average	1.90	45.94	4.04	176.89
Median	1.85	44.00	4.00	162.36
Minimum	0.88	15.00	1.00	63.89
Maximum	2.70	90.00	9.00	383.51
Standard Deviation	0.38	12.12	1.29	65.79

Table 1. Summary statistics for stand height, stem count, number of plants, and yield for sampled stands.

Table 1 shows the summary statistics for several stand metrics. Regressions were performed for each of these metrics to yield. Only stand height was shown have a significant correlation with an R^2 of 0.243.

Soil pH	Proportion of Stands
	----------------------%------------------------
High (>7.0)	23.00
Ideal (6.5 to 7.0)	36.00
Low (6.0 to 6.4)	30.00
Very Low (<6.0)	11.00

Table 2. Proportion of sampled stands at each pH range.

Soil pH was low in 30% and very low in 11% of sampled stands (Table 2). Rice and coauthors (1977) found that yield declines alfalfa were reported at pH levels below 6.0. Moreira and Fageria (2010) reported that alfalfa had significantly higher dry matter yields and tissue N, Ca, and Mg concentrations after liming acidic soils.

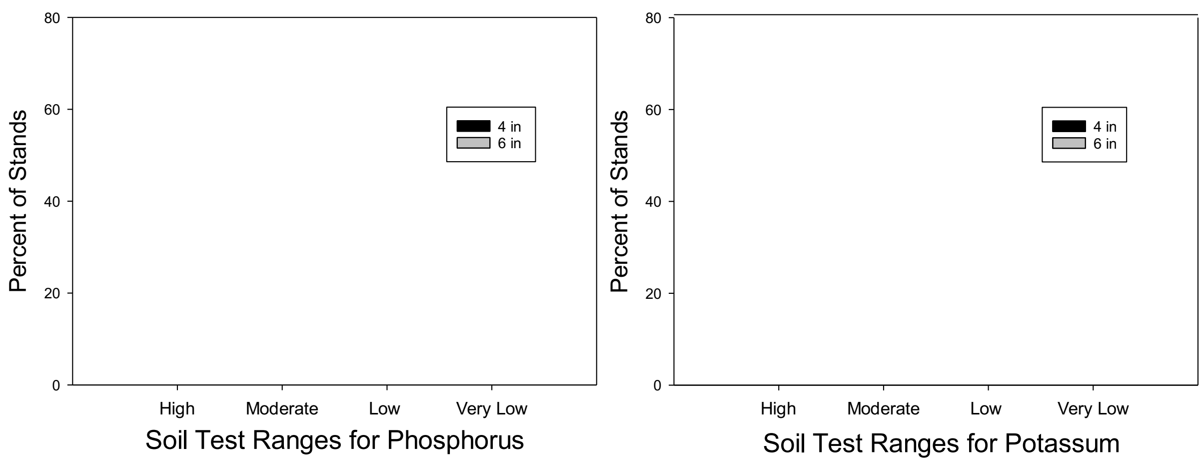

Figure 1. Soil test phosphorus and potassium ranges of sampled stands according to University of Kentucky Cooperative Extension AGR-1 (2020-2021 Lime and Fertilizer recommendations, 2020).

Soil analysis reported approximately 5% and 28% of stands were categorized as low in P and K at the 4-inch sampling depth when compared to the University of Kentucky's Cooperative Extension's fertilizer recommendations for alfalfa (Figure 1). When analyzed using the 6-inch depth, K was categorized as low in 38% of stands and very low in 2% of stands (2020-2021 Lime and Fertilizer Recommendations).

However, tissue analysis reported no stands were below the phosphorus sufficiency level and only 25% of stands were below the potassium (Table 3). The discrepancy between soil and tissue nutrient status of P and K is likely caused by the soil test result falling on the upper edge of the low range and the wide range of nutrient contents that can support optimal plant growth.

Nutrient Status	P	K	S	Mg	B
	------------------------------%------------------------------				
High	0	0	0	0	0
Sufficient	100	74	87	77	94
Low	0	26	13	23	6

Table 3. Percent of sampled alfalfa fields falling into the high, sufficient, and low ranges for P, K, S, Mg, and B as indicated by plant tissue testing. Ranges from UK AGR-92. (Schwab et al., 2007).

Applications of P and K when these nutrients are deficient have been shown to increase yields. Berg et al (2005) conducted a three-year study and found that a split application of P, half after the first cutting and half at the end of the growing season, increased yields in all cuttings. They found that split applications of K did not increase yields until later in the growing season when much of the available K had been removed by previous harvests (Berg et al., 2005). Alternatively, Walworth and Sumner (1990) reported a yield increase after a spring K application in two out of three years. This result only occurred when Mg applications were applied in conjunction with K. Magnesium applications alone had no effect on alfalfa yield. Soil and tissue tests from their study indicated that Mg levels were suppressed with K applications, leading for them to conclude that these two nutrients were in competition with each other (Walworth and Sumner, 1990). This offers a potential explanation for the Mg results reported in Table 3.

Sulfur was reported to be below sufficiency ranges in approximately 13% of sampled stands. The University of Kentucky currently does not have soil test recommendations for sulfur. Gunes and coauthors (2008) found that applications of Gypsum significantly increased yields on sulfur deficient soils. Alfalfa yield in response to sulfur fertilization has not been studied as in-depth as other nutrients due to atmospheric deposition historically supplying enough S to support yields. However, due to the reduction in the use of fossil fuels, deposition levels across Kentucky have decreased from 9 - 16 lb S/ac to 0 - 5 lb S/ ac over the last 20 years (US EPA, 2021). Sulfur deficiencies are likely to increase nationwide as the decline in atmospheric deposition continues.

Boron was reported low in 6% of the sampled stands according to tissue analysis. The University of Kentucky recommends applying 1.5 to 2.0 lb B/ac of elemental boron every other year unless soil tests indicate current B levels exceed 2.0 lb B/ac. Symptoms of a boron deficiency include yellowing of the upper leaves and shortening of the upper internodes. Overall, low boron levels can result in slight yield losses and a decline in forage quality (Lanyon & Griffith, 1988).

In summary, pH was reported below the ideal range in approximately 41% of the sampled stands. Soil test results averaged over the 4- and 6- inch depths indicate phosphorus and potassium are low or very low in approximately 5% and 33% of stands. This contrasts with tissue analysis which reports no stands below the sufficiency ranges for phosphorus and only 26% for potassium. Tissue analysis also indicated that approximately 13%, 23%, and 6% of stands were below the sufficiency ranges for S, Mg, and B. More work is needed to better understand the yield dynamics of these nutrients and if they are truly limiting. All other macro and micronutrients were reported to be sufficient according to tissue analysis. Nutrient management is likely playing a role in the alfalfa yield plateau but is unlikely to be the sole cause. This survey was repeated in 2023 and 61 more stands from Kentucky and surrounding states were sampled, but data has yet to be analyzed.

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WATER USE EFFICIENCY AND SOIL CHANGES AFTER LONG-TERM CROP ROTATION UNDER LIMITED IRRIGATION

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ABSTRACT

Long-term crop rotation intensity and diversity can affect key soil properties. In semi-arid regions, the combined factors of rotation and soil properties may also affect the overall water use efficiency from either limited irrigation or rainfall. The objective of this study was to evaluate changes in soil properties, and water use efficiency of corn grown under different rotation intensity and diversity and limited/supplemental irrigation. A field experiment was conducted over seven years in Gothenburg, Nebraska, to compare different irrigated crop rotations including five rotation intensity/diversity. All plots were irrigated with an annual average of 150 mm/year, and 100 mm in 2021. After seven years, soil samples were collected in 2021 to include at least two full rotations for the 3-year rotation treatment. Soil samples were collected using a Giddings probe at six depths (0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm), and were analyzed for soil C. Grain yield was measured for every crop every year, data for corn yield is presented for the 2021 harvest season only. Corn grain yield in 2021 was numerically higher when following wheat in the rotation. Water use efficiency for corn in 2021 was higher when following winter wheat in the rotation. After seven years, soil organic matter was higher for rotations with more frequent corn in the rotation, and continuous corn and the C-C-W rotation showed significantly lower soil pH. Soil carbon in the soil profile was also generally higher for rotations with high biomass and carbon input.

INTRODUCTION

Nebraska relies heavily on its groundwater and surface water resources for agricultural production. Enhancing water use efficiency ensures the sustainable management of these resources, helping to avoid over-extraction and depletion. Effective crop rotation can optimize water use efficiency. Some crops may require more water than others, and by selecting crops with water requirements suited to the local climate, you can make better use of available water resources. This is especially important in semi-arid regions with limited irrigation or rainfall.

Changes in crop rotation can lead to various soil property improvements, including nutrient balance, pest and disease management, organic matter content, microbial activity, soil structure, pH adjustment, erosion control, and weed management. These benefits collectively contribute to healthier and more productive soils, which are essential for sustainable and high-yield agricultural practices.

The aim of this research was to assess changes in both soil characteristics and the efficiency of water use when cultivating corn under different levels of rotation intensity and diversity, in conjunction with restricted irrigation.

MATERIALS AND METHODS

A field study was established at Gothenburg, NE in 2015, and five rotation intensity/diversity were included (Table 1).

Table 1. In long-term crop rotation systems, all phases of the rotation are present every year.

Rotation/crops	Rotation/years	
1	Corn (C)	1
2	Corn - Wheat (C-W)	2
3	Corn - Soybean (C-S)	2
4	Corn - Corn - Wheat (C-C-W)	3
5	Corn - Sorghum (C-Sg)	2

All plots were irrigated with an annual average of 150 mm/year, and 100 mm in 2021, and the annual accumulated precipitation for 2021 at the study site was 589 mm.
Soil samples were collected in 2021, after seven years to include at least two full rotations for the 3-year rotation treatment. A Giddings probe was used to take soil samples at six depths (0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm).
Soil samples were analyzed for soil C using dry combustion.
Grain yield was measured for every crop every year, and the data for corn yield is presented for the 2021 harvest season only.

RESULTS AND DISCUSSION

Corn Yield and Water Use Efficiency

Corn grain yield in 2021 was numerically higher when following wheat in the rotation, likely due to the summer fallow after the wheat harvest, allowing for additional water storage and availability to the corn crop. (Figure 1) On the other hand, water use efficiency for corn in 2021 was higher when following winter wheat in the rotation (treatments with corn-wheat and corn-corn-wheat).(Figure 2)

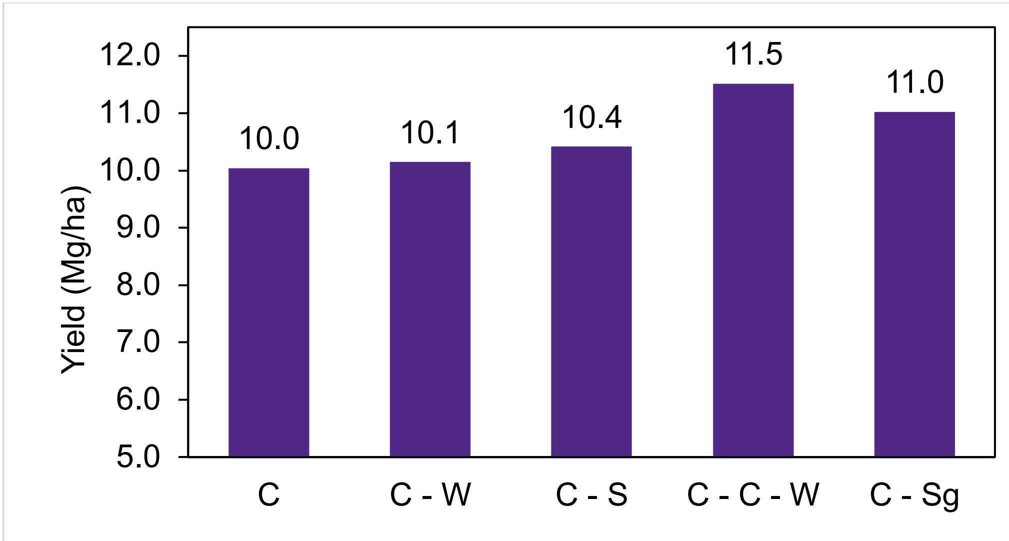

Figure 1. Corn Yield (Kg/ha) in 2021 after long-term crop rotation under limited irrigation.

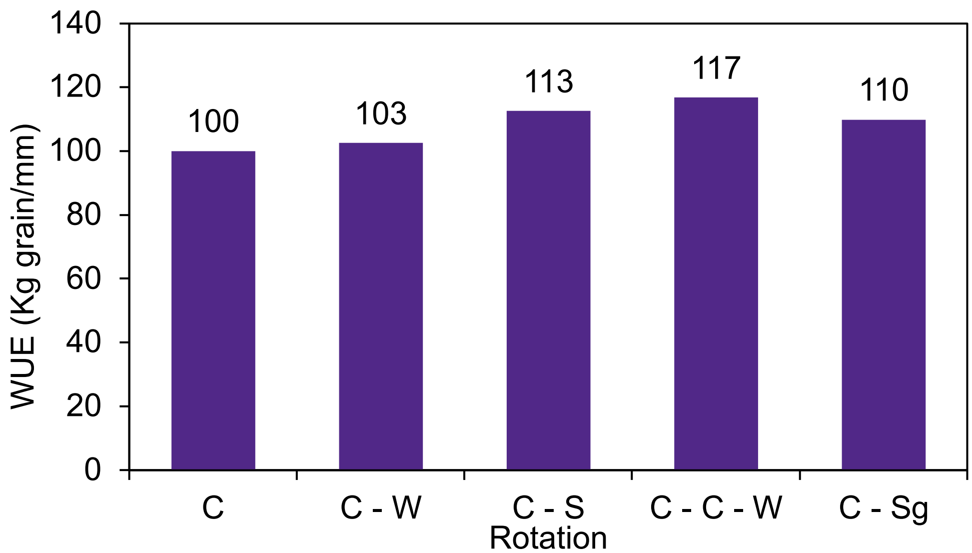

Figure 2. Water use efficiency expressed in Kg of grain/ mm water from irrigation.

After seven years (two full cycles for the 3-year rotation), soil organic matter was higher for rotations with more frequent corn in the rotation (C and C-C-W). (Figure 3).
Continues corn and the C-C-W rotation showed significantly lower soil pH after seven years. This was likely due to the higher total nitrogen fertilizer applied over this period, which will require additional/more frequent investment in lime application. (Figure 4).

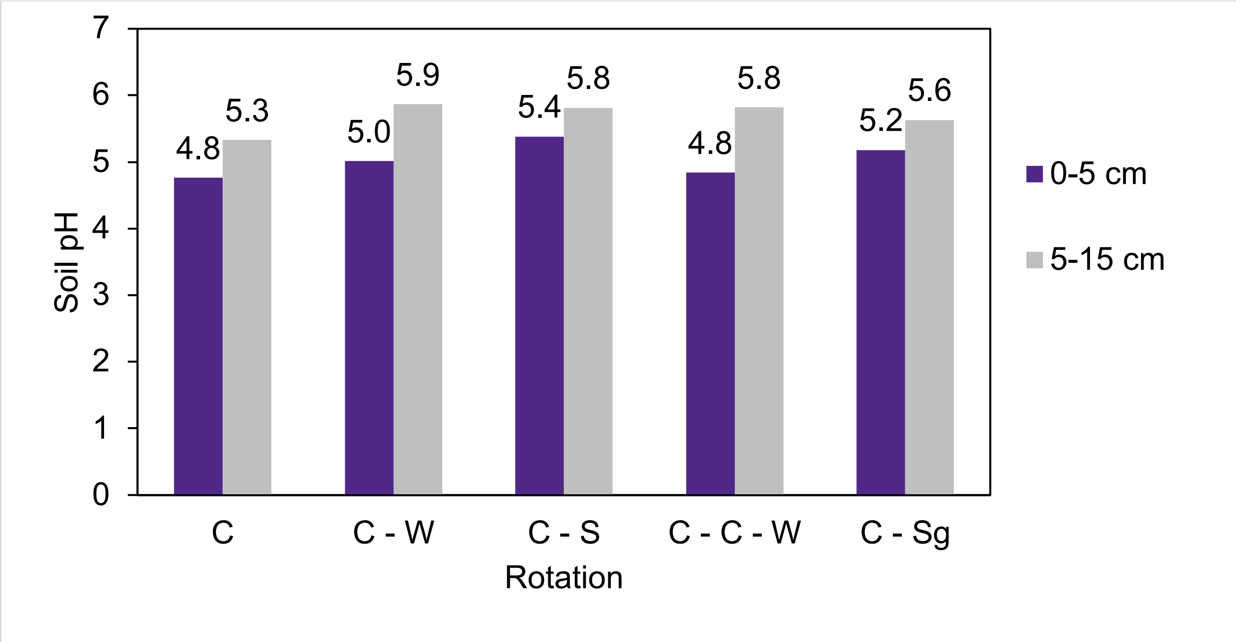

Figure 3. Soil pH at two depths for each long-term crop rotation. Values with different letters within each depth are statistically different at $p < 0.1$.

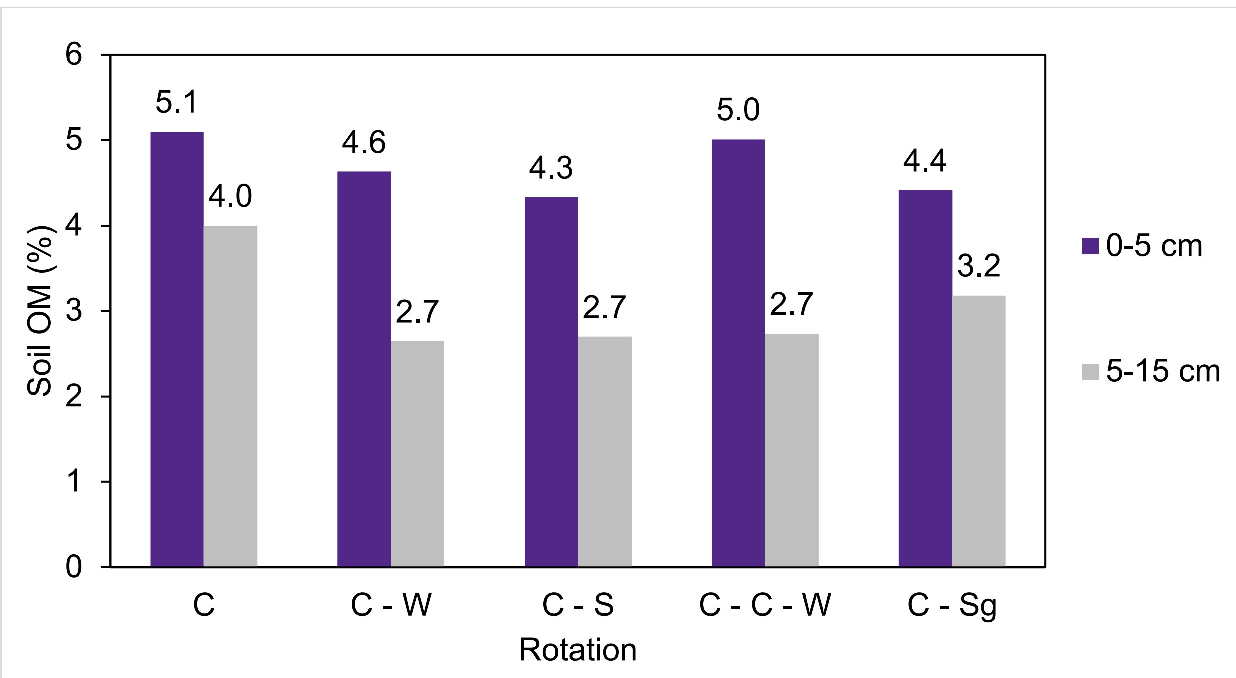

Figure 4. Soil OM at two depths for each long-term treatment crop rotation.

About soil carbon in the soil profile, it was also generally higher for rotations with high biomass and carbon input. (Figure 5).

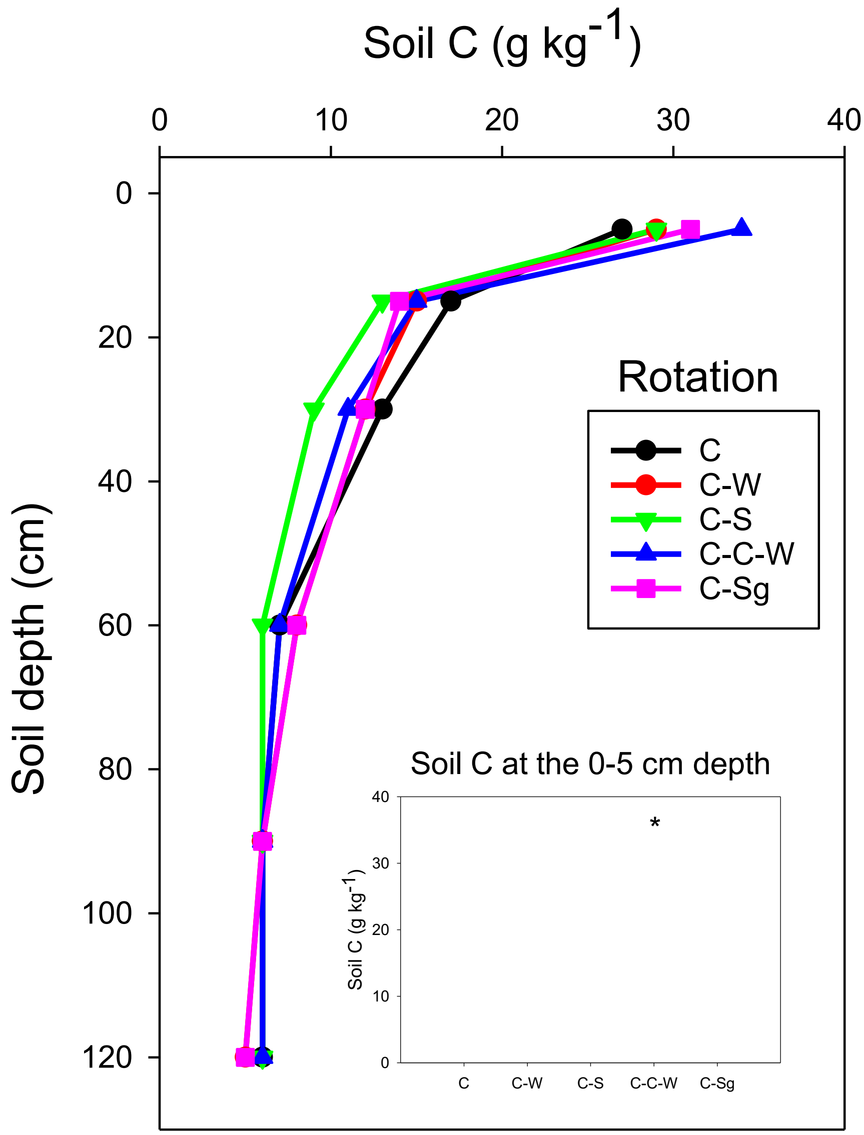

Figure 5. Soil carbon (g kg-1) at different depths after six years of crop rotation.

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EFFECT OF LONG-TERM TILLAGE AND CROP ROTATION ON MINERAL ASSOCIATED ORGANIC MATTER DISTRIBUTION ALONG THE SOIL PROFILE

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ABSTRACT

Soil carbon (C) stability in soil organic matter (SOM) is critical for mitigating climate change as well as for providing food security. SOM associated with mineral Mineral-associated organic matter (MAOM) has a longer residence time than the light, sand-sized particulate organic matter (POM). Therefore, it is important to study the effect of conservation practices like no tillage and crop rotation on MAOM distribution to better understand carbon stability and persistence. The objective of this study is to understand the effect of long-term tillage and crop rotation on MOAM distribution along the profile. The soil samples are collected from the long-term tillage site established in 1975 at Purdue University Agronomy Center for Research and Education (ACRE) at West Lafayette, IN in 2022 after 46 years of treatment establishment. The experiment was Randomized Complete Block design in a split-plot design with all treatments replicated four times. The treatments combination includes 3 types of tillage practices (No-tillage, chisel plow and mold board plow) and 3 types of crop rotation (continuous corn, continuous soybeans, and corn-soybeans). The result of the study showed that the MAOM C concentration across the soil profile followed the similar trend as SOC concentration (g kg^{-1}) only for no-till. However, MAOM C were significantly lower in the tillage treatments across all the depth. The significantly higher MAOM C in no-till until 50-75 cm explains the evidence of translocation of C towards the subsoil layers. The ratio of MAOM C to the total soil carbon content showed the potential carbon saturation of in the surface layer of no-till system whereas translocation of the carbon in the lower profile.

INTRODUCTION

Soil has the largest pool of carbon and is key in the process of carbon sequestration for minimizing climate change and providing food security. No-tillage and crop rotation are adopted conservation practices for C sequestration. In the literature, the positive to neutral effect of no-till on C sequestration has been documented (Sun et al. 2020). Mineral associated organic matter (MAOM), organic matter attached to silt and clay, is hypothesized to have a longer residence time than the light, sand-sized particulate organic matter. The subsoil layer has a greater potential for C sequestration but very few studies have considered the soil sampling depth below 60 cm (Osanai et al. 2020). None of the studies have considered MAOM studies below the surface layer although knowing the importance of MAOM for long term storage of C. Therefore, it is imperative to understand the long-term impact of residue management and crop rotation on MAOM distribution along the profile in addition to the carbon distribution of the profile.

MATERIALS AND METHODS

The experimental site was established in 1975 at Purdue University Agronomy Center for Research and Education (ACRE) at West Lafayette, Indiana in a fine, silty, mixed, mesic Typic Endoaquoll soil. Plots were arranged in a Randomized Complete Block Split-plot design. The soil samples were collected after 47 years of continuous management. The top 15 cm samples were collected using hand push probes. Sub-surface soil was sampled using a hydraulic probe. Total N and total C percentages were analyzed using a dry combustion method (LECO, St. Joseph, MI). The samples with a pH greater than 6.8 and showing positive response to HCL effervescence test were treated with 1 M HCL to remove the inorganic carbon from the samples. Soil organic matter fractionation was carried out by using size and density fractionation with Sodium polytungstate (SPT) of density 1.8 g/cm^3 (Figure 1.).

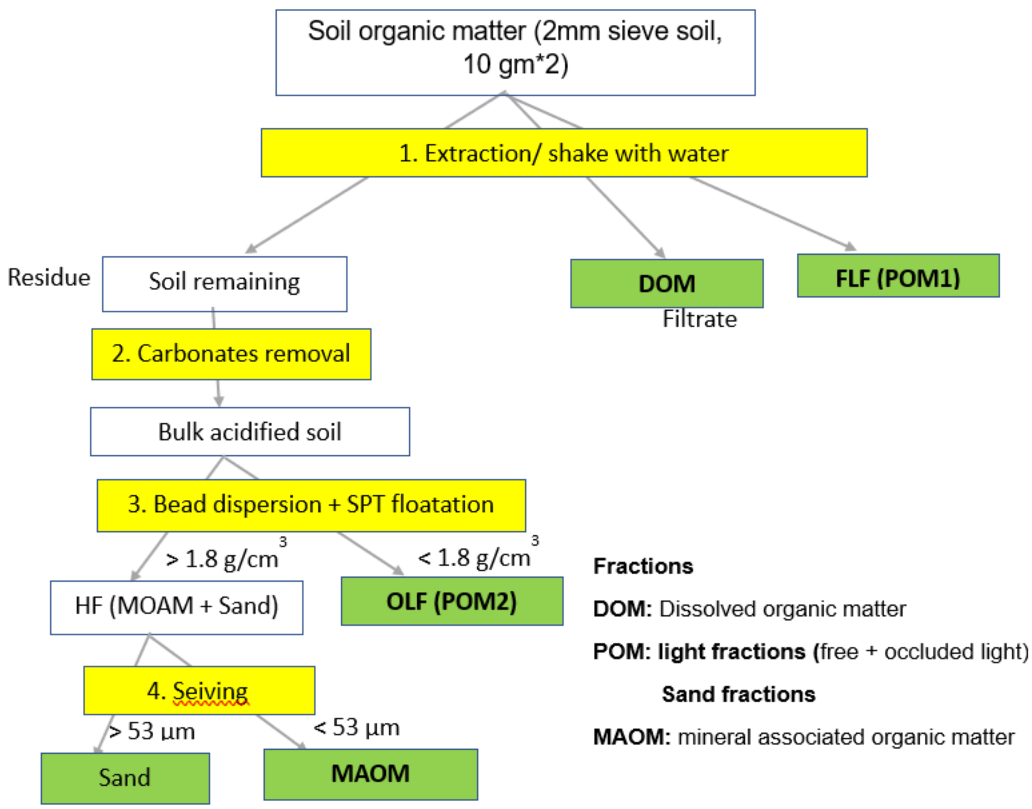

Figure 1: Schematic figure of SOM fractionation

MAOM mass obtained from the SOM fractionation was grounded and analyzed to determine the C and N concentration. MAOM mass is the weight of MAOM (gram) obtained per gram soil used in fractionation, expressed in percentage. Similarly, MAOM C per total SOC is calculated as the ratio of the carbon content in MAOM mass per total SOC expressed in percentage.

RESULTS AND DISCUSSION

The MAOM C is significantly higher in no-till, as compared to chisel plow and MB plow until 75 cm soil depth (Figure 2). Less soil disturbance in no-till increases soil aggregation and soil structure that promotes organo-mineral association. SOC concentration in no-till is equivalent to chisel plow at 5 - 15 cm and MB plow at 15 - 30 cm soil depths (Table 1). This result demonstrates the SOC contribution through residue incorporation within the plow depths. However, MAOM C was greater for no-till relative to the tillage treatments from 5-30 cm, demonstrating that SOC contributions do not always equal MAOM C. The percentage of MAOM C follows a similar trend as MAOM mass (Figure 7 and 8). MAOM C follows a similar trend as SOC concentrations in no-till. However, the trends differ when comparing MAOM C and SOC among tillage treatments, indicating the importance of soil texture for the formation of MAOM C in each depth. There are no significant differences between continuous corn and corn-soybean cropping systems considering SOC and TN concentration, as well as MAOM C and MAOM N concentration.

Table 1: Impact of tillage intensity on soil organic matter (SOC) and total nitrogen (TN) concentration.

Depths (cm)	SOC (g kg^{-1})†			TN (g kg^{-1})		
	No-Till	Chisel plow	MB plow	No-Till	Chisel plow	MB plow
0 – 5	39.4 a	25.4 b	21.7 c	2.86 a	2.04 b	1.73 b
5 – 15	25.2 a	24.1 a	22.01 b	2.07 a	1.81 b	1.72 b
15 – 30	20.7 a	17.2 b	20.5 a	1.70 a	1.45 b	1.61 a
30 – 50	9.55	9.03	9.08	0.96	0.97	0.85
50 – 75	5.4 a	4.2 b	4.15 b	0.56 a	0.33 b	0.31 b
75 – 100	3.4	3.0	3.14	0.25	0.21	0.23

†Different letters indicate that the values are significantly different across treatments at the given depth

Table 2: Impact of crop rotation on soil organic carbon (SOC) and total nitrogen (TN) concentration.

Depths (cm)	SOC (g kg^{-1})†			TN (g kg^{-1})		
	C-C	C-B	B-B	C-C	C-B	B-B
0 – 5	30.2 a	29.9 a	26.4 b	2.49 a	2.27 a	1.86 b
5 – 15	24.8 a	24.0 a	22.4 b	2.01 a	1.90 a	1.69 b
15 – 30	20.5	19.3	18.6	1.65 a	1.58 ab	1.53 b
30 – 50	9.90	8.81	8.95	1.02	0.88	0.88
50 – 75	4.57	4.49	4.70	0.39	0.38	0.43
75 – 100	3.04	3.39	3.06	0.22	0.26	0.22

†Different letters indicate that the values are significantly different across treatments at the given depth

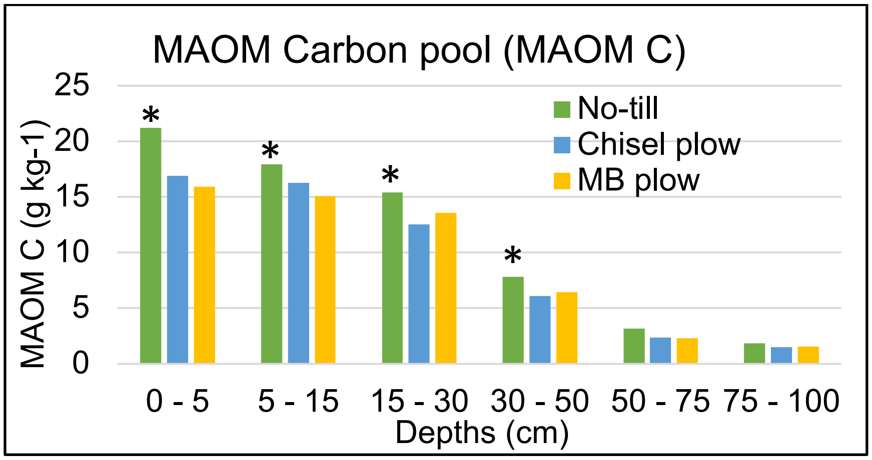

Figure 2: Impact of tillage on carbon concentration of mineral associated organic matter (g kg^{-1})

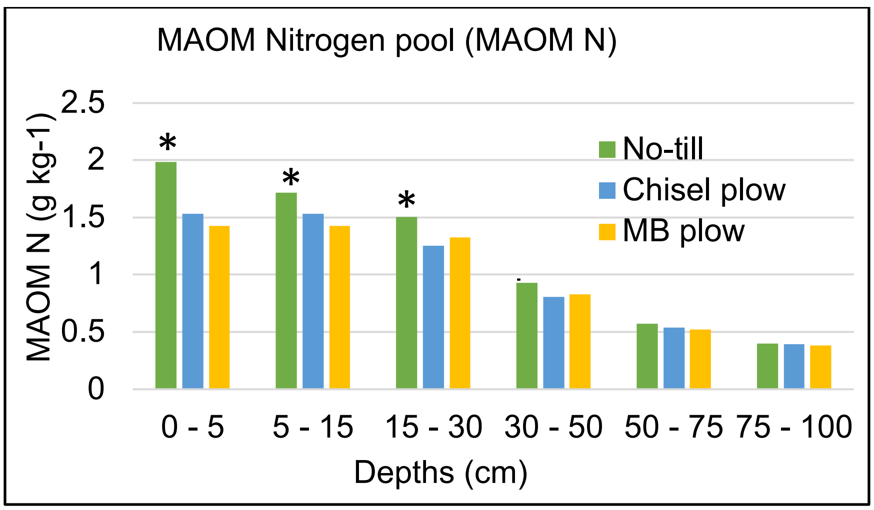

Figure 3: Impact of tillage on nitrogen concentration of mineral associated organic matter (g kg^{-1})

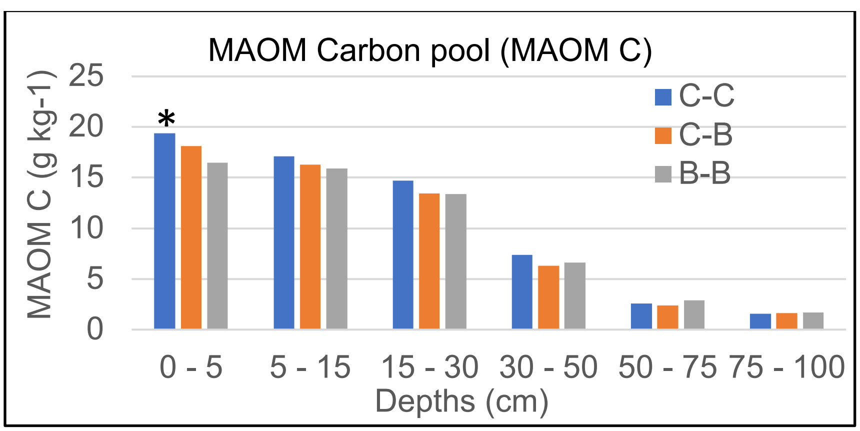

Figure 4: Impact of crop rotation on carbon concentration of mineral associated organic matter (g kg^{-1})

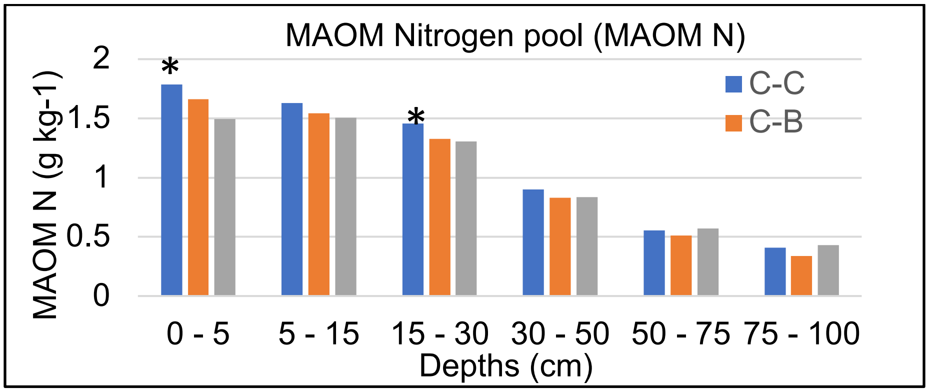

Figure 5: Impact of crop rotation on nitrogen concentration of mineral associated organic matter (g kg^{-1})

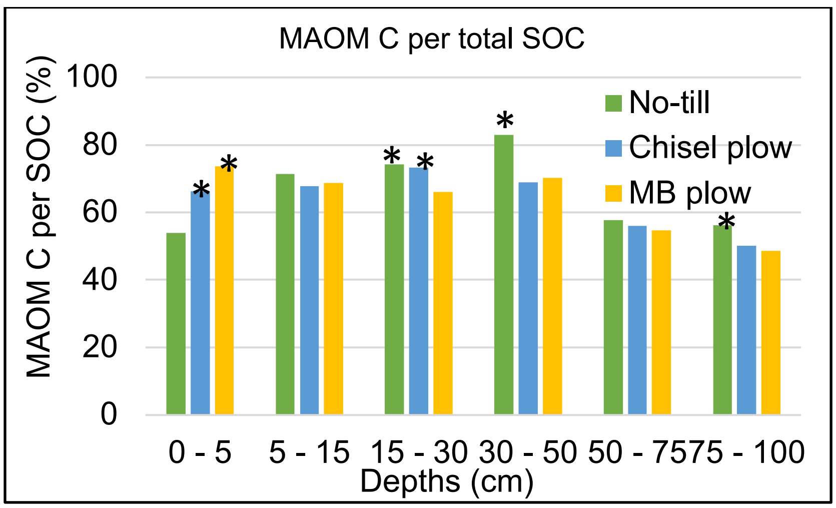

Figure 6: Impact of tillage on MAOM C per total SOC.

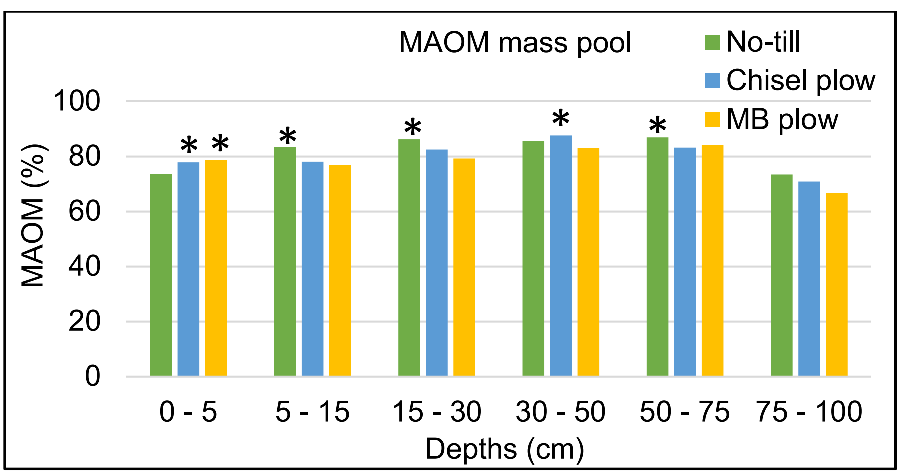

Figure 7: Impact of tillage on MAOM mass.

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DOES SENSOR-BASED NITROGEN MANAGEMENT MAINTAIN CROP PRODUCTION AND DECREASE NITROGEN LOSSES?

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ABSTRACT

To improve water quality, nitrogen (N) management in corn production systems should shift from current N decision support system [maximum return to N (MRTN)] which suggests a single rate N addition to sensor-based (GreenSeeker) active N management (variable N rate approach). Single rate N recommendations often result in under- and over-N addition and either increase environmental N losses or cause corn yield penalty. Our objectives were to evaluate if sensor-based N management improves N fertilizer use, and influence soil nitrate-N dynamics, nitrous oxide (N_2O) emissions, and nitrate-N leaching during a corn growing season as compared to the MRTN and a no-N control. Our results indicated that compared to a flat-rate N management (MRTN), sensor-based decreased N fertilizer requirement, reduced corn grain yield by 10 bu ac^{-1}, and significantly reduced N_2O-N emissions and nitrate-N leaching. Future research should explore sensor-based N management effect on corn yield and environmental footprints at multi-site-years.

INTRODUCTION

Illinois Nutrient Reduction Strategy has set a goal to reduce nitrate-N leaching by up to 15% by 2025 (IEPA, IDOA, and University of Illinois Extension, 2015). 4R nitrogen (N) management practices are among recommended strategies to minimize nutrient losses to Illinois water and the Gulf of Mexico. 4R N practices not only can benefit a reduction leaching of N as nitrate-N, it can also reduce nitrous oxide (N_2O) emissions. Applying the right rate is one of the most effective strategies that could significantly reduce environmental N losses (Morris et al., 2018). Nitrogen requirement to achieve maximum yield for corn is determined by N responsiveness, N availability, and potential yield. All three factors vary spatially and temporally. All three factors are independent of each other and independent of time. Precision N management could reduce this variability and improve N use and thus, reduce N losses. There is a knowledge gap about evaluating variable rate N management effect on corn grain yield and N loss and therefore, our objective was to evaluate MRTN performance vs. a GreenSeeker N rate on corn grain yield and nitrate-N leaching.

MATERIALS AND METHODS

Experimental Site, Design, and Treatments

The trial was conducted at the Agronomy Research Center in Southern Illinois University in Carbondale, IL. Treatments were laid out in a randomized complete block design (RCBD) with five replicates in 2022 and is replicated in 2023 (data for 2023 are not shown). The treatments were (i) no-N control; (ii) N fertilizer at MRTN recommended at planting; (iii) N fertilizer at MRTN recommended rate at sidedress timing; (iv) N fertilizer applied based on GreenSeeker algorithm recommendation (sidedress). Experimental plots were 60 ft long and 10 ft wide. A no-till drill was used to plant corn (Dekalb “DKC64-35RIB”) at 32,000 seeds ac^{-1} on 18 May 2022. Corn N fertilization occurred at V8 growth stage and UAN 32% was used to fertilizer the plants at sidedress timing. Each plot that had N (except zero-N control) received a 55 lbs N ac^{-1} as starter N. The rate of MRTN was 203 lbs N ac^{-1}.

Measurements

Soil samples were collected using a soil probe (0-6 inches) over the corn growing seasons of 2022 and analyzed for nitrate-N and ammonium-N. Closed vented chambers made of aluminum were constructed for the gas sampling. The chambers were placed in between the corn rows on anchors fixed to the soil. Air samples were collected a total 21 times during the corn growing seasons using syringes at 0, 15, 30 and 45 minutes each sampling day and analyzed for N_2O using gas chromatography (GC). Nitrous oxide emission rates were calculated by regressing N_2O concentration (ppm) vs. time. The cumulative N_2O emissions were estimated by linear interpolation between sampling periods. Soil volumetric water content (VWC) and temperature were measured at each N_2O emission sampling date. Corn grain yield was combine harvested. Prior to harvest, grain subsamples and plant subsamples were collected to measuring grain N and aboveground N content. Yield-scaled N_2O emissions were calculated as N_2O fluxes/corn grain yield. Nitrate-N leaching was evaluated using resin bag lysimeters. These resin bags placed around 12-16 inches in the soil (depending on the clay pan layer). After removal, they were analyzed for nitrate-N concentrations. We used an OI analytical flow solution IV for analyzing nitrate-N.

RESULTS AND DISCUSSION

Corn Grain Yield

Corn grain yield was 175 bu ac^{-1} for the MRTN treatment which was 10 bu ac^{-1} higher than that of the GS treatment. However, about 80 lbs N ac^{-1} less was applied to corn based on GreenSeeker recommendation which compensated for the lower yield in 2022 (data not shown).

Soil nitrate-N trends

Soil nitrate-N was consistently higher in the MRTN-upfront treatment as compared to the no-N control and GS treatment. Soil nitrate-N reached its peak before VT stage of corn and then at R1 and any dates after that, all treatments had similar nitrate-N concentrations (Fig. 1).

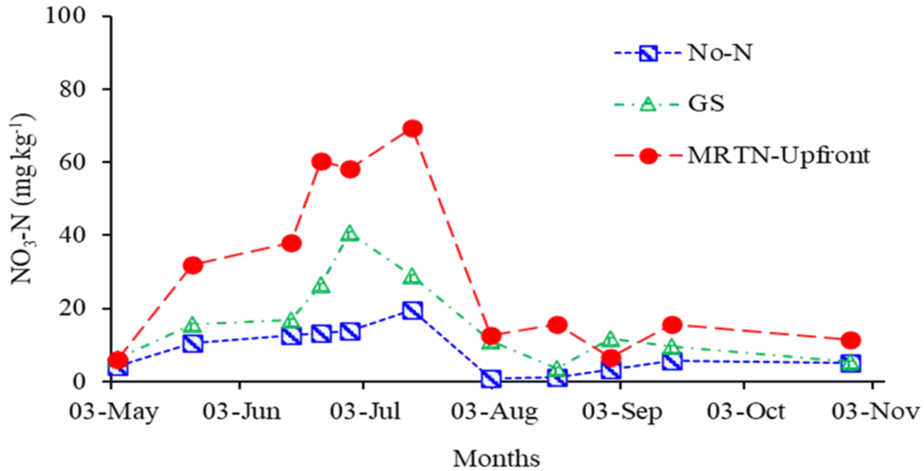

Fig. 1. Soil NO_3-N as influenced by N management in 2022. No-N is no fertilizer control, GS indicates GreenSeeker-based N rate and MRTN-Upfront is 203 lbs N ac^{-1} at planting.

Cumulative N_2O-N emissions

Cumulative N_2O-N emissions were higher in the MRTN-upfront treatment than the GS and the no-N control (Fig. 2) in line with higher N availability during the corn growing season in that treatment. Cumulative N_2O-N emissions were comparable to other reports in IL (Preza-Fontes et al., 2022; Wiedhuner et al., 2022).

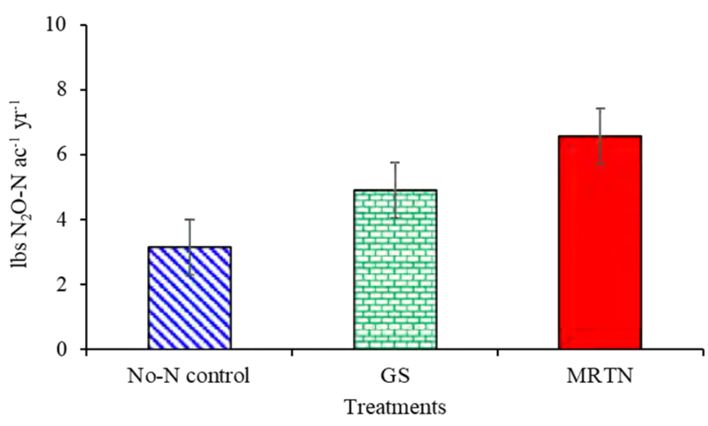

Fig. 2. Cumulative N_2O-N emissions during the corn growing season as influenced by N management in 2022. No-N is no fertilizer control, GS indicates GreenSeeker-based N rate and MRTN-Upfront is 203 lbs N ac^{-1} at planting.

Nitrate-N leaching

Nitrate-N leaching was higher in the MRTN treatment (upfront and sidedress) as compared to the GS and the no-N control. Implementing GS resulted in much lower N application that the MRTN which in turn, decreased both corn grain yield (10 bu ac^{-1}) and nitrate-N leaching. In 2022, nitrate-N leaching from the GS treatment was similar to that of the no-N control which is encouraging (Fig. 3).

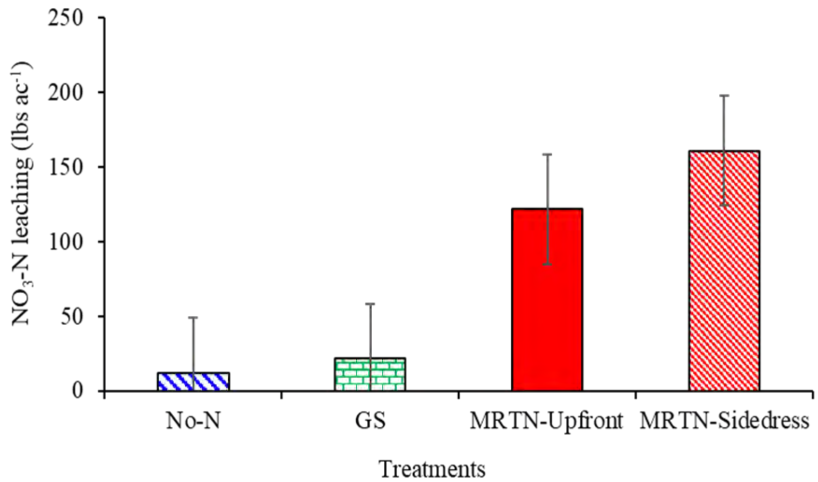

Fig. 3. Nitrate-N leaching during the corn growing season as influenced by N management in 2022. No-N is no fertilizer control, GS indicates GreenSeeker-based N rate and MRTN-Upfront is 203 lbs N ac^{-1} at planting and MRTN-sidedress is 203 lbs N ac^{-1} that was applied as 55 lbs N ac^{-1} at planting and the rest at sidedress timing.

PRELIMINARY CONCLUSION

In this preliminary trial, we observed that GS algorithm suggested 80 lbs ac^{-1} less N application to corn resulting in 10 bu ac^{-1} less yield. However, both N_2O-N and nitrate-N losses were reduced by the GS treatment compared to the MRTN. We require more site-years to confirm these results and fine tune the GS algorithm.

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EFFECTS OF SOIL PHOSPHORUS AND POTASSIUM LEVELS ON CORN YIELD RESPONSE TO NITROGEN FERTILIZATION, NITROGEN USE EFFICIENCY, AND PROFITABILITY

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ABSTRACT

Annual investment in nitrogen (N) fertilizer for corn production represents a significant portion of annual input costs. Yield response to N fertilization is affected by soil N supply, crop N demand, and interacting factors that affect crop N use, such as phosphorus (P) and potassium (K) supply. To investigate the effects of soil-test P and K levels on corn yield response to N fertilizer, a four-year study was conducted at two southern Wisconsin sites. Soil-test P and K were maintained at low, optimum, and high levels corresponding with currently used interpretation class ranges for fertilizer guidelines in Wisconsin. Ranges of low, optimum, and high soil-test (Bray-1 P) levels for P were 6 to 17, 16 to 27, and 31 to 51 ppm P, respectively, across both sites. Ranges of low, optimum, and high soil-test (Mehlich-3 K) levels for K were 50 to 104, 120 to 173, and 164 to 262 ppm K, respectively, across both sites. Six N rates (0, 40, 80, 120, 160, and 200 lb. N/a) were applied to each corn crop in a corn-soybean rotation. Agronomic optimum N rate (AONR), economic return to N (RTN), economic optimum N rate (EONR), and partial factor productivity nitrogen use efficiency (NUE) were identified using grain yield response to N and multiple N:grain price ratios ($ lb N and $ bu corn grain). Corn yield response to N fertilization varied by soil-test P and K level. In optimum and high soil-test P and K soils, corn grain yield increased to a plateau with increasing N rates and an EONR (0.1 ratio) of 130 lb N/a was observed across all site-years, with no difference in AONR or yield at the AONR (240 to 242 bu/a) between optimum and high levels. Low soil-test P and K led to inconsistent yield responses to N and reduced profitability regardless of N rate. Results suggest that optimum ranges of soil-test P and K, confirmed with identification of critical soil-test concentrations in this study, of 16 to 23 ppm Bray-1 P and 138 to 182 ppm Mehlich-3 K resulted in maximized corn grain yield and profitability response to N fertilization.

INTRODUCTION

Annual investment in nitrogen (N) fertilizer for corn (Zea Mays) grain systems represents a significant portion of annual input costs. Yield response to N fertilization is affected by soil N supply, crop N demand, and interacting factors that affect crop N use, such as phosphorus (P) and potassium (K) supply. Decades of research has addressed N, P, and K management for corn individually, but published information on the interaction of these nutrients is scarce. Schlegel and Havlin (2017) showed positive effect of N and P interaction on corn grain yield and fertilizer N recovery in a 50-year study in Western Kansas. Hirniak and Mallarino (2017) identified positive interactions of

N and K fertilization on corn yield in continuous corn rotations in Iowa. Other Iowa work showed significant interactions of N and K on corn yield, but no interactions among other nutrients (Mallarino and Rueber, 2003). Research summaries or reviews highlight the importance of macronutrient interactions, and suggest that N uptake and use requires adequate P and K supply (Dibb and Thompson, 1985; Usherwood and Segars, 2001). Many studies investigating N, P, or K interactions focus on applied fertilizer rates as experimental variables or treatments. Rarely are soil-test levels of P and/or K used as treatment levels. To align nutrient interaction research with assessments of soil-test interpretation classes (Low, Optimum, or High), target soil-test ranges must be maintained as treatment levels with N fertilization then randomized in a factorial design.

Recent pressure from either high or volatile fertilizer prices has posed questions regarding priority of macronutrients for corn production and if fertilization of nutrients such as P and K can be avoided. Alternatively, discussions of nutrient interactions can lead to ideas that higher P and K testing soils will require high N fertilization rates, or vice versa, with little data supporting this approach. Regardless, if yield or profitability is the metric used to assess nutrient management and fertilization planning, clear relationships between soil-test P and K levels and corn yield response to N fertilization would inform on-farm decisions.

Therefore, the objectives of this study were to: (1) determine and compare the economically optimum N rate, nitrogen use efficiency, and partial profit for corn at varying soil-test P and K levels, and (2) corroborate critical soil-test P and K concentrations with optimum levels for corn N response and examine crop removal of macronutrients in grain.

MATERIALS AND METHODS

Two field experiments with corn-soybean rotations harvested for grain were conducted from 2019 to 2022. Selected soil information and properties for each site is shown in Table 1. One site was located at the Arlington Agricultural Research Station near Arlington, Wisconsin in Columbia County on a Plano silt loam soil (fine-silty, mixed, superactive, mesic Typic Argiudolls). The second site was located at the Lancaster Agricultural Research Station near Lancaster, Wisconsin in Grant County on a Fayette silt loam soil (fine-silty, mixed, superactive, mesic Typic Hapludalfs). Each site was managed with chisel-plow/disk tillage and a 30-inch row spacing. Treatments replicated four times at both sites were the factorial combinations of three maintained soil-test P and K levels (Low, Optimum, and High; see Table 1) and six N rates applied to corn (0, 40, 80, 120, 160, and 200 lb N/a). Treatments and replications were arranged as a randomized complete block (RCBD) design. Phosphorus and potassium fertilizer were broadcast applied and incorporated as triple super phosphate (0-46-0) and potassium chloride (0-0-60), respectively, in the fall after harvest and soil sampling to maintain specific soil-test ranges (Table 1). Initial soil-test values for P and K at each site are also shown in Table 1. Nitrogen fertilizer was applied as urea treated with a urease inhibitor (NBPT) in spring and incorporated prior to corn planting.

Each year soil samples were collected (6-inch depth) and analyzed for pH (1:1 ratio of soil to deionized water), soil organic matter (loss on ignition), for P by the Bray-1 test, and for K by the Mehlich-3 test following the procedures suggested by the NCERA-13 north-central region soil testing committee (Frank et al., 1998). Beginning in 2021, soil samples were collected after corn harvest to a depth of 0 to 3-feet and analyzed for nitrate. Nitrate-N was determined from 0.2M KCl extracts and analyzed using the Cadmium 40 reduction method (Gelderman and Beegle, 1998) with a modified Technicon Auto-Analyzer (SEAL Analytical, Inc., Fareham, UK). Grain yield was collected and adjusted to 15.5% moisture. Grain samples were collected from each plot and analyzed for P and K concentration using (Zarcinas et al., 1987). Grain removal of nutrients with harvest was calculated by using the measured nutrient concentration multiplied by the plot-level grain yield and adjusted for consistent moisture.

Corn grain yield response to N fertilizer rate for each soil-test P and K level was evaluated with a segmented polynomial quadratic-plateau model for all site-years combined using PROC NLIN in SAS ODA (SAS Institute, Cary, NC). The agronomic optimum N rate (AONR) was identified as the joint point where the quadratic and plateau portions of the model joins and where no statistical difference between treatments above the model joint point were observed. Economic optimum N rates (EONR) were identified by setting the first derivative of the response model to an N ($/ lb. N fertilizer) to corn price ($/ bushel) ratio of 0.05, 0.1, 0.15, and 0.2 and solving for N rate. Additionally, EONR was calculated when considering the added price of P and K fertilizer to maintain the optimum and high soil-test levels. Static P and K fertilizer prices of $0.85/ lb. P_2O_5 and $0.55/ lb. K_2O, respectively, were used, in addition to the yield increases over the low soil-test category, to calculate partial profit or maximum return to N, P, and K fertilizer.

Relative corn grain yield was calculated for each site-year-treatment by expressing the mean yield (across replication) without fertilization as the percentage of the mean yield of treatments produced by the statistically maximum yield (the mean of all treatments, including the control, was used as maximum yield when there was no P or K response). Each relative yield value was calculated for every N rate and is expressed as such to avoid distortion of the relative yield term. This method of relative yield determination is termed “STATMAX” (Pearce et al., 2022). Critical soil-test P and K concentration ranges were identified by the range of linear-plateau and quadratic-plateau model joint points (Jones et al, 2022, Clover and Mallarino, 2013). All statistical analysis, response model fits, and critical concentration identification was done in SAS ODA (SAS Institute, Cary, NC).

Target soil-test P and K level ranges to maintain throughout the study roughly relate to soil-test interpretation classes from University of Wisconsin-Madison Recommendations (Laboski and Peters, 2012). Low, Optimum, and High designations shown in Table 1 relate to the Very Low to Low, Optimum, and High classes of Laboski and Peters (2012). After study initiation, STP for the Low, Optimum, and High categories was maintained at 6 to 11, 16 to 23, and 31 to 42 ppm Bray-1 P, respectively, at Arlington; and 6 to 17, 18 to 27, and 34 to 51 ppm Bray-1 P, respectively, at Lancaster. Soil-test K for the Low, Optimum, and High levels was maintained at 50 to 90, 120 to 160, and 164 to 236 ppm Mehlich-3 K, respectively, at Arlington; and at 80 to 104, 143 to 173, and 182 to 262 ppm Mehlich-3 K, respectively, at Lancaster. These Optimum ranges are similar to the critical STP and STK concentrations for the Bray-1 and Mehlich-3 tests, respectively, reported by Jones et al. (2022) on similar soils.

RESULTS AND DISCUSSION

Corn Yield Response to Nitrogen and Soil-test Level

The relationship between corn grain yield and N rate for each soil-test level for all site-years combined is shown in Figure 1. For the Low, Optimum, and High soil-test levels, corn yield ranged from 154 to 236, 189 to 263, and 178 to 259 bu/a across all N rates. Nitrogen rated affected corn yield each site-year of the study when soil-test levels were Optimum and High ($p \leq 0.05$), and inconsistently affected corn yield when soil-test levels were Low. The only significant ($p \leq 0.05$) effect of N rate on corn yield for the Low soil-test level was in 2021 at Arlington between zero and 200 lb. N/a rates (not shown). Orthogonal comparisons between the zero N rate and all other rates indicated an N fertilization effect across all site-years, thus the AONR was set to the lowest experimental N rate, 40 lb. N/a (Fig. 1). Corn yield increased incrementally to a plateau with higher N rates when soil-test levels were both Optimum and High. Across all site-years, the AONR and yield at AONR (YAONR) were 188 lb. N/a and 240 bu/a for Optimum soil-test level, and 164 lb. N/a and 242 bu/a when soil-test P and K were High (Fig. 1). The 95% confidence intervals for each ANOR are shown in Fig. 1 and were calculated using a bootstrapping approach. Practically, the AONR and YAONR for both Optimum and High soil-test levels do not differ if using the 95% confidence intervals to differentiate, however the AONR at Optimum soil-test levels was 24 lb. N/a lower. The lower AONR for Optimum may also be a result of lower corn yield levels at lower N rates in the High soil-test level compared to Optimum (Fig. 1). The relative yield increase with added N fertilizer was greater at High soil-test levels, as seen by the larger quadratic coefficient of the quadratic-plateau response model function seen in Figure 1. Across site-years and at each N rate, corn yield for the Optimum and High soil-test level did no differ and were always greater than the Low soil-test levels. At 0, 40, 80, 120, 160, and 200 lb. N/a rates, the corn yield mean of Optimum and High level was 29, 47, 48, 59, 58, and 48 bu/a greater than if the soil-test P and K were in the Low range.

Soybean grain yield within the corn-soybean rotation of this study is not shown. Across site-years, no significant effect of the N rate applied to the previous corn crop on soybean grain yield was observed ($p \leq 0.05$). Soil-test P and K level did affect soybean yield, with Low, Optimum, and High levels resulting in 61, 75, and 77 bu/a yield, respectively. Soybean yields at Optimum and High levels did not differ across the study and were significantly greater than yields at Low levels every site-year (not shown).

Economic Optimum N Rates and Partial Profit

Figure 3 shows the economic return to N fertilizer and N, P, and K fertilizer at four different price ratios of N fertilizer to corn grain for all soil-test levels. No return to NPK fertilization is shown for the Low testing range. Economic return to fertilization lines are calculated using the quadratic-plateau yield response function and applying the price scenarios for N, P, and K. Return to fertilization increased to a maximum economic return value, which corresponded with an N rate, the EONR (Fig. 3). Figures 3a to 3c show only the return to N fertilization for each soil-test level. When the price of N fertilizer and corn grain was considered, no N rate produced a profitable return to fertilizer N for the Low testing category (Fig. 3a). The EONR for the 0.05, 0.1, 0.15, and 0.2 price ratios for Optimum testing P and K soils was 157, 130, 101, and 72 lb. N/a with maximum return to N values of 160, 88, 44, and 18 $/a, respectively (Fig. 3b). For High testing P and K soils, the maximum return to N occurred at 146, 129, 112, and 95 lb. N/a rates (Fig. 3c). Similar to the yield response results, the higher economic return to N for High testing soils is a function of the lower yielding zero N rate compared to the Optimum level. At the 0.1 price ratio, $0.6/ lb. N and $6/bu corn, the EONR values for the Optimum and High soil-test P and K levels were similar (130 and 129 lb. N/a), though the return to N was greater if soil-tests were High.

Figures 3d and 3e show the economic return to N fertilizer and the P and K fertilizer needed to maintain either Optimum or High soil-test ranges. Phosphorus and K fertilizer prices were held static and the four aforementioned N fertilizer and corn grain price scenarios are shown. When taking P and K fertilizer into consideration, economic returns were higher for the Optimum level for each price ratio scenario. The EONR for the 0.05, 0.1, 0.15, and 0.2 price ratios for Optimum testing P and K soils was 147, 120, 91, and 62 lb. N/a with maximum return to N values of 278, 171, 104, and 53 $/a, respectively (Fig. 3d). At the 0.1 price ratio, maintaining Optimum soil-test P and K levels led to a $32/a greater return to fertilization and a 3 lb./N lower EONR compared to High soil-test levels (Fig 3d, 3e). Overall, the increased price of maintaining High soil-test levels reduces partial profit while using similar or more N fertilizer compared to targeted Optimum soil-test P and K ranges. This supports the approach of monitoring soil-test levels so that avoiding applying unneeded P or K fertilizer to high testing soils, and optimizing a response to N, can be accomplished.

Nitrogen Use Efficiency and Residual Soil N

Nitrogen use efficiency (NUE) is expressed as the ratio of bushels of corn grain to pounds of N applied (as fertilizer), thus the units of NUE in this paper are bu/lb. N. As expected, across soil-test levels as N rate increased NUE decreased. Low soil-test P and K levels led to lower NUE at each N rate; however, there was no difference in NUE between Optimum and High levels (Fig. 2a). At the 0.1 price ratio EONR for both Optimum and High soil-test levels (130 lb. N/a), the NUE would be 1.1 bu/ lb. N or 0.90 lb. N per bushel of corn grain. Results of post-harvest residual soil N (RSN) samples analyzed for nitrate, expressed at NO_3-N, are shown in Figure 2b. Residual soil N for 3-

foot depths are shown for each soil-test level and N rate. Two-way segmented linear models fit to the data showed change in RSN for N rates of zero to 80 lb. N/a (Fig. 2b). For the 120 lb. N/a and higher N rates, the Low soil-test level had higher RSN compared to the Optimum and High levels. Maintaining a Low soil-test P and K level led to a mean RSN 21 lb NO_3-N/a higher than Optimum or High for N rates of 120, 160, and 200 lb. N/a. At the 0.1 price ratio EONR, RSN was 32 lb. NO_3-N/a for Optimum or High levels, compared to 48 lb. NO_3-N/a for Low soil-test levels. Overall, with increasing N rates, NUE was lower and RSN higher for Low testing P and K soils and generally did not differ for Optimum or High soil-test levels.

Critical Soil-test Concentrations and Removal

As a *post hoc* assessment of corn grain yield at the three maintained soil-test levels, critical soil-test concentrations were identified for corn using all site-years. Important to note is that relative yield was calculated individually for each N rate so that this evaluation could be done. Figure 4 shows the relationship of relative corn grain yield with Bray-1 soil-test P and Mehlich-3 soil-test K. Critical soil-test P concentrations were 16-22 ppm P and 138-182 ppm K (Fig. 4). These ranges align with those reported by Jones et al. (2022) on similar soils using the same soil test methods. No differences were observed in critical concentrations above or below the EONR values for the entire study, indicating that independent of N fertilizer applied, target optimum soil-test ranges for P and K should be the same. Crop nutrient removal of P and K is commonly used to guide fertilization rates where soil-test levels are being maintained (ideally not increased or decreased). Table 2 shows the mean removal of N, P, and K with corn grain harvest across all site-years. Grain removal of N is used in some NUE calculations, but is only reported as lb. N removed per acre here. Nitrogen rate affected removal of all nutrients at each soil-test P and K level except for grain N removal at the Low level (Table 2). An interaction between N rate and soil-test level was observed for each nutrient, with larger amounts of N, P, and K being removed as corn yield increased. No differences in removal of N, P, or K were observed between the Optimum and High soil-test levels for any N rate, indicating that effects of removal on the soil-test level following corn grain harvest would be similar. Small or no differences in removal were observed at the 120 lb. N/a rate or higher, suggesting that applying N above the EONR would not draw down soil-test levels any faster than applying at the economically optimum rates. Overall, corn yield linearly and positively correlated with removal of N, P, and K, as expected.

Conclusions

The results of this study should be interpreted in context of the soils and physiographic region of Wisconsin where they were conducted. The soils in southcentral and southwest Wisconsin can provide significant amounts of inorganic N from soil organic N mineralization and are considered high yield potential soils for corn grain in Wisconsin. Nevertheless, results from this work indicate that when determining N rates to apply in corn-soybean rotations, considering soil-test P and K levels is important for optimizing yield and profitability. Low soil-test P and K levels led to an inefficient use of applied N fertilizer and did not support profitable corn production. Additionally, maintaining soil-test P and K at optimum ranges between 16-27 ppm Bray-1 P and 120-173 ppm Mehlich-3 K led to maximum corn grain yield and economic return to the N, P, and K fertilizer needed to both supply annual N to the corn crop and maintain soil-test levels. Soil-test levels above the critical concentration ranges identified in this study resulted in lower economic return to fertilization. Overall, investments of N fertilizer can be partially safeguarded by closely monitoring soil-test P and K levels and maintaining them where yield is optimized. These results can aid farmers and agronomists working with similar soils to assess how balancing optimum soil-test levels with profitable N rates can affect corn production profitability.

Acknowledgements

The authors would like to thank Andrew Larson for work and support of field trials discussed in this paper. This research is supported by the Wisconsin Fertilizer Research Program.

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Tables and Figures

Table 1. Site descriptions and selected soil properties.

	Arlington		Lancaster	
County	Columbia		Grant	
Soil series	Plano (Typic Argiudoll)		Fayette (Typic Hapludalf)	
Surface texture	silt loam		silt loam	
Parent material	loess over glacial till		deep loess	
Drainage class	well drained		well drained	
Soil pH	6.0		6.3	
Soil organic matter, %	4.85		2.33	
Initial Bray-1 P, ppm	6.0		8.6	
Initial Mehlich-3 K, ppm	72		78	
	Phosphorus	Potassium	Phosphorus	Potassium
Low soil-test range, ppm[1]	6 – 11	50 – 90	6 – 17	80 – 104
Optimum soil-test range, ppm[1]	16 – 23	120 – 160	18 – 27	143 – 173
High soil-test range, ppm[1]	31 - 42	164 – 236	34 - 51	182 - 262

[1] Low, Optimum, and High soil-test ranges maintained throughout the study.

Table 2. Corn grain crop macronutrient removal as affected by soil-test P and K level, and nitrogen rate.

	Nitrogen				
	Soil-test P and K level				
Nitrogen rate	Low	Optimum	High	*p*	LSD (0.05)[1]
lb. N/a	---------- lb. N/a ----------				
0	106	114	113	0.244	NS
40	107	122	126	< 0.001	11
80	109	129	129	< 0.001	15
120	105	131	136	< 0.001	16
160	111	141	147	< 0.001	16
200	115	142	139	0.001	19
p	0.332	< 0.001	< 0.001		
LSD (0.05)	NS	14	15		

	Phosphorus				
	Soil-test P and K level				
Nitrogen rate	Low	Optimum	High	*p*	LSD (0.05)
lb. N/a	---------- lb. P_2O_5/a ----------				
0	51	60	63	0.003	9.2
40	49	70	78	< 0.001	13
80	48	75	76	< 0.001	9.1
120	45	73	80	< 0.001	14
160	52	80	81	< 0.001	10
200	55	70	77	< 0.001	14
p	0.074	< 0.001	< 0.001		
LSD (0.05)	13	13	13		

	Potassium				
	Soil-test P and K level				
Nitrogen rate	Low	Optimum	High	*p*	LSD (0.05)
lb. N/a	---------- lb. K_2O/a ----------				
0	30	35	37	< 0.001	4.5
40	29	40	43	< 0.001	6.3
80	29	42	43	< 0.001	4.4
120	27	41	45	< 0.001	7.2
160	30	43	45	< 0.001	5.4
200	33	39	43	< 0.001	6.6
p	0.060	< 0.001	0.008		
LSD (0.05)	5.8	6.8	6.0		

[1]LSD(0.5), least significant difference at the 0.05 significance level

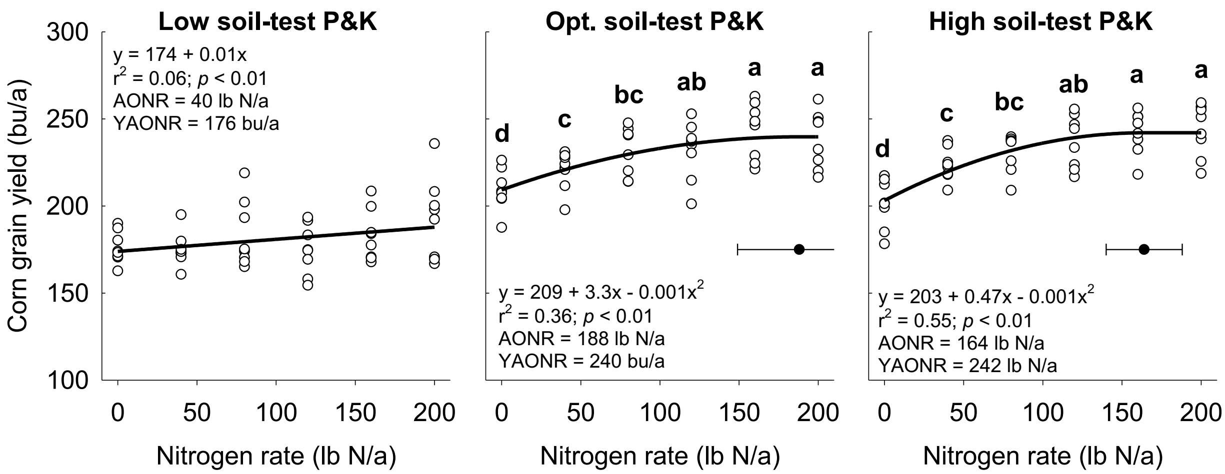

Figure 1. Relationship between corn yield and nitrogen rate when soil-test P and K levels are maintained at Low, Optimum, and High ranges for all site-years of the study. Agronomic optimum N rate (AONR), yield at the AONR, and mean separation by N rate is shown. Letters represent significant differences ($p \leq 0.05$).

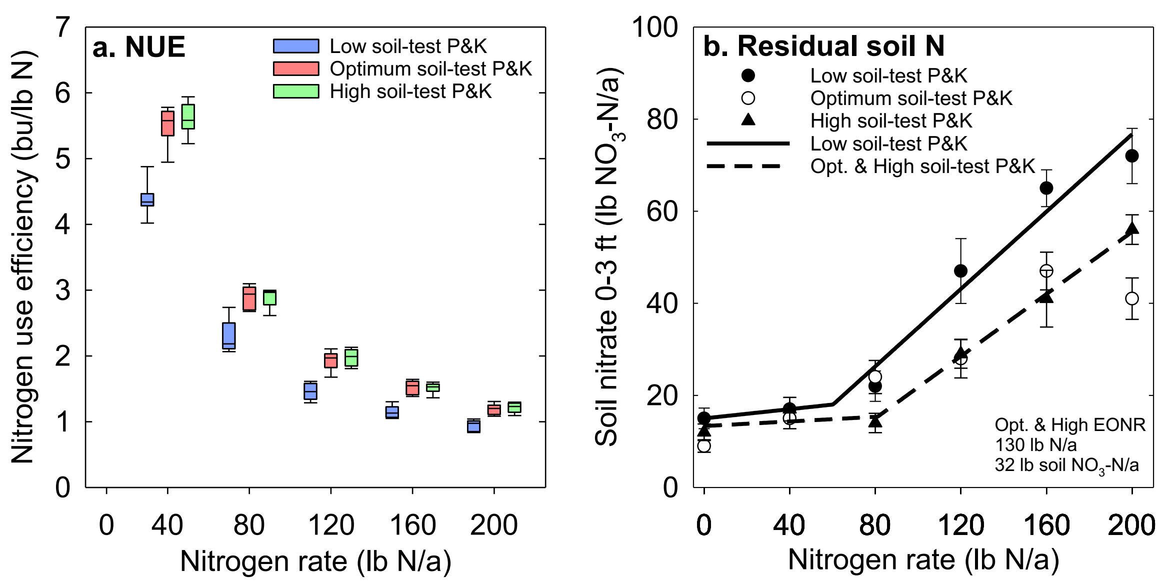

Figure 2. (a) Relationship between nitrogen rate and partial factor productivity nitrogen use efficiency and (b) residual soil nitrate from 3-foot depth collected after corn harvest as affected by nitrogen rate for each soil-test P and K level.

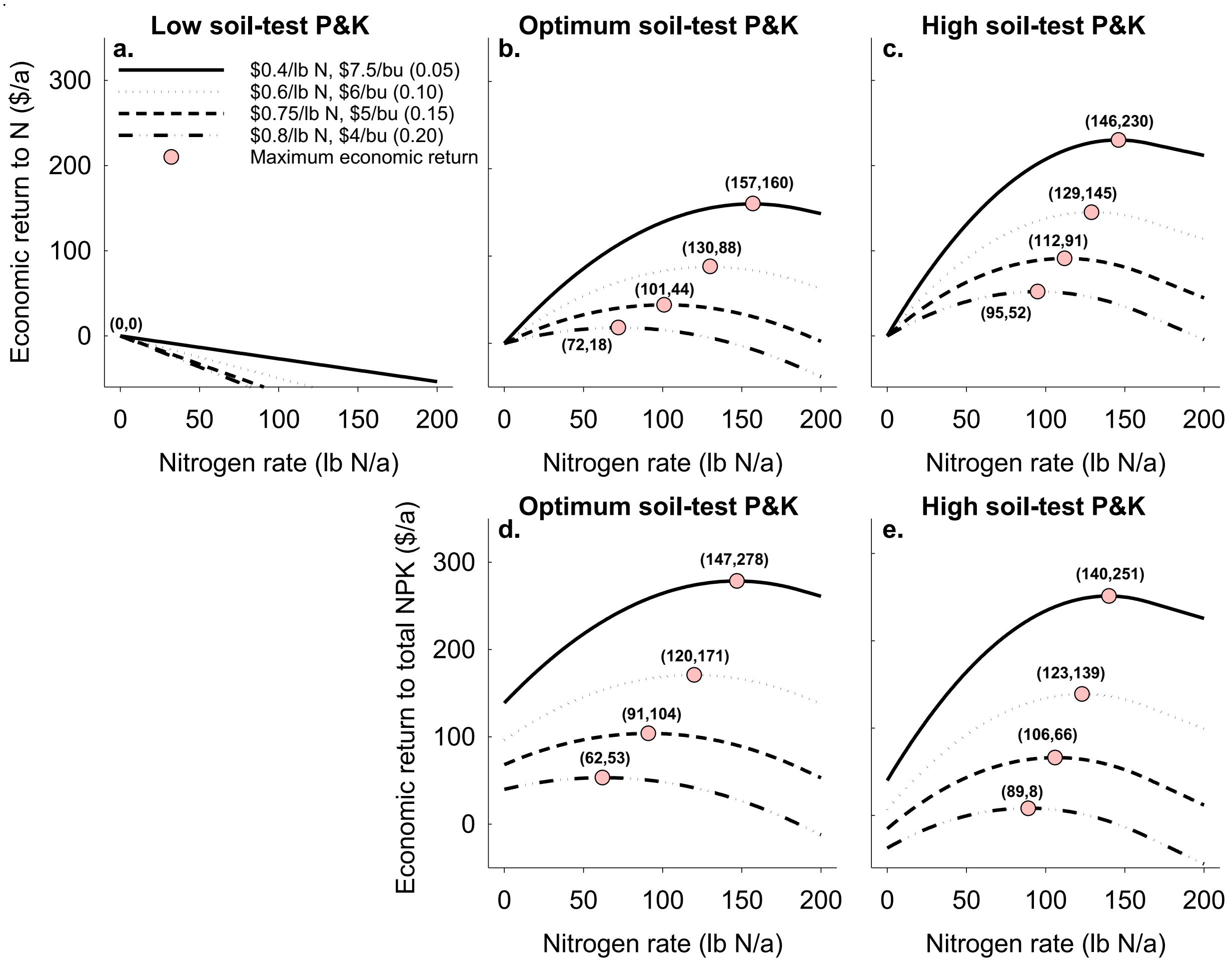

Figure 3. Relationship between nitrogen rate and economic return to fertilization of corn using four different ratios of the price of N fertilizer to the price of corn grain. Economic returns to only N fertilizer are shown in figures 3a-3c, Economic returns to N, and P and K fertilizer needed to maintain Optimum and High testing levels are shown in figures 3d and 3e. Phosphorus and potassium fertilizer price was set to $0.85/ lb. P_2O_5 and $0.55/ lb. K_2O. Values in parentheses are the nitrogen rate at where the maximum economic return to either only N or total N, P, and K was reached, and the value of the return in $/ac.

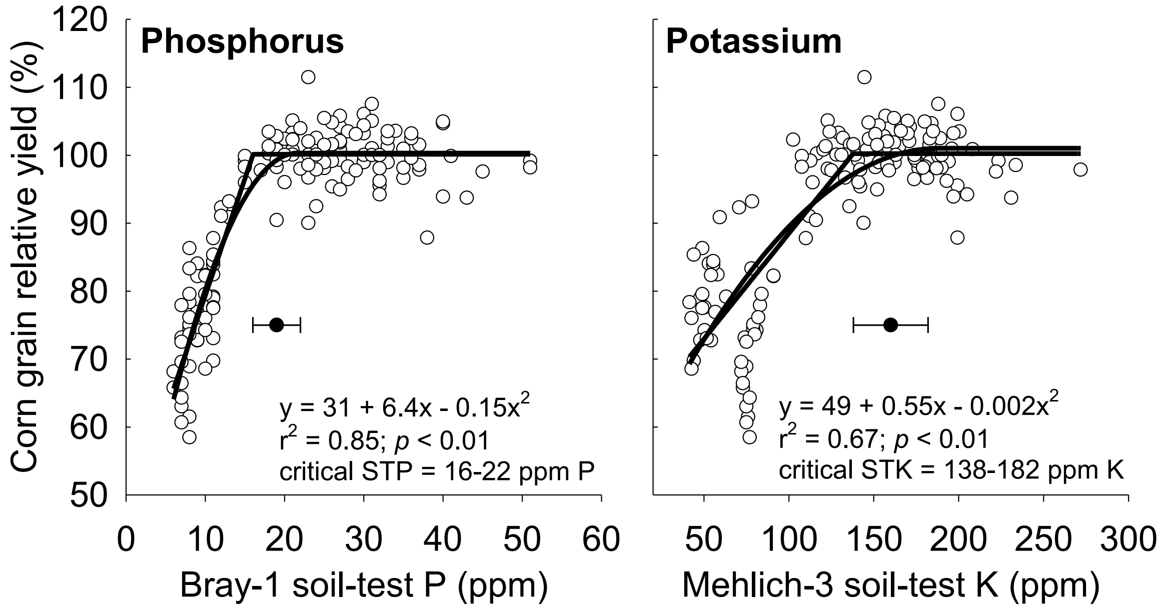

Figure 4. Relationship across all site-years between corn yield response to P or K and soil-test P or K. Critical concentration ranges for P and K are ranges of the linear-plateau and quadratic-plateau model joint points.

IMPACT OF COVER CROP COMPOSITION IN NITROGEN APPLICATION RATES AND THE SUBSEQUENT YIELDS OF CORN AND SOYBEAN

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ABSTRACT

Interseeding cover crops presents a promising strategy for enhancing the sustainability of agricultural systems. Nevertheless, the practice of interseeding cover crops introduces a dynamic element to nitrogen (N) cycling, potentially altering both the quantity and timing of N release through decomposition (mineralization). This variability in N availability may, in turn, influence the optimal nitrogen fertilizer requirements to maximize corn grain yield. However, long-term studies are essential to comprehensively assess the influence of cover crops on crop yields, as short-term investigations may not capture the full scope of soil and environmental factors. Therefore, a long-term study was initiated in South Dakota, encompassing two locations (Brooking and Beresford) within a corn-soybean rotation to explore the impact of cover crop composition on N fertilizer requirements and subsequent yields of corn and soybean. The study employed a split-plot design with three cover crop treatments (no cover crop, single grass species, multi-species - a mixture of grasses and broadleaf species) and 4-6 N rate treatments ranging from 0-250 lbs./acre. Results from 2019-22 indicate that corn with grass cover crop required anywhere from 10 lbs./ac less to 70 lbs./ac more N compared to no cover crop. In 2 of 6 N responsive site years, including a grass/broadleaf cover crop reduced corn yield at EONR (Economical Optimum Nitrogen Rate) by approximately 10 bu/ac compared to the grass or no cover crop treatments. Corn with grass cover crop compared to the grass/broadleaf mix and no cover crop yielded anywhere from 10 bu/ac less to 10 bu/ac more at EONR. In conclusion, interseeding grass cover crops into corn enhances corn yield and reduces N requirements. Furthermore, interseeeding of cover crops, both grass and grass/broadleaf mixes, into soybeans has no adverse effects on soybean yield.

INTRODUCTION

Corn production and productivity in South Dakota have steadily increased over time. However, this heavy reliance on a limited number of crops can lead to reduced agricultural biodiversity. Interseeding cover crops into a corn-soybean rotation system have the potential to improve the biodiversity in these systems. Such rotations enhance soil biodiversity, nutrient availability, resource use efficiency, and soil organic matter (McDaniel et al., 2014; Tiemann et al., 2015). The inclusion of cover crops has become increasingly popular in corn (Zea mays L.) and soybean (Glycine max L. Merr.) rotations in the US Midwest. Cover crops offer additional benefits, including improved soil quality, pest control, and biological nitrogen fixation (Schipanski et al., 2014).

The recent surge in the use of cover crops can be attributed to their potential to enhance soil and water quality (Thompson et al., 2021). Between 2012 and 2017, there was a 50 percent increase in the adoption of cover crops in the US. However, this adoption still represents only a small fraction of the total cultivated area. Several factors currently limit the widespread adoption of cover crops, including high seeding costs, concerns about return on investment, insufficient breeding efforts and variety improvement, and difficulties in achieving successful cover crop establishment (Wayman et al., 2017). The northern Midwest faces particular challenges due to its shorter growing season, which limits the options for cover crop seeding after corn harvest. Winter cereals are the primary choice for cover crops in this region, but their establishment is constrained by the limited growing season (Baker & Griffis, 2009). Grasses are the most commonly interseeded species, followed by clovers and Brassica species (USDA ERS - Cover Crops, n.d.). Researchers have explored interseeding various cover crop species, including annual ryegrass (Lolium multiflorum Lam.) and crimson clover, both as single species and in mixtures.

One major concern associated with interseeding cover crops is competition with the main crop, in this case, corn (Hall et al., 1992). The competitiveness of weeds in corn depends on factors such as the timing of weed emergence relative to corn emergence, weed species, and weed density. It has been observed that weeds are not competitive with corn when they emerge after the V2 or V4 corn growth stages (Travlos et al., 2011), or even as late as the V5 stage. This suggests that cover crops could potentially be interseeded in corn as early as the V2 stage without negatively impacting corn grain yields. However, the competitiveness of cover crops, like weeds, may vary depending on the species and density of the cover crop. While cover crops do not compete with corn plants after the V5 stage, they can still affect the N requirements for optimal corn yields. Therefore, it is crucial to understand how different cover crop compositions influence soil biological measurements, N requirements for corn, and the yields of both corn and soybeans. This study aims to explore the effects of cover crop composition (both single and multispecies) on these important factors.

MATERIALS AND METHODS

In 2019, a long-term study was established in Brookings and Beresford, South Dakota in a corn-soybean rotation with both crops being present each year. The study utilized a split-plot design within each corn and soybean area. The whole plot included three distinct cover crop treatments: No cover crop, a single grass species, and a mixture of grass and broadleaf cover crops. The split-plot was N fertilizer rate with four or six N rates ranging from 0 to 250 lbs. N/acre. Ammonium Nitrate or Super U served as the source of N. Nitrogen fertilizer treatments were applied 7-10 days after planting and cover crops were interseeded when the corn and soybean plants reached the V5 developmental stage.

Soil sampling

Prior to planting, soil samples were collected from the treatment plots that were previously under corn and transitioning to soybeans at two depths: 0-6” and 6-24”. The 0–6” samples were subjected to analyses pertaining to soil health and fertility, while the 6-24” samples were analyzed for ammonium, nitrate, and sulfur content (Table 1). In-season soil samples were collected at specific developmental stages. For corn, these stages included V6, R1, and R6, while for soybeans, they encompassed V5, R1, and R6. The in-season soil samples were analyzed for soil health and fertility measurements (Table 1.) Post-harvest soil samples were obtained from three different depths: 0-12”, 12-24”, and 24-36”. These samples were analyzed to determine the remaining nitrate-N content in the soil after the conclusion of the growing season (Table 1).

Plant and grain sampling

Plant samples were collected at specific developmental stages. For corn, these stages included V6, R1, and R6, while for soybeans, they encompassed V5, R1, and R6. In corn six plants were collected at the above-mentioned growth stages. In soybean plans from 1m^2 were collected at the above-mentioned growth stages At harvest, grain samples were obtained and analyzed for complete nutrient analysis.

Sample type	Collection time/stage	Sampling depth/type	Measurements
Soil	Pre-plant	0-6”	Nitrate-N Ammonium-N Soil Organic matter Organic Carbon Active C Potentially mineralizable N (PMN) Wet aggregate stability
		6-24”	Ammonium-N Nitrate-N S
Soil	In-season	0-6”	Nitrate-N Ammonium-N Soil Organic matter Organic Carbon Active C PMN Wet aggregate stability
Soil	Post- Harvest	0-12”	Nitrate-N
		12-24”	
		24-36”	

Table 1. Soil sample collection and parameters under investigation

RESULTS AND DISCUSSION

Corn Yield Response and N requirements

Corn yields responded to N fertilization in six out of eight site-years (Figure 1). The lack of response observed in the remaining site-years can be attributed to corn lodging due to strong winds and drought-induced potassium (K) deficiency in corn.

The results spanning from 2019 to 2022 revealed that corn grown with a grass cover crop required N ranging from 40 lbs./acre less to 25 lbs./acre more when compared to corn without any cover crop (see Figure 1a-f). In four out of six site-years where there was a response to N, the inclusion of a grass/broadleaf cover crop led to a reduction in corn yield at the Economical Optimum N Rate (EONR) by 15-30 bu/acre, in contrast to the grass-only or no cover crop treatments. Conversely, incorporating a grass cover crop significantly increased corn yield by 15 to 30 bushels per acre at the EONR compared to both the grass/broadleaf mix and no cover crop treatments, all while requiring less N and without any significant yield losses.

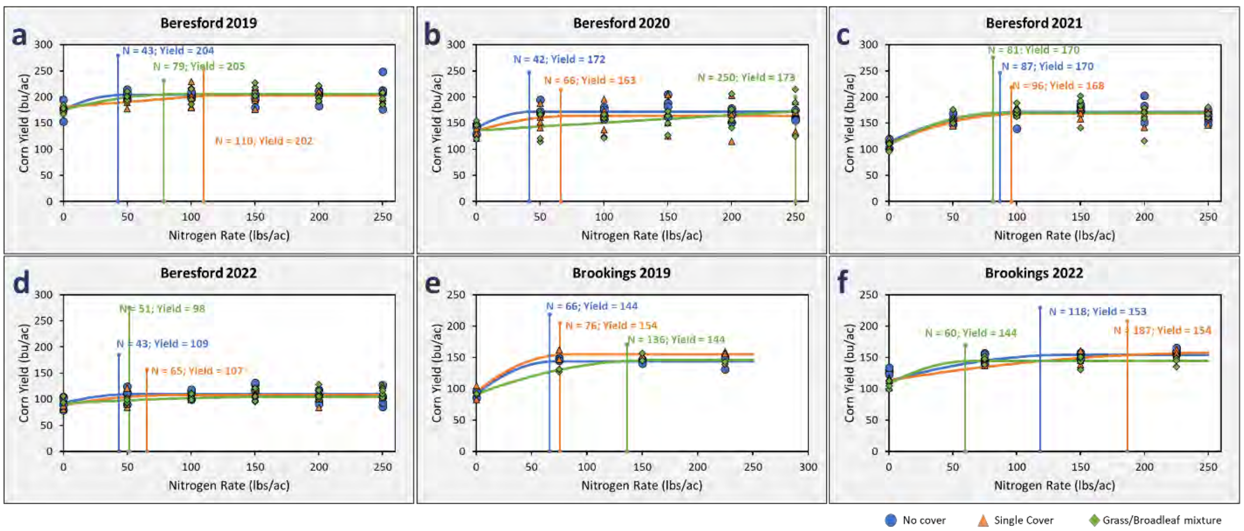

Figure 1. Corn yield response as a function of N rates across the cover crop treatments.

Soybean Yield Response

Across different N rates applied in the previous corn year, there were no significant differences in soybean yields among the cover crop treatments, except for at the Beresford site in 2021 (see Figure 2a-d). These findings suggest that, for soybeans, interseeding either grass or a mixture of grass and broadleaf cover crops had minimal to no impact on soybean yield. Therefore, it is reasonable to interseed cover crops into soybeans without affecting yield.

However, at the Beresford site in 2021, there was a trend towards reduced yields with interseeded single or cover crop mixtures at 50 and 100 lbs. N/acre rates from the previous year (see Figure 2b). This trend could be attributed to the drought conditions experienced during 2021, which may have played a role in the reduction in yields when cover crops were planted. Nevertheless, it's worth noting that the 2021 Brookings site also faced drought conditions, yet the inclusion of cover crops did not influence soybean yield. As we gather more data from various site years under different moisture conditions, our understanding of how interseeded cover crops affect soybean yield will continue to grow.

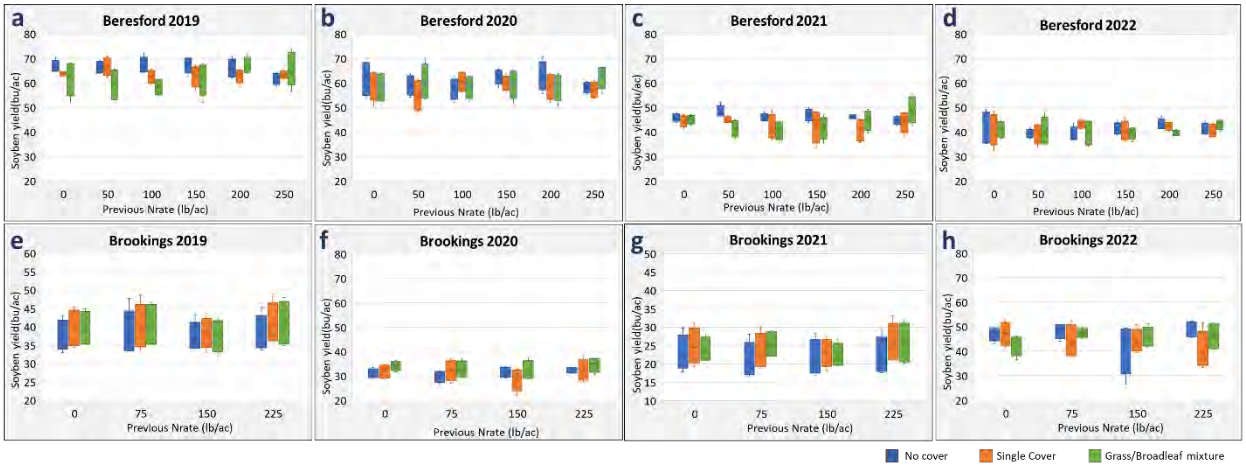

Figure 2. Soybean yield response as a function of previous N rates across cover crop treatments.

CONCLUSIONS

Interseeding cover crops into the corn-soybean rotation has the potential to bring about various direct and indirect benefits to overall soil health and fertility, all while maintaining crop yields. It's been observed that both single and multiple cover crop mixtures can be successfully interseeded into soybean without causing any adverse impact on yield. However, when it comes to the influence of cover crop composition on corn yields and N requirements, the results have been inconsistent during the initial three years of this study. Consequently, we need to gather additional data before we can draw definitive conclusions regarding the impact of cover crop composition on N requirements and corn yield.

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IMPACTS FROM AUTUMN STARTER FERTILIZER, LATE-SEASON NITROGEN, AND FUNGICIDE TIMING ON WINTER WHEAT YIELD, STRAW, AND GRAIN QUALITY

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INTRODUCTION

Michigan winter wheat (*Triticum aestivum* L.) encompasses nearly 500-600 thousand acres and is the third most planted annual row crop following soybean and corn (*FAOSTAT*, n.d.). To mitigate seasonal yield and soil spatial variabilities, growers continue to explore more intensive production practices. Current guidelines suggest 40-120 lb. N A^{-1} top-dressed at green-up with foliar fungicide applied five to six days following early flowering (i.e., Feekes [FK] 10.5.1) to protect against Fusarium head blight (FHB) (*Fusarium graminearum* Schwabe [telemorph *Giberella zea* (Schweinit) Petz]. Given the rising demand for wheat amid climate uncertainties, growers increasingly wish to address specific winter wheat production challenges beginning in autumn and lasting through harvest. This field study investigated the influence of autumn starter fertilizer, late-season nitrogen (FK 7), and multiple fungicide timings on the yield and quality of winter wheat grain and straw.

MATERIALS AND METHODS

Field studies were established in Lansing, MI on a Conover loam soil (Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*) following silage corn (SC) and soybean (SB) during the 2022-2023 growing season. Soft red winter wheat 'Wharf', a short-strawed, high-yielding variety (Michigan Crop Improvement Association, Okemos, MI), was planted following SC (30 Sept. 2022) and SB (04 October 2022). Treatments were arranged in a full factorial, randomized complete block design with three experimental factors across four replications (2×5×2). Experimental factors included two levels of autumn starter (AS) (12-40-0-10-1, N-P-K-S-Zn) (0 and 250 lb AS A^{-1}) applied at planting, five levels of fungicide timing (FT) (none, FK 5-7 and 10.5.1, FK 9 and 10.5.1, FK 10.5.1 individually, and FK 5-7, 9 and 10.5.1) and two levels of late-season N (LN) (0 and 30 lb N A^{-1}) applied at FK 7. All treatments received a base green-up N application of 100 and 75 lb N A^{-1} at FK 5 following SC and SB, respectively, except for the non-treated check. Pre-plant and spring soil characteristics are summarized in Table 1.

RESULTS

Environmental Condition. Cooler autumn air temperatures provided fewer growing degree days (GDD) resulting in delayed spring plant development. March precipitation was +83% above the 30-year average while May, June, and July 2023 precipitation was -73%, -82%, and -40%, respectively, from 30-year averages resulting in a narrowed grain-filling growth stage (Table 1).

Grain Yield, Quality, and Straw Yield. Following SC, grain yield ranged from 33.1 – 115.2 bu. A^{-1} with a mean of 90.0 bu. A^{-1}. An interaction between AS and FT significantly affected SC grain yield (Table 2, p = 0.0682). Across FT, AS consistently increased mean grain yield by 20.8 – 38.2 bu. A^{-1}. Conversely, FT only had a significant effect on mean grain yield with no AS and no fungicide (84.8 bu. A^{-1}) as compared to fungicide applications at FK 5-7 and 10.5.1 (67.3 bu. A^{-1}). The interaction between AS and LN significantly influenced grain protein content (Table 4, p = 0.038). With AS application, LN increased protein concentration but without LN application AS decreased protein concentration. Straw yield ranged from 0.2 – 1.8 T A^{-1} with a mean of 1.1 T A^{-1}. Only AS had a significant influence on mean straw yield with 0.60 T A^{-1} greater than no AS (Table 3, p < 0.0001).

Following SB, grain yield ranged from 57.3 – 134.8 bu. A^{-1} with a mean of 103.3 bu. A^{-1}. Neither AS (p = 0.1544), FT (p = 0.8609), or LN (p = 0.7767) significantly influenced grain yield. Grain protein content was significantly affected by AS and LN main effects. AS and LN improved mean grain protein content by 0.34% (p = 0.0109) and 0.78% (p < 0.0001), respectively (Table 5). Straw yield ranged from 0.3 – 2.3 T A^{-1} with an average of 1.2 T A^{-1}. Autumn starter increased mean straw yield by 0.30 T A^{-1} when compared to no AS (Table 3, p < 0.0001).

Potential Economic Profitability. Traditional management was defined as green-up N applications of 100 and 75 lb N A^{-1} following SC and SB, respectively, during FK 5 and late-season fungicide spray at FK 10.5.1.

Following SC, mean grain and grain + straw potential economic profitability (PEP) for traditional management (GRNUP + L) was USD 456.49 and USD 566.69, respectively. Without late-fungicide spray at FK 10.5.1, the addition of AS increased mean grain PEP by USD 95.20 (p = 0.0452). Meanwhile, incorporating multiple fungicide spray programs and LN decreased grain PEP by USD 98.25 – 156.58 (p = 0.0014 – 0.0389). Autumn starter increased grain + straw PEP by USD 111.20 – 158.99, regardless of mid-season fungicide spray at FK 9 (p = 0.0738 – 0.0117). Incorporating additional early (FK 5-7) and mid-season (FK 9) fungicide sprays with LN reduced grain + straw PEP by USD 111.05 – 171.09 (p = 0.0069 – 0.0742).

Following SB, the mean grain and grain + straw PEP for traditional management (GRNUP + L) was USD 606.69 and USD 768.78, respectively. The addition of AS with LN or multiple fungicide sprays at FK 5-7 or 9 reduced grain PEP by USD 129.33 – 188.70 (p = 0.0075 – 0.0624). Further, the addition of AS with mid-season fungicide spray at FK 9 decreased grain + straw PEP by USD 185.89 (p = 0.03).

DISCUSSION

Influence of autumn starter on yield and agronomic components.

Tillering and headcount. One of the benefits of autumn starter application was increased spring tiller density. In SC, tiller density ranged from 62 – 233 tillers ft^{-2}, with an average of 161 tillers ft^{-2}. In SB, tiller density ranged from 146 – 386 tillers ft^{-2}, with an average of 232 tillers ft^{-2}. Autumn starter increased tiller density in SC and SB by 34% ($p < 0.0001$) and 27% ($p = 0.0002$), respectively. However, only in SC, did tiller density have a moderate positive influence on grain yield ($r = 0.60$, Table 6).

Tiller production helps determine the potential headcount. In SC, headcount ranged from 37 – 102 spikes ft^{-2} with a mean of 67 spikes ft^{-2}. In SB, headcount ranged from 48 – 150 spikes ft^{-2} with a mean of 83 spikes ft^{-2}. Autumn starter increased headcount 31% ($p < 0.0001$) and 23% ($p < 0.0001$), following SC and SB, respectively. Consequently, headcount exerted a moderate positive influence on grain yield (SC $r = 0.63$, SB $r = 0.42$, Table 6). Results align with Quinn and Steinke (2019) where both tiller and head production were enhanced by the application of autumn starter in a low-input management system. The minimal influence of tiller density on grain yield highlights the significance of tiller survival to develop into productive wheat heads later in the season.

Head length. Head development is most rapid during stem elongation (FK 5-7). As the wheat stem elongates, the "heading stage" is initiated suggesting that as the stem extends, there is a greater opportunity for the head to stretch thereby producing a longer head (Simmons et al., 1985). Longer head length corresponds to more spikelets that can be filled with grain. Autumn starter increased the mean head length at both sites (SC $p < 0.0001$; SB $p < 0.0001$). However, only in SC did head length have a moderate positive influence on grain yield ($r = 0.62$, Table 6). According to Broeske et al., (2020), the number of spikes per head is determined at FK 5. Early nutrient application offers the potential for greater stem elongation, especially in unfavorable mid-season environments such as hot and dry May – June 2023 weather conditions that resulted in a shorter grain-filling period.

Plant height and straw yield. Autumn starter increased mean plant height. Autumn starter increased plant height 15% ($p < 0.0001$) and 1% ($p = 0.0549$) following SC and SB, respectively. Consequently, plant height exerted a moderate to strong positive influence on straw yield (SC $r = 0.82$, SB $r = 0.57$, Table 6).

The positive correlation between straw yield and plant height demonstrates stem elongation's influence during straw accumulation. The active growing stage of wheat starts at FK 5 when leaf sheaths are fully elongated and pseudostems are strongly erect up until FK 10 when the head is visible in the leaf sheath (Broeske et al., 2020). Rapid N uptake begins at FK 5 to 7 (Waldren & Flowerday, 1979). The early nutrient application promoted N uptake and improved stem elongation translating into enhanced straw production.

Influence of late-season N at Feekes 7 on flag leaf N, grain N, and protein content.

As a yield-limiting nutrient, insufficient N application risks suboptimal photosynthetic capacity leading to lower grain yield potential while excessive N fertilizer may result in over-application, environmental contamination, and reduced profitability.

Growers benefit from the application of N fertilizer depending on the wheat crop stage. Early N application promotes yield component formation while later N fertilization often boosts post-yield parameters such as grain protein content.

In the current study, main effects of late-season N at FK 7 improved mean grain protein content following soybean ($p < 0.0001$) where autumn starter had less impact on tiller counts. Late-season N interacted with autumn starter ($p = 0.038$) following silage corn where tiller counts were more affected than following soybean. Results may indicate that where autumn starter had greater impacts on tiller counts, LN increased protein due to N dilution across a greater number of spikes. Conversely, where LN was not applied, AS may have decreased protein content also due to growth dilution across a greater number of spikes. Previous studies observed variability regarding the influence of late-season applied N on grain yield, nutrient concentration, and quality (De Oliveira Silva et al., 2021; Sowers et al., 1994). This can be attributed to low N fertilizer recovery of wheat ranging from 30-50% (Raun et al., 2002) and increases at anthesis from 55 to 80% in irrigated wheat (Wuest & Cassman, 1992) which demonstrates that the late N can be supplemented with available soil moisture.

Flag leaf N and grain N concentrations were measured at FK 9 and harvest, respectively. The interaction between late-season N and autumn starter significantly influenced flag leaf N concentration (SC $p = 0.0802$, SB $p = 0.0035$). Late-season N increased flag leaf N regardless of autumn starter application. The flag leaf contributes 30-50% of assimilates for grain filling (Sylvester-Bradley et al., 1990), and its longevity correlates with grain protein accumulation (Blake et al., 2007). Flag leaf N concentration had a moderate positive influence on grain protein content only in SB (SB $r = 0.45$, Table 6). Late-season N increased grain N content (SC $p < 0.0001$, SB $p < 0.0001$). Further, grain N content had a strong positive influence on grain protein content (SC $r = 0.87$, SB $r = 0.93$, Table 6). These results were supported by Waldren and Flowerday (1979) in which the N accumulation peaked at the grain-filling stage with 70% of N uptake going into grain.

Table 1. Site description, soil chemical properties and mean P, K, S, and Zn nutrient concentrations (0 – 8 inches) obtained prior to winter wheat planting and spring soil nitrate levels (0 – 12 in.) before green-up application at Feekes 5, following silage corn and soybean, Lansing, MI, 2022-2023.

									Soil Nitrate	
		Soil pH	OM	P	K	S	Zn	CEC	Pre-plant	Spring
Site	Soil Description		$g\ kg^{-1}$	——ppm——				meq $100g^{-1}$	—NO_3-N kg^{-1} soil—	
Foll. silage corn	Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*	7.2	18	55	68	12	2.5	8.2	4	No AS: 2.0 AS †: 3.75
Mehlich-3≠				74 (30)	78 (120)		(2)			
Foll. soybean	Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*	7.8	18	142	96	9	6.1	16.2	5	No AS: 1.75 AS: 2.0
Mehlich-3≠				192 (30)	109 (120)		(2)			

† Autumn starter (12-40-0-10-1, N-P-K-S-Zn) applied at a rate of 250 lb N A^{-1} at planting.
≠ Conversions of soil analyses into Mehlich-3 values. Soil test values in parentheses represent critical values. Bulletin 974: Tri-State Fertilizer Recommendations, pp. 28, 41

Table 2. Interaction of autumn starter (12-40-0-10-1, N-P-K-S-Zn) and fungicide timing on grain yield (bu A^{-1}) in field following silage corn, Lansing, MI., 2022-2023.

	Autumn Starter		
Treatment	0 lb AS A^{-1}	250 lb AS A^{-1}	
Fungicide Timing	——Grain Yield§ bu A^{-1}——		P > F †
No fungicide	84.75aB	108.45aA	***
Feekes 5-7, 10.5.1	67.32cB	105.50aA	***
Feekes 10.5.1	84.48aB	107.00aA	***
Feekes 9, 10.5.1	75.38bcB	108.49aA	***
Feekes 5-7, 9, 10.5.1	81.41abB	102.25aA	***
P > F **#**	**	ns	
Nontreated check	38.90		

§ Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Asterisks indicate thresholds of significance (ns, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001). Nontreated check is not included in the analysis. **#** Means within columns followed by the same lower-case letters are not statistically different (LSD, P < 0.10). † Means within rows followed by the same upper-case letters are not statistically different (LSD, P < 0.10).

Table 3. Mean straw yield (T A^{-1}) as influenced by autumn starter (12-40-0-10-1, N-P-K-S-Zn) in field following silage corn (SC) and following soybean (SB), Lansing, MI., 2022-2023.

Treatment	**SC**	**SB**
Autumn Starter Fertilizer	—— Straw Yield§ T A^{-1}——	
0 lb AS A^{-1}	0.79b	1.09b
250 lb AS A^{-1}	1.39a	1.38a
P > F	***	***
Nontreated check	0.27	0.52

§ Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Values followed by the same lowercase letter are not significantly different. Asterisks indicate thresholds of significance (ns, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001). Nontreated check is not included in the analysis.

Table 4. Interaction of autumn starter (12-40-0-10-1, N-P-K-S-Zn) and late-season nitrogen on grain protein content (%) in field following silage corn, Lansing, MI., 2022-2023.

	Late-season Nitrogen		
Treatment	0 lb N A^{-1}	30 lb N A^{-1}	
Autumn Starter Fertilizer	—— Grain Protein §%——		P > F †
0 lb AS A^{-1}	10.70aA	10.88aA	ns
250 lb AS A^{-1}	9.96bB	10.74aA	**
P > F #	**	ns	
Nontreated check	8.76		

§ Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Asterisks indicate thresholds of significance (ns, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001). Nontreated check is not included in the analysis. # Means within columns followed by the same lower-case letters are not statistically different (LSD, P < 0.10). † Means within rows followed by the same upper-case letters are not statistically different (LSD, P < 0.10).

Table 5. Mean grain protein content (%) as influenced by autumn starter (12-40-0-10-1, N-P-K-S-Zn) and late-season applied nitrogen in field following soybean, Lansing, MI, 2022-2023§.

Treatment	
Autumn Starter Fertilizer	———— **Grain Protein§** %———
0 lb AS A^{-1}	10.60b
250 lb AS A^{-1}	10.94a
P > F	**
Late-season Nitrogen	
0 lb N A^{-1}	10.38b
30 lb N A^{-1}	11.16a
P > F	***
Nontreated check	9.02

§ Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Values followed by the same lowercase letter are not significantly different. Asterisks indicate thresholds of significance (ns, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001). Nontreated check is not included in the analysis

Table 6. Correlations between agronomic components, flag leaf (Feekes 9), and grain nutrient concentrations at harvest with grain yield, straw yield, and grain protein content in fields following silage corn (SC) and soybean (SB), Lansing, MI, 2022-2023. †

	Following silage corn (SC)												
	Agronomic				**Flag leaf at Feekes 9**				**Grain**				
	T	PH	HC	HL	N	P	S	N:S ratio	N	P	S	N:S ratio	KW
GY	0.60***	0.88***	0.63***	0.60***	0.63***	-0.05	0.84***	-0.85***	-0.47***	-0.43***	0.76***	-0.81***	-0.69***
SY	0.61***	0.82***	0.60***	0.41**	0.56***	0.05	0.76***	-0.75***	-0.30*	-0.38**	0.73***	-0.70***	-0.72***
GP	-0.42**	-0.43***	-0.20	-0.47***	-0.07	0.34**	-0.28*	0.44**	0.87***	0.30*	-0.26*	0.57***	0.20
	Following soybean (SB)												
	Agronomic				**Flag leaf at Feekes 9**				**Grain**				
	T	PH	HC	HL	N	P	S	N:S ratio	N	P	S	N:S ratio	KW
GY	-0.05	0.75***	0.42**	0.10	0.34**	0.06	0.49***	-0.53***	-0.15	-0.12	0.20	-0.46***	0.03
SY	0.33**	0.57***	0.44***	0.35**	0.38**	0.37**	0.64***	-0.66***	0.25*	0.13	0.52***	-0.46***	-0.40**
GP	0.41**	-0.05	0.06	0.38**	0.45**	0.39**	0.33**	-0.14	0.93***	0.40**	0.59***	0.12	-0.58***

† Pearson correlation coefficient analysis using PROC CORR procedure. Asterisks indicate thresholds of significance (*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$). Nontreated check is not included in the analysis. Abbreviations: GY – grain yield; SY – straw yield; GP – grain protein; T – tiller population; PH – plant height; HC – head count; HL – head length; KW – 1000-kernel weight

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EXAMINATION OF TOPOGRAPHY AND SOIL HEALTH PROPERTIES AND THEIR RELATIONSHIP TO CORN YIELD STABILITY IN CENTRAL IOWA AGRICULTURAL FIELDS

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ABSTRACT

Croplands in the North Central region are managed for high crop yields that are stable across years and fields. Nevertheless, yields fluctuate from year to year. Moreover, the magnitude of these fluctuations can vary across the field such that yield in some portions of the field is relatively stable and relatively variable in other portions of the field. Previous research has found that yield stability can be partially explained by topographic variables, but potential relationships between yield amount, yield stability, topography and soil health indicators are poorly understood. The objective of this research is to explore the relationship between corn yield stability, topography, and soil health properties in conventionally managed central Iowa agricultural fields. Collaborating with independent growers, five fields with variable yields and topography were selected for this study. The participating growers provided 3 to 12 years of spatially resolved corn yield history from combine yield monitors. Using ArcGIS Pro 3.1.0, yields were standardized for each year and the fields were analyzed on a 10 m x 10 m grid for average yield and standard deviation of yield (yield stability) across years. A three-meter digital elevation model, derived from LiDAR data, was used to analyze each field for topographic variables including aspect, slope, hillslope position, and topographic wetness index. Based on the yield and topographic parameters, 200 soil sampling points were identified for each field and five 0-15 cm soil cores were collected at each point. One homogenized soil sample from each point was analyzed for potentially mineralizable nitrogen, potentially mineralizable carbon, potentially oxidizable carbon, water holding capacity, ACE Protein, C:N, total carbon and total nitrogen. Results indicate that topographic variables, specifically slope and hillslope position, have a strong correlation to average yield and yield stability across all fields in this study. Soil health parameters however were inconsistent in their correlation to yield. None of the soil health parameters had a significant correlation to average yield or yield stability consistently across fields analyzed in this research.

IOWA PHOSPHORUS AND POTASSIUM SOIL-TEST INTERPRETATIONS WERE UPDATED IN 2023: CHANGES AND REASONS

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ABSTRACT

The Iowa State University phosphorus (P) and potassium (K) soil-test interpretations for crops were updated in 2023 because the previous update had been in 2013 using data until 2012 and research since then indicated a need for some changes. The general goal of the guidelines since the 1990s has been to accomplish long-term profitability from fertilization and low risk of yield loss while maintaining or improving crop production sustainability. This has been attained by emphasizing crop response-based P and K rates to maximize yield in most conditions for the low-testing interpretation categories and suggesting build-up rates for at most 2 years, suggesting removal-based maintenance using prevailing crop yields (not yield goal), and suggesting P-K starter for specific conditions. The categories Very Low, Low, Optimum (maintenance), High, or Very High have been defined based on decreasing probability of yield response of approximately 80, 55, 25, 5, and 1%, respectively. Changes to the interpretation categories for P tests (Bray-1, Mehlich-3 colorimetric and ICP, Olsen) and K tests (ammonium-acetate or Mehlich-3 with dry and moist or slurry sample handling procedures) were that borders between the Very Low, Low, and Optimum interpretation categories were increased slightly but the Optimum category was made much wider by a larger increase of the boundary with the High category. Changes were justified by the new research to maintain the criteria for the categories' definitions, better awareness of very high soil-test small-scale spatial variability in most fields, and large bias among soil-test laboratories. Suggested fertilization rates for Very Low and Low categories were increased due to increased crop yield to maintain the criterion of attaining maximum yield in most conditions. Fertilizer placement guidelines did not change.

INTRODUCTION

Field research on P and K fertilization and relationships between soil-test values and yield response is continuously conducted in Iowa to assure that management guidelines are kept current. The last update of Iowa State University P and K guidelines (publication PM 1688) was in 2013 including soil-test and yield response data by 2012. Improved crop genotypes have been introduced in agriculture and crop yields continued increasing. Field-response trials with corn and soybean from 2013 until 2020 involved 799 site-years for P and 724 site-years for K, encompassed 36 Iowa soil series with predominant crop production, and soil (6-inch depth) pH was 4.9 to 8.1 and organic matter was 1.5 to 10% across P and K trials. The new results were combined with results of previous trials from which lowest yield levels were excluded (489 site-years for P and 240 site-years for K). This article summarizes changes and shows new relationships between corn and soybean soil-test results for selected soil-test methods. The criteria for establishing guidelines, updated soil-test interpretation categories, and suggested fertilization rates are included in the revised Extension publication PM 1688 (Mallarino et al., 2023).

WHAT DID NOT CHANGE?

The fundamental concepts for the interpretation and rate guidelines did not change. The general goal since the early 1990s has been to accomplish long-term profitability with minimal risk of yield loss while maintaining or improving crop production sustainability and water quality. This has been attained by emphasizing crop response-based P and K fertilization rates to maximize yield in most conditions for the Very Low and Low interpretation categories, suggesting build-up rates for at the most 2 years, suggesting removal-based maintenance using prevailing crop yields (not yield goal) only for the Optimum category using provided P and K concentrations in harvested crop parts, and suggesting P-K starter only for specific conditions. The categories Very Low, Low, Optimum, High, or Very High have been defined based on decreasing probability of yield response of approximately 80, 55, 25, 5, and 1%, respectively.

Recent research confirmed that the Bray-1 soil P extractant is unreliable in highly calcareous soils and either the Olsen or Mehlich-3 P extractants should be used, different soil-test interpretations are needed for any soil P test (but especially the most widely used Mehlich-3 extractant) when using the colorimetric or inductively-coupled plasma (ICP) measurements of extracted P, and K tests by the ammonium-acetate or Mehlich-3 K extractants are much more reliable when using the field-moist or slurry sample handling procedure than the common dried sample procedure especially in soils having moderately poor to very poor drainage. New research confirmed that with all tillage systems, equivalent responses typically occur for broadcast and planter-band P and K applications when using comparable rates. New research for deep banding was not repeated but extensive previous research had shown that deep-band P is not better than broadcast P for corn or soybean whereas deep-band K is a must with ridge-till but only occasionally is beneficial with no-till or strip-till (Mallarino, 2019).

WHAT WAS CHANGED?

One important change was that the recommended P and K fertilization rates for the Very Low and Low interpretation categories were increased to preserve the concept of assuring maximum yield for most conditions because of increased yield levels and P and K removal (see suggested rates in PM 1688, Mallarino et al., 2023). The most important change, however, was that the boundaries of the interpretation categories were adjusted in attention to the new research results to preserve the probabilities of response for each category defined since the early 1990s. The boundaries between the Very Low, Low, and Optimum categories were increased slightly but the Optimum category was made much wider by a large increase of its boundary with the High category. This was justified by the observed yield responses, further recognition of the inherent uncertainty of soil-test results mainly due to high small-scale spatial variation despite using improved dense soil sampling methods, and large bias among soil testing laboratories despite improvements from many years of proficiency soil testing programs.

Figure 1 shows the relative grain yield responses of corn and soybean to P fertilization for a wide range of soil-test values using the Bray-1 tests using the standard colorimetric measurement of extracted P. A handful of trials on highly calcareous soils, where the Bray-1 underestimated plant-available P were excluded and, therefore, the data approximately apply to the Mehlich-3 test with a colorimetric P measurement since these tests are statistically equivalent except in highly calcareous soils. For reference, the figure includes the previous interpretations in 2013 and the new interpretations. The bargraph shows that the probabilities of response across both crops are higher than 80% for Very Low and around 60%, 25%, 5%, and 0% for the Low, Optimum, High, and Very High categories, respectively.

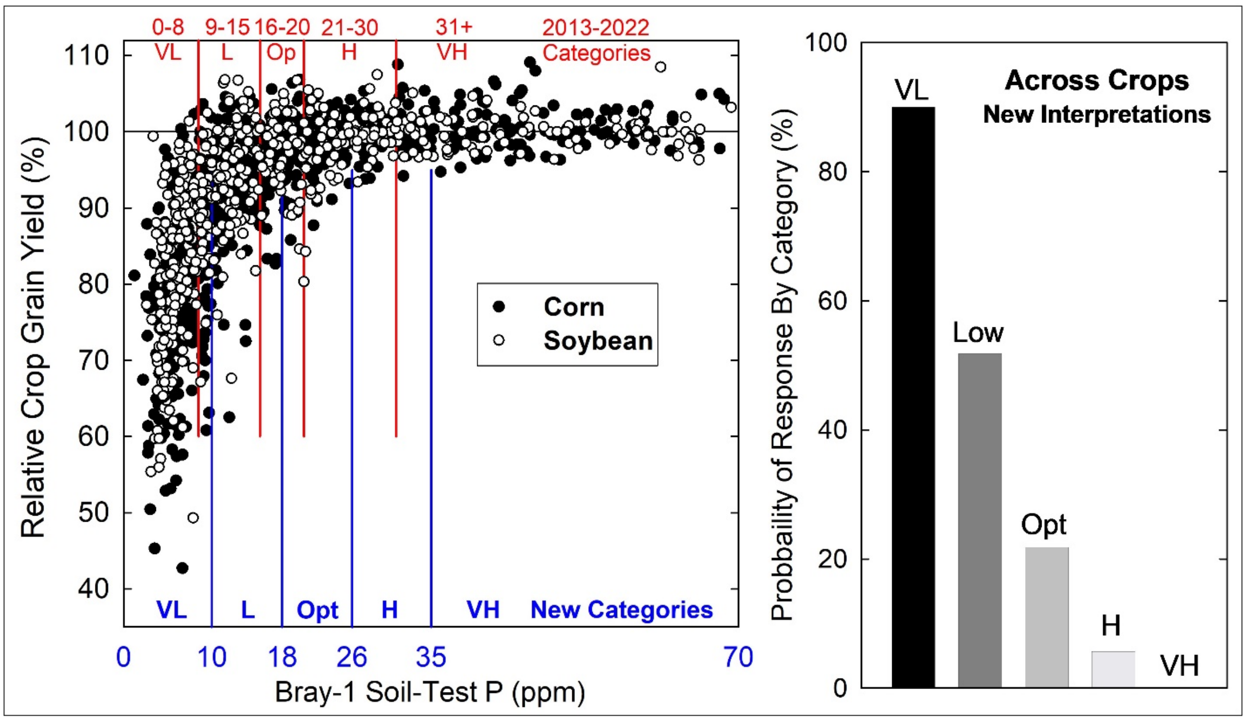

Fig. 1. Relationships between Bray-1 colorimetric soil P and relative corn and soybean grain yield response showing old and new categories and the probability of response across both crops for each new category (VL=Very Low, L=Low, Opt=Optimum, H=High, VH=Very High).

Figure 2 shows the relationships between corn and soybean yield increases and soil-test P and the new interpretation categories. The observed variability is common for P trials and results from different environmental conditions, soil-test spatial and temporal variability, and experimental error. Yield increases frequently were very large in the Very Low category, moderate in the Low category, very small in the Optimum category (on average around 4 bu/acre), and varied around zero for the high-testing categories. Therefore, recommended removal-based P or K rates for the Optimum category will maximize yield in most conditions although may not optimize profitability and producers can reduce it mainly with unfavorable prices or unsafe land tenure. Fertilization, other than the usually low starter rates, will not offset the costs of fertilizer and its application.

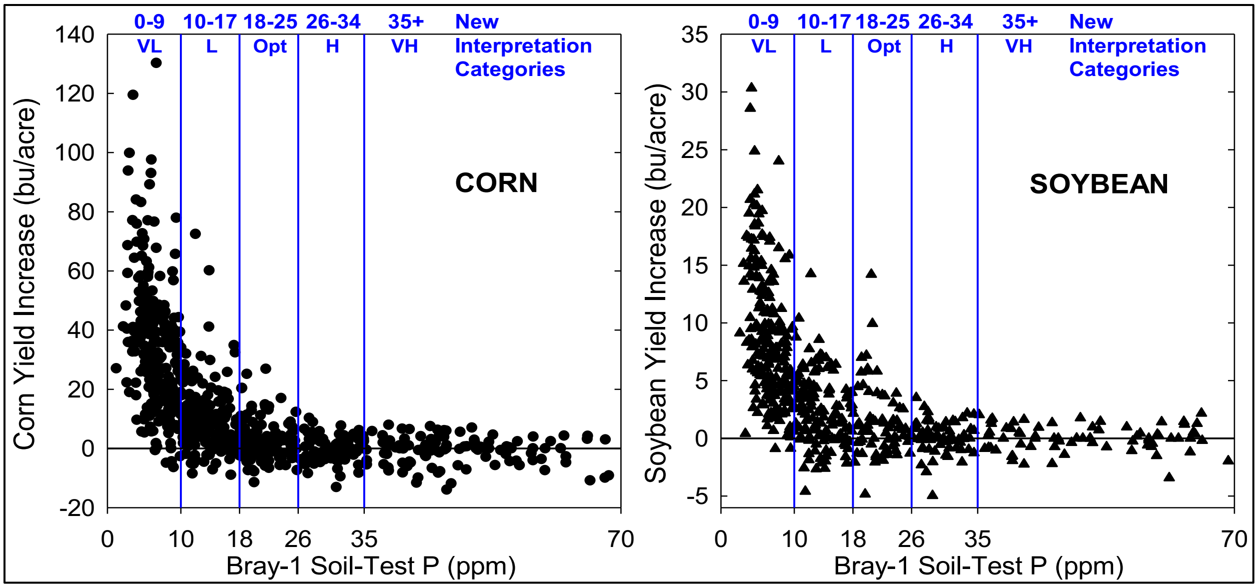

Fig. 2. Relationships between corn and soybean grain yield increases from P fertilization and Bray-1 soil P indicating the new interpretation categories.

Figure 3 shows relationships between relative grain yield responses and soil-test K by the ammonium-acetate test (statistically equivalent to the Mehlich-3) using the dry and field-moist or slurry sample handling procedures (Gelderman and Mallarino, 2012). Interpretation changes for K and the reasons were like those for P.

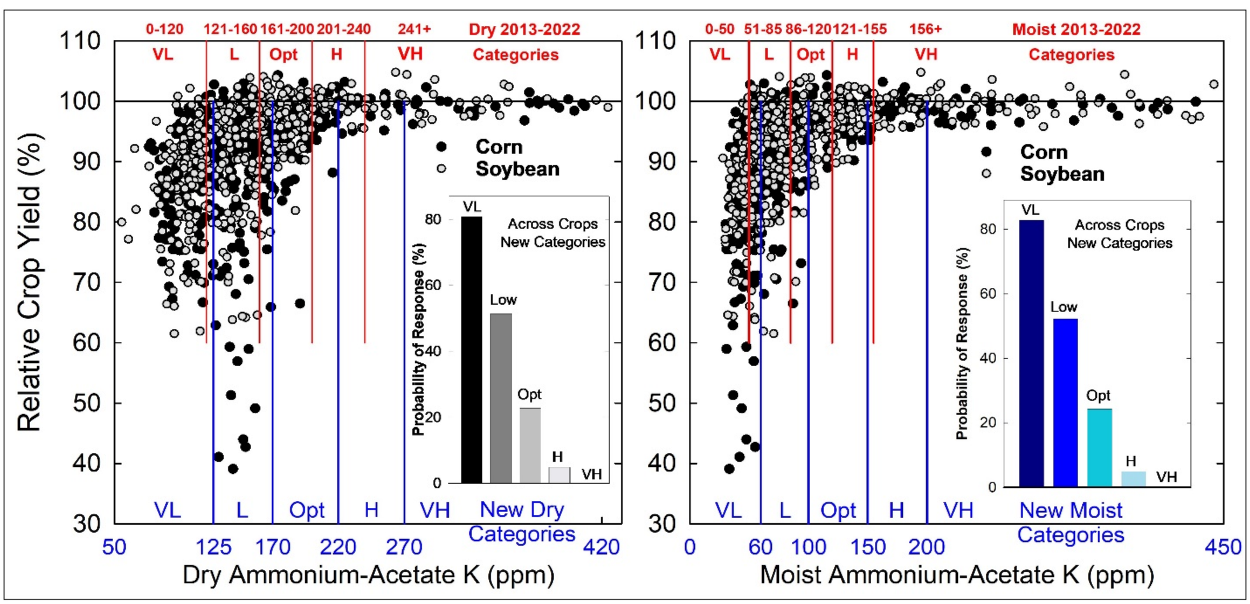

Fig. 3. Relationships between ammonium-acetate soil-test K using dry or moist sample handling procedures and relative corn and soybean grain yield responses showing the previous and new categories. Bargraphs show probability of response across both crops for each new category.

Yield increases from K fertilization related to soil-test values for both sample handling procedures in Fig. 4 show the usually much higher K response variability than for P observed in Iowa and other states. But the data show well the better performance of the moist (or slurry) K test as well as unlikely and very small yield responses in high-testing soils which seldom would offset costs of fertilizer application.

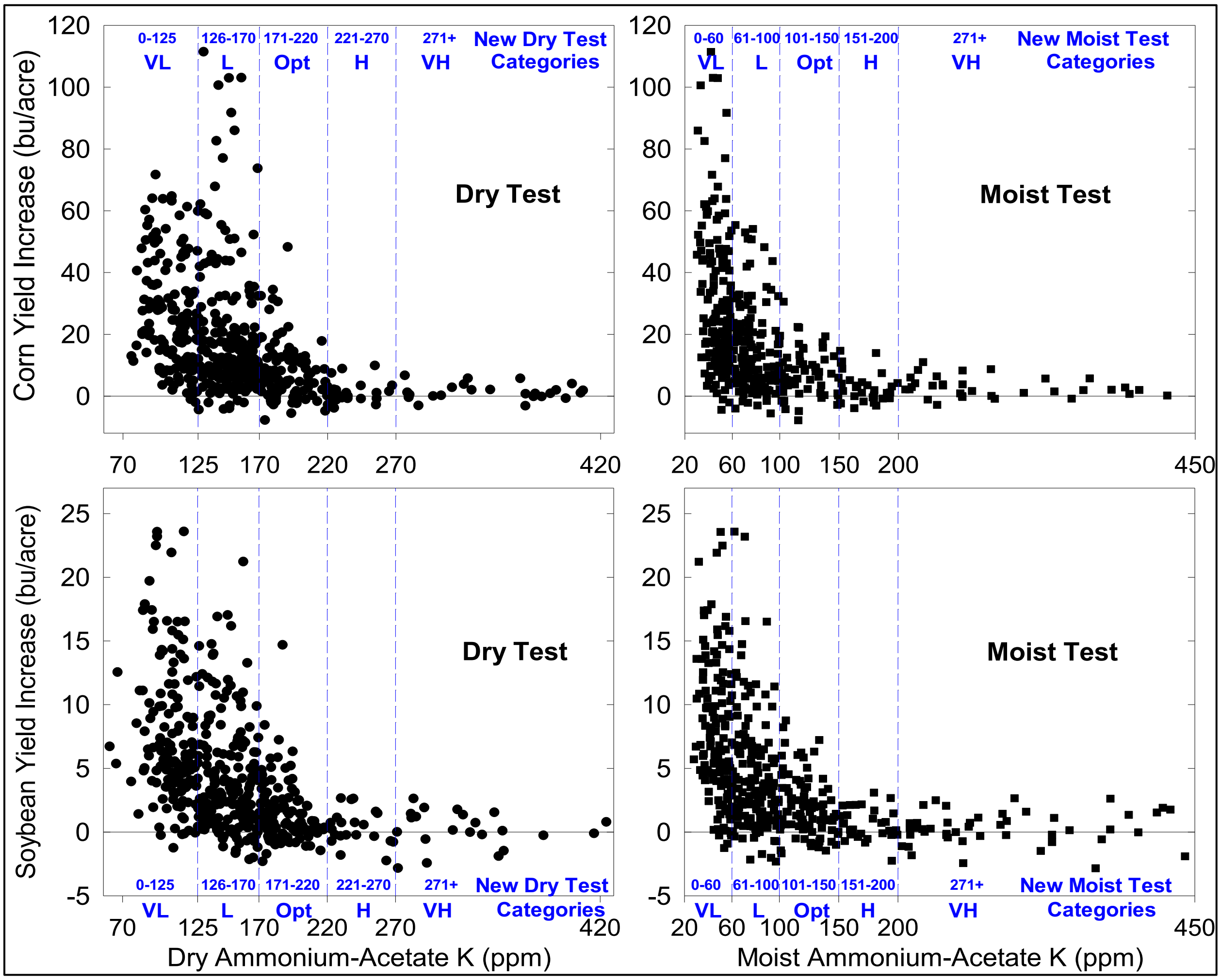

Fig. 4. Relationships between corn (top two graphs) and soybean (bottom two graphs) grain yield increases from K fertilization and ammonium-acetate soil K using dry or moist sample handling procedures indicating the new interpretation categories.

Figure 5 confirms that the moist K test is much more reliable than the dry test and results in more accurate K fertilization management for many soils. This is the case for soils with moderately poor to poor drainage even with tiles present such as the Iowa series Canisteo, Clyde, Coland, Colo, Edina, Haig, Harps, Kalona, Marcus, Okoboji, Taintor, Webster, and Zook. Research suggested that alternating dry and saturated soil moisture is the main reason for the dry test bad performance, although soils had slightly higher organic matter and smectite clay dominance than others. The meaning of a moist K test value for yield response was similar across soils but not for the dry test and its use complicates good K management.

New data in Fig. 6 confirm that soil K cation saturation is not good to decide K fertilization and using the recommended 2 to 5% range by some consultants would result in unneeded fertilization and reduced profitability in many fields.

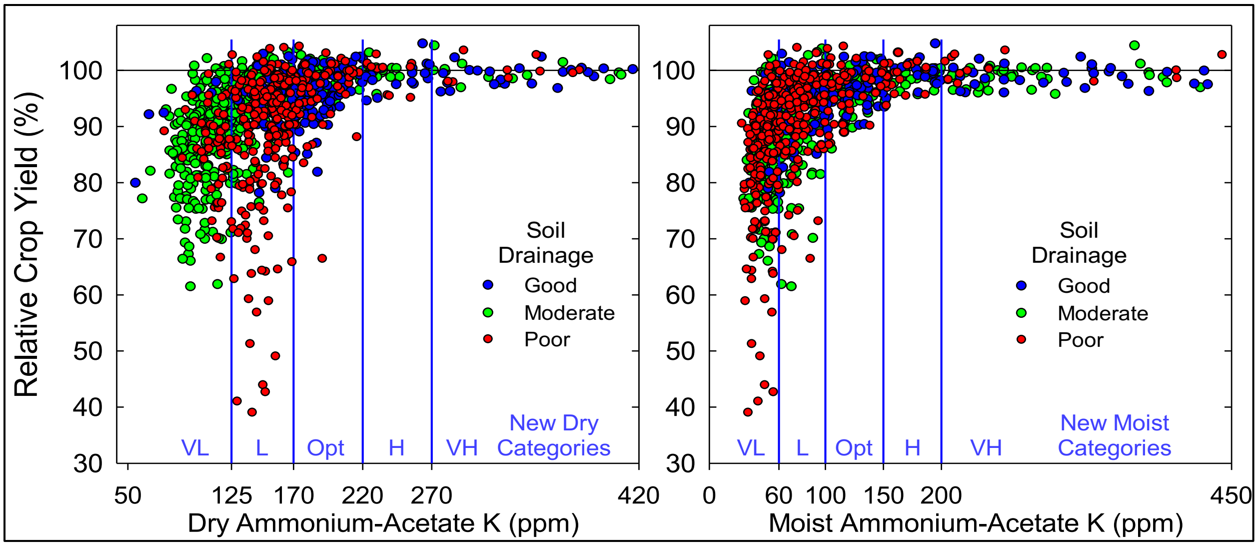

Fig. 5. Relationships between ammonium-acetate soil K with dry or moist sample handling procedures and relative corn and soybean grain yield response for soils with different drainage.

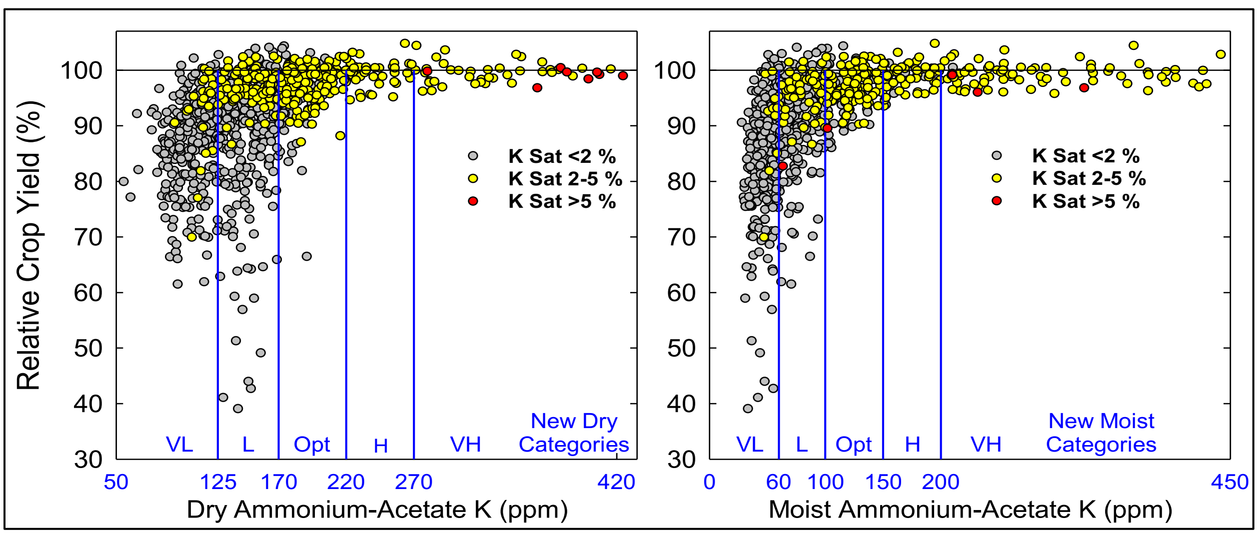

Fig. 6. Relationships between ammonium-acetate soil K with dry or moist sample handling procedures and relative corn and soybean yield response for soils with different K saturation.

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INTEGRATION OF SATELLITE AND UAV IMAGERY FOR ASSESSING CORN NITROGEN UPTAKE AT EARLY VEGETATIVE GROWTH STAGES

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ABSTRACT

Post-emergence sidedress applications of nitrogen (N) fertilizer can reduce N loss and improve plant uptake, so efficient and practical ways to identify corn N status at early corn growth stages is key to assessing plant N needs. The objectives of this study were to 1) compare metrics from aerial imagery for predicting biomass, 2) compare vegetation indices (VI) from satellite and unmanned aerial vehicle (UAV) imagery for estimating N uptake and concentration, and 3) identify if integration of canopy cover fraction (CC) from UAV imagery integrated with VI from satellite imagery can improve N uptake prediction at early growth stages. To accomplish this, two large scale field trials during the 2019 crop growing season in Indiana were used for the study. Multispectral UAV (MicaSense Altum on DJI Matrice 200, 2-in resolution) and satellite imagery (Planet, 118-in) was acquired at early corn growth stages (ranging V3 to V5) prior to the sidedress application of fertilizer treatments. Imagery was post-processed in Pix4D and ArcGIS to calculate multiple VI and extract CC. Biomass samples were collected from pre-determined sampling areas to obtain plant height, dry matter weight, and calculate N uptake. Regression analysis determined the relationship between biomass, nitrogen uptake, plant height, and metrics derived from UAV and satellite imagery. The results suggest that the integration of satellite and UAV imagery derived metrics can be used to assess corn N status and identify N needs in a time efficient way.

MATERIALS AND METHODS

Field experiments were conducted in 2019 at the Pinney-Purdue Agricultural Center ("PPAC", 50 acres), near La Crosse, IN, and at an on-farm location ("Simpson", 60 acres), near Morristown, IN. Starter fertilizer was applied 2 inches below and 2 inches to the side of the seed at planting at a rate of 40 lb acre^{-1} N as 28-0-0 urea-ammonium-nitrate (UAN) at PPAC. Starter fertilizer was not used at Simpson, but 18 lb acre^{-1} N as 28-0-0 UAN was broadcast applied prior to planting.

Establishment of ground-truth sampling locations was determined based on multi-year NDVI zones to take into consideration the spatial variability of each field. A total of 96 and 54 sampling locations were randomly established at PPAC and Simpson respectively. Individual sampling locations were defined as two corn rows wide (60 inches) by 6.5 feet long.

Image acquisition, plant height measurements, and biomass harvest were conducted on the same date within each field, June 14 (growth stage V3-V4) at PPAC and June 26 (V4-V5) at Simpson. Biomass samples were sent to a commercial laboratory to be analyzed for N concentration. Nitrogen uptake was calculated as the product of biomass dry weight and N concentration. Multiple VI were calculated from both UAV and satellite imagery (Table 1), and canopy cover (CC) from UAV imagery only. Regression analysis determined the relationship between biomass, nitrogen uptake, plant height, and metrics derived from UAV and satellite imagery.

For this study, plant height was evaluated as a predictor variable for biomass and nitrogen uptake. Even though plant height was collected manually, it is also a metric that can be derived from UAV aerial imagery.

Table 1. Vegetation indices (VI), their formulas, and the researchers who first developed each VI evaluated.

VI	Index full name	Formula
VDVI	Visible-band Difference Vegetation Index	[(2G-B-R)/(2G+B+R)]
VIG	Vegetation Index Green	[(G-R)/(G+R)]
NDVI	Normalized Difference Vegetation Index	[(NIR-R)/(NIR+R)]
GNDVI	Green Normalized Difference Vegetation Index	[(NIR-G)/(NIR+G)]
OSAVI	Optimized Soil-Adjusted Vegetation Index	[(NIR-R)/(NIR+R+0.16)]

RESULTS

Tables 2 to 4 summarize the coefficient of determination (R^2) results from the linear regression analysis. The column name indicates the predictor variable(s) used to predict biomass (Table 1), N concentration and uptake (Table 2), and N uptake (Table 3). The higher the R^2 value, the better the regression formula predicted the variable. No data shown (-) indicates that regression model was not significant (P<0.10).

Table 2. Coefficient of determination (R^2) results derived from linear regression analysis between biomass dry weight and plant height, canopy cover fraction, and vegetation indices (VI).

Height	Canopy	VI		
			UAV	Satellite
PPAC				
0.71	0.53	VDVI	0.07	-
		VIG	0.11	-
		NDVI	0.54	0.05
		GNDVI	0.57	0.06
		OSAVI	0.49	0.05
Simpson				
0.92	0.88	VDVI	0.48	0.26
		VIG	0.67	0.33
		NDVI	0.73	0.52
		GNDVI	0.71	0.40
		OSAVI	0.79	0.52

Table 3. Coefficient of determination (R^2) results derived from linear regression analysis between N (concentration and uptake) and canopy and vegetation indices (VI).

	N concentration		N uptake	
	VI		VI	
	UAV	Satellite	UAV	Satellite
PPAC				
VDVI	0.17	-	0.25	-
VIG	0.19	-	0.22	0.13
NDVI	-	-	0.38	-
GNDVI	-	-	0.31	0.14
OSAVI	-	-	0.29	-
Simpson				
VDVI	0.02	-	0.23	0.28
VIG	0.17	-	0.64	0.38
NDVI	0.46	-	0.74	0.48
GNDVI	0.60	-	0.69	0.31
OSAVI	0.37	-	0.81	0.48

Table 4. Coefficient of determination (R^2) results derived from linear regression analysis between N uptake, canopy cover fraction, and vegetation indices (VI).

Canopy		VI + canopy	
		UAV	Satellite
PPAC			
0.57	VDVI	0.58	0.57
	VIG	0.60	0.59
	NDVI	0.58	0.59
	GNDVI	0.62	0.61
	OSAVI	0.60	0.59
Simpson			
0.87	VDVI	0.89	0.87
	VIG	0.87	0.88
	NDVI	0.90	0.88
	GNDVI	0.92	0.88
	OSAVI	0.92	0.88

CONCLUSIONS

- Differences among locations were likely related to differences in growth stage, with Simpson (V4-V5) resulting in models with greater R^2 values than PPAC (V3-V4).
- Although metrics derived from UAV (canopy cover and VI) at early vegetative growth stages were better indicators of biomass and N, satellite imagery may be a viable alternative at later growth stages when the crop canopy is more complete
- **Objective 1.** Plant height and canopy cover were the best predictors of biomass, followed by VI derived from UAV and satellite.
- **Objective 2:** VI are better indicators of N uptake than N concentration, with models based on VI from UAV resulting in greater R^2 values.
- **Objective 3:** Integration of canopy cover (from UAV imagery) and VI (from satellite imagery) into the N uptake regression model resulted in greater R^2 values than using only canopy cover. However, increase in R^2 was small, ranging from 0.01 up to 0.05.

NITROGEN FERTILIZER RATES AND NITRIFICATION INHIBITOR IMPACT ON AGRONOMIC AND ECONOMIC RETURNS IN CORN PRODUCTION IN KANSAS

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ABSTRACT

Nitrogen (N) is an essential nutrient for corn crops. Nitrification inhibitors (NI) aim to increase yields, promote Nitrogen Use Efficiency (NUE), and reduce N losses. This study was carried out in ten site-years in Kansas from 2017-2021 crop seasons, with the objectives of evaluating and comparing the agronomic and economic optimum N rates (AONR, EONR), N uptake in the grains, N agronomic efficiency (NAE) and maximum return to N (MRTN) in corn production with and without the use of NI. Nitrogen fertilizer at the rates of 100, 150 and 200 lbs. N a^{-1} using anhydrous ammonia (AA) as source was applied to the soil with and without the combination of NI (nitrapyrin) in the spring, also a treatment with 0 lbs. N a^{-1} without NI was used as control. AONR and EONR values were lower with the use of NI, higher N grain uptake was obtained when 150 lbs. N a^{-1} was applied with NI combination, and nitrification inhibitor contributes to obtaining a higher average net return to nitrogen fertilizer over multiple site-years.

INTRODUCTION

Nitrogen (N) fertilizer application is necessary to maximize corn yield; however, it is difficult to precisely supply enough N to meet crop requirements while also controlling the risk of N losses to the environment (Cassman and Doberman, 2022). While N rates lower than the optimum will increase the risk of lower yields, N rates above the optimum will cost more, may not offer additional yield, and could be lost (Kranz, 2015). The agronomic optimum N rate (AONR) represents the amount of fertilizer N required to maximize yield, but not necessarily profit (Camberato et al., 2021), the economic optimum N rate (EONR) is defined as the N rate that makes the most effective use of N on a monetary basis, being dependent to the economic environment (Oglesby et al., 2022). Both AONR and EONR are terms used to develop N rate recommendations based on data-driven on-field trials, aiming to increase nitrogen use efficiency.

The return to N (RTN) represents the profit obtained from N at each N rate, the maximum return to N (MRTN) is the highest yield increase from adding N just paid for the N added (Fernandez et al., 2012).

Nitrogen use efficiency (NUE) is defined as the ratio of the crop nitrogen uptake to the total input of N fertilizer (NRCS/USDA, 2007). Increasing N rates are often associated with progressively lower corn NUE values (Ciampitti and Vyn, 2011). A management practice option to reduce N losses during crop production and increase the NUE is using nitrification inhibitors (Omonode and Vyn, 2013). Nitrogm inhibitors are substances developed to reduce the process of nitrification and keep N available for plant uptake for a longer time, especially during the highest crop demands (Corrochano-Monsalve et al., 2021). The objectives of this study were to evaluate and compare the agronomic and economic optimum N rates (AONR, EONR), N uptake from the grains, N agronomic efficiency (NAE) and maximum return to N (MRTN) in corn production with and without the use of nitrification inhibitor under field conditions in Kansas.

MATERIALS AND METHODS

Field studies were conducted from 2017 to 2021 crop growing seasons in 10 site-years in Kansas (Table 1). Nitrogen fertilizer at the rates of 100, 150 and 200 lbs. N a^{-1} using anhydrous ammonia (AA) was applied to the soil with and without the combination of a nitrification inhibitor (nitrapyrin – N Serve®) in the spring. A control treatment was included with no N application. The experimental design was a randomized complete block with four replications. Soil composite samples were collected using hand probes by block at 0-6 and 0-24 in depths before planting.

Plant and grain samples were collected from six plants from middle rows when corn reached R6 maturity growth stage; samples were dried at 140°F (60°C) and ground to 2 mm. N content in the plant and grain was determined through dry combustion. Yields were determined by harvesting the two middle rows from each plot and correcting grain moisture to 15.5%. Nitrogen Agronomic Efficiency (NAE) was calculated as:

$$NAE = \frac{(Y_N - Y_{0N})}{F}$$

Where Y_N represents the grain yield (lbs. a^{-1}) obtained from the N fertilized plots, Y_{0N} represents grain yield (lbs. a^{-1}) obtained from the plots with 0 lbs. N a^{-1}, and F represents the amount of N fertilizer applied (lbs. N a^{-1}).

Analysis of variance (ANOVA) using function lmer from lme4 package and pairwise comparisons using function cld from multcomp package at $\alpha < 0.05$ was performed using the RStudio 2023.09.1+494 software version.

To determine the agronomic and economic optimum rates, quadratic regressions were performed. To determine economic parameters corn price of \$4.95 bu^{-1}, nitrogen price of \$400 ton^{-1} of anhydrous ammonia and nitrogen inhibitor price of \$0.038 lbs^{-1}. per each lb. of nitrogen fertilizer were used.

RESULTS AND DISCUSSION

Corn Grain Yield

Corn grain yield was affected by the nitrogen rates, obtaining higher yields with the higher rates. The AONR value obtained with the use of the inhibitor (156 lbs. N a^{-1}) was lower than the obtained without the use of the inhibitor (170 lbs. N a^{-1}). Also, EONR value with the inhibitor (138 lbs. N a^{-1}) was lower than that obtained without using the inhibitor (149 lbs. N a^{-1}). Results indicate that using the nitrification inhibitor corn grain yield could reach an agronomic and economic maximum using less amount of N fertilizer.

Nitrogen Agronomic Efficiency and Corn Nitrogen Uptake

Grain nitrogen uptake shows similar results to the obtained with the grain yield, at the rate of 150 lbs. N a^{-1} uptake increases significantly with the use of the inhibitor (Figure 2). The nitrogen agronomic efficiency decreases with higher N rates. At the rate of 150 lbs. Numerical advantages, but not significant, were observed with the inhibitor at the rates of

100 and 150 lbs. N a^{-1}, at the rate of 200 lbs. N $a^{-1,}$ there was no difference with or without the use of the inhibitor, suggesting that the potential effectiveness of the product might disappear with higher N rates (Figure 3).

Maximum Return to Nitrogen

The maximum return to nitrogen was affected by corn-to-nitrogen price ratios with the nitrification inhibitor (Figure 4). The use of the inhibitor contributes to obtaining a higher average net return to nitrogen fertilizer over multiple site-years.

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Table 1. Experimental locations, soil type, pH, organic matter, and mineral nitrogen before planting and treatment application.

Site-year	County	Soil	Texture	Planting Date	0-6 in		0-24 in	
					pH	OM	NO_3^-	NH_4^+
						%	lbs. a^{-1}	
1	Riley	Smolan	Silt Loam	4/24/17	7.3	1.8	22.6	55.8
2	Republic	Hastings	Silty Clay Loam	4/25/17	5.8	3.3	31.3	50.2
3	Riley	Smolan	Silt Loam	4/28/18	8.0	1.9	105.2	44.0
4	Shawnee	Eudora	Silt Loam	5/07/18	6.9	1.4	16.8	-
5	Riley	Smolan	Silt Loam	5/25/19	5.7	1.6	43.0	12.0
6	Shawnee	Eudora	Silt Loam	4/25/19	6.6	1.5	13.2	11.6
7	Riley	Belvue	Silt Loam	4/30/20	6.5	2.2	15.5	28.0
8	Shawnee	Eudora	Silt Loam	4/23/20	6.4	1.3	30.4	29.6
9	Riley	Belvue	Silt Loam	4/28/21	5.9	1.7	29.5	35.9
10	Shawnee	Eudora	Silt Loam	4/29/21	7.5	2.1	29.3	36.2

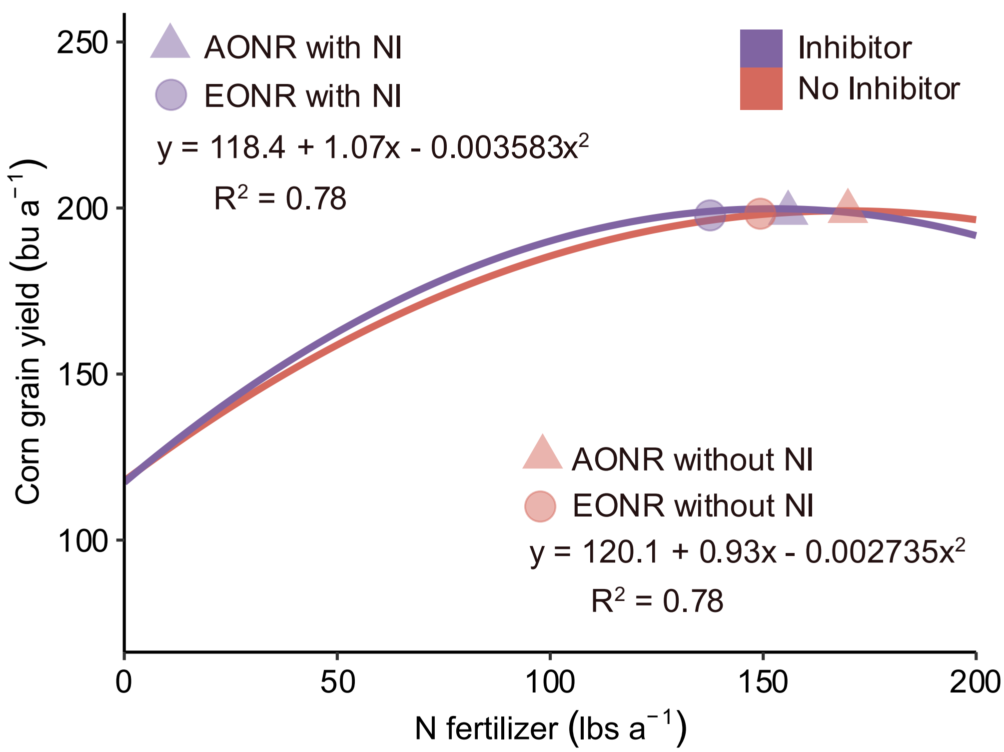

Figure 1. Agronomic optimum nitrogen rate (AONR) and economic optimum nitrogen rate (EONR) with and without nitrification inhibitor. EONR at 13 corn:N price ratio (\$4.95 bu^{-1} corn : \$0.38 lb^{-1} N) without inhibitor, and at 11.84 corn:N price ratio (\$4.95 bu^{-1} corn : \$0.38 lb^{-1} N + \$0.038 NI) with inhibitor.

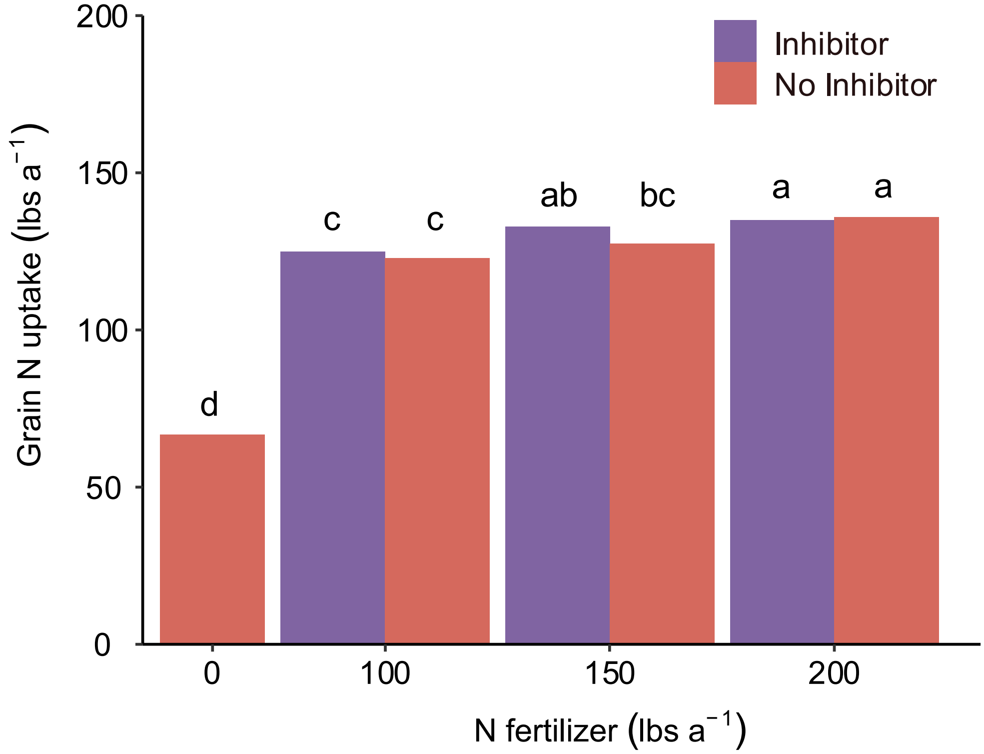

Figure 2. Corn grain N uptake as affected by nitrogen rates and nitrification inhibitor. Means followed by different lowercase letters indicate significant differences ($\alpha = 0.05$).

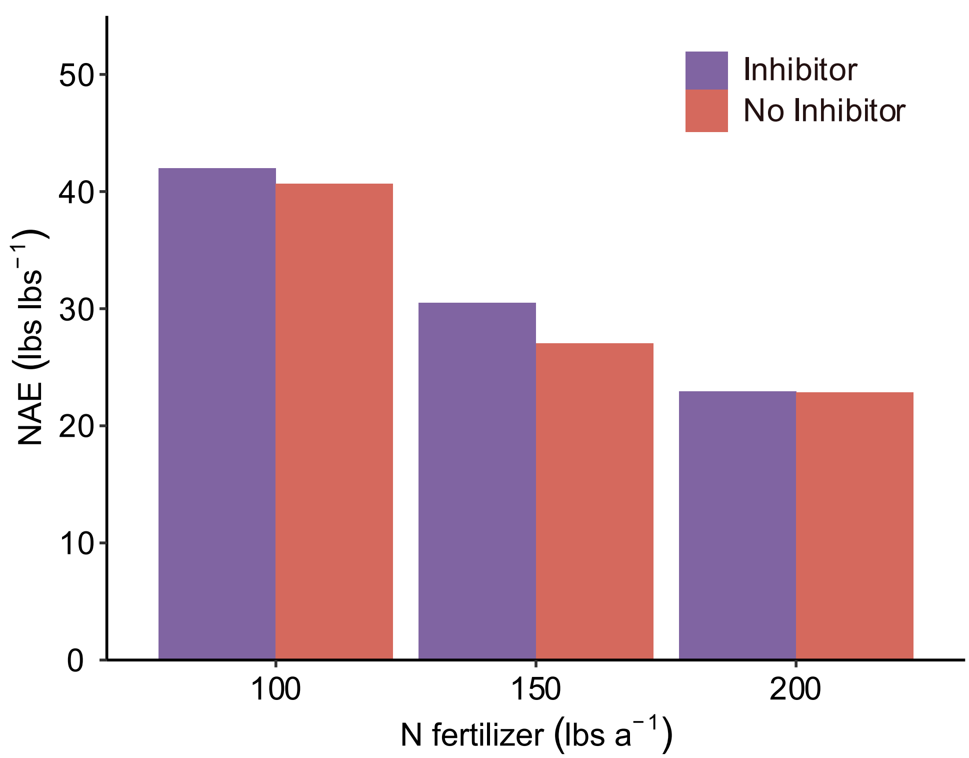

Figure 3. Nitrogen agronomic efficiency (NAE) as affected by nitrogen rates and nitrification inhibitor.

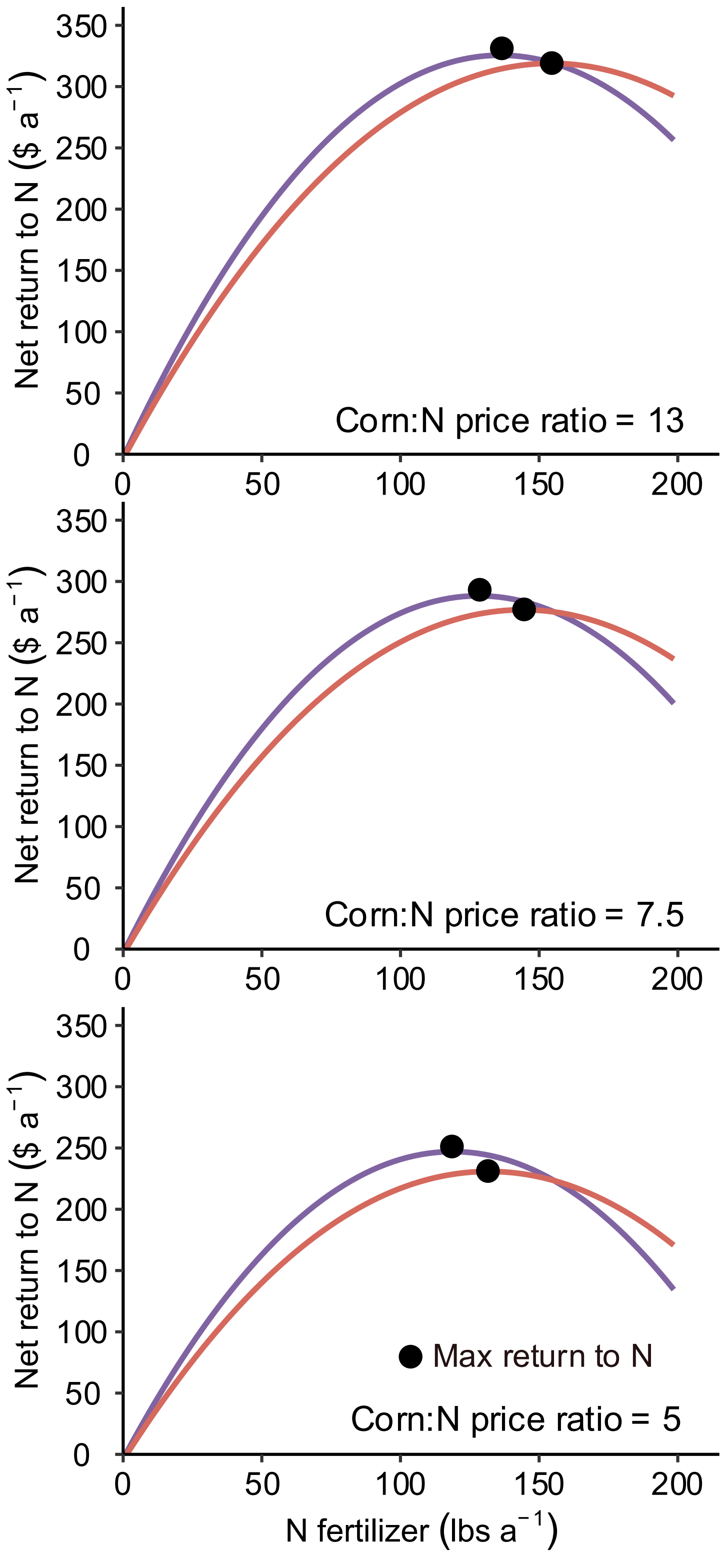

Figure 4. Net return to nitrogen fertilizer under different corn to nitrogen price ratios with and without the use of the nitrification inhibitor.

COMPARISON OF WHEAT AND BARLEY TO RYE AS A COVER CROP FOR MAIZE

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ABSTRACT

Winter cereal cover crops have become an essential management practice for sustainable corn production. Rye (*Secale cereale* L.) is the most popular winter cereal cover crop, but wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) may provide a comparable value due to their similar fibrous root systems. Winter cereals provide organic matter, scavenge residual nutrients, and protect the soil from erosion. Winter cereals can immobilize nutrients for the corn crop and can reduce corn stands in some situations, reducing corn yield. This study's main objective was to determine if wheat and barley cover crops have fewer corn yield penalties than rye. Three site-years included Lexington, KY, 2022, Lexington 2023, and Glendale, KY, 2023. The study consisted of four cover crop treatments, five nitrogen rates, and two nitrogen timings. The cover crop treatments were 'Somerset' barley, 'Pembroke' wheat, 'Aventino' rye, and a no cover crop control. Five nitrogen rates were 40, 110, 210, 310, and 410 lb N/acre. Liquid UAN (32-0-0) was surface applied at 40 lb N/acre to all plots at planting; the remaining nitrogen was applied at planting or side dress (V3 growth stage) as Urea (46-0-0). Cover crop biomass accumulation in 2022 was a fraction of the 2023 biomass resulting from a longer growing period. Wheat produced significantly more biomass than rye in Lexington 2023 and the most average biomass in all site-years. Barley produced the least biomass of the winter cereals. There were no significant N or P interactions from the 2022 VT ear leaf tissue sample analysis. There was no significant effect from cover crops on yield in 2022. Sidedress N at 310 lb N/acre yielded significantly higher than 210 lb N/acre applied all at-planting but there were no effects of fertilization timing at the same N rate. 2023 yield data will be presented at conference.

INTRODUCTION

Cereal rye is the most popular cover crop utilized by farmers before corn in the United States. A 2022-2023 SARE survey of 575 cover crop growers found that of those growers 134,000 acres of cereal rye cover crops were planted with the next closest cover being radishes with around 43,000 acres (SARE, 2023). There are numerous benefits associated with a rye cover crop such as reduced nitrate runoff (Kaspar et al, 2012), weed suppression (Haramoto, 2019), and erosion control (Kaspar et al, 2001) in both the fall and spring since rye will not winterkill. The erosion benefits of a winter cereal are especially important since 75% of all farmlands in Kentucky have significant erosion potential (Wells, 1982). Rye unfortunately has some potential drawbacks that could affect the subsequent corn crop. A prior study in Kentucky found that a late terminated rye cover crop could reduce plant stand by as much as 35% and decrease yield by up to 24% (Quinn, 2021). The risk of a yield penalty associated with winter cereals can be diminished with an earlier cover crop termination, but the risk is still present (Otte et al., 2019). Wheat and barley are other winter cereals with similar fibrous roots systems as rye. Wheat already performs well in Kentucky when cultivated for grain and barley is a new addition to current rotations. The potential drawback persists beyond rye since winter cereals such as wheat have the potential to decrease corn yields (Kaspar & Bakker, 2015). Splitting nitrogen fertilizer applications to later in vegetative corn growth stages could potentially alleviate potential yield penalties from winter cereals. Sidedress nitrogen can improve corn yields regardless of cover crop (Quinn, 2020). The objective of this study was to compare wheat and barley to rye as cover crops to see if they provide comparable benefits for the subsequent corn crop.

METHODS AND MATERIALS

Study Site and Dates

This experiment was conducted at the University of Kentucky North Farm in Lexington and an on-farm site in Glendale, Kentucky for a total of Three-site years including: Lexington 2022, Lexington 2023, and Glendale 2023. The soil textures for Lexington 2022/2023 were predominately a Lowell-Bluegrass Slit Loam, Glendale 2023 was mainly a Pembroke Silt Loam. Soil cores were collected at a 6-in depth at cover crop termination and after harvest to quantify soil nutrient contents. Soil samples were analyzed at the University of Kentucky Regulatory Services using Mehlich 3 extractant. Table 1 details important planting and termination dates from the study. Wet field conditions in the fall of 2022 delayed cover crop planting until December and a wet spring delayed Glendale corn planting until May 31st. Lexington 2023 corn was initially planted May 11th but pest pressure in the cover crop residues severely decreased plant stands requiring replanting. Replant occurred on June the 1, 2023 6 weeks post cover crop termination.

Table 1: Cover Crop/Corn Planting & Cover Crop Termination

Site-Year	Cover Crop Planting	Cover Crop Termination	Corn Planting
Lexington 2022	12/4/2021	4/27/2022	5/11/2022
Lexington 2022	10/24/2022	4/20/2023	6/1/2023*
Glendale 2023	10/20/2022	4/19/2023	5/31/2023

***Corn was replanted because pests destroyed the first planting. The replanting occurred 6 weeks after termination.

Experimental Design

The Lexington research design was a split-plot, randomized complete block with 3 replications. There were 4 cover crop treatments planted in the fall following a soybean crop, which is a regular rotation in Kentucky. The cover crop treatments include ‘Somerset’ barley, ‘Pembroke’ wheat, ‘Aventino’ rye, and a no cover crop control. In the spring, two weeks before targeted corn planting, cover crops were terminated with 40 oz/ac of glyphosate (Round-up Brand). Cover crop biomass at each site was collected within a day of the termination timing. Once the corn was planted, the study implemented two fertilization timings with five nitrogen treatments. All plots received 40 pounds of urea ammonium nitrate (32-0-0) per acre at planting. Both nitrogen timings used the same 40 lb/acre control. The five nitrogen rates of 0, 70, 170, 270, and 370 lb/acre were applied at planting or sidedress at the V3 growth stage with urea (46-0-0) surface broadcast by hand. Total N applied was 40, 110, 210, 310, and 410 lb N/acre. Glendale 2023 was arranged as a factorial design with all the same treatments but with the addition of 2 sulfur treatments and was replicated 3 times. The 2 sulfur treatments were 30 lb S/acre applied as gypsum (0-0-0-16) and a no-sulfur control applied to each nitrogen rate/timing. In Lexington, in both site years, drip irrigation was installed at the V6 growth stage to limit drought stress. At the V10 and VT growth stages, 5 SPAD readings per plot were collected to assess chlorophyll content. The highest developed leaf was used at V10, and the ear leaf at VT. Also, at VT 5 ear leaves per plot were collected for nutrient analysis. Pest presence was evaluated weekly throughout the corn growing season, and pesticides were applied as needed to eliminate any effect on corn. Lexington 2022 corn was harvested with a Wintersteiger Delta combine with a 2-row Geringhoff corn head and Juniper Weighing Systems HarvestMaster weigh bucket on October 3, 2022. Data were analyzed with an ANOVA linear mixed effect model lme4 in R. Cover crop, Nitrogen Timing, Nitrogen Rate, and Sulfur Rate were the fixed effects, and replication was the random effect. Locations were analyzed separately to account for environmental and irrigation differences.

RESULTS AND DISCUSSION

Cover Crop Biomass

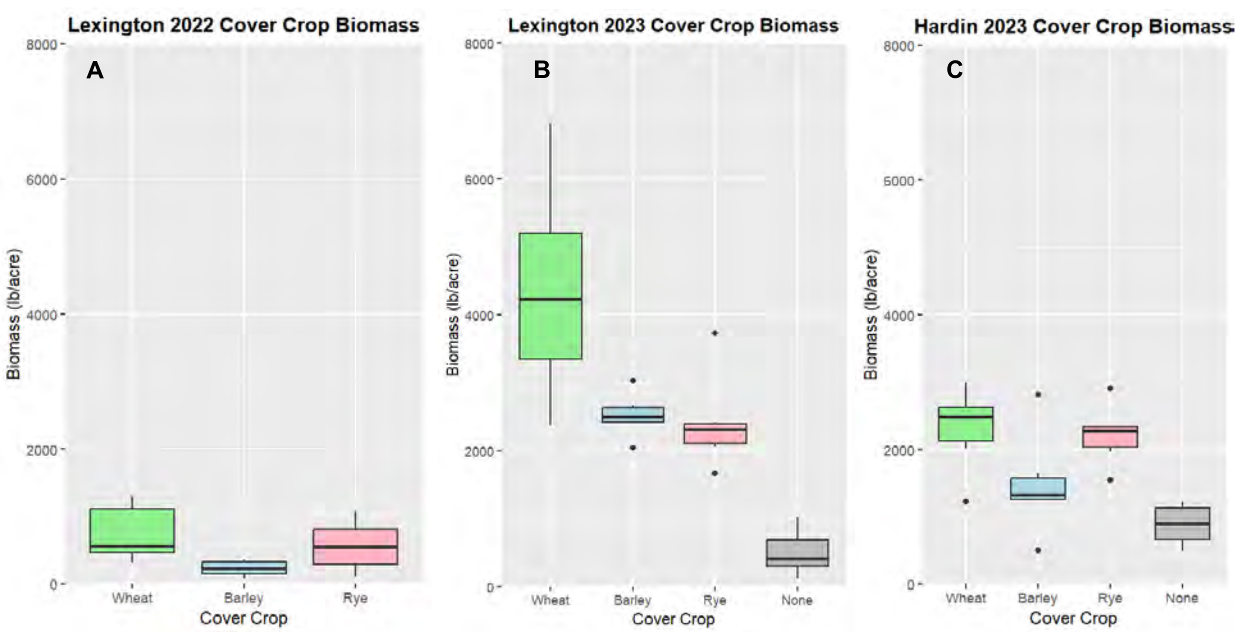


Figure 1: Average Cover Crop Biomass In Pounds Per Acre In Each Site-Year
There were significant cover crop biomass effects in every site-year. Lexington 2022 (A) had very little biomass accumulation compared to other site-years (B, C) due to a delayed cover crop planting. Even with low biomass production, wheat produced significantly more biomass than barley but not more than rye. Lexington 2023 had a more "normal" growing season, with biomass growth and ground cover in fall and spring—wheat produced significantly more biomass than all other cover crop

treatments. Barley and rye produced the same biomass level but still significantly more than the no-cover crop control. Glendale 2023 had similar planting/termination dates as Lexington 2023 but produced different rates of biomass. Wheat and rye produced more biomass than barley and fallow. Barley and fallow biomass were not significantly different from each other.

VT Tissue Sample (Lexington 2022)

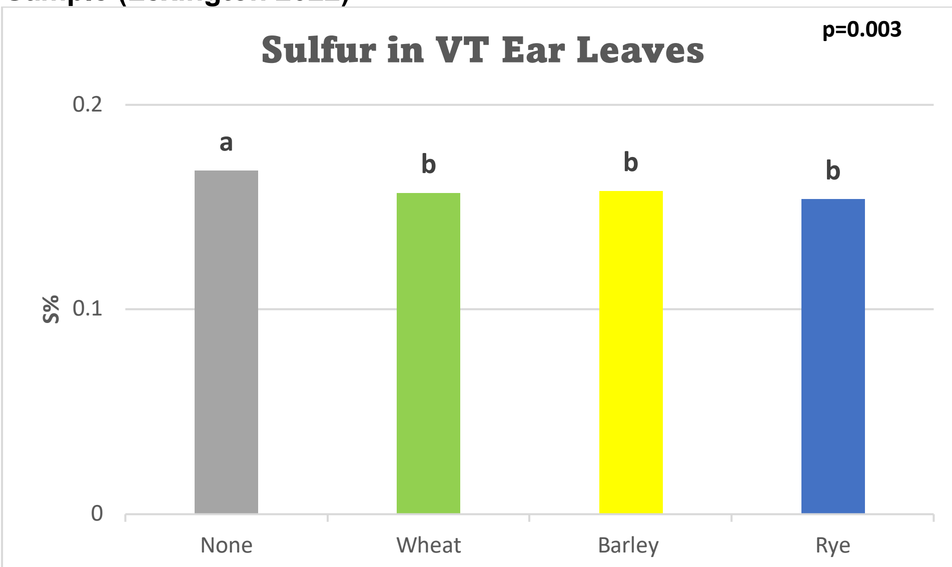


Figure 2: Cover Crop Effect on Sulfur Content in Ear Leaves at the VT Corn Growth Stage. Different letters are significant different at P≤0.1

Wheat, barley, and rye cover crops resulted in roughly 9% less S on VT corn ear leaves than the no cover crop control. There was no cover crop effect on any other primary/secondary macronutrients analyzed.

Corn Yield (Lexington 2022)

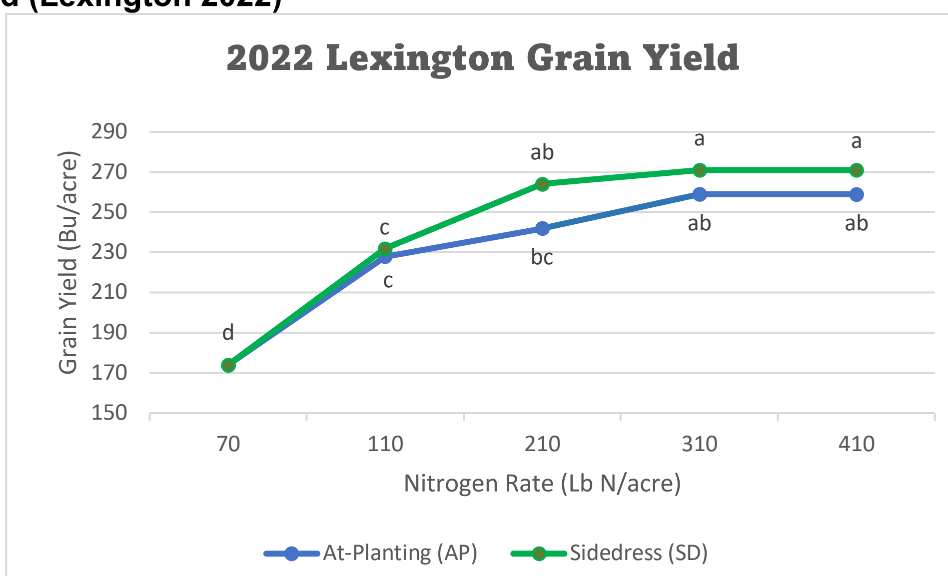
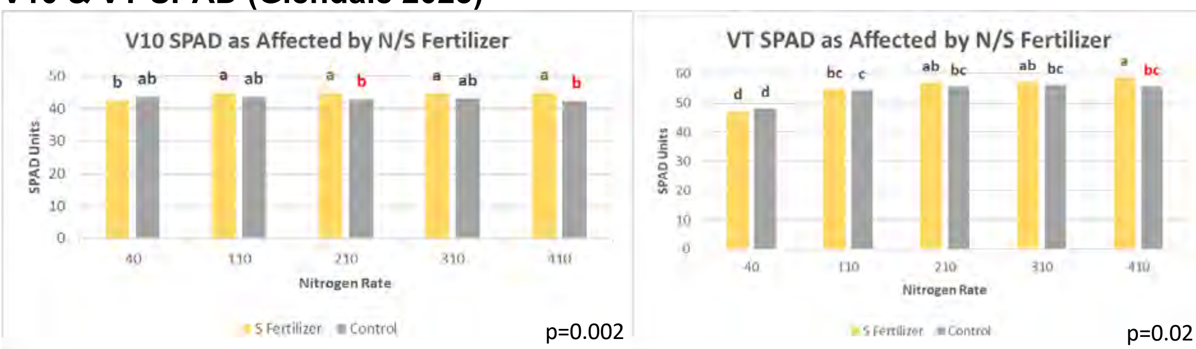


Figure 3: Line Graph of Corn Yields Averaged Across Cover Crops Response to Timing X Nitrogen Rate, Lexington, KY. Different letters are significant different at P≤0.1

The main significant interaction was Timing X Nitrogen Rate. There was no effect from cover crop on yield and all cover crop treatments only varied by 5 bu/acre. Corn treated with 40 and 110 lb N/acre yielded significantly less than corn at the higher nitrogen rates (Figure 3). Sidedress N rates trended higher yields than the At-Planting timings but were not significantly different at the same N rate. Sidedress N at 310 lb N/acre (40 At-planting + 270 at Sidedress) yielded significantly higher than 210 lb N/acre applied all at-planting

V10 & VT SPAD (Glendale 2023)



Figures 5-6: Effect of Sulfur Fertilizer on SPAD Readings at the V10 and VT Corn Growth Stage Across Nitrogen Rates. Different letters are significant different at P≤0.1

A significant interaction was found in Glendale 2023 from the sulfur fertilizer treatments. Sulfur treatments with 210 and 410 total N applied at V10 had significantly higher SPAD readings than the no-sulfur control. The 110 and 310 total N with a sulfur treatment had higher average SPAD readings by approximately 2 SPAD units but this difference was not significant. At the VT growth stage only the highest N rate+sulfur had a significantly higher SPAD than the control. Future analysis of VT ear leaf tissue samples will further investigate these differences.

ACKNOWLEDGMENTS

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DOES NITROGEN MANAGEMENT IN WINTER WHEAT AFFECT ITS YIELD AND NITRATE-N LEACHING IN A WHEAT-SOYBEAN DOUBLE CROPPING SYSTEM?

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ABSTRACT

Conventional corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation contributes to nitrate-N and phosphate leaching to waterbodies causing water quality concerns. Two strategies that could minimize N and P losses include (i) incorporating winter rye (*Secale cereale* L.) (WR) as a cover crop to capture residual nutrients or (ii) intensifying the corn-soybean rotation with winter wheat (WW) (*Triticum aestivum* L.) (Double cropping). Double cropping WW at a right N management could increase farm profit and provide incentives for adoption as well. A trial was established at two sites (Carbondale, and Belleville, IL) to evaluate soybean and overall cash crop performance along with nitrate-N and phosphate losses in a single season [soybean following a no-cover crop control vs. WR as compared to three double cropping scenarios (low, medium, and high intensity N management of WW prior to soybean). The results indicated that double cropping decreased soybean yield regardless of N management intensity during the previous WW. Nitrogen addition to WW resulted in increased nitrate-N leaching during the WW phase but, at medium and high N intensity scenarios, decreased the nitrate-N leaching during the following soybean phase and overall WW-soybean growing seasons suggesting double cropping could minimize N losses and provide farm profit.

INTRODUCTION

Nitrate loss in row crop agriculture remains a global concern due to its impact on the environment. To this effect, the Illinois Nutrient Reduction Strategy has set a goal to reduce nitrate-N leaching by up to 15% by 2025 (IEPA, IDOA, and University of Illinois Extension, 2015). Planting cover crops (CCs) including cereal rye (CR; *Secale cereale* L.) has been recommended as the most effective strategy to manage nitrate-N leaching. However, growers are reluctant to plant cover crops such as cereal rye in corn (C; *Zea mays* L.)-soybean (S; *Glycine max* L.) rotation. Double cropping corn-wheat (W; *Triticum aestivum* L.)-soybean, however, is fairly common in Southern Illinois. While the economic potential of double cropping wheat and soybean is well established (Tsiboe *et al*., 2017), literature is limited on the effects of N and P loss during wheat and soybean growing seasons at different N management intensities during wheat production season. Therefore, our objective was to evaluate the effect of N management during the wheat growing season to find best N management for reducing nitrate-N and phosphate leaching in a wheat-soybean rotation as compared to a no-cover crop or a cereal rye-soybean rotation.

MATERIALS AND METHODS

Experimental Site, Design, and Treatments

The study was laid out in a Randomized Complete Block Design (RCBD) with four replicates at the Agronomy Research Center (ARC), Carbondale, and Belleville Research Center (BRC), Belleville. The eight treatments, applied at the same time were (1) corn-soybean rotation with no-CC (control), (2) corn-rye-soybean-rye rotation (maximum nitrate-N reduction control), (3) corn-wheat (medium input)-soybean-no-CC, (4) corn-wheat (low input)-soybean-no-CC, (5) corn-wheat (high input; NREC growers suggestions)-soybean-no-CC, (6) corn-wheat (medium input)-soybean-rye CC, (7) corn-wheat (low input)-soybean-rye CC, and (8) corn-wheat (high input; NREC growers suggestions)-soybean-rye CC.

Winter Wheat, Soybean, and Cereal Rye Establishment

A no-till drill was used to plant wheat (var. AgriMaxx 495) and CR (var. SoilFirst) at 2 million seeds ac^{-1} and 78 lbs ac^{-1}, respectively in October 2021. Cereal rye was terminated in May 2022 while wheat was harvested in June 2022. Soybeans (var. Asgrow 47xF0) were planted after the termination of cereal rye and harvesting of wheat in May (single season) and June 2022 (double crop). Soybean was harvested and cereal rye was planted on October 2022.

Nitrogen Management for Wheat

The low input treatments (4 and 7) were subjected to a nitrogen (N) application regimen, wherein 40 lbs of N ac^{-1} was applied in the form of Urea Ammonium Nitrate (UAN) both at the tillering stage and during the jointing stage. In contrast, the medium input treatments (3 and 6) received a total of 70 lbs of N ac^{-1} in the form of UAN, with applications taking place at the tillering and jointing stages. Conversely, the high input treatments (2 and 5) followed a distinct N application strategy. These treatments involved the application of 27 lbs of N ac^{-1} in the form of Diammonium Phosphate (DAP) during the fall season, in addition to 70 lbs of N ac^{-1} in the form of UAN, administered at both the tillering and jointing stages. Therefore, the total N applied for treatments 2,3, 5, and 6 was 167 lbs N ac^{-1}.

Data Collection

Prior to crop termination, 7.25 ft^2 per plot were harvested with grass shears at 2 inches above the ground surface. Plant heights (from the ground to the top of the canopy) were measured with a yardstick. At each site, a GreenSeeker Handheld Crop Sensor HCS 100 (Trimble Ltd., Sunnyvale, CA) was used to measure the canopy reflectance and NDVI for each crop by passing it over the two center rows for the full length of each plot. An AccuPAR (LP–80; METER Group, Pullman, USA) ceptometer was used to calculate the LAI from above and below canopy photosynthetically active radiation (PAR) measurements.

Nitrate-N and Phosphorous Leaching Measurement
Resin lysimeters were meticulously positioned within each experimental plot to facilitate the direct measurement of nitrogen (N) fluxes. These lysimeters consisted of a combination of cation and anion exchange resins interposed between Nitex R nylon cloth and sand layers, all enclosed within polyvinyl chloride tubes measuring 6 centimeters in diameter. The deployment of these lysimeters spanned the entire duration of the cash crop growing seasons and continued through the subsequent cover crop growth, thus enabling the comprehensive year-round monitoring of N losses. Each individual lysimeter was carefully situated at a depth of 20 inches within the respective plot, ensuring that it maintained undisturbed contact with the soil profile. Following the harvest of the cash crops, each resin lysimeter was collected for subsequent analysis of nitrate-N and phosphorous concentrations.

RESULTS

The wheat biomass and grain yield did not exhibit significant differences across the various treatments at both research sites (Figure 1). Similarly, the measurements of nitrate-N and phosphorous leaching in each treatment plot were comparable to those in the no-cover crop plot, with no significant differences noted (Figure 2).

The soybean grain yield from the double crop treatment significantly differed from that of the no-cover crop treatment, with the latter yielding higher results compared to both the double crop and winter rye treatments. However, there was no significant disparity in grain yield between the no-cover crop and winter rye treatments (Figure 3).

Significant distinctions emerged in the nitrate-N leaching when comparing the double crop with the single-season approach. Nitrate-N leaching levels were lower in the double crop treatment compared to the no-cover crop and winter rye treatments. However, there were no significant differences in phosphorous leaching measurements. The yield-scaled leaching potential exhibited a similar trend to nitrate-N leaching (depicted in Figure 3).

The cumulative nitrate-N and phosphorous leaching in both wheat and soybean crops did not reveal significant differences when subjected to a one-way analysis of variance (ANOVA). Nonetheless, contrast analysis indicated that the medium and high input treatments, as well as winter rye, exhibited similarity in leaching patterns, which were lower than those in the low input treatment and no-cover crop (Figure 4).

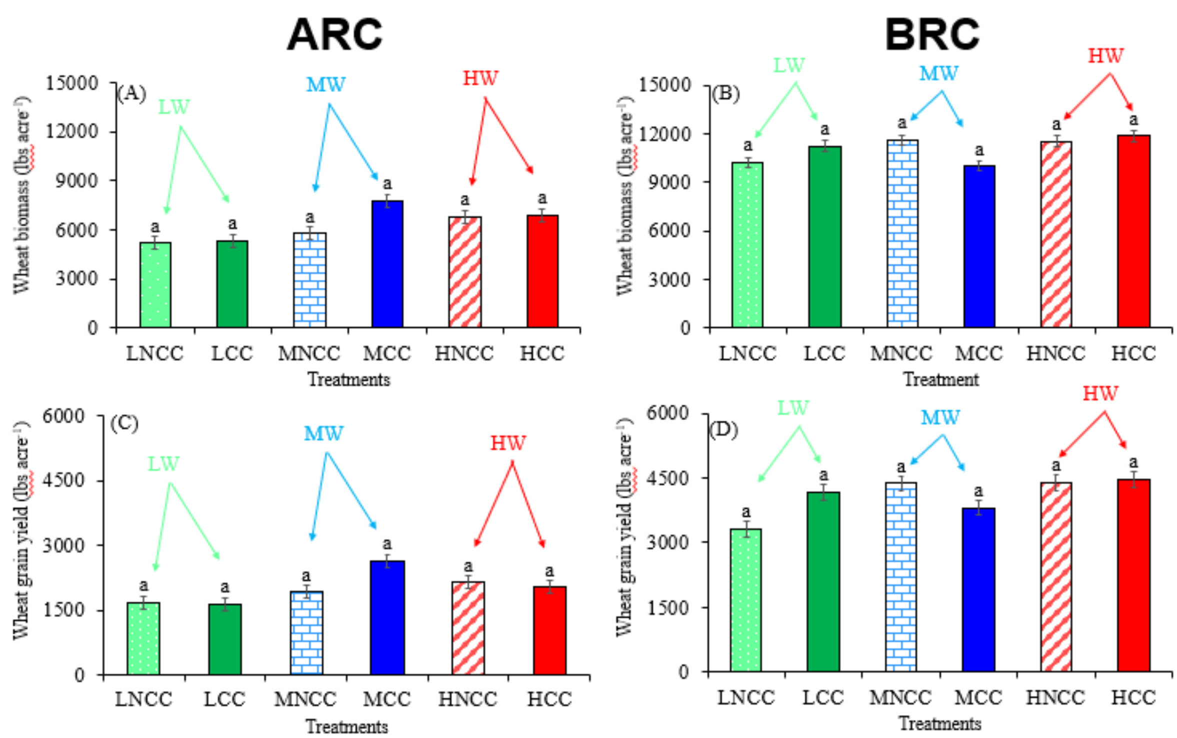

Fig. 1. Response of winter wheat biomass (A-B) and grain yield (C-D) to different N fertility management intensities and crop rotation. Error bars are standard errors. LNCC = low N rate with no cover crop; LCC = low N rate with CC; MNCC = medium N management with no cover crop; MCC = medium N management with CC = HNCC: high N management with no cover crop; HCC = High N management with CC.

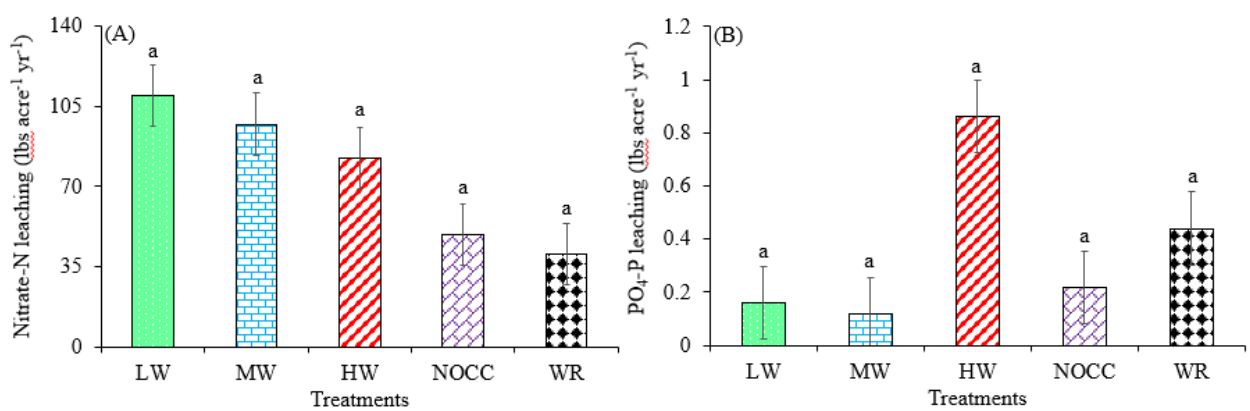

Fig. 2. Effect of treatments on nitrate-N leaching potential (A), and P-leaching potential (B) in wheat growing season at the BRC site.

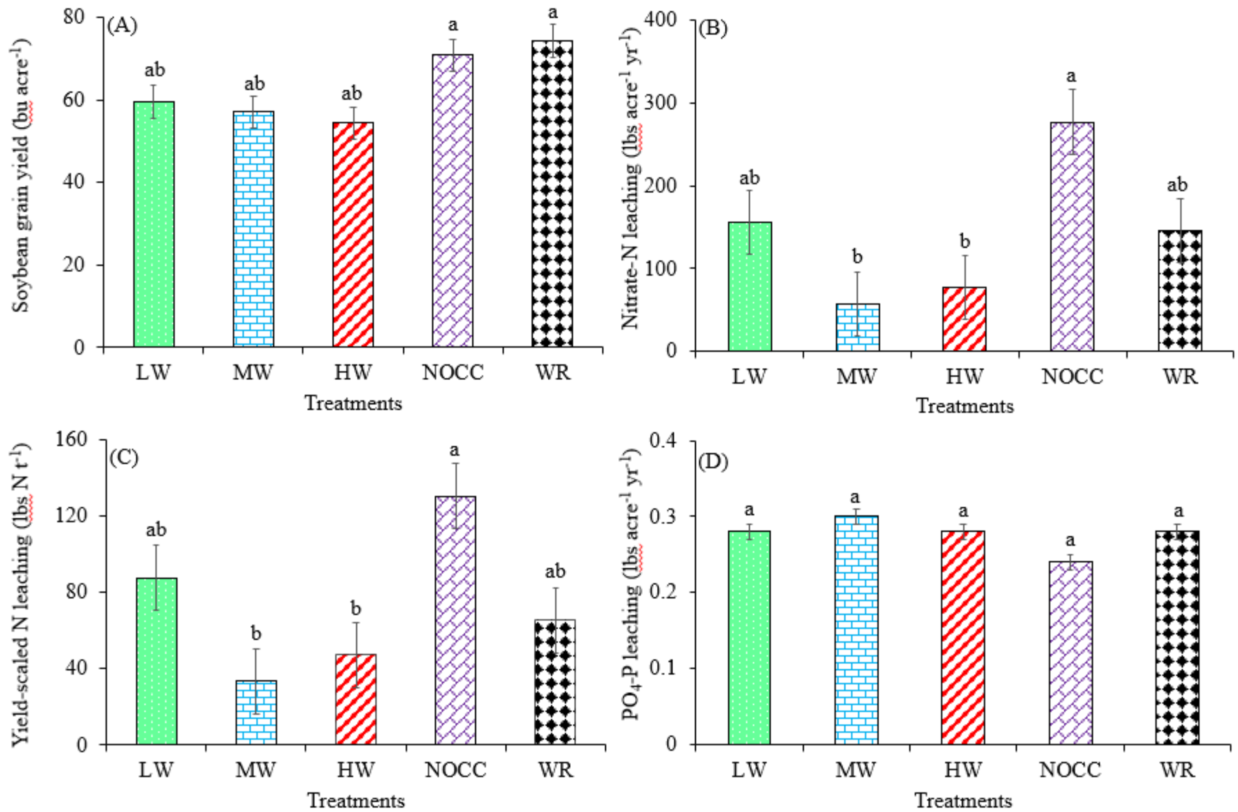

Fig. 3. Effect of treatments on yield (A), nitrate-N leaching potential (B), yield-scaled N leaching potential (C), and P-leaching potential (D) in soybean at the BRC site.

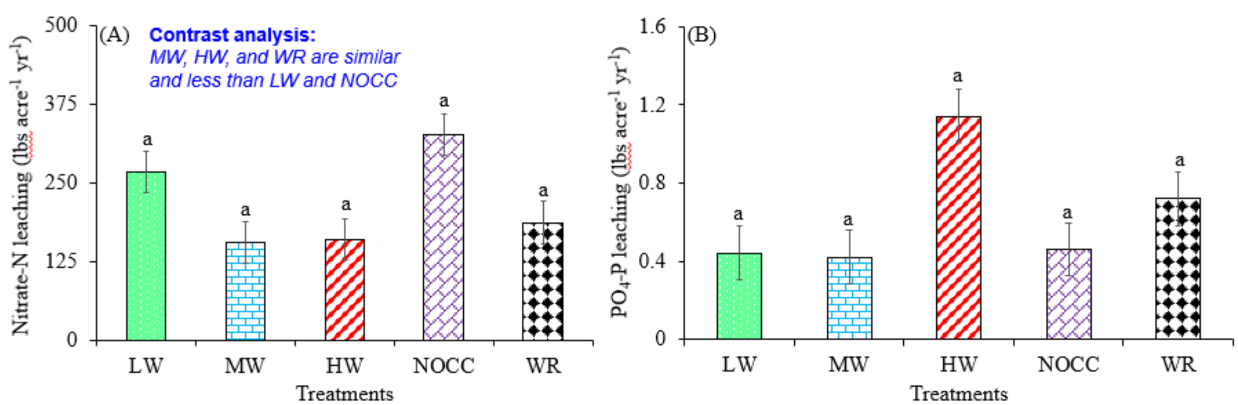

Fig. 4. Effect of treatments on cumulative nitrate-N (A) and PO_4-P (B) leaching potential in wheat and soybean at BRC site.

PRELIMINARY CONCLUSION

Low N intensity management during the wheat phase resulted in almost 30% less wheat biomass at ARC and BRC. Grain yield for wheat followed its biomass trend with medium and high intensity N management resulting in higher grain yields. Nitrate-N leaching during the soybean year was higher in the no-CC treatment indicating wheat or CR prior to soybean resulted in nitrate-N leaching reduction. Cumulative nitrate-N leaching indicated nitrate-N loss was decreased by double cropping compared to a no-cover crop control.

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EMPLOYING STATISTICAL MODELS TO DETERMINE THE SOIL TESTS AND/OR SOIL CHARACTERISTICS THAT IMPROVED EONR PREDICTION IN CORN

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ABSTRACT

In corn production, nitrogen (N) fertilization is crucial for increasing yield. However, in the last few years, there has been a push to use less N due to environmental concerns and production costs. There has been an interest in using soil health tests to predict N mineralization potential and further understand soil N availability to adjust N recommendation rates. Different statistical models like regression or decision tree analysis have been used to determine how the Economic Optimum N Rate (EONR) can be predicted using only soil test results and/or combining them with soil characteristics. The objective of this study was to evaluate statistical models to identify which soil test and/or soil characteristics predict the EONR for corn in Wisconsin. In total, 23 N response trials were conducted in 2019 and 2020. Samples from 0-15 cm depth were taken at planting from the no N treatments. A total of six soil tests were conducted: total organic carbon (TOC), total carbon (TC), active carbon, soil respiration, ammonium content (NH_4) at 0 and 7 days, and mineralizable N (PMN). EONR and yield were determined for each site. Regression and decision tree analyses were evaluated to predict EONR. The results identified NH_4 and active carbon as soil tests that can predict EONR in corn. Ammonium proved useful for detecting non or minimally responsive sites (mean 11.6 lb. N acre^{-1}), while active carbon was valuable for predicting EONR at responsive sites. The segmented, the decision tree, and multiple stepwise regression models performed similarly when evaluating actual vs. predicted EONR, with an average R^2= 0.7242. These diverse statistical analyses highlight the potential to assess optimal sidedress N rates for corn production, including identifying minimally or non-responsive sites.

INTRODUCTION

In corn production, for farmers, it is important to decrease nitrogen (N) use to maintain economic profit and avoid leaching and environment contamination. Better prediction of the potential N mineralization in the soil is key to understanding soil N availability. Recently, there has been an increase in interest in using soil health tests to potentially predict N mineralization. Further the use of different statistical models can be used as tools to predict EONR. These different statistical models allow to predict EONR based on single test results, combination of tests, and include soil characteristics in the models.

The objective of this study was to evaluate statistical models to identify which soil test and/or soil characteristics predict EONR for corn in Wisconsin.

METHODS

In 2019 and 2020, 23 small-plot field trials were conducted in 16 counties on private and university farms. Soil texture and drainage class, previous crop, use of cover crop, and manure history varied by site (Table 1). Corn grain yield response to sidedress N (0 to 200 lb. N acre^{-1} in 40 lb. N acre^{-1} increments at ~ V6; 4 replications) was evaluated. At each site, the EONR was calculated using an N: corn price ratio of 0.1 (e.g. 0.5 $ per lb. N:5 $ per lb. grain) after fitting a model to the yield response data (quadratic plateau, linear plateau, or linear; best-fit model chosen based on R^2).

Soil samples (0-15 cm) were collected in the no N control plot within 3 days of planting. Samples were dried (90 °F) and ground (2mm) and analyzed for six bio/chemical soil tests: total organic carbon (TOC), total carbon (TC), and total N (TN) all analyzed on a LECO CN928 combustion analyzer; active carbon (permanganate oxidizable carbon, modified from Weil et al., 2003); soil respiration (CO_2 measured after 4 day incubation with sample rewet, CASH manual); Ammonium content (NH_4) and Potential Mineralizable N, (PMN) measured as NH_4 content after 7 days of anaerobic incubation at 40 °C, both PMN and NH_4 were extracted with 2M KCL and read with a spectrophotometer. The soil characteristics included as predictors were Soil drainage class, Texture class, and Available water capacity.

The relationship between EONR and soil tests was evaluated using correlation. Regression, stepwise regression, and decision tree analysis were used to predict EONR based on soil test results and soil characteristics. All analyses were performed in R studio.

RESULTS

Using correlation analysis, the tests that best correlate to EONR were NH_4 (r= -0.75), Respiration (r= -0.72), and Active carbon (r= -0.56) (Figure 1). Visual inspection showed that a segmented model may best fit the relationship between NH_4 and EONR. The result was a linear plateau model with R^2=0.71, p value <0.001, and a critical point of 9.98 ppm (Figure 2). In the stepwise regression analysis, the best single predictor was NH_4 with Adj R^2=0.64 (Table 1). In addition, when using more than a single test, the overall best predictor of EONR was the model that includes NH_4 and active carbon Adj R^2=0.68 (Table 1). The model formula was EONR= 300.27 – 0.150*Active carbon – 20.36*NH_4.

When including the soil characteristics as predictors, the decision tree analysis identified NH_4 and active carbon as the most effective parameters for EONR prediction. Ammonium proved useful for detecting non or minimally responsive sites (mean 11 lb N $acre^{-1}$), while active carbon was valuable for predicting EONR at responsive sites (Figure 2). Because the models predicting EONR from active carbon were not significant, and model parameters were very similar regardless of high or low active carbon in the original decision tree, a Modified decision tree was created by combining the active carbon branches (Figure 3). The resulting prediction of EONR when NH4 < 6.8 ppm was EONR = -0.2236*Active carbon + 244.68 with an R^2= 0.48 and a p value= 0.001 (Figure 3). Incorporating soil drainage class, texture class, and available water into decision tree analysis did not yield any significant predictors for EONR. The model outputs were used to calculate a predicted EONR, which showed that all models could predict EONR based on test results (Figure 4). Overall, the modified decision tree was the best model with an R^2=0.82.

Table 1. Stepwise regression analysis using soil health tests to predict EONR

# Of Parameters	Test combination	R^2	Adj R^2	AIC	BIC	Cp	RMSE
1	NH_4	0.64	0.62	220.4	222.1	1.3	40.5
1	Respiration	0.45	0.42	229.3	231.1	11.0	50.1
2*	NH_4+ Active carbon	0.72	0.68	218.3	220.0	-0.67	36.8
2	NH_4 + Respiration	0.70	0.67	219.3	221.0	0.02	37.7
3	NH_4 + TC + ActiveC:TN	0.73	0.68	220.6	221.9	0.53	36.8
3	NH_4 + TOC + ActiveC:TN	0.72	0.68	221.1	222.3	0.82	37.2

*Indicates the best model

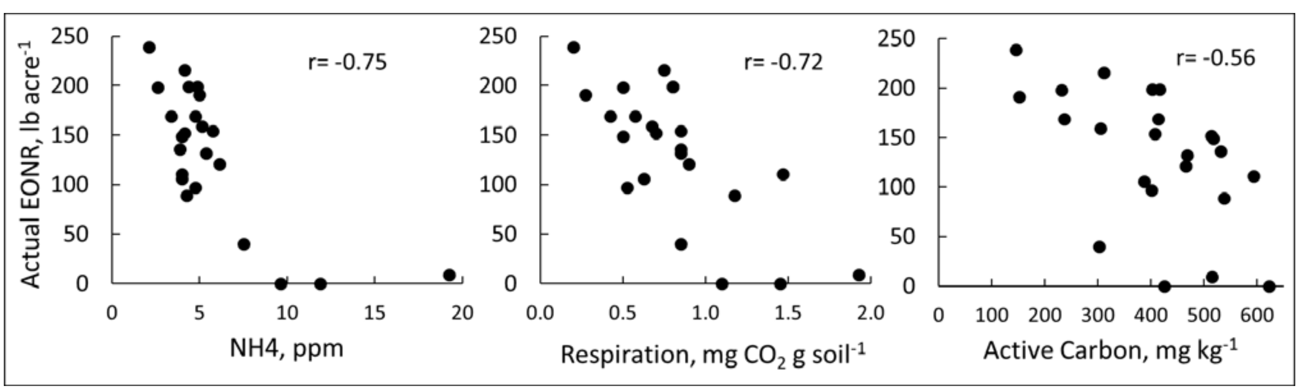

Figure 1. Correlation analysis between EONR and soil test results.

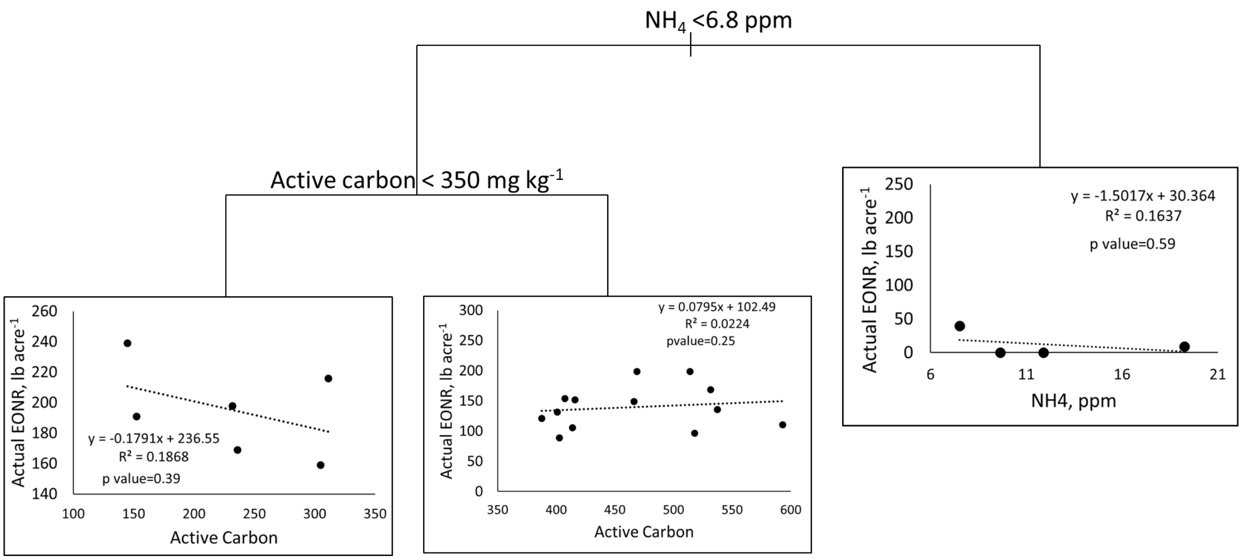

Figure 2. Decision tree analysis results using soil tests and soil characteristics to predict EONR.

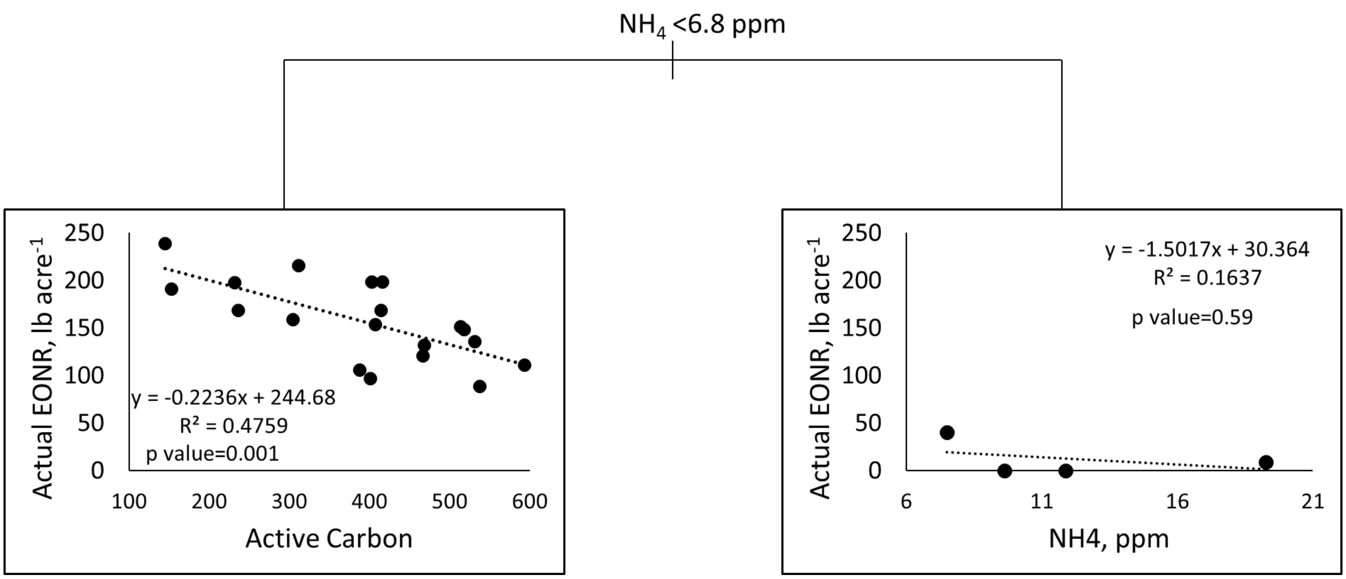

Figure 3. Modified Decision tree analysis results using soil tests and soil characteristics to predict EONR.

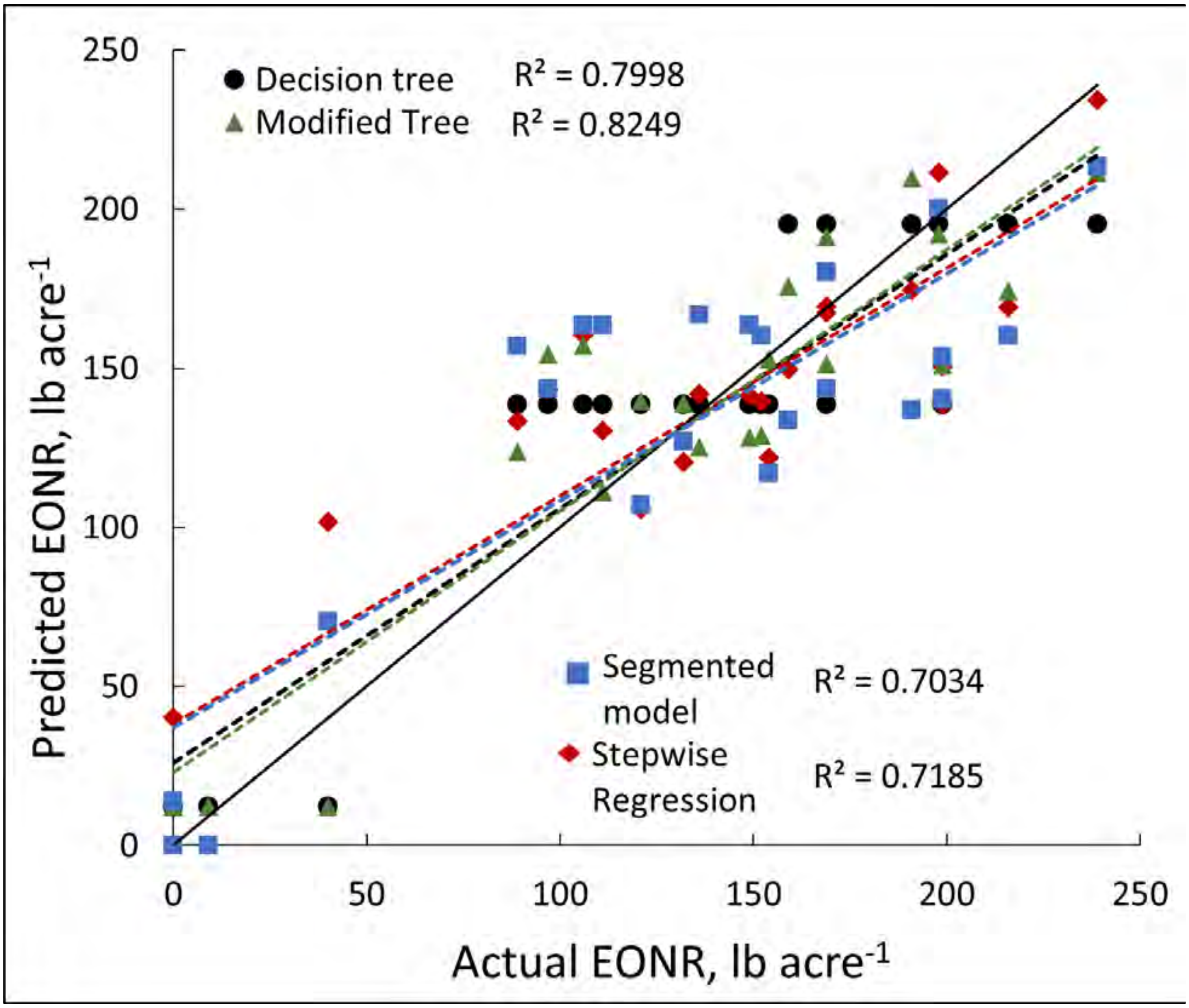

Figure 4. Actual EONR vs predicted EONR using outputs of the 4 different models.

CONCLUSION

The segmented model, decision tree, and multiple regression models performed similarly when evaluating actual vs predicted EONR, with an average R^2= 0.72 (Figure 4). The modified decision tree showed a marked increase in R^2 (R^2= 0.83) compared to the other models. While the modified decision tree has the highest R^2, it requires two soil tests. Thus, a segmented model, which is somewhat less predictive, may be more cost-effective since it requires only one soil test (Ammonium). In conclusion, these diverse statistical analyses highlight the potential to assess optimal side-dress N rates for corn production, including identifying minimally or non-responsive sites by analyzing 0-15 cm soil samples collected at planting for NH_4 and active carbon.

ACKNOWLEDGEMENTS

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COMPARING THE EFFECTIVENESS OF CALCIUM PRODUCTS IN NEUTRALIZING SOIL ACIDITY

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ABSTRACT

Proper pH management is the foundation of a good soil fertility program. Soil pH influences nutrient availability, root growth and function. Acid soils are neutralized by the addition of carbonates, oxides, and hydroxides present in limestone products. However, there is a common perception among some producers that calcium is responsible for the neutralization of acid soils rather than the carbonates associated with calcium in the limestone. The effectiveness of three calcium products in raising soil pH were compared to an untreated check in acid soils. A field study was conducted at 16 locations across Kentucky. A laboratory incubation study was conducted at the University of Kentucky Research and Education Center using the same application rates as the field trial. Treatments included an untreated check, liquid calcium chloride (5 gallon acre-1), pelletized lime (RNV 83), and ag lime (RNV 79). Pelletized lime and ag lime were applied at a rate of 2 ton acre-1 of 100% effective lime after adjusting for product RNV. The field study resulted in significantly higher soil pH at the 3 month, 12 month and 24 month sample dates with ag lime and pelletized lime compared to the untreated check and liquid calcium. The lab study resulted in higher soil pH values with ag lime and pelletized lime than the check and liquid calcium at each sample date (1, 3, 6 and 12 month). The untreated check and liquid calcium products did not change soil pH. This was expected due to the inability of liquid calcium ($CaCl_2$) to consume acidity. To effectively neutralize soil acidity and increase soil pH, the addition of products that contain carbonates, oxides, or hydroxides must be utilized. The results of this study support the chemical foundations associated with soil acidity neutralization reactions - calcium chloride doesn’t neutralize acidity and calcium carbonates do.

INTRODUCTION

Proper soil pH management is the foundation of a good forage soil fertility program. Soil pH indicates the amount of active acidity present in the soil and influences nutrient availability, plant root growth and function, the rate of many biological processes and herbicide activity (Miller and Kissel, 2010). Lime application rate is based on the amount of active acidity and the soil buffer pH (Sikora, 2006). Application of acid neutralizing products are added to the soil to neutralize acid soil pH. The primary products used for pH management in field agricultural settings are some form of calcitic or dolomitic limestone. Some producers and ag retailers believe or claim that calcium is responsible for the neutralization rather than the carbonates associated with calcium in the limestone, but this is not true. Limestone application rates are adjusted according to their relative neutralizing value (RNV). The RNV is influenced by the purity and the fineness of the limestone. Some companies offer products that claim to neutralize acidity by adjusting the amount of base cations (Ca, Mg, K, or Na) present on the exchange complex by adding minute amounts of Ca in the form of calcium chloride ($CaCl_2$). To neutralize acidity, the proton (H^+) must be consumed. The neutralization reaction of calcitic limestone is demonstrated in equation 1.

Equation 1. $CaCO_3 + 2H^+ \rightarrow H_2CO_3 \rightarrow H_2O + CO_2 + Ca^{2+}$

The acidity or proton in equation remains after the addition of $CaCl_2$ and has no liming ability according to equation 2.

Equation 2. $CaCl_2 + 2H^+ \rightarrow Ca^{2+} + 2H^+ + 2Cl^-$

Based on numerous questions and concerns from Kentucky producers, agribusiness, and agricultural producers we designed a field and laboratory experiment to test the effectiveness of liquid calcium chloride compared to traditional liming materials utilized in forage production.

MATERIALS AND METHODS

Field and laboratory incubation studies were established concurrently in the summer of 2021. The same treatments were used for both studies: a non-treated check (nothing applied), liquid calcium at 5 gallon acre^{-1}, pelletized lime (RNV = 83), and agricultural lime (RNV 79). Both pelletized lime and ag lime were applied at 2 ton acre^{-1} 100% effective lime, after adjusting the rate for the RNV of the product. Data was analyzed using SAS version 9.4 (Cary, NC).

The field study was conducted at 16 locations across Kentucky on private farms with assistance from agriculture agents and on two University of Kentucky Agricultural Experiment Stations (UKAES) located at Lexington, KY and 200 miles away at Princeton, KY. The field study utilized a randomized and replicated small plot treatment arrangement with 25 ft^2 plots and three replications. Soil samples for the field study were collected prior to treatment application, approximately 3 months later and approximately one year after initial treatment application. The two sites on the UKAES had samples collected again two years after treatment applications. Results for the field study were reported as the average soil water pH across locations. Forage data was collected approximately 3 months after treatment application immediately prior to hay harvest and analyzed by near infrared spectroscopy to include: dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and total digestible nutrients (TDN).

The incubation study utilized the surface 6 inches of a Crider silt loam (Typic Paleudalf) soil with an initial soil water pH of 5.2. This soil was removed of large clods, roots and plant material prior to screening to pass a 2-mm sieve. We placed 1.8 oz (50 g) of air-dried soil in 4 oz specimen cups with small holes in the cap to allow for gas exchange. Treatments were replicated 4 times. Cups were maintained at 80% water filled pore space by weight until shortly before the 6-month sample date. Shortly before the 6-month samples were to be analyzed the building was destroyed by an EF-4 tornado. Most samples were recovered after the tornado but cup moisture wasn't maintained for the 12-month samples. Destructive sampling occurred at 1, 3, 6 and 12 months. Results for the incubation study were reported as soil water pH.

Figure 1. Generalized plot layout for field study. Plot whiskers were used to mark plot location when flags had to be removed for general plot management operations.

RESULTS AND DISCUSSION

Field Trial pH Change

Soil pH values in the field trials reacted as expected according to equation 1 and equation 2. The soil pH values were similar (pH = 5.8) at the beginning of the experiment prior to any treatment being applied. Treatments that received products containing carbonates (i.e. ag lime and pelletized lime) resulted in an increase in soil pH and treatments that did not contain carbonates (check and liquid calcium) did not change within a given period (Table 1). The addition of limestone to agricultural fields is not considered an immediate reaction, like an application of urea fertilizer. A noticeable pH change isn't expected to occur immediately rather it will occur over several months or up to a few years (Ritchey and McGrath, 2022). A slight increase in soil pH (0.3 to 0.4 units) was noticed with ag lime and pelletized lime at the 3-month sample collection time where soil pH showed a slight decrease at the 3-month sample collection time with the check and liquid calcium. Soil pH 1 year after application was 0.7 units higher for the ag lime and pelletized lime compared and significantly greater than the check and liquid calcium product. Soil pH for the two locations sampled at 24 months were statistically greater with the ag lime and pelletilzed lime than the check and liquid calcium chloride product. There was no statistical difference in pH between the Ag lime and pelletized lime for the field experiment (Figure 1).

Table 1. Soil pH values for the field trial, prior to treatment application and 3, 12, and 24 months following treatment application. Results for 3 and 12 months are averaged across 16 locations. Results for 24 months are averaged over 2 locations.

	------------------------------------ Soil pH ------------------------------------			
Treatment	Initial pH Pr>F (0.854)	pH 3 month Pr>F (<0.001)	pH 12 month Pr>F (<0.001)	24 month Pr>F (0.003)
Check	5.8 a[1]	5.6 a	5.9 a	5.4 a
Liquid Calcium	5.8 a	5.7 a	5.8 a	5.4 a
Pelletized Lime	5.8 a	6.1 b	6.5 b	6.0 b
Ag Lime	5.8 a	6.2 b	6.5 b	5.8 b

[1] Letters in the same column that are different indicate significant treatment differences at the 0.1 level of significance.

Lab Incubation pH Change

Soil pH values responded to the applied treatments in the lab incubation as expected according to equation 1 and equation 2. The initial soil pH value was 5.2 at the onset of the experiment prior to treatment application. One month after treatment application the pelletized lime and ag lime had significantly increased soil pH by 0.7 and 0.9 units from the initial soil pH (Table 1). Soil pH increased 1.1 and 1.0 units at the 3-month sample date for the pelletized and ag lime treatments. However, during the same time period the untreated check and the liquid calcium treatments were 0.1 to 0.2 units less than the initial soil pH (i.e. soil pH decreased with time). The short-term results of the incubation were very promising for the limestone products. Ideal soil and environmental conditions led to a rapid neutralization reaction of soil acidity in this incubation time.

Results up to the 6-month sampling date were very promising and illustrate how ideal, controlled laboratory conditions will improve the speed of a neutralization reaction compared to those that occur in the field in ambient soil conditions. Conditions were maintained in the laboratory where we expected the neutralization reaction to proceed as fast as possible. For example, soil moisture was maintained at 80 pore filled volume, temperature was near room temperature, and gas exchange between the cups and atmosphere were allowed to occur. A one unit change is soil pH would not be expected to occur in field settings in 1 to 3 months due to less than ideal environmental conditions being constantly present where they occurred in the laboratory setting.

An F-4 tornado destroyed the storage room where the samples were stored for this experiment on Dec 10, 2021. The samples that were recovered were collected and moved to another location but soil moisture and temperature was not maintained moving forward. The specimen cups dried and were exposed to greater fluctuations in ambient temperatures. This might have slightly influenced the results of the 6-month incubation time and particularly the 12-month incubation duration. The soil pH was still increasing at the 6-month sample time and resulted in an increase of 1.5 and 1.4 units with the pelletized and ag lime over that of the untreated check (Table 1). This was a slight increase in soil pH over the 3-month sample date, but not as much as expected based on the previous results. The soil pH for the untreated check and liquid calcium were 5.0, which is slightly lower than the original pH values at the initiation of the incubation and statistically lower than the soil pH values resulting from the calcium carbonate products. This is a clear indication that the liquid calcium product ($CaCl_2$) has no liming ability.

Soil pH values resulting from the 12-month sample date had increased over the initial samples but were not as high as the 6-month sample date, they had decreased slightly. The soil pH for the pelletized lime was 6.3 and was 6.2 for the ag lime at the 12-month sample date (Table 1). The untreated check and liquid lime had also remained around 5.0 - 5.1. These results could potentially be due to the soil drying and fluctuating soil temperature after the tornado event. These results would be more typical of what would be expected in field settings.

Table 2. Soil pH values for the laboratory incubation trial for soil pH 1-month, 3-month, 6-month, and 12-month after treatment application. Initial soil pH was 5.2 for all treatments prior to treatment application.

	-------------------- Soil Laboratory Incubation Time --------------------------			
Treatment	1 month	3 month	6 month	12 month
Pr>F	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Check	5.2 a[1]	5.1 b	5.0 a	5.1 a
Liquid Calcium	5.3 a	5.0 a	5.0 a	5.0 a
Pelletized Lime	5.9 b	6.3 d	6.5 b	6.3 b
Ag Lime	6.1 b	6.2 c	6.4 b	6.2 b

[1] Letters in the same column that are different indicate significant treatment differences at the 0.1 level of significance.

Forage Yield and Feed Nutritive Value

Although no positive results for a change is soil pH were observed from the liquid calcium, we wanted to test the influence of the treatments on the yield and feed value of the different forages in this experiment. No significant results were seen for yield or any of the feed nutritive components 3 months after treatments were applied (Table 3). Although soil pH is an important component to a good soil fertility, significant improvement in pH, thus yield or feed nutritive factors were not expected in the time frame of this study (i.e. between the first and second cutting). The random variation of the results is indicative of variable stand densities within given hayfield or pasture situations. We maintained the small plot size to reduce soil pH variation within individual fields. The small plot size used for yield determination was good to limit soil pH differences within the study site, but better estimates of forage yield may have benefited from a larger sampling size.

Table 3. Forage yield and feed nutritive results from the field study approximately 3 months after treatment application. The results are averaged across 16 field locations.

Treatment	DM[1] (lb $acre^{-1}$)	CP[2] (%)	ADF[3] (%)	NDF[4] (%)	TDN[5] (%)
Pr>F[6]	0.620	0.865	0.793	0.693	0.575
Check	1,874	11.6	37.1	60.3	58.8
Liquid Calcium	1,968	11.5	36.7	60.8	59.2
Pelletized Lime	2,119	11.0	37.6	61.5	58.3
Ag Lime	1,832	11.1	37.4	60.2	58.5

[1] DM = forage dry matter reported in kg ha^{-1}

[2] CP = crude protein reported as a percent

[3] ADF = acid digestible fiber reported as a percent

[4] NDF = neutral digestible fiber reported as a percent

[5] TDN = total digestible nutrients

[6] No statistical differences observed at the 0.1 level of significance

CONCLUSIONS

Results of the field trials indicate that proven practices to neutralize soil acidity still hold true. The results of the field trials support the results of the laboratory incubation study, which agree with sound chemistry foundations. The products that were expected to neutralize soil pH (i.e. those containing carbonates) did neutralize soil pH and increased soil pH within a given incubation period. However, there was no consistent difference between liming products. Products not containing carbonates – liquid calcium ($CaCl_2$) have no mechanism to change soil pH and did not change soil pH in this experiment. In short, to effectively neutralize soil acidity and increase soil pH the addition of products that contain carbonates, oxides, or hydroxides must be utilized – not products that just contain calcium or chloride. Forage yield and feed nutritive values were similar regardless of treatment. Economics of liming material, coupled with the effectiveness, should be considered when determining liming materials.

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CORN NITROGEN REQUIREMENT IN WINTER CEREAL COVER CROP TRIALS IN SOUTHERN ILLINOIS

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ABSTRACT

Winter cereal cover crops, including wheat (*Triticum aestivum* L.) and winter rye (*Secale cereale* L.) are recommended as the best in-field management strategy by the Illinois Nutrient Loss Reduction Strategy (INLRS) to minimize nitrate-N leaching to the Mississippi River Basin and the Gulf of Mexico. We evaluated the effect of wheat and winter rye on corn grain yield, and nitrogen (N) requirement. Treatments were laid out in a randomized complete block design with four replicates and split-plot arrangements. The main plots were wheat or winter rye vs. a no-cover crop control and the subplots were six-seven rate of N fertilizer. Corn grain yield was consistently higher in the no-cover crop (NOCC) treatment reflecting on higher N availability during the corn growing season. Corn N requirement ranged from 0 to more than 250 lbs of N ac^{-1} reflecting weather conditions and cover crop C:N ratio. Our results indicate that corn N requirement should be adjusted for corn following winter cereal cover crops and it is critical to track N beyond the corn season to evaluate when the immobilized N will be released to capture and utilize that N source.

INTRODUCTION

Illinois Nutrient Loss Reduction Strategy (Illinois EPA, 2015), among other states in the Midwestern, USA, identifies winter cereal cover crops (WCCCs) as the most effective in-field conservation strategy to reduce surface water contamination from nonpoint sources. Among CC species, WCCC can scavenge large amount of residual N and therefore, are much more effective in reducing nitrate-N loss to tile drainage (Singh et al., 2018) than the legumes. However, growers are often hesitant to plant WCCCs before corn due to concerns about soil N immobilization caused by the CC and the slow release of N when corn has its peak N requirement after terminating the WCCC (Nevins et al., 2019).

Currently, Illinois as a part of the North Central region utilizes the Maximum Return to Nitrogen (MRTN) calculator, a tool designed to optimize N fertilizer applications to corn, also known as economic optimum nitrogen rate (EONR). This calculator uses corn price and N fertilizer price to calculate the N rate at which corn yield has the largest economic return (Sawyer et al., 2006). However, the current MRTN version, does not consider the inclusion of CCs prior to corn planting. Therefore, there is a need to gather data and establish a dataset that differentiates corn's N requirements based on CC options and management practices to develop more precise and tailored N management recommendations. The objectives of this study were to evaluate the effects of wheat and winter rye cover crop as compared to a no-cover crop control on corn grain yield and N requirement.

MATERIALS AND METHODS

Field trials were conducted at the Agronomy Research Center (ARC) in Carbondale, IL (37.750 N, 89.060 W) and Belleville Research Center (BRC). During 2019-2020, two trials were conducted at the ARC site and during 2020-2021, two trials were conducted at the ARC and BRC sites. Treatments were laid out in a randomized complete block design with four replicates and split-plot arrangements. The main plots were wheat or winter rye vs. a no-cover crop control and the subplots were six-seven rate of N fertilizer (0-250 or 300 lbs N/acre with 50 lbs N /acre increments).

Cover crops were planted on late-Oct. to early Nov. with a John Deere 450 series grain drill (John Deere, Moline, IL, USA) and terminated via burndown mid- to late-April. Prior to termination cover crops were sampled from a 7.2 ft^2 area using grass shears. Cover crops were oven dried at 60 °C and then ground for carbon (C), N, and C:N determination. We used combustion method with an elemental analyzer to measure C and N.

Corn was planted on mid-May to late-May and harvested on mid-October to early-Nov. Dekalb DKC 64-35 RIB corn seed was planted to depths of 1”-1.25” using a no-till drill at 32 to 33000 ac^{-1} plant population. We used 32% urea ammonium nitrate as fertilizer source and N was injected between V5 to V6 stage of corn. Harvest was conducted on the middle two rows of each subplot with a XP Plot Combine (Kincaid, Haven, KS, USA). Weights were corrected to 15.5% moisture content. We used several models (linear, quadratic, linear plateau, and quadratic plateau) and to identify the best fit for assessing economic optimum rate of N (EONR). Best model was used based on P values and R^2, and root mean square error (RMSE). Statistical analysis was performed with SAS 9.4 (SAS Institute Cary, North Carolina). When treatments were significant, mean separation was conducted using Least Square Means adjusted for Tukey.

RESULTS and DISCUSSION

Cover Crop Performance

Wheat biomass in 2018-2019 (hereon reported as 2019) season was 314 lbs ac^{-1} reflecting late planting and waterlogging conditions at the site in that year. In 2019-2020 (hereon reported as 2020) season, wheat biomass was 3,392 lbs ac^{-1} which was almost 10 times higher than that of 2019. Wheat C:N ratio was 21.9 in 2019 and 35.8 in 2020 (data not shown).

Winter rye biomass in 2020 was 2890 lbs ac^{-1} at the ARC site and 2908 lbs ac^{-1} at the BRC site. Winter rye C:N ratio was 20.6 and 17.1 for ARC and BRC, respectively. Differences in C:N ratio was mainly due to N in the plant in which the N in winter rye was higher at the BRC site.

Corn Grain Yield and Optimum Nitrogen Rate

In 2019, a challenging year, corn grain yield was low but the NOCC treatment responded linearly to the N application (Fig. 1A) and therefore, EONR could not be calculated and could be higher than 250 lbs N ac^{-1}. In 2019, for the wheat treatment, corn grain yield was around 150 bu ac^{-1} at which the EONR was 164 lbs N ac^{-1}. In 2020, there was a clear separation between the NOCC treatment and wheat treatment (Fig. 1B). This indicated that there was a yield drag with wheat incorporation into the corn system. In 2020, the EONR for the NOCC was 161 and for the wheat cover crop was 220 lbs N ac^{-1} (Fig. 1B). This presents a 59 lbs ac^{-1} N difference between the two cover crop management practices.

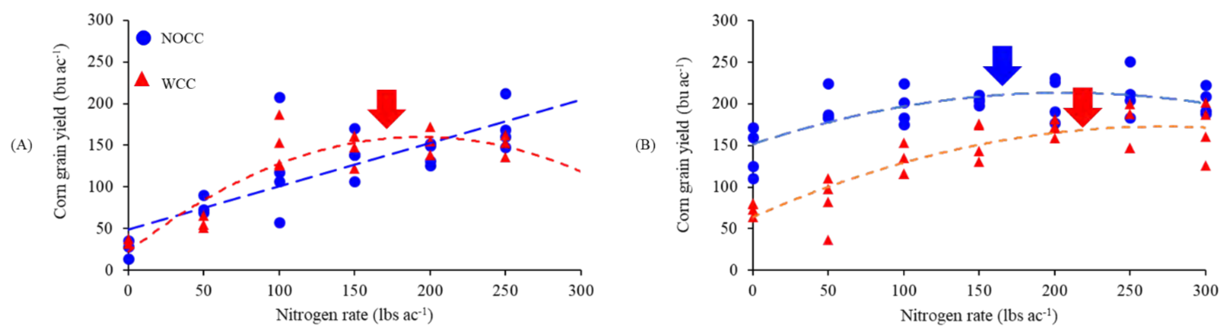

Fig. 1. Corn response to N rate and cover crop management (NOCC vs. wheat) in 2019 (A) and 2020 (B). Circles indicate NOCC and triangles indicate wheat as cover crop (WCC).

In 2020, at the ARC site, corn grain yield was comparable between winter rye and the NOCC treatment and the EONR was slightly higher for the NOCC (204 lbs N ac^{-1}) than the NOCC (201 lbs N ac^{-1}) (Fig. 2A). In contrast, winter rye impacted soil N (data not shown) and resulted in response of corn to N fertilization (EONR = 184 lbs N ac^{-1}). The NOCC treatment produced comparable grain yield with no N fertilizer requirement which could be due to excessive N mineralization during the growing season of corn (Fig. 2B).

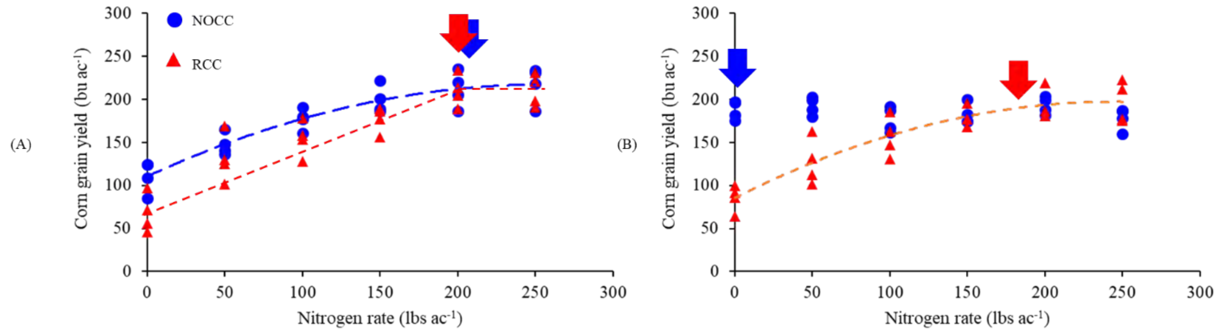

Fig. 2. Corn response to N rate and cover crop management (NOCC vs. winter rye) in 2020 at the ARC (A) and BRC (B) sites. Circles indicate NOCC and triangles indicate winter rye as cover crop (RCC).

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RESPONSE OF CORN TO PLANTING METHODS OF COVER CROP SPECIES AND NITROGEN RATE IN SOUTHERN ILLINOIS

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ABSTRACT

It is well established that planting cover crops prior to corn (*Zea mays* L.) can influence soil temperature, volumetric water content (VWC), and nitrogen (N) dynamics. These changes in soil along with the effects of cover crop on corn plant population can influence corn grain yield and N requirement. Two strategies to facilitate corn establishment and avoid N immobilization especially in winter cereal cover crops is by mixing legumes with winter cereals or skipping the corn row (precision planting). A randomized complete block design trial with split plot arrangement was conducted in 2020-2021 and replicated in the 2021-2022 growing season. The main plots were cover crop treatments including winter rye (*Secale cereale*), crimson clover (*Trifolium incarnatum*), their mixture, precision planted crimson clover, and precision planted crimson clover and winter rye in mixture. The subplot were six N rates (0 – 320 lbs N ac^{-1}). We measured cover crop performance, corn morphology and physiology, grain yield, N removal, N balance, and N use efficiency. In 2021 among cover crops, the mixture had the largest cover crop biomass with a lower (C:N) at 26:1 compared to 31:1 in winter rye alone. Precision planted clover had similar biomass production to solid planted clover indicating lower clover seeding rate and skipping the corn row had no influence on clover performance but decrease cost of cover crop planting. Corn yield was similar among all cover crop treatments in 2021 and corn economic optimum rate of N (EORN) was 179 lb N ac^{-1}. Data for the year 2022 is continuing to be collected.

INTRODUCTION

In response to the growing algal blooms and eutrophication within the Mississippi River Basin, the state of Illinois is implementing the Nutrient Loss Reduction Strategy[1]. The goal of this strategy is to reduce the impact of N and phosphorus (P) loading in water bodies through the integration of best management practices[1]. Two of the strategies included are the selection of winter cover crops and the optimized use of N fertilizer[1]. It is known that winter rye offers a host of ecosystem services due to its ability to scavenge nutrients, reduce soil erosion, sequester carbon, lessen compaction, and suppress weeds[1,2]. While winter rye provides these benefits, it can negatively influence the following corn cash crop through several mechanisms [1,2]. Winter rye can immobilize N, deplete soil water, interfere with corn establishment, decrease corn stand and therefore, decrease corn yield[2,3]. Solutions that can help alleviate the soil-N immobilization include the termination stage and integration of legumes, such as crimson clover, which can reduce the C:N below 25:1 where immobilization will no longer happen[3]. Previous studies have shown that a mixture of winter rye with crimson clover can decrease the negative effects of winter rye on the subsequent corn[4] and alter its N requirement. It is unclear how precision planting (skipping the corn row) or integrating precision planting into winter rye-crimson clover mixture can affect corn establishment, soil N, corn grain yield and N requirement. Therefore, the objectives were to explore the impact of cover crop selection and planting method on cover crop biomass, weed suppression, corn plant population (stand density), grain yield, and N requirement. We hypothesized that precision planting and including crimson clover could decrease N requirement of corn.

MATERIALS AND METHODS

Trial was conducted at the Agronomy Research Center in Carbondale, IL (37.75◦ N, 89.06◦ W). Experimental design was split plot arranged in a randomized complete block design with four replicates. Main plots were cover crop treatments: no cover crop control (NOCC), crimson clover precision planted (CLPP), crimson clover solid planted (CLNP), crimson clover on corn row winter rye (WCR) on middle rows (CLRMIXPP), crimson clover mixed with WCR (CLRMIX), and solid planted WCR (RNP). Subplots were the fertilizer N treatments: 0, 40, 80, 160, 240, 320 lbs ac^{-1}. All plots except for the zero-N control received a stater fertilizer (2×2×2) at the rate of 40 lbs ac^{-1}. Cover crop seeding rates were: CLPP (18.75 lbs ac^{-1}); CLNP (25 lbs ac^{-1}); CLRMIXPP (CL: 6.25 & WCR: 45 lbs ac^{-1}); CLRMIX (CL: 20 & WCR 30 lbs ac^{-1}); RNP (60 lbs ac^{-1}). Each subplot treatment consisted of four rows totaling ten feet wide and forty feet long with four feet alleys.

Cover crops were planted on Sept. 23rd, 2020 with a John Deere 450 series grain drill (John Deere, Moline, IL, USA) and terminated via burndown on April 13th, 2021. Prior to termination cover crops were sampled from a 7.2 ft^2 area using grass shears. Cover crops were oven dried at 60 $^{\circ}$C and then ground for nutrient, carbon, and N analysis using the combustion method with an elemental analyzer.

Corn was planted on May 11th, 2021 and harvested on October 5th, 2021. Dekalb DKC 64-35 RIB corn seed was planted to depths of 1”-1.25” using a no-till drill at 35000 ac^{-1} plant population. 32% urea ammonium nitrate was liquid injected on June 24th, 2021 at V5 stage. Harvest was conducted on the middle two rows of each subplot with a XP Plot Combine (Kincaid, Haven, KS, USA). Weights were corrected to 15.5% moisture content and converted into bu ac^{-1}.

We used several models (linear, quadratic, linear plateau, and quadratic plateau) and to identify the best fit for assessing economic optimum rate of N (EORN). Among those, linear plateau model was the best fit. Statistical analysis for cover crop biomass, percentage of weed biomass, and corn stand density was performed with SAS 9.4 (SAS

Institute Cary, North Carolina) using a one-way ANOVA. Cover crops were considered as the fixed effect and block was the random effect. Statistical analysis for corn grain yield was performed using a two-way ANOVA with SAS 9.4 (SAS Institute Cary, North Carolina) using mixed models with cover crop and fertilizer set as fixed effects and block set as a random effect. When treatments were significant, mean separation was conducted using Least Square Means adjusted for Tukey.

RESULTS and DISCUSSION

Cover Crop Performance

All cover crop treatments decreased weed pressure. In general, WCR was most effective in controlling weeds and the treatments with WCR were either weed free or less weedy (Figure 1). Among cover crop species, WCR biomass was higher than crimson clover and we found that precision planting did not decrease the biomass of crimson clover. This indicates that precision planting could 1) minimize cover crop root interference with corn and also 2) price of planting crimson clover can be decreased because of lower seeding rate used in precision planting. Overall, WCR was the driving factor of total biomass among cover crop treatments leading to high biomass in treatments that included WCR.

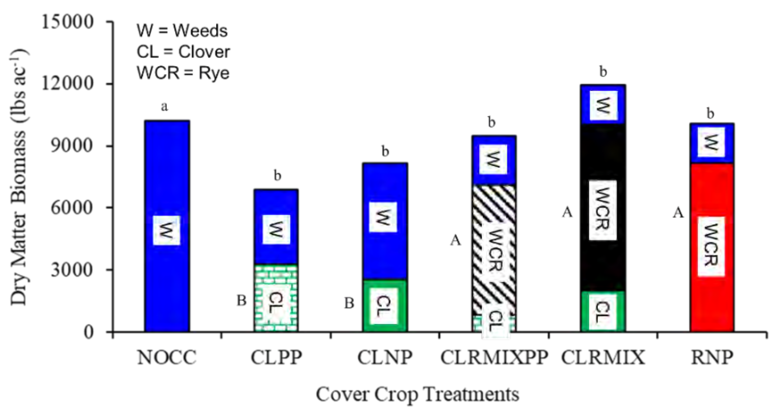

Figure 1. Cover crop (clover and rye) and weed dry matter biomass in each cover crop treatment. (lower case letters compare weed biomass and capital letters compare cover crop biomass) indicate significant difference (<0.05, Tukey). Treatments were no cover crop control (NOCC), crimson clover precision planted (CLPP), crimson clover solid planted (CLNP), crimson clover on corn row winter rye (WCR) on middle rows (CLRMIXPP), crimson clover mixed with WCR (CLRMIX), and solid planted WCR (RNP).

Corn population was only found significant between WCR and the control (NOCC), solid planted clover, PP clover, and PP mixture treatments (Figure 2). This indicated that the WCR had interfered with corn establishment and resulted in corn stand density reduction further emphasizing the importance of precision planting of cover crops.

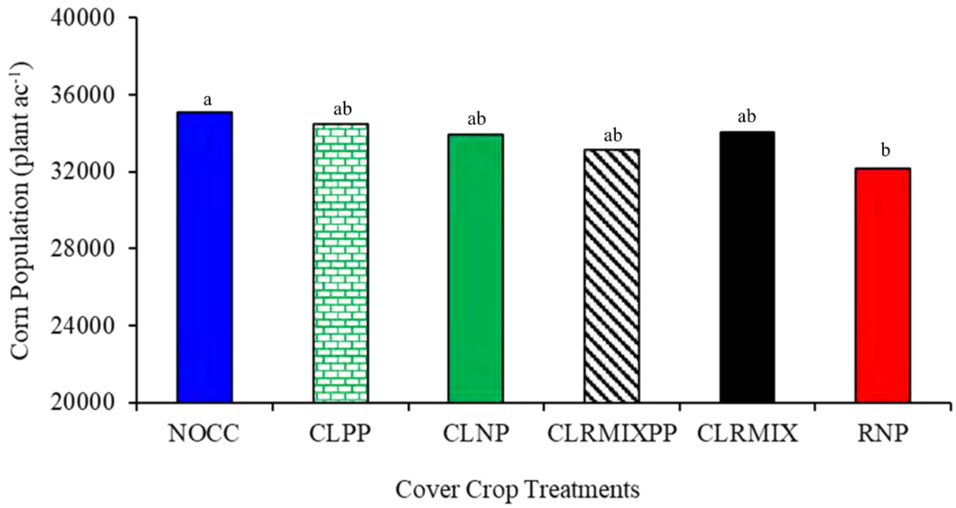

Figure 2. Corn plant population as influenced by cover crop treatments. (a, ab, b) indicate significant difference (<0.05, Tukey). Treatments were no cover crop control (NOCC), crimson clover precision planted (CLPP), crimson clover solid planted (CLNP), crimson clover on corn row winter rye (WCR) on middle rows (CLRMIXPP), crimson clover mixed with WCR (CLRMIX), and solid planted WCR (RNP).

Corn grain yield was not affected by cover crop or cover crop by N fertilizer interaction. This indicates, at this site-yr, reduction in corn stand density by WCR did not translate into yield penalty. Nitrogen fertilization influenced the corn grain yield and corn N requirement. Linear plateau model explained corn grain yield response to N rate the best (Figure 3). Corn grain yield was 11,021 lbs ac^{-1} at the EORN of 179 lbs ac^{-1}. This indicates that N addition beyond 179 lbs ac^{-1} can lead to N surplus and thus potential environmental N losses.

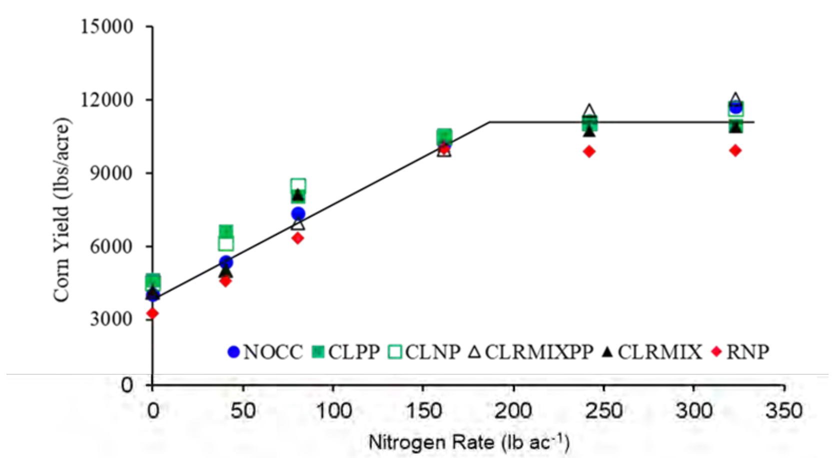

Figure 3. Response of corn grain yield to N fertilization rates and EORN for corn in 2021. Treatments were no cover crop control (NOCC), crimson clover precision planted (CLPP), crimson clover solid planted (CLNP), crimson clover on corn row winter rye (WCR) on middle rows (CLRMIXPP), crimson clover mixed with WCR (CLRMIX), and solid planted WCR (RNP).

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REVAMPING NITROGEN FERTILIZER RECOMMENDATIONS FOR MISSOURI

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ABSTRACT

Multiple nitrogen (N) fertilizer rate decision tools have been developed over the years for recommending N to growers. These tools are based on mass balance equations with expected yield and yield goal, economically optimum N rate, preplant soil nitrate test, pre-sidedress and late spring soil nitrate test, plant tissue nitrogen, crop growth models, and canopy reflectance sensing. These tools rarely include biological N in the rate recommendations. Advances in soil health assessment providing soil health scores and soil respiration estimates have been documented to improve N recommendations for corn in the Midwest. In Missouri, N fertilizer rate recommendations are based on yield goals and include organic matter adjustment factors for most crops. This N recommendation system does not integrate practices that improve soil health such as cover crops, applying biological N efficiency enhancers to increase plant-available nitrogen, N stabilizers such as nitrification and urease inhibitors, and variations in N supply across the landscape. A multi-site project funded by the Missouri Fertilizer Control Board began in 2023 to address these gaps and connect soil health practices and N supply to N fertilizer recommendations for Missouri. The specific objectives are to quantify the N impact of biological input products; cover crops; nitrification inhibitors; and other biological management technologies on N supply, evaluate soil health indicators and weather data as predictors of changes in landscape position and soil conditions impact productivity and soil organic N supply at different landscape positions, calibrate the integration of soil health measurements into fertilizer N recommendations, and improve calibrations of in-season N prediction tools. To achieve these objectives, 12 multilocation trials were established in Missouri in 2023 and first-year results are presented from upstate Missouri sites.

INTRODUCTION

The Missouri soil test interpretations and recommendation handbook was last updated in year 2004 (Brown et al., 2004). Crop N requirements are based on yield goals and are adjusted on plant population, N removal, and organic matter content. The total N requirement for corn grain is determined as (population/acre) x (4 lbs N/1000 plants) + (0.9 lbs N/bu) x (Yield Goal) – Organic matter adjustment factor. The organic matter adjustment factor is based on three soil textural classes including sand to sandy loam, silt loam to loam, and clay loam to clay. Soil N credit is provided based on organic matter and varies from 20 to 80 lbs. N/ac for these soil textural classes. Similarly, N rate recommendations for other major row crops and small grains are provided in the soil test interpretations and recommendation handbook (Brown et al., 2004). With advances in new products such as N stabilizers, biological N efficiency enhancers, and soil health management practices, the N rate recommendation needs further improvement for Missouri growers.

Historically, most of the research studies in Missouri have been conducted on N source, rate, timing, and placement (Scharf, 2001; Scharf, et al., 2002; Scharf, et al., 2005; Noellsch, et al, 2009; Nelson, et al, 2014; Johnson, et al, 2017). In some of the recent publications, spatial variability caused by landscape has been identified as an important factor for N management in Missouri claypan soils. Landscape positions accumulating water like toeslopes were reported to have denitrification enzyme activity fluxes as high as 1.7 lbs. N ac^{-1} d^{-1} (Johnson, et al., 2022). Nitrogen rate recommendation for the high, mid, and low productive ground classified based upon the topographic positions is not explored to a larger extent due to challenges related to conducting controlled trials on the spatially variable fields. Spatial variability results from differences in the accumulation and deposition of organic matter and soil particles which controls soil water storage and movement, thereby impacting the overall results of the N response trials. In Missouri, management practices such as tillage on soils with slopes used for row crop production resulted in significant soil loss, therefore soil health management practices including cover crops and no-till adoption are been prompted throughout the state. Nitrogen rate recommendation for row crop production systems with cover crops is not available for Missouri. Biological N mineralization (aerobic incubation) and chemical extraction (5-min tetraphenylborate) assays are some of the soil tests that have been reported to improve N fertilizer recommendations in the Midwest US, where, on average these tests can reduce 40% over-application and 37% under-application of N fertilizer (McDaniel et al., 2020). Ransom et al. (2020) evaluated the performance of N fertilizer recommendation tools in eight Midwest states and reported that all N fertilizer recommendation tools produced similar returns compared to the economically optimal N rate tool except the Corn-N crop growth model. Ranson et al., (2022) also reported that the environmental cost of yield goal-based method of N fertilizer rate recommendation was highest among all N fertilizer recommendation tools evaluated in their study. The overall goal of this study is to improve N fertilizer stewardship and update recommendations to enhance 4R management. The specific objectives include 1) quantifying the N impact of cover crops, N inhibitors, and other biologicals, 2) evaluating soil health measurements and weather data as predictors of how changes in landscape position and soil conditions impact productivity and soil organic N supply, 3) calibrate the integration of soil health measurements into fertilizer N recommendations and 4) improve calibrations of in-season N prediction tools.

MATERIALS AND METHODS

A multi-location project funded by the Missouri Fertilizer Control Board began in 2023 to address gaps and connect soil health practices and N supply to N fertilizer recommendations for Missouri. The cropping systems in Missouri are different when evaluated from Bootheel Hill Missouri, to central Missouri and upstate Missouri. The seven delta counties in Missouri have cotton, rice, corn, and soybean as major crops, and the cropping system is different from the rest of the state. More than 90% of the cropland in central and upstate Missouri is under dryland corn and soybean production. In Bootheel Missouri, more than 90% of the agricultural land is irrigated. Therefore, this project is not crop-specific and addresses regional priorities for understanding the impact of biological management and landscape on N recommendations for the state. A total of 12 locations were established with the following projects in 2023:

Lee Greenley Jr. Memorial Research Farm (GRF): Timing (3) X Inhibitor (2) X N rate (5) - Corn, GRF. Evaluate N response with and without the inhibitor Centuro in fall with anhydrous ammonia, at preplant with anhydrous ammonia, and V6 with urea ammonium nitrate (UAN). Landscape (3) X Inhibitor (3*) X N rate (5) – Corn, GRF. Evaluate N response in three slope positions down a slope testing the inhibitors Centuro and N-serve at 120 and 180 lbs. N/acre. Biological (3) X N rate (5) - Corn, GRF. Evaluate N response with three biologicals including Biological 1, Envita, and UtrishaN, with an untreated control.

Bradford Research Farm (BRF): Landscape (2) X Cover Crop (2) X N rate (6) – Corn, BRF. Evaluate N response with and without cover crop at two landscape positions. Cover crop (2) X N rate (6) – Corn, BRF. Evaluate N response with and without a cover crop.

Fisher Delta Research, Extension, and Education Center (FDREEC): Biological (2) X N rate (7) – Corn, Evaluate N response with and without biologicals. Crop rotation (2) X Timing (3) X N rate (7) – Cotton, FDREEC. Evaluate N response in rotation with peanut versus cotton. Late application N response tested at three early application rates. N rate (5) – Rice, FDREEC. Evaluate N response at three irrigation positions (top, middle, bottom).

South Farm: Landscape position (3) X N rate (5) – Fall stockpile fescue, South Farm. Evaluate response to August N fertilizer at three landscape positions down a slope. Landscape position (3) X Grazing (2) X N rate (7) – Fescue, South Farm. Evaluate spring N response with and without fall grazing at three landscape positions down a slope. Fall N rate (7) – Fall stockpile fescue, South Farm. Determine the optimum N rate. Previous N rate (7) X Spring N rate (7) – Fescue, South Farm. Evaluate the impact of fall N rate on spring N response of fescue.

In this proceeding, data from upstate Missouri is provided from 2023. In upstate Missouri, corn response to N fertilizer rate, source, and timing was evaluated at the GRF near Novelty in the first trial. The N rates selected for the study were 0, 60, 120, 180, and 240 lbs N/ ac. Anhydrous ammonia with and without centuro (nitrification inhibitor) was applied in the fall and in the spring as pre-plant. Additionally, UAN with and without centuro at the same rates as anhydrous ammonia was applied at the V6 corn growth stage as a single application. In the second trial at GRF, three landscape positions were classified using a topographic position model using LiDAR data in ArcGIS (Esri). The N rate response on corn was evaluated for anhydrous ammonia applied as spring pre-plant at 0, 60, 120, 180, and 240 lbs N/ ac rate. Additionally, 120 and 180 lbs N/ac nitrification inhibitors (Centuro and N-serve) were also included as treatments. In the third-rate response trial, we evaluated three biological products applied at 0, 60, 120, 180, and 240 lbs N/ ac N rate. Urea ammonium nitrate (32%) was used as an N-source applied at the V6 growth stage. The weather data for these locations was collected from Missouri Mesonet (Figure 1). Nitrogen rate response curves were developed from these three trials and are provided in Figures 2 to 5. The statistical analysis was performed in r-studio and graphs were developed in Origin Pro software.

RESULTS AND DISCUSSION

The year 2023 was dry. From April to July, the study locations received between 1.7 to 4.8 inches. lower precipitation when compared to the historical average (Figure 1). Lower precipitation during the reproductive stages of corn results in lower grain yield. For the first trial at GRF, corn grain yield for fall-applied anhydrous ammonia averaged 156 bu/ac at an N rate of 133 lbs N/ac. Corn grain yield for fall-applied anhydrous ammonia with centuro peaked at 160 bu/ac with 122 lbs N/ac. Nitrification inhibitor increased corn grain yield by ~5 bu/ac compared to no nitrification inhibitor for fall N applications. Additionally, a lower 11 lbs N/ ac was needed to make the 160 bu/ac yield when compared to for use and no use of nitrification inhibitor in the fall (Figure 2).

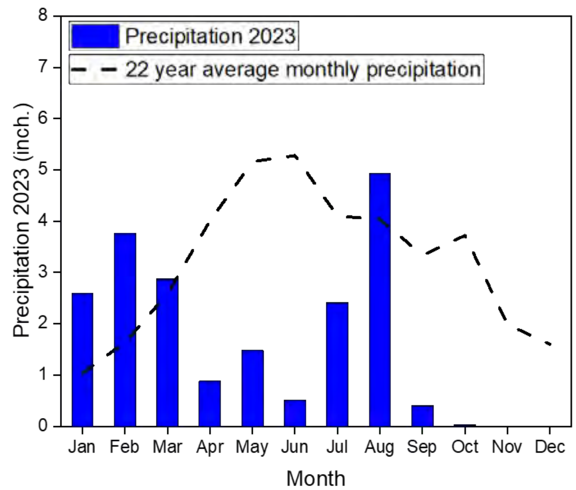


Figure 1. Monthly precipitation for the year 2023 is represented by bars and twenty-two years of historical precipitation data is represented by line from Novelty, MO weather station.

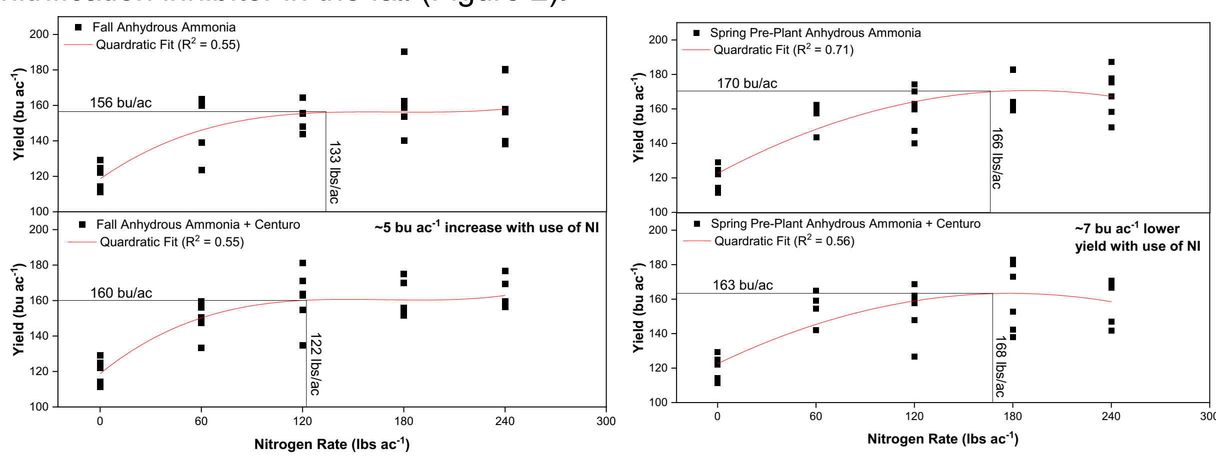


Figure 2. Nitrogen rate response curves for fall and spring pre-plant applied anhydrous ammonia with and without nitrification inhibitor Centuro at the Lee Greenley Jr. Memorial Research Farm.

Nitrification inhibitors are meant to slow the mineralization process thereby making the availability of fertilizer N for a longer period. During the dry year, this process can impact N availability as seen in Figure 3 where 16 lbs N/ac of additional N was needed to make a similar yield when no nitrification inhibitor was added with UAN.

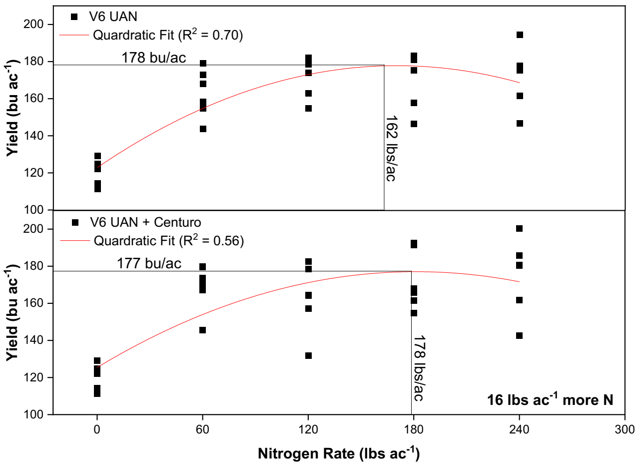
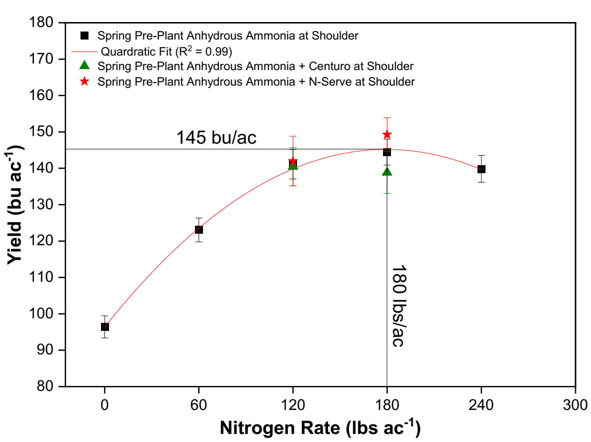
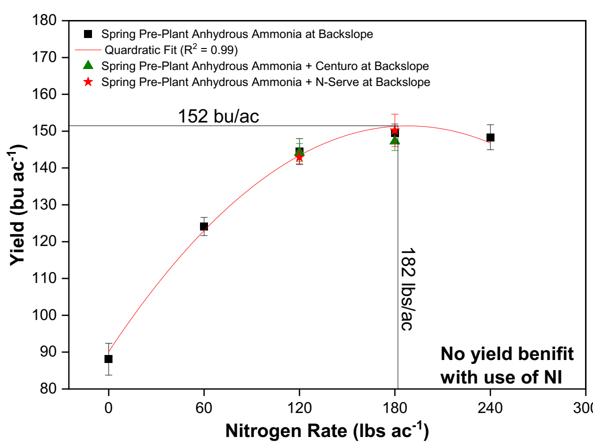


Figure 3. Nitrogen rate response curves for fall and spring pre-plant applied UAN with and without nitrification inhibitor Centuro at the V6 growth stage of corn.

Nitrogen rate response curves for three landscape positions shoulder backslope and footslope representing high, mid, and low productive ground are presented in Figure 4. The optimum N fertilizer rate for continuous corn at the shoulder and backslope position was 180 lbs N/ac whereas it was 10 lbs N/ac lower for the footslope position. The highest corn grain yield of 152 bu/ac was observed at the backslope position with 182 lbs N/ac. Biological products evaluated at the third study location did not result in any yield benefit (Figure 5)





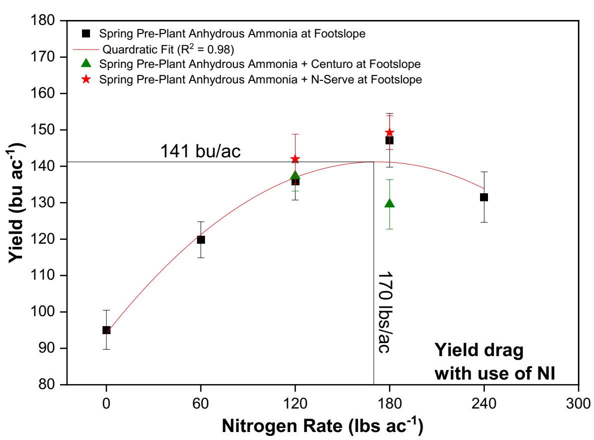


Figure 4. Nitrogen rate response curves for spring pre-plant applied anhydrous ammonia with and without nitrification inhibitor Centuro and N-serve at three landscape positions. The rotation was continuous corn.

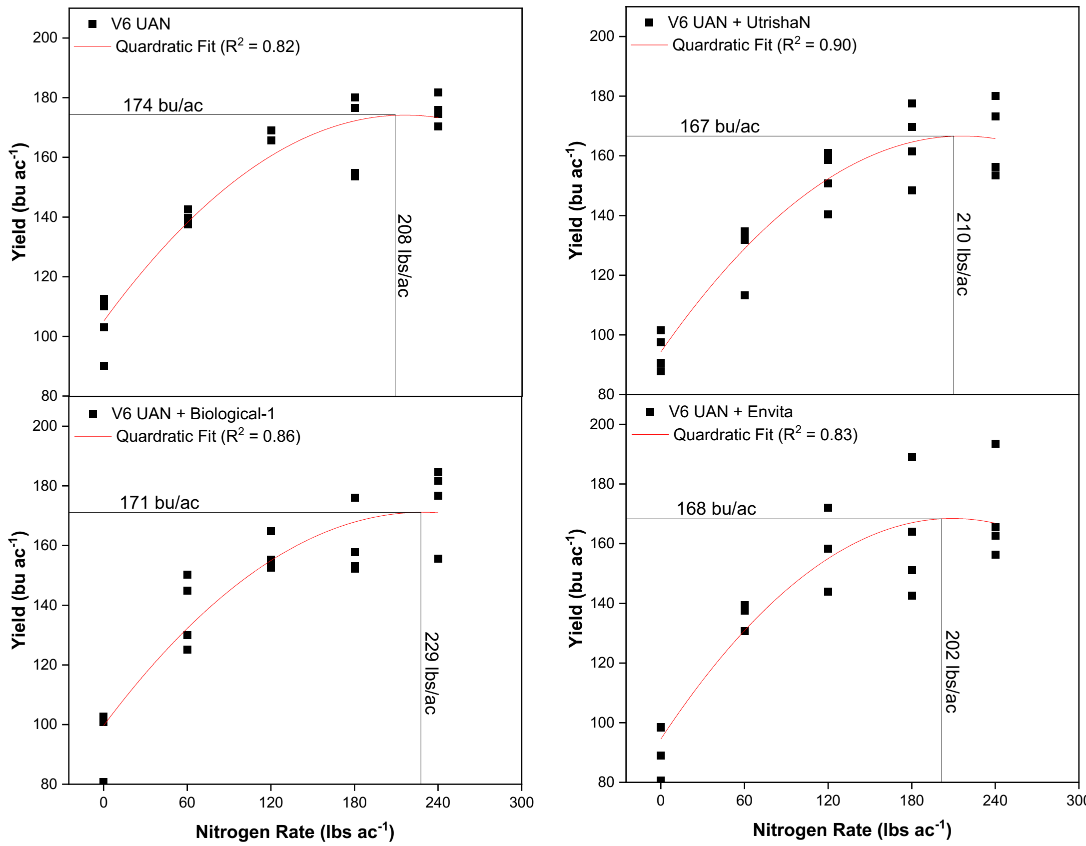


Figure 5. Nitrogen rate response curves for V6 applied UAN with and without biological N efficiency enhancers.

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CORN RESPONSE TO NITROGEN FIXATION TECHNOLOGY IN UPSTATE MISSOURI

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ABSTRACT

Nitrogen is one of the most expensive corn input costs and is critical for grain production. Nitrogen (N) fixing bacteria convert atmospheric N into organic forms that can be utilized by the plant are common with legumes. The symbiosis between Rhizobia and legumes is a critical plant-microbe mutualism that is essential for high yielding soybean. Recently, an emphasis on developing technology to supply corn with additional N through biological processes has been the focus of several agribusinesses throughout the Midwestern U.S. A reduction in N rates using biological N efficiency enhancers could reduce environmental N loss (i.e. leaching and gaseous) commonly experienced in soils throughout Missouri. Biological N efficiency enhancers ("bugs-in-a-jug") may increase plant-available nitrogen and could be incorporated into our current nitrogen recommendation systems if there is a valid and repeatable increase in corn grain yields. The objective of this research was to quantify the N impact of biological management products (*Gluconacetobacter diazotrophicus*, *Methylobacterium symbioticum*, and *Klebsiella variicola* + *Kosakonia sacchari*) on corn response. Field research was conducted from 2020 to 2023 at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty. Leaf greenness was similar among treatments when combined over years. At nitrogen responsive sites, significant interactions in grain yield between years and biological management products indicate inconsistency of this technology due to environmental conditions, hybrids, and/or nitrogen management systems. A better understanding of responsive sites is critical for refining nitrogen recommendations using this technology.

INTRODUCTION

Many studies have shown that increasing nitrogen availability increases corn productivity (i.e. increased yields, biomass, plant height). In addition, it is very common for corn to use less than 50% of the synthetic fertilizer applied during the growing season. A University of Illinois study conducted in 2018 showed that fall applied NH_3 with nitrapyrin in a corn soybean rotation resulted in the corn nitrogen use efficiency to be 42.4% which was the highest among treatments (Griesheim et al., 2019). This has led many farmers to overapply nitrogen in order to help protect themselves against the risk of having nitrogen as a limiting factor affecting crop growth and development. Thus, applying biological N fixing products could provide an environmentally friendly way of supplementing nitrogen to corn which could reduce synthetic nitrogen sources like anhydrous ammonia and help keep the nitrogen in crop fields.

In a study by Tufail et al. (2021), *Gluconacetobacter diazotrophicus* (Envita, Table 1) applied to corn increased shoot and root dry weight 67% and 80%, respectively. When compared to the untreated control, *Gluconacetobacter diazotrophicus* increased N concentration in corn shoots when grown under moderate drought stress, severe N deficiency, and a combination of moderate and severe drought stress and N deficiency. These results have shown that the bacteria were able to colonize with the corn roots, increase plant N concentration, and increase plant growth. *Klebsiella variicola* and *Kosakonia sacchari* are both asymbiotic N fixing bacteria that are found in ProveN (Table 1). A study by Wen et al. (2021) showed that these bacteria increased corn yield by 5.2 bu ac^{-1} and reduced field variability by 8-25%.

METHODS

Experiment 1

Field research was conducted from 2020 to 2022 at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty. A summary of the biological stimulant active ingredient organism or common chemical name, application rate, and timings of N efficiency enhancers is reported in Table 1. Treatments included Urea at increasing nitrogen rates (0, 50, 100, 150, and 200 lbs of N per ac^{-1}) as well as biological products plus 100 lbs of N per ac^{-1}. Experiments were arranged in a randomized complete block design with six replications. Plots were 10 by 40 ft. Corn was planted in 30 inch wide-rows at 34,000 seeds ac^{-1}. Planting date and in-furrow applications of products occurred on 30 April 2020, 27 April 2021, and 10 May 2022. The in-furrow application was made at 18.8 gallons ac^{-1} at 5 psi with water as the carrier. The postemergence broadcast application was applied at the V5 stage of development with a CO2 propelled sprayer on the 12 June 2020, 10 June 2021, and 13 June 2022.

Leaf greenness was determined using a SPAD chlorophyll meter (Konica Minolta, Tokyo, Japan). Plant populations prior to harvest were determined from the entire length of one row. Grain weight, moisture, and test weights were determined for each plot using a plot combine (Wintersteiger Delta) equipped with a HarvestMaster GrainGage. The harvest dates for this study were 23 September 2020, 21 September 2021, and 28 September 2022. Grain yields were adjusted to 15% prior to analysis. Grain samples were collected and analyzed for starch, protein, and oil concentrations (Foss 1241, data not presented).

Data were subjected to ANOVA and means separated using Fisher's Protected LSD (P=0.1).

Experiment 2

The first year (2023) of a split-plot study was conducted at the University of Missouri Lee Greenley Jr. Memorial Research Center near Novelty, MO. The plot size was 10 by 30 ft and had four replications. DK62-44 was planted 24 May 2023 in 30 in wide-rows at 35,000 seeds ac^{-1}. In this study, we evaluated different biological nitrogen fixation products for nitrogen use efficiency in corn. The treatments included a control which had no biological product applied, UtrishaN at 5 oz per acre, and Envita at 3.2 oz per acre. In addition, each treatment was applied prior to 32% UAN at 0, 60, 120, 180, and 240 lbs N ac^{-1}. The biological nitrogen treatments were all applied preplant and the UAN treatments were all sidedress applied at V6.

A handheld SPAD Chlorphyll meter was used to collect chlorophyll content in leaves at V10 and again at VT (Konica Minolta, Tokyo, Japan). Satellite imagery was also recorded during these times. Stand counts were taken at VT. Ear weight and nutrient concentration were taken on 8 August 2023. Whole plant biomass weight and nutrient concentration were taken 19 September 2023. Grain weight, moisture, and test weights were determined for each plot using a plot combine (Wintersteiger Delta) equipped with a HarvestMaster GrainGage. The harvest date for this study was 25 September 2023. Grain yields were adjusted to 15% prior to analysis. Grain samples were collected and analyzed for starch, protein, and oil concentrations (Foss 1241, data not presented).

The data was analyzed using quadratic plateau model in R. The agronomic optimum nitrogen rate (AONR) was estimated for each biological treatment.

RESULTS

There was no significant interaction between years and treatments for leaf greenness in late June and plant population at harvest; therefore, data were combined over years (Table 2). Leaf greenness increased as N rate increased. All of the biological N management treatments had leaf greenness values similar to urea at 100 lbs of N ac^{-1}. Plant populations at harvest were 32,150 to 34,640 plants ac^{-1}. All treatments had plant populations that were similar or greater than the non-treated control. Plant populations of all treatments were similar to urea at 100 lbs N ac^{-1}.

Average yields over the three years were reported in Table 2. Grain yields increased as N rate increased. At 100 lbs N ac^{-1}, an in-furrow application of Envita increased average corn yields 6.3 bu ac^{-1} compared to urea applied alone but was only responsive one of the three years. Over the three years ProveN and Utrisha were no different from each other and the same as the 100 lbs of N treatment.

For experiment two we see increasing corn yields with increasing N rates (Figure 1). At 0 lbs N/acre yields are about 100 bu/acre. The greatest yield obtained was with non-treated urea at 240 lbs N/ac (178 bushels ac^{-1}, Table 3). The agronomically optimal N rate for urea in the absence of a biological N treatment was greater than Envita or Utrisha in 2023.

CONCLUSIONS

After four site years of data in Missouri, there have not been consistent yield advantages with using biological N products. More research is needed to better understand how the biology of these products interact under varying field conditions.

Table 1. Biological product active ingredient organism, trade name, application rate, and placement in 2020, 2021, and 2022 in Missouri.

Biological product	Trade name	Application rate	Application placement
Gluconacetobacter diazotrophicus	† Envita™	4.5 oz ac^{-1}	In-furrow
Methylobacterium symbioticum	‡ Utrisha™ N	5 oz ac^{-1}	Postemergence V4-V8
Klebsiella variicola + *Kosakonia sacchari*	⁋ ProveN™, ProveN®40	13-14 oz ac^{-1}	In-furrow

† Azotic North America. 2022. The Science Envita. https://azotic-na.com/science-behind-envita/. Accessed 13 Nov. 2022.
‡ Corteva. 2022. UtrishaTM N Nutrient Efficiency Biostimulant. https://www.corteva.ca/content/dam/dpagco/corteva/na/ca/en/files/brochure/DF-Utrisha-N-Technical-BrochureEnglish.pdf. Accessed 13 Nov. 2022. ⁋Pivot Bio. 2020. Pivot Bio ProveNTM Safety Data Sheet. https://www.pivotbio.com/hubfs/Safety%20Data%20Sheets/2022%20SDSPivot%20Bio%20PROVEN40%20LIF.pdf. Accessed 13 Nov. 2022. ⁋Pivot Bio. 2022. Pivot Bio ProveN®40 Safety Data Sheet. https://info.pivotbio.com/hubfs/Safety%20Data%20Sheets/Pivot-Bio-2020-08-07-PBP-Safety-DataSheet.pdf?hsLang=en-us. Accessed 13 Nov. 2022.

Table 2. Corn plant SPAD at VT and plant population at harvest averaged over years and corn yield response to biological N management treatments in 2020, 2021, and 2022. Corn grain yield was also averaged over years.

Nitrogen Treatments (lbs ac^{-1})	SPAD	Plant Population (plants ac^{-1})	Corn Grain Yield (bu ac^{-1})			
			2020	2021	2022	Average
0N	44.6	32,150	84.7	89.9	78.4	84.3
50N	47.3	34,440	101.9	124.5	117	114.4
100N	50.7	33,660	124.7	135.2	155.7	138.5
150N	51.5	33,940	166.9	156.3	163.7	162.3
200N	53.5	34,124	184.7	177.6	183.6	182
100N + Envita in-furrow	49.5	34,640	139.1	140.2	155.2	144.8
100N + ProveN in-furrow	50.5	34,130	123.9	130.4	156.6	137
100N followed by Utrisha postemergence	50.1	34,380	127.3	145.2	154.7	142.4
LSD (*P*=0.1)	1.7	1,180	9.9	9.9	9.9	5.7

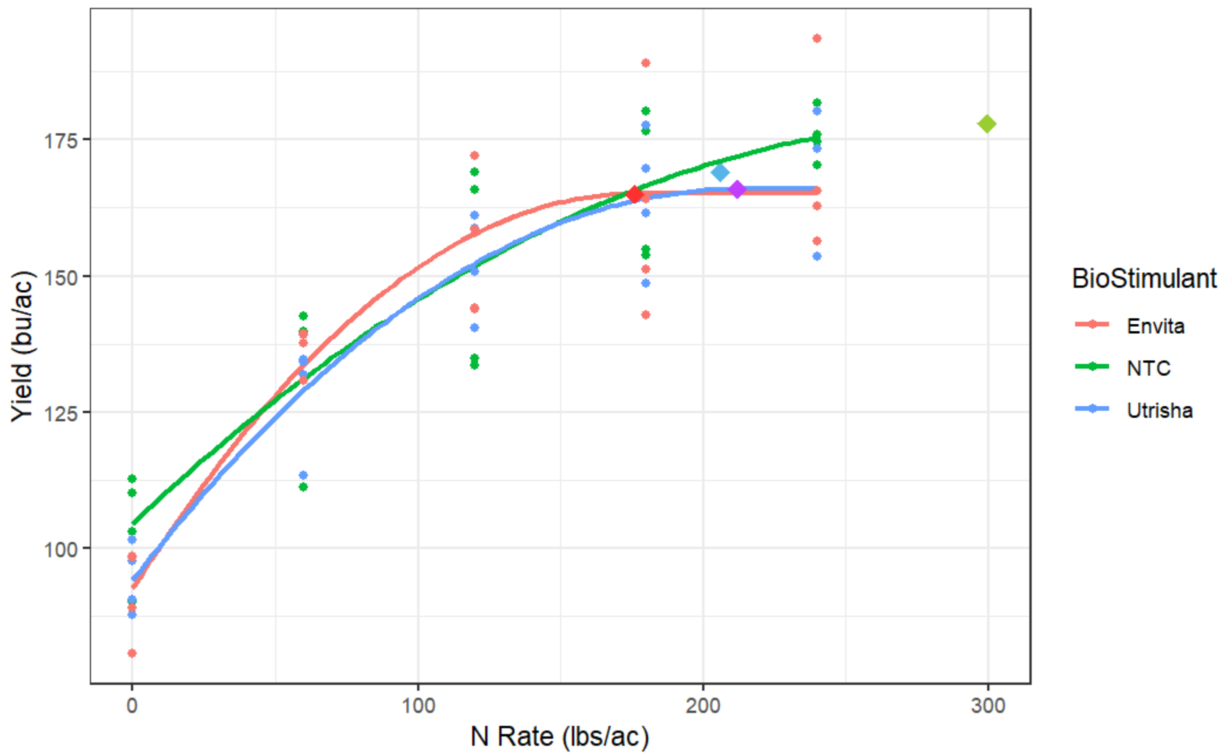

Figure 1. Corn grain yield response to UAN and biological N products in 2023. Diamonds represent the agronomically optimal nitrogen rates (Table 3).

Table 3. Agronomically optimal nitrogen rate (AONR) and grain yields at the agronomically optimal nitrogen rate (YAONR) for the non-treated control (NTC) and biological treatments.

Treatment	AONR (lbs ac^{-1})	YAONR (bu ac^{-1})
NTC	299.50	178.32
Envita	175.85	165.08
Utrisha	212.40	165.96

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IN-SEASON APPLICATION OF SWINE MANURE TO CORN

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ABSTRACT

In agricultural areas with cool climates, application of livestock manure for crop production can be challenging. For example, spring in the upper Midwest can be short and is increasingly wet due to climate change, making it difficult to apply manure and plant crops in a timely manner. This results in a significant amount of manure applied in the fall after the cash crop is harvested. The nitrogen in fall-applied manure has ample time to mineralize and leave the root zone before next season's crop can utilize the nutrients. This excess nitrogen outside of the growing season can end up in ground and surface waters. Applying manure to corn (*Zea mays*) during the growing season, referred to as sidedressing, could provide farmers with another window of opportunity to apply their manure, maximize nutrient uptake efficiency, and protect water quality. Replicated, on-farm studies were initiated in 2018 to evaluate sidedressing liquid swine manure to corn using tanker or drag hose application systems. Both systems were able to inject the manure between corn rows to reduce ammonia volatilization. In the first study using a drag hose applicator, liquid manure was compared to sidedressed anhydrous ammonia, 32% urea ammonium nitrate, and a no-sidedressed-nitrogen control. All sidedressed N sources resulted in similar corn yield in 2018 (approximately 206 bu ac^{-1}) but not 2019. In 2019, yield was significantly lower in the manured plots than the other N sources (171 vs approximately 218 bu ac^{-1}). This is likely because the application rate was lower than expected due to operator error, applying only 90 lb N ac^{-1} instead of 140 lb N ac^{-1}. In the second study using the tanker applicator, manure application timing was the experimental factor. Manure was applied when the fourth and seventh corn leaf collars had emerged (V4 and V7 growth stages) and compared with anhydrous ammonia sidedressed around V4 (the farmer's standard practice). Corn sidedressed with swine manure by tanker decreased yield in both years compared to the sidedressed anhydrous ammonia. This may have been due to compaction issues from the tanker or perhaps the manure N did not release quickly enough during these growing seasons.

INTRODUCTION

Spring application of manure prior to planting corn is often difficult to fit into a farmer's schedule in the upper Midwest, as the growing season is shorter than other parts of the country. Fall and winter applications give the farmer more time, but run the risk of losing nutrients through runoff, erosion, leaching, and denitrification. There is growing interest in sidedressing manure in place of chemical fertilizers to reduce costs and increase the window of opportunity for application. In Ontario, corn yields were higher than the long-term average when sidedressed swine manure was injected but were variable for topdressed manure (Ball Coelho et al. 2005). In Ohio, a four-year study showed a yield increase in corn sidedressed with 200 pounds of plant available nitrogen per acre of swine manure compared with the same rate of 28% urea-ammonium nitrate (Arnold 2015). Both studies used swine manure from finishing operations, as this is more nutrient dense than other types of swine operations. The researchers in Ohio have recently expanded from using manure tankers to apply the manure to using dragline systems, with positive results. They also did a study dragging a line over corn at various growth stages and found that corn yields were not diminished if the corn was draglined at stage V3 (about 3 inches high) or earlier (Arnold 2017). This practice has not been evaluated in the upper Midwest, however.

MATERIALS AND METHODS

Replicated, on-farm studies were initiated in 2018 in second-year corn to evaluate sidedressing liquid swine manure to corn using tanker or drag hose application systems. Both systems were able to inject the manure between corn rows to reduce ammonia volatilization. In the first study using a drag hose applicator, liquid manure was compared to sidedressed anhydrous ammonia, 32% urea ammonium nitrate, and a no-sidedressed-nitrogen control. At planting, 40 lb ac^{-1} of nitrogen (N) was applied to the whole field. The remaining 140 lb N ac^{-1} was applied at sidedress with the different nutrient sources. For manure, about 3,500 gal ac^{-1} was applied to reach the targeted first year available N rate. Each treatment strip was replicated four times in the field. The farmer harvested the corn and yield data was verified with a weigh wagon. Moisture content was measured and used to standardize yield to 15.5% moisture content.

In the second study using the tanker applicator, manure application timing was the experimental factor. Manure was applied when the fourth and seventh corn leaf collars had emerged (V4 and V7 growth stages) and compared to the farmer's traditional practice – applying anhydrous ammonia around the V4 growth stage. At planting, 40 lb ac^{-1} of N was applied to the whole field. The remaining 155 lb N ac^{-1} was applied at sidedress. For manure, about 4,000 gal ac^{-1} was applied. Each treatment strip was replicated three times in the field. The farmer harvested the corn and yield data was verified with a weigh wagon. Moisture content was measured and used to standardize yield to 15.5% moisture content.

RESULTS AND DISCUSSION

In the first study using a drag hose applicator, we observed that N-deficient striping had occurred in the corn in the swine manure plots due to possible issues with flow distribution or soil compaction (Figure 1). At harvest time, all sidedressed N sources resulted in similar corn yield in 2018 but not 2019 (Figure 2). In 2019, we found out afterwards that the application rate had been much lower than expected, applying only 90 lb N ac^{-1} instead of 140 lb N ac^{-1}. This likely explains lower yield in the manured plots compared with commercial fertilizer plots. More details can be found in Pfarr et al. (2020).

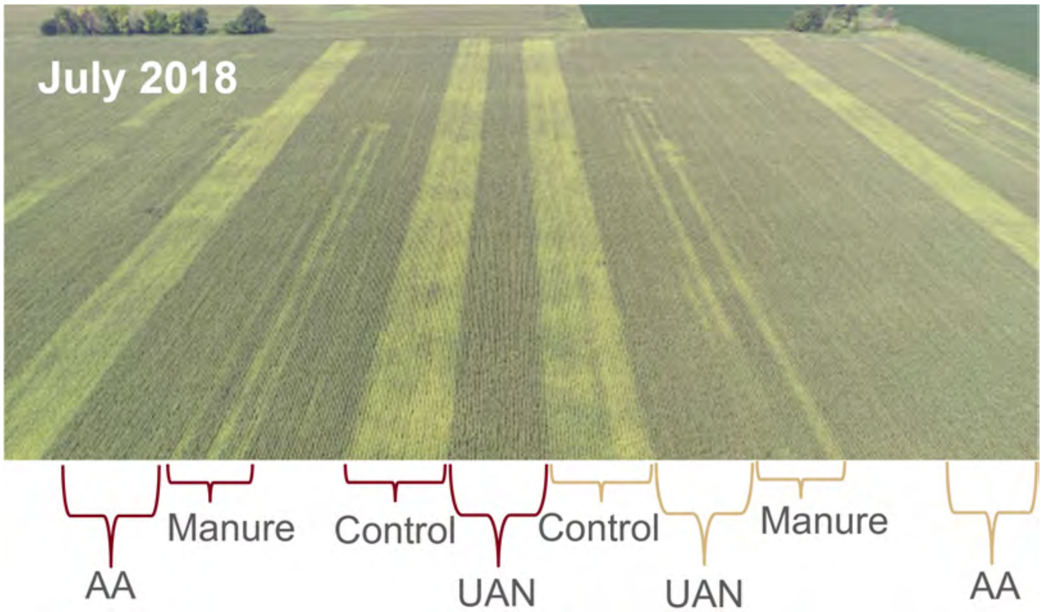

Figure 1. An aerial photo of maize taken mid-season approximately one month after sidedressing in 2018. Treatments include anhydrous ammonia (AA), swine manure, 32% urea ammonium nitrate (UAN), and a no-sidedressed N control.

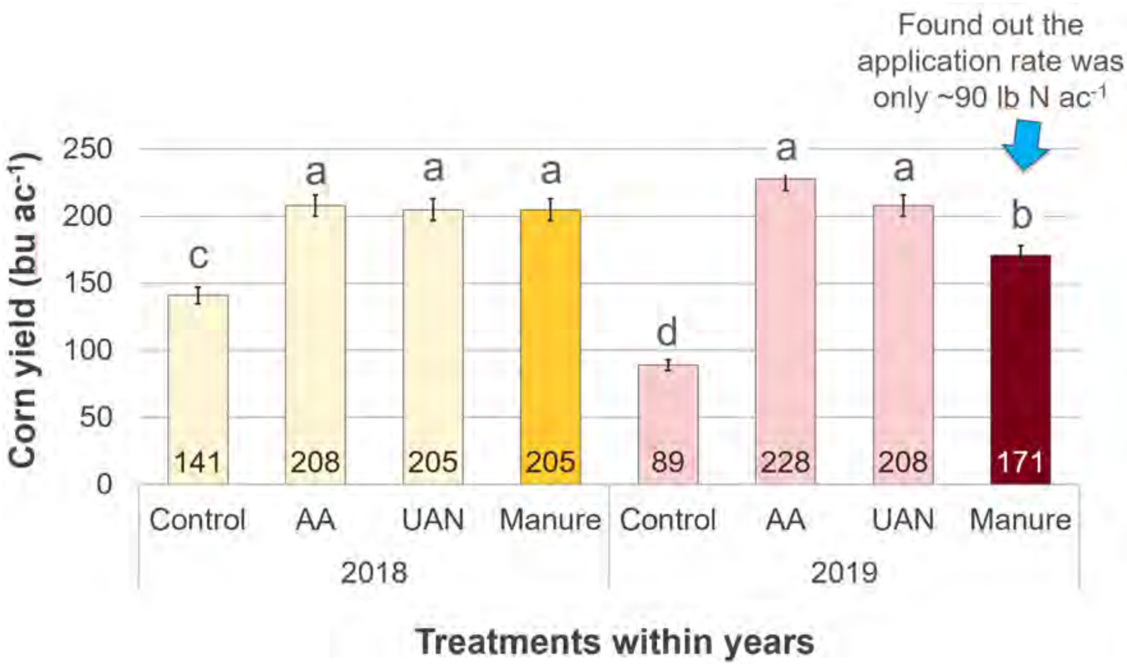

Figure 2. Corn yield following different sidedressed N sources: Control (no N beyond 40lbs N applied at planting across entire field), anhydrous ammonia (AA), liquid urea-ammonium nitrate (UAN), and liquid swine manure applied with a dragline application system (manure). All N sources were applied to supply an additional 140 lb N ac^{-1}. Bars with different letters were significantly different ($P < 0.05$).

In the second study using a tanker applicator, corn sidedressed with swine manure resulted in a 6 to 15% yield decline compared with the anhydrous ammonia treatment (Figure 3). This may have been due to compaction issues as the manure tanker system is much heavier than a dragline system. The narrow-row tires that were used to fit between rows of corn, compared to the much wider flotation tires used during the non-growing season, may have enhanced compaction, thus affecting crop growth and nutrient uptake.

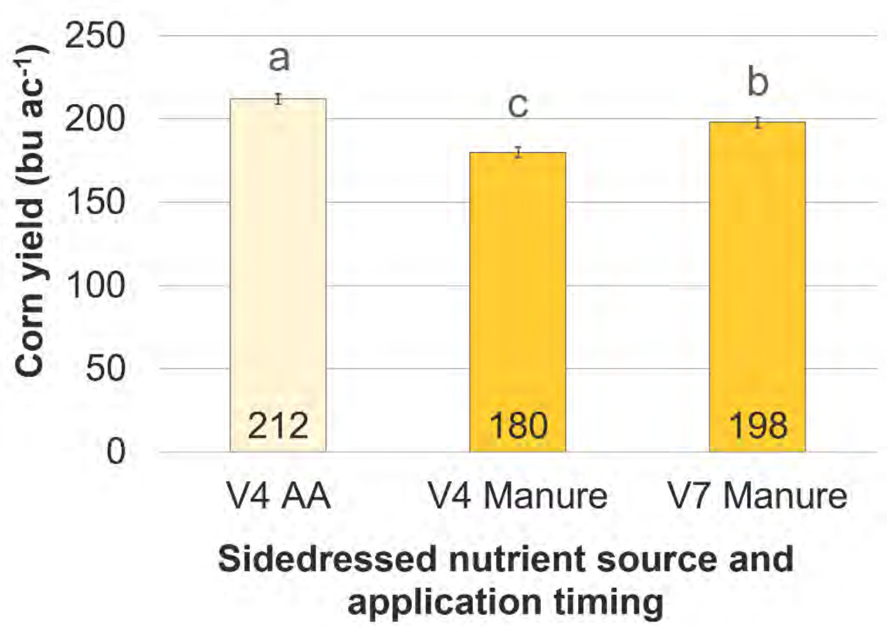

Figure 3. Corn yield following different sidedressed N sources at different times: Anhydrous ammonia (AA) applied at the 4th leaf collar (V4) growth stage and liquid swine manure applied with a tanker application system (manure) at the V4 and seventh leaf collar (V7) growth stages. All N sources were applied to supply an additional 155 lb N ac^{-1} (40 lb N ac^{-1} was applied over the entire field at planting). Bars with different letters were significantly different ($P < 0.05$).

Overall, swine manure was a good nutrient source for sidedressing corn during the growing season, particularly when applied with a dragline hose system. A tanker application system, however, may have caused too much compaction during application, leading to reduced corn yield. More research is needed to determine if there are adjustments to the implements that can be made to reduce compaction issues.

ACKNOWLEDGEMENTS

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CONSERVATION PRACTICES LOWER SOIL TEST PHOSPHORUS REQUIREMENTS AND OPTMIZE CROP YIELD

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ABSTRACT

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

INTRODUCTION

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

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

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

MATERIALS AND METHODS

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

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

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

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

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

RESULTS AND DISCUSSION

Soil testing

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

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

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

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

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

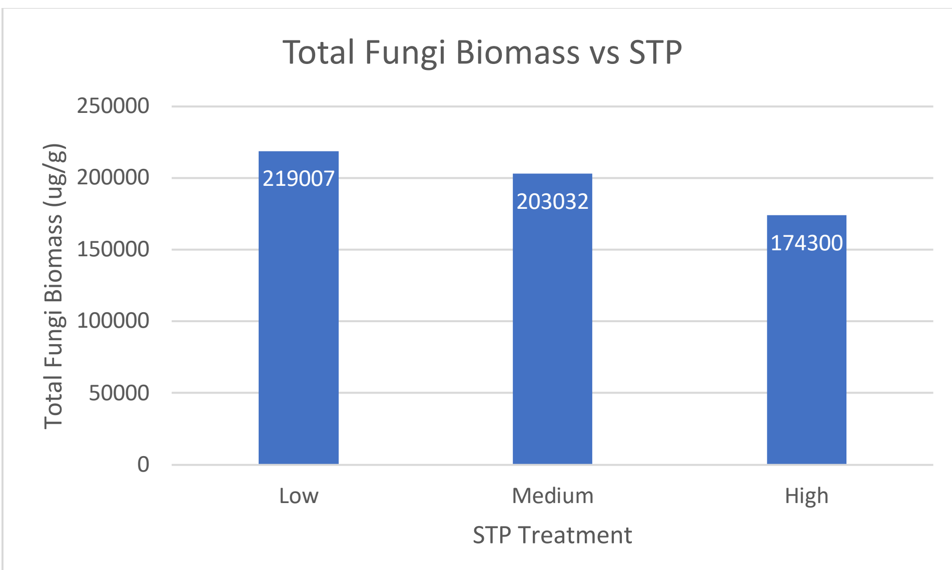

Figure 1. Total fungi biomass as calculated through NLFA processing as affected by the low, medium, and high soil test P category treatment areas.

P Uptake- Plant Samples

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

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

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

Water testing

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

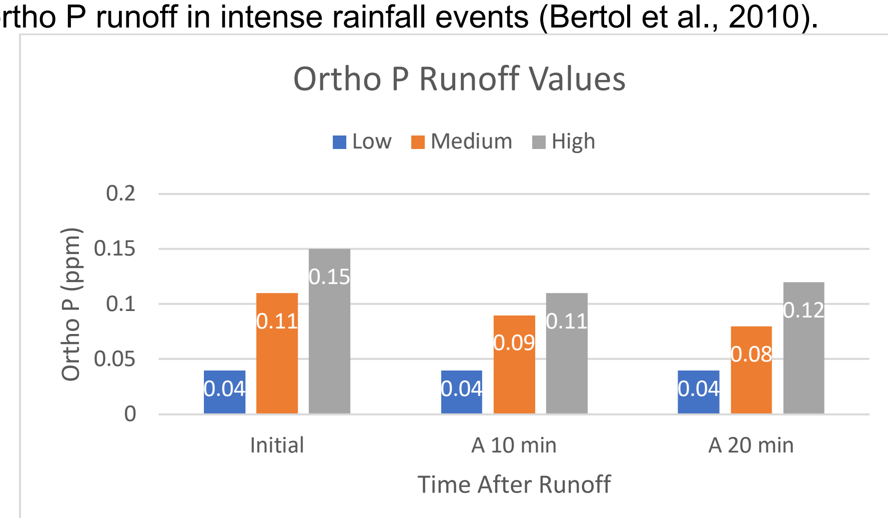

Figure 2. Average ortho P runoff values for low, medium, and high P treatment categories.

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