51st Annual

NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

17-18 November 2021

PROCEEDINGS

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ORAL PROCEEDINGS

FARMING THE DATA: NEW PARADIGM IN PRECISION AGRICULTURE

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ABSTRACT

Precision Agriculture has been around for over two decades. The first decade had a strong focus on quantifying spatial variability in soils, the second decade spent significant time on science and technology of precision management of nutrients. Now, with increasing adoption of Precision management techniques and practices there is interest in harnessing the power of data to grapple the new paradigm of making management decision based on evidence. The success of future farming practices, output, efficiency and sustainability, would rely heavily on “farming the data” as much as “farming the land”. This presentation will empower the audience with research based information on how precision agriculture is embracing information and communication technologies and numerous aspects of big-data to transform agronomy and crop production systems. This presentation will include examples of where big-data has been pivotal in addressing agronomic challenges as well the greater role big-data can play in enhancing our understanding of variability in crops and soil properties as well as analyzing spatially dependent datasets to make highly accurate and timely agronomic decisions.

A NEW FRONTIER BELOW THE HORIZON: MY WORK WITH PIVOT BIO BIOLOGICALS

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ABSTRACT

Symbiotic Nitrogen (N) fixation is an amazing process that harnesses the power of two organisms (a legume and rhizobium) to mutually benefit one another. However, the process of biological N fixation or the reduction from dinitrogen gas to ammonia/ammonium via the nitrogenase enzyme is an expensive one. The relationship between host plant and rhizobium hinges on the free exchange of N for carbon and other metabolites. Nitrogen fertilizer is often the most limiting nutrient for cereal crop production around the globe and for many regions nitrogenous fertilizer production constitutes a significant cost that many developing countries cannot afford. Due to the constraints of production, cost, and environmental implications of commercial fertilizer use there is growing interest to investigate the potential for biological N fixation to help feed nonlegumes which supply the bulk of human calories. To investigate and develop meaningful relationships between nonlegumes and free-living, N fixing bacteria a group of scientists came together and founded Pivot Bio.

During the winter of 2015 I was contacted by a group that were interested in using ^{15}N to track N through various biological processes and determine its fate inside the corn plant (*Zea mays* L.). After a series of discussions, a trial was developed to estimate the N contributions of free living microbes to corn produced in an irrigated environment under severe N limitations and moderate N limitations. This first series of trials focused on the interaction of N fertilizer rate and microbial strain on the corn response parameters as well as the estimated N contribution from the microbial strain. Early results suggested that as much as 33 kg N ha^{-1} was being supplied to the corn plant via the free-living microbes under various environments and fertilizer additions. Over the course of the next four years our group would investigate several new microbial strains and found that many of the products developed by Pivot Bio were providing not only supplemental N to the corn plants but other potential benefits that lead to increased yield not explained by N uptake alone. Increased investigation of free-living microbes that can fix N and provide other benefits to the corn plant or other cereals could be a true game changer rivaling the Green Revolution or development of the Haber-Bosch process.

THE MRTN APPROACH: PAST, PRESENT, AND FUTURE

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ABSTRACT

The method of using crop N response data assimilation, now called the “MRTN approach,” was conceived at a September, 2004 meeting in Bettendorf, Iowa of scientists from several Corn Belt states. This meeting was prompted by findings in field trials that showed substantially lower optimum N rates than those based on using corn yield goal to predict crop N needs; most also showed no correlation between EONR and yield at EONR across trials. The MRTN method is straightforward: yield data from N rate response trials are converted to “return to N” (RTN) responses by multiplying the predicted yield increase (from a best-fit model) from N at each N rate by the price of corn, and subtracting N cost (rate times the price of N.) These predicted RTN responses, by 1 lb N/acre increment, are averaged over trials within specific states or regions of states, and the apex of the resulting mean curve identifies the N rate that produces the Maximum RTN (MRTN). The Corn N rate calculator (CNRC) at http://cnrc.agron.iastate.edu/ allows the user to input N and corn prices to find MRTN values for corn following corn and corn following soybean in seven Corn Belt states. It has links to more information about the approach.

One ongoing issue with the MRTN approach is the size of the database needed to produce accurate MRTN values. Both the size of the database used initially in the CNRC and the pace of addition of new data differ among states. While it is difficult to gauge the effect of trial number on soundness of MRTN values, adding substantial numbers of trials to the Illinois and Iowa databases, and dropping some older data, have resulted in MRTN values increasing. This has happened in all three regions in in Illinois, and has been more pronounced in southern Illinois, where the corn-following-soybean MRTN (at the $/lb N:$/bushel ratio of 0.1) rose from 171 lb N/acre in 2015 to 200 lb/acre in 2021. Much of the added data in Illinois has come from on-farm trials managed by the Illinois Fertilizer & Chemical Association. While some states may not have the means to add very many trials, it would be useful to conduct a few “validation” trials each year to see if the MRTN based on previous data remains valid.

Nitrogen responses vary greatly among fields, soils, and growing seasons, and so the RTN curves used to produce the MRTN vary widely, with EONR (MRTN of individual response curves) values ranging from less than 100 lb N/acre to more than 250 lb/acre. The CNRC displays the distribution of EONR values as an option. The current MRTN value for central Illinois, for corn following soybean and at the 1:10 price ratio, is 181 lb N/acre, based on based on 284 N response trials. EONR values among these trials range from 42 to 276 lb/acre, with an average of 168 lb N, 13 lb less than the MRTN. This difference arises from the fact that the Δyield (yield at EONR minus yield at zero N) distribution is skewed to the right, with the mean Δyield (109 bu/acre) higher than the median (102 bu/acre.) Of the 284 sites, 78 (37%) have EONR values higher than the MRTN, and the N rate needed to reach 95% chance of sufficiency across trials is 240 lb/acre. Using 240 lb N (59 lb more than the MRTN) adds 2.9 bushels to the yield, but deceases RTN by about $15 per acre: adding enough N to assure maximum yield across all fields and seasons is neither profitable nor environmental friendly. High fertilizer N requirements are found over a wide range of yield levels in N rate trials, in both dry and wet seasons, and it is not clear that our ability to identify fields that need additional N, at least early enough to make in-season adjustments, will improve.

Although the MRTN approach has been used and promoted for 15+ years, the fact that the MRTN N rate is substantially lower than yield-based N recommendations, especially as yields continue to increase, has worked against producer acceptance of the MRTN approach. In Illinois we are looking at ways to build on the foundation of the MRTN to extend and improve its value and use. As an example, we are initiating a project to establish two rates—one the field rate and one higher or lower, depending on the field rate—in order to compare near-MRTN rates with rates 50 to 60 lb higher than the MRTN. We are also examining how ecological adjustments, such as increasing the price of N once N rate exceeds the EONR (as a way to cover the cost of increasing nitrate leaching losses), might influence the MRTN. These are only a few examples of how we might build different N-input decision methods once we have a solid foundation of research-based N response data to build upon.

IMPLEMENTATION AND VALIDATION OF THE MRTN RECOMMENDATION SYSTEM IN WISCONSIN

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ABSTRACT

The maximum return to N (MRTN) recommendation system for corn was implemented in Wisconsin in 2006. In many ways, MRTN is a dynamic extension of N response-based N recommendation that was implemented in 1991. Vanotti and Bundy (1994) demonstrated the utility of using N rate response trials as the basis for N recommendations. And that grouping soils by N response and soil characteristics was useful could improve N recommendations. In Wisconsin recommendations, relative yield potential was qualitatively defined for each soil series in using inherent soil properties and professional judgement of several experienced pedologists from University of Wisconsin-Madison and USDA-NRCS. Relative yield potential rankings of low, medium, high, and very high were based on soil water holding capacity, drainage class, depth of root zone, and length of growing season. Data from N response trials were grouped by based on each site's relative yield potential category and soil texture (sand and loamy sand vs all other textures) and N rate recommendations developed for each group.

As MRTN was initially implemented in Wisconsin, the concept of soil groups as previously defined was maintained. MRTN rates at the 0.10 N:corn price ratio were very similar to the previous N rate guidelines that were based on N response which has been calculated at a N:corn price ratio of 0.075. MRTN provides a clear advantage over the previous N response-based system. First, N recommendations can be adjusted to reflect changing prices of N and corn. Second, a range of N rates that produce profitability within $1/a of the MRTN can be calculated.

Wisconsin MRTN rates can be calculated using the Corn N Rate Calculator website (http://cnrc.agron.iastate.edu), but are also provided in a table in UW Extension publication A2809 Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin (Laboski and Peters, 2012). While the table is less dynamic than the website, it provides an MRTN rate and range of profitable N rates for four N:corn price ratios (0.05, 0.10, 0.15, and 0.20), soil yield potential groups, and different previous crops. Our primary dataset is corn following corn or corn following soybean. Sites where corn followed wheat responded to N similarly to where corn followed soybean; thus, a previous crop of small grains was grouped with soybean. Where corn follows forage legumes, legume vegetables, and green manures, growers are instructed to use the same MRTN values for corn following corn and take the appropriate N credits. From the outset, we have provided growers with guidance on selecting which end of the MRTN range might be most useful. This guidance was based on previous guidance. Furthermore, the preplant nitrate test (PPNT) and presidedress nitrate test (PSNT) interpretations were adjusted to be compatible with MRTN.

Quantitative criteria for grouping soils was established in 2012. The goal of this effort was to clearly define how soils were grouped such that anyone with the criteria and necessary soil property data could place soils in groups. University of Wisconsin and USDA-ARS soil scientists went through numerous iterations before finding a set of criteria that grouped a large majority of soils the same as previous qualitative grouping. Re-evaluating how soils are grouped into N response categories is on the horizon. One key area that could result in an improvement in MRTN is related to medium yield potential soils. Currently, medium yield potential is defined by soils that are: poorly or very poorly drained, less than 6 inches of available water capacity in the top 60 inches of soil, and/or less than 30 inches of soil over bedrock. New grouping might include splitting up the medium yield potential into two groups that reflect different N loss mechanisms (leaching vs denitrification) and/or using soil organic matter to separate sands and loamy sands with less than 1% organic matter.

Currently small plot trials are on-going at university research stations and in small plots on grower fields in collaboration with county extension educators and Nutrient and Pest Management Program outreach specialists. The objective of this work if to obtain more data to use in the recommendations, evaluate how well the recommendations are preforming, and increase grower acceptance and adoption of MRTN guidelines. Overall MRTN is performing reasonably well. MRTN frequently under recommends N, on coarse textured soil (sand to sandy loam), especially in years where there is untimely or excessive

rainfall after N application. This, perhaps, is not so much a failure of MRTN as it is chronic challenge to managing N on sandy soils.

In 2012, the MRTN approach was used develop N rate guidelines for winter wheat. Grouping of soils for winter wheat is less complex than for corn, partly because of much smaller database for wheat. Soils are grouped based on texture: sandy (sandy and loamy sands) and loamy (all other textures) categories. For loamy soils, previous crops of soybean and small grain are grouped together because N response was similar. When corn is a previous crop, the preplant nitrate test can be used to further subdivide the N response for wheat. As with corn, the MRTN and range of profitability within $1/a is presented for four N:corn price ratios (0.05, 0.075, 0.10, and 0.125). The MRTN concept will continue to be developed for winter wheat.

INDEPENDENCE OF YIELD WITH N-RATE AND THE USE OF EONR FOR N RECOMMENDATIONS IN NORTH DAKOTA

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ABSTRACT

Evidence for the independence of N-rate and yield comes from the improved relationship of N-rate with relative yield compared to raw yield in corn, spring wheat and sunflower N-rate experiments in North Dakota. Relationships were also improved in corn by grouping experiments by regional location and whether the soils are high clay (>40% clay) or not, and discriminating between long-term no-till (6 years or more continuous no-till) or conventional till. In spring wheat, regional differences were also important, as is tillage. Also, there is an area of shale-containing soil along the Canadian border that acts like a natural slow-release N fertilizer, so that area is also segregated. In spring wheat, since market price depends heavily on grain protein concentration, the EONR algorithm includes not only the grain yield response with N rate, but also grain protein response to N rate. In sunflower, segregation is based on region and tillage, and the EONR algorithm includes not only grain yield response to N, but also oil concentration with N rate. Soil analysis for residual nitrate-N to 2 feet in depth is an important modifier to corn, spring wheat and sunflower N recommendations.

INTRODUCTION

There has been a long history of trying to relate crop yield to nutrient availability (Johnson, 1991) beginning with Mitscherlich (1909). From this relationship, the logical step was to relate yield goal with N rate (Bray, 1954). For about 60 years, the accepted formula for recommending fertilizer N and other nutrients was based at least in part on yield goal (Dahnke et al., 1988; Rehm and Schmitt, 1989; Fernandez et al., 2009).

Raun et al. (2010) and Arnall et al. (2013) showed that the response index (maximum yield in an N rate experiment divided by the check yield) was not related to maximum yield. Therefore, there was no relationship between yield and N rate. Mid-west corn-belt states contributed corn N rate experimental data and found that there was no relationship between yield and N rate. Segregating the data by state and using relative yield rather than actual yield, relationships were much improved. An economic production function was imposed on the resulting equations to factor in the cost of N and price of corn (Sawyer and Nafziger, 2005) and produce corn N recommendations.

At North Dakota State University, N recommendations for spring wheat, corn and sunflower began to be reexamined in 2005. From 2005-2009, spring wheat/durum wheat N rate trials were conducted. From 2010-2014, corn N rate trials were conducted, and sunflower N rate trials were conducted from 2015-16. The independence of yield and N rate were tested within each data set. The objective was to produce a modern set of N rate recommendations for each crop, to help North Dakota producers achieve the greatest net income from the application of N fertilizer inputs.

METHODS

Spring wheat/durum

Archived data from 50 North Dakota experiments conducted from 1970-2005 (Bauer, 1970, 1971; Dahnke, 1981; Etchevers, 1970; Goos et el., 1981, 1982; Scheider, 1980; Sobolik, 1977; Vanden Heuvel, 1980) were added to a database consisting of results of 50+ experiments conducted from 2005-2009 in North Dakota. Residual soil nitrate data was available for all sites. Total known available N is defined as the sum of residual soil nitrate-N, the N treatment rate, and consideration of any N credit from an immediately previous crop. Combined data analysis was compared with segregated data from east/north of the Missouri River to west of the Missouri River. These data were compared with tillage combined (conventional tillage with long-term no-till sites) and then segregated within region. In addition, data from an area named ‘the Langdon Region’ achieved maximum yield with markedly less N compared to the remainder of eastern North Dakota, so these were segregated as a separate region. The Langdon Region was previously described by Redmond and Omodt (1967) as a ‘shaley soil zone’ within North Dakota. In addition, Power et al. (1974) found that this shale contained large amounts of mineralizable ammonium. Therefore, the soil in The Langdon Region acts as a natural slow-release N soil, reducing the N required to grow a crop.

N rate studies from 2005-2009 were carried out on farmer cooperator fields, using their own hybrid choices and field equipment. Treatments were N rates of 0, 40, 80, 120, 160 and 200 lb N/acre were applied as urea treated with Agrotain™ (Koch Agronomic Services, Wichita, KS). Some sites were conventional tillage while others were long-term no-till. Experimental units were 10 feet wide by 25 feet long. The experiments were harvested using a Hege™ (Hege Company, Waldenburg, Germany) plot combine with a 4-foot head. Wheat was cleaned before weighing, and a subsample was taken after weighing and sent to the NDSU quality laboratory for protein analysis.

Corn

Data were collected from 130 N-rate trials from 2002-2015. With permission, 9 sites were from southern Manitoba (courtesy of Dr. John Heard), 6 sites were located in northern South Dakota, and 23 sites were from studies performed in northwest Minnesota (courtesy of John Lamb & Russ Severson), with the remaining 92 studies performed in North Dakota. Datasets segregated into eastern and western North Dakota. All serious corn production in western North Dakota is performed under no-till, so no further segregation was warranted in this region. In eastern North Dakota, data segregated under conventional till and long-term (6 years or more continuous no-till), and high-clay soils and medium-textured soils (other) with high or low production history. The low production history soils consisted of those with a history of seasonal water saturation and subsequent denitrification if high clay, and leaching in medium-textured soils (which includes coarser textures). The low production categories were prompted to strongly consider split applications/side-dress, because N rate is not the problem in these soils, but timing to miss the late April through mid-June wet season. Corn experiments in North Dakota consisted of randomized complete block designs, with four replications and N treatments of 0, 40, 80, 120, 160 and 200 pound N per acre applied near planting with Agrotain™-treated urea. Experimental units were 10 feet wide and 40 feet long. A single row was hand-harvested from each unit and shelled for grain weight, moisture off site.

Sunflower

Data were collected from 2015-16 from 28 sites in North Dakota. Experiments were randomized complete block designs with 6 N treatments of 0, 40, 80, 120, 160 and 200 pounds N per acre applied as ammonium nitrate near seeding. Experiments were located in farmer cooperator fields using the cultivars of their choice, and were seeded and weeds controlled using their equipment. Experimental units were 10 feet wide and 40 feet long. A single row was hand harvested from each unit and was threshed off site. A subsample was saved and later submitted for oil concentration analysis at the USDA-ARS sunflower laboratory in Fargo, ND, on the NDSU campus. The project graduate student conducted the oil analysis following training. Confection-type sunflower sites were not subjected to oil analysis.

Data was segregated into western North Dakota (all long-term no-till) and eastern North Dakota. In Eastern North Dakota, further segregation was made into conventional till and long-term no-till. Confection sunflower and oil-seed sunflower were segregated within each region.

2-Row Malting Barley

Data were collected from 2020-2021 from 4 sites in North Dakota. Experiments were randomized complete block designs in a split plot, with main plots being two cultivars, and 5 N treatments, 0, 40, 80, 120, and 160 pounds N per acre as SuperU. Experimental units were 8 feet wide by 40 feet long. Experiments were harvested with a plot combine with a 5-foot head. Subsamples were obtained after weight/moisture measurements and delivered to the Barley Quality Laboratory on the NDSU campus for protein and plump determination.

Statistics were calculated using SAS 9.3/9.4 for Windows, and graphs were constructed using Excel 2010.

RESULTS

The best visual demonstration of the independence of yield and N rate is through comparing graphs of the relationship of raw yields with N rate with standardized yields with N rate. A standardized yield, sometimes also referred to as 'normalized' yield, is the yield within an experiment divided by the greatest yield in the experiment. Standardized yield is also sometimes referred to as 'relative yield'.

Figures 1a shows the raw yield relationship with total known available N (N rate applied plus spring residual nitrate-N to 2 feet in depth plus any previous crop credits from previous year legumes or sugarbeet leaves) with an r^2 of 0.16 and 1b showing the standardized yield relationship with total available N, with an r^2 of 0.53. When a standardized yield relationship with total known available N is greater than the raw yield relationship, it demonstrates that relative yield is the most important factor, not actual yield.

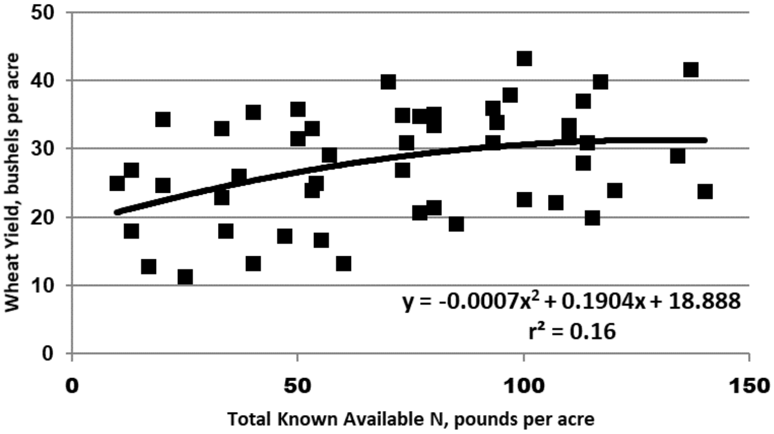

Figure 1a. North Dakota spring wheat/durum yields, west of the Missouri River, compared with total known available N, conventional tillage.

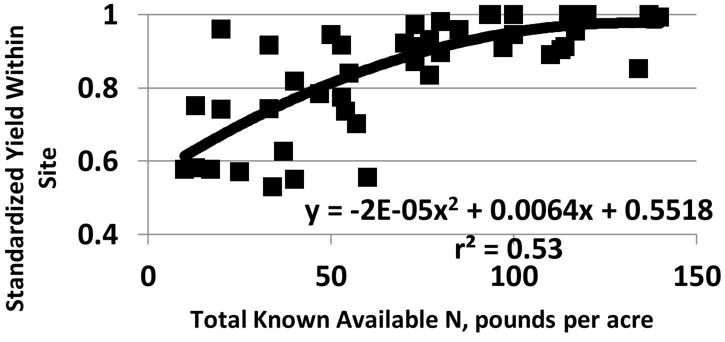

Figure 1b. North Dakota standardized spring wheat/durum yields, west of the Missouri River, compared with total known available N, conventional tillage.

Table 1. Regression of spring wheat/durum, corn, sunflower and 2-row malting barley yields vs total known available N using raw yield and standardized yield.

Comparison			**r^2 with total known available N**	
Crop	**Region**	**Tillage**	**Raw Yield**	**Standardized Yield**
SW/Durum	West	CT	0.16	0.53
SW/Durum	West	NT	0.19	0.62
SW/Durum	East	CT	0.32	0.39
SW/Durum	East	NT	0.26	0.45
Corn	West	NT	0.35	0.68
Corn	East HClay	Ct	0.22	0.47
Corn	East Med Tx	CT	0.29	0.50
Corn	East NT	NT	0.20	0.68
Sunflower	West	NT	0.27	0.47
Sunflower	East	CT	0.14	0.41
Sunflower	East	NT	0.16	0.30
2-row MB	East	NA	0.01	0.55

SW = Spring wheat; MB=malting barley; CT = conventional tillage; NT = no-tillage at least 6 years continuous. HClay are sites with >40% clay; Med Tx are sites with <40% clay.

From Table 1, all comparisons of yield with total known available N (TKAN) show a larger r^2 with standardized yield compared with the raw yield relationship. In wheat, corn, sunflower and 2-row malting barley, use of standardized data increased the relationship between yield and available N to the crops. This indicates that the 'cloud' of data around a raw yield vs available N relationship is a series of nearly parallel response curves. When standardized, the data around the normalized curve falls much tighter around the response curve as a result of the stacking of the individual site curves nearly on top of each other; the r^2 and the real N vs relative yield relationship of the whole is better expressed.

These phenomena may surprise crop management practitioners and farmers; however, the basis for similar recommended N rates regardless of realized yield might be explained by the sources of N availability to plants. Soil moisture acts to increase or decrease the availability of N to crops (Martin et al., 1982). In dry soils, N does not move to the roots with mass flow, but is restricted in its path to the root and uptake may be limited to diffusion or root contact. Also, in dry soil, N mineralization rate is lower. The result of poor N efficiency in dry soil is that the rate of N per bushel achieved is greater than in a moist soil. In a moist soil, N mineralization rate is high and movement of N to roots is more efficient, so N efficiency is high and higher N rates are not required to achieve higher yield. The old yield goal formulas did not consider other sources of N to crops. In N rate trials, application of zero-N never results in zero-yield. Nitrogen even in the absence of supplemental N, is provided through mineralization of N from residue and organic matter; N is added through atmospheric deposition; N is provided in smectitic soils through release of non-exchangeable ammonium; and N is provided from the activity of free-living (asymbiotic) N fixers from several genus of soil bacteria. Conditions that increase the contributions of 'natural' N sources also serve to increase crop yield. Contributions of soil N sources are apparently able to 'fill in the gap' to support greater crop yield with more favorable N supply. Also, the ability of the crop to access soil N and supplemental N is increased with more favorable moisture conditions.

In designing the N calculator for spring wheat/durum, the response of grain protein was included in the industrial production function (EONR). Below 14% protein a dockage was included, and above 14% and protein premium was included up to 15%. In sunflower, the oil concentration with N rate was considered, since oil percentage decreases always with increasing N rate. The dockage for low oil and premium for higher oil was considered.

This investigation supports the use of the MRTN concept in wheat, corn, sunflower, and 2-row malting barley, and also indicates that use of standardized, or relative yield within site may be a better factor to model with available N or N rate compared to raw yield data.

ACKNOWLEDGEMENTS

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CHLORIDE FROM FERTILZIER AND WATER POLUTION – SHOULD I BE CONCERNED?

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ABSTRACT

Chloride is a more recently recognized pollutant of concern in many states. In Minnesota, 50 lakes and stream reaches are impaired for chloride, 30% of shallow monitoring wells exceed the secondary health standard, and chloride is on the rise in many other waters. Chloride is toxic to aquatic life, can contaminate groundwater, and has additional environmental impacts. How much does fertilizer contribute? This presentation will cover chloride sources and how chloride impacts our waters.

SHOULD POTASSIUM CHLORIDE BE APPLIED TO SOYBEAN?

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ABSTRACT

Chloride (Cl) application as part of potassium chloride (KCl) fertilizer has never been identified for a potential to reduce crop yield. Chloride exists as an anion in the soil and can be leached from well drained soils. The objective of this work is to identify whether chloride can reduce the yield of corn (*Zea mays* L.), soybean (*Glycine max* var. Mer.), and hard red spring wheat (*Triticum aestivum* L. em thell.). Two separate trials were established in Minnesota to evaluate the application of different sources of potassium fertilizer, potassium chloride (KCl) and potassium sulfate (K_2SO_4), and calcium chloride ($CaCl_2$). Potassium (K) increased yield in situations where soil tests indicated a high potential for potassium to be deficient. Chloride did not impact grain yield of corn or hard red spring wheat and reduced the yield of soybean. Soybean grain yield reductions were small when KCl was applied directly ahead of the soybean crop either in the fall or spring at a rate to supply the expected removal of K for a two-year crop rotation. Yield reduction were less with the K was applied ahead of the rotational crop with soybean. The impact of Cl on soybean yield may be tempered by soil drainage and soil moisture content. While KCl is the most economical source of K for crops, soybean producers should keep the rate applied ahead of the soybean crop low and focus application ahead of crops more tolerant to Cl. In addition, more research is needed regarding Cl excluders for Northern soybean varieties for situations where high application rates of K are required.

MATERIALS AND METHODS

Long term trials were established at four locations in Spring 2017 [Crookston, Lamberton, Morris, and Waseca (Table 1)]. Two-year cropping rotations were established at each site in two blocks, one for each crop. A two-year corn-soybean rotation was established at Lamberton, and Waseca. A two year hard red spring wheat-soybean rotation was established at Morris and Crookston. Treatments are a combination of fertilizer rate, timing, and source. Fertilizer is based on a K application at a K rate of 100 and 200 lbs K_2O per acre which is roughly 1 and 2 times expected crop removal for the rotations (Kaiser et al., 2020a, 2020b, 2013). Two sources of K, KCl and K_2SO_4, are compared with a non-fertilized control. An additional source treatment includes $CaCl_2$ (calcium chloride) applied at a rate which supplies an identical amount of Cl as applied in the KCl treatments. The $CaCl_2$ treatment is used to determine if any impacts from KCl may be due to the Cl. Soil Ca content at the beginning of the study will be measured, but the Ca applied is not anticipated to have a significant impact on yield. Gypsum will be applied to balance S applied with the K_2SO_4 so all plots will receive a relatively high rate of S and Ca annually. Timing will consist of all fertilizer applied before soybean or before wheat or corn. A split plot design will be used where main plots will consist of a factorial combination of rate and time while the sub-plots will consist of fertilizer source (none, KCl, K_2SO_4, and $CaCl_2$).

Table 1. Summary of soil test data collected in spring 2017. Samples were collected from the 0-6 and 6-24” depths and are a composite of 8 separate cores collected from each main block.

Location	Soil Type	Sample Depth	Soil Test† P	K	pH	OM	Cl‡ Avg	StDev	K Base Sat.
		inches	--ppm--			-%-	-----ppm------		
Crookston	Wheatville	0-6"	11	124	8.1	2.9	5.0	0.9	1.12
		6-24"	--	--	--	--	2.5	2.2	--
Lamberton	Amiret	0-6"	7	131	5.0	3.5	4.2	0.9	2.67
		6-24"	--	--	--	--	2.8	0.6	--
Morris	Forman	0-6"	4	168	7.7	4.3	3.4	1.0	1.37
		6-24"	--	--	--	--	3.0	0.7	--
Waseca	Webster	0-6"	5	146	6.0	4.2	3.7	0.9	1.89
		6-24"	--	--	--	--	2.2	0.4	--

† P, Olsen phosphorus; K, ammonium acetate K; pH, soil pH; OM, organic matter.

‡ Average (AVG) and standard deviation (StDev) for the soil Cl extraction

Soil samples are collected after harvest from all plots sampling from the 0-6 and 6-24” depths. All samples will be air dried and ground prior to analysis. Exchangeable K is determined on the 0-6” samples while Cl will be analyzed on all depths. Initial soil test data are summarized in Table 1.

A second set of soybean trials were established at 3 sites (Becker, Morris, and Waseca, MN) in 2020 and 2021 comparing or four varieties which vary in IDC/salt tolerance to determine if salt tolerance is an indicator of potential tolerance of excess Cl. The variety sets varied by year and consisted of Asgrow 14X7, 14X8, 17X7, and 17X8 in 2020, and Asgrow 13XF0, 14X8, 17X8, and Gold Country 1827X in 2021. Three Cl treatments, no Cl and 500 lb/ac of Cl applied either as KCl or $CaCl_2$ were applied. A strip plot design was utilized where varieties were planted as strips over top the fertilizer treatment. Soil test results are not shown for the second study. Soil types for Morris and Waseca were similar as those given in Table 1. The soil type at Becker was a Hubbard loamy sand. Becker was the only site which supplemental irrigation was applied. Average chloride content in the irrigation water was 32 ppm measured in 2020 at Becker.

All crops were harvested with a research grade plot combine. Corn grain yield is reported at 15.5% grain moisture content. Hard Red Spring wheat and soybean yield are reported at 13% moisture. Statistical analysis was conducted using SAS 9.3 assuming fixed effect of fertilizer source, rate, and timing in the long-term study and source and variety fixed effects in the second trial and random year and block effects. All significant results are reported at the $P \leq 0.10$ probability level.

RESULTS AND DISCUSSION

A summary of source main effects is given in Table 2 across four cropping years for each crop at each location. Rate and timing main effects were seldom, if ever, significant and are not included. Fertilizer source affected corn and hard red spring wheat yield at one of two locations and at three of four soybean locations. Single degree of freedom contrasts were used to determine response to K and Cl. Potassium almost always increased yield in situations where source main effects were significant. The exception was Crookston where the source main effect was not significant but single degree of freedom contrasts indicated a small response to potassium. Overall soybean yields were relatively low at Morris and Crookston along with hard red spring wheat yield at Morris due to generally dry conditions and relatively high levels of soybean cyst nematode at Morris (not shown). Corn grain yield was increased at Lamberton but not at Waseca while hard red spring wheat yield was increased by K at Crookston but not at Waseca. Current fertilizer guidelines for corn and soybean in Minnesota suggest a response to K is more likely when soil test K is less than 200 ppm (Kaiser et al., 2020a, 2020b. All sites tested less than 200 ppm but not all sites responded to K. No K is suggested for wheat when the soil test is 160 ppm or greater (Kaiser et al., 2013).

Table 2. Summary of corn, hard red spring wheat, and soybean grain yield data across four growing years at four locations averaged for fertilizer source main effects across two fertilizer application rates and application timing where fertilizer was applied in the fall directly ahead of the soybean crop or in the fall ahead of the rotational crop. Response to K and Cl is given from results of single degree of freedom contrasts when the contrast indicated a significant effect of K or Cl. Small letters following numbers indicate significance among treatments at the $P \leq 0.10$ probability level.

		Source Main Effect				Response to	
Crop	**Location**	**None**	**$CaCl_2$**	**KCl**	**K_2SO_4**	**+K**	**+Cl**
		--------------------bushels per acre--------------------					
Corn	Lamberton	175c	176bc	181a	179ab	4.2	2.4
	Waseca	204	206	206	204	0	0
Wheat	Crookston	62b	62b	64a	64a	1.9	0
	Morris	36	36	37	36	0	0
Soybean	Crookston	38	38	39	39	0.7	0
	Lamberton	52b	51c	53bc	54a	1.3	-1.0
	Morris	25b	23c	26ab	27a	2.3	-1.7
	Waseca	67a	66ab	65b	67a	0	-0.8

There were seldom interactions between source and timing or rate so the data are not shown. The exceptions were all for the soybean crop. At Crookston there was a significant timing by source interaction which was due to the variation among sources only being significant when the fertilizer was applied ahead of the soybean crop. Rate and timing main effects are not shown as they were seldom significant except for the timing main effect which differed for soybean at Lamberton and Waseca. In both cases soybean yield was 1.5 bushels per acre greater when fertilizer was applied for soybean ahead of the corn crop. The fact that the timing by source interaction was not significant for soybean at Lamberton and Waseca is odd as soybean grain yield was greater when fertilizer was applied ahead of the corn crop, the negative impact of Cl on soybean grain yield did not seem to be affected by time of application. Additional data has shown that application ahead of the crop in rotation with soybean greatly reduces the risk of a reduction in grain yield (not shown). In the current study the reductions appear to be consistent regardless of fertilizer timing.

Chloride only increased yield at one location, Lamberton Corn. When impacted, soybean grain yield was always less when Cl was applied regardless of rate. The increases were generally small and likely would not be noticeable to soybean growers. When K was deficient K did increase yield, but the increase was typically greatest when potassium sulfate was the K source.

Table 3. Summary of soybean grain yield data averaged across four soybean varieties when 500 lbs of Cl per acre were applied as either KCl or $CaCl_2$. Small letters following numbers indicate significance among treatments at the $P \leq 0.10$ probability level.

Year	**Location**	**None**	**KCl**	**$CaCl_2$**
		--------------------bushels per acre--------------------		
2020	Becker, Waseca	67a	64b	65ab
	Morris	68a	49b	50b
2021	Becker, Morris, Waseca	45a	42b	39b

High rates of Cl were applied to study 2 in order to induce a negative soybean response to the nutrient. Data were analyzed by year across most sites as the variety sets differed between the years. Variety main effect grain yield data are not given in this article. Soybean grain yield did vary by variety but there was no interaction between variety and fertilizer source indicating consistent effects of K or Cl among the four varieties used. Yield data for Morris in 2020 was analyzed separately from Becker and Waseca due to greater impact on soybean grain yield from the fertilizer treatments at Morris (Table 3). Soybean grain yield was decreased by Cl by 18 bushels per acre at Morris in 2020 while the reduction was much smaller at Becker and Waseca which is consistent with the long-term study results. All sites responded similarly to fertilizer application in 2021. Average yield for the KCl and $CaCl_2$ treatments did not differ in 2021 and averaged a 4 bushel per acre reduction in grain yield. There was a tendency in 2021 for soybean grain yield to be numerically higher for KCl but the difference was not significant. The data in study 2 further indicates a general risk of yield reduction from Cl and that more work is needed to determine which soybean varieties could be considered Cl excluders.

Weather data are not given for the individual locations but likely impacted results at the given sites. The large yield reduction at Morris in 2020 in Study 2 and consistent reductions in soybean grain yield in the long-term trial are a result of poor drainage at the site and lower than normal precipitation in 2020 and 2021 (not shown). Crookston was similarly dry which resulted in lower yield potential in most years when studies were conducted at Crookston. What is interesting is the decrease in soybean grain yield at Becker which has a sandy soil that is excessively drained. However, well water samples indicate high amounts of Cl applied through the irrigation water on top of any Cl applied in fertilizer. The additional consistent reductions in soybean grain yield at Waseca, where rainfall should leach Cl out of the root zone, indicate a general risk of yield loss across most soils regardless of internal drainage. It should be noted that the rate of fertilizer applied in both studies was more than what is suggested for a single year application of K for corn, soybean, or wheat. It is possibly that yield would not be reduced by a lesser rate of fertilizer.

CONCLUSIONS

Soybean grain yield can be reduced by chloride contained in KCl fertilizer. These studies were not designed to determine the exact rate of KCl that would result in a reduction in yield. Research on rate of application is needed to determine whether rates lower than what would be applied to supply expected crop removal for a two-year corn-soybean or wheat-soybean rotation would not result in a reduction in grain yield. Potassium can increase yield and should be applied if soil tests indicate a potential deficiency. The reduction in soybean grain yield was less when fertilizer was applied ahead of the rotational crop. If higher application rates need to be applied as KCl it should be applied of the preceding crop. More research is needed to determine exact tolerance of soybean to Cl and whether alternative sources of K fertilizer should be considered if K is needed for soybean production.

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EVALUATION OF SOIL TEST METHODS AND EARLY TISSUE ANALYSIS TO ASSESS POTASSIUM RESPONSE IN SOYBEAN

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ABSTRACT

Multiple soil test methods have been evaluated as diagnostic tool for potassium management in soybeans. However, more research is needed to find the K extraction method that better correlates to soybean grain yield. Some soil test methods (e.g., 1 M NH4OAc) are not always good K uptake and grain yield indicators. Another extraction method (Mehlich-3) is similar to NH4OAc for most soils, and we know from previous research that these two extraction methods are strongly correlated, suggesting that they could be used indistinctively. They can be considered as a measure of the same soil K pool.

This study compared different soil test K methods (STK), evaluated the correlation to soybean yield and K uptake response in low testing soils, and assessed tissue analysis as an alternative for in-season correction options. The study was conducted at ten locations throughout eastern Kansas during 2019 and 2020. The treatments were a control with no K fertilization and rates with 50 lbs K2O/acre increments to a maximum of 150 lbs K2O/acre. Aboveground plant samples were collected at R6 stage to measure plant K uptake. Soil K was analyzed using five different methods for both dry and field-moist samples: NH4OAc, Mehlich-3, CaCl2, Resin- K, NaBPh4.

In general, soil extraction methods using moist soils were better correlated to K response than dry tests, especially for NH4OAc. Among all evaluated methods, the CaCl2 dry and moist, NH4OAc moist, Resin K, and NaBPh4 tests were the best when correlating to relative yield and K uptake. The CaCl2 dry is one the easiest and cheapest tests, also having a consistent correlation coefficient. Furthermore, it might be an alternative to the NH4OAc moist test because of the high correlation (r=0.91). Overall, the NH4OAc moist test was one of the best methods to estimate response to K in low testing soils; however, other non-conventional tests like CaCl2 dry might perform similarly but without the typic disadvantages of moist samples.

Plant tissue samples were collected at the V4, R2, R4, and R6 stages to measure plant K and Magnesium (Mg) concentration. Potassium concentration and K/Mg ratio at the V4 growth stage correlated well to whole plant K uptake at R6 and grain yield. Considering grain yield as the response variable, the critical concentration range for K and K/Mg ratio was 1.6 to 1.8 % and 2.3 to 2.4, respectively. The nutrient ratio was slightly better in predicting K uptake. Preliminary results from this study suggest that tissue analysis at early stages can be used as a diagnostic tool to assess the K status of the soybean crop. A new reference for K concentration was developed along with a K/Mg ratio that could be useful when sampling flexibility is needed.

FERTILIZER MANUFACTURE – CONVERTING NATURE’S NUTRIENT STORAGEHOUSE TO PLANT NUTRITION

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ABSTRACT

North American farmers rely on reliable supply of key fertilizer inputs to maintain productivity and profitability. Nitrogen fertilizers are produced from atmospheric nitrogen gas, while phosphate and potash fertilizers are mined from major North American deposits as well as others around the world. All the major fertilizers are supplied, in large part, by North American producers from domestic production supplemented by some imports from international producers.

Nitrogen production starts with one of earth’s most abundant materials, atmospheric nitrogen gas (nitrogen gas) that is easily accessible to everywhere. Because of the high energy needs to break the nitrogen triple bond, nitrogen production plants are in areas of abundant energy at low cost. New, low-carbon ammonia manufacturing processes are being explored.

Most US phosphate production occurs in Florida where phosphate rock is abundant. The phosphate “matrix” is a mixture of phosphate ores, sand and clay. This mixture is processed with sulfuric acid to produce phosphoric acid, which is then reacted with ammonia to form mono- and di-ammonium phosphate, the two most-used granular phosphate forms. Phosphoric acid is also used to make polyphosphate solutions.

North American potash supplies come largely from rich deposits deep underground in Saskatchewan, where some of the world’s largest deposits are found. Today, these deposits represent nearly half of known world reserves. The geological formation of these deposits is such that they provide a consistent ore body that is ideal for dry potassium mining. Potash is also extracted from mines in New Mexico and Utah, and from salt brines in the Great Salt Lake. Potash ores are crushed, washed, screened in a complex process that separates potash from other salts in the ore.

This presentation intends to provide a background on the production of the commercial fertilizers and the nature of the fertilizer industry from the perspective of fertilizer manufacturers.

IMPACT OF SITE-SPECIFIC VARIABILITY ON THE EFFECTIVENESS OF ACTIVE CANOPY SENSORS FOR IN-SEASON N MANAGEMENT IN CORN

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ABSTRACT

In-season nitrogen (N) management in corn guided by active canopy sensors is often associated with higher yields, profit and nitrogen use efficiency (NUE). However, these benefits could vary from field-to-field and year-to-year. These inconsistent relationships between technology and benefits represent a major challenge for increasing adoption of sensor-based N application in corn. Thus, a better understanding of which site-specific factors determine positive benefits from sensor-based N application is needed. Five years of on-farm research using field length strips were used to compare the cooperating grower's traditional N management with the sensor-based N management. Differences in yield, NUE, and profit between grower and sensor-based N application were associated with site-specific characteristics. Across sites and years combined, the sensor-based method used 33 lb N ac^{-1} less than the grower's method. This reduction in N applied resulted in non-significant yield losses and an increase of ~30% in NUE. Despite the spatial variability of the fields, base N rate applied pre-plant or at planting and the economic optimal N rate (EONR) were found as the most important management factors directing the success of sensor-base N applications. Variability in field specific factors such as organic matter (OM), sand content, and water holding capacity explained the success of active crop canopy sensors to direct in-season N applications. Total N savings from sensor-based N application decreased with OM from 1 to 3% and increased within OM higher than 3%. Understanding the importance and impact of site-specific variability on the effectiveness of active crop canopy sensors is vital to promote adoption of this technology.

INTRODUCTION

Site-specific N management is the strategy to apply at the economically optimal N rate (EONR) within a field, which can vary based upon soil type, water holding capacity, landscape position, and weather conditions (Mamo et al., 2003; Tremblay et al, 2012). Active crop canopy sensors that adjust N rates according to changes in crop reflectance have been adapted for real-time N applications to account for the spatial variability within fields.

Since 1988, the nitrate concentration in groundwater in Nebraska's Central Platte River valley has been steadily declining, largely due to the conversion from furrow to center-pivot irrigation. However, over the last 25 years, fertilizer nitrogen use efficiency (NUE) has remained static. This trend points to the need for adoption of available technologies such as crop canopy sensors for further improvement in NUE. Strategies that direct crop N status at early growth stages are promising to improve N fertilizer efficiency. Several crop active canopy sensors have been field tested and reviewed with promising results to improve NUE (Barker and Sawyer, 2010; Calaco and Bramley, 2018). In addition, research has been done to improve sensor-based N recommendations by adjusting the estimated target N rate used to initiate the sensor system (Franzen et al., 2016) and evaluate implementation strategies such as application timing (Samborski et al., 2009).

In this study we used six years of on-farm research testing on active canopy sensors combined with open-source soil data to summarize the economic and environmental benefits from active crop canopy sensors to direct in-season N application and relate its benefits to the magnitude of within field spatial variability.

MATERIALS AND METHODS

Field experiments

The Nebraska On-Farm Research Network launched a project in 2015 focused on improving the NUE. Project SENSE (Sensors for Efficient Nitrogen Use and Stewardship of the Environment) compares crop canopy sensors to fixed-rate, in-season nitrogen application in corn. From 2015 to 2020, 58 site-studies were conducted, with five partnering Natural Resources Districts (NRDs): Central Platte, Little Blue, Lower Loup, Lower Platte North, and Upper Big Blue.

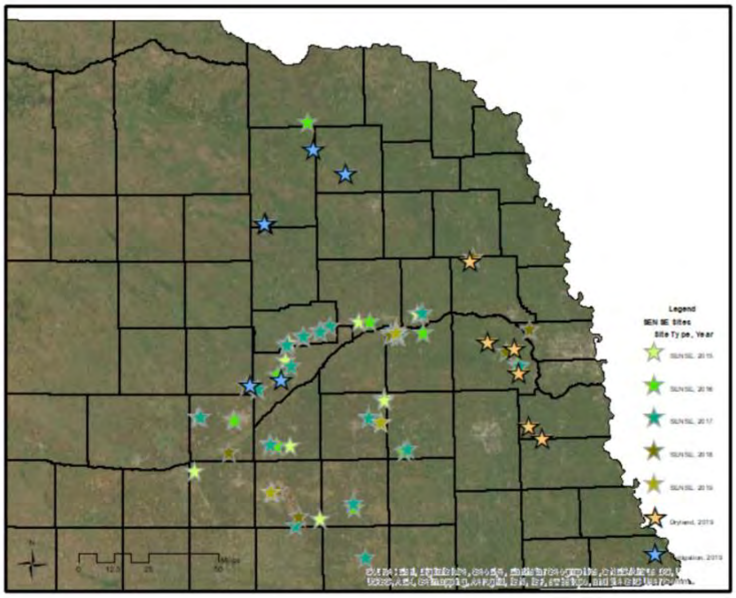

Figure 1. On-Farm research trials distributed across Nebraska.

A high-clearance applicator was equipped with an Ag Leader® Integra in-cab monitor and four OptRx® sensors. Each sensor is capturing the normalized difference red edge (NDRE) index, and the Ag Leader® in-cab monitor will compute the recommended N rate. An application rate module communicates the target rate from the Ag Leader® monitor to the rate controller. The applicator was equipped with straight stream drop nozzles to apply UAN fertilizer to the crop as it was sensed (Figure 2). This configuration of active sensors with a high-clearance machine has several benefits. Nitrogen rates were prescribed in real-time by the system and account for spatial variability across the field, application could occur up until the V12 growth stage, and sensing does not rely on sunlight, as the active sensors provide their own light source.

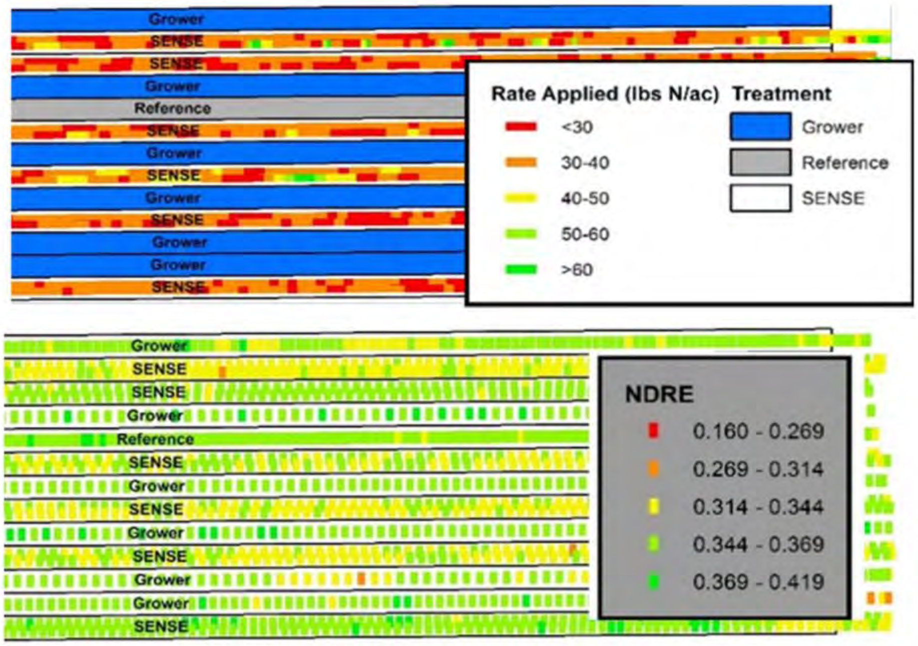

Figure 2. Layout of Project SENSE field trials with grower, SENSE, and reference strips (Top). NDRE values recorded during sensing/application through grower, SENSE, and reference strips (Bottom).

Project SENSE plots were arranged in a randomized complete block design with six replications (Figure 2, top). The grower's normal N management was compared with the Project SENSE N Management. For the Project SENSE strips, a base rate (75 lb N/ac for most sites) was applied at planting or very early in the growing season. Between V8 and V12, corn was sensed with the crop canopy sensors and variable-rate N was applied on the-go (NDRE values shown in Figure 2, bottom). The collected data consisted of grower N rates, Project SENSE in-season N rates, and yield, which were averaged by treatment strip.

Data Analysis

Each field was harvested by the grower collaborator and data were collected from the yield monitor. The raw data files were imported into farm management software (SMS Advanced v20.0 Ag Leader Technologies, Ames, IA) and were post-corrected for load weights if provided. The files were then exported into an Ag Leader advanced format file type and imported into a yield post-processing software (Yield Editor v 2.0.7, USDA-ARS, Columbia, MO) tool.

For each site, the average difference in N applied and the average difference in yield were calculated. NUE was also calculated as partial factor productivity of N (PFPN) (grain/N fertilizer). The coefficient of variation (CV, %) was calculated for grower and SENSE yields to assess the spatial variability.

To compare yield responses to N treatments (Grower vs SENSE), field N application data, NDRE, soil properties (e.g., organic matter, OM; sand content; soil water capacity), digital elevation maps (DEM), topographic wetness index (TWI) and yield points were aggregated. The optimal economic N rate (EONR) and the base N rate (Base_N) was also considered in the analysis. Regression analysis was used to associate differences in yield, total N, NUE, and profit with soil and management characteristics. All data analysis was done using R (R Core Team, 2021).

RESULTS AND DISCUSSION

Yield, total N, NUE and Profit differences

The sensor-based approach used 33 lb-N/ac less than the cooperating growers' approaches; the result was an average of 1.1 bu/ac less corn produced using the sensor-based method. In terms of productivity and NUE, the sensor-based approach produced an additional 15.5 lb-grain/lb-N compared to the cooperator approaches (Table 1). The sensor-based approach resulted in an average increase in profit compared to the grower approaches. At higher N and corn prices ($0.65/lb-N and $3.65/bu) noted during the study, the sensor-based approach was $16.70/ac more profitable. At lower N and corn prices ($0.41/lb-N and $3.15/bu), the sensors were $9.40/ac more profitable compared to the grower approaches. Input costs and crop revenues are important considerations regarding decisions about technology adoption; however, the sensors were a viable option for improving economic returns based on this study.

Table 1. Summary of 58 sites from 2015 to 2020 comparing sensor-based N management to the grower's traditional method.

Six-Year Average	SENSE	Grower
Total N rate (lb-N/ac)	159.3 B*	190.8 A
Yield (bu/ac)	216.9 B	218.0 A
Partial Factor Productivity of N (lb grain/lb-N)	81.4 A	65.9 B
Nitrogen Use Efficiency (lb-N/bu grain)	0.75 B	0.92 A
Partial Profitability ($/ac) [@3.65/bu and $0.65/lb-N]	$693.17 A	$676.44 B
Partial Profitability ($/ac) [@3.15/bu and $0.41/lb-N]	$622.20 A	$612.82 B

*Values with the same letter are not significantly different at a 95% confidence interval (SENSE vs. Grower).

Profitability and NUE

Figure 3 shows the overall distribution of the 58 irrigated field sites in terms of profitability and partial factor productivity of N (PFPN). Since 2015, 64% of field sites benefitted in terms of both profit (+$28/ac) and productivity (+22 lb-grain/lb-N) from using the sensor-based approach. Another 22% of field sites showed increased productivity (+13 lb-grain/lb-N); however, profit was negatively impacted (-$14/ac). About 10% of sites exhibited less profitability (-$25/ac) coupled with less productivity (-12 lb-grain/lb-N). In irrigated production, these data indicate there is high potential for improving productivity and profitability if growers could utilize a sensor-based, in-season approach to N management.

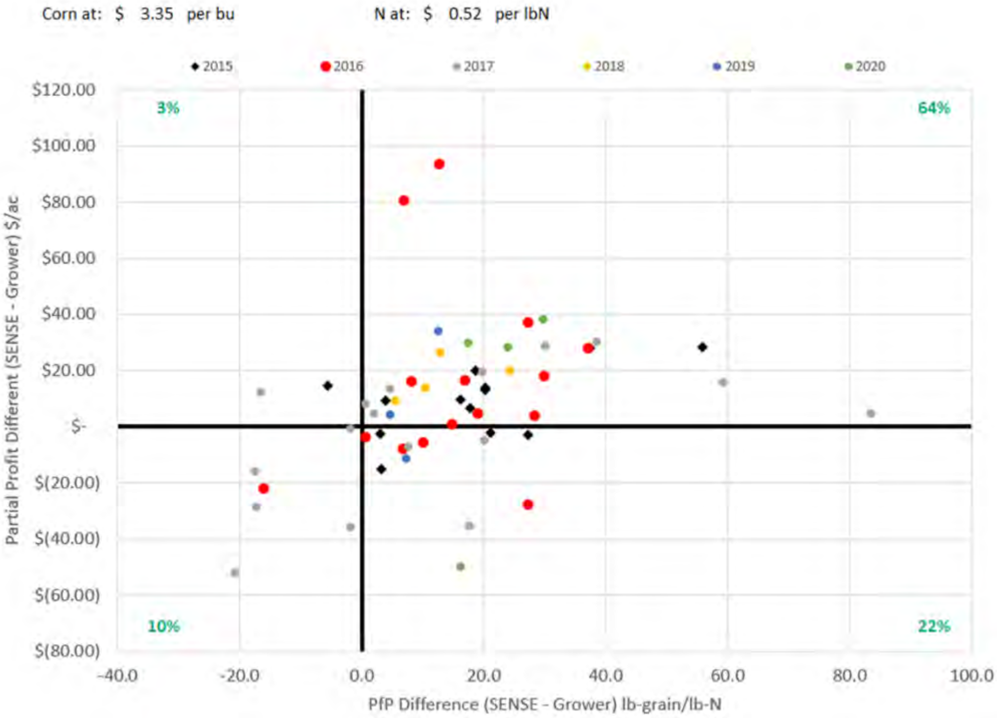

Figure 3. Profitability and nitrogen use efficiency of sensor-based N management compared to the grower's traditional management.

Canopy sensors benefits and associated soil and management factors

Spatial variability was associated with positive differences in yield and N savings from canopy sensors. The relationship between growers and SENSE yield variation showed that below 10% of CV, grower and sense yield variability was similar. Fields with grower's yield variability higher than 10% CV had an average reduction in yield spatial variability of 25% using crop canopy sensors.

Regression analysis across all sites and years showed that ~40% of the total N differences between SENSE and grower treatment could be explained by the EONR, Base_N, and DEM. The higher the EONR and Base_N application, the lower the N savings when using crop canopy sensors compared to grower's management. Elevation, thus landscape position, was also found to be positive related with N savings using crop canopy sensors. Thus, lower N rates from canopy sensors compared with grower's N rate on more sandier soils and low OM content. In contrast, N rate savings tended to be lower with higher OM in the soil when compared with grower's N rate.

In three out of the five years, the site-specific characteristics were able to explain 20 to 57% of the variability in N savings when using canopy sensors. The range of the explanatory variables was different within and across years. Thus, depending on the observed level of OM, the magnitude and direction of the effect was different. When OM was lower than 3%, the higher the OM the lower the benefits of crop canopy sensors. In contrast, when field observations were above 3% of OM, the higher the OM the higher the N savings from sensors. In 2015, for example, the N savings were lower with higher OM content.

In 2015 and 2017 the Base_N was a significant factor in the regression analysis, and EONR in 2016 and 2017. Consistently, the higher the EONR, the lower the differences between SENSE and Grower N rates (less N savings). In 2015, the N savings tended to increase when Base_N was higher than 90 lb N ac ^{1}.

Our study showed that the EONR imputed into the algorithm to direct the in-season sensor-based N recommendation was a critical factor determining the benefits from crop canopy sensors when compared to grower's N management. In addition, OM and Elevation were two of the main factors explaining N savings from canopy sensors. Further analysis will be conducted to better understand these finding and to translate results into a practical tool to recommend the use of crop canopy sensors into more targeted field base on their spatial variability.

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CORN NITROGEN FERTILIZER MANAGEMENT PRACTICES IN EASTERN SOUTH DAKOTA

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ABSTRACT

The factors that lead farmers to use N best management practices (BMPs) that can lessen N loss needs to be understood to help increase adoption rates. Understanding the local, small-scale factors (geographic location, tillage type, and farm size) that influence the use of N BMPs will help nutrient management professionals provide the research and information needed to increase the use of N BMPs. South Dakota (SD) survey data from 465 producers was used to examine the above local, small-scale factors that influence farmers decisions regarding N rate, source, placement, and application timing. Location and tillage only influenced fertilizer-N rate with eastern SD and conventional- and reduced-till farmers applying more N than western SD and no-till farmers. Farm size did not affect any of the N management practices. Urea fertilizer applied in the spring was the most used N source and application timing (47-49%) followed by UAN and in-season application (12-19%). Enhanced efficiency fertilizers–urease or nitrification inhibitors or slow-release fertilizers–were minimally used (≤ 15%). Broadcasting fertilizer application was the most common placement (29-53%) with other methods minimally used (≤ 12%). The local, small-scale factors of geographic location, tillage, and farm size were limited in their influence on these N management practices. Future research needs to continue evaluating other local factors influence on N management practices to help researchers better understand the factors involved when farmers make N management choices.

INTRODUCTION

Nitrogen moving from agricultural fields to ground and surface waters is an environmental and health concern (Ribaudo et al., 2011). Fertilizer-N from agricultural land can move from fields via runoff, denitrification, leaching, and ammonia volatilization all of which are influenced by management, soil, and climate factors (Dinnes et al., 2002; Chen et al., 2008). As such, programs like the 4Rs of nutrient management—Right: product, rate, timing, and placement—have been developed to be used by farmers to help them make choices that minimize the potential for N loss. However, a 2011 study in the U.S. determined that even with these programs only 35% of fields followed N fertilizer best management practices (Ribaudo et al., 2011).

Many studies have worked to understand the factors that influence farmers adoption of BMPs. However, in a recent review article, it was determined that few individual variables had a consistent impact (Prokopy et al., 2019). Some of the variables that had a positive impact on adopting BMPs included positive attitude of a practice, larger farms, more income and education, and an information seeking attitude. However, one thing that was pointed out about why consistent factors may have not been found, is that many of these studies take place on a large regional scale. Thus, local factors that are likely to affect adoption and effectiveness of BMPs are not evaluated such as soil type, geography, and climate (Weber and McCann, 2015). Understanding these and other local, small-scale factors on farmer's decisions regarding N management practices can give guidance to government agencies, extension, and other professionals regarding needed research, educational resources, and trainings that are needed to help farmers adopt N BMPs.

The N management practices that we will focus on in this paper will be the rate of N fertilizer applied, the N source and any additives used to enhance efficiency, its placement, and the timing it is applied. The local factors evaluated will be geographic location within SD, tillage type, and farm size. Our objective with this survey information is to identify the local factors that influence the use of various N management practices.

MATERIALS AND METHODS

Data in this paper comes from a 2019 nutrient management survey of 465 farmers in central and eastern South Dakota (SD). This survey was conducted to determine current N fertilizer practices among SD corn producers. The survey asked questions regarding fertilizer-N source, rate, timing of application, and placement. Demographic and farm characteristic information was also ascertained to determine if or when these factors influenced N management practices.

Geographic location within SD, tillage type, and farm size were the three variables we investigated to determine their effect on fertilizer-N management practices. For geographic location, the eastern portion of SD was divided into two regions—eastern and central. This division is based on precipitation differences with the eastern region (22–28 in.) receiving more annual rainfall than the central region (16–22 in.) (Fisichelli et al., 2016). Many farmers in SD are transitioning from conventional to conservation tillage practices. This transition has the potential to alter N management practices. Therefore, we evaluated the effect of tillage (no-till, reduced-till, and conventional tillage) on N management practices. Lastly, farm size has been shown to affect the adoption of conservation practices due to larger farms greater ability to absorb financial risk (Ulrich-Schad et al., 2017). Thus, we divided farms into four categories (1-499, 500-999, 1,000-1,999, and >1,999 ac) to determine their effect on N management practices. Descriptive analysis including percentages was conducted to provide information about N management practice usage among farmers. Chi-square analysis was used to evaluate the effect of location, tillage, and farm size on N management practices.

RESULTS AND DISCUSSION

Fertilizer N Rates

Fertilizer-N rates used in corn production were related to location, tillage type, but not farm size ($\alpha = 0.05$). Farmers in eastern compared to central SD applied more N to their corn crop (147 vs 139 lbs N ac^{-1}) (Table 1). This difference in fertilizer-N rate applied may be due to the often lower yield levels in central SD (USDA-NASS, 2021). Following the university recommended yield goal system to determine fertilizer-N rates, these lower yield potentials in central SD would require lower fertilizer-N rates. This result suggests that farmers are likely following the university recommendation system. Regarding tillage, no-till farmers applied the least amount of N to their corn crop (137 lbs N ac^{-1}) while conventional- (146 lbs N ac^{-1}) and reduced-till farmers (155 lbs N ac^{-1}) applied the most. This lower application rate by no-till farmers may be due to improved soil quality from switching to no-till from conventional tillage (Veum et al., 2014). This does contradict the SD university recommendation system where no-till fields are recommended an additional 30 lbs N ac^{-1} compared to a conventional tillage system (Clark et al., 2019). However, it is in accordance with research from North Dakota where after five or six years of no-till, fertilizer recommendations are less with no-till than conventional tillage (Franzen, 2018). These results indicate that further research is needed regarding the effect of long-term no-till on corn N fertilizer needs in SD to determine if adjustments to the current recommendation system is needed. The fact that farm size did not affect fertilizer-N rates (141-147 lbs N ac^{-1}) among farmers indicates that these rates applied are not likely being changed based on number of acres operated, equipment availability, or ability to absorb financial risk.

Table 1. The effect of location, tillage system, and farm size on fertilizer-N rate.

Location		Tillage			Farm size (ac)			
East	Central	No-till	Reduced	Conventional	>2000	1,000-1,999	500-1,999	1-499
lbs N ac^{-1}								
147a	139b	137b	155a	146ab	147	141	142	141

[a] Mean values with different letters within each variable category (i.e. location, tillage, and farm size) are statistically different ($P \leq 0.05$).

Nitrogen Products and Timing

Nitrogen fertilizer source and timing of application used by farmers regardless of application timing was not related to location, tillage, or farm size (P ≥ 0.05). This result suggests that fertilizer sources are similarly available and used by SD farmers regardless of their location. Further, these results suggest that the precipitation differences between central and eastern SD also did not affect the timing of fertilizer-N applications used by SD farmers. For farmers in SD, urea was the most utilized N fertilizer source across all application timings (49%) followed by manure (24%) and urea ammonium nitrate (UAN) 28% (19%) and lastly UAN 32% and anhydrous ammonia (3-5%) (Table 2). Urea and UAN 28% were similarly used (8-19%) once application timings moved to during the growing season.

Minimal fertilizer-N applications were applied in the fall except for manure (Table 2). This is important because N fertilizer applied in the fall has a large window where loss can occur before corn the following season can utilize it. This is reassuring as many states have moved to regulating N fertilizer application timings and prohibited them in the fall after freezing soil conditions. This result is important as it shows farmers in SD are generally choosing to apply N closer to when the crop needs it by applying it in the spring or during the growing season. These types of voluntary actions will minimize the likelihood of policies being created to enforce N BMPs. Across N sources and among the four synthetic N sources (not including manure), spring N fertilizer applications were the most common (47%) followed by early and mid/late growing season applications (12-17%). These results suggest that the primary time for synthetic N fertilizer application is the spring, and that in-season applications are minimally used. Some studies have suggested that splitting N fertilizer applications and moving most of the N fertilizer application to in-season can reduce N loss potential (Dinnes et al., 2002). However, these survey results show that most SD farmers likely apply their whole N application prior to planting in the spring. Further research in the US Midwest has shown that the effectiveness of split-N applications depends on precipitation occurring in-season at the time of the second application (Spackman et al., 2019; Clark et al., 2020). Precipitation in SD decreases and is less consistent during the growing season as we move west and therefore would likely affect the effectiveness of splitting up a N fertilizer application. However, more research needs to be completed in the various precipitation regions of SD to better provide information regarding the effectiveness of splitting up N applications.

Table 2. Percentage use of N fertilizer source by application timing along with percentage use across N fertilizer sources and application timings.

	Nitrogen Fertilizer Source[a]					**Across**
Application timing	**Urea**	**UAN 28%**	**UAN 32%**	**AA 82%**	**Manure**	**products**
	%					
Fall	11	0	0	4	33	24
Spring	57	18	5	1	13	47
Early Season	19	12	3	1	1	17
Mid/Late Season	12	8	2	0	2	12
Across timings	49	19	5	3	24	

Note. Percentages may not add up to 100 as individuals could input data in multiple categories.
[a]UAN, Urea ammonium nitrate; AA, Anhydrous ammonia

Placement and Timing of N Applications

Placing nutrients on or below the soil surface can influence the availability of N to crops and its susceptibility to loss. For example, urea left on the soil surface can lead to ammonia volatilization loss, reducing the total N available to a crop. In this survey we evaluated various placement methods both when N was single and split applied. Our evaluations occurred across the location, tillage, and farm size categories as there was an insufficient number of farmers in these categories once they were divided into single and split-N application methods to make strong comparisons. For single-N applications, broadcast application of N in the spring was by far the most common placement method and was evenly split between broadcasting with and without incorporation (39 vs. 26%). The lack of incorporating after broadcast is likely partially due to approximately 50% of SD farmers using no-till practices that would inhibit them from using tillage to incorporate a broadcast application of N fertilizer (Wang, 2019). All other fertilizer placement methods and application timing combinations were minimally used (≤ 10%).

For farmers that split up their N applications, broadcast placement and spring timing compared to the other options were still the dominant placement by timing combinations (28-50% vs 1-23%) (Table 3). However, likely due to the nature of splitting up the Applications, the percent use of early and mid/late season applications increased from 1-6% to 1-23%. Additionally, when split applying N compared to single-N applications, application methods that place the fertilizer below the soil surface during in-season applications were also more frequently used (1-5% vs. 1%). This greater use of below the surface application with in-season applications is likely due to the lower likelihood of precipitation events occurring after in-season applications to move the fertilizer from the soil surface to the roots. Therefore, farmers use a placement method that increases the likelihood of the fertilizer being able to move with soil moisture to the roots and be taken up by the crop. However, the use of placement methods that place fertilizer below the surface are still minimally used (≤ 5%). This low usage is likely due to the specialized equipment that is often needed to place fertilizer below the soil surface. These types of applications also frequently require the use of liquid-N sources that are commonly more expensive than dry-N sources. Additionally, many farmers hire co-ops to apply fertilizer for them. These co-ops most frequently broadcast fertilizer on the soil surface as this method can be used to apply N to more acres each day compared to methods that place fertilizer below the soil surface. To change any of these practices it will take research results and educational programs geared to farmers and fertilizer applicators, showing a combination of improved yields and profits with the use of placement methods that place fertilizer below the soil surface or applications completed in-season.

Table 3. Percentage use of N fertilizer application timing by placement method along with percentage use across application timings and placement methods.

	N fertilizer application timing				
Placement Method	**Fall**	**Spring, preplant**	**Early Season**	**Mid/late season**	**Across timings**
	——— % ———				
			Using single-N applications		
Broadcast: incorporated	10	39	4	0	53
Broadcast: not-incorporated	2	26	6	0	32
Banding: with strip till	3	1	0	0	4
Banding: under the row	1	1	0	0	1
Sub-surface banding: next to row	1	1	1	0	3
Sub-surface banding: mid row	2	1	0	0	3
Surface banding: next to row	0	0	1	0	1
Surface banding: mid row	0	0	1	0	1
Top dress: foliar feed	0	0	1	1	2
With irrigation	0	0	0	0	0
Across placement methods	18	67	14	1	
			Using split-N applications		
Broadcast: incorporated	9	50	6	4	29
Broadcast: not-incorporated	8	28	23	13	29
Banding: with strip till	13	2	2	1	7
Banding: under the row	0	4	2	0	3
Sub-surface banding: next to row	1	3	2	2	3
Sub-surface banding: mid row	2	1	5	3	4
Surface banding: next to row	0	3	2	7	5
Surface banding: mid row	1	2	4	3	4
Top dress: foliar feed	2	4	6	17	12
With irrigation	0	0	4	6	4
Across placement methods	15	40	22	23	

Note. Percentages may not add up to 100 as individuals could input data in multiple categories.

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SOME THOUGHTS ON NUTRIENT MINERALIZTION AND CYCLING IN NO-TILL SYSTEMS

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OVERVIEW

Over the last 2 decades, heavy accumulations of post-harvest crop residues have been observed in no-till fields in North Dakota (Aher et al., 2016). This generally has been promoted by a relatively short growing season (120-130 days) and a shift from small grain production to corn-soybean production systems. Aher et al. (2016) noted that more than 10 Mg/ha post-harvest crop residue had accumulated in some conservation cropping systems study crop sequences after 12 years (Table 1). An evaluation of the quality of aged (over-wintered) residues showed a range in C:N ratios of 36 to 67 which when decomposed could require 56 to 105 kg N/ha of additional fertilizer N for subsequent crops to offset potential immobilization. Although not all of the crop residue is likely to decompose over a given growing season, seasonal residue decomposition could potentially create an N “drag” on subsequent crops. A review of the literature indicated that only Montana, Wisconsin, New York, and Vermont (all Northern Tier states) provided recommendations for up to 34 kg N/ha when high levels of crop residues are present (Alghamdi and Cihacek, 2021). However, the origins of these recommendations were not clear from the literature. Moreover, contradictory to these recommendations, North Dakota has been recommending a 56 kg N/ha credit for most crops that have been under no-till culture for more than 6 years (Franzen, 2018).

During the 2013-2015 time period, we were working with ethanol distillers by products (CDS, WDGs, DDGs) to evaluate their suitability as a source of crop nutrients. Of particular interest were condensed distillers solubles (CDS), which are normally are incorporated into the dry distillers’ grains (WDGs) when destined as animal feed products. However, in the northern Great Plains, an early frost will substantially increase the yield of CDS creating an excess which cannot be easily incorporated into the DDGs and may need to be disposed of by other means (land application, land filled, etc.). In addition, periodic rail car shortages and limited onsite DDG storage may cause a backup supply of wet distiller’s grains (WDGs). Since these materials can contain significant levels of N (2-4 %) and P (~ 1 %), we conducted mineralization studies to evaluate the availability of N and P from these materials. Since these materials would be surface or shallow injected and incorporated in fields with corn and/or residue, we included residue treatments in our lab incubations.

Figure 1 shows the results of CDS and WDG incubation on yield of NH_4^+-N and NO_3^-- N with soybean residue utilizing an untreated soil as a comparison control. Figure 2 shows the results of CDS and WDG incubation with corn residue and the untreated soil as a control. In both cases, the CDS and WDG enhanced the availability of mineral N. The incubations were similarly conducted as reported by Keeney and Bremner (1966). However, both the soil plus soybean or corn residue showed reduced N mineralization (or immobilization) when compared to the soil alone.

Table 1. Crop rotation treatments, residue weight, residue C and N, residue C:N ratio and residue N fertilizer deficit for the spring 2011 aged residue sampling. (From Aher et al., 2016)

Crop Rotation Treatments†	Residue Weight	Residue C	Residue N	Residue C:N Ratio§	Residue N Fertilizer Deficit
	--kg/ha--	--kg C/ha--	--kg N/ha--	--------	--kg N/ha--
SW-WW-C-S	10080ab‡	4230ab	85.3b	49.4b	99.7a
SW-C-S	9080ab	3799ab	77.7b	49.4b	88.5ab
SW-S	8895ab	3660ab	54.8bc	36.1c	105a
C-S	11768a	5018a	124a	66.6a	95.1a
SW-WW-F-C-C-S	8359b	3443b	80.6b	54.9b	70.1bc
WW-CC-C-S	7405bc	3145b	68.4b	55.7b	69.2bc
SW-WW-A-A-C-S	4232c	1782c	22.3c	35.7c	55.7c

†SW-WW-C-S = spring wheat-winter wheat-corn-soybean; SW-C-S = spring wheat-corn- soybean; SW-S = spring wheat-soybean; C-S = corn-soybean; SW-WW-F-C-C-S = spring wheat-winter wheat-flax-corn-corn-soybean; WW-CC-C-S = winter wheat-cover crop-corn-soybean; SW-WW-A-A-C-S = spring wheat-winter wheat-alfalfa-alfalfa-corn-soybean.

‡Means with the same letter are not significantly different at $p \leq 0.05$.

§C:N = carbon:nitrogen ratio.

Figure 3 shows the results of the P mineralization studies that were conducted in a similar manner to the N mineralization studies. In these incubations, P was extracted by the Olsen method. Although P extracted was similar for the soil alone, soil + soybean residue, and soil + corn residue, both the soybean residue and corn residue appeared to depress the mineralization of P (immobilization) when compared to the soil alone.

These combined observations created more questions about the interactions of crop residues and the cycling of nutrients from residues or in the presence of residues in no-till systems where heavy residue accumulations occur. Again, in reviewing the literature, we found several classical reports that indicated that additional fertilizer would be required to compensate for accumulations of residues either in conventionally tilled or no-till systems (Alghamdi and Cihacek, 2021).

Thus, we initiated and incubation study following the method of Stanford and Smith (1973) to look at N mineralization from residues of seven common North Dakota crops over a 12 week period representing a North Dakota growing season. This study was carried out on three common soils varying in texture and organic matter content with biweekly leaching to quantify NO_3^--N mineralized. These results are shown in Figure 4. Using the soil alone control as the baseline level of N mineralization, the three soils showed differences in the magnitude of N mineralized due to their OM content but all post-harvest crop residues generally showed N immobilization. Only winter pea and radish grown as bio-strip late season cover crops showed N mineralization due to their green condition at freeze up. We have since conducted additional studies (results not shown) that confirm our initial study.

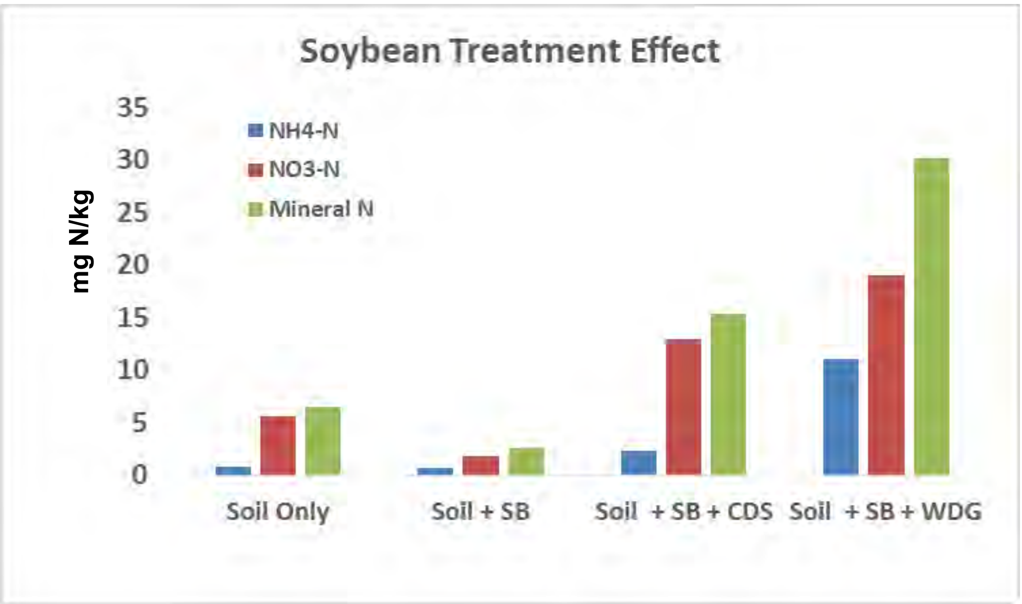


Figure 1. Mineral N yield for CDS and WDG in the presence of post-harvest soybean residue.

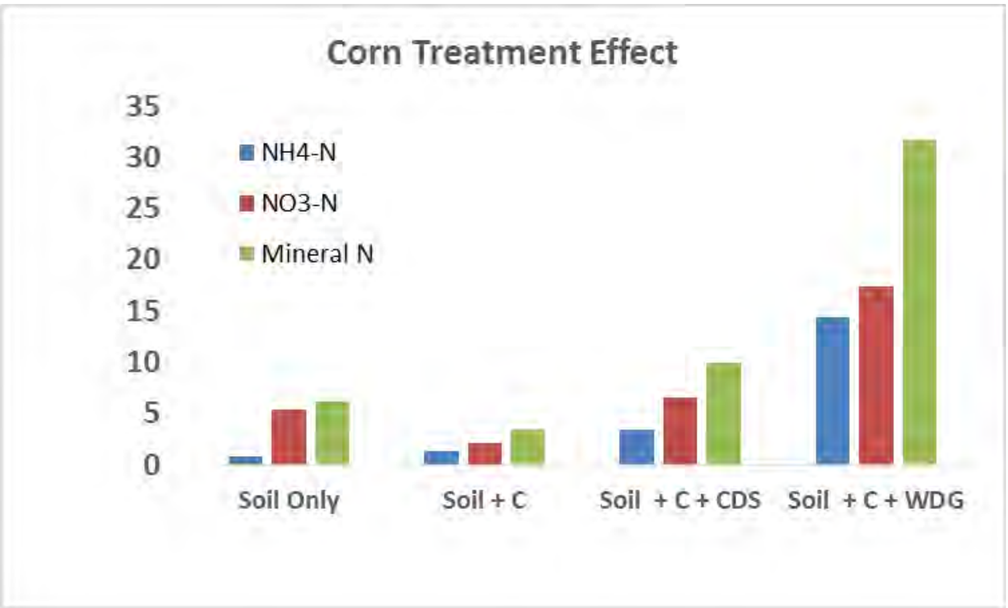


Figure 2. Mineral N yield for CDS and WDG in the presence of post-harvest corn residue.

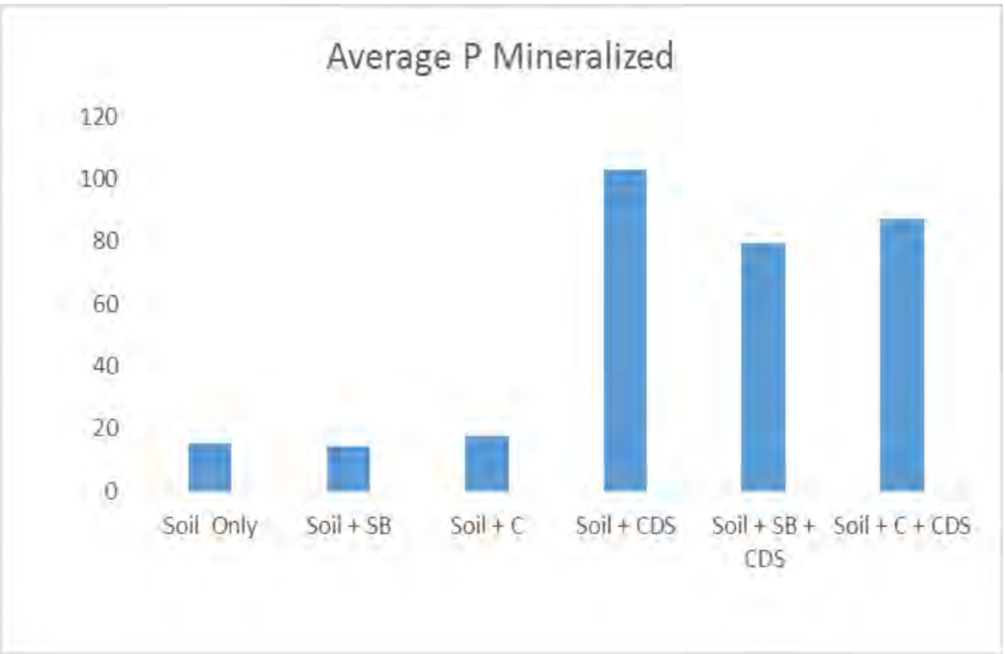


Figure 3. Suppression (immobilization ?) of Olsen-extractable P due to CDS mineralization in presence of either post-harvest soybean (SB) or corn (C) residue after 56 days of incubation.

CONCLUSIONS

The soil system is still essentially a "black box" with many processes and reactions going on simultaneously that are impacted by variability in temperature and moisture conditions. We have made several observations that illustrate our gaps in knowledge that illustrate the difficulty studying these processes:

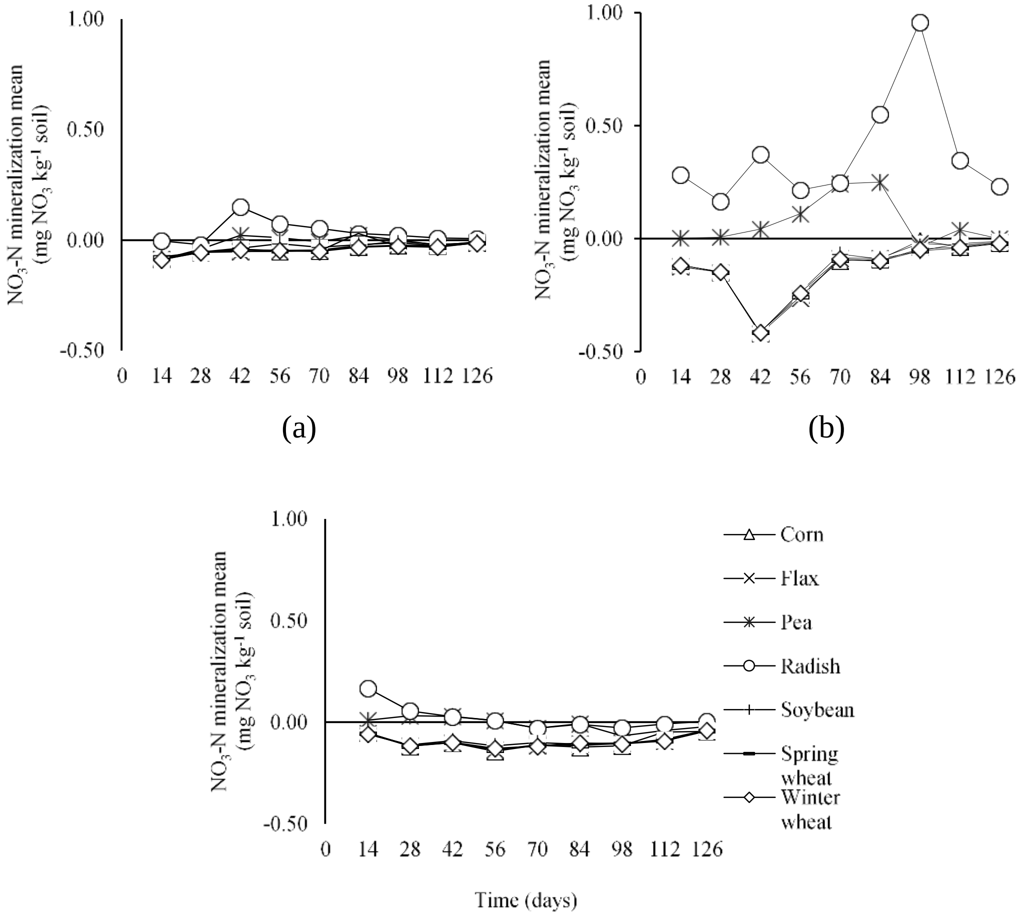
1. A clear understanding of the crop residue decomposition processes laying on the soil surface in no-till fields and the environment in the zone of decomposition is still lacking. The difficulty of measuring N released from the decomposing residue on the surface and its fate in partitioning to the soil (or loss to volatilization as greenhouse gas) and its contribution to direct pathways between microbes and plants is still not clear in many research studies

2. Further research is needed to provide the data needed to support fertilizer recommendations for no-till systems in the northern Great Plains to maximize both economic return and minimize environmental risk to ground and surface waters.

3. Soils in the field are open systems and following N changes and transitions are difficult across all seasons and even parts of a season unless we use ^{15}N tracer methodologies which are expensive and laborious.

4. Following reactions that occur at or across soil residue interfaces is difficult, especially under field conditions which would be necessary to get a much better indication of nutrient kinetics.

Ongoing work by researchers in the area of soil health already have and may be able to give to give us a much clearer picture of the nutrient cycling processes we have been attempting to quantify.



(a)

(b)

(c)

Figure 4. Mean NO3-N mineralization patterns over time for soil control, corn, flax, pea, radish, soybean, spring wheat, and winter wheat crop residue treatment for the Heimdal-Emrick (a), Fargo (b), and Forman (c) soil series and their associated incubation days. The baseline at 0 indicates the N mineralization of the soil alone relative to the N mineralization of the crop residues. (From Algahmdi et al. - in review).

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POSTER PROCEEDINGS

IMPLICATIONS OF CLAY MINERAL ANALYSIS FOR IMPROVED CALIBRATION OF CORN POTASSIUM FERTILIZER RECOMMENDATIONS

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ABSTRACT

Eastern South Dakota has seen an increase in soil potassium (K) deficiencies. To correct those deficiencies and avoid yield reductions, corn producers rely on accurate K fertilizer recommendations (KFRs). Among the various parameters used to estimate a KFR, clay mineralogy has significant potential to increase KFR accuracy. The study has two objectives: first, to determine the relationships among clay mineralogy, K uptake by corn, and KFRs, and second, to calibrate KFRs in South Dakota to incorporate clay mineralogy as a variable. In 2020, corn was planted at 6 sites across central and eastern South Dakota. Each site contained 4 blocks, and each block received 6 treatments of potash fertilizer (0-0-60). Preplant soil samples were taken at depths of 0-6 and 6-12 in. Harvested grain was shelled and weighed to determine yield. Preliminary results from the preplant soil sampling indicated higher soil test K (STK) and lower smectite:illite (S:I) in central South Dakota. A correlation analysis indicated that there is a moderate, negative relationship between STK and S:I, supporting the theory that soils containing predominately smectite clays will have less exchangeable potassium. An Analysis of Variance found no significant differences between corn yields and KFRs, which can be attributed to the very high STK levels present (>200 ppm at the 0-6 in. depth). In 2021, 9 field trials have been established throughout eastern South Dakota to continue this research.

INTRODUCTION

Corn yield is optimized when there is a sufficient amount of K (>160 ppm) in the soil solution. Historically, South Dakota soils have supplied ample K to cropping systems. However, in eastern South Dakota, where a majority of the state's corn production occurs, intensive corn-soybean crop rotations have begun to deplete exchangeable-K reserves, as 1 bu. of soybeans removes approximately 1.3 lbs. of K_2O (Clay, D.E. and Clay, D.W., 2016). As a result, an increase in STK deficiencies has been reported by Agvise Laboratories (Northwood, ND).

Correction of K deficiencies in soil is often accomplished using K fertilizers. Application rates are determined by a number of parameters, which may vary throughout different regions in the Corn Belt. Nearly all KFRs incorporate corn yield potential and STK, though other recommendations may include soil parameters such as removal rates, cation exchange capacity, critical levels, and/or dry vs. field moist STK (Culman et. al., 2020; Mallarino et. al., 2013) In South Dakota, current KFRs are calculated using STK values and yield goals, and there is a 60 lb. $ac.^{-1}$ minimum when K is recommended (Gerwig et. al., 2019). Furthermore, these guidelines categorize STK levels from 0-160 ppm, with a "very low" STK between 0 and 40 ppm and a "very high" STK above 160 ppm. Above 160 ppm K, there is deemed to be enough K to adequately meet demands for optimal corn yield. Subsequently, there is little (<20%) probability of observing a yield response when STK exceeds 160 ppm.

Predicting corn yield increases from K fertilizer applications can be difficult due to the multiple factors that influence crop responses. Poor aeration, either by excessive soil moisture or compaction, restricts corn roots from growing and subsequently taking up K^+ ions (Hanway, 1962). K uptake can also be restricted when soil moisture and temperatures are low, and where there is a high concentration of other cations (Hanway, 1962). It is for these reasons why adverse soil and weather conditions can induce K deficiencies in corn, even when there is adequate K in the soil. Therefore, it is essential that fertilizer recommendations today not only address the direct nutritional needs of corn, but also the potential issues with K assimilation by corn.

Improving the accuracy of KFRs is essential not only to optimize corn yield, but also to ensure that overapplication does not occur, thus limiting unnecessary costs. However, there are multiple factors that can influence the optimal amount of K fertilizer needed. One particular topic of interest is clay mineralogy, which has been found to be successful in the calibration of KFRs in North Dakota. Breker et.

al. (2019) used a cluster analysis to partition field trials in North Dakota based upon the respective portion of smectite clays, relative to illite clays. They discovered that the K critical level was higher for fields with a S:I ratio greater than 3.5. Conversely, fields with a ratio less than 3.5 had a lower K critical level. These findings are consistent with the fact that smectite clays are highly charged and hold onto K^+ ions more tightly compared to illite clays. Therefore, the relative amounts of smectite and illite clays in different soil types may influence the optimum amount of K that should be applied for corn.

Provided the success of incorporating clay mineralogy into K fertilizer rate calibration by researchers in the Northern Great Plains, we propose a similar study that will be used to benefit corn producers in the state of South Dakota. The first objective is to determine preliminary relationships among soil clay mineralogy, K uptake by corn, and K fertilizer requirements. The second objective is to then calibrate and adjust our current K fertilizer recommendations in South Dakota to include clay mineralogy as a variable. The goal of this research project is to provide meaningful and interpretive data for South Dakota corn producers to make profitable fertilizer decisions.

MATERIALS AND METHODS

The project began in 2020 and is expected to continue into the 2022 growing season. In the first 2 years of this study, trials were successfully established at 15 sites across central and eastern South Dakota, 3 of which were located at research farms comprising the South Dakota Agricultural Experiment Station. The experimental design used is a randomized complete block design with 4 blocks. At each site, there were 6 plots in each block containing a unique rate of fertilizer: 0, 30, 60, 90, 120, and 150 lbs. K_2O ac.$^{-1}$. Treatment fertilizer was broadcast applied by hand as muriate of potash (0-0-60). Seeding rates, corn hybrids, tillage operations, pest control, row width, cover crops, and amendments were selected by the individual producer. Additional fertilizers were applied to the research area to ensure that non-nutrients of interests were not limiting. Nitrogen, phosphorus, and sulfur fertilizers were broadcast applied following current South Dakota fertilizer guidelines (Gerwig et. al., 2019).

Soil samples were collected at depths of 0-6 and 6-12 in. during the 2020 growing season, and 0-6, 6-12, and 12-24 in. during the 2021 growing season. A soil sample was collected for each of these depths from each of the 4 blocks. Additionally, a single 0-6 in. composite sample was collected from the research area at each field trial. A portion of each 0-6 in. sample was sent to Activation Laboratories Ltd. (Ancaster, Ontario, Canada), where they were analyzed for mineral identification and clay speciation using the Rietveld method. The mineral identification provides a semi-quantitative, relative abundance of smectite, illite, and kaolinite content. All other soil samples were sent to Ward Laboratories (Kearney, NE) for soil fertility and health analysis.

Plant samples were collected during the 2021 growing season only. At V6, 6 corn plants from outside of the harvest area are randomly selected and cut approximately 1-2 in. above the soil surface. After being dried in a forced air oven at 140°F for 2 days, samples are ground using a Wiley mill, passed through a 2 mm sieve, and sent to Agvise Laboratories (Northwood, ND and Benson, MN) for analysis.

At physiological maturity, the center 2 rows of each plot were harvested either by hand (100 ft^2) or with a plot combine (entire length of plot). Yield, moisture, and test weight were calculated for every plot. Additionally, a subsample of grain was taken in every plot, which was dried, ground, and sent to Agvise Laboratories for analysis.

Data analysis was conducted using R, R-Studio, Excel, and JMP. ANOVA was used to find any statistically significant treatment means at the 0.05 significance level. Major emphasis was put on analyzing the effects that various K fertilizer rates and blocking have on corn yield, as well as proper calibration of K fertilizers depending on the relative amounts of smectite and illite clays. Further analysis of the aforementioned topics will be conducted once all results become available to us.

RESULTS AND DISCUSSION

For the first 2 years of this study, field trials were very unique in terms of clay content, STK, soil properties, cropping system, tillage, and management styles (Table 1). A two-way ANOVA (α=0.05) for all sites found corn yield to be significantly different between sites, but not between KFRs (Table 2). As mentioned, the uniqueness of each field trial resulted in corn yields to be significantly different at all sites. However, KFRs did not cause corn yields to be significantly different, which can be attributed to the very high STK levels present (>160 ppm at 13 of our 15 sites). This is consistent with current guidelines for South Dakota, which state that the probability of a yield response when STK exceeds 160 ppm is less than 20%. There were a few sites that displayed a slight yield response to applied K fertilizer (Figure 1). However, yield response curves began to plateau between 60 and 90 lbs. K_2O ac.$^{-1}$, suggesting that it would not be feasible to apply K fertilizers beyond that point.

Table 1: Agronomic data for all field trials during the 2020-2021 growing seasons.

		Soil Test Parameter[†]						
Site	Year	K	Smectite	Illite	S:I	Texture[‡]	Previous Crop	Tillage[§]
Clay	2020	202	36.3	52.0	0.74	SiL	Soybean	NT
Kingsbury	2020	322	77.5	16.3	5.14	SiCL	Soybean	NT
McCook	2020	200	76.3	18.3	7.18	CL	Soybean	RT
Potter	2020	501	41.8	48.0	0.92	SiL	Wheat	NT
Tripp N	2020	634	55.3	34.3	1.66	SiC	Wheat	NT
Tripp S	2020	735	48.5	39.3	1.30	SiC	Wheat	NT
Brookings	2021	327	-[††]	-	-	SiCL	Soybean	CT
Codington	2021	155	-	-	-	SiCL	Soybean	CT
Hutchinson	2021	132	-	-	-	L	Soybean	NT
Lincoln	2021	436	-	-	-	SiCL	Soybean	RT
Minnehaha E	2021	170	-	-	-	SiCL	Corn	CT
Minnehaha W	2021	161	-	-	-	SaL	Corn	CT
Roberts	2021	287	-	-	-	SaL	Soybean	VT
Turner	2021	143	-	-	-	SiCL	Soybean	RT
Yankton	2021	241	-	-	-	L	Wheat	NT

†K, potassium, ammonium acetate extractable-K, ppm, composite, 0-6 in. depth; Smec., smectite, <2 μm fraction, mean of 4 replications, 0-6 in. depth; Ill., illite, <2 μm fraction, 0-6 in. depth; S:I, smectite:illite ratio.

‡SiL, silt loam; SiCL, silty clay loam; CL, clay loam; SiC, silty clay; L, loam; SaL, sandy loam.

§NT, no tillage; RT, reduced tillage; CT, conventional tillage; VT, vertical tillage.

†† Results pending.

Table 2: Overall two-way ANOVA for all sites during the 2020-2021 growing seasons.

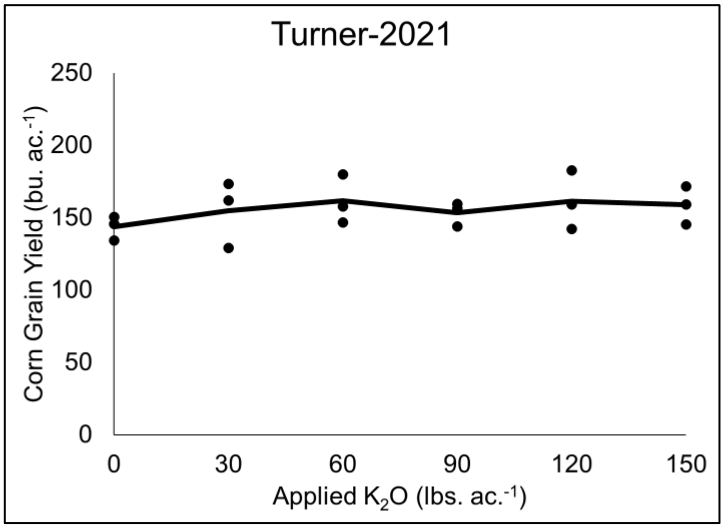
Source of Variation	Statistical Parameter† SS	df	MS	F	P-value
Site	9.52E+08	10	95243694	170.092	0.00
KFR‡	1028046	5	205609.1	0.36719	0.87
Site x KFR	34566718	50	691334.4	1.23463	0.16
Error	1.11E+08	198	559952.7		
Total	1.1E+09	263			

†SS, sum of squares; df, degrees of freedom; MS, mean square; F, F statistic; P-value, α = 0.05.
‡KFR, potassium fertilizer rate.

The 2021 growing season was characterized by drought conditions throughout the Northern Great Plains, including South Dakota. Lack of soil moisture greatly limits K movement in the soil, as K moves primarily via diffusive properties Furthermore, clay mineral type also influences how K moves throughout the soil. Of the 3 dominant clay types in South Dakota soils (kaolinite, illite, and smectite), smectite is the only one that exhibits shrink/swell properties. In a dry year, smectites in the soil will shrink and collapse due to lack of soil moisture.

When they collapse, interlayer K^+ ions are trapped between clay layers, and thus are unavailable for plant uptake. Therefore, K uptake by corn will be more difficult in a dry year, especially if the soil has a higher amount of smectite clays, relative to illite clays. In 2021, we observed several sites that exhibited K deficiencies, regardless of STK or K fertilizer treatment. For example, in July of 2021, during the peak of the drought, we observed K deficiencies in V14 corn in every plot of the Brookings site. However, Table 1 shows a 0-6 in. composite STK value of 327 ppm, more than twice the amount of K deemed “very high” by current South Dakota guidelines. We hypothesize that the dry weather experienced in 2021 limited K uptake by corn, regardless of how much STK was present in the soil. The influence of clay mineralogy will be included once all data for 2021 becomes available.

Figure 1: Yield response curve for the field trial in Turner County, SD during the 2021 growing season. The STK value for this site was 143 ppm, and corn yield increased with additional K fertilizer, up to 60 lbs. ac.$^{-1}$ K_2O, before plateauing.



The first 2 years of this study provided data that verifies our current guidelines. When STK values exceed 160 ppm, there is a small probability of observing a corn yield response to applied K fertilizer. The ANOVA found no significant differences in corn yield when varying the rate of KFRs. Despite the high STK levels present in many of our field trials, there were still K deficiencies observed, which we hypothesize were stimulated by the dry weather in 2021. When clay mineralogy data becomes available to us, we plan to correlate the data to examine how different clay minerals in soil may influence the amount of K available for uptake, thus influencing the proper KFR needed. This study will continue for the 2022 growing season. Our goal is to collect more data and better understand how clay minerals influence the optimum amount of K needed for corn production in South Dakota.

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CAN PROVEN REDUCE CORN NITROGEN REQUIREMENT IN MINNESOTA?

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ABSTRACT

ProveN is a microbial product applied in-furrow with the goal of reducing the total amount of nitrogen fertilizer needed for corn (*Zea mays* L.). Four field trials were established over two growing seasons in Minnesota to evaluate corn response to nitrogen with and without ProveN applied at planting on the seed. Nitrogen was applied as urea prior to planting at three locations and split applied with 1/3 of the total rates of nitrogen applied at -planting, at V4, and V8 growth stages at one irrigated location. ProveN was applied at suggested rates with the planter directly on the seed at planting. Corn plant mass at V5 and R1, corn nitrogen uptake, and corn grain yield was always affected by nitrogen rate. V5 and R1 corn plant mass was not affected by ProveN or it's interaction with nitrogen rate. Only one of the four field trials showed a yield response to ProveN. In 2020, the Waseca plots with ProveN yielded more than their counter parts without the microbe. Maximum yield was also achieved with 30 lbs. N ac^{-1} less with ProveN. ProveN can have an impact on corn growth but may not reduce the rate of N required by corn across all locations, and benefits may be specific to soil types and specific environmental conditions.

MATERIALS AND METHODS

Four field trials were established at four different University of Minnesota research and outreach centers over three years. Lamberton (2019), Rosemount (2019), Becker (2020), and Waseca (2020). Sixteen treatments were arranged in a strip plot design, consisted of two factors (nitrogen and ProveN), and were replicated six times. Nitrogen applications weren't the same for all sites. Application methods and amounts were altered depending on University of Minnesota nitrogen guidelines for that region. In 2019, nitrogen was applied before planting as urea at eight different rates (0, 50, 100, 150, 175, 200, 225, and 275 lbs. nitrogen per acre). ProveN was applied directly to the seed at planting at a rate of 5 gallons per acre (GPA). The liquid solution contained either 0 or 67 (2019) or 12.8 (2020) oz of ProveN mixed in deionized water and applied at a total rate of 5 GPA of water/ProveN mixture. In 2020, nitrogen was split applied at planting, V4, and V8 for Becker and nitrogen at Waseca was applied before planting. The nitrogen rates changed to 0, 100, 175, 200, 212.5, 225, 250, and 300 lbs. N per acre for Becker and 0, 50, 100, 125. 137.5, 150, 200, and 250 lbs. N per acre for Waseca. Triple superphosphate and potassium sulfate were applied at none limiting rates to supply all phosphorus, potassium, and sulfur needs.

Whole plant samples were collected by sampling six plants at the ground level from non-harvest rows at the V5-V6 and R1 growth stages. Plant samples were dried at 95°F, weighed, ground, and analyzed for total N concentration by dry combustions analysis with a Leco. Corn grain yield was determined by harvesting the middle two rows using a research grade plot combine. Corn grain yield is reported adjusted to 15.5% grain moisture.

Statistical analysis was conducted in SAS using the GLIMMIX procedure. Analysis was conducted considering the fixed effects of N fertilizer rate and ProveN application, and random blocking effects for each location. Data presented in subsequent tables may include LS means values which are adjusted for missing values and covariance structure within the dataset. The model selected was determined using AIC values from the statistical output. When possible, the simpler model was favored when analyzing and presenting data.

RESULTS AND DISCUSSION

The main effect of N rate was always significant. The main effect of ProveN was only significant for grain yield at Waseca. Nitrogen rate by ProveN interaction was never significant which indicates that nitrogen effects did not vary whether ProveN was or was not used.

Both N uptake in individual plants along with total N uptake, calculated in lbs. N per acre considering plant population, were assessed but did not differ in how both main effects affected either N uptake. Therefore, only individual N uptake by the plants is summarized. Plant N uptake was highly related to plant mass and was not impacted using ProveN. Since N requirement is generally low through V5 small differences in uptake of N when ProveN was applied may not be detectable. The uptake of N was affected by a slightly higher N application rate which demonstrates luxury uptake of N by the corn crop at V5.

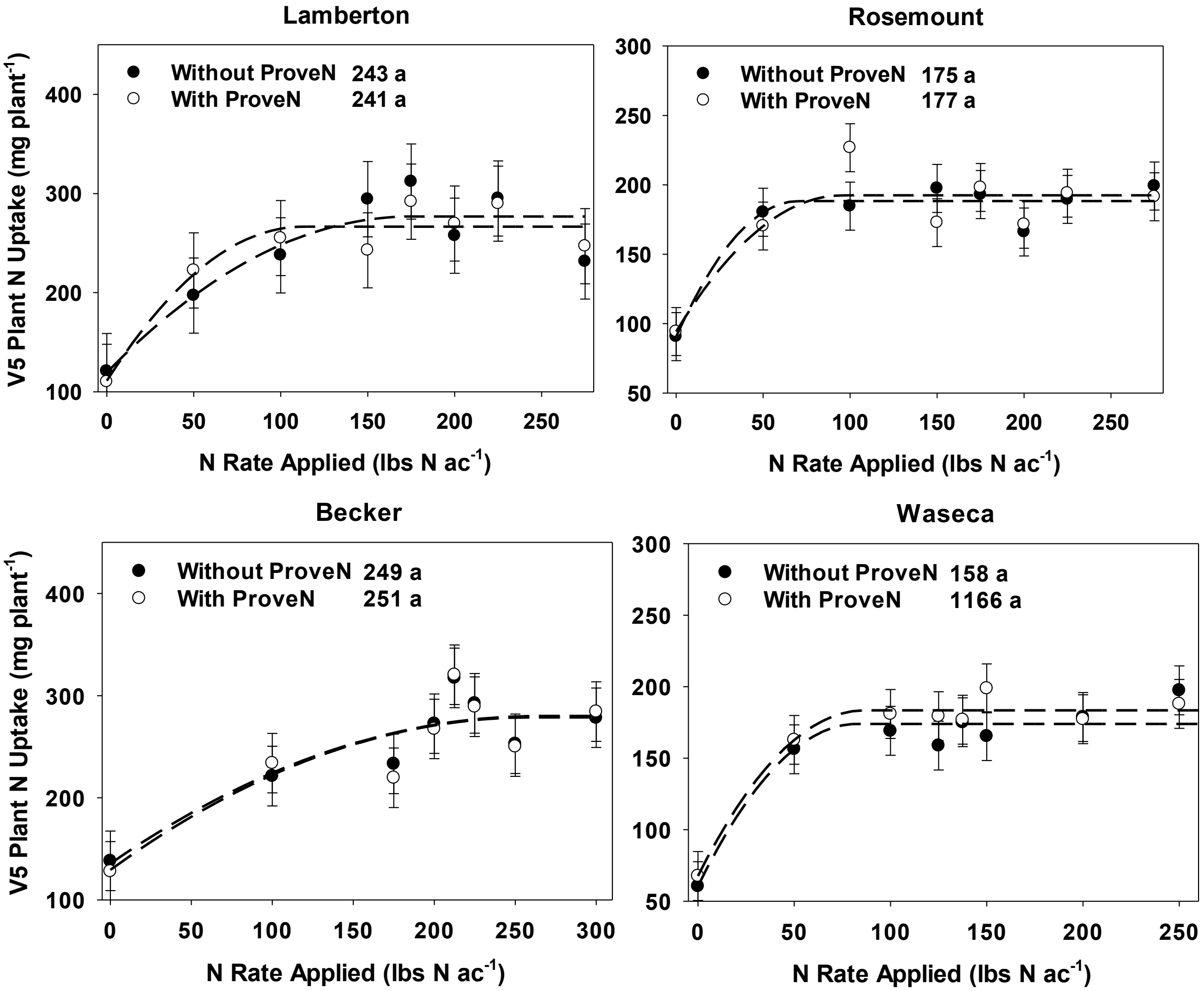

Figure 1. Summary of the impacts of N rate and ProveN on individual corn plant nitrogen uptake at the V5 growth stage.

Uptake of N was maximized by the highest rate of N applied but typically increased up to that point. ProveN did not impact R1 N uptake nor was there an interaction between N rate and ProveN even though the curves did appear to separate around the highest rates of N applied at Waseca.

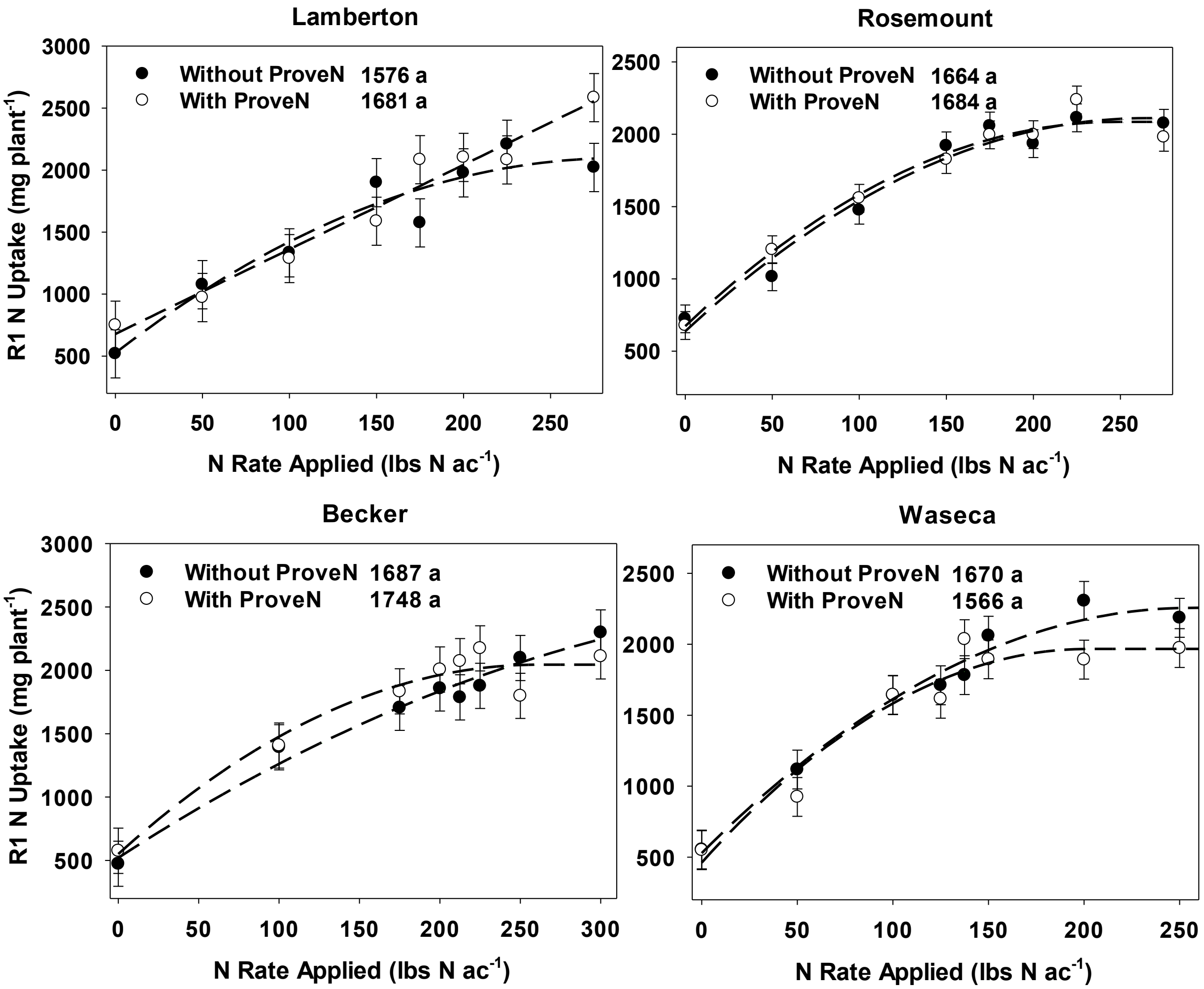

Figure 2. Summary of the impacts of N rate and ProveN on individual plant nitrogen uptake at the R1 growth stage.

Corn grain yield was impacted by N rate at all four locations (Figure 3). Corn grain yield response was similar when ProveN was and was not applied at Becker, Lamberton, and Rosemount. Although means separation indicated little difference in N rates greater than 200 lbs. At Waseca, corn grain yield was maximized with roughly 210 lbs. of N without ProveN while grain yield was maximized with 180 lbs. of N with ProveN which is a 30 lbs. reduction in the N required for maximum grain yield. The amount of N needed to reach maximum yield was more than suggested by current guidelines. Higher N requirement has been more common with soils at Waseca which are very poorly drained and tend to denitrify. Corn grain yield was 9 bu/ac greater with ProveN at Waseca but given enough N is applied, yield could be maximized with fertilizer alone.

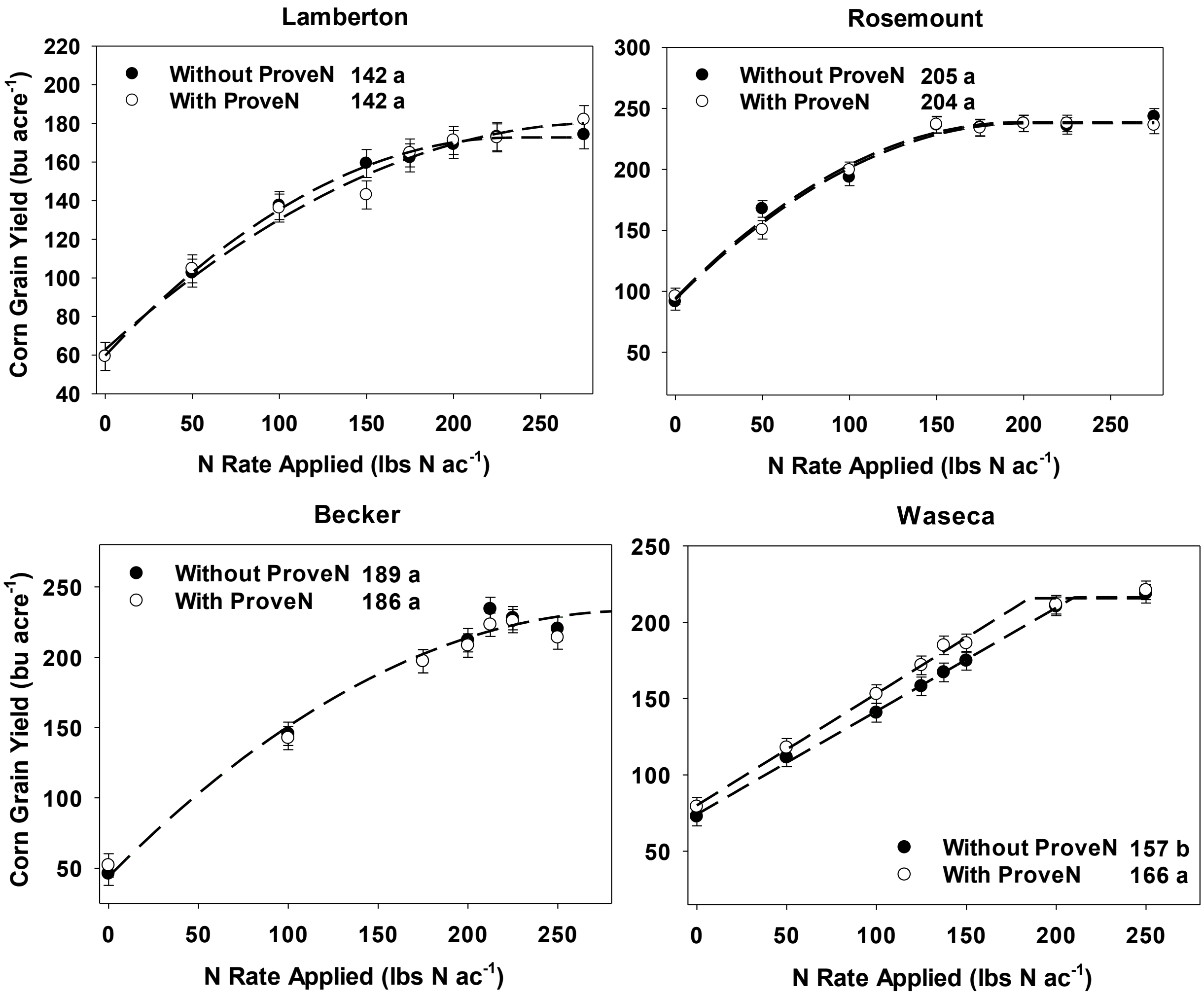

Figure 4. Summary of the impacts of N rate and ProveN on corn grain yield reported at 15.5% moisture.

Overall, ProveN did not increase corn N uptake at early vegetative and reproductive growth stages and only reduced the amount of N needed to maximize grain yield at one location. The plan for 2021 is to follow up with an additional site at Waseca and a site at Morris on a very poorly drained soil. This is to determine whether ProveN may work better for tougher soils which seem to need more N and more consistently respond to side-dress N because of poor drainage. Nitrogen fertilizer rates were adjusted for the 2021 locations to better match optimum N rates determined by research plots at the Waseca and Morris locations instead of using rates suggested by the current U of M guidelines.

SOIL AND SOYBEAN RESPONSE TO PLANTING INTO TERMINATED PRAIRIE STRIPS

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ABSTRACT

Prairie strips are a new conservation practice currently implemented in 11 Midwest US states. Prairie strips reduce runoff, increase soil health, retain sediment and nutrients, increase biodiversity and have no effect on surrounding crop yield. Due to the comprehensive improvements to soil health under prairie strips, growers and researchers are interested in rotating them on 10-15 year cycles. We have little-to-no knowledge on the effects of planting crops in soil that was formerly a prairie strip. Here we plant soybeans into soil that has previously been prairie for 13 years, and monitor plant and soil responses including: soybean nodule counts, nodule size, leaf greenness, crop stand counts, soil nitrate, and soil erosion.

We showed that planting soybean into a terminated and tilled prairie strip had minimal effect on individual soybean growth or leaf greenness compared to tilled cropland. However, former prairie strips did have effects on soybeans and soils. Soybean stand counts were lower in former prairie strip soils compared to tilled cropland, but nodule size was larger. Soil under previous prairie was more stable, eroded less, had lower soil nitrate concentrations, and greater microbial biomass than cropland soils. Planting into recently terminated prairie strips lowers soybean stand count but might have benefits to individual crops, and has soil benefits that extend into the following growing season. Overall, rotating prairie strips across a crop field shows potential to spread the soil benefits but lowers soybean stand count, and thus likely yield, after the first year of termination.

INTRODUCTION

Prairie strips (PSs) are a new management practice that is rapidly gaining popularity in the Midwest US. One of the benefits of PSs are their flexibility, allowing numerous configurations within a watershed, allowing a farmer to customize the conservation to their land. Including PSs has these positive environmental effects compared to a cropland with no PS: 67% reduced nitrate export [1], 90% reduced phosphorus export [1], and 96% reduced sediment export [2]. Prairie strips also have additional benefits including 37% reduced total water runoff [3], and increasing total nitrogen (TN) and SOC by 100% and 37% respectively[4].

Since the publication of much of this research, PSs have become popular across the Midwest and over 11,000 acres of PSs are planted across 11 states[5]. Prairie strips are now also a part of the USDA Conservation Reserve Program's (CRP) CLEAR initiative[6]. This growing trend in PSs demonstrates the demand for conservation and evidence of the benefits. However, looking to the future, many of these acres may not remain in PS and be returned to row crops, as evidence with changes in CRP land when crop prices are high[7].

Due to the fragility of conservation practices and interest in rotating PSs throughout a watershed, we asked the question, how will crop yield and soil be affected by cultivating a former PS? More specifically we asked 1) how does land previously under PS affect new crop health (measured as SPAD), 2) how does land previously under PS affect the quantity and size of soybean nodules, and 3) how prior land, previously under PS but now cropped, affect soil health? To answer these questions, we used a long-term (13-year), paired-watershed PS study in Jasper County, Iowa.

MATERIALS AND METHODS

Site Characteristics and Experimental Design

The study was located on the Neal Smith National Wildlife Refuge (NSNWR 41° 33’ N;93°16’ W), a 3000-ha complex managed by the U.S. National Fish and Wildlife Service. In 2007, a watershed PS experiment was established within NSNWR. These watersheds are planted with Soybeans at 38 cm row spacings and maize at 91 cm row spacings.

For this study we selected PSs in three paired watersheds, where the paired treatments included the PS treatment and a no-till, corn-soybean cropland control with no PS (i.e., PS vs. cropland). These watersheds were digitally mapped using a 3×3 m^2 digital elevation model (DEM, ARCGIS Pro) and used to produce plan curvature and flow accumulation maps. Cropland locations were selected by similarity to PS locations in flow accumulation and plan curvature. Prairie strips were terminated in late April using glyphosate then tilled shallowly in early May. Tillage was performed using an off-set disk set to a depth of 10 cm. Tillage was completed in 3-5 passes. Control cropland locations were also tilled similarly. Additionally, sample locations were selected 3 m above and below the tilled sections at each sample location in the tilled section.

Soybean Collection and Analyses

Soybean (*Glycine max* L. mer) stand counts were assessed at each data point within all treatments. Soybeans were planted in 38 cm rows, thus at each sample point (n=9) a 2.64 m transect was used to count soybean emergence. Entire soybean plants were collected at the V3-V5 stage. Two plants were collected at each sample location within the tilled prairie strip and tilled cropland sections (n=3). Plants were taken to the lab where aboveground biomass was removed and dried at 50 ℃ and weighed. We measured root nodule count and size using the Soybean Nodule Acquisition Pipeline (SNAP)[8]. Soil Plant Analysis and Development (SPAD) meter readings were taken at the R2/R3 stage to assess leaf greenness as a proxy for plant health[9]. SPAD readings were taken at each sample point within the PS and tilled cropland treatments: 3 m above, within, and 3 m below the tilled strip treatment (n=9). At each sample point SPAD readings were taken on 10 different plants, the 10 readings were then averaged to a single value for that sample location.

Soil Sampling and Analyses

We collected soil samples at the same time and locations as the plant samples. Four soil cores were taken on each side of the collected plants from 0-15 cm depth. Two plant samples were associated with each sample point within the tilled treatments and the correlating eight soil cores were composited together for each sample point (n=3). In the lab, soils were sieved to less than 2 mm. Microbial biomass was analyzed using the chloroform fumigation[10], samples were then extracted using 0.5 M K_2SO_4 and analyzed for total organic C using a TOC analyzer. Nitrate and ammonium were analyzed with a spectrophotometer[11].

We deployed erosion pads on May 14th and the final collection was on July 26th. The erosion pads were located 3 m above the tilled strip, within the tilled strip, and 3 m below the strip of both cropland and PS watersheds (n=9). This configuration was used in PS and cropland watersheds. Additionally, pads were place in no-till (NT) watersheds in a similar arrangement but without a tillage treatment (n=9). Pads consisted of two layers of nylon mesh that were 15 × 15 cm[12]. Pads were laid flat on the soil and held in position with wood stakes. Pads were collected after 5 cm of rainfall occurred. Erosion rates were averaged per pad for the collection period.

RESULTS AND DISCUSSION

Prior land-use had a significant effect on soybean stand counts (Table 1, Fig. 1). Soil that had formerly been PSs decreased stand counts by 36% compared to the cropland, tilled cropland. Above and below the former PS were not significantly different. Prior land-use had no effect on aboveground soybean seedling biomass, SPAD meter readings, and soybean nodule count nor size (Table 2).

Prior land-use significantly affected soils (Table 3). Prairie strips significantly increased microbial biomass C and N by 60 % and 123 % respectively (Fig. 3). Consequently, the PS also had a lower microbial biomass C:N ratio by 29%. Nitrate was significantly reduced under the former PS when compared to the cropland by 37% (Table 3, Fig. 4). Ammonium was increased significantly under the terminated PS by 416% (Fig. 4). These findings suggest that soil formerly under PS had more microbial biomass and reduced the mobile form of plant-available N (Fig. 4).

Soil erosion was affected by treatment, position relative to the PS and the interaction of treatment and position (Table 3, Fig. 5). No-till cropland, on average, reduced erosion compared to tilled soils by 18%. Prairie strips reduced erosion by 24% and 37% compared to both no-till and tilled cropland respectively. Despite also being tilled, the soil directly under former PS, reduced erosion rates by 66% and 88% compared to both no-till and tilled cropland respectively (Fig. 5).

Conclusion

With increased interest of using prairie strips (PSs) and need to rotate out of them, we wanted to test the effect of prior prairie strip on crop production and soils. Planting into terminated PSs lowered soybean stand counts but had no other observable negative effect on individual soybean plants. We will have crop yield data at the end of the year to confirm final effects on productivity.

Soils under terminated PSs maintained elevated nutrient availability, increased microbial biomass, and reduced erosion during first year under soybeans. We propose to measure how long these soil benefits will persist. This will allow us to better understand the long-term effects of rotating PSs throughout a field.

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TABLES

Table 4 Prior land-use effect on crop health

Crop Health Metric	Effect	Df	F-statistic	p-value
Stand Counts	treatment	1	2.32	0.202
	position	2	36.22	<0.001
	treatment:position	2	21.47	<0.001
Aboveground Biomass	treatment	1	0.27	0.613
SPAD Meter	treatment	1	0.73	0.406
	position	2	0.60	0.555
	treatment:position	2	0.02	0.976

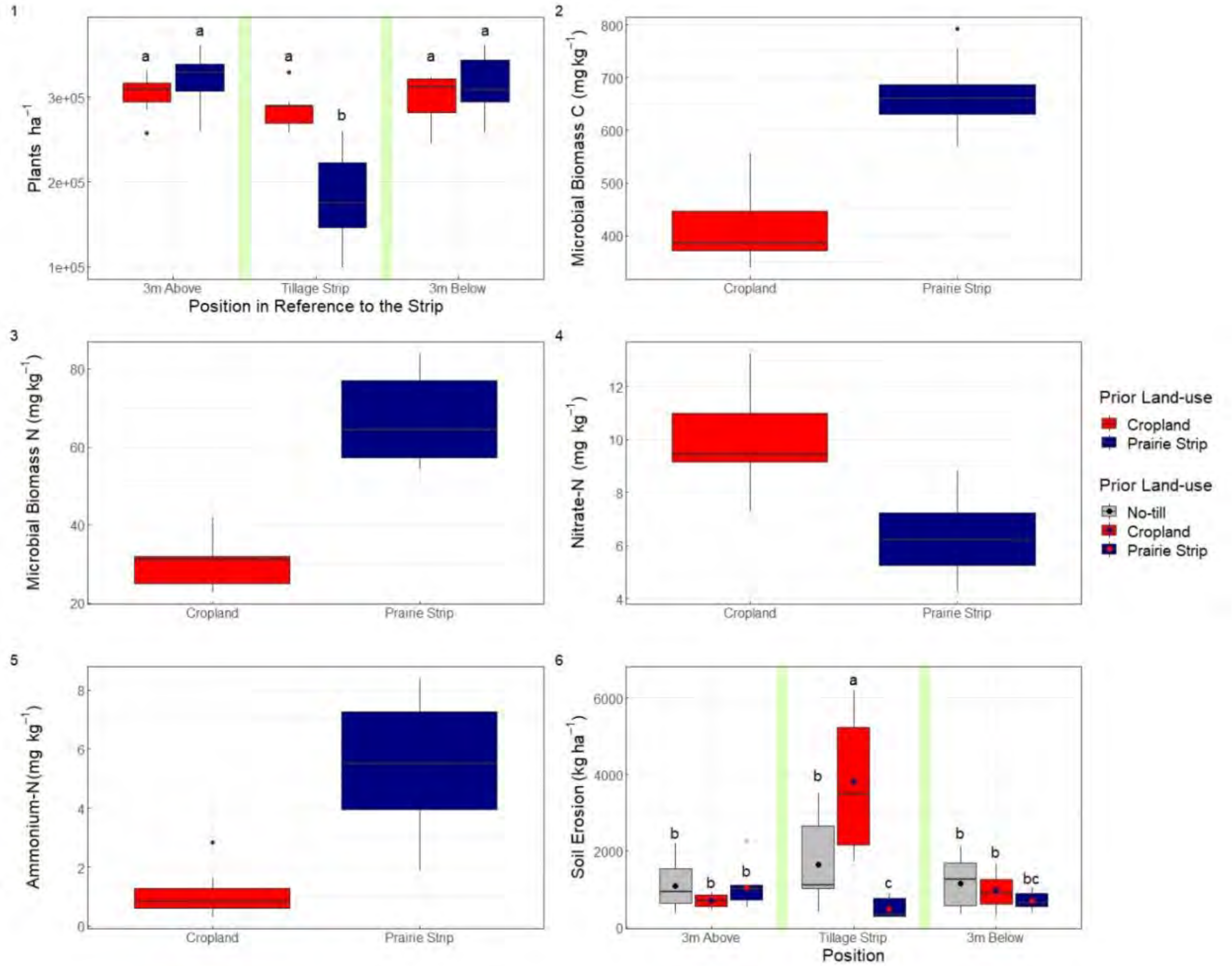
Table 5 Prior land-use on nodules of Soybean plants

Nodule Metric	Effect	Df	F-statistic	p-value
Total Nodules	treatment	1	0.10	0.767
Nodules on Tap Root	treatment	1	0.37	0.547
Nodule Size	treatment	1	4.17	0.109
Nodules per Plant	treatment	1	0.10	0.762

Table 6 Prior land-use effect on soil

Soil Metric	Effect	Df	F-statistic	p-value
Gravimetric Water Content	Treatment	1	34.57	0.004
Microbial Biomass C	Treatment	1	35.40	0.004
Microbial Biomass N	Treatment	1	90.54	<0.001
Microbial Biomass C:N	Treatment	1	15.05	0.018
Salt-extractable Organic C	Treatment	1	0.21	0.674
Salt-extractable Total N	Treatment	1	0.88	0.363
Salt-extractable Organic N	Treatment	1	0.22	0.645
Nitrate	Treatment	1	21.03	<0.001
Ammonium	Treatment	1	23.18	0.009
Inorganic N	Treatment	1	0.37	0.577
Erosion	Treatment	2	4.72	0.014
	Position	2	3.25	0.046
	Treatment:Position	4	9.80	<0.001

FIGURES



1) Stand counts for soybean plants at R2/R3 stage. Counts are reported in plants per hectare (n = 9). The tillage strip in the prairie strip treatment has a stand count reduction of 36% compared to the cropland.

2-3) Microbial biomass carbon and biomass nitrogen (n = 9). Microbial biomass C is elevated 60% and microbial biomass N is elevated 123% compared to the cropland. 4-5) Nitrate and Ammonium in the tillage strip of each treatment (n=9). Soil Nitrate in the prairie strip was 37% lower that the cropland. Ammonium is increased 416% under the prairie strip compared to the cropland. 6) Mean soil erosion measured by mesh pads from May 12th to July 26th (n=9). Treatments include: 1) a treatment that was never tilled (No-Till), 2) a cropland strip that was previously no-till but tilled in 2021 (Cropland), and 3) a prairie strip that was terminated and tilled in 2021 (Prairie Strip). Prairie strip tillage strips eroded 88% less that cropland tillage strips and 66% less than no-till watersheds

♫ BANDED FERTILITY: MUSIC FOR HIGHER CORN YIELDS

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ABSTRACT

There is a need in production agriculture to reduce nutrient loss to the environment and implement more sustainable production practices, but grower adoption has been slow and inconsistent due to fear of reduced yields and profit. However, if new fertilizer technologies can be used to increase fertilizer efficiency and grain yield simultaneously, grower willingness to adapt environmentally sustainable practices is far more likely. We implemented a two-year corn (*Zea mays* L.) yield study in central and southern Illinois with the goal of comparing standard and advanced fertilization practices for phosphorus (P), potassium (K), sulfur (S), zinc (Zn), and boron (B). Fertilizer placements included traditional preplant broadcasting, preplant banding, in-season liquid Y-Drop banding, and a new method that surface bands dry fertilizers next to the crop row in-season (Dry-Drop). Fertilizer placement, specifically Dry-Drop, had the greatest impact on corn yield and fertilizer efficiency compared to variations in fertilizer source, timing, and rate. The effect of S, Zn, and B fertilization on corn yield response was affected not only by fertilizer source but also the interaction of fertilizer source and timing. Our results showed that innovations in source, timing, and placement of fertilizers can simultaneously increase fertilizer efficiency and grain yield, with the end result being improved profitability and lower environmental impacts.

INTRODUCTION

Although many mid-western and Illinois growers believe that better nutrient stewardship is essential (Hoselton and Boerngen, 2021), sustainable nutrient management plans have had minimal voluntary adoption due to fears of reduced yields and overall decreased profit (Stuart et al., 2014). In an effort to link science to practicality the fertilizer industry formulated and launched the global 4R Nutrient Stewardship Framework. 4R Nutrient Stewardship is centered around four different “rights” of nutrient management: the Right Source, Rating, Timing, and Placement. The 4R’s were developed to convey how fertilizer applications, when managed properly, can meet not only a grower’s economic goals but also worldwide social and environmental goals (Johnston and Bruulsema, 2014). The acceptance of the 4R nutrient stewardship concept on a global level has allowed a single language to be spoken and understood by all stake-holders including the fertilizer industry, scientists, growers, and the general public (Fixen, 2020). Although the 4R’s concept has laid the framework for better nutrient stewardship, innovations in source, rate, timing, and placement must continually be explored in order for this concept to stay relevant and trusted by all stakeholders.

Right source

Choosing the right source means choosing plant available nutrient forms that release a balanced supply of all essential nutrients in a manner that compliments naturally available sources and matches crop demand (Harold F. Reetz, Jr., 2015; Moody and Bruulsema, 2020). The best way to increase the use efficiency of an applied nutrient is to make sure that no other nutrients are limiting, also conceptualized in Liebig’s law of the minimum (Paris, 1992). This concept implies that fertilization of multiple nutrients together would produce greater nutrient use efficiency than the fertilization of only one nutrient. With this in mind, advancements in fertilizer source technology have led to the introduction of co-granulated fertilizers such as MicroEssentialsSZ (MESZ; 12-40-0-10S-1Zn) and Aspire (0-0-58-0.05B The Mosaic Company, Plymouth, MN) which combine multiple mineral nutrients into a single fertilizer granule. Similar to the dry fertilizer market, liquid fertilizer sources have also experienced technological advances. Examples include new, more-stable chelation formulations for liquid Zn applications such as Levesol Zn (CHS Inc, Inver Grove Heights, MN), and liquid K fertilizers with organic acid carriers like potassium acetate (Kac, 0-0-24), which has been shown to have higher plant adsorption due to acetate being a natural plant metabolite (Shafer and Reed, 1986). In addition to source technology advancements, fluid fertilizers have application flexibility such as planter-applied fertilizer and crop-targeted side-dress applications.

Right timing and placement

Fertilizer timing and placement are closely linked because some fertilizer placements are only available at certain timings within the crop production cycle. Most fertilizer applications of P and K are broadcast applied in the fall due to fewer time constraints and drier soils (Fernández et al., 2011). Although fall broadcast applications increase P and K fertility uniformly across the entire upper soil profile, this application method can reduce nutrient use efficiency due to the greater likelihood of P and K fixation (Boomsma et al., 2007). Conversely, concentrating nutrients near the crop rooting zone has also been shown to increase nutrient use efficiency (Boomsma et al., 2007; Hopkins and Hansen, 2019). Two methods that can achieve fertilizer timings closer to crop uptake and higher nutrient concentrations are pre-plant subsurface banding and in-season surface banding next to the crop row.

Subsurface banding

Due to improvements in subsurface fertilizer banding capabilities and GPS technology, fertilizer can be placed at a specific depth with minimum disruption to soil structure in all tillage systems, and using real-time kinematic (RTK) guidance the seed can be planted directly over the fertilized bands (Vyn, 2008). Banding fertilizers increases nutrient use efficiency and grain yield compared to broadcast fertilization (Borges and Mallarino, 2001; Boomsma et al., 2007; Adee et al., 2016; Potratz et al., 2020).

In-season applications

Although the practice of strip-till/banding has been increasing in Illinois, this production system accounts for less than 25% of total Illinois corn acres (Sellars et al., 2019). An alternative to pre-plant banding of fertilizers is the use of in-season fertilizer applications. In the past, placement of in-season fertilizer has been limited to broadcasting fertilizers over the crop (top-dress), foliar sprays, or liquid fertilizer applied in the center of the interrow. Recently, 360 Yield Center developed a system that allows for the placement of a liquid nutrient solution on the soil surface directly next to the crop row called Y-Drop® (360 Yield Center, Morton, IL). Commercially available application technologies that allow for surface banding of nutrients next to the crop row are currently limited to liquid fertilizers. The Crop Physiology Lab (University of Illinois), however, has developed and tested a proof of concept application method that can surface band dry fertilizers in-season near the crop row, referred to in this paper as Dry-Drop. This type of application method can be incorporated with water naturally due to the upright nature of corn leaves which creates a water funneling system that can take rainfall or even heavy due and divert the water down to the base of the plant. This water funneling can increase water placement to the base of a corn plant from an incident rainfall by 40-50% (Warner and Young, 1991; Paltineanu and Starr, 2000), which can incorporate dry P & K fertilizers.

Agriculture is changing at a faster pace now than it did when the 4R’s of nutrient stewardship framework was created. Innovations in source, rate, timing, and placement have the potential to change how we think about crop nutrition, fertilizer use efficiency, and environmental sustainability. The goal of this research is to better understand how some of those innovations, and their interactions, can be used to maximize corn yield while increasing nutrient use efficiency and improving environmental sustainability.

MATERIALS AND METHODS

In 2020 and 2021 three field trials were conducted at two locations in Champaign, Illinois (Central, IL; 40°04'45"N, 88°14'34"W), and Nashville, Illinois (Southern, IL; 38°19'04"N, 88°20'10"W). Soybean was the previous crop for all site-years. A composite soil sample of each site was taken from a 0-6 inch depth immediately prior to planting and analyzed by A & L Great Lakes Laboratories, Inc (Fort Wayne, IN) using the Mehlich 3 extraction method (Table 1). All plots received a base N rate of 180 lb acre^{-1} applied preplant incorporated as 32% UAN. All plots across Illinois were planted with the same ALMACO SeedPro 360 research plot planter (Nevada, IA) to achieve an approximate final stand of 36,000 plants acre^{-1}.

Eleven fertilization strategies were evaluated to assess the impact of nutrient source, rate, placement, and timing on crop growth and development. Nutrient sources included: co-granulated NPSZ (MESZ; 12-40-0-10S-1Zn), co-granulated K & B (Aspire; 0-0-58-0.5B, muriate of potash (MOP; 0-0-60), mono-ammonium phosphate (MAP; 11-52-0), ammonium polyphosphate (APP; 10-34-0), potassium acetate (K acetate; 0-0-24), potassium thiosulfate (KTS; 0-0-25-17S), liquid B derived from polyborate (10%B; 0-0-0-10B), ortho-ortho EDDHA chelated zinc (Levesol Zn; 4-0-0-4.5Zn). Nutrient placements included: 1.) preplant broadcast using a Gandy drop spreader (Gandy Company, Owatonna, MN); 2.) subsurface banding 4 to 6 inches deep directly beneath the crop row using a Montag Gen II fertilizer delivery system (Montag Manufacturing, Emmetsburg, IA) mounted on top of a four-row Dawn Coulter-type toolbar (DAWN 6000 Universal Fertilizer Applicator, Dawn Equipment, Sycamore, IL); 3.) liquid surface banding near the crop row (Y-Drop; 360 Yield Center, Morton, Illinois); and, 4.) dry surface banding near the crop row (Dry-Drop; Crop Physiology Lab – University of Illinois, Champaign, Illinois). Nutrient timings included: fertilization immediately prior to planting (preplant), and fertilization at the V5 crop growth stage (side-dress). Nutrient rates included: 80lbs of P_2O_5 acre^{-1} compared to 40lbs of P_2O_5 acre^{-1}, 60lbs K_2O acre^{-1} compared to 30lbs K_2O acre^{-1}, and the addition or omission of (20lbs of S acre^{-1}, 2lbs of Zn acre^{-1}, and 0.5lbs of B acre^{-1}) or (10lbs of S acre^{-1}, 1lbs of Zn acre^{-1}, and 0.25lbs of B acre^{-1}).

The center two rows of each experimental plot were mechanically harvested with an ALMACO SPC40 combine (ALMACO, Nevada, IA) for determination of grain yield and harvest moisture, and the yield was subsequently standardized to bushels acre^{-1} at 15.5% moisture. Fertilizer efficiency was calculated by dividing the bushel acre^{-1} yield increase compared to the N only Control by the total lbs of P and K applied per acre.

RESULTS AND DISCUSSION

Soil test values for P and K in Central and Southern, IL (Table 1) were both within the recommended maintenance levels based on the Illinois Agronomy Handbook (Fernández and Hoeft, 2009). Corn grown with only nitrogen produced a respectable grain yield of 235 bu acre^{-1}. Although this study has an unfertilized control to make references about overall fertilizer response, the standard grower practice for corn fertilization in Illinois is a broadcast application of MAP & MOP. For this reason, most fertilizer treatments are compared to preplant broadcast MAP & MOP, which resulted in a 9 bu acre^{-1} yield increase compared to the N only control.

The influence of fertilizer placement had a significant effect on grain yield and fertilizer efficiency. When compared to preplant broadcast, the result of preplant banding had an 8 bu acre^{-1} yield increase with MAP & MOP but a negative 5 bu acre^{-1} effect for MESZ & Aspire. Visual assessments of plots in-season revealed that corn grown with MESZ & Aspire banded directly beneath the row had more stunted plants early in the season which has been attributed to early season boron concentrations being to high near the seedling. Although preplant banding for MAP & MOP resulted in markedly higher grain yield and fertilizer efficiency, preplant banding is a difficult operation to implement. The results of this trial suggest that a feasible alternative to preplant banding MAP & MOP could be an in-season surface band application of P & K directly next to the crop row. When liquid P & K was applied to corn as a V5 Y-Drop, grain yield production was identical to corn grown with preplant broadcast MAP & MOP yet only half the rate of nutrients had to be applied due to the increased fertilizer efficiency. Corn grown with a half rate of MAP & MOP applied as Dry-Drop resulted in the same yield as corn grown with a half rate of Liquid P & K applied as Y-Drop. Due to the lower cost of dry fertilizers and ease of handling, Dry-Drop MAP & MOP has a distinctly higher return on investment and ease of application. Although Dry-Drop applications are not currently an option for commercial applications of fertilizers in-season, the technology for such applications is not far off. Air boom fertilizer spreaders, which are commonly used for variable rate fertilizer applications, have already been tailored with drop tubes for in-season applications. In order to apply dry fertilizers in a “Y-Drop” fashion these drop tubes would only need to be retrofitted with a device that can partition the fertilizer blend to the base of the plants.

The effect of fertilizer source was dependent upon both fertilizer placement and fertilizer rate. When applied at a full rate, MESZ & Aspire resulted in a 6 and 5 bushel acre^{-1} yield advantage over MAP & MOP for preplant broadcast and V5 Dry-Drop, respectively. However, when MESZ & Aspire was applied at a half rate as V5 Dry-Drop there was no numerical difference in grain yield production compared to MAP & MOP applied as V5 Dry-Drop. This mimics the lack of response to liquid S, Zn and B applied at a half rate as V5 Y-Drop. However, the greatest grain yield production and fertilizer efficiency of the trial was achieved from corn grown with a full rate of MESZ and Aspire applied as V5 Dry-Drop.

Excluding preplant banded MESZ & Aspire, all other fertilization strategies increased fertilizer efficiency compared to the traditional preplant application of MAP & MOP. These results showed that innovations in source, timing, and placement of fertilizers can increase both fertilizer efficiency and grain yield, resulting in improved profitability, lower environmental impacts, and greater likelihood of grower adoption.

TABLES

Table 1. Trial and soil information for three corn fertilizer management trials evaluated at two locations in Illinois in 2020 and 2021.

Site-year	Planting date	Harvest date	CEC†	pH	OM	P	K	Ca	Mg	S	Zn	B
Central, IL			meq 100g^{-1}		%	------------------------ ppm --------------------						
2021	06 Apr.	15 Sep.	20.1	5.6	3.8	30	100	2248	457	6	1.3	0.6
Southern, IL												
2020	07 June	12 Oct.	9.9	6.5	2.1	36	84	1557	83	12	2.4	0.4
2021	22 Apr.	08 Oct.	7.9	6.0	2.3	25	83	932	78	4	1.1	0.3

†CEC, cation exchange capacity; OM, organic matter.

Table 2. Effect of fertilization strategy on grain yield and fertilizer efficiency for corn grown at Central and Southern Illinois in 2020 and 2021.

Rate	Timing & Placement	Fertilizer Source	Grain Yield	Fertilizer Efficiency
			bushels/acre	Δ bu / lb P & K
	Nitrogen Only Control		235	-
Full	PrePlant Broad	MAP & MOP	244*[†]	0.06
	PrePlant Broad	MESZ & Aspire	250*	0.11*[‡]
	PrePlant Band	MAP & MOP	252*	0.12*
	PrePlant Band	MESZ & Aspire	245*	0.07
Half	Y-Drop	Liquid P & K	244*	0.13*
	Y-Drop	Liquid P, K, S, Zn, & B	244*	0.13*
	Dry-Drop	MAP & MOP	244*	0.13*
	Dry-Drop	MESZ & Aspire	244*	0.13*
Full	Dry-Drop	MAP & MOP	251*	0.11*
	Dry-Drop	MESZ & Aspire	256*	0.15*

† * Yield significantly different than the nitrogen only control at $P < 0.05$.

‡ * Fertilizer efficiency significantly different than broadcast MAP & MOP at $P < 0.05$.

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MANAGING NITROGEN TO OPTIMIZE YIELD AND QUALITY OF NORTH DAKOTA TWO-ROW MALTING BARLEY

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ABSTRACT

As the demand of two-row malting barley (*Hordeum vulgare* L.) increases, having sound nitrogen (N) recommendations is increasingly necessary. Not only does N play a role in grain yield, but it may also significantly impact grain malting characteristics including protein, plump, and test weight. To determine the impacts N rate and N availability have on two-row malting barley, two experimental sites were established in both Spring 2020 and 2021. The experiments were organized as a randomized complete block design with a split-plot arrangement; each site consisted of 100 experimental units in 2020 and 50 experimental units in 2021. Treatments consisted of five fertilizer rates (0, 40, 80, 120, and 160 lbs N ac^{-1}) and two barley cultivars (ND Genesis and AAC Synergy), with cultivar as the main plot treatment and N rate as sub-plot treatment. Soil nitrate-N samples were taken prior to planting and N credits from the previous crop were considered to determine the total known available soil N (TKAN). It was determined there was a strong relationship between N rate and grain yield. There was also a strong positive correlation between N rate and grain protein. When the relationship between grain yield and TKAN was modeled using a best-fit regression, it was determined maximum yield can be reached at 186 lbs TKAN ac^{-1}. Additionally, grain protein content at 186 lbs TKAN ac^{-1} was 12.8%, which meets malting quality requirements. No significant interactions between N rate and kernel plump or test weight were noted at the N rates applied in these experiments.

INTRODUCTION

One of the keys to producing an economical crop is to apply mineral nutrients at a rate which maximizes profitability. Farmers need improved, locally-based recommendations which address each specific crop. In the case of two-row spring malting barley (*Hordeum vulgare* L.), a more accurate determination of nitrogen (N) rate is essential not only to limit costs due to excessive rate and to enable application rates which support the most profitable yield, but also to meet the strict grain quality requirements of the maltsters, who are the primary buyers of this commodity (Franzen and Goos, 2019). McKenzie et al. (2005) asserted N fertilization is the most important factor in malting barley production. Having sound N application rates for two-row malting barley, aside from mitigating potential environmental impacts, will help to maximize yield, quality, and economic returns for growers.

Historically, the state of North Dakota has been a large producer of barley, ranking third in the USA for total barley production in 2020 (Jantzi et al., 2020), which has been traditionally of six-row type cultivars. However, in recent years, malting companies have begun to buy only two-row barley types over six-row types–thus production has followed these decisions. Of the 38 malting barley cultivars recommended by the American Malting Barley Association, 31 of them are two-row types (Heisel, 2020). One of the reasons behind this change in preference from six-row to two-row barley for malting is their generally lower grain protein content (McKenzie et al., 2005; Franzen and Goos, 2019). Barley with lower protein content allows for more rapid water uptake during malting, which allows the grain to progress through the process more quickly (Hertsgaard et al., 2008), decreasing malting cost. Additionally, high levels of protein in the malt creates problems during beer fermentation processes, particularly cloudiness in the final product.

For grain to meet quality requirements set by maltsters, the percentage of plump kernels in the grain, in addition to protein content not more than the industry standard, have to be met (Lauer and Partridge, 1990; O’Donovan et al., 2015). Furthermore, there is a correlation between the aforementioned quality factors and N fertilization (McKenzie et al., 2005). Although specific quality requirements vary amongst maltsters, the American Malting Barley Association sets the ideal criteria for two-row barley as follows: protein content ≤13.0% and >90% plump kernels retained on a 6/64 inch sieve (American Malting Barley Association Inc., 2019). Two of the most common reasons for malting barley rejection are high protein content and a low percentage of plump kernels (Institute of Barley and Malt Sciences, 2007). The consequence of grain rejection by maltsters is very severe; often feed-barley is priced about half of malting grade, and rejection most often results in a wasted journey to and from the malting receiving station back to the farm.

Studies indicate a positive relationship between N rate and grain protein (Lauer and Partridge, 1990; McKenzie et al., 2005; O'Donovan et al., 2015). Additionally, a minor inverse relationship between grain protein content and kernel plump has also been reported (Clancy et al., 1991; Baethgen et al., 1995; McKenzie et al., 2005). In some cases, the supplemental N rate needed to attain maximum grain yield is greater than the N rate at which grain quality is within the optimum range. Baethgen et al. (1995) stated a balance must be found between obtaining maximum yield for malting barley and meeting quality requirements. This balance between yield and quality should also consider N use efficiency. As a result, grain could be produced at a level which will maximize economic returns for the farmer and meet malting quality requirements. To accurately reflect the N needs of two-row malting barley, it is necessary calculate the recommendation directly from the crop through field N-rate trials. The purpose of this study is to determine, specifically for two-row barley, the rate of available N which will maximize yield and optimize grain quality characteristics for malting at an economically optimum level.

METHODS AND MATERIALS

Site Description

This experiment occurred over two years, 2020 and 2021, with two experimental sites each year. In total, four site-years of data were generated at locations in Grand Forks and Barnes Counties in North Dakota. The experiments were located near Valley City (VC) and Logan Center (LC). The soil at the VC 2020 site was dominated by the Swenoda loam soil series; the 2021 site was Barnes loam (Soil Survey Staff, 2020). This site has been under no-till management for 40 years with the previous crop in 2020 being sunflower (*Helianthus annuus* L.) and corn (*Zea mays* L.) in 2021. At the LC site, the soil in 2020 and 2021 was Barnes loam (Soil Survey Staff, 2020). This site was only recently transitioned to a no-till system (< 5 years ago). The previous crop on this site was pinto bean (*Phaseolus vulgaris* L.) in 2020 and 2021.

Experimental Design

The independent variables in this experiment consist of five N treatments within two cultivars of two-row barley. The N treatments were from 0 to 160 lbs N ac^{-1} (0, 40, 80, 120, 160 lbs N ac^{-1}), which spans the range above and below current North Dakota N recommendations for two-row barley. The two cultivars used were ND Genesis and AAC Synergy–two-row malting barley recommended by the American Malting Barley Association (Heisel, 2020). Each experimental unit was 8 ft wide by 40 ft long and were organized in a randomized complete block design with a split-plot arrangement. Barley cultivar was the whole-plot treatment and N rate the sub-plot treatment. The experiment was replicated 10 times in 2020 (n=100) and 5 times in 2021 (n=50)

Total known plant available N (TKAN) was calculated as outlined by Franzen (2018) which is the sum of preplant soil nitrate (N_S), previous crop N credits (N_{PC}), no-tillage N credits (N_{TC}), and amount of fertilizer N applied (N_{Fert}). Preplant soil nitrate tests were taken to a depth of 2 feet across a transect of each site within 2 weeks of seeding.

Crop Management

Barley was sown at a 7.5-inch row-spacing with John Deere 1890 air drills at the rate of 1.5 to 3 bu ac^{-1}, depending on the site. In-season crop management was completed by the cooperating farmers, as they saw fit, to manage pest and disease pressure, as outlined by the North Dakota Extension Integrated Pest Management Program.

At the time of planting, N fertilizer was broadcast applied to the specific treatments. To limit the amount of N lost to volatilization, SUPERU was used as the fertilizer N source. SUPERU is a urea-based fertilizer treated with *dicyandiamide* and *N-(n-butyl) thiophosphoric triamide*, a nitrification and urease inhibitor, respectively (Koch Industries, Wichita, KS). Additionally, 100 lbs ac^{-1} of pelletized gypsum (calcium sulfate, 20% S) was broadcast applied at the time of N application.

Data Collection and Analysis

Grain moisture and test weight were measured using a Dickey-John model GAC500 XT grain analyzer (Dickey-John, Auburn, Illinois). Grain harvest weights were adjusted to the standard moisture content of 13.5% for yield calculations. Quality measurements were conducted by the NDSU Barley Quality Laboratory. Quality relating to kernel size was determined by sieving. Percent plump kernels were considered the weight of kernels which do not pass through a 6/64-inch sieve. Grain protein content was determined using near infrared spectroscopy (NIR).

Data analysis was performed using SAS and JMP (SAS Institute, Cary, NC). Analysis of variance (ANOVA) was carried out as randomized complete block design with a split plot arrangement using PROC MIXED. Regression analysis was performed using JMP. Data in this study was considered statistically significant at $p \leq 0.05$.

RESULTS AND DISCUSSION

Grain Yield and Quality

Weather conditions in 2020 varied greatly from 2021, most notably in terms of precipitation. At the LC location, April-July precipitation was 0.84 inches above normal in 2020, in 2021 precipitation was 5.66 inches below normal (NDAWN, 2021). A similar situation was noted at the VC sites as well, precipitation data collected approximately 9 miles from the site show 1.17 inches above normal 2020 and 6.65 inches below normal for 2021 April-July precipitation (NDAWN, 2021). The drought conditions experienced in 2021 lead to lower average yields compared to the 2020 trials. Additionally, higher grain protein content was noted in the 2021 trials, expectedly a result of the drought conditions, an interaction noted in previous studies (Erbs et al., 2015; Gordon et al., 2020; Liang et al., 2021). Although yield and protein varied between years and locations treatment means were considered homogeneous based on the rule of 10-fold, allowing for combined analysis.

No statistical differences were noted between the two barley cultivars for any of the parameters measured in this study. It was determined the relationship between N rate and grain yield was significant [Table 1]. Grain protein content showed a significant increase with increasing N rates, a relationship previously established by Lauer and Partridge (1990), McKenzie et al. (2005), and O'Donovan et al. (2015). No significant interactions between N rate and kernel plump or test weight were noted at the N rates applied in this experiment. [Table 1].

Table 1. N rate means combined across varieties and environments

N Rate	Grain Yield	Grain Protein	Kernel Plump	Test Weight
lb ac-1	bu ac-1	%	%	lb bu-1
0	39.4a†	11.2a	92.2a	47.1a
40	51.7ab	11.9b	93.2a	47.3a
80	58.9b	12.5c	93.7a	47.9a
120	60.3b	12.9d	93.3a	47.8a
160	60.0b	13.3d	93.0a	47.8a

†Means with the same letter are not significantly different at the 0.05 probability level.

Total Known Available N

The sum of soil available nitrate (N_S), N credits from previous crops (N_{PC}), and tillage (N_{TC}) ranged from 52 lb ac^{-1} to 93 lb ac^{-1} across research sites and years. In 2020 and 2021, the LC site received a 40 lb ac^{-1} N credit from the previous crop of pinto beans but was penalized 20 lb ac^{-1} for being in the transitional no-till stage (Franzen, 2018). No previous crop credits were assessed at the VC site, but a 40 lb ac^{-1} long term no-till N credit was added each year (Franzen, 2018).

Optimum Nitrogen Rate

To allow representative combination of yield data, the yield at each site was calculated on a proportional/relative basis where the maximum yield is equal to 1. When relative grain yield is plotted against TKAN and fitted with polynomial trendline (r^2=0.66), maximum yield is realized at 186 lb TKAN ac^{-1} [Figure 1]. The relationship between grain protein content and TKAN was modeled using a linear regression (r^2=0.29) [Figure 1]; using this equation, grain protein content at 186 lb TKAN ac^{-1} is 12.8%.

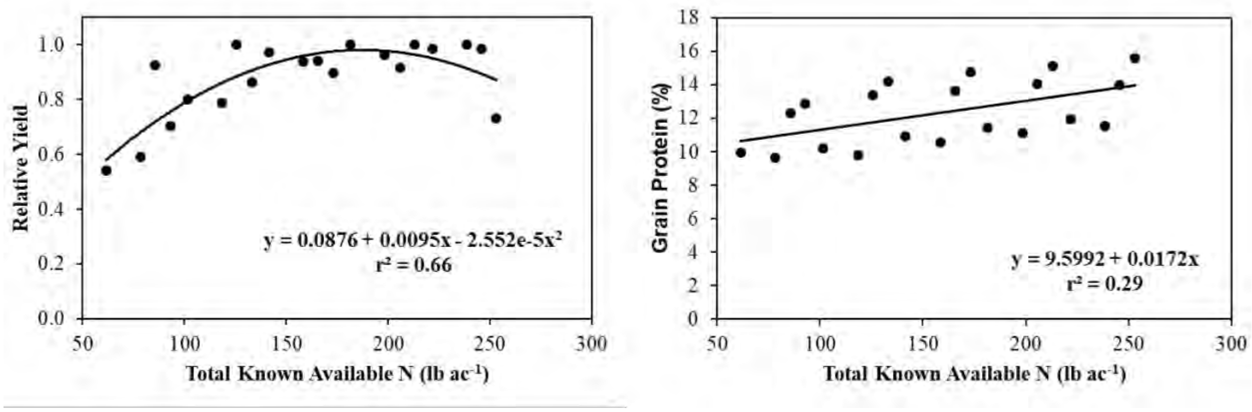

Figure 2. Left: Relative yield data averaged across replications and varieties compared to total known available N (TKAN), fitted with a quadratic trendline. Right: Grain protein averaged across replications and varieties compared to TKAN fitted with a linear trendline.

CONCLUSION

After two years of field experiments resulting in four site-years of data, we determined grain yield and protein content in two-row malting barley is driven by the amount of N available to the plant. No relationship was noted between N rate and kernel plump or test weight. Regression analysis of grain yield and TKAN determined maximum grain yield was attained at 186 lbs N ac^{-1}. Additionally, when fertilized at the rate of maximum yield, grain protein content averaged 12.8%, which is below the 13.0% standard maximum protein content for malting (American Malting Barley Association Inc., 2019).

To calculate the TKAN for use with this recommendation, pre-plant soil nitrate-N to a depth of 2 feet must be determined. Additionally, N credits from the immediately previous crop and tillage system must be taken into consideration. More specific information on N credits are outlined in Franzen (2018).

ACKNOWLEDGEMENTS

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CAN SOIL HEALTH MEASUREMENTS HELP WITH SOIL FERTILITY DECISIONS IN SOUTH DAKOTA CORN?

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ABSTRACT

South Dakota (SD) fertilizer recommendations for major nutrients in corn were generated using soil fertility measurements and a yield goal. These recommendations have a critical value where increased application of a certain nutrient should no longer increase yield. Also, an increase in soil health understanding has created the possibility for soil health measurements to be used in the fertilizer recommendations along with soil fertility levels. The objectives of this study are 1) to determine if the critical values for phosphorus (P), potassium (K), and sulfur (S) need to be adjusted and 2) determine the effect of including soil health indicators on accuracy of yield response to fertilizer addition predictions. Locations were chosen throughout central and eastern SD that varied in tillage and crop rotation practices. Fertilizer addition treatments of 100 lbs. P_2O_5/ac, 100 lbs. K_2O/ac, and 25 lbs. S/ac were compared to a control (no P, K, or S). Soil samples for fertility and health were obtained prior to planting and fertilization. For P, increasing the critical value from P 16 ppm to 24 ppm (Olsen) increased the accuracy of our current recommendations by 10%. Furthermore, by using arylsulfatase and soil pH, instead of Olsen P, the R^2 value for the equation could be significantly increased (11.5%). For K, a decrease in the critical value from K 160 to 120 ppm significantly increased the accuracy of the recommendation (20%). By using soil test K and soil pH, the R^2 also increased (11.6%). When examining S, there was no correlation between soil test S, and moving the critical value would not help improve the accuracy. Two variables were found, active carbon (POXC) and the soil test K, which significantly raised the R^2 value for the equation (9.3%). More years/locations of data will be added and analyzed as this study continues.

INTRODUCTION

Corn (*Zea mays*) is one of the most widely grown crops in SD. It has been said that 1 out of every 3 dollars generated by SD agricultural production starts in a corn field, bringing in nearly 3 billion dollars in 2020 (USDA, 2020). Yields of SD corn fields have been steadily increasing from averaging below 100 bu/ac in the 1990's to a SD record average of 162 bu/ac in 2020. (USDA, 2020). To supplement this drastic increase in yield, SD farmers have been applying fertilizers in increasing amounts per acre. In 2017, SD farmers surveyed showed the highest P and K rates in the state's history, as well as being applied on the highest percentage of corn acres (USDA, 2017). This is logical because the SD fertilizer recommendations for major crop nutrients include soil test levels and a yield goal. If the yield goal has increased drastically from what it was 20 years ago, the amount of fertilizer needed will increase as well.

The South Dakota Fertilizer Recommendation Guide (EC-750) is routinely revised, but the actual fertilizer recommendations and equations have not been changed in over a decade. In that time, seed, fertilizer, and land prices have all increased, and weather patterns across SD have brought increases in rainfall. Examination of the critical values, or the soil test level where more application of that nutrient should no longer result in yield responses, is the first step in deciding if the fertilizer recommendations need to be adjusted.

Along with other agricultural changes, the emerging understanding of the importance of soil health has resulted in the adoption of conservation management practices including reduced tillage, organic matter amendments, and cover crops. Many studies have been conducted that looked into the benefits of increasing certain soil health measurements. Management practices such as no-till and cover-cropping have led to dramatic increases in soil health parameters and increases in yields (Chahal et al, 2021) One goal of improving soil health is to reduce fertilizer applications. Studies have found that nitrogen applications can correlate well with soil health metrics and have the possibility of reducing nitrogen rates (Yost et al., 2018). Other studies have been conducted that indicate increases in organic matter can reduce the loss of nitrogen to the atmosphere (Chaterjee and Clay, 2016). While a nitrogen and soil health interaction has been explored, P, K, and S has not been extensively evaluated.

The objectives of this project were 1) to determine if the critical values for P, K, and S need to be adjusted and 2) determine the effect of including soil health indicators on accuracy of yield response to fertilizer addition predictions. Through this study, we aim to find a correlation between soil health measurements and yield responses that can be useful in improving fertilizer recommendations.

MATERIALS AND METHODS

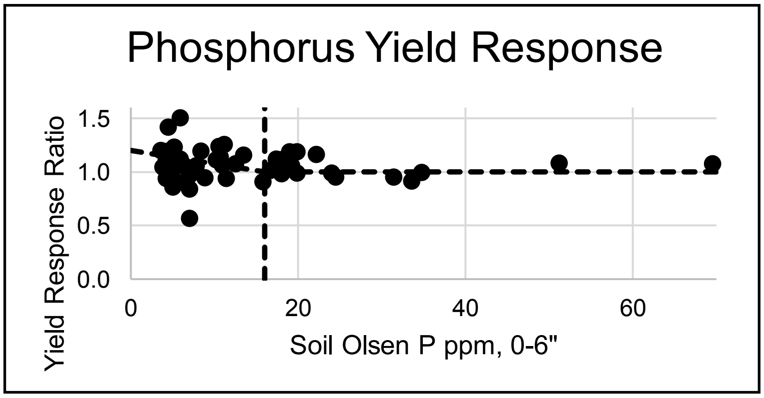
From 2019-2021, 28 locations across central and eastern SD were chosen that included different soil types, topography, crop rotations, and management practices. Each location had 4 replications of a control plot with no P, K, or S applied and 3 treatments that included 100 lbs. P_2O_5/acre, 100 lbs. K_2O/acre, or 25 lbs. S/acre. All plots were fertilized with the same nitrogen rate as the rest of the field. Fertilizer sources included urea (46-0-0) for N, triple super phosphate (0-46-0) for P, potassium chloride (0-0-60) for K, and ammonium sulfate (21-0-0-24) for S. Soil health and fertility preplant soil samples were taken at 0-6” depths. A 0-36” preplant soil sample was also taken for soil characterization purposes. Soil health measurements included the enzymes beta-glucosidase, acid-phosphatase, and arylsulfatase, as well as soil respiration (Zibilske, 1994), active carbon (Weil et al., 2003), total protein (Wright and Upadhyaya, 1998), and combustible C and N. Whole plant tissue samples were also taken at the V6 corn development stage and a grain sample was taken at harvest for nutrient analysis. Plots were harvested by hand or with a plot combine, and yields were adjusted to 15.5% moisture.

RESULTS AND DISCUSSION

Phosphorus

Across all plots fertilized with P, plants had 16% more dry mass than control plots. Corn V6 tissue analysis showed a 28% increase in P uptake as well as a 24% and 26% increase in uptake of K and S, respectively. Grain P content averaged 11% more than the control plots. Yield was raised an average of 6.5% across all sites, about 10 bu/ac, especially on soils that had higher clay contents. On clay soil types, yields were raised 10% while it was lowered 3% on loam soils. Corn V6 P content generally increased on coarser textured soils and grain P content did not differentiate based on soil type.

Our current P recommendations were compared to yield responses (**Figure 1**). The data points ranged from less than Olsen P of 5 ppm to approximately 70 ppm. Yield responses ranged from 50% losses to 50% gains.



Olsen P 16 ppm 0-6”		
	Insufficient	Sufficient
Response	0.38	0.20
No Response	0.26	0.16
Olsen P 24 ppm 0-6”		
	Insufficient	Sufficient
Response	0.54	0.04
No Response	0.32	0.1

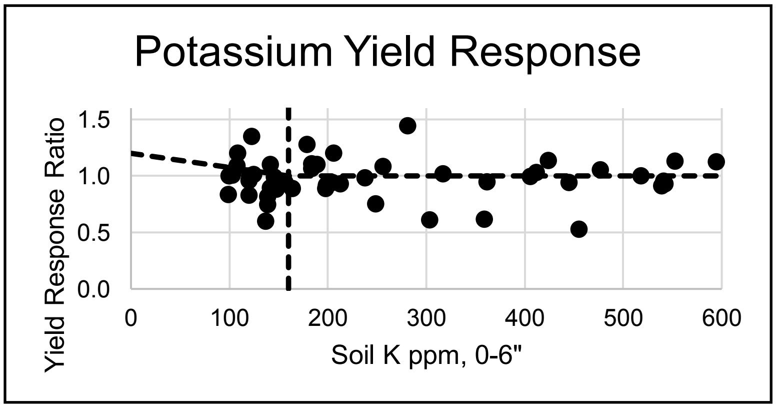
Figure 1. Corn yield response with added P fertilizer as a function of soil test P levels (Olsen-P). A yield response of 1 means the treatment plot yielded the same as the control plot. A vertical line represents the current critical value (Olsen P 16 ppm). The horizontal line represents the theoretical ideal regression line where yield responses should no longer be seen past the critical value. The yield response is considered a “response” in the tables when it is at least 5% higher than the control plot (a yield response ratio of ≥1.05).

The current recommendations are considered “correct” when Olsen P is below the critical value and yield was raised with a P application or if yield did not increase when Olsen P was above the critical value. The current critical value of 16 ppm was right 54% of the time. By increasing the critical value to Olsen P 24 ppm, the current recommendation increased to being right 64% of the time.

Potassium

In the K fertilized plots, V6 dry mass decreased by 3% from the control plot but K uptake increased by 15%. Both P and S uptake also slightly increased by 5% and 8%, respectively. Grain K content averaged 5% higher while P and S remained roughly the same as the control. Across all sites, yield was lowered 3% with a K application, possibly due to 60% of sites already being sufficient in K.

For soil types, the only texture that significantly raised yield was sandy clay loam, but this soil type was only present at one site. Silt loam soils also showed a slight increase in yield when they were deficient in K. The V6 K content generally increased with K application on coarser textured soils with insufficient K in the soil. Grain K content was not significantly different among soil types.



K 160 ppm 0-6”		
	Insufficient	Sufficient
Response	0.08	0.22
No Response	0.32	0.38
K 120 ppm 0-6”		
	Insufficient	Sufficient
Response	0.04	0.26
No Response	0.08	0.62

Figure 2. Corn yield response with added K fertilizer as a function of soil test K levels. The vertical line represents the current critical value (K 160 ppm), and the horizontal line is the theoretical ideal regression line.

Lowering the current K critical value from 160 ppm to 120 ppm would increase the accuracy of the recommendations from 46% to 66% (**Figure 2**). Since only 12% of sites would be considered insufficient at a critical value of 120 ppm, more testing needs to be done on K-deficient sites to see how they react to K applications.

Sulfur

Plots fertilized with S had 9% higher V6 dry plant weight and S uptake increased by 26%. Both P and K content slightly increased by 3% and 7%, respectively. Grain S content increased by 11%, but both P and K remained the same as the control. Across all sites, yield was decreased 1% even though all sites showed deficient S in the soil.

All soil types showed deficient S levels (<40 ppm), with the highest being loam at 11 ppm average soil test S. Soil type played no factor in yield although coarser textured soils resulted in increased uptake of S at V6. Grain S content was affected by soil type as fine-textured soils, with the exception of clay, resulted in higher S grain content.

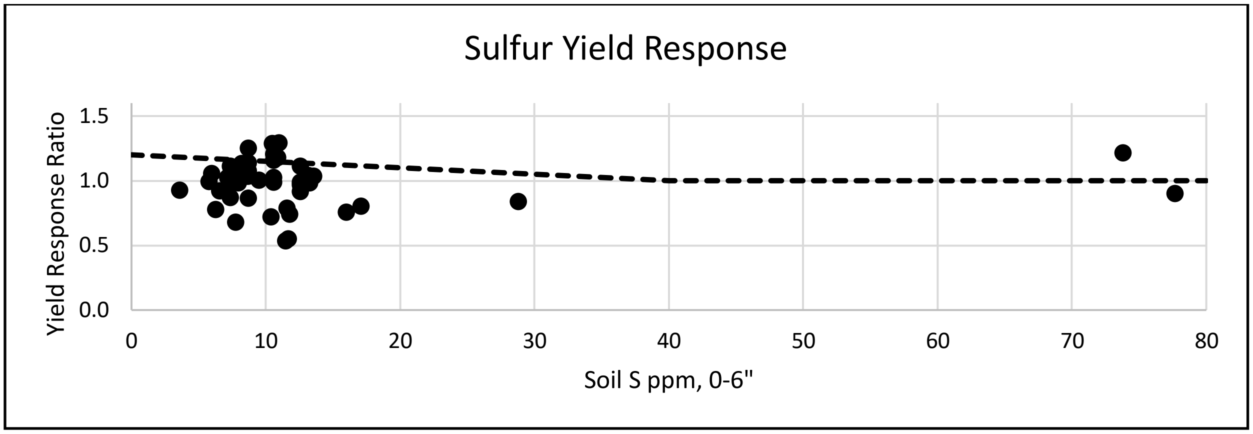


Figure 3. Corn yield response with added S fertilizer as a function of soil test S levels.The horizontal line represents the theoretical ideal regression line if a critical value of 40 was used.

The critical value for S is 40 ppm in SD, but it uses a 0-24" soil test instead of the 0-6" test used to stay consistent with other states involved in this study. Studies have shown a majority of plant usable sulfate-S (SO_4^{2-}) is present near the soil surface (Tabatabai and Bremner, 1972). Therefore, the SD critical value cannot be applied to this data set. This data does however show that little correlation exists between the 0-6" soil test S and yield responses (**Figure 3**).

Soil Health Variables

When looking to add variables to the soil health equations, the most important factors we considered were to 1) improve the R^2 value and 2) resulted in a regression line where a plateau or joint point could be calculated to determine a critical value. Variables were tested using stepwise comparisons from a list of many physical, chemical, and biological soil factors. The variables selected had a relatively higher R^2 value and a low number of variables.

Table 1. Current recommendations compared to a combination of new variables. The R^2 and the possibility for critical values are shown for each group of variables

Variable Comparisons			
Nutrient of Interest	Variables Used	R^2 Value	Slope sufficient for critical value
Current P Variable	Olsen P ppm	0.005	Yes
Best P Variables	Soil pH, Arylsulfatase	0.120	No
Current K Variable	Soil K ppm	0.003	Yes
Best K Variables	Soil K, Soil pH	0.012	Yes
Current S Variable	Soil S ppm	<0.01	No
Best S Variables	Soil K, Active Carbon	0.094	Yes

For P, using a combination of arylsulfatase and pH increased the R^2 from 0.005 to 0.120 but lost the possibility to add a critical value due to the regression line being nearly horizontal (**Table 1**). For K, a combination of soil K and soil pH slightly raised the R^2 (9%) and retained the possibility of adding a critical value. For S, a grouping of soil K and active carbon dramatically increased the R^2 (9.3%) while also adding the possibility of adding critical value.

All variables were only tested using linear models, and interaction tests were not completed for this paper. These models should not be used as a replacement for current recommendations, but they can show that soil health variables have the potential to improve the predictability of corn yield responses to added P, K, and S fertilizers.

CONCLUSIONS

This study has shown the value of adding P fertilizer in SD soils and shown inconclusive results for adding K and S. It has also shown the possibility for changes to the critical values for P from Olsen P 16 ppm to 24 ppm and has also shown the potential for K critical values to be adjusted if more K-deficient sites are studied. Secondly, soil health variables show the potential to improve predictions of yield response compared to only using soil test levels. More variables will be tested in the future as this is an ongoing study. All results of this study are preliminary, and more testing and statistics need to be run before final conclusions can be made.

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NITROGEN TIMING FERTILIZATION STRATEGIES FOR WINTER WHEAT IN WISCONSIN

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ABSTRACT

Economically optimum winter wheat (*Triticum aestivum* L.) production relies on effective N application rate and timing. Previous research in Wisconsin indicates a need to better understand winter wheat response to N rate and application timing for growing conditions specific to the state. This study evaluated the effect of N application timing on yield, economic optimum N rate (EONR), agronomic N use efficiency (NUE), and profitability. A three-year study was conducted at three locations where winter wheat was planted following corn (*Zea mays.* L.) silage. Sites included soils formed from varying parent materials, had varying drainage classes, slightly acidic to neutral soil pH, 2.1 to 3.4% soil organic matter, and represented the range of winter hardiness zones where winter wheat is commonly grown in Wisconsin. Nitrogen was applied at rates of 0, 30, 60, 90, and 120 lb N/a at a combination of different timings that included fall pre-plant, spring green up (GU), Zadoks growth stage 30 (GS30), GS40, 30 or 60 lb N/a preplant plus the remainder at GS30 or GS40. Fertilization of P and K occurred when instances of soil-test levels were below optimum. Grain yield data was collected and used to determine return to N and NUE values. Reponses models were fit to determine the EONR for each site-year and N timing strategy using an N:grain ($ lb/ N to $/bu grain) price ratio of 0.05 and N price of $0.35/lb N. While N rate and timing affected mean N uptake and yield for the entire study, analysis was partitioned into two groups that were differentiated by sites where EONR for preplant applied N was greater than EONR at GU applied N (n=3), and sites were EONR for preplant and GU applied N was similar (n=5). Where EONR for preplant application (120 lb N/a) was greater than GU application (69 lb N/a), the yield response to N was linear ($r^2 = 0.99$), suggesting N loss occurred in fall and/or overwinter. At these sites, application of N at GU, GS30, or 30 lb N/a at GU plus the remainder at GS30 had the greatest yield and NUE; however profitability was greatest for single applications at GU or GS30. Delaying some or all N application to GS40, compared to earlier application, resulted in a yield penalty (which averaged about 20 bu/a) and less profitable N management. A quadratic plateau model ($r^2 = 0.98$) best described the sites where yield response to N was similar between preplant (72 lb N/a) and any spring application timing (74 lb N/a). At 60 and 90 lb N/a (N rate surrounding EONR), GU application was most profitable, but was not significantly greater than preplant or preplant plus GS30 application. At these sites, waiting to apply N until GS30 or GS40 resulted in yield loss and significantly lower profitability. Some of the N fertilizer applied in the fall was lost at 3 of 8 sites in this study and fall N never resulted in significantly greater yield, profitability, or NUE. Application of N at GU always resulted in superior yield and profitability, and at GS40 always resulted in inferior yield and profitability. Thus, growers should target N application to coincide with GU. If soil or weather conditions prevent this, then applications should be made no later than at GS30. Regardless of whether or not fall N loss occurred, there was no clear economic advantage, nor was NUE significantly improved, by split N applications.

SYNERGISM BETWEEN LIME AND PHOSPHATE FERTILIZER APPLICATION ENHANCES SOIL PHOSPHORUS AVAILABILITY

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ABSTRACT

Phosphorus (P) is a non-renewable resource and an essential mineral element for plant development; therefore, a greater understanding of factors that affect soil phosphorus bioavailability is crucial for sustainable food production. Soil organic P can account for a large fraction of the total soil P, and its mineralization can replenish the soil solution with plant-available P. Raising the soil pH with a liming agent can enhance soil biological activity and increase soil P availability in acidic soils, but it is not clear how adding lime or lime plus phosphate fertilizer affects P availability in neutral soils, which was the objective of this research. The research was conducted at Champaign, IL, on a soil with a pH of 7 and a Mehlich III soil P test of 28 ppm at the 0-6 in depth. Corn (*Zea mays*) was the tested crop and was planted following soybean (*Glycine max* (L.) Merr.) as the previous crop. The treatments were broadcast-applied in the fall of 2020 and consisted of pelletized lime (Lime) at a rate 800 lbs acre^{-1}, and/or monoammonium phosphate (MAP; 11-52-0) at 80 lbs P_2O_5 acre^{-1} with an additional untreated control (UTC). The soils were sampled in the spring six days before planting (preplant) and at the VT corn growth stage. Soil samples were taken at the depths of 0-6 and 6-12 inches for both sampling timings, with additional samples at the 12-24 and 24-36 inch depths for the preplant sampling. At preplant, applying MAP+Lime resulted in 51% and 39% more P available than the MAP and Lime treatments, respectively. At VT, there was no change in P availability at either depth from MAP or Lime applications compared to the UTC, whereas MAP+Lime applications significantly increased P availability at both the 0-6 and 6-12 in layers. The application of MAP+Lime increased soil P availability, V8 aboveground biomass, P uptake and concentration, fertilizer P recovery, and corn grain yield.

INTRODUCTION

Nutrient deficiencies in plants greatly impact food production globally, and limited world fertilizer reserves make food security a constant concern. While nitrogen is commonly seen as the main limiting nutrient for plant production (LeBauer and Treseder, 2008), phosphorus (P)-based yield limitation cases are surging in previously non-problematic areas (Hou et al., 2020). Research and development of improved P fertilizer management has significantly increased the efficiency and recovery of applied P fertilizer, raising the question of why P deficiency is starting to become a problem in areas where it previously was not prevalent. Consistant increases in crop yield, resulting in higher P removal without the appropriate soil replenishment, is likely the main reason for this emerging problem.

Soil P is subject to several chemical processes that limit plant uptake. In highly weathered acidic soils, P availability is heavily restricted due to P fixation to iron and aluminum oxides. Whereas in alkaline soil, P can react with calcium (Ca), forming poorly soluble inorganic Ca phosphates. These abiotic processes depend highly on soil pH, with a near-neutral soil pH considered optimal for the greatest P availability. In acidic soils, lime ($CaCO_3$) is commonly applied to increase soil pH and thus the availability of P.

However, not only abiotic processes govern soil P availability. Phosphorus is one of the seven plant nutrients found in soil organic matter (SOM). Phosphorus bound with carbon is known as organic P (OP), and typically accounts for 30 to 65% of the total soil P (Tabatabai, 1989). Thus, SOM transformations are essential in determining the availability of P for plant uptake. Soil OP transformations are dependent on a combination of chemical, biological, and physical factors, which in turn, depend on environmental conditions like temperature and moisture (Condron et al., 2005). Plants and microorganisms can absorb inorganic orthophosphates from the soil solution, converting inorganic P into OP, a process known as P immobilization. The reverse process (mineralization) can also occur, where a phosphate group is cleaved from the organic matter, transforming complex forms of OP into plant-available phosphates. Certain forms of OP are known to be more mobile in the soil, resulting in a higher infiltration rate through the soil profile (Chardon et al., 1997). Since P is known to increase root growth, increases in P levels deep in the soil might result in greater root development and soil mining capacity.

Organic P mineralization is highly controlled by the action of phosphatase enzymes, which plant roots, soil bacteria, and fungal mycorrhizae can produce. Phosphatase activity depends on soil properties like pH, moisture, microbial biomass and diversity, actively growing plants, soil composition, and nutrient supply (Dietrich et al., 2016). Three main phosphatase enzymes are known to catalyze the mineralization of OP, each with a distinct proposed optimal pH: acid phosphomonoesterase (pH 5-6), phosphodiesterase (pH 8), and alkaline phosphomonoesterase (pH 11) (Margenot et al., 2018). Not only will changes in the soil pH affect the enzymes' activities, but they will also have an increase in overall SOM cycling (Biasi et al., 2008), mainly attributed to greater microbial activity (Garbuio et al., 2011).

Cultural practices, like P fertilization, may also impact phosphatase activity, but there are uncertainties regarding a possible inhibition or promotion of microbial phosphatase production (Margenot et al., 2018). The increase in P availability in the soil solution after fertilization was found to decrease phosphatase enzyme activity by Olander and Vitousek (2000), whereas Margenot et al. (2018) found that P fertilization did not reduce phosphatase enzyme activity.

Since pH changes can greatly impact the abiotic and biological processes governing soil P availability, the application of lime can substantially impact the net plant-available P. It is still unknown the effect on P availability when applying lime and/or MAP to a pH-neutral soil, as an increase in pH can negatively affect soil P availability through the precipitation of calcium phosphates or positively through increased biological P cycling. The objective of this study was to assess the effects of lime and phosphorus fertilizer on plant-available P in neutral pH soils and the resulting corn growth, nutrient uptake, and grain yield.

MATERIALS AND METHODS

Site characteristics and cultural practices

A field under corn-soybean rotation and conventional tillage at the Crop Sciences Research and Education Center at Champaign, IL (40° 3'8.85"N, 88°14'2.46"W), was used, which had an adequate soil test for P (28 ppm) and a pH of 7.0 at the 0-6 inch depth. The trial was established in November of 2020 when the fertilizer treatments were applied on soybean stubble. Corn hybrid DKC 62-52 was planted on April 25 of the following year to achieve a population of 36,000 plants acre^{-1}. To ensure adequate soil fertility, 180 lbs acre^{-1} of nitrogen (N) as UAN was applied to all plots prior to planting. The field experienced average total rainfall and average temperatures during the entire experiment duration.

Treatments and soil sampling

The treatments were broadcast-applied with light incorporation on 6 November 2020 and consisted of monoammonium phosphate (MAP; 11-52-0) at 80 lbs P_2O_5 acre^{-1}, pelletized lime (Lime; 36 % calcium, <0.5 % magnesium, 94 % calcium carbonate equivalent) at 800 lbs acre^{-1}, or a combination of the two (MAP+Lime). An untreated control (UTC) was also included with no P or lime application.

The soils were sampled six days before planting (preplant) and at the VT corn growth stage using a soil testing probe. Soil samples were taken at the depths of 0-6 and 6-12 inches at both sample timings, with additional samples at the 12-24 and 24-36 inch depths at the preplant sampling. The soils were analyzed for P by A&L Great Lakes Laboratories (Fort Wayne, IN) using Mehlich III extraction.

Corn data collection

Total aboveground plant biomass sampling was conducted at the V8 growth stage by sampling two plants from each of the center two rows of each plot and then drying to 0% moisture. Dried stover samples were ground in a Wiley mill to pass through a 2 mm mesh screen, and a representative subsample was evaluated for P concentration by A&L Great Lakes Laboratories. Nutrient accumulation in the plant was determined using total plant biomass weight and stover P concentrations.

The center two rows of each plot were mechanically harvested to determine grain yield and harvest moisture, and the yield was subsequently standardized to bushels per acre at 15.5 % moisture. Subsamples of the harvested grain were evaluated for kernel number and average kernel weight. Kernel weight is presented at 0 % moisture.

Experimental design and analysis

Experimental units were plots four rows wide and 17.5 feet in length with 30-inch row spacing. Plots were arranged in a randomized complete block design with six replications. Statistical analysis was performed using a linear mixed model approach with PROC MIXED in SAS (version 9.4; SAS Institute, Cary, NC), and means were separated using Fisher's protected LSD test at the 0.10 level of significance. The normalities of residuals were assessed using PROC UNIVARIATE.

RESULTS AND DISCUSSION

Soil P Availability at Preplant

At the preplant sampling timing, all treatments, MAP, Lime, and MAP+Lime increased soil P availability compared to the UTC in the 0-6 in layer (Fig. 1). When MAP was applied with lime, there was a synergistic increase in P concentration in the 0-6 in layer, resulting in 51% and 39% more P available than MAP and Lime treatments, respectively (Fig. 1). Therefore, increasing the amount of P available for microbial uptake stimulated microbial production of phosphatase enzymes with a subsequent increase in plant-available P.

Fertilization with MAP+Lime also increased P availability at the 12-24 in and 24-36 in layers at the preplant sampling. Increases in P availability in deeper soil layers were likely due to the infiltration of soluble organic P forms from surface depths, possibly derived from enhanced SOM mineralization when MAP+Lime was applied. The MAP and Lime treatments affected P availability similarly throughout the soil profile (Fig. 1).

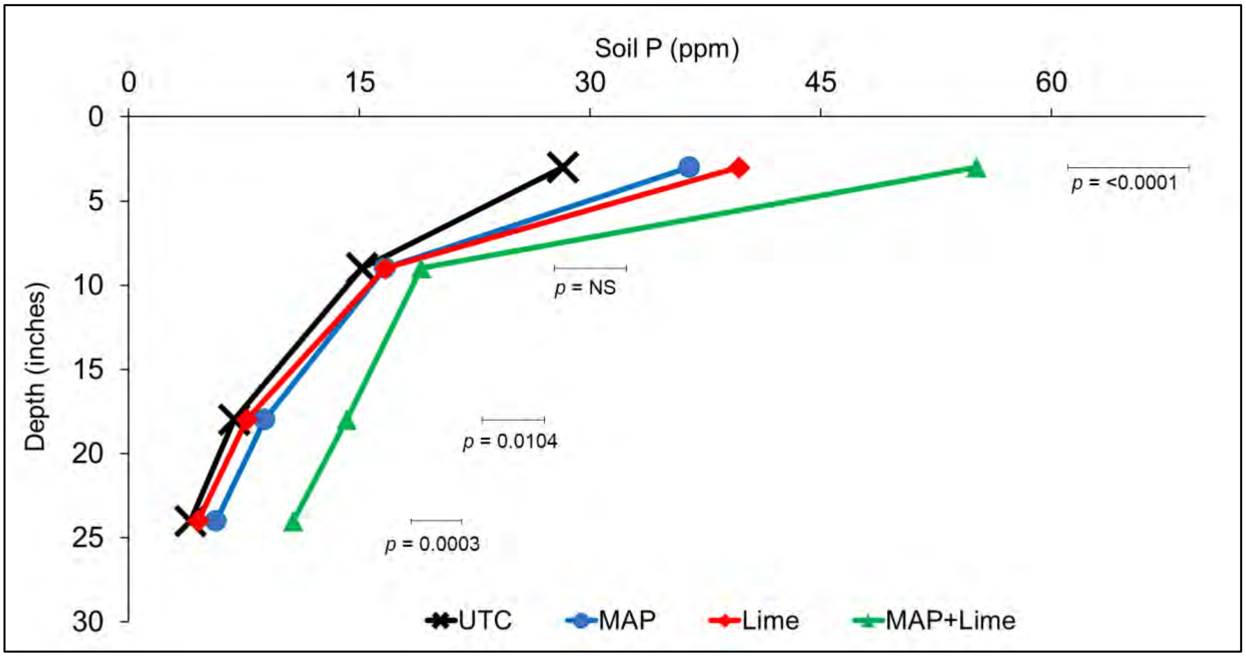

Figure 1. Soil P availability at preplant by treatment (UTC, MAP, Lime, and MAP+Lime) and sampling depths (0-6, 6-12, 12-24, and 24-36 in). Horizontal error bars indicate LSD at *p* = 0.10 for each depth.

Soil P Availability at VT

Neither MAP nor Lime increased P availability, regardless of the soil layer that was sampled at VT (Table 1). There were larger reductions in P availability over time from both treatments containing Lime than for MAP, which indicates that the declines are not only coming from plant uptake, but also from organic P cycline that wa accelerated and led to P immobilization by the microbes (Fig.1 and Table 1).

Similar to the preplant sampling observation, MAP+Lime increased P availability at VT. There was an increase at both the 0-6 and 6-12 inch layers, further indicating that soluble organic P forms are being produced and are penetrating below 6 inches in the soil profile (Fig.1 and Table 1).

Table 1. Soil P availability at corn VT stage by treatment (UTC, MAP, Lime, and MAP+Lime) and sampling depths (0-6 and 6-12 in).

Treatment	Soil P Availability		
	0-6 in	6-12 in	Average
	ppm		
UTC	30.5	13.5	22.0
MAP	35.3	12.5	23.9
Lime	31.0	13.3	22.2
MAP+Lime	45.3	17.7	31.5
LSD (.10)	8.3	3.3	5.5

Corn V8 Sampling and Grain Yield

All fertilizer applications statistically increased V8 biomass accumulation and P uptake over the UTC. The application of Lime resulted in a higher P concentration in the plant than MAP, even though no fertilizer P was added to the soil. The application of MAP+Lime increased P uptake, P concentration, and fertilizer P recovery (FPRE). The FPRE of MAP+Lime doubled compared to MAP only, further indicating a synergistic effect of MAP+Lime (Table 2).

Grain yield was unaffected by MAP or Lime treatments alone. However, there was a synergistic effect of combining MAP+Lime, resulting in a yield increase compared to either the UTC or MAP treatments. The grain yield increase from the MAP+Lime treatment was driven by an increase in kernel number, indicating better initial growth conditions or less kernel abortion (Table 3).

Table 2. Aboveground plant biomass, P_2O_5 uptake, P concentration and fertilizer P recovery as affected by fertilizer sources for corn grown at Champaign, IL in 2021. All parameters were measured at the V8 stage.

Treatment	Biomass†	P uptake††	P Concentration	FPRE
	lbs acre-1		%	
UTC	1788	16.4	0.40	-
MAP	2131	18.8	0.38	3.0
Lime	2097	19.1	0.42	-
MAP+Lime	2205	21.4	0.43	6.2
LSD (0.10)	183	2.1	0.03	2.4

†Biomass at 0% moisture. †† P uptake as P2O5.

Table 3. Corn grain yield and yield components as affected by different treatments for corn grown at Champaign, IL in 2021. Grain yield is reported at 15.5% moisture, and kernel weight is reported at 0% moisture.

Treatment	Grain Yield	Kernel Number	Kernel Weight
	bu acre^{-1}	kernels m^{-2}	mg kernel $^{-1}$
UTC	234	4978	250
MAP	235	5200	240
Lime	236	5177	242
MAP+Lime	246	5453	240
LSD (0.10)	10	260	NS

CONCLUSIONS

There was a positive synergistic effect of MAP+Lime on all the parameters evaluated in the study (soil P availability, V8 biomass, P uptake, P concentration in the plant, fertilizer P recovery, and corn grain yield). The data show that applying MAP+Lime has advantages over supplying either product alone. The application of lime, with or without MAP, increased soil P availability at preplant, which indicates that previously non-available P became more available, likely due to increased organic P mineralization. There was an increase in P availability deep in the soil profile when MAP was applied with lime, which may promote increased root growth, greater access to water and nutrients, and limit soil P run-off. Therefore, P fertilization with lime has great potential as an application for no-till production systems, where P stratification can limit crop yield potential.

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HIGH GYPSUM APPLICATION RATES IMPACTS ON IOWA SOIL PROPERTIES, DISSOLVED PHOSPHORUS LOSS, AND CROP YIELD

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ABSTRACT

Gypsum (calcium sulfate) is a common sulfur (S) source for crops and rates in the northcentral region seldom are greater than 250 lb/acre. It is known that even higher gypsum rates do not raise soil pH. Research in eastern and southeast states showed that in some conditions high gypsum rates can improve other chemical or physical properties and can reduce dissolved phosphorus (P) loss from fields. However, there is little research available on the potential benefits of high gypsum rates in prairie-developed soils of Iowa and neighboring states. This article summarizes results of two studies conducted from 2016 to 2020 in Iowa. A 3-year study conducted at two sites with corn-soybean rotations managed with no-tillage evaluated single or annual gypsum rates of 0, 250, 500, 1000, 2000, and 4000 lb/acre on several soil chemical properties and aggregate stability, crop tissue nutrient concentrations, and grain yield. The other study assessed gypsum effects on dissolved and total P loss with surface runoff by conducting two one-year trials using rainfall simulations in two different years and no-till fields with soybean residue. In the first trial of this runoff study, soil-test P was very low, treatments were granulated or finely ground gypsum each broadcast once in the fall at rates of 0, 500, 1000, or 2000 lb/acre with or without broadcast P fertilizer and three time periods from the materials application to a first runoff event (within 2 days, after 15 days, or natural snowmelt runoff from first snowfall until early spring) all from different plots. In the second trial of the runoff study the soil had very high soil-test P and treatments were similar except that only granulated gypsum was used.

Results from the 3-year study with corn-soybean rotations showed that gypsum increased yield one year at one site (soybean) with no rate differences and increased S content of crop vegetative plant tissue but had no consistent effects on other macro-, secondary, or micro-nutrients. Gypsum rates of 250 lb/acre or higher increased topsoil (6 inches) sulfate-S, rates greater than 1000 lb/acre also increased S in the 6 to 12-inch depth, and reduced topsoil water-extractable P only one year at both sites. The two highest annual rates increased topsoil calcium (Ca) concentration and saturation but decreased magnesium (Mg) concentration. Single or annual gypsum rates of 2000 lb/acre or higher improved soil aggregate stability only at the site where grain yield was not affected. The runoff trials showed that no gypsum source or rate affected dissolved P loss with runoff.

Overall, we conclude that gypsum application at rates higher than needed to supply S for crops did not increase yield further, increased topsoil Ca but reduced Mg, did not reduce dissolved P loss from fields, and improved soil aggregate stability at one site where yield was not affected. Benefits from applying high gypsum rates may be more likely in soils with poorer physical and chemical properties.

INTRODUCTION

Gypsum (calcium sulfate) has been used for decades to supply sulfur (S) to crops in Iowa and other states. Gypsum also has been used in states with poorer soils (weathered, sandy, or extremely acid) to supply calcium (Ca) to crops and improve both cation balance and soil physical properties and also to alleviate excess sodium (Na) levels in saline or strongly alkaline soils. Since the early 2000s, research in several states began studying the potential value of soil amendments such as alum (aluminum sulfate) and gypsum at high rates to reduce dissolved phosphorus (P) loss from fields through surface runoff or subsurface tile drainage. In response to these new developments, numerous farmers, soil conservationists, and nutrient management planners of Iowa and northcentral region have been asking questions about the value of these amendments, especially with no-till management. However, there is little research available on the potential benefits of these amendments, especially gypsum, in prairie-developed soils of Iowa and neighboring states.

Previous Iowa studies have focused on effects of alum and gypsum on dissolved P loss with surface runoff when mixed with manure and effects of gypsum application on P loss with subsurface tile drainage. Mallarino and Haq (2012) conducted research at three Iowa fields collecting surface runoff from rainfall simulations and natural snowmelt runoff when finely ground alum (aluminum sulfate) or gypsum were mixed with poultry (egg layers) manure. Results showed that across all rainfall and snowmelt runoff events, alum and gypsum decreased dissolved reactive P by 65 to 88 and 17 to 58%, respectively, compared with manure applied alone. A 4-year study conducted by Dougherty et al. (2020) in northeast Iowa evaluated the effect of 2000 lb/acre of gypsum on P loss with subsurface tile drainage from a field testing very high in P and managed with continuous corn, tillage, and N-based liquid swine manure. Gypsum application did not affect P loss with tile drainage.

Therefore, two new complementary studies were implemented from 2016 to 2020 to study the potential benefits of high gypsum rates in Iowa. One study focused on evaluating impacts of gypsum on dissolved and sediment-bound P loss with surface runoff. The other study focused on assessing gypsum impacts on several soil chemical properties, soil aggregate stability, crop tissue nutrient concentrations, and grain yield.

SUMMARY OF PROCEDURES

For the study of gypsum effects on crop and soil properties, two 3-year field trials with similar treatments for corn-soybean rotations managed with no-tillage were conducted at two Iowa State University research farms. One was in central Iowa (Boone County) at a field with Clarion loam soil (Typic Hapludolls) and the other in the northeast Iowa research farm (NERF) at a field with Floyd loam soil (Aquic Hapludolls). Soil tests (6-inch depth) for pH, organic matter, cation exchange capacity (CEC), extractable calcium (Ca) and magnesium (Mg), and Ca saturation were 5.6, 4.1%, 19 meq/100g, 2105 and 294 ppm, and 55% Ca saturation at Boone and 5.6, 3.4%, 17 meq/100g, 1908 and 268 ppm, and 57%, respectively. Soil test methods were those recommended for the north central region (NCERA-13, 2015) and soil water-extractable P was measured by the method described by Pote et al. (1996). Phosphorus and potassium (K) were applied in the fall of each year. Initial treatments replicated three times were commercial granulated gypsum broadcast at rates of 0, 250, 500, 1000, 2000, and 4000 lb/acre in the fall. The 250-lb rate applied 43 lb S/acre, which is at the high end of S rates suggested for corn or soybean in the region. After harvest of the first-year crop (soybean), all plots were split into two halves to apply either no gypsum or the same initial rates each year. Soil samples (6-inch depth) and plant samples were taken at the crops V5 to V6 growth stage (in June) to assess potential early treatment effects on soil P and soil sulfate-S and on plant growth and nutrient uptake. Vegetative tissue and grain samples were analyzed for total nitrogen (N), P, K, Ca, Mg, S, boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). After each grain harvest in the fall, soil samples were collected from depths of 0-6 and 6-12 inches and were analyzed as for the initial soil samples plus water-extractable P. In the spring of the third year, after all treatments had been applied, undisturbed soil samples (6-inch depth) were taken from all replications of selected treatments to measure aggregate stability by the method by Kemper and Rosenau (1986). Results were expressed as mean weight diameter (MWD) and the percentage of aggregates with a diameter of 1.0 mm or larger (greater values indicate better soil structure).

For the study of gypsum effects on total and dissolved P loss with surface runoff interacting with the timing to a first runoff event after the application we used a field rainfall simulation technique. Two trials were conducted in different no-till fields and years, both with Clarion loam soil (Typic Hapludolls) beginning in the fall (October) after soybean harvest. The first trial site had 5 ppm Bray-1 P (6-cm depth), pH 6.7, 3.2% organic matter, and 66% residue cover. The second trial site had 29 ppm Bray-1 P, pH 5.9, 3.3% organic matter, and 95% residue cover. First-site treatments replicated three times were 100 lb P_2O_5/acre applied alone or with gypsum 0, 500, 1000, or 2000 lb/acre using granulated or finely ground gypsum. The timings to a first runoff event after the materials application to different set of plots were within 2 days, after 15 days, or natural snowmelt runoff from first snowfall to early spring plus a final last rainfall simulation because there was little snow cover that winter. Second-site management and treatments were similar to those used for the first site except that only granulated gypsum was applied with or without the same P rate and no spring rainfall simulation was needed because there was high snow cover and snowmelt runoff. Runoff was analyzed for total P and filtered runoff (0.45 um) was analyzed for dissolved reactive P. Soil loss also was measured but is not shown.

RESULTS

Gypsum effects on crop and soil properties

Gypsum did not affect crop yield in any year at NERF but Boone increased soybean yield in the last year (a year with excess rainfall at this site that limited yield) with no statistical differences among application rates. Yield of the control was 36 bu/acre whereas the average across all treatments receiving gypsum was 50 bu/acre. Gypsum often increased S content of crop vegetative plant tissue but not of grain, and had no consistent effects on other macro-, secondary, or micro-nutrients (not shown).

Gypsum greatly increased soil S at June sampling dates each year (0-6 inches) and slightly reduced water-extractable P in one year at both sites (not shown). Gypsum also greatly increased soil S at depths of 0-6 and 6-12 inches at both sites, although the effects varied greatly over time and across sites (Figs. 1 to 3). The lowest rate seldom increased soil S over the control and the residual effects of higher single applications decreased sharply over time. However, annual rates higher than 500-lb rate resulted in very high soil S levels and significant leaching to a depth of 6-12 inches.

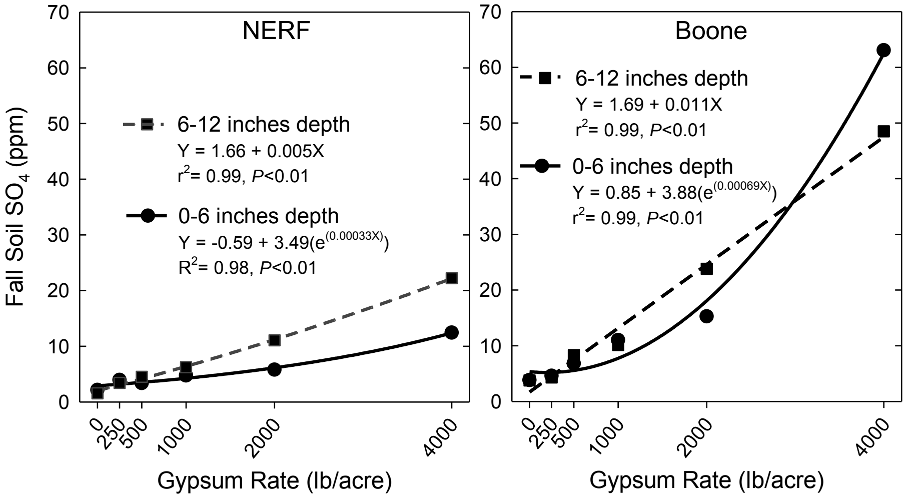

Fig. 1. Effects of first year gypsum application rates on post-harvest soil S.

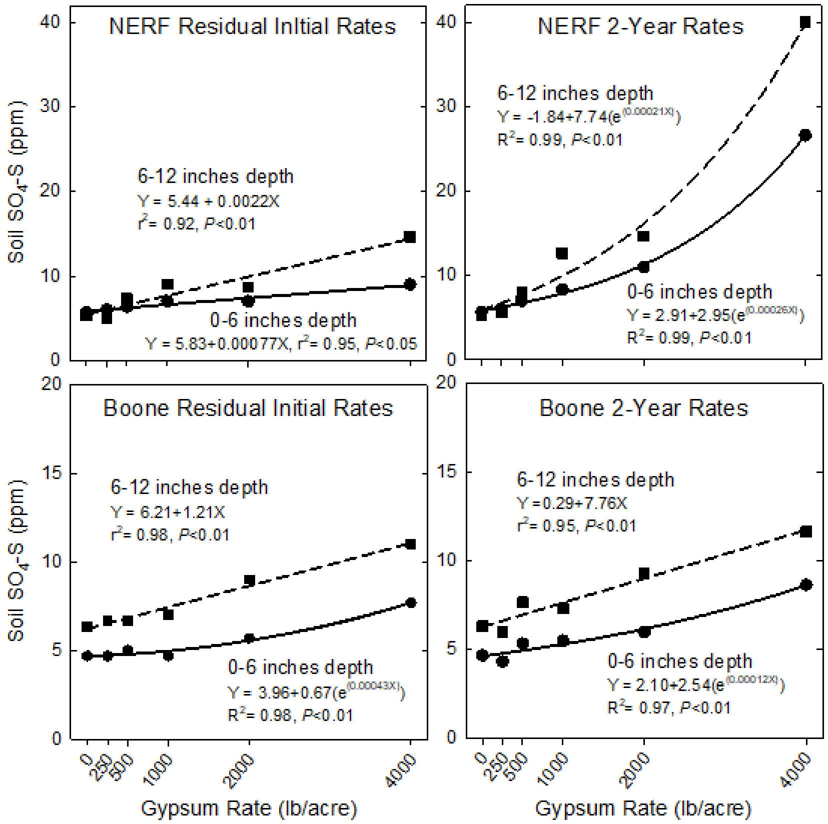

Fig. 2. Effects of single or annual gypsum applications on soil S after the second crop.

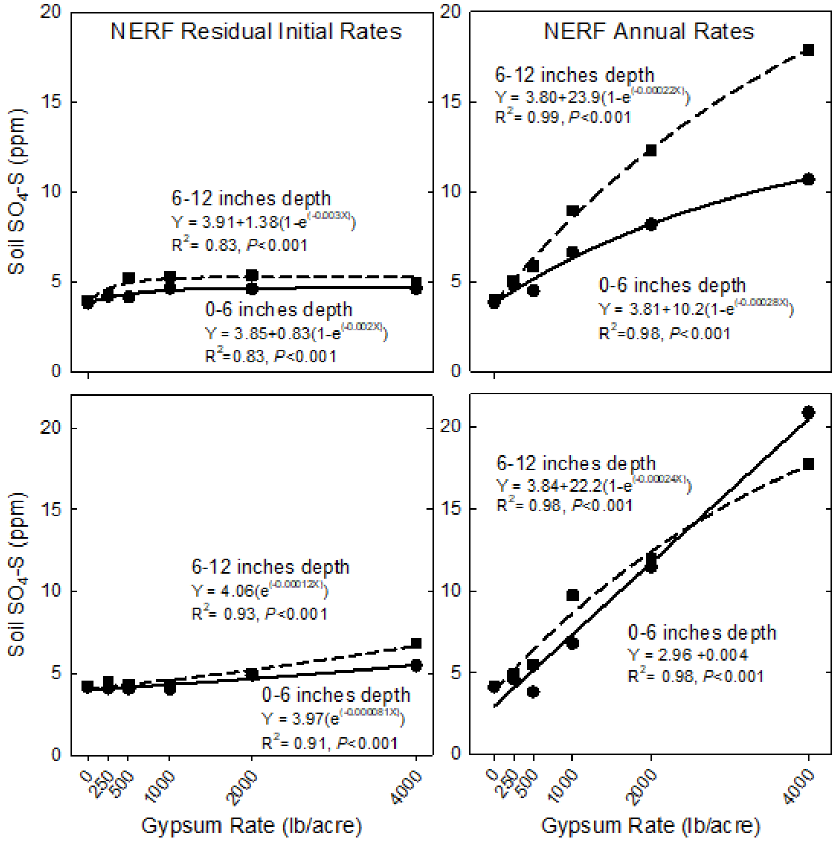

Fig. 3. Effects of single or annual gypsum applications on soil S after the third crop.

Figure 4 shows results for some of the other soil measurements that were affected by gypsum. By the end of the third year of the study, gypsum application increased soil extractable Ca and Ca saturation but decreased extractable Mg. In spite of linear or curvilinear observed responses, large differences were between initial or annual rates of 1000 lb/acre or higher compared with the control or lower rates.

Aggregate stability of untreated or treated soil as indicated by mean weight diameter (MWD) and the percentage of aggregates with a diameter of 1.0 mm or larger (greater values indicate better soil structure) was better at NERF than at Boone. Figure 5 shows results of the aggregate stability expressed only by MWD because results for aggregate size were proportionally similar at both sites. Gypsum did not affect aggregate stability at Boone. At NERF, however, gypsum single initial or annual rates of 2000 or 4000 lb/acre improved aggregate stability compared to the control or lower rates. It is remarkable that gypsum improved aggregate stability only at the NERF site, where it was better than at Boone and where gypsum did not increase crop yield.

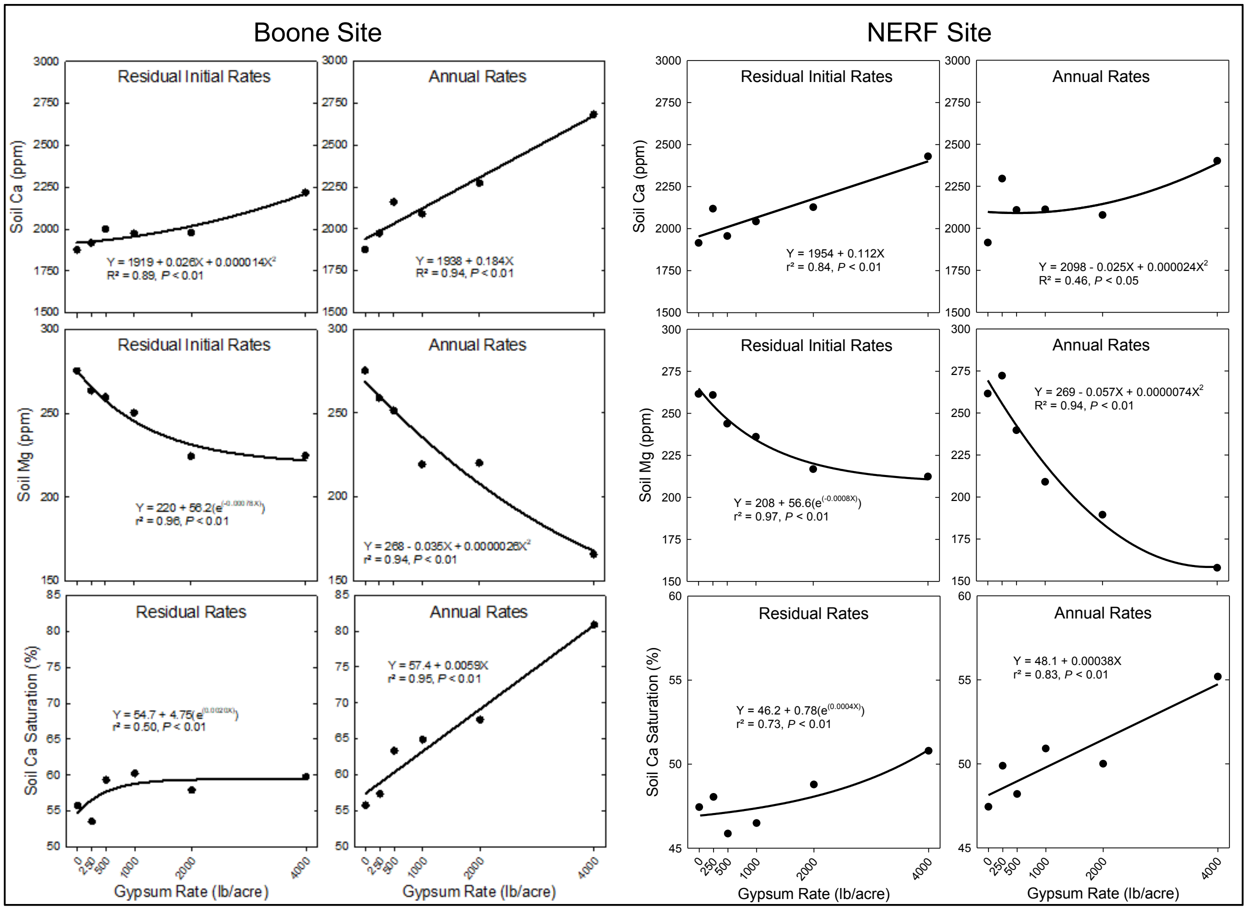

Fig. 4. Soil Ca, Mg, and Ca saturation after the third crop at depth of 0-6 inches at two sites as affected by single or annual gypsum applications rates.

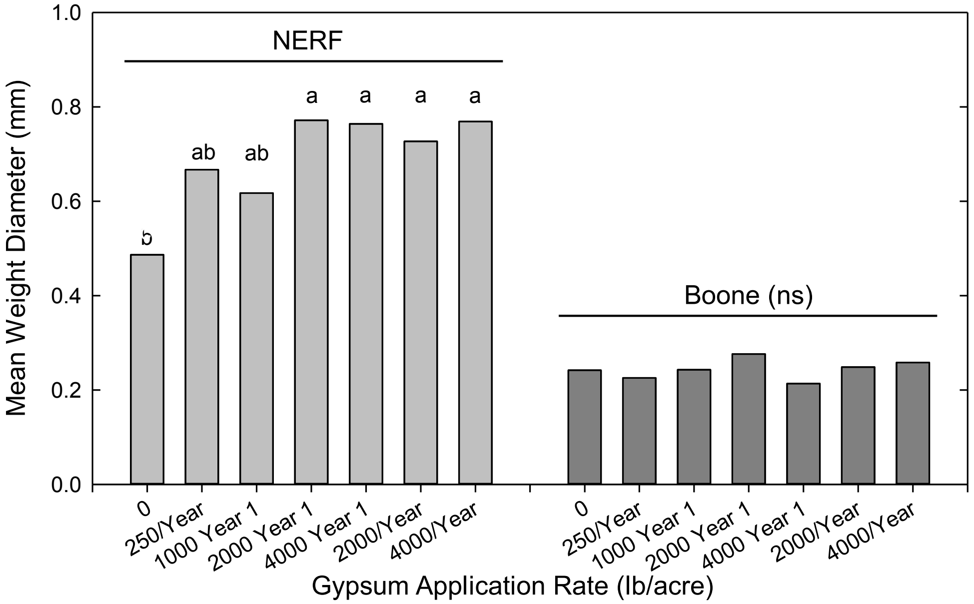

Fig. 5. Effects of selected gypsum single initial or annual applications on soil aggregate stability at the end of two three-year trials expressed as mean weight diameter. Bars with similar letters indicate no differences at *P* ≤ 0.05; ns, not significant.

Gypsum effects on dissolved P loss with runoff

Figures 6 and 7 summarize results of gypsum effects on dissolved (DRP) and total P loss with surface runoff at two trial sites. Gypsum application rates of 500 to 2000 lb/acre using granulated or finely ground sources did not affect DRP or total P losses at any trial and for any time to runoff treatment. Additional research with natural rainfall and a longer evaluation time would be desirable to confirm these results.

CONCLUSIONS

Increasing gypsum rates increased sulfate-S levels in the top 6 inches of soil, with no increase for a rate of 250 lb/acre, small for rates of 500 and 1000 lb/acre and large for rate of 2000 and 4000 lb/acre. The highest S increases were observed with annual gypsum applications, with significant S leaching to a depth 6 to 12 inches with applications greater than 500 lb/acre/year. The highest annual gypsum rates increased soil Ca, decreased Mg, and increased Ca saturation at both sites. However, gypsum rates higher than needed to supply S for crops did not increase yield further at any site and improved soil aggregate stability only at one site. The runoff study showed no gypsum source or rate effects on dissolved or total P loss with surface runoff.

Overall, we conclude that gypsum application at rates higher than needed to supply S for crops may improve some soil chemical and physical properties but crop yield increases are unlikely. Benefits from applying high gypsum rates may be more likely in soils with much poorer physical and chemical properties.

ACKNOWLEDGMENTS

We recognize funding to study P loss with surface runoff by The Leopold Center for Sustainable Agriculture and to study crop and soil properties by the Division of Soil Conservation and Water Quality of the Iowa Department of Agriculture and Land Stewardship, and funding for both studies by Calcium Products Inc.

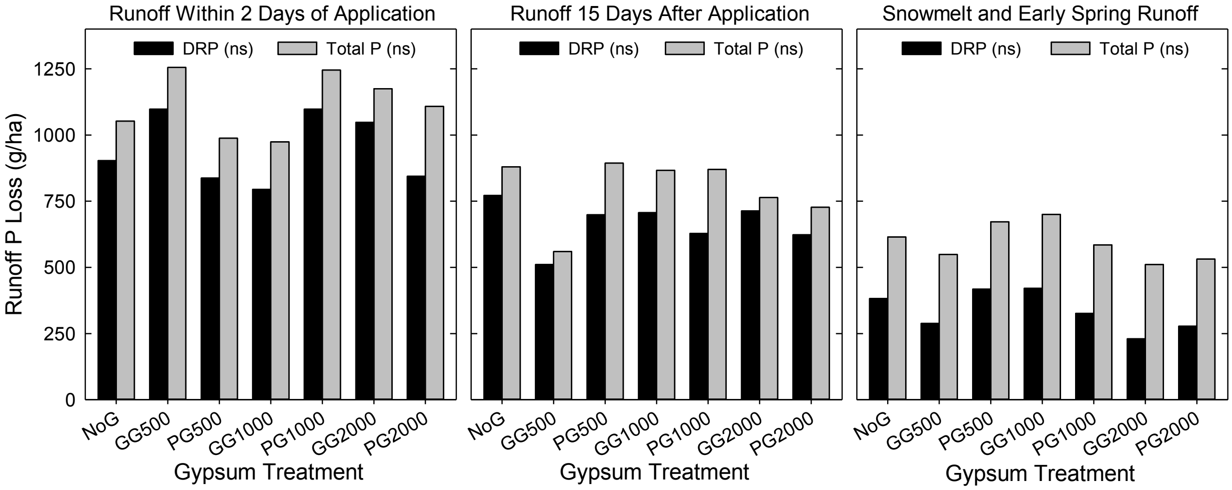

Fig. 6. First-year site runoff dissolved reactive P (DRP) and total P loss for events at different times after fall applied P (No G) and P applied with granulated (GG) or powdered (PG) gypsum.

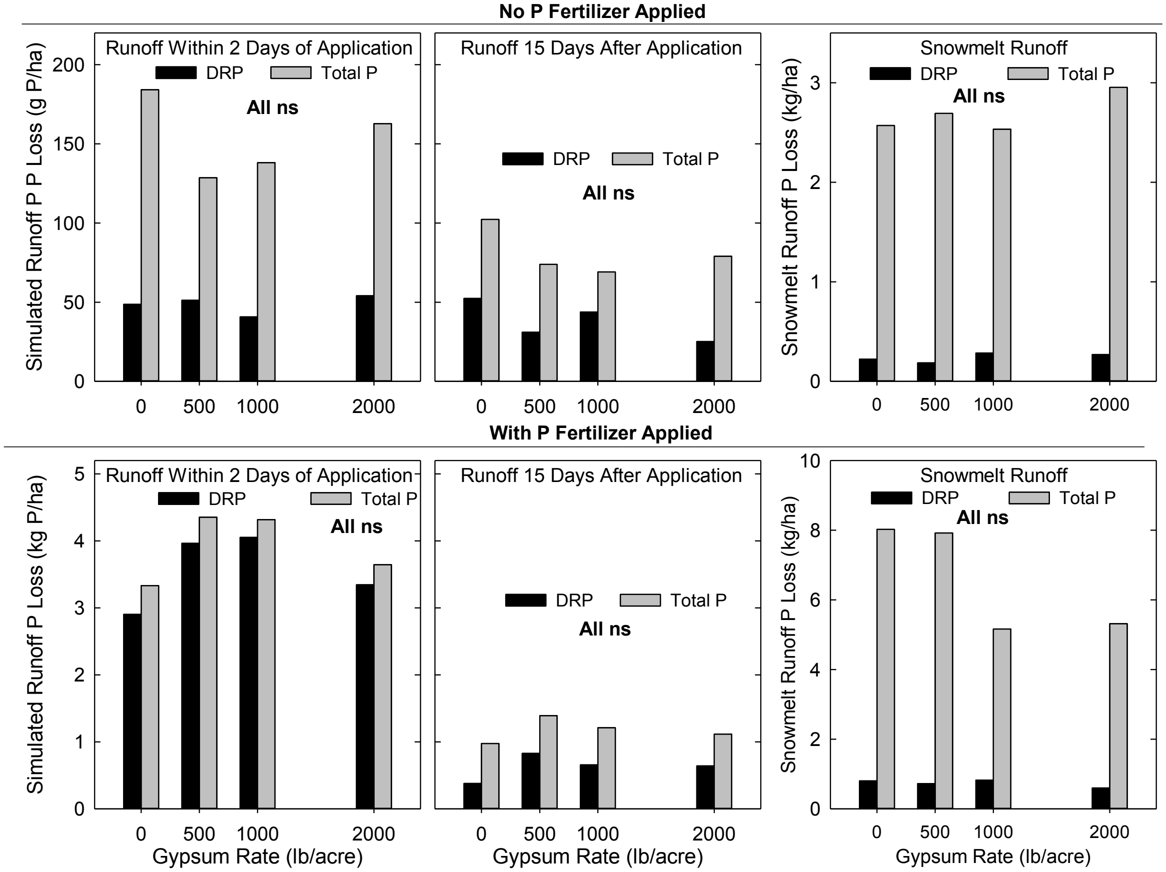

Fig. 7. Second-year site dissolved reactive P (DRP) and total P losses for runoff events at different times after fall applied granulated gypsum with or without P fertilizer.

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IN-SEASON CHANGES OF SOIL MINERAL NITROGEN WITH NITROGEN FERTILIZER APPLICATION IN CORN

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ABSTRACT

Soil Mineral Nitrogen (SMN) supply during the growing season plays a crucial role in the growth and productivity of corn. Nitrogen (N) demands vary during the growing season, and maintaining the highest amount of N in the form of ammonium (NH_4^+), or nitrate (NO_3^-) during the peak times of plant N uptake can help support high yields. The objective of this study was to assess changes and the supply of soil mineral nitrogen during the growing season in corn under field conditions in Kansas. This study was carried out in 8 locations across Kansas during the 2017, 2018, 2019, and 2020 crop seasons. Fertilizer rates included 100, 150, and 200 lbs N/acre in addition to a control in a factorial arrangement with and without the use of a nitrification inhibitor. Since the V2 through the R6 grow stage in corn, soil samples were collected every two to three weeks. Samples were collected at 0-12 and 12-24 inches and analyzed for NO3 and NH4. Soil NO3 concentration showed an initial increase followed by a rapid decrease after the V10 growth stage. This trend was likely due to the initial nitrification process from N fertilizer followed by a rapid corn N uptake. Soil NH4 was generally higher early in the season, with slightly higher values with the use of nitrification inhibitors. Results from this study indicated that the delayed nitrification process with nitrification inhibitors was detectable with regular soil sampling. However, differences were small, and under regular field production systems is unlikely this small effect will be detectable with soil sampling. Results from this study also provided field values for SMN during the growing season under corn production. Weather and soil variables for each location in this study will be explored to investigate the interaction of soil, weather, and SMN under field conditions.

THE IMPACT OF NITRIFICATION INHIBITORS, HERBICIDES, AND NITROGEN SOURCES ON NITRIFICATION AND CORN GRAIN YIELD

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ABSTRACT

Nitrogen management in crops can be challenging due to nitrogen transformations and losses in soil. Nitrate nitrogen can be lost through leaching when nitrogen input exceeds crop nitrogen demand. Nitrification inhibitors are used to temporarily slow the nitrification process by reducing the abundance of nitrifying bacteria. Herbicides can also generate non-target effects on soil microorganisms and can be used as an alternative to slow the nitrification process. Several studies have been conducted in laboratory settings to observe the effects of herbicides on nitrification and nitrate leaching. However, the effect of herbicide on nitrification in field corn (Zea mays) production remains uncertain. To determine the effects of nitrification inhibitors, herbicides, and nitrogen sources, we conducted a two-year field experiment at the University of Nebraska-Lincoln South Central Agricultural Laboratory. Treatments were laid out in a split-plot factorial design with 4 replications. The main plot included 3 herbicide treatments. The subplot included 5 nitrogen fertilizer treatments. Herbicide applications did not affect nitrification rate. Anhydrous ammonia and urea with inhibitor had variable effects on nitrification across both years. Nitrogen sources had a significant effect on nitrification. Anhydrous ammonia retained ammonium concentrations at significantly higher levels when compared to urea in both years. Herbicide use increase crop yield, while nitrogen inhibitors and nitrogen sources had a variable effect on crop yield in both years.

INTRODUCTION

Nitrogen (N) fertilizer inputs can be lost to the environment through several pathways (Peng et al., 2015). Nitrogen loss through nitrate leaching is of major concern because it not only reduces nitrogen use efficiency (NUE) and crop yield but also affects drinking groundwater quality in Nebraska. Nitrification inhibitors can temporarily inhibit nitrification and slow the rate of conversion of ammonium to nitrate and improve crop N uptake. Similarly, herbicides could also generate non-target effects on soil microorganisms, including those involved in N reactions (Zhang et al., 2018).

A comparative effect of nitrification inhibitors, herbicides and nitrogen sources has not yet been studied at field scale. The objectives of this study were 1) to evaluate the effect of nitrogen sources, nitrification inhibitors, and pre-emergence herbicides and their interaction on nitrification, and 2) quantify the impact of nitrification inhibitors, herbicides and nitrogen sources on crop nitrogen availability, NUE, corn N uptake, and grain yield. We hypothesized that like nitrification inhibitors, a pre-emergence herbicide application will reduce soil nitrification and improve nitrogen use efficiency and crop yield.

MATERIALS AND METHODS

A two-year (2020 and 2021) field research experiment was conducted at the University of Nebraska-Lincoln (UNL) South Central Ag Lab near Clay Center, Nebraska. Each year, corn was grown following soybean at a different site. Both sites had silt-loam soil. The research plots were arranged in a split-plot design with four replications. Three herbicide treatments were the main plot treatments including a) No pre-emergence herbicide, b) Acuron (active ingredients: Atrazine/bicyclopyrone/mesotrione/s-metolachlor, c) Resicore (active ingredients: Acetochlor/mesotrione/clopyralid). Each main plot had the following five nitrogen treatments as subplots: 1) no fertilizer, 2) anhydrous ammonia with a nitrification inhibitor (N-serve), 3) anhydrous ammonia with no inhibitor, 4) urea with a nitrification inhibitor (Guardian, Instinct II), 5) urea with no inhibitor. An economical optimum nitrogen rate (EONR) of 168 kg ha-1 was used for all treatments receiving nitrogen inputs. Herbicide, and nitrogen treatments were applied on the corn planting date. All plots received post-emergence glyphosate and dicamba/tembotrione.

To determine nitrification, weekly soil samples at 0-10 and 10-20cm were collected from April to July of each year. Soil samples were extracted using 2MKCL (Jones & Willett, 2006) and analyzed for NO3-N and NH4-N using Griess-Illosvay reaction with vanadium chloride (III) as a reducing agent and the Berthelot reaction, respectively (Hood-Nowotny et al., 2010). Data were analyzed using SAS 9.4. PROC GLIMMIX procedure was used to run ANOVA. Significant treatment differences were assessed through Tukey-Kramer test.

RESULTS AND DISCUSSION

Across both years, herbicides did not affect nitrification rates in all nitrogen treatments (data not shown). This was contrary to previous lab studies where herbicides decreased nitrification rates. One possible reason for this difference could be the use of higher herbicide rates in lab studies, while we used the recommended herbicides rates in the field. We found a variable effect of nitrification inhibitors on nitrification rates during the growing season.

In the year 2020, anhydrous ammonia with inhibitor had significantly higher soil NH_4^+-N concentration at four out of 8 sampling times while it had significantly lower NO_3^--N release 50% of the sampling dates (Figure 1A, 1B). In the year 2020, nitrification inhibitor did not significantly affect nitrification rates but had significantly lower nitrate release across 5 of 8 sampling times (Figure 1C, 1D).

Nitrogen sources had a significant effect on nitrification rates. Anhydrous ammonia with and without inhibitor retained significantly higher NH_4^+-N content than urea with and without inhibitor (Figs. 1). Urea fertilizers with and without inhibitors resulted in significantly higher NO_3^--N concentration than anhydrous ammonia with and without inhibitors (Figures 1).

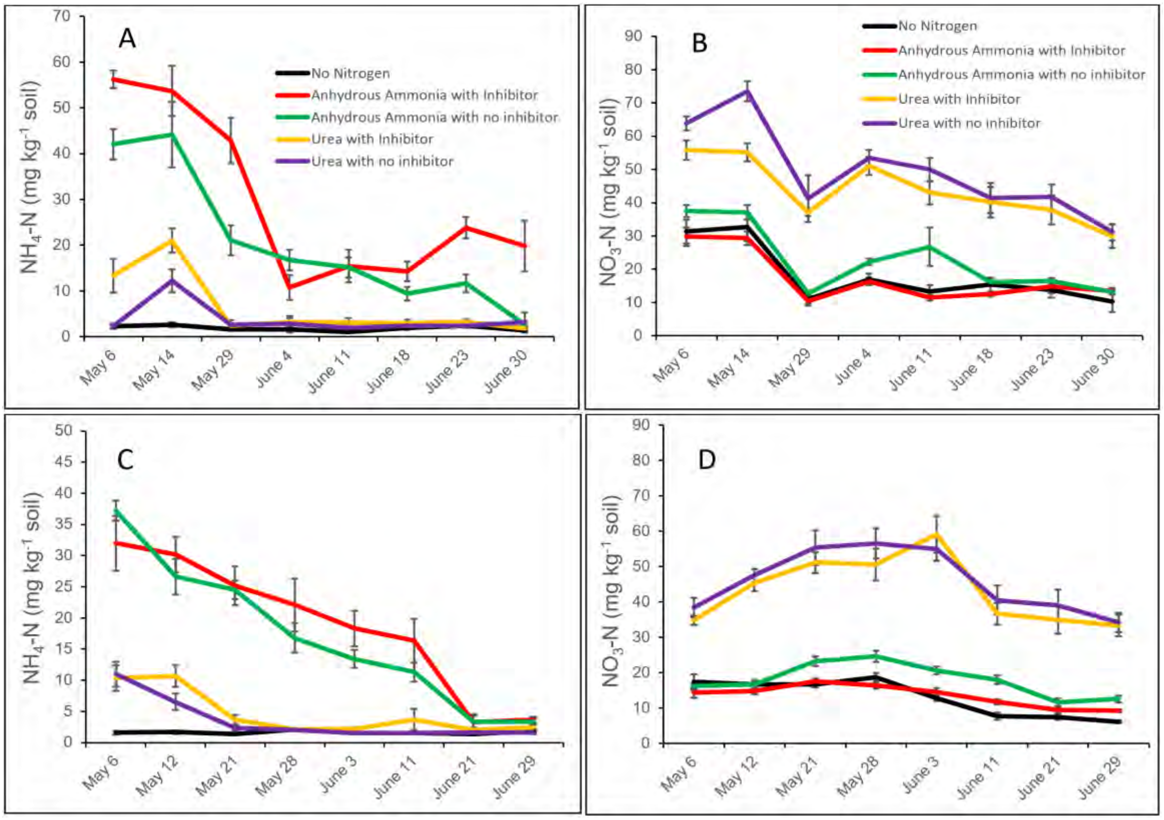

Figure 1. The effect of nitrification inhibitors and nitrogen sources on soil NH_4^+-N and NO_3^--N concentrations during year of 2020 (A,B) and 2021 (C,D).

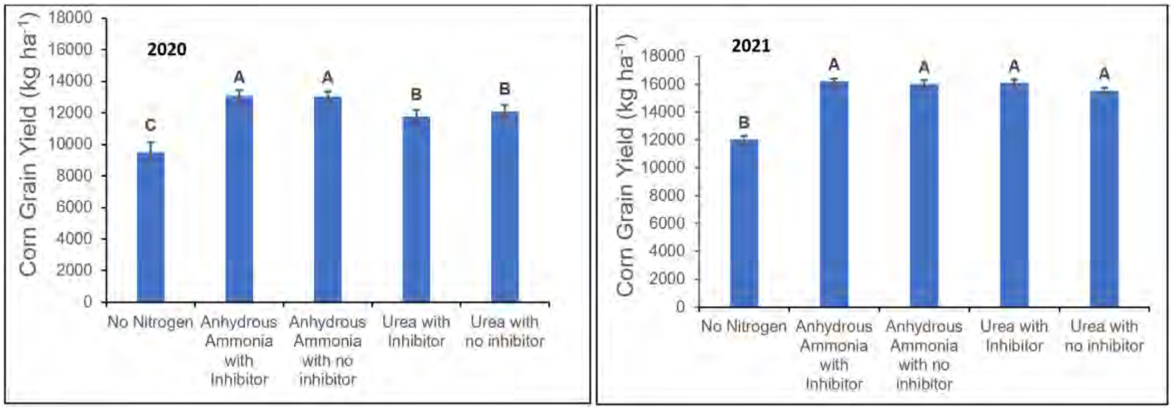

Figure 2. The effect of nitrification inhibitors and nitrogen sources on corn grain yield during two years of study at South Central Ag Lab, University of Nebraska-Lincoln, Lincoln NE.

Anhydrous ammonia with and without inhibitor resulted in significantly higher corn grain yield than urea with and without inhibitor in 2020, but no significant N sources effect was found in 2021 (Figure 2). Urea with inhibitor yielded 528 kg ha^{-1} more corn grain yield than urea without an inhibitor in 2021.

CONCLUSION

Nitrogen source had a significant effect on soil nitrification rates (Anhydrous Ammonia < Urea) and potential N losses during the early season, compared to nitrification inhibitors. Though previous lab studies have shown that herbicide reduces nitrification, our field study does not agree with previous findings. Nitrification inhibitors had a variable effect on crop yield as Urea with inhibitor resulted in a higher yield than Urea with no inhibitor in 2021. N source can significantly impact crop yield compared to nitrification inhibitors.

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SITE-SPECIFIC YIELD AND PROTEIN RESPONSE TO NITROGEN RATE AND TIMING IN WINTER WHEAT

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ABSTRACT

Nitrogen (N) fertilizer management is crucial in cereal crop production. Improved prediction of optimal N fertilizer rates for winter wheat can decrease N losses and enhance profits. We tested seven N fertilizer rates (0, 25, 50, 75, 100, 125, and 150 kg N ha^{-1}) applied at three timings (Fall, Spring, and Split Fall/Spring) in seven small plot trials located in commercial fields and contrasting landscape positions in Nebraska. Our objectives were to (a) characterize the winter wheat yield and protein content response to N rate and timing in farmer's fields; (b) determine the site-specific economic optimal N rate (EONR), the yield at the EONR (YEONR) and the protein content; and (c) compare the observed EONR with the N rates estimated by existing N recommendations models. Results showed no significant effect of timing of N application on yield and protein. However, within sites, yield and protein tended to be higher for Spring than Fall and Split Fall/Spring N application timing. Across N rates and sites, yield ranged from 1850 kg ha^{-1} to 10800 kg ha^{-1} and the protein content from 11.3% to 15.5%. The yield response to N (difference between yield at 150 kg N ha^{-1} and the non fertilized plot) was on average 2193 kg ha^{-1} with a standard deviation of 1550 kg ha^{-1}. EONR ranged from 50 to 140 kg N ha^{-1}. Different methods for N recommendation in winter wheat will be discussed. Our results will contribute to improving current N recommendations for winter wheat producers in Nebraska.

BIOMASS AND NITROGEN PARTITIONING OF THE MODERN RUSSET VARIETIES OF POTATOES UNDER NITROGEN STRESSED AND OPTIMUM CONDITIONS

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ABSTRACT

Dry matter biomass and nitrogen (N) uptake and partitioning in the biomass can be different based on the varieties and nutrient availability. These differences can result in the wide variations in production and quality and nitrogen use efficiencies (NUE). However, there is a lack of quantitative understanding of the N uptake and partitioning in the biomass of the different varieties of potato. Lack of this understanding can lead to the lumping all the varieties as one during fertilizer applications and other N management practices. This can further lead to the leaching down of the nutrients as well as decrease in the NUE of the plants due to either excess or deficient supply of N to the plants. Therefore, quantifying and understanding these differences are important to improve N management based on the N demand of the plants, improve NUE of the crops, and decrease the N leaching out of the system. Hence the objectives of this study is to increase the fundamental understanding of the quantitative differences in N and dry matter partitioning dynamics of modern Russet varieties of potatoes at various fertilization rates and to provide evidence if the most commonly grown Russet varieties can be managed similarly or not. For this purpose, the study was conducted for two years (2020-21) on four modern Russet varieties of potato (Goldrush, Russet Norkotah, Silverton, and Russet Burbank) under two N rates (0 and 267 lbs-N/ac) at Hancock Agricultural Research Station. The in-season biomass was collected weekly or bi-weekly throughout the growing season which was then partitioned into foliage and tuber biomass. Total nitrogen (TN %) by dry combustion and dry matter biomass was measured for each sample which was then used to quantify N accumulation in the biomass. ANOVA and multiple comparison tests to compare the differences in the treatments was performed. Dry matter, N accumulation in the in-season and yield biomass was different based on the varieties, N rates, or their interactions.

INTRODUCTION

The states in the Midwest region annually rank among the top in the nation in potato production, including Wisconsin (3rd), North Dakota (6th), Michigan (7th), Minnesota (8th), and Nebraska (11th) (USDA, NASS., 2020). Wisconsin also offers the most varieties of potatoes grown in the USA. N is the most limiting nutrient in the development and growth of crop yield and quality (Bowen et al., 1999). Deficiency or excess of plant N can decrease tuber yield and quality due to premature leaf senescence, decreased leaf chlorophyll contents or delayed tuber maturation. N and dry matter accumulation and partitioning in the crop biomass depends on potato varieties (Geremew et al., 2007), nutrient and water availability, and environmental conditions (Koch et al., 2020). This can result in variations in their NUE as well (Zvomuya et al., 2002). Outside of Hornacek and Rosen (2008), there is not much information on N uptake patterns of potato in the Midwest. Based on the latest available information (https://www.potatopro.com/wisconsin/potato-statistics), Russet Burbank, Goldrush, Russet Norkotah, and Silverton Russet were the 2nd, 3rd, 4th, and 6th most popular varieties grown in Wisconsin, and they represent 16, 12, 11, and 6 percent of the acreage. Each potato has their own unique features, but direct comparison of their growth patterns and nitrogen accumulation has not been evaluated. The question remains – how different are these varieties?

Hence the objectives of this study was to increase the fundamental understanding of the quantitative differences in N and dry matter partitioning dynamics of modern Russet varieties of potatoes grown at optimum and stressed N conditions and to provide evidence if the most commonly grown Russet varieties can be managed similarly or not.

MATERIALS AND METHODS

Site Description

The on-going study was conducted for two years from 2020-21 at the University of Wisconsin-Madison Hancock Agricultural Research Station (HARS; 44°8'23" N, 89°31'23" W; elevation: 328 m) in 2020-21 on Plainfield loamy sand soils (sandy, mixed, mesic, Typic Udipsamments) and will be at the participating farmer's field on 2022.

Sampling Design and Treatments

The experimental treatments consist of four most popular modern Russet varieties of potatoes grown under two N fertilization rates (0, 276 lbs-N/ac) as ammonium sulfate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3) in a randomized complete block design (RCBD) with three replications. Each replication was divided from each other by an alley of 5 ft. (2020) and 12 ft. (2021) wide. Each experimental plots were divided into four rows and the in-season samplings was conducted on second row while final harvesting on third rows of the main plots. Whereas, the "clean plots" were 25 ft. long which were only harvested at the end of the growing season from rows two and three. The fertilizers were broadcast applied three times during the growing season (25-50% at emergence, 50% at tuber initiation and 2 weeks after tuber initiation) depending on the levels of N fertilizers in the treatment plots. All the experimental plots were non-limited by all other resources and nutrients. The seed pieces (which were either cut 'A' size or whole 'B' size) were mechanically planted on 1 May (2020) and 22 April (2021) and were harvested on 28 Sept (2020) and 9 Sept (2021). The four modern Russet varieties in the study were Russet Norkotah (an early to mid-season flowering variety, determinate), Goldrush (an early-season flowering variety, determinate), Silverton (a mid to late- season flowering variety, determinate), and Russet Burbank (a late- season flowering variety, indeterminate). It is expected based on previous trials that 276 lbs-N/ac is a non-limiting application of N when split applied three times during the growing season (76 kg-N/ha at emergence as ammonium sulfate, 100 lbs-N/ac at tuber initiation and 100 lbs-N/ac 2 weeks after tuber initiation as ammonium nitrate) (Laboski and Peters., 2012).

Experimental Measures

Between planting and harvesting the total of ten and nine weekly or bi-weekly in-season plant samplings were conducted in all the experimental plots starting from 28 days after planting (DAP) to 110 dap in 2020 and 34 dap to 111 dap in 2021 (Bélanger et al., 2001). Final harvesting was conducted at 150 dap and 140 dap in 2020 and 2021 respectively. Three to six plants were sampled during in-season sampling depending on the biomass where six plants were sampled initially, reducing it to five, four, and three plants later in the growing season as plants grow bigger (Bélanger et al., 2001). The plants were then partitioned into leaf, stem, and tuber biomass. Whereas, roots were removed from the plant body. The vines and tubers were dried at 70ºC until a constant weight was obtained for determination of dry matter (DM) concentration. TN% was analyzed through Dumas dry combustion method. N uptake in the plant biomass was calculated based on the TN% concentration and dry matter in the biomass for each treatment at each sampling dates.

Data Analysis

Biomass and N uptake data was analyzed by using analysis of variance (ANOVA) test to measure the significant differences in the above ground and tuber biomass (lbs/ac), TN (%), and N accumulations/uptake (lbs-N/ac) between the treatments. All analysis was performed in R 3.6.3. We have tested the null hypothesis for all the treatments (varieties and N rates) where, H_01: Mean dry matter biomass (aboveground, tuber, and total) and N uptake in the biomass is the same among all the varieties and N rates. H_02: There is no interaction effects of varieties and N rates on mean biomass and N accumulation.

RESULTS AND DISCUSSION

Dry Matter Biomass

Year 2020: There was a difference in the mean dry matter biomass partitioning between tubers and foliage biomass due to the differences in the N fertilization rates (Fig 1). Although Goldrush and Russet Burbank produced higher foliage biomass and Russet Norkotah and Silverton produced lower foliage biomass at optimum N fertilizer conditions measured up to 110 dap. However, there was no significant difference in the foliage biomass between different varieties and at different N rates. Similarly, although there was no interaction between varieties and N rates or varietal effect on tuber biomass. However, there was a significant differences between N rates on tuber biomass ($p<0.018$). All the varieties in an unfertilized plots produced higher tuber biomass as compared to the plants in fertilized plots up to 110 dap. There was no differences in the total biomass between varieties and N rates.

Year 2021: There was a difference in the mean dry matter biomass partitioning in the foliage and tuber biomass due to the interaction between N fertilization rates and varieties (Fig 2). There was no interaction between varieties and N rates or varietal effect alone on foliage biomass. However, there was a significant difference on foliage biomass between fertilized and unfertilized plots ($p< 9.064 * 10^{-5}$) where foliage biomass was higher in the fertilized plots. There was no differences in the tuber or total biomass among all the treatments up to 111 dap. We took only three to four plant samples and calculated biomass based on the planting density. The biomass thus collected and TN (%) in the biomass was used to measure N uptake and accumulation in the biomass. Therefore, the sampling errors must be considered in the measurements as well.

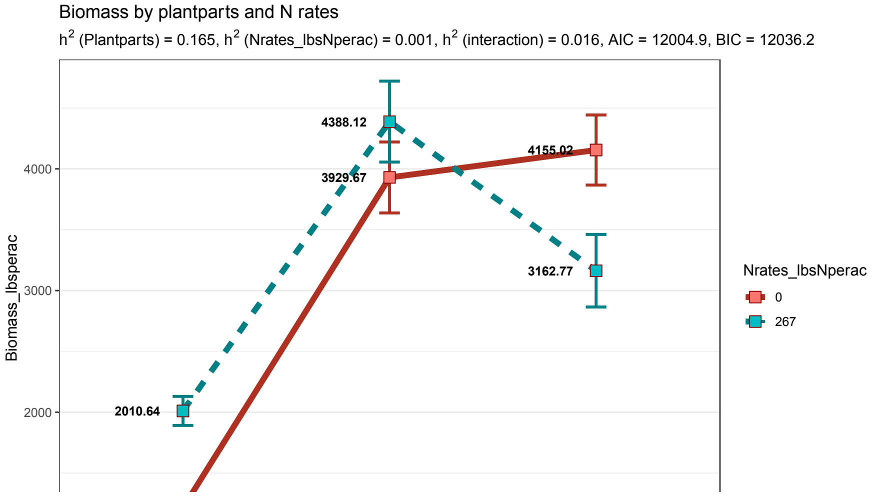


Fig 1: Interaction plot of Biomass~ Plant parts (foliage, tubers, and total)*N rates (0, 267 lbs-N/ac) for all the four varieties in the experiment measured in the year 2020 with 99% conf ints. AIC means Akaike's Information Criteria and BIC means Bayesian Information Criteria.

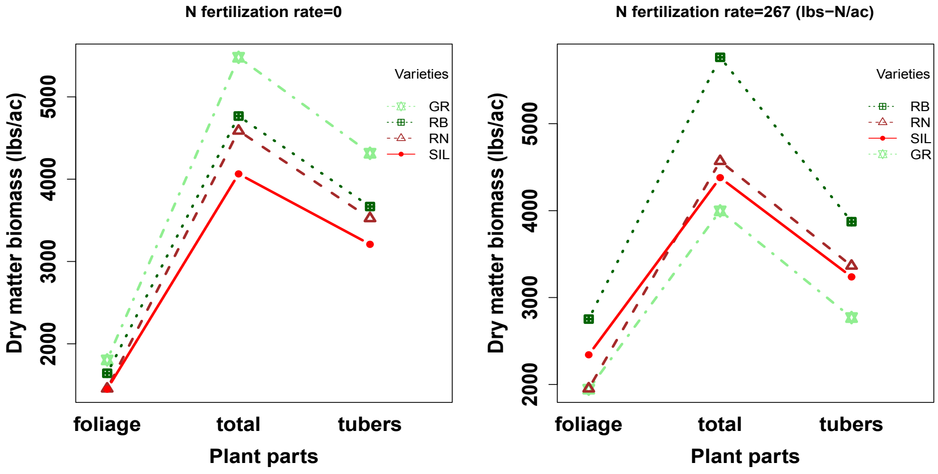


Fig 2: Interaction between N rates and varieties on dry matter foliage, tuber, and total plants grown in 2021 at HARS. RB = Russet Burbank, RN = Russet Norkotah, GR= Goldrush, SIL= Silverton. The effect of the interactions of N rate and variety biomass was sig at 95% conf ints.

N Uptake in the Biomass

Year 2020: There was a difference in the N uptake and accumulation between foliage and tuber biomass due to N rates, varieties, and the interaction between plant parts and N rates. However, there was no interaction effect of varieties and N rates on foliar N uptake. Whereas, there was a significant difference on foliage N uptake among varieties ($p<0.0495$) and N rates ($p<10^{-16}$) where N uptake was higher in the fertilized plots. Similarly, Goldrush had the highest N uptake in the foliage biomass followed by Silverton, Russet Burbank, and Russet Norkotah respectively (Fig 3). There was an effect of only N rates on N uptake in tuber ($p< 0.06359$) and total ($p<1.921*10^{-11}$) biomass with higher N uptake under optimum fertilization up to 111 dap.

Year 2021: There was a difference in the N uptake and accumulation between foliage and tuber biomass (Table 1). These differences were due to interaction of N rates and plant parts. However, there was a difference in the N accumulation due to the interactions between N rates and varieties. However, There was no interaction or varietal effect on foliar N uptake. However, there was a significant difference on foliage N uptake between N rates (p<2.381 *10^{-8}) where N uptake was higher under optimum fertilization. There was no significant differences in the tuber N uptake. Whereas, there was a higher N uptake (p<3.654*10^{-6}) in the total biomass under fertilized conditions.

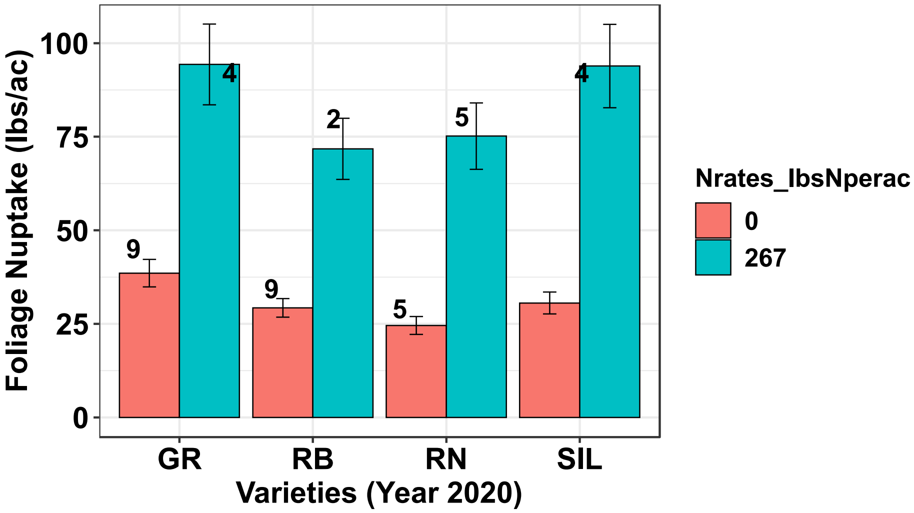


Fig 3: N uptake in the foliage biomass of the four modern Russet varieties (where RB=Russet Burbank, RN=Russet Norkotah, GR=Goldrush, and SIL=Silverton) grown under two N rates (0, 267 lbs-N/ac) at HARS in the year 2020

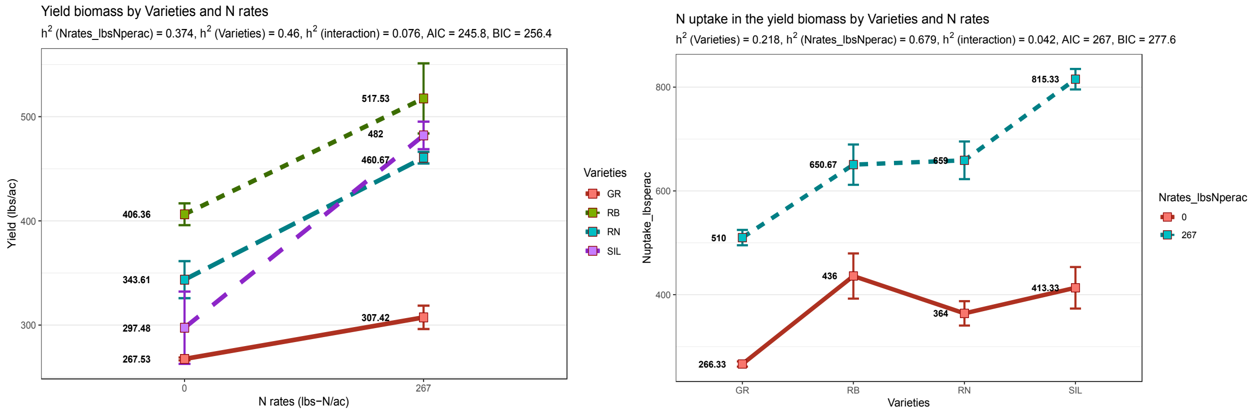
Table 1: N uptake and accumulation as a function of plant parts, varieties, and N fertilization rates in the year 2021 among four modern Russet varieties in the study under two N rates

N uptake ~ Plant parts * Varieties * N rates	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr (>F)**	
Plant parts	2	249349	124674	64.518	< 2e-16	***
Varieties	3	5858	1953	1.011	0.38757	
N rates	1	101494	101494	52.522	1.37E-12	***
Plant parts : Varieties	6	4192	699	0.362	0.93154	
Plant parts : N rates	2	28359	14180	7.338	713	***
Varieties : N rates	3	15884	5295	2.74	0.04264	*
Plant parts : Varieties : N rates	6	2175	362	0.188	0.98284	
Residuals	579	1118865	1932			
Sig. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1						

Yield Differences among Treatments

In the year 2020, Russet Burbank (an indeterminate, longer growing season) variety had the highest total yield (at 150 DAP) and Goldrush (determinate, a shorter growing season) variety had the lowest yield (Fig 4a). There was an effect of variety, N rates, and their interactions on N uptake where Silverton had the highest N accumulation under optimum fertilization and Goldrush had the lowest (Fig4b). Russet Burbank, however had the highest N accumulation under minimum fertilization as compared to all other varieties. There was no difference in the yield biomass between Russet Norkotah and Silverton and in the N accumulation between Russet Norkotah and Burbank. The study was conducted at the research station with a history of higher mineral N fertilizer applications. Therefore, to accurately understand the varietal and N fertilization effects on dry matter biomass and N accumulation in the biomass, the experiment is recommended to be conducted in the on-farm fields as well managed under lower N fertilization application rates.

Fig4: (a) Yield biomass (b) N accumulation in the biomass of all the varieties in the study at optimum and minimum N fertilization rates.



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CORN RESPONSE TO PHOSPHORUS FERTILIZATION AND EVALUATION OF SOIL TEST METHODS IN KANSAS SOILS

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Phosphorus is a critical nutrient for corn (Zea mays L.) productivity. Inadequate early season P supply can result in limited corn growth. A combination of available soil P, and pre-plant fertilization can help meet the demands for early corn establishment and growth.

The main objective of this study was to evaluate early-season corn response to different rates of pre-plant broadcast phosphorus fertilizer and determine the optimum levels using four different soil test methods.

MATERIALS AND METHODS

The study was conducted in 8 locations across Kansas during 2021. The experimental design is a randomized complete block with four replications. Fertilizer treatment consisted of five rates of phosphorus (P) fertilizer (0, 30, 60, 90, and 120 lbs P_2O_5 acre^{-1}), using mono-ammonium phosphate (MAP) (11-52-0). Fertilizer was applied one time by broadcast pre-plant. Soil samples were collected 0-6 in before treatment application, composite by blocks, and analyzed for soil test P using four different extraction methods (Mehlich-3, Haney H3A, Bray 1, and Bray 2) and analyzed colorimetrically. Whole plant sampling at V6 was collected for P uptake analysis. Statistical analysis was performed using R ($p<0.05$). The critical level for each soil test method was determined using the Linear Plateau model across replications in R.

SUMMARY

Using early season P uptake response provided critical levels of 24 and 23 ppm for the Mehlich-3 and Bray 1 methods, respectively. For the Haney H3A, the critical level was estimated at 9 ppm with an R^2 of 0.64. The Bray 2 method has the lowest R^2 value (0.36), and an estimated critical value of 67 ppm. Phosphorus uptake at early season (V6) showed a significant response to broadcast P fertilization at two of eight sites.

RESULTS

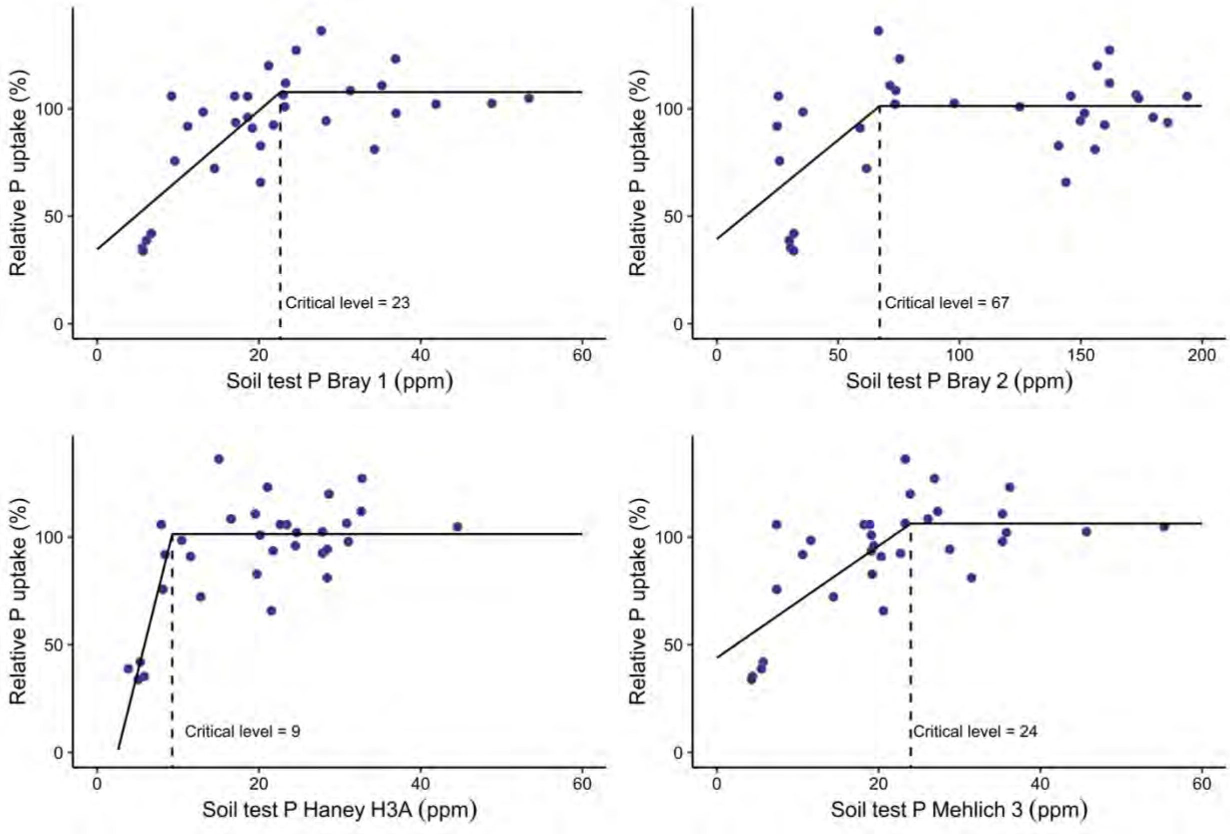

Figure 1: Relative P uptake in corn at the V6 growth stage using four different soil P extraction methods and analyzed colorimetrically.

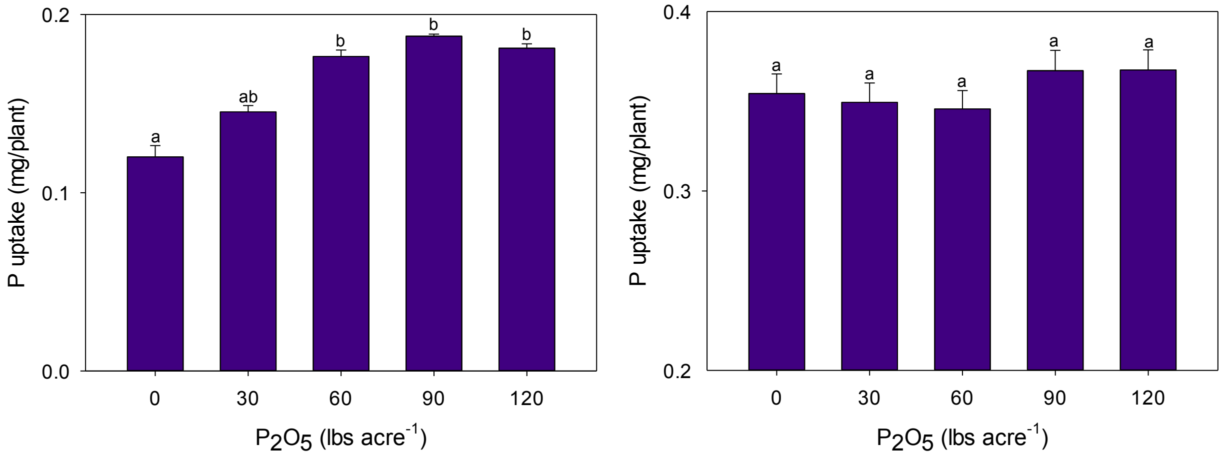

Figure 2: P uptake at different P_2O_5 application rates across responsive sites (left) and non-responsive sites (right). †Means with the same letter are not significantly different among treatments ($P<0.05$)

COMPARISON OF MEHLICH-3 AND HANEY H3A-4 SOIL TESTS FOR PHOSPHORUS IN KANSAS SOILS

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ABSTRACT

Use of a soil test to determine fertilizer application rates requires correlation and calibration to crop yield response and/or total nutrient uptake. The Haney H3A soil test procedure has gained popularity in recent years for soil health evaluation and has been used in some circles to adjust fertilizer management practices. However, data relating this test to current soil fertility tests, relative crop yield, or total nutrient uptake are nonexistent in Kansas soils. The objective of this study is to evaluate the correlation between H3A soil test phosphorus and potassium with soil tests currently used in Kansas (e.g., Mehlich-3), and investigate the relationship between these soil test P and K values and total nutrient uptake in corn (Zea mays L.). Soils from soybean phosphorus response studies were extracted using both Mehlich-3 and H3A (ver. 4) soil test procedures. Mehlich-3 and Haney extractable P and K were positively correlated (r = 0.9 and 0.91, respectively) in data combined from all sites. Linear regression models fit to the combined data indicate that Mehlich-3 extracts approximately 25% more P and 250% more K. The RMSE of these models (15.4 mg P kg^{-1} and 83.4 mg K kg^{-1}) indicate that existing calibration based on Mehlich-3 values are not suitable for use with H3A-4.

INTRODUCTION

The availability of phosphorus (P), and other immobile soil nutrients, is typically assessed with a soil test and a calibration curve relating test values to relative yield or nutrient uptake. Several soil tests for P and K have been introduced over the years. Historically, Bray-1 and Olsen have been the dominant soil test methods used for P analysis in the Central Plains region, while ammonium acetate has been used for base cations (e.g., K, Ca, Mg, Na). Usage of Bray-1 vs Olsen is largely dependent on soil pH, where Bray-1 is preferred in acidic soils and Olsen in calcareous soils. The Mehlich-3 (M3) procedure has gained popularity in recent years and is intended for use in acidic to neutral pH soils. It has been dubbed a “universal” extractant by some, due to its ability to extract multiple nutrients across a wide range of soil pH. When combined with modern spectroscopic techniques (e.g., ICP-AES), this procedure allows for simultaneous measurement of multiple macro and micronutrients from a single extract. This has led to wide adoption of the M3 soil test procedure at labs across the US.

One criticism of the M3 procedure, particularly with regards to P assessment, is due to the nature of its chemistry. The M3 solution has a pH of 2.5 and is strongly buffered. This acidity, in conjunction with the presence of F^- ions, increases the solubility of Al- and Ca-bound P and reduces its re-precipitation during the extraction process. These actions are thought by some to over-estimate the availability of P in some soils, as the extraction environment is quite different than what would be observed in the rhizosphere.

The Haney H3A extracting solution was developed with these criticisms in mind, and is intended to simulate the chemistry of actively growing roots more closely (Haney, Haney et al. 2006). The H3A extracting solution is comprised of a dilute mixture of organic acids, but has undergone numerous iterations since its initial development (Haney et al. 2017). The current iteration, version 4, is comprised of malic, citric, and oxalic acids, and has a weakly buffered pH of approximately 3.75 (Haney et al. 2017). This method has been adopted by some soil testing labs and is typically used in soil health assessments. Data relating H3A-4 soil test values to relative crop yield and nutrient uptake are scarce for Kansas soils. The primary objectives of this study are to investigate relationships between M3 and H3A-4 soil test P, and their relationships to relative grain yield and P uptake components in soybean.

MATERIALS AND METHODS

Field studies were initiated at multiple sites across the state of Kansas during the 2017, 2018, 2019, and 2020 soybean growing seasons, 18 site-years in total (Table 1). Treatments consisted of P and K fertilizer combinations broadcast at rates ranging from 0 to 90 lbs P_2O_5 ac^{-1} and 0 to 120 lbs K_2O ac^{-1}. These treatments were applied to 10 ft wide by 40 ft long plots. Plots were arranged as a randomized complete block design with four replications at each site. Measurements collected include whole plant biomass at the V4 growth stage, trifoliate P concentration at R2-R3 growth stage, harvest yield, grain P concentration. Soil samples were collected from each plot using a hand probe to a depth of six inches prior to treatment application. Soil measurements include soil pH, M3 and H3A-4 extractable P, K, Ca, Mg, Al, Cu, Fe, Mn, and Zn.

Soil samples were dried at 40 °C and ground to pass a #10 sieve. Soils were extracted following procedures for M3 and H3A-4. Briefly, M3 extractions were performed using 2 g of soil and 20 mL of M3 extracting solution (0.2N CH_3COOH, 0.013N HNO_3, 0.015N NH_4F, 0.25N NH_4NO_3, and 0.001N EDTA) and shaken for five minutes at 180 cpm (Mehlich 1984). H3A-4 extractions were collected by mixing 2 g of soil with 20 mL of H3A-4 extracting solution (0.35 g L^{-1} citric acid monohydrate, 0.55 g L^{-1} malic acid, and 0.225 g L^{-1} oxalic acid dihydrate) and shaken for 10 minutes at 180 cpm. The resultant suspensions were then centrifuged at 3500 rpm for 5 minutes. All extracts were filtered through Whatman 2V filter paper. Extractable P was measured at 660 nm using a colorimeter (Lachat QuikChem 8500 Series 2). Extractable K was determine using ICP-OES (Varian 720-ES). Soil pH was measured from 1:1 soil-water suspensions using a pH meter equipped with glass electrodes (Skalar, Inc).

Relationships between Mehlich-3 and H3A-4 extractable P were evaluated using linear regression models. Relationships between harvest yield and soil test P, and grain-P content and soil test P were investigated using nonlinear regression, where linear plateau models were fit using the self-starting functions provided in the “nlraa” R package. All data analyses were performed in R version 4.0.2 (R Core Team, 2021) and evaluated at the 95% confidence level.

RESULTS AND DISCUSSION

A wide range of soil conditions were observed in the study, particularly with regards to soil pH, which ranged from approximately pH 4.8 to 7.8. This is particularly relevant for this study given the influence of soil pH on soil mineralogy and the solubility of soil-P. Under acidic conditions, P solubility is reduced through direct precipitation with aluminum (Al) and iron (Fe) and/or sorption to Al- and Fe-(oxy)hydroxides; while in higher pH calcareous soils, P-solubility is reduced through precipitation of Ca-P compounds (e.g., hydroxyapatite). Given the wide variability in soil pH across the state of Kansas, it is important to understand evaluate soil tests over a wide range of soil pH conditions.

Relationship between soil test phosphorus methods

Mehlich-3 and H3A-4 extractable P were positively correlated ($r = 0.758$), with Mehlich-3 extracting more P than H3A-4 in general (Figure 1). However, linear regression analysis suggests that this relationship was substantially influenced by soil pH, where the inclusion of a soil pH main effect and interaction term increased the R^2 from 0.742 to 0.89 ($P<0.001$). Mehlich-3 extracted well over 2x more P than H3A-4 in some calcareous soils in this study (Figure 1). This suggests that converting Haney H3A-4 P to M3-P for interpretation would, at minimum, require knowledge of soil pH. Such conversions would likely lack the precision needed to predict crop response to P fertilizer accurately and are not advised. Based on these results, assessment of soil-P availability using the Haney soil test will require separate calibration curves relating H3A-4 P to crop response parameters.

Soil test phosphorus and P uptake parameters

The relationship between soil test P determined using both M3 and H3A-4 and whole plant P content at V4 (whole plant, V4P), relative harvest yield, and grain P content was evaluated using nonlinear regression analysis. There were no significant relationships between either M3 or H3A-4 and V4P (Figure 2). In general, relationships between relative harvest yield (RY) and soil test P were similar between Mehlich-3 and H3A-4. Linear plateau models fit to these data identified a critical soil test P value of 16.9 mg kg^{-1} for M3 and 13 mg kg^{-1} for H3A-4. However, fitting linear plateau models to the H3A-4 data required filtering out soils with high pH (pH > 7.8) and soils with a pH < 5.2 (Figure 3). Similar linear plateau models were also fit to the grain-P data. These models identified critical values at 18.6 mg kg^{-1} for M3 and 14.8 mg kg^{-1} for H3A.

Summary

While M3 P and H3A-4 P were positively correlated, the relationship varied substantially with soil pH in the soils included in the study. In calcareous soils, M3 extracted substantially more P than H3A-4. This pH dependence renders attempts to simply convert H3A-4 P to M3 P for soil fertility purposes complicated, at best. Linear plateau models suggest relative grain yield in soybean was maximized at approximately 16.9 mg kg^{-1} for M3P and 13 mg kg^{-1} for H3A-4 P. However, these models indicated that the H3A-4 soil test is difficult in soils with either very low (<5.2) or very high (>7.8) soil pH. Based on these results, interpretation of H3A-4 with regards to plant-availability of soil-P also requires knowledge of soil pH and may be less informative in either highly acidic or highly calcareous soils.

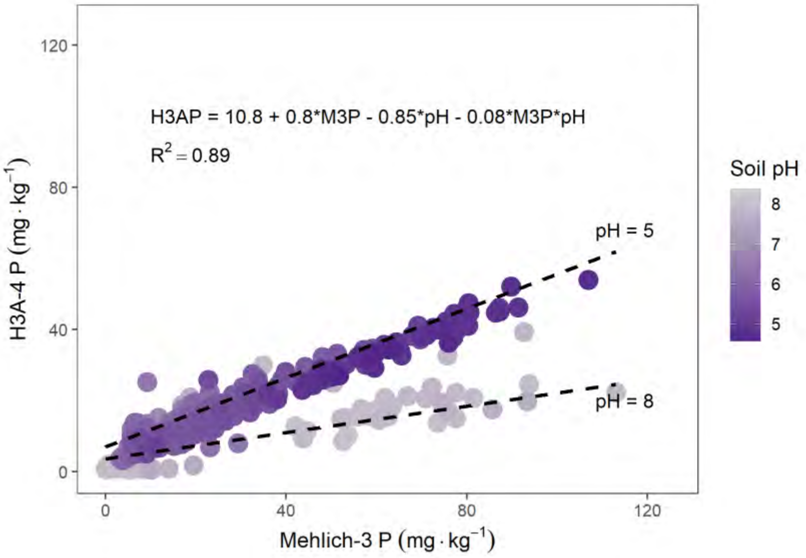

Figure 1. Haney H3A-4 extractable phosphorus (vertical axis) as a function of Mehlich-3 extractable phosphorus (horizontal axis) and soil pH (color).

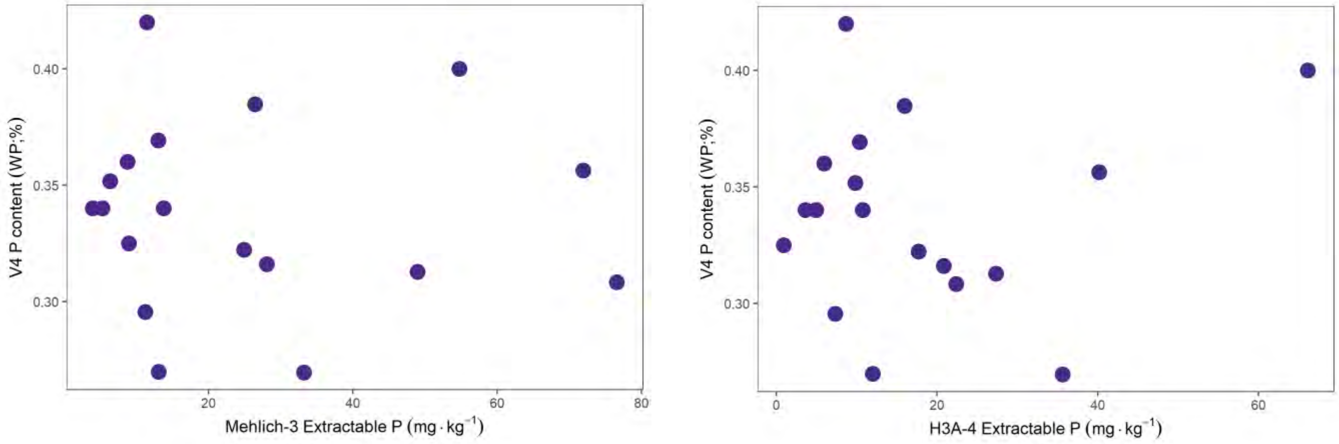

Figure 2. Phosphorus concentration of whole soybean plants at the V4 growth stage (vertical axis) versus Mehlich-3 (left panel, horizontal axis) and Haney H3A-4 (right panel, horizontal axis). Grain-P contents displayed were averaged across replications within each location.

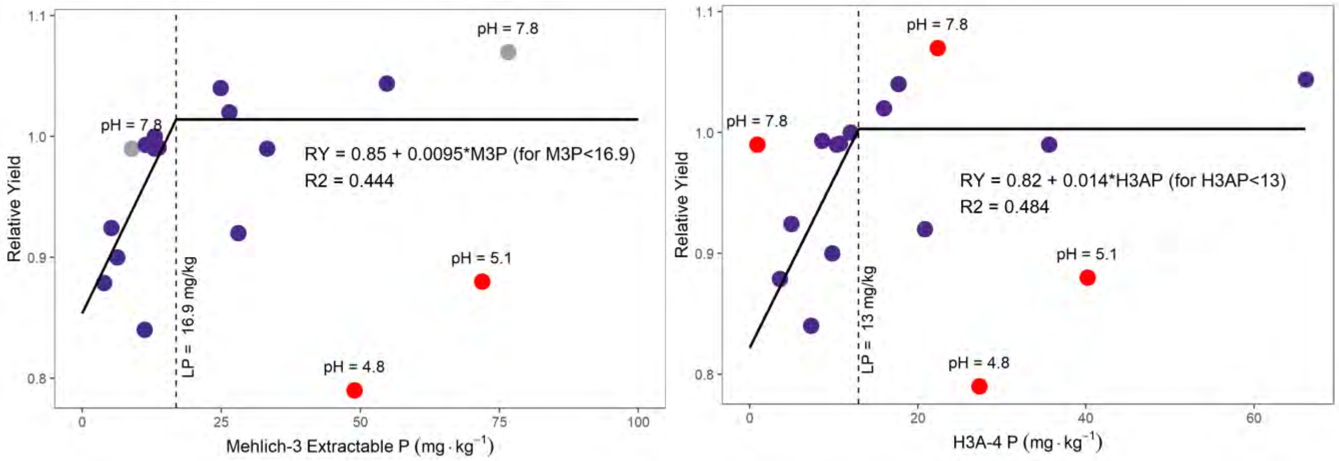

Figure 3. Relative soybean grain yield (vertical axis) as a function of Mehlich-3 (left panel, horizontal axis) and Haney H3A-4 (right panel, horizontal axis). Relative yield was calculated as the ratio between grain yields harvested from the control plots (no fertilizer) and 90 lbs P2O5 acre-1 and were averaged across replications within each location. Points shaded in red were excluded from the data prior to fitting the linear plateau models.

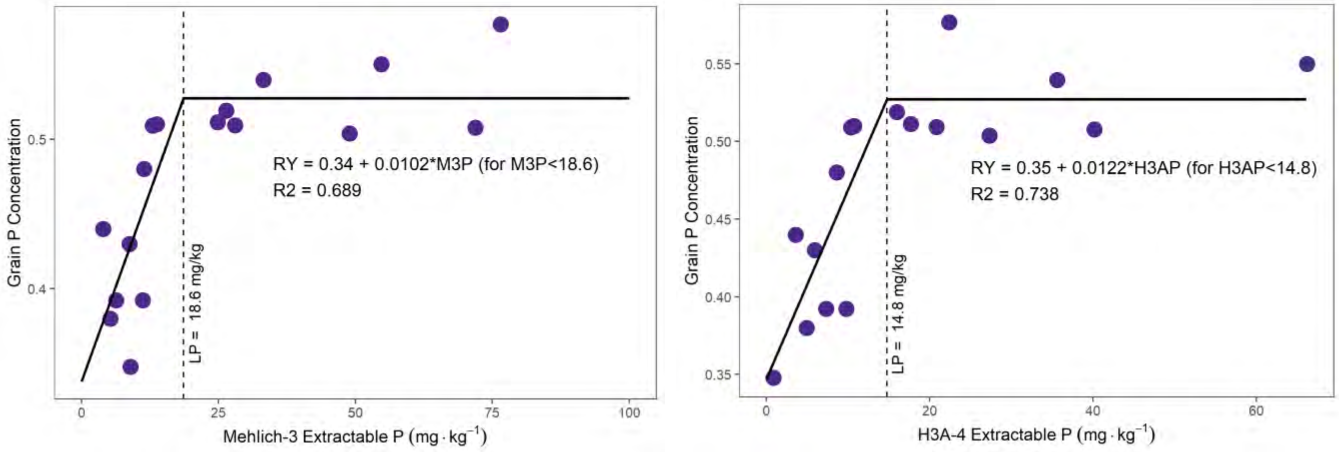

Figure 4. Phosphorus concentration of harvested grain (vertical axis) as a function of Mehlich-3 (left panel, horizontal axis) and Haney H3A-4 (right panel, horizontal axis). Grain-P contents displayed were averaged across replications within each location included in the study.

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MAIZE YIELD INCREASED BY OPTIMAL TIMING AND PLACEMENT OF ENHANCED-N FERTILIZER

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ABSTRACT

Nitrogen (N) fertilizer application timing and placement can manage N availability to improve maize (*Zea mays* L.) productivity, but polymer-coated N fertilizer offers a different approach to season-long N availability and creates new N management opportunities. The objective of this study was to compare the effectiveness of conventional and enhanced N sources across fertilizer timing and placement combinations to optimize maize productivity. Field trials were conducted at three locations in Illinois in 2019 and 2020 and utilized a complete factorial design. Nitrogen timings included supplying 180 lbs N acre^{-1} pre-plant or divided equally across pre-plant and side-dress applications. Pre-plant fertilizer placement was either broadcast on the soil surface or sub-surface banded 6 inches directly below the future crop row, while side-dress provided urea ammonium nitrate (UAN; 32-0-0) at V6 along the crop row (Y-drop). Nitrogen fertilizers applied pre-plant consisted of one standard source, i.e., conventional urea, and two enhanced sources, Environmentally Smart Nitrogen (ESN; polymer-coated urea 44-0-0) and a 1:1 mixture of urea and ESN referred to as the Blend. Using a split application of N fertilizer increased yield by 4 bushels acre^{-1} compared to only applying N fertilizer pre-plant. Banded placement of N fertilizer induced the greatest yield response of any factor and increased yield over broadcast applications by 5 bushels acre^{-1}. Overall, when averaged over timing and placement treatments, applying ESN or the Blend did not increase grain yield compared to urea. However, placing ESN in a band increased yield by 8 bushels acre^{-1} compared to broadcast applications of urea, and when broadcasting all N pre-plant, applying the Blend increased yield by 5 bushels acre^{-1}. These findings indicate that N fertilizer application timing and placement can increase yield, but utilizing enhanced N sources with the proper timing and placement combinations is key to optimizing maize productivity.

INTRODUCTION

Nitrogen fertilizer is applied every year to maize crops across the Midwest because it is required in the greatest amount for crop growth and development (Bender et al., 2013). It is also often the most limiting nutrient for maize production due to the many environmental loss mechanisms that act on N (Below, 2002). Advanced management practices and improved fertilizer sources have been developed to address increasing concern surrounding N fertilizer efficiency, but the effectiveness of these practices at improving N fertilizer efficiency and maize yield are not fully understood.

One strategy for improving N fertilizer efficiency and grain yield is to change the time of N fertilizer applications. A standard grower practice across much of the Midwest is to apply 100% of the N fertilizer needed for the year before or at planting because of the ease of application and available equipment. However, this practice can lead to both increased environmental loss and reduced grain yield as N fertilizer faces increased exposure to leaching, denitrification, and volatilization when applied all at once. A lack of plant available N due to these losses can negatively impact crop grain yield as one-third of maize N uptake occurs during reproductive growth stages (Bender et al., 2013). The rapid uptake of N from V8 to R1, approximately 7 lbs of N acre^{-1} day^{-1}, creates opportunities for split applications of N fertilizer to not only reduce environmental loss but also improve grain yield (Bender et al., 2013). Applying fertilizer in-season can match the maize N uptake pattern to increase yield and reduce the opportunity for environmental N loss, but providing full season N availability is key as yield potential can be impacted as early as V4 with the beginning of ear shoot development.

Improved fertilizer placement with subsurface banding can also be used as a strategy for increased N fertilizer efficiency and grain yield. Broadcast applications of N on the soil surface are a standard grower practice but are susceptible to surface volatilization or runoff through physical movement. This uniform application is not completely accessible to the crop as maize roots only explore a faction of the total soil area and the majority do not cross the interrow. Banding N fertilizer in the root zone creates better plant access to applied N by concentrating fertilizer 6 inches below the soil surface and making it readily available to the plant root system (Shapiro et al., 2016). Environmental losses from volatilization and physical runoff are also reduced with subsurface placement making banding an important agronomic practice for improving N fertilizer efficiency and yield.

Polymer-coated N fertilizer sources offer a different approach to improve fertilizer efficiency and yield by controlling the release of N throughout the growing season. These enhanced sources are designed to synchronize their nutrient release with the known pattern of crop nutrient demand to increase fertilizer uptake and reduce environmental losses, goals similar to a side-dress application (Shaviv, 1993). Polymer-coated N has not been shown to out-perform split N applications or banded placement reducing wide-spread adoption of these fertilizer sources which leaves the full potential of this technology to reduce environmental loses and improve maize yield yet unrealized (Shapiro et al., 2016). However, combining management with enhanced fertilizer sources may optimize the environmental and yield benefits of all these practices. It is hypothesized that enhanced fertilizer sources will increase N uptake and yield compared to standard urea fertilizer and that banded placement of these sources will replicate the benefits of a split application. Thus, the objective of this study was to compare the effectiveness of N sources across fertilizer timing and placement combinations.

MATERIALS AND METHODS

Site characteristics and cultural practices

This experiment was conducted across the 2019 and 2020 growing seasons at four locations in Illinois (Ewing, Nashville, Yorkville, and Champaign). The Ewing and Nashville sites were combined for analysis as they were 43 miles apart and representative of Southern IL soil types and growing conditions over two years. The primary soil types at these locations were Flanagan silt loam (Yorkville), Drummer silty clay loam (Champaign), and Hoyleton silt loam (Ewing and Nashville). All field experiments were conducted following a soybean crop [*Glycine max* (L.) Merr.] the previous year and under conventional tillage. This trial was planted using a precision plot planter (SeedPro 360, ALMACO, Nevada, IA) and the same hybrid, DeKalb 64-34 SSRIB, was grown in every site-year to target a final stand of 36,000 plants/acre.

Nitrogen applications

All treatment plots received a total of 180 lbs of N acre^{-1}. A complete factorial design was used for this experiment to compare three N sources, two N management systems, and two fertilizer placements (Table 1). Nitrogen sources consisted of urea [$CO(NH_2)_2$; 46-0-0], ESN [environmentally-smart nitrogen, 44-0-0], or a mixture of urea and ESN with a N ratio of 1:1 referred to as Blend. All three N sources were used only in pre-plant applications. Nitrogen management systems included supplying all of the N pre-plant or splitting the N across two application timings, pre-plant and V6 side-dress. Pre-plant N was applied either broadcast on the soil surface or sub-surface banded 6 inches directly below the future crop row using a Dawn Coulter toolbar with a dry fertilizer applicator (6000 Series Universal Fertilizer Applicator, Dawn Equipment, Sycamore, IL) and real time kinetic (RTK) guidance pre-plant. Split applications received 90 lbs of N acre^{-1} as one of three N sources at pre-plant either broadcast or banded. An additional 90 lbs of N acre^{-1} was supplied at the V6 growth stage using urea ammonium nitrate (UAN 32-0-0) poured on the soil surface along the crop row (simulated Y-drop method). All treatments were compared to an unfertilized control.

Table 1. Source, placement, and rate of N applied at-planting (AP), N rate applied at V6 with Y-drop, and the total N rate applied for each treatment. Nitrogen was applied as UAN for all V6 applications.

Treatment ID	Source	AP Placement	AP	V6	Total
			---------------------- lbs N acre^{-1}		----------------------
UTC		-	0	0	0
Urea Broad 180	Urea	Broadcast	180	0	180
Urea Broad 90:90	Urea	Broadcast	90	90	180
Urea Band 180	Urea	Band	180	0	180
Urea Band 90:90	Urea	Band	90	90	180
Blend Broad 180	†Blend	Broadcast	180	0	180
Blend Broad 90:90	†Blend	Broadcast	90	90	180
Blend Band 180	†Blend	Band	180	0	180
Blend Band 90:90	†Blend	Band	90	90	180
ESN Broad 180	ESN	Broadcast	180	0	180
ESN Broad 90:90	ESN	Broadcast	90	90	180
ESN Band 180	ESN	Band	180	0	180
ESN Band 90:90	ESN	Band	90	90	180

†Blend: A mixture of urea and ESN with a N ratio of 1:1.

Data collection

Total N uptake was determined by the sum of total N in the grain and stover. Nitrogen concentrations in the grain were calculated by converting protein concentration in the grain, obtained using near-infrared transmittance spectroscopy (Infratec 1241Grain Analyzer; FOSS, Eden Prairie, MN). Total N in the grain was determined using total grain weight and grain N concentration. Total N in the stover was measured in 2020 for the Champaign location and estimated in all other site-years. In 2020, total aboveground biomass was obtained in Champaign by sampling six random plants at the R6 growth stage. The plants sampled at R6 were partitioned into grain and stover. Dried stover samples were ground to pass through a 2 mm mesh careen and a representative 50 mg subsample was evaluated for N concentration using a combustion-based analyzer. Nutrient accumulation in the plant was determined using total plant biomass weight and stover N concentrations. Stover N was estimated in all other site-years using known harvest index values. The center two rows of each plot were mechanically harvested for grain yield and harvest moisture, and the yield subsequently standardized to bushels acre^{-1} at 15.5% moisture.

Experimental design and statistical analysis

Treatments were arranged in a randomized complete block experimental design. In total, 13 unique treatments were replicated six times at each of three locations for a total of 468 plots across 2019, 2020, and 2021. Statistical analysis was conducted using PROC MIXED in SAS (version 9.4; SAS Institute, Cary, NC). Each site-year was analyzed separately with N source (Urea, ESN, or Blend), fertilizer placement (Broadcast or Banded), and management system (all pre-plant or pre-plant and side-dress) included as fixed effects, while replication was considered a random effect. The unfertilized control was included in initial statistical analyses but was significantly different from all N treatments. Therefore, the unfertilized control was removed from the analysis to better identify differences between treatments. All of the statistical analysis and results displayed below are with the unfertilized control plots removed. Because of significant abiotic impacts on pollination, yield and nutrient uptake data collected at the Champaign site in 2019 was dropped from analysis and is not reported.

RESULTS AND DISCUSSION

Total N uptake was increased with N fertilization over the unfertilized check at all locations, and changes in N source, placement and timing had wide ranging effects by treatment (Table 2). Using ESN increased total N uptake over both Urea and the Blend averaged across all timing and placement combinations with the Blend being no different from Urea (Table 2). Averaged across all sources and placements, split applications of N with a side-dress resulted in greater N uptake than pre-plant only applications (Table 2). Banded placement resulted in the largest increase in total N uptake over a standard broadcast application (Table 2). This finding suggests that banded fertilizer placement would be the best practice for improving N fertilizer efficiency. ESN resulted in more N uptake than Urea in every timing and placement combination, but was the least efficient when all the N was broadcast as ESN pre-plant. This difference, combined with the data showing ESN exhibiting the greatest N recovery when it was banded, highlights that ESN is best used in a banded placement system. The Blend was less efficient at recovering N when used in a split application system, but when the Blend was broadcast all at pre-plant, the Blend resulted in the greatest increase in total N uptake compared to Urea of any placement and timing combination (Table 2).

Grain yield was not impacted by fertilizer source as ESN and the Blend resulted in the same yield as Urea averaged across all placement and timing combinations (Table 3). Averaged across fertilizer sources, delaying some N fertilizer to V6 with a side-dress application increased yield by 4 bushels acre^{-1} compared to only applying N pre-plant (Table 3). Banded placement of N at planting increased grain yield by 5 bushels acre^{-1} compared to broadcast applications (Table 3). When broadcasting fertilizer, the addition of a side-dress application increased yield by 5 bushels acre^{-1}. The same 5 bushels acre^{-1} yield increase was observed with a banded application of N all at pre-plant (Table 3). ESN was best utilized with banded placement increasing yield by 8 bushels acre^{-1} over broadcast applications of Urea while the Blend performed best when broadcast pre-plant without a side-dress application, increasing yield by 6 bushels acre^{-1} (Table 3).

CONCLUSIONS

Split applications and banded placement were effective at improving N fertilizer efficiency and grain yield regardless of the N fertilizer source used. Enhanced fertilizer sources are not effective in all management systems as there was no difference between sources in yield when averaged across all treatment combinations. Using enhanced fertilizer sources with agronomic management resulted in greater yield increases than any management practice alone. A pre-plant only banded application of N fertilizer increased yield identically to the addition of a side-dress application when pre-plant fertilizer was broadcast. This data collected across two years of research shows that enhanced N fertilizers can maximize N uptake and grain yield when used in optimal fertilizer placement and timing combinations.

TABLES

Table 2. Total nitrogen uptake at R6 at all locations in Illinois in 2019 and 2020. Lowercase letters indicate a treatment mean significant difference within location at $P < 0.10$.

Treatment ID	Yorkville 2019	Ewing 2019	Yorkville 2020	Champaign 2020	Nashville 2020	Average
	-------------	-------------	------------- lbs N acre^{-1} -------------	-------------	-------------	-------------
UTC	129 g	59 g	130 f	153 e	96 d	113 i
Urea Broad 180	221 f	94 f	169 e	263 d	196 c	188 h
Urea Broad 90:90	230 cd	127 e	159 d	284 ab	218 a	204 df
Urea Band 180	237 ab	145 bc	180 b	259 a	222 a	206 ad
Urea Band 90:90	233 ab	151 ab	183 b	243 a	219 a	208 be
Blend Broad 180	239 de	100 f	170 e	324 cd	202 bc	207 ad
Blend Broad 90:90	229 c	131 de	174 cd	239 ac	224 a	200 fg
Blend Band 180	230 bc	139 cd	185 bc	246 a	226 a	205 cf
Blend Band 90:90	236 bc	140 c	187 b	210 ab	229 a	200 ef
ESN Broad 180	223 ef	100 f	161 e	281 bd	203 bc	193 gh
ESN Broad 90:90	232 c	128 e	167 d	310 a	218 a	211 ab
ESN Band 180	244 a	155 a	200 a	232 a	221 a	213 ac
ESN Band 90:90	235 bc	142 bc	186 bc	284 a	216 ab	210 a
			Level of Significance $P > F$			
Source (S)	ns	ns	ns	ns	ns	*(ESN)
Placement (P)	***(Band)	***(Band)	***(Band)	***(Band)	**(Band)	***(Band)
Timing (T)	*(90:90)	***(90:90)	**(90:90)	**(90:90)	*(90:90)	*(90:90)
S X P	*	*	ns	ns	ns	**
S X T	ns	ns	ns	ns	ns	***
P X T	***	***	***	*	**	***
S X P X T	ns	ns	*	ns	ns	**

* Significant at $P < 0.10$; **Significant at $P < 0.01$;
***Significant at $P < 0.001$; ns, non- significant at $P = 0.10$.

Table 3. Grain yield as affected by nitrogen treatment at all locations in Illinois in 2019 and 2020. Grain yield is reported at 15.5% moisture. Lowercase letters indicate a treatment mean significant difference within location at *P* < 0.10.

Treatment ID	Yorkville 2019	Ewing 2019	Yorkville 2020	Champaign 2020	Nashville 2020	Average
	-----------------------	-----------------------	bu acre^{-1}	-----------------------	-----------------------	-----------------------
UTC	138 c	68 h	133 f	131 e	106 e	115 g
Urea Broad 180	220 b	109 g	150 be	212 ab	190 d	176 c
Urea Broad 90:90	220 b	129 bd	141 ef	214 ab	206 ac	181 b
Urea Band 180	221 b	124 ce	156 bc	201 ac	202 ac	181 b
Urea Band 90:90	223 ab	144 a	157 bc	207 bd	203 ac	187 a
Blend Broad 180	232 a	117 eg	151 be	219 ac	198 bd	181 b
Blend Broad 90:90	223 ab	128 bd	153 be	210 ac	209 a	184 ab
Blend Band 180	218 b	127 be	160 b	190 d	208 ac	181 b
Blend Band 90:90	228 ab	134 ac	159 b	205 ad	208 ab	188 a
ESN Broad 180	219 b	113 fg	142 df	220 a	197 cd	176 c
ESN Broad 90:90	224 ab	123 df	146 ce	210 ac	211 a	182 b
ESN Band 180	227 ab	135 ab	172 a	199 cd	203 ac	187 a
ESN Band 90:90	222 ab	138 ab	155 bd	204 ac	202 ac	184 ab
			Level of Significance *P* > *F*			
Source (S)	ns	ns	ns	ns	ns	ns
Placement (P)	***(Band)	***(Band)	ns	***(Band)	ns	***(Band)
Timing (T)	ns	***(90:90)	ns	ns	*(90:90)	***(90:90)
S X P	ns	ns	ns	ns	ns	ns
S X T	ns	*	ns	ns	ns	ns
P X T	ns	ns	ns	ns	*	ns
S X P X T	ns	ns	ns	ns	ns	*

* Significant at *P* < 0.10; **Significant at *P* < 0.01;
***Significant at *P* < 0.001; ns, non- significant at *P* = 0.10.

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EFFECT OF LIQUID CALCIUM AS A LIMING AGENT IN SOIL

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INTRODUCTION

Agriculture has many overhead expenses required to operate a profitable farm each year. Most successful farmers budget those costs to purchase only the necessities for a successful harvest. However, some salesmen of agricultural products sell products that are unproven, unwarranted, or simply don't work as claimed. One product in question that falls under this category is liquid calcium, otherwise known as calcium chloride ($CaCl_2$). In this report the science behind raising soil pH will be discussed, including why calcium chloride is not an effective liming agent.

Soils can become acidic for different reasons, but the primary reason in production agriculture is nitrogen (N) fertilizer application. Managing soil pH is a crucial part of managing your crop production program and can be monitored by soil testing. Soil testing determines the proper amount of liming material a soil will need to neutralize the acidity present. When a soil is acidic there is a higher concentration of hydrogen ions (H^+) than hydroxyl anions (OH^-) in the solution. Liming agents such as AgLime ($CaCO_3$) , QuickLime (CaO) or Hydrated Lime ($Ca(OH)_2$) are effective at raising soil pH because of one shared characteristic: proton (H^+) accepting anions. These OH^-, O^{2-} and CO_3^{2-} anions are required in this chemical process to accept and thereby neutralize H^+ ions, effectively raising soil pH. The objectives of this study were to determine the effectiveness of liquid calcium in raising soil pH and influencing hay quality as compared to pelletized lime and agricultural lime.

MATERIALS AND METHODS

The experiment was conducted at 16 locations across the state. The target soil pH for sites used for this experiment was <6.0, but this target was not always met. Producers and sites were typically identified with the help of the local county extension agent. Three locations were on University of Kentucky Experiment Station Farms. Once the site was identified, plots (5 ft by 5 ft) were established, an initial soil sample was collected, and treatments were applied. Treatments include a non-treated check, liquid calcium at 5 gallon per acre, pelletized lime (RNV of 83) adjusted to 100% RNV at 2 ton/A, and agricultural lime (RNV of 77) adjusted to 100% RNV at 2 ton/A. An additional treatment was used at some locations which was based on current UK Cooperative Extension Recommendations for lime, phosphorus (P) and potassium (K). A randomized complete block with three replicates was used at each location.

Forage samples were collected to determine dry matter yield, as well as the nutrient content of the forage. Soil samples were collected at this time and analyzed for soil pH and buffer pH. Soil samples and plant biomass samples will be collected again, after a year, to determine any long-term changes in soil pH or hay yield and quality.

A laboratory incubation study was also conducted to complement field results. Soil with an initial pH of 5.2 was utilized for the incubation. Specimen cups were filled with 50 g of air-dried soil and maintained at approximately 80% water-filled pore space with deionized water. The lime treatments were imposed as was done in the field, including a non-treated check, liquid calcium at 5 gpa, 2 ton/A of ag lime and 2 ton/A of pelletized lime adjusted to 100 % RNV. Each treatment was replicated 4 times. Cups will be sacrificed and soil pH measured at 1, 3, 6, 9 and 12 months after treatment application.

The change in soil pH between the initial soil pH before treatment application and the soil pH measured at the first forage harvest was calculated and analyzed for the field experiment. The time varied among locations but was typically between 1 and 2 months. Since all soil pH values were initially the same in the lab incubation study, measured pH values for the treatments were directly compared at each sampling time. Statistical analyses were done with SAS version 9.4 (SAS Institute, 2020).

RESULTS AND DISCUSSION

Though the results from this experiment are still being collected, knowing the chemical composition of liquid calcium will provide evidence as to why this product is not likely to raise soil pH. Equation 1 represents the AgLime neutralization reaction of acid in soil which shows the hydrogen ion being consumed by carbonate to produce H_2O and CO_2, reducing concentration and ultimately raising soil pH. In contrast, the product formed from Equation 2 represents liquid calcium which lacks the essential characteristic of a proton accepting anion that is necessary to raise soil pH.

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

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

Analyzing the liquid calcium product’s pH straight from the manufacturer’s plastic jug gave a pH of 4.5. Completing the same analysis of a suspension of AgLime in distilled water gave a pH of 12.4. The low pH of liquid calcium, coupled with the absence of proton consuming constituents, provides strong evidence that this product will fail to neutralize acidic soils. The chemistry doesn’t support the manufacturer’s claims.

Of the 16 initial field locations, 11 locations collected soil samples 1 to 2 months after the experiment plots were established (Table 1). AgLime caused the greatest change in soil pH, followed by pelletized lime. The untreated check and liquid calcium did not raise soil pH (Table 1). The treatments caused no statistically significant differences in forage dry matter at this harvest. Another harvest will be conducted next spring, approximately one year after initial treatment application. There were no differences in hay quality indices due to the treatments (Table 2).

After one month of incubation, the soil pH results were similar to those found in the field experiment. There were no differences between the check or liquid calcium, which failed to increase soil pH above that found in the check treatment (Table 1). The pelletized lime and aglime both increased soil pH above that in the check treatment. The change in pH was larger than expected and greater than in the field experiment, but the incubation was done with moisture conditions ideal for limestone reaction.

CONCLUSIONS

Both the field experiment and laboratory incubation study thus far confirm that liquid Ca will not neutralize soil acidity. Calcium chloride, a neutral salt, does not have the ability to consume protons and reduce soil acidity. Although a recent claim is that liquid Ca “balances base saturation around pH 7”, this claim is still unachievable, especially given the formulation as a chloride salt and an application rate of a mere 5 gpa. Further, liquid Ca’s initial pH of 4.5 does not lend credibility to the claim that the product will increase soil pH. This report will be updated in the future to reflect emerging data and further test the hypothesis that liquid Ca is not an effective product for raising soil pH. Soil tests will be taken six months and one year after plot establishment. To adjust low pH soils, it is advised that the grower follow guidelines given in UK Cooperative Extension Bulletin AGR-1: Lime and Nutrient Recommendations, to optimize soil pH and minimize costs. Unproven products should be avoided.

Table 1. Treatment effects on soil pH change in the field, lab incubation soil pH and forage yield.

Treatment	Change in field soil pH	Soil pH at 1 month of incubation	Forage Yield (lb DM/A)
Pr > F	0.0001	0.0005	0.6197
Check	-0.08 a	5.20 a	1873 a
Liquid Calcium	-0.03 a	5.25 a	1968 a
Pelletized Lime	+0.28 b	5.93 b	2119 a
Ag Lime	+0.40 c	6.10 b	1831 a

Values within a column followed by the same letter are not significantly different at the 90% level of confidence.

Table 2. Treatment effects on harvested hay nutritive value.

Treatment	Crude Protein (%)	ADF (%)	NDF (%)	TDN (%)
Pr > F	0.8646	0.7928	0.6928	0.7930
Check	11.6 a	37.1 a	60.3 a	58.8 a
Liquid Calcium	11.5 a	36.7 a	60.8 a	59.2 a
Pelletized Lime	11.0 a	37.6[J1] a	61.5 a	58.3 a
Ag Lime	11.1 a	37.4 a	60.2 a	58.5 a

Values within a column followed by the same letter are not significantly different at the 90% level of confidence.

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SOYBEAN GROWTH AND YIELD EFFECTS FROM STARTER FERTILIZER AND NITROGEN APPLICATION

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ABSTRACT

Spring Michigan weather variabilities and earlier planting dates may provide opportunities for starter fertilizer to affect soybean (*Glycine max* L) early season dry matter production while also decreasing the time interval for nutrient accumulation (i.e., lag-phase). However, starter fertilizer timing impacts on inhibiting biological N fixation (BNF) are not well known. Two trials were established near Lansing, MI to examine the effects of starter fertilizer and multiple nitrogen (N) application timings across two planting dates in both irrigated and non-irrigated environments on nodulation, biomass, N accumulation, grain yield, and expected profitability. Studies were arranged as randomized complete block split-plot design containing four replications. Main plots consisted of two planting dates (23 April and 17 May) while sub-plots evaluated six fertilizer strategies including: no fertilizer, 25 lb. N, 60 lb. P_2O_5, and 15 lb. S A^{-1} (12-40-0-10S with 46-0-0) applied two inches to the side and two inches below the seed (2x2) at planting, 25 lb. N, 60 lb. P_2O_5, and 15 lb. S A^{-1} (12-0-0-26S with 10-34-0) applied 2x2 at planting, 100 lb. N A^{-1} (46-0-0) broadcast and pre-plant incorporated, 100 lb. N A^{-1} (28-0-0) band applied along each row at V4, and 100 lb. N A^{-1} (28-0-0) band applied along each row at R2. Data collection and preliminary discussion may include bi-weekly canopy coverage, NDVI at V4, R1 and R5, biomass accumulation at V4, R2, R6, and R8, 15N analysis at R2 and R6, R4 nodulation, R8 pod counts, and grain yield. Results will assist growers with determining when N-fixation begins and the impact of nutrient application strategies across irrigated and non-irrigated soybean environments.

INTRODUCTION

More frequent occurrences of spring weather variability may provide opportunities to influence early-season dry matter and nutrient accumulation by reducing the lag-phase of soybean growth and account for potential delays in biological N fixation contributions to the plant. Earlier planting dates may offer additional opportunities for Michigan soybean growers to capitalize on a longer growing season and maximize investment in nutrient application strategies.

The benefits of early planting to Michigan soybean growers may outweigh the risks in some years. Despite the risk of up to 1 bu/A/day yield loss with a post-May 10 planting date, earlier planting dates have obstacles (Hankinson et al., 2015). Soybeans rely on a combination of soil mineral N and biological N fixation to satisfy plant N requirements and the percentage from each source will vary with soil temperatures, soil moisture, soil physical properties, soil nutrient concentrations, and genetics (Chang et al., 2015). Early season Michigan planting conditions are frequently cool but may be wet or dry. Cool soil temperatures will often restrict root growth, inhibit soil microbial activity, and impede nutrient mineralization. Thus, earlier soybean planting dates may be subject to more sub-optimal growing days and display differential responses to nutrient application as compared to an optimal planting date under warmer soil conditions. Investigating this aspect as part of a larger management regime will generate useful nutrient application data for those growers pursuing earlier planting dates.

Avoiding reductions to seed quality and ensuring grain yield of current higher-yielding varieties may be two reasons 44%, 43%, and 69% of Michigan soybean acres are fertilized with either N, P, or K, respectively (Purucker & Steinke, 2020). Biological N fixation and soil N have the potential to satisfy grain N requirements in yields <67 bu/A and will also provide 95-97% of maximum yield when soil P, K, and micronutrients are above critical levels (Purucker & Steinke, 2020; Warncke, Dahl & Jacobs, 2009). However, at-plant sub-surface fertilizer applications may increase both early and late season nutrient availabilities and help account for minimal biological N fixation contributions prior to growth stage V2-V4. Additionally, staggering the N application timing may address the knowledge gap as to when N -fixation begins in earnest under Michigan growing conditions. Lack of soil moisture due to 4-8 week mid-to-late-summer periods without rainfall have hindered soybean production potentials. Regardless of whether nutrient transport is dependent upon mass flow (N) or diffusion (P, K), water is still required to move nutrients within the soil profile. Recent research has demonstrated up to an 11% yield increase to N applications but ranged from no effect in stressful environments where yield potential was <40 bu/A to as much as a 13 bu/A increase in greater yield potential environments (>85 bu/A). Comparing similar nutrient application strategies across irrigated and non-irrigated systems and multiple planting dates will provide vital management information for Michigan soybean growers moving forward.

MATERIALS AND METHODS

Field studies initiated in Lansing, MI with planting dates of 23 April 2021 and 17 May 2021 on irrigated and non-irrigated Conover Loam soil. Both fields were autumn chisel plowed following corn and field cultivated in the spring prior to planting with a Monosem six row vacuum planter. Plots were 15 ft. wide by 40 ft. long and utilize a four-replication randomized complete block split-plot design. The whole plot factor was planting date (early and normal planting timings) with 6 subplot factor fertilizer strategies. At the irrigated site, the irrigation was supplied by a Micro Rain traveling irrigation unit. This was used to supplement around two inches of additional water prior to reproductive stages and three inches of water during and following reproductive stages. Grain yield was harvested by a small plot harvester (Kincaid 8XP) from rows 4 & 5 for a total harvest area of 200 ft^2 per plot.

Aboveground biomass was sampled at V4, R2 and R6. The R2 and R6 collections are collected for testing of ^{15}N natural abundance. Five feet of one row is sampled by cutting plants at ground level. The number of plants and weight of the five feet is recorded, as well as five whole plants and five stem-only samples. Two soil samples are then pulled from each plot, 0-8” & 8-24”. A non-fertilized corn plot is also sampled for a non-leguminous comparison. The subsamples are weighed, dried, and ground for analysis. This will determine how much nitrogen comes from the environment, biological nitrogen fixation, and the various treatments.

RESULTS AND DISCUSSION

Preliminary data suggests as planting date was delayed from April 23 to May 17 grain yield decreased 4.3 bushels A^{-1} at the irrigated site and 3.0 bushels A^{-1} at the non-irrigated site. Total dry matter accumulation was influenced by planting date, but not fertilizer application at either the irrigated or non-irrigated sites. The early plant timings produced the greatest TDM with increases of 27.7% at the irrigated site and 24.4% at the non-irrigated site when compared to May planting. Although the May planting had a more efficient dry matter accumulation or harvest index, it did not correlate to yield as the April planting had significantly greater yield. Nodulation was significantly greater in the April planting. Across fertilizer treatments, nodulation counts were generally reduced in applied N treatments (Table 1). Pending ^{15}N isotope testing results could provide further insight to whether applied N and changes in nodulation relate to yield. Planting date did have significant effect on net economic return at the irrigated site implying that under the current conditions of this study yield potential from planting early could outweigh the climactic variability encountered during this time. The non-fertilized control treatment increased profitability while all other treatments decreased due to increasing fertilizer costs and lack of unrealized yield gains at the irrigated and non-irrigated site. In the above critical nutrient concentration field environments tested in 2021, preliminary data suggest that pre-plant, at planting, and in season fertilizer applications did not result in greater yield or profitability across irrigated and non-irrigated soybean systems.

Table 1. Average nodule count per plant, Irrigated and non-irrigated, Lansing MI, 2021

Treatment	Irrigated	Non-irrigated
Planting date	————Nodules per plant ————	
23 April	93.54 a †	87.72 a
17 May	73.47 b	56.44 b
P > F	0.08	0.05
Fertilizer		
None	86.15 a	94.08 a
Dry 2x2	93.05 a	76.18 ab
Liquid 2x2	88.03 a	68.45 b
PPI N	73.15 a	58.75 b
V4 N	71.53 a	69.70 b
R2 N	89.13 a	65.33 b
P > F	ns ‡	0.08

† Values followed by the same lowercase letter are not significantly different at α=0.1
‡ ns, not significant.

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CAN SOIL HEALTH METRICS IMPROVE STANDARD SOIL FERTILITY RECOMMENDATIONS?

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ABSTRACT

It is speculated that integrating soil health (SH) testing with soil fertility (SF) testing would improve fertilizer recommendation decisions. However, quantified impacts of SH properties, specifically soil biological properties, on fertilizer demand have not been well established. The objective of this research was to explore corn (Zea mays L.) yield response to phosphorus (P) and potassium (K) fertilization as influenced by established SF analysis and common SH metrics. From 2018 to 2020, 532 fertilizer response plots (148 m2) were implemented in 84 producer fields across central Missouri. Response plot treatments were 1) an unfertilized control, 2) 100 lbs acre-1 of K2O, and 3) 100 lbs acre-1 of P2O5. Each treatment received the same producer-specific nitrogen (N) rates, with an additional 40 lbs N acre-1 applied near V6 corn growth stage to prevent N deficiencies. Random forest analysis was used to model yield response to P and K fertilization and to investigate the influence of SH and SF analysis on model performance. Two-thirds of established monitoring sites were below established P and K soil-test critical concentrations—with 32% and 36% of the low fertility plots responding to P and K fertilizer application. The most consistent yield responses occurred in established "Low" and "Very Low" fertility ratings, with yield improvement at 56% of these monitoring sites. However, integrating SH and SF for predicting yield response was only minimally helpful, resulting in r2 values of 15% and 7% for the P and K treatments, respectively. The low r2 values are likely due to the variability in P and K availability and crop demand introduced by the diversity of cropping systems, management practices, and soils in which the plots were deployed. Assessment of variable importance in the models indicated that the established University of Missouri recommended SF tests best predicted grain yield responsiveness to P and K fertilization. The addition of SH metrics provided minimal additional predictive power. Although improved SH may offer multiple environmental or agronomic benefits, this study indicates that across central and northern Missouri soils, established SF analysis remains the most effective tool to guide P and K fertilizer decisions in corn production.

INTRODUCTION

Modern-day fertilization contributions to 40-60% of current corn grain yield in the United States and England, but offsite transport of fertilizer nutrients leads to regional, local, and worldwide environmental issues (Stewart et al., 2005). Continued environmental pollution stimulated from off-field nutrients, especially in freshwater systems, is leading to political pressure and restrictions on fertilizer application in many regions. Moving forward, sustainable agroecosystems require functional fertilizer recommendations that balance crop productivity and minimize environmental losses.

Soil fertility testing is the bedrock of current crop fertilizer recommendations (McGrath et al., 2014). Fertility testing utilizes established correlation datasets between soil nutrient concentrations and yield response to identify whether soil nutrient supply suffices for crop demand (McGrath et al., 2014). For crop P and K nutrient needs, these relationships remain an effective tool and are especially effective at identifying nutrient concentration thresholds where additional fertilizer will not improve yield (Fryer et al., 2019). This, in-turn serves to recommend where not to fertilize, and therefore helps prevent potential nutrient runoff from cropped fields (Osmond et al., 2019). However, recent research has highlighted possible improvements in fertilizer recommendations associated with soil-test P (STP) and soil-test K (STK), with reported accuracies as low as 40% (Fryer et al., 2019). Investigating inadequacies and improving these recommendations are crucial in averting ongoing environmental degradation from excessive agroecosystem fertilization.

The University of Missouri phosphorus (P) and potassium (K) recommendations rely upon chemical soil extractions and yield response relationships largely developed decades ago (Bray, 1945). These correlation relationships were developed under soil and crop management practices typical of that time, which included regular and deep tillage, limited crop rotations, and fallow periods. Current grain crop production has replaced these practices with conservation practices such as no-till, diversified crop rotations, and the implementation of cover crops. These modern conservation practices have been shown to improve soil physical, chemical, and biological properties (Bünemann et al., 2018). Monitoring these improvements led to the development of 'soil health' (SH) and the focus on improved soil biological properties. However, it remains uncertain whether enhancements in nutrient cycling and availability from improved soil biological properties affect SF recommendations. Current SF assessments of nutrient status are physiochemical and do not measure soil biological properties and do not directly measure the impact from soil improvements through conservation systems on labile soil nutrients. Because of this void, some have recommended expanding SF assessments to include soil biological assessments to inform fertilizer recommendations (Franzluebbers, 2016). However, most of these asserted benefits from improved SH remain conceptual, with little empirical evidence (Bünemann et al., 2018).

Integrating soil biological tests into SF tests offers a unique opportunity to refine fertilizer recommendations to reflect modern cropping systems and recent improvements to assess soil biology. The development of economical soil biological tests in the modern era provides opportunities to explore how characterizing the living part of the soil could improve fertilizer recommendations (Wade et al., 2020). The research objectives include evaluating current University of Missouri P and K fertilization recommendations, and evaluating corn yield response to P and K fertilization as impacted by SF and SH metrics.

MATERIALS AND METHODS

Research was implemented in mid-Missouri across a diversity of management practices, climate patterns, and soils over three growing seasons (2018-2020) To evaluate response to P and K fertilization across these diverse environmental conditions, multiple fertilizer response trials (i.e. 'monitoring sites') were established on these fields. Each monitoring site was a 148 m^2 and included four 37 m^2 non-replicated single-rate fertilizer treatments with a total of 446 total monitoring sites in on 84 total commercial fields. Monitoring sites followed a standardized plot plan that included the following fertilizer treatments: 1) control (i.e., no fertilizer treatment), 2) K treated with 100 lbs $acre^{-1}$ of K_2O using KCL (0-0-60), and 3) P treated with 100 lbs $acre^{-1}$ of P_2O_5 using triple superphosphate (0-46-0). Fertilizer treatments were applied before or at planting while cooperating farmers selected hybrids, weed control, tillage, N fertilization, planting dates and other practices based on their standard management for each individual field. An additional 40 lbs N $acre^{-1}$ applied near V6 corn growth stage to prevent N deficiencies. Planting dates varied by climate and soil conditions and ranged from April 5-June 10.

Each monitoring site was sampled in March-April prior to planting to evaluate SF, SH, and characterize soil profiles. Soil fertility and SH samples were collected from eight 0-15 cm depth cores sampled randomly at each monitoring site. Soil fertility samples were air-dried and submitted for analysis to Ward laboratories (Ward Laboratories, Kearney, NE). Standard SF analyzes were conducted for organic matter (OM), Bray-1 P, ammonium acetate K extraction, sulfate sulfur, cation exchange capacity (CEC), pH, and particle size. Soil biological tests for SH metrics were completed in the USDA-ARS Soil Quality Lab on the University of Missouri Columbia Campus; these included soil organic carbon (SOC), total nitrogen, permanganate oxidizable carbon (POXC), 4-day soil respiration, autoclaved citrate extractable protein (ACE Protein), acid phosphatase activity, aryl-sulfatase activity, and β-glucosidase activity. Soil health samples were broken into two horizons 0 to 5 and 5 to 15 cm, stored in a cooler at 1.6° C, and later processed by passing through a 1 cm screen, air-drying, and dry sieving through a 2 mm screen. For POXC and SOC, soils were ground to a powder prior to analysis. Grain yield was hand harvested at maturity and weights were adjusted to 15.5% moisture from 11 m^2 from each treatment. Yield response was calculated as the control treatment divided by the respective fertilizer treatment (P and K) at that monitoring site. Statistical approaches used relative yield as the response variable, with the suite of SF and SH metrics as explanatory variables. Relative yield was fit with standard quadratic plateau models to evaluate current SF recommendations with soil test K and soil test P. Random forest algorithms with variable importance plots were used to evaluate improvements in predicting relative yield from integrating soil biological tests with SF analysis.

RESULTS AND DISCUSSION

University of Missouri Soil Fertility Recommendations

At monitoring sites below the recommended soil test P and K levels, there was an average 10% yield increase for P fertilization and 11% yield increase for K fertilization. Fertilizer application of P and K improved yield at 32 and 36% of total monitoring sites. The greatest rate of responses to fertilization occurred in the “Low” and “Very Low” fertility ratings with yield response at 52 and 32% of monitoring sites for P fertilization respectively (Figure 1). Despite being below recommended STP critical concentration, monitoring sites with “Medium” STP responded with similar rates as sites above the critical concentration (High, Very High, and Extremely High). Similar trends were observed in the K treatments, with the greatest rate of response to K fertilization occurred in the “Low” fertility rating (Figure 1). The “Medium” and “High” fertility ratings contained similar response to fertilization. The response rate in the “High” fertility rating was greater than expected considering the soil test K concentration was above recommended evaluations.

Variability in fertilization above the critical concentration of STP and STK are well documented; distributions of relative yield in the University of Missouri correlation datasets range 80-120% at high soil STP and STK values (Fisher 1974). Stronger relationships between STP and STK relative yield have been observed, but these strong relationships often include few sites typically under similar management practices—and can still demonstrate significant variability in critical soil test concentrations. Dodd and Mallarino (2005) observed that between three research sites that the most productive site soil test P critical level was 6-10 ppm lower than the other sites. The authors attributed this to better drainage, which suggested overall better plant growth conditions. This dataset reflects over 20+ soil types with unique properties and management practices. Distinctive critical concentrations between soil types would introduce significant variability in yield response to fertilization near established critical levels and could explain the variability in yield response to fertilization.

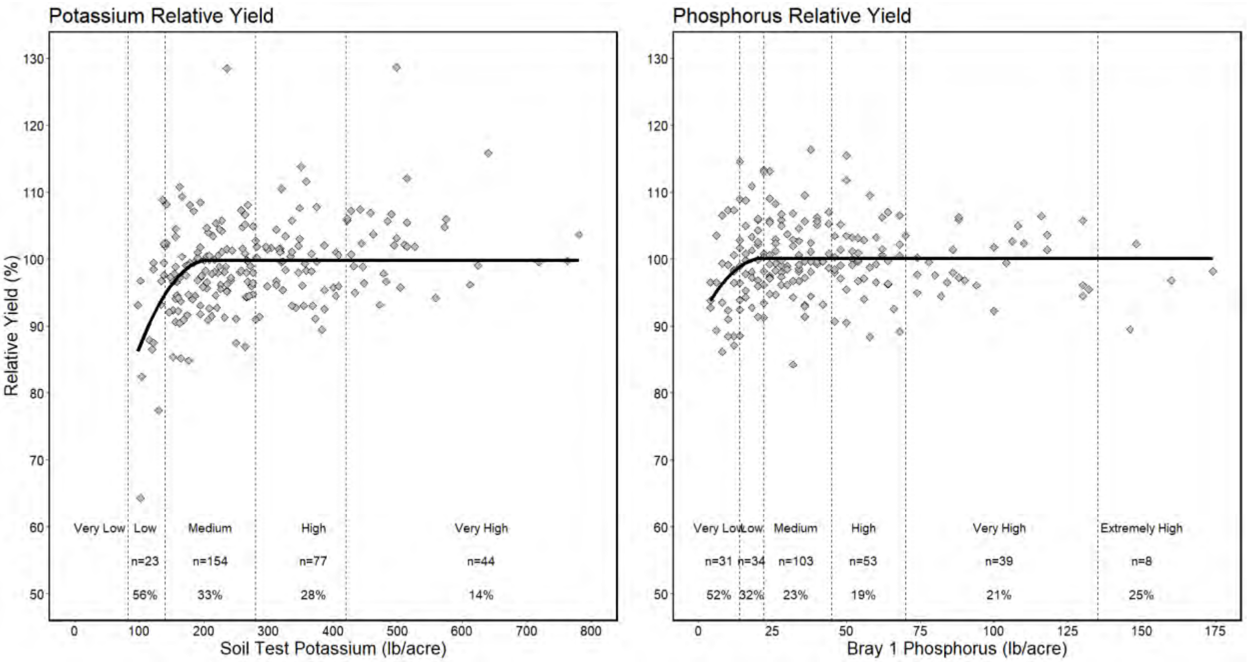

Figure 3: Relationships between soil test phosphorus and soil test potassium and relative yield of corn across all experimental years and overlaid with best-fit quadratic plateau linear functions. Vertical dashed lines represent University of Missouri SF ratings, which reflect the probability of yield improving from fertilizer application. Under each rating label is the number of observations and percent of observations with ≥ 5% yield increases shown.

Integrating Soil Health and Soil Fertility Metrics

The variability in yield response to P and K fertilization introduced significant challenge for model development and prediction. Traditional linear approaches were unsatisfactory in capturing trends in this dataset; and statistical learning approaches were required. Despite the improved accuracy from statistical learning approaches, random forest model prediction of relative yield for P and K fertilization performed poorly, with a training dataset r^2 of 6 and15% respectively. Low r^2 values are common in regional assessment of relationships between soil test P and K with similar values observed in a regional assessment in the Northeast USA and Ohio (r^2 = 0.11—0.28) (Heckman et al., 2006). Poor model performance is likely due to the variability in P and K crop demand introduced by the diversity of cropping systems, management practices, and soils in which the plots were deployed.

Table 1. Model statistics for random forest algorithms with relative yield response to phosphorus or potassium fertilization as dependent variables. Included explanatory variables were suites of soil fertility, soil health, management, and environmental variables. That dataset was partition into 80 % (n=183) for model calibration with the remaining 20% (n=45) used for validating developed model with each random forest model trained on 501 trees. RMSE was calculated from the difference between predicted relative error and observed relative error.

Model Inputs and Dependent Variable		**Calibration**		**Validation**	
	mtry	r^2	*RMSE*	r^2	*RMSE*
Relative Yield to Potassium Fertilization					
Soil Fertility	1	86%	3.7%	11%	6.7%
Soil Fertility + Soil Health Metrics (Integrated)	2	92%	3.2%	22%	6.4%
Relative Yield to Phosphorus Fertilization					
Soil Fertility	1	89%	3.2%	7%	6.5%
Soil Fertility + Soil Health Metrics (Integrated)	2	94.0%	3.0%	1%	3.0%

Relative yield response to P or K fertilization was the explanatory variable used to evaluate the integration of SH into established SF analysis. Integration of SH metrics marginally improved model performance relative to current SF soil tests (Table 1). Evaluation statistics r^2 and RMSE for both the calibration and validation datasets failed to improve with the addition of further explanatory variables included in the SF analysis. These results are contrary to conclusions observed with N fertilization in which soil biological tests have improved traditional SF metrics (McDaniel et al., 2020). These differences likely evolve from difference in P and K crop demand, crop sensitivity to fertilization, and differences in nutrient cycling. Biological processes govern the cycling and availability of N, while chemical and physical processes drive P and K availability to crops (Khan et al., 2014). The SH metrics included in this study were biological analyses and reflect nutrient cycles that are microbiologically driven. Chemical and physical processes dominate P and K nutrient transformations and availability; therefore, introducing biological analysis might not directly translate to improvements in evaluating P and K crop availability.

Variable importance analysis of relative yield response to P and K fertilization was used to evaluate the importance of each explanatory variable. In both the SF and integrated random forest models predicting yield response to P fertilizer application, Bray-1 and CEC were the top two variables. The Bray-1 soil extraction is the only soil metric used to evaluate yield response to P fertilization. These data suggest that CEC could reflect factors that govern yield response to P fertilization that are not currently realized in the Bray-1 test. Similar observations were made in Iowa where differences in yield response to P fertilization between field sites were attributed to drainage properties and an overall soil environment in addition to the Bray-1 soil test (Dodd and Mallarino 2005). Cation exchange capacity is related to several soil properties, including soil texture and soil OM. However, percent clay was also included in the SF model and considered relatively unimportant. Therefore, CEC likely reflects additional soil properties beyond soil texture, such as OM, to explain its relatively high importance in predicting yield response to P fertilization. For both the SF and integrated random forest models, the ammonium acetate K extraction was considered the most important variable in predicting yield response to K fertilization with CEC also considered an important factor. This follows the current University of Missouri recommendation system that integrates these two variables. The inclusion of soil test K as the top variable for both variable importance methods confirms the relative power of this measurement in identifying soils responsive to K fertilization. However, further refinement of the current University of Missouri recommendations is required, when considering the relatively inconsistent response to P and K fertilization across central Missouri soils and cropping systems.

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SEED GERMINATION AS INFLUENCED BY FERTILIZER TYPE, SEED COATING AND DURATION OF STORAGE

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INTRODUCTION

Productive pastures and hay fields begin with good stands of desirable forage species. Proper management of the forage can maintain stand persistence and performance if certain practices are followed. Red clover (*Trifolium pretense L.*) is a short-lived perennial legume that produces high-quality pasture and hay. Red clover can be used in a pure stand but is typically mixed with cool-season grasses in Kentucky. Stands of red clover often persist for three years following establishment before stand decline. Red clover is often used to renovate established pastures due to the relative ease of establishment by overseeding. Orchardgrass (*Dactylis glomerata* L.) is a perennial cool-season grass that is well suited for utilization in Kentucky pastures and hayfields. While not as common of a practice as legume overseeding, cool-season grasses such as orchardgrass are sometimes overseeded into existing stands of forages.

Overseeding pastures and hay fields can strengthen the stand to provide more desirable biomass, reduce weed competition, and prolong the stand life. A late-winter to early-spring application of nitrogen (N) fertilizer is commonly applied to stimulate early spring growth of non-leguminous forages. Furthermore, this provides an opportunity to apply phosphorus (P) and potassium (K) fertilizers in the same operation, as needed. However, there are potential negative effects from mixing the seed with fertilizer, especially reduced germination.

Salt index (SI) is a measure of the influence a fertilizer has on the osmotic pressure of a soil solution relative to a standard reference of sodium nitrate (Rader et al., 1943). In other words, the SI is a measure of the salt concentration of a fertilizer in the soil solution (Mortvedt, 2001). The SI does not precisely predict the amount of fertilizer that will cause injury, but SI can be used to compare fertilizer sources, which can vary considerably in their SI values (Mortvedt et al., 1999). For example, P fertilizers typically have lower SI values (~10 to 30) than K and N fertilizers (~40 to 120). Fertilizers with higher SI have greater potential to injure plants and seedlings than fertilizers with lower SI.

Different fertilizer sources contain different forms or can transform into different intermediary forms that can inhibit germination and/or damage seedlings. Biuret toxicity from urea use was known to negatively affect seed germination, but modern urea production practices have greatly reduced this potential. Ammonia produced from urea hydrolysis can reach levels toxic to germinating seed and young seedlings. The reaction of anhydrous ammonia in the soil can inhibit germination or desiccate plant roots upon germination.

Some seed are coated with materials that improve handling and placement, raise germination, and/or to provide nutrients or specific inoculants to improved plant nutrition. The coatings can consist of many different components, including diatomaceous earth, lime, clay, polymers, hydration enhancers, various inoculants, and adhesives alone or in combination to improve germination and seedling performance. Some coatings are designed to increase water adsorption and holding capacity around the seed to aid water imbibition and germination.

Integrating fertilizer additions with pasture/hayfield overseeding in late-winter or early spring can maximize resources by minimizing inputs such as fuel and labor while improving the fertility and stands of those fields. However, little data is available on the impact of fertilizer type or the duration of seed exposure to fertilizer on the germination of raw (uncoated) and coated seed. The repercussions of seed exposure to fertilizer would be beneficial to know, especially if the seed/fertilizer mixture is not spread immediately. This study was conducted to determine if orchardgrass or red clover seed germination was influenced by fertilizer mixture, seed coating, or storage duration under ambient conditions similar to those experienced in a typical production situation in the mid-south area of the United States.

MATERIALS AND METHODS

Red clover and orchardgrass seed were obtained from a local seed dealer, and was either uncoated (raw) or coated with a proprietary mixture of lime, hydration enhancer, inoculant and adhesive. Fertilizer was obtained from a local farm supply store and consisted of urea (46-0-0), DAP (18-46-0), and KCl (0-0-60). Two different fertilizer combinations were utilized for the fertilizer treatment. One approach some forage producers use is to apply 50-50-50 (N-P_2O_5-K_2O in lb/A) bulk blend mix that assumes soil tests for P and K are in the medium range and there is sufficient N to increase forage production. The blended application rate was 258 lb fertilizer/A using the fertilizer sources above. The other approach was to mix the seed with a rough fertilizer, such as muriate of potash (KCl), to help with seed distribution. This treatment was employed at a rate of 100 lb 0-0-60/A or 60 lb K_2O/A.

A 10 lb/A seeding rate was used for the raw and coated red clover and raw orchardgrass seed. A 30% higher seeding rate was used for the coated orchardgrass seed to adjust for the additional weight and assuming the coating did not improve seed germination. Seed and fertilizer mixtures were placed in specimen cups at the above rates and stored in a tobacco barn to replicate ambient outdoor conditions during May and June. A control treatment, consisting of only seed, without any fertilizer, was subjected to the same environmental conditions. Treatments were started/placed into storage in reverse order of storage length (longest storage period initiated first) to allow all seed/fertilizer mixtures to be removed on the same day for seed germination determination. Eight storage times were used (1, 3, 5, 7, 10, 14, 21, and 28 days of storage after seed were placed in the cup). Each treatment combination was replicated four times and the entire experimental trial was repeated twice.

All seed treatments were removed at the end of the assigned storage treatment time and then tested for germination. Germination testing followed University of Kentucky Regulatory Services seed testing protocol. Briefly, 50 seed were removed from the mixture and placed on filter paper inside a petri dish moistened with deionized water (Figure 1). Germination counts were determined for red clover seed at days 3 and 7 after petri dish placement and at days 7, 10 and 14 for orchardgrass seed. The experimental design was a randomized complete block design with 4 replicates of the factorial combination of seed coating, fertilizer treatment and storage time treatment design. A quasi-binomial generalized linear model was used in the R statistical program to determine treatment differences. Red clover and orchardgrass were statistically evaluated separately. Fixed effects were fertilizer, seed coating, storage time and trial. Pairwise comparisons were made to investigate the differences in treatment effects.

RESULTS AND DISCUSSION

Orchardgrass

For orchardgrass, the main effects of fertilizer, seed coating, time and trial were significantly different, as were the interactions of fertilizer by time, fertilizer by trial, coating by time and coating by trial, all at the 95% level of confidence.

Germination in the control and blended fertilizer treatments behaved similarly for the different seed treatments, across trials, but the potash-orchardgrass treatments exhibited a different trend (Figure 2). Germination rate was similar across storage times for the control. Orchardgrass germination decreased with time of exposure to blended fertilizer, approaching zero after 28 days of storage. The coated orchardgrass seed had a much lower germination rate with blended fertilizer than in the potash treatment. Blended fertilizer contained urea which is more hygroscopic than either the DAP or KCl. This caused the mixture to adsorb more water than the potash treatment, so much so that there was a “slurry” of fertilizer and seed with this treatment. It was initially hypothesized that the higher SI for KCl (SI = 116) would lead to more injury and lower germination, but the urea (SI = 74) component of the blended fertilizer was a greater detriment to germination. Most likely, a combination of the SI and ammonia formation from the slurry was the reason the poor seed germination with time. The seed coating further decreased orchardgrass seed germination with greater storage times.

Orchardgrass germination was similar between uncoated and coated seed in the potash treatments in the first trial, but raw seed germination rate decreased significantly, relative to coated seed, with exposure to potash in the second trial (Figure 2). The reason for these differences is not known. Although increased storage times increased moisture content of the potash treatments, they never approached the moisture levels of the blended fertilizer treatments. The orchardgrass germination values for the potash treatments with 28 days were similar to the blended fertilizer-coated seed treatments with 3 days of storage and with 10 days of storage of the blended fertilizer-uncoated orchardgrass seed treatments.

Red Clover

With red clover germination, the main effects of storage time and trial were significantly different, along with the interactions of fertilizer by time, coating by time, fertilizer by trial, time by trial and fertilizer by coating by trial, all at the 95% level of confidence. With red clover, the two trials gave similar trends in germination, but the seed coating treatments exhibited different germination trends in the presence of blended fertilizer (Figure 3). The fertilizer control treatment exhibited similar germination across trials and seed coatings and storage times (Figure 3).

Red clover germination decreased with storage time in the clover-blended fertilizer and clover-potash treatments (Figure 3). Seed coating reduced clover germination slightly in the clover-potash treatment, but not as much as in the clover-blended fertilizer treatment (Figure 3). Again, the potash fertilizer treatment did not adsorb as much moisture with time as the blended fertilizer mixture containing the urea did.

One noticeable difference between the two trials for the clover-blended fertilizer treatments was that in trial 1 germination was similar between raw and uncoated seed with 1 day of storage but in the second trial germination differed by more than 25% at day 1 (Figure 3). One possible explanation for this difference could be the greater relative humidity during trial 2, causing the hydration enhancer in the coating to adsorb more of the fertilizer salt solution than the hard raw seed, which led to decreasing germination. From day 14 to 30 the results for the clover-blended fertilizer treatments were similar for the two trials. The blended fertilizer was much more detrimental to germination of coated red clover seed than that of uncoated red clover.

The uncoated red clover seed was much more tolerant than the coated seed to the blended fertilizer with storage time. Both trials show that raw seed germination was about 50% after 28 days of storage while coated seed germination was about 0% at day 21 (Figure 3). Red clover germination with raw seed-blended fertilizer was still lower than that in the potash-clover treatments, but more acceptable than any of the blended fertilizer-coated red clover results or any of the blended fertilizer-orchardgrass results. The “hard” nature of the raw red clover seed surface appears to provide some level of protection from injury due to seed storage in the presence of fertilizer.

SUMMARY

Seed storage in fertilizer for extended periods of time was detrimental to germination. The longer the storage time the greater the decrease in germination. Although potash has a higher SI, it had less tendency to collect moisture and resulted in greater seed germination when seed was stored with blended fertilizer containing urea. Even a short storage time with the blended fertilizer for orchardgrass was detrimental to seed germination, regardless the seed coating. Red clover was more tolerant of storage with the blended fertilizer, especially when no seed coat was used. Mixing seed with fertilizer is a viable method when overseeding pastures, but the longer that seed is in contact with fertilizer, the lower the germination will be. These results indicate that if the seed-fertilizer mixture cannot be spread in a short period of time after mixing, a mix of blended fertilizer containing urea or coated seed should not be contemplated. If the fertilizer mixture does contain urea, uncoated red clover would be preferred over orchardgrass.

Figure 1. Seed germination testing procedure.

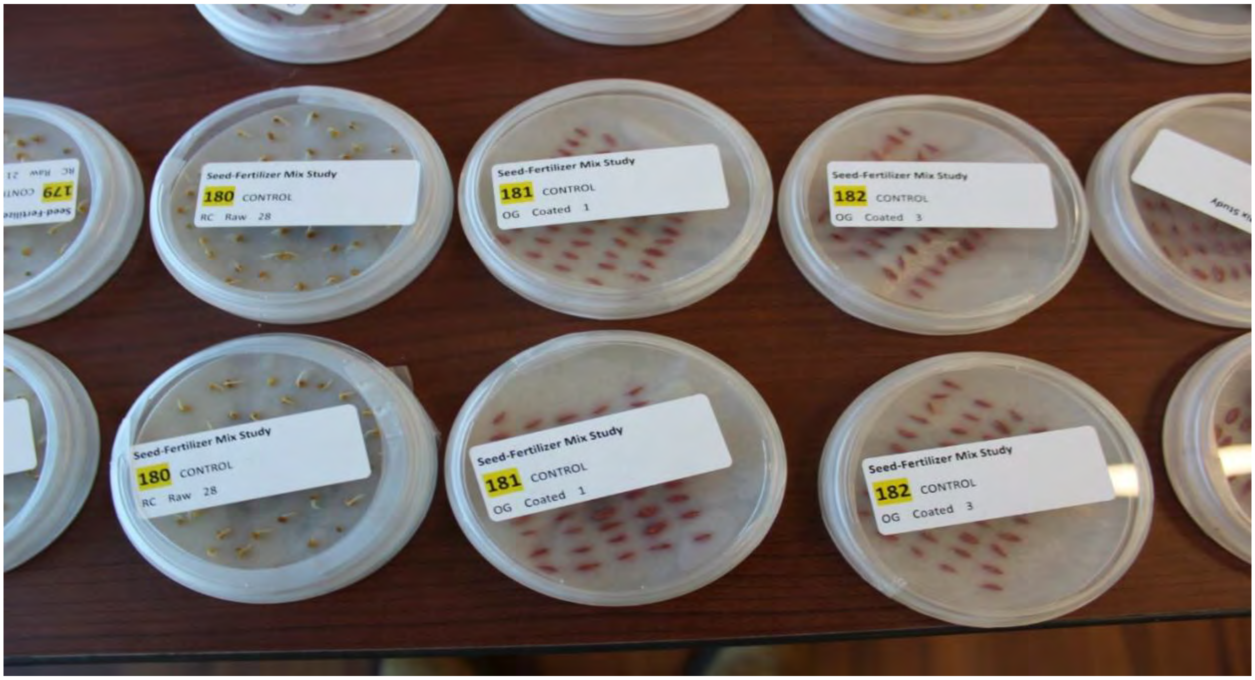


Figure 2. Seed germination results for the orchardgrass control, blended fertilizer and potash treatments for trial 1 and trial 2.

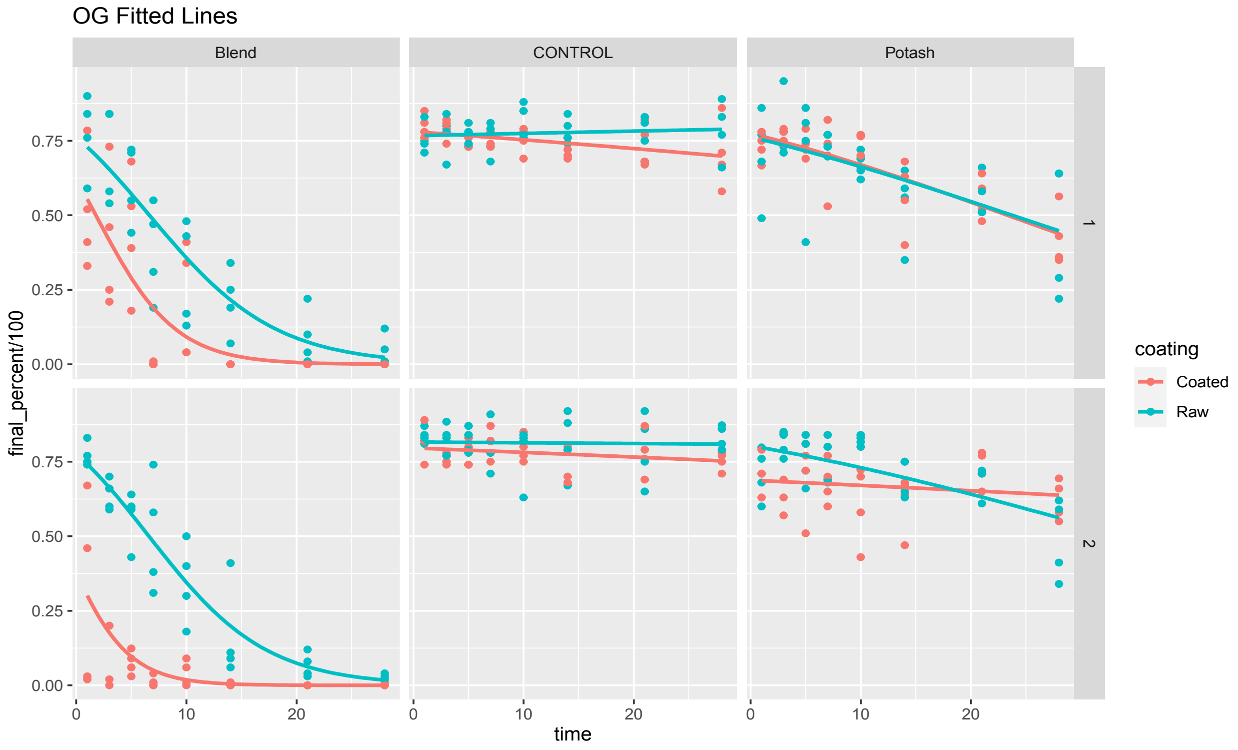
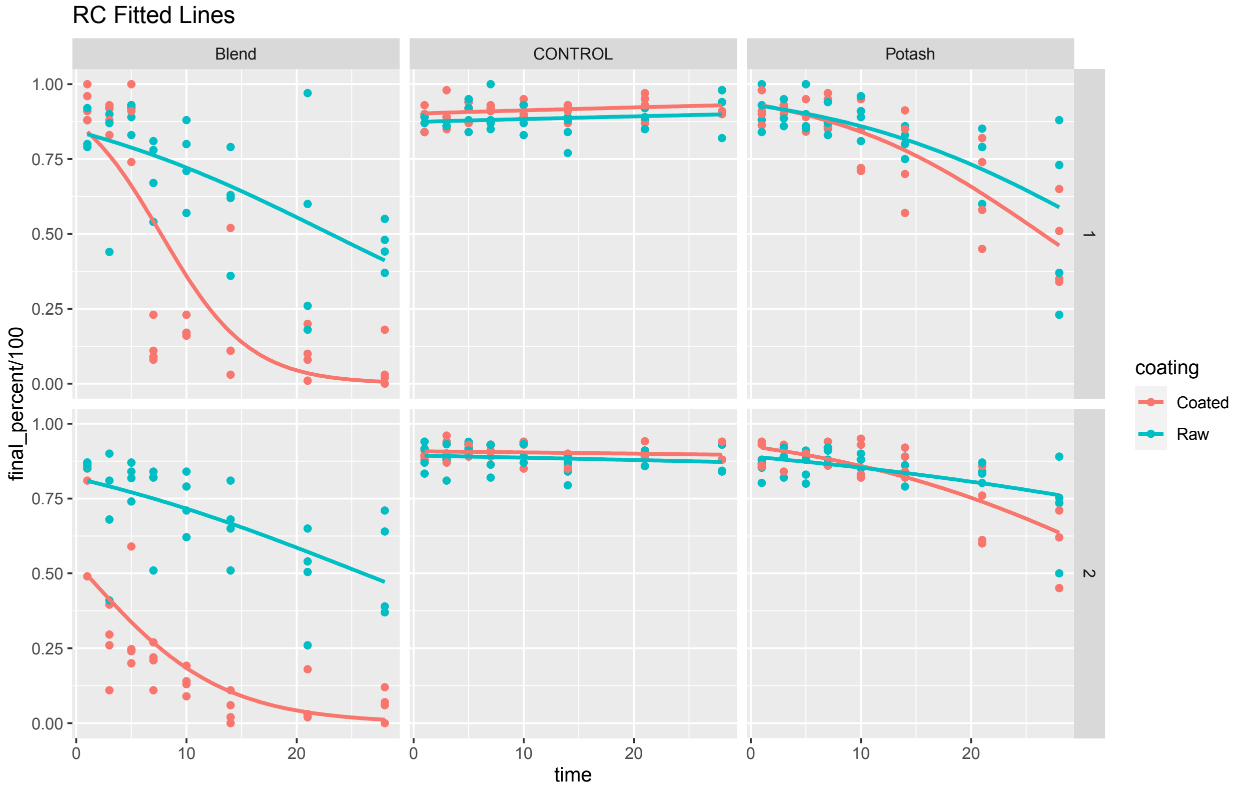


Figure 3. Seed germination results for the red clover control, blended fertilizer and potash treatments for trial 1 and trial 2.



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WINTER WHEAT GRAIN AND STRAW IMPACTS FROM AUTUMN STARTER AND SPRING NITROGEN FERTILIZER STRATEGIES

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ABSTRACT

The establishment and overwintering success of winter wheat (*Triticum aestivum* L.) are determining yield factors in Michigan. The objective of this study was to evaluate soft red winter wheat (SRWW) grain and straw yield in response to autumn applied starter fertilizer, spring nitrogen (N), and varietal stature. A two-year randomized complete block split-plot design study with four replications was established in Lansing, MI examining three autumn starter fertilizer rates and three spring nitrogen (N) rates on both a short- and tall-statured SRWW variety (i.e., 'Flipper' and 'Red Dragon'). Main plots included a no (0 lbs A^{-1}), mid (125 lbs A^{-1}), and high (250 lbs A^{-1}) rate of 12-40-0-10S-1Zn. Subplots consisted of spring-applied N (28-0-0) at low (50 lbs A^{-1}), base (100 lbs A^{-1}), and high (150 lbs A^{-1}) application rates. In 2020, an autumn starter and spring N interaction affected both grain and straw yield. The low starter, high N treatment increased yield 31.4 bu A^{-1} and 21.4 bu A^{-1} as compared to the no starter, high N treatment for 'Flipper' and 'Red Dragon', respectively. In 2021, autumn starter fertilizer and spring N interacted to affect both grain and straw yield in SRWW variety 'Flipper' with both mid- and high-autumn starter rates combined with low spring N exceeding the yield of the no starter and high N treatment. Main effects of mid- and high- autumn starter increased grain yield 17-21 bu $A^{-1}$and straw yield 0.34-0.46 T A^{-1} in 'Red Dragon'. Increased tiller counts and plant height due to autumn starter affected straw yield across site years. Low pre-plant residual nitrate concentrations, inclusion of sulfur, and timely autumn planting likely resulted in the positive grain and straw yield response to autumn starter fertilizer observed in this study.

INTRODUCTION

Increases in wheat (*Triticum aestivum* L.) grain and straw yield along with heightened awareness of soil spatial variability have motivated growers to focus on season-long soil nutrient availability. Michigan produces some of the nation's greatest wheat yields averaging between 75-81 bu A^{-1} in 2020-2021 (USDA-NASS, 2020-2021). As the demand for wheat straw increases (e.g., livestock bedding, feed, and biofuel) management strategies to optimize both grain yield and straw production are critical to the economic return for Michigan growers.

Previous studies indicate a positive correlation between wheat yield and biomass production. For maximum production, methods of determining N fertilization rates in winter wheat are based on fixed N removal rates per unit of produced grain and projected yield goals (Lukina et al., 2001). Nitrogen deficiency during establishment may result in reduced tiller counts and growth rates setting limitations on grain yield and biomass production before initiating primary development (Zhang et al., 2020). Application of autumn starter provides greater nutrient availability during early crop development stages thus impacting yield potential (Nkebiwe et al., 2016; Steinke et al., 2021). To promote autumn tillering and stand establishment, 25 lb N A^{-1} may be utilized in Michigan winter wheat production (Warncke et al., 2009). Autumn starter recommendations are impacted by residual soil nitrate levels which may depend crop rotation diversity and frequency (Mourtzinis et al., 2017).

Variety selection is an important management strategy for achieving high yielding grain and straw. Tall wheat varieties are better suited for stressed environments due to improved emergence and harvestability. However, selecting varieties less susceptible to lodging and shattering is important to both grain and straw production (Klein, 2007). Although, short statured varieties are often overlooked for straw production, responses to input manipulation have overcome limitations specific to wheat variety and environmental conditions (Beuerlein et al., 1989; (Karlen & Gooden, 1990).

MATERIALS AND METHODS

Trials were conducted in Lansing, MI on a Conover loam soil with pre-plant soil characteristics (0-8 inch depth) including 6.8-7.0 pH, 42-99 ppm P, 91-99 ppm K, 7-8 ppm S, and 3.1-3.8 ppm Zn. Fields were previously cropped to corn (*Zea mays* L.) in 2020 and 2021 and tilled prior to planting. Individual plots measured 8 ft. in width by 25 ft. in length with a 7.5 in. row spacing. A randomized complete block split-plot design with four replications was used to evaluate three autumn starter (12-40-0-10S-1Zn, MicroEssentials SZ (MESZ)) rates, three spring N (28-0-0) rates, and two varietal statures (Table 1). Main plots consisted of three rates of autumn starter fertilizer while sub-plots consisted of three spring N rates. The untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

SRWW 'Flipper', a short-statured, high disease tolerance, early maturing variety and SRWW 'Red Dragon', a tall-statured, high-yielding, mid maturing variety (Michigan Crop Improvement Assoc., Okemos, MI) were selected to evaluate autumn starter implications on plant height, yield, and biomass production. Studies were seeded on 8 Oct. 2019 and 21 Sept. 2020. Grain yield was harvested from the center 3.75 ft. of each plot utilizing a small plot combine (Kincaid 8XP) on 13 July 2020 and 14 July 2021 and adjusted to 13.5% moisture. Harvest cost of grain was US\$30.29 and US\$33.44 A^{-1} and baling of straw was US\$12.46 and US\$11.98 A^{-1} in 2020 and 2021, respectively. Net returns were calculated by multiplying grain price (\$4.75 and \$6.27 bu^{-1} in 2020 and 2021, respectively) by grain yield, straw price (\$140.00 T^{-1} in 2020 and 2021) by straw yield, subtracting total treatment and harvest cost. Harvest costs were estimated from the Michigan State University Extension Custom Machine and Work Rate Estimates. Product, grain, and straw estimates were taken from local agriculture retailers, grain elevators, and producers.

RESULTS AND DISCUSSION

Autumn starter fertilizer and spring N interacted to affect both grain and straw yield in SRWW in 2020 (Table 3 & 4). The mid-starter, high nitrogen and mid-starter, base nitrogen treatment resulted in an increase of 31.4 bu A^{-1} and 15.6 bu A^{-1}, respectively, as compared to the no starter, high nitrogen treatment with varieties 'Flipper' and 'Red Dragon' (Table 3 & 4). In addition, grain yield increased in 'Red Dragon' with the low autumn starter, base nitrogen treatment exceeding the yield of the no starter, high nitrogen treatment (Table 4). Straw yield increased for 'Flipper' with the mid starter, low N treatment exceeding the yield of the no starter, high N treatment (Table 3). Straw yield increased in 'Red Dragon' with mid-starter, base N exceeding the yield of no starter, base N (Table 4). Addition of autumn starter increased plant height of SRWW with both low autumn starter and high autumn starter applications as compared to no autumn starter (Table 2).

In 2021, autumn starter fertilizer and spring N interacted to affect grain yield, straw yield, and plant height in short-statured SRWW variety 'Flipper' (Table 2 & 3). The high starter, low nitrogen treatment resulted in an increase of 22.5 bu A^{-1} as compared to the no starter, high nitrogen treatment (Table 3). No significant difference was observed in straw yield between mid autumn starter, base or high N as compared to no autumn starter, base or high N treatments (Table 3). However, straw yield increased 0.89 T A^{-1} with the high autumn starter, low N treatment as compared to no autumn starter, low N treatment in 2021 (Table 3). Increased straw yield was not directly attributed to changes in plant height as no significant differences occurred between zero, mid, or high autumn starter, base N treatments (Table 2). Main effects of autumn starter increased both grain and straw yield in tall-statured SRWW variety 'Red Dragon' 17.2 bu A^{-1} and 0.34 T A^{-1}, respectively in 2021 (Table 4).

Results from 2020 indicate application of above recommended spring N did not compensate for the lack of autumn applied starter fertilizer. This was further confirmed in 2021 grain yield results of 'Flipper.' Soil nitrate concentrations were 3.5 and 5.9 ppm, respectively, in 2020 and 2021 well below the 10 ppm threshold (Alley et al., 2009) to indicate a probable yield response. The interaction between sulfur and nitrogen has shown to impact wheat biomass and grain yield by improving the nitrogen use efficiency when no sulfur deficiency is present (Salvagiotti & Miralles, 2008). Pre-plant soil S levels were 7-8 ppm across 2020 and 2021 with $\leq$ 3% OM, and no history of S application within 2-3 years. The pre-plant Bray P-1 phosphorus concentrations of 42 and 99 ppm were above the critical soil test P values (i.e., 25 ppm) indicating reduced likelihood of a yield response to phosphorous application (Warncke et al 2009).

Results from SRWW varieties 'Flipper' and 'Red Dragon' agree with (Steinke et. al, 2021) who observed a grain yield decrease of 18.7 and 37.5 bu A^{-1} when autumn starter fertilizer was removed from enhanced management and a grain yield increase from 17.4 and 25.9 bu A^{-1} when autumn starter was added to traditional management. In 2020, straw yield for the mid starter, high nitrogen treatment was 46 and 37% greater than no starter, high nitrogen treatment in ‘Flipper’ and ‘Red Dragon,’ respectively. In 2021, addition of autumn starter resulted in a 24% increase in straw yield in ‘Red Dragon.’ No significant difference was observed in straw yield and plant height between mid and high autumn starter rates across three of four site-years or grain yield in all four site years. This suggests that the mid-autumn starter rate was sufficient but not excessive and may improve grower profitability as compared to the greater starter fertilizer application rates. Low pre-plant residual nitrate concentrations, inclusion of the sulfur component, and timely autumn planting likely resulted in the positive grain and straw yield response to autumn starter fertilizer observed. Be sure to consider a pre-plant nitrate test as part of a proactive approach to address soil variability. Autumn starter can help winter wheat “Start Right to Finish Well” for optimal grain and straw production but responses will be field- and site-specific.

Table 1. Overview of split plot trial design, treatment names, and inputs applied to soft red winter wheat, Lansing, MI 2020 and 2021.

		------Autumn Starter and Spring Nitrogen (N) Applied------	
Treatment	**Treatment Name**	**Rate† 12-40-0-10S-1Zn**	**Rate‡ UAN (28%)**
1	Mid Starter, Base N	125 lb A^{-1}	100 lb A^{-1}
2	Mid Starter, High N	125 lb A^{-1}	150 lb A^{-1}
3	Mid Starter, Low N	125 lb A^{-1}	50 lb A^{-1}
4	High Starter, Base N	250 lb A^{-1}	100 lb A^{-1}
5	High Starter, High N	250 lb A^{-1}	150 lb A^{-1}
6	High Starter, Low N	250 lb A^{-1}	50 lb A^{-1}
7	No Starter, Base N	0 lb A^{-1}	100 lb A^{-1}
8	No Starter, High N	0 lb A^{-1}	150 lb A^{-1}
9	No Starter, Low N	0 lb A^{-1}	50 lb A^{-1}
10	**Check**		

† Autumn starter (12-40-0-10S-1Zn) applied as top-dress application 15 Oct. 2019 and 6 Oct. 2020.

‡ Spring nitrogen (UAN 28%) applied at green-up 20 Mar. 2020 and 23 Mar. 2021.

Table 2. SRWW mean plant height ‘Flipper’ & ‘Red Dragon’**.**

	2021		**2020**	**2020**	**2021**
Treatment	**Flipper**	**Treatment**	**Flipper**	**Red Dragon**	**Red Dragon**
No Starter, Low N	67.8 c †	No Starter	73.4 c	82.7 b	77.9 b
No Starter, Base N	71.6 a	Mid Starter	77.7 b	88.7 a	82.6 a
No Starter, High N	68.8 bc	High Starter	79.2 a	90.3 a	83.7 a
Mid Starter, Low N	72.6 ab	*Pr > F*	< 0.01	< 0.01	=0.01
Mid Starter, Base N	71.5 ab				
Mid Starter, High N	72.6 a	Low N	74.7 b	83.1 b	77.2 b
High Starter, Low N	72.5 a	Base N	77.9 a	89.7 a	83.1 a
High Starter, Base N	71.2 ab	High N	77.7 a	89.0 a	83.9 a
High Starter, High N	71.6 ab	*Pr > F*	< 0.01	< 0.01	< 0.01
Check‡	58.2				
$P_r > F$	= 0.06	Check‡	57.7	62.0	63.1

† Values followed by the same lowercase letter are not significantly different at α=0.1

‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Table 3. SRWW mean grain and straw yield 'Flipper'**.**

Treatment	**2020**		**2021**	
	Grain Yield	**Straw Yield**	**Grain Yield**	**Straw Yield**
	----Bu A^{-1}----	**----T A^{-1}----**	**----Bu A^{-1}----**	**----T A^{-1}----**
No Starter, Low N	88.5 e †	1.16 f	90.6 ef	1.07 c
No Starter, Base N	107.3 d	1.60 de	98.3 de	1.38 bc
No Starter, High N	101.3 d	1.02 f	88.6 f	1.36 bc
Mid Starter, Low N	105.7 d	1.50 e	106.7 bcd	1.48 bc
Mid Starter, Base N	123.2 c	1.92 c	104.0 cd	1.66 ab
Mid Starter, High N	132.7 ab	1.88 c	113.8 ab	1.54 ab
High Starter, Low N	108.3 d	1.76 cd	111.1 abc	1.96 a
High Starter, Base N	129.3 bc	2.10 b	105.6 bcd	1.52 b
High Starter, High N	141.7 a	2.32 a	118.0 a	2.00 a
Check‡	53.0	0.66	43.7	0.53
$P_r > F$	= 0.06	< 0.01	= 0.04	= 0.04

† Values followed by the same lowercase letter are not significantly different at α=0.1

‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Table 4. SRWW mean grain and straw yield 'Red Dragon'**.**

2020			**2021**		
Treatment	**Grain**	**Straw**	**Treatment**	**Grain**	**Straw**
	-Bu A^{-1}-	**-T A^{-1}-**		**-Bu A^{-1}-**	**-T A^{-1}-**
No Starter, Low N	84.3 d †	1.45 e	No Starter	71.4 b	1.07 b
No Starter, Base N	97.3 bc	1.49 e	Mid Starter	88.6 a	1.41 a
No Starter, High N	89.7 cd	1.50 e	High Starter	92.3 a	1.53 a
Mid Starter, Low N	86.9 d	1.60 e	$Pr > F$	< 0.01	= 0.04
Mid Starter, Base N	105.3 ab	2.08 cd			
Mid Starter, High N	111.1 a	2.37 ab	Low N	64.9 b	1.00 a
High Starter, Low N	92.2 dc	1.72 de	Base N	92.4 a	1.48 a
High Starter, Base N	106.5 ab	2.32 bc	High N	94.9 a	1.53 a
High Starter, High N	111.1 a	2.57 a	$Pr > F$	< 0.01	< 0.01
Check‡	51.4	0.84			
$P_r > F$	= 0.07	< 0.01	Check‡	40.8	0.58

† Values followed by the same lowercase letter are not significantly different at α=0.1

‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

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GRAIN YIELD AND NUTRIENT REMOVAL RELATIONSHIPS IN HIGH-YIELD MODERN CORN HYBRIDS UNDER IN-SEASON SULFUR AND POTASSIUM APPLICATIONS

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ABSTRACT

Advancements in modern corn genetics and adoption of intensive management practices, including in-season sulfur (S) and potassium (K) applications, have helped corn farmers set higher yield goals while prompting new questions about plant nutrient dynamics during the season and cumulative nutrient removal with grain at harvest. The primary goal of this study was to investigate how hybrid and fertility management decisions in situations with high yield potential (>225 bushels acre^{-1}) impact plant nutrient uptake dynamics and the relationship between grain yield and nutrient removal. Two separate field-scale experiments were conducted at the Agronomy Center for Research and Education (ACRE) near West Lafayette, IN, during the 2020 and 2021 growing seasons. The first experiment compared corn hybrids grown in 3 distinct nutrient management scenarios involving in-season S and K applied at V4. The S and K treatments included: ammonium thiosulfate (ATS) (12-0-0-26S at 20 lbs. SO_4 ac^{-1}), the same ATS treatment plus Aspire™ (0-0-58 (K_2O)-0.5(B) at 100 lbs. K_2O ac^{-1}), and a non-treated control (NTC) with no S or K application. Grain yields following ATS and ATS plus Aspire™ treatments were similar (averaging ~232 bu.ac^{-1} across the 4 hybrids) but much higher than NTC (194 bu.ac^{-1}). Interactions between hybrid and fertility treatments were not observed for grain yields, but were – in preliminary results - observed for certain grain nutrients. In year one, removal of S and K through the grain was greatest in ATS plus Aspire™ (57 lbs. K ac^{-1}, 10.9 lbs. S ac^{-1}), followed by ATS (50 lbs. K ac^{-1}, 9.6 lbs. S ac^{-1}), and NTC (41 lbs. K ac^{-1}, 6.6 lbs. S ac^{-1}). The second experiment involved a single hybrid in the Long-Term Tillage trial at ACRE, where 4 tillage systems (no-till (NT), strip-till (ST), chisel-plow (CP), and moldboard-plow (MP), were evaluated under continuous versus rotation corn with 2 contrasting fertility treatments (ATS and NTC). Under the corn-soybean rotation, ATS (243 bu.ac^{-1}) slightly increased grain yields over NTC (235 bu.ac^{-1}). In continuous corn, yields averaged 214 bu.ac^{-1} and were not increased with ATS. In year one, ATS increased average grain removal of S by 14%, or 1.3 lbs. S ac^{-1} ,over NTC across all tillage and rotation treatments. Regressions with grain yields confirmed that certain grain nutrient concentrations had slightly negative relationships with yield; these included Zn (r^2=0.20), Fe (r^2=0.25), and B (r^2=0.20). However, nutrient removal of K (r^2=0.31) and S (r^2=0.25) had slightly positive relationships with yield. Weak relationships of specific nutrients to grain yield suggest that applying in-season S and K fertility can lead to increases in grain nutrient removal that are independent of corn yield gains associated with hybrid or tillage systems.

MATERIALS & METHODS

Two separate 2-year field-scale experiments were conducted at the Agronomy Center for Research and Education (ACRE) near West Lafayette, IN.

The first experiment (Exp. 1) followed a corn-corn rotation where fall strip-tillage was implemented prior to each growing season. The Pioneer hybrids used in the study included P0574AMXT (105 CRM), P1055Q (110 CRM), P1197AMXT (111 CRM), and P1464AML (114 CRM). Plot dimensions were 15' wide by 200' long and planting density was 34,000 plant.ac^{-1}. R1 earleaf and R6 grain samples were collected and sent to Ward Laboratories (Lincoln, NE) for PT2 analysis. Soil fertility samples were collected prior to planting in year one and after fertility applications in year two, then sent to A&L Great Lakes Laboratory (Fort Wayne, IN) for S1M3 analysis.

The second experiment (Exp. 2) was conducted within the long-term-tillage (LTT) study at ACRE. The design was a split-split-plot with four blocks. The 12-row plots were split by a fertility treatment, consisting of an early-season broadcast ATS application versus NTC. ATS was applied both years of the experiment, regardless of the crop rotation. The hybrid used each year was P1464AML, planted at 34,000 plant.ac^{-1}. Plot dimensions were 15’ wide by 150’ long. Earleaf samples were collected at R1 in addition to grain samples collected at R6.

Study, Year	Location (at ACRE)	Exp. Design	Fertility Treatments	Reps	Total Plots	Sulfur Rate via ATS Broadcast	Potassium Rate via Aspire^{TM} Broadcast	Starter Rate 2x2 Band	Final Nitrogen Rate via UAN 28% Side dress
						(lbs. S ac^{-1})	(lbs. K$_2$O ac^{-1})	(10-34-0)	(lbs. N ac^{-1})
Exp. 1 2020-21	Field 85 3 Fertility Blocks 4 Hybrids	RCBD within 3 separate fertility blocks	NTC (Control)	4	16	0	0	15 gal.ac-1	227.5
			ATS (S Only)	4	16	20	0	15 gal.ac-1	227.5
			ATS+ASP (S & K)	4	16	20	100	15 gal.ac-1	227.5
Exp. 2 2020-21	Long Term Tillage 2 Rotations (Main) 4 Tillage (Sub)	Split-Split Plot	NTC (Control)	4	32	0	0	15 gal.ac-1	210
			ATS (S Only)	4	32	20	0	15 gal.ac-1	210

Table 1. An in-depth look at fertilizer treatments across the two experiments observed in this study.

RESULTS AND DISCUSSION

Year	Trial	Sample	pH	OM	CEC	P	K	Critical K	Mg	Ca	S	Zn	Mn	Fe	Cu	B
			(1:1)	%		Method: M3_ICP									Unit: ppm	
2018	Exp 2	Field Avg.	6.8	4.1	25	49	222	139	900	3237	7	2	18	131	3	1
2020	Exp 1	Field Avg.	6.9	3.8	18	29	142	120	706	2294	4	1	30	99	2	1
2021	Exp 1	NTC	7.0	3.9	22	33	118	131	873	2871	9	1	15	100	3	0
2021	Exp 1	ATS	6.7	2.8	16	32	129	114	575	1862	14	1	39	104	2	0
2021	Exp 1	ATS+ASP	6.8	4.2	24	45	147	134	907	3008	15	2	15	110	3	1

Table 2. Soil fertility (15-core composite samples) from the Exp.1 & 2 at ACRE. Critical K was calculated using the equation 75+2.5*CEC. “Field average” samples were collected prior to fertilization. Results available for Exp. 2 were from 2018. Exp. 1 in 2021 had each fertility block sampled separately after fertility application.

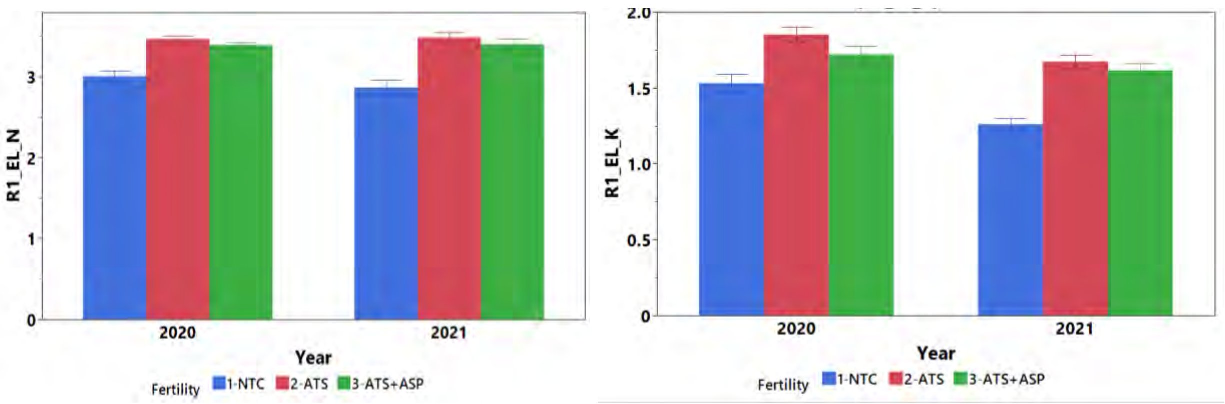

Figure 1. Exp. 1: R1 earleaf N% (left) and K% (right). Error bars represent standard error. Blue bars represent NTC, red bars represent ATS alone, and green bars represent ATS and Aspire^{TM}.

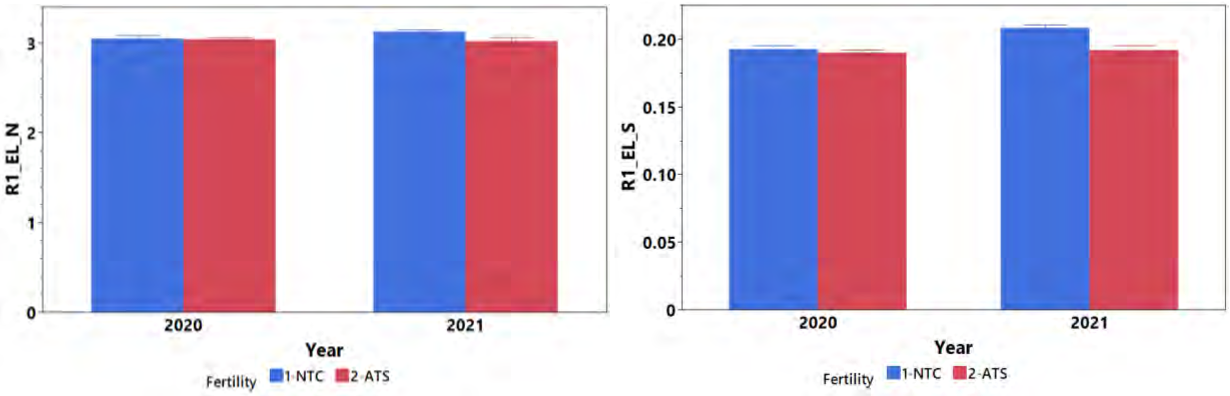

Figure 2. Exp. 2: R1 earleaf N% (left) and S% (right). Blue bars represent NTC, red bars represent ATS. Averaged across all rotations and tillage systems. Error bars represent standard error.

Applying in-season S & K to increase corn yields

The critical K level was calculated to be 130 ppm based on guidelines in the Tri-State Fertilizer Recommendations (Vitosh et al., 1995). Soil K concentration increased 29 ppm after ATS & Aspire^{TM} was applied (ASP+ATS, 147 ppm K) compared to the non-treated control (NTC, 118 ppm K), which was below the critical K level. Soil test S increased with the addition of ATS fertilizer by 4.7 ppm over the NTC treatment.

Mid-season earleaf samples were collected at R1 to evaluate plant health status during the critical period, right as the plant's high demand for K is starting to diminish. Figure 1 shows that in Exp. 1, N and K concentrations increased with the addition of S fertilizer over the control, however no difference was found between S fertilizer alone versus S & K fertilizer. S concentrations varied considerably by year in Exp. 1. Figure 2 shows that in Exp. 2, N concentrations were similar, while S concentrations increased in NTC over the S treatment in 2021. Figure 3 shows that in Exp. 1, grain yield increased with the addition of an S treatment over NTC. No further yield increases were observed in the S & K treatment. Overall grain yields for ATS and NTC plots in Exp. 2 (Figure 3) were similar each season. However, Exp. 2 yields were much lower in year two.

The soil data collected after the fertility applications in year two of Exp. 1 show that in-season S applications can increase soil test S despite some spatial variability in the field (as demonstrated by the decline in OM in S plots). This variability was likely due to the location of the S fertility block in year two, partly located on a Raub-Brenton complex (RcA, 0 to 1 percent slopes) soil type whereas the other treatments were located on a Chalmers silty clay loam (Cm) according to NRCS-USDA Web Soil Survey in 2021. While the in-season S & K application increased soil test K above the critical K threshold, it is important to note that tissue concentration and grain yield responses were not significant. When yields in Exp. 1 are combined over both years, the fertility treatments averaged 232 bu.ac^{-1} each, a 38 bu.ac^{-1} increase over NTC (194 bu.ac^{-1}).

Soil fertility results indicated Exp. 2 had higher soil fertility than Exp. 1. Weather conditions around fertility treatment timings may have been a factor. Both years consisted of cool, wet springs which likely delayed mineralization of organic matter in the soil. In Exp. 1, S deficiency symptoms were seen in both years, however the 2021 NTC plants experienced considerable yellowing due to an imbalanced N:S ratio within the plant (data not shown), likely exacerbated by the timing of the side dress N application. These early S deficiency symptoms manifested into stunted plants as the season progressed and it was clear that the plants would not fully recover by maturity. Switching to a more balanced N fertilization strategy involving split-application timings could lessen the nutrient imbalances seen in Exp. 1. With regard to the K fertility treatment, precipitation was limited in the 2 weeks following the broadcast Aspire™ application in both 2020 and 2021 (data not shown). While drought conditions were not realized in either year, a lack of moisture close to the soil surface likely delayed the movement of K to the plant roots at a time of very high K demand. Furthermore, Exp. 1 did not evaluate the residual effects of repeated K fertilization, which is a proven strategy to optimize soil K levels, since the fertility blocks in year two were imposed where K was not applied in year one.

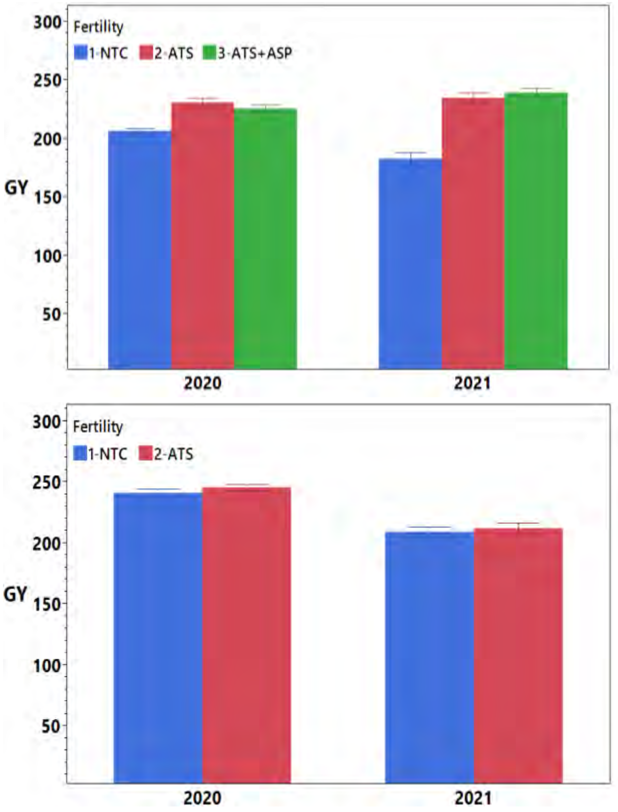

Figure 3. Experiment one (top): Grain yield adjusted to 15.5% moisture content averaged across all four hybrids. Experiment two (bottom): Grain yield adjusted to 15.5% moisture content averaged across averaged across all rotations and tillage systems. Error bars represent standard error.

Relationship between grain yields and nutrient removal after S & K application

Research in the past decade has suggested that high-yielding modern corn hybrids may remove less nutrients per bushel of grain yield than older, lower yielding hybrids. This "dilution effect" is sometimes observed in grain nutrient components at high yield levels and is attributed to increased nutrient-use-efficiencies, as observed in a large on-farm trial (Culman et al., 2019). Other prior studies have identified specific nutrient concentrations in grain, such as P and K, as being positively associated with yield level and, in some cases, with soil nutrient levels as well (Heckman et al., 2003).

This Purdue University study is uniquely positioned to study the impact of S and K fertility treatments on grain nutrient removal trends due to the wide range in observed yield levels (141 to 271 bu.ac^{-1}) at constant N rates in addition to the absence of yield response to K in Exp. 1, and to S in Exp. 2. A multivariate regression analysis was performed to detect relationships between grain yield and grain nutrient dynamics. Grain K (r^2=0.31) and S (r^2=0.25) content (i.e. removal) had the strongest positive relationships with grain yield, while grain K (r^2=0.16) and S (r^2=0.13) concentrations had slightly weaker positive relationships with grain yield (Figure 4).

Current trends observed in the data indicate a positive relationship between certain grain nutrient dynamics and increasing grain yields. We expect these trends to increase in strength once processing of all samples is complete.

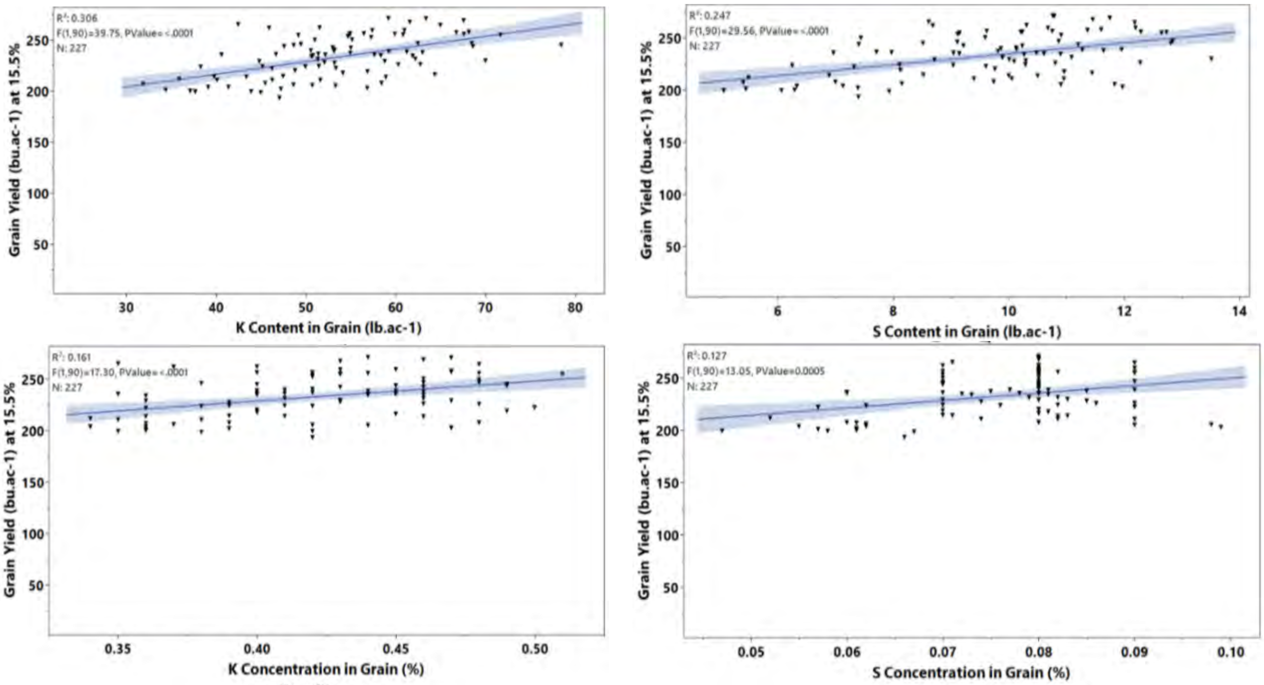

Figure 4. Regressions combine the available R6 datasets from year one of each experiment. 95% confidence interval shown in blue. Yield range for the dataset shown is 193 to 271 bu.ac^{-1}. All regressions were performed using JMP Pro Ver. 16 (SAS). Top Left: Grain yield regressions versus Grain K content (lbs. K ac^{-1}). Top Right: Grain yield regression versus Grain S content (lbs. S ac^{-1}). Bottom Left: Grain yield regressions versus Grain K concentration (%). Top Right: Grain yield regression versus Grain S concentration (%).

An important finding from the first year of Exp. 1 was the consistent increase in grain nutrient removal when K was applied in addition to S. Removal of most nutrients analyzed (P, K, S, Zn, Fe, Mn, B) increased by over 10%. Grain N removal increased by ~9% when K was applied (from 148 lbs. N ac^{-1} to 158 lbs. N ac^{-1}). Because yields were not higher when in-season K fertilization was added to the S application, these results indicate that the added K either increased remobilization efficiency from stover to grain, otherwise known as nutrient harvest index, or decreased the nutrient-use efficiency of some nutrients. Further results are needed to confirm the physiological drivers of these trends.

CONCLUSIONS

Further research that incorporates the disciplines of soil fertility and crop physiology will be crucial to helping farmers optimize yields in specific genotype and management scenarios as yields continue to improve. This S and K fertility research demonstrates the variable results that can occur. For example, when S is applied in-season, deficiency symptoms can be reversed resulting in substantial yield gains. However, no yield returns from S applications were also observed even when S nutrient removal through the grain increased. This on-going study has also confirmed the current best-management practices of K fertilization, demonstrating that in-season K applications have a minimal chance of increasing grain yield despite enhancing grain K removal.

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