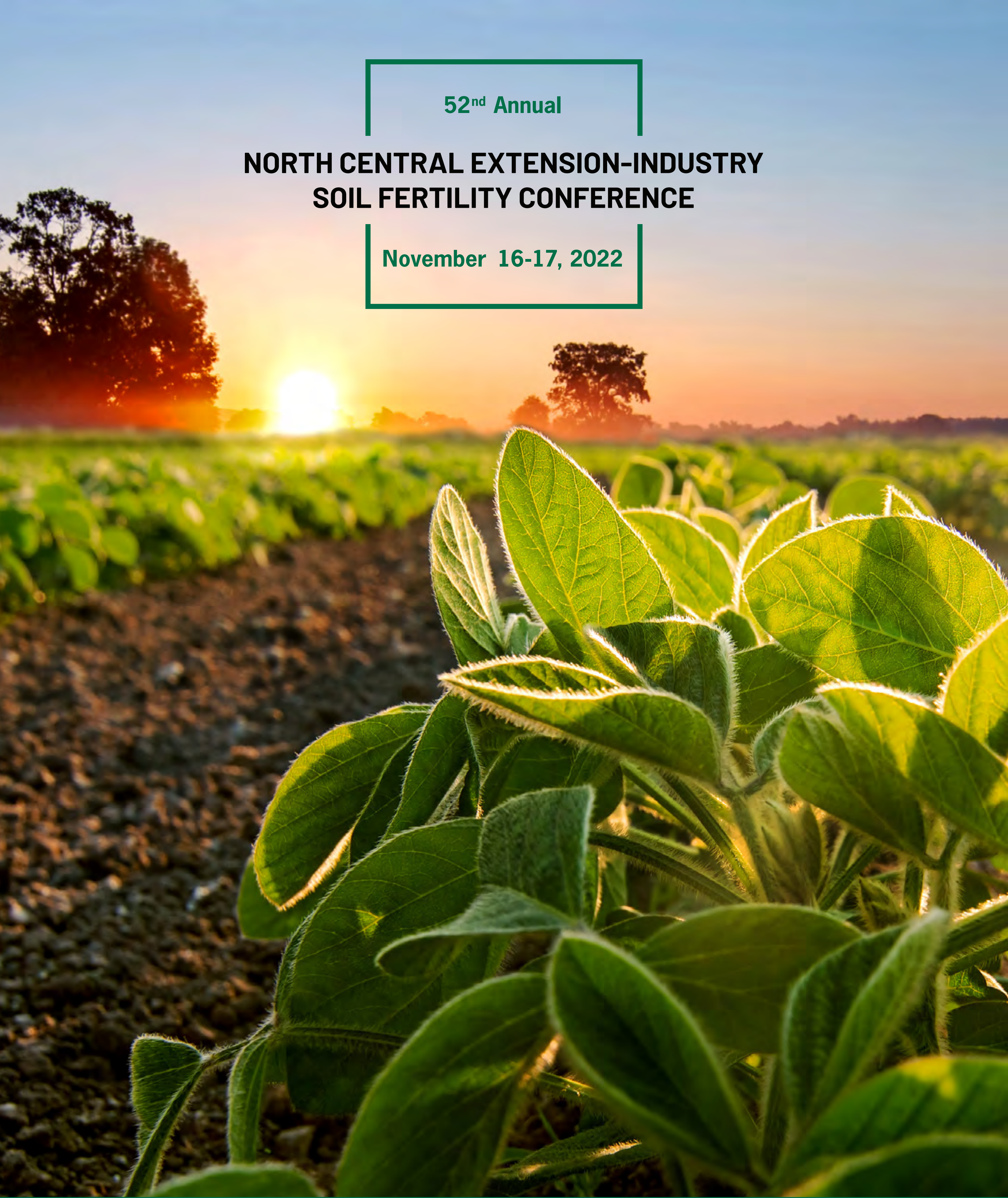
52nd Annual

NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

November 16-17, 2022



PROCEEDINGS

Table of Contents

Oral Proceedings

Poster Proceedings

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ORAL PROCEEDINGS

INTEGRATED AND IMPACTFUL RESEARCH AND EXTENSION THROUGH DIGITAL ON-FARM RESEARCH

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ABSTRACT

The Nebraska On-Farm Research Network helps farmers evaluate products and practices that impact the productivity, profitability, and sustainability of their operations. On-farm research has the potential to center farmers in the discovery and innovation process and integrate the research, extension, and teaching missions of the university. Synergistic partnerships with industry advance technology adoption. Advancements in digital agriculture tools have increased the scale and complexity of agricultural challenges which can be addressed through on-farm research. Opportunities to leverage the changing landscape of on-farm experimentation will be discussed, drawing examples from 30+ years of on-farm research in Nebraska Extension.

INTRODUCTION

The complex challenges facing agricultural producers require collaboration and dynamic solutions. On-farm research can play a critical role in both generating solutions and transferring technology to farmers (Kyveryga, 2019; Thompson et al., 2019; Lacoste et al., 2021). Within the University of Nebraska – Lincoln (UNL) Extension, on-farm research efforts formally began in 1990 with a pilot group of farmers in one county. In subsequent years, additional efforts were launched throughout the state. In 2012, the Nebraska On-Farm Research Network (NOFRN) was formed, and the program scope was expanded to be statewide. The program is supported by the Nebraska Soybean Board, Nebraska Corn Board, Nebraska Corn Growers Association, and Nebraska Dry Bean Commission. Currently 80 to 100 studies are completed each year.

MATERIALS AND METHODS

The NOFRN operates within the six principles for on-farm experimentation as outlined by Lacoste et al. (2021): farmer-centric, real systems, evidence-driven, scalable, co-learning, and specialist-enabled. The practical approaches NOFRN uses to implement these principles are described as follows:

Farmer-Centric

The development and execution of the on-farm research project is collaborative and can involve the farmer, crop consultants, industry, commodity organizations, conservation partners, UNL extension faculty, and graduate students. Farmers take an active role in determining the research question and the process is generally viewed as collaborative and iterative (Thompson et al., 2019). Through the project, the farmers participating are engaging in transformational learning which leads to adoption. At the same time, research data which is generated can be used to inform future recommendations for a broader group of farmers.

Real Systems

Farmers participating in the program generally implement the trials and collect the data using their own equipment. The protocols are designed to fit each farmers' unique management system, growing conditions, and questions. All studies are conducted using sound experimental designs featuring randomization and replication. Traditionally on-farm research has relied on field-length strips (Kyveryga et al., 2018). While this approach is still used, GPS technology can make establishing studies and collecting data more convenient for the farmer. For example, GPS technology is used to log the application location for strips of products, such as nitrification inhibitors and biologicals. Then, yield data is recorded on-the-go using a calibrated yield monitor. Finally, yield data is then summarized for each application strip, allowing for whole strip analysis. Due to the spatial yield data collection, sub-field analysis can also be used to detect site-specific responses to products.

While strip trials can provide meaningful data, the availability of variable-rate application (VRA) equipment has made it possible to move to more complex experimental designs, expanding the potential questions which can be addressed through on-farm research. Variable-rate application equipment is being used to establish seeding rate and N rate blocks throughout farmer fields in whole-field "checkerboard" designs (Alesso et al., 2019; Bullock et al., 2019) or within contrasting homogenous sub-field zones. An example is provided in Figure 1, detailing the process of developing the variable-rate prescription, applying the varying N rates, collecting the yield data, post-processing data, extracting yield data for corresponding N rates, and estimating the economic optimum N rate (EONR).

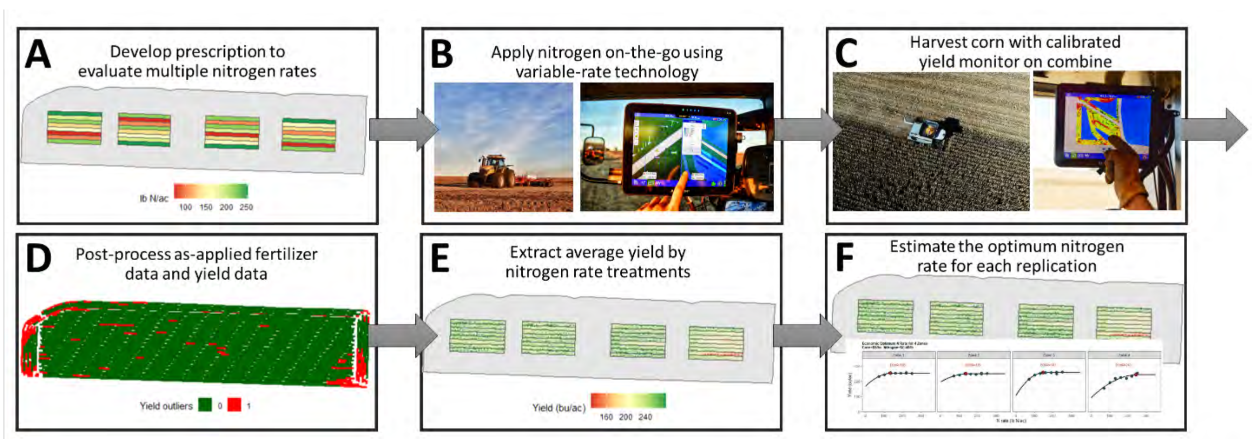

Figure 1. On-farm research nitrogen trial implementation workflow: A) variable nitrogen rate prescriptions are created with the nitrogen rate blocks, B) trial is applied on the go while the producers apply fertilizer, C) end of season yield data collection with yield monitor, D) post-processing to clean as-applied fertilizer and yield data, E) data summary, F) analysis of economic optimum nitrogen rate by replication.

Evidence-Driven

In many cases, extension educators, specialists, graduate students, and crop consultants collect in-season data including imagery, soil moisture, disease pressure, leaf area index, soil chemical, physical, and biological properties, crop establishment, and others. Farmers collect the end-of-season yield data, either with weights of field length strips or on-the-go using a yield monitor. Data post-processing and statistical analysis is conducted by extension faculty and individual reports are generated. In addition to yield analysis of treatments, all reports also include an economic analysis to assess if the treatments evaluated resulted in a positive return on investment. All studies go through a standard peer-review process for extension publications. Reports are published in an extension circular that is available in hard copy and online at: https://onfarmresearch.unl.edu/result-publications. Additionally, extension articles and peer-review journal articles often result from the aggregation of multiple on-farm research studies.

Scalable

The NOFRN works closely with the network of local extension educators to implement the program statewide. These educators provide structure and support for farmers conducting on-farm research. Educators are able to build close and long-term relationships with farmers and agronomists in the area. This results in 80 to 100 studies being conducted each year on topics including cover crops, crop production, crop protection, equipment, soil fertility, and non-traditional products (Figure 2). Coordinated efforts among the group of extension educators and specialists results in the development of aligned protocols, ensuring that generalizable insights can be gained from individual farmer efforts.

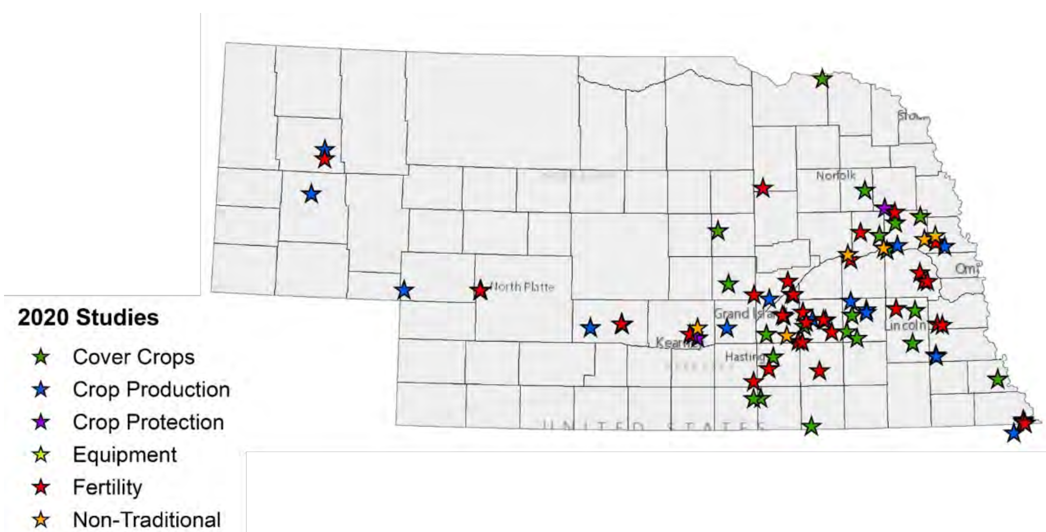

Figure 2. Example of on-farm research study topics and state-wide distribution from the 2020 growing season.

Specialist-enabled

In the NOFRN, specialists enable on-farm research through subject matter expertise, technical expertise enabling use of digital tools, and through development of tools to support on-farm research. Here we focus on several tools that have been developed by specialists to support on-farm research efforts. First, the *Growers Guide to On-Farm Research* provides an overview of the fundamentals of conducting on-farm research in the form of text, embedded audio, and video. Second, the *Results Finder Database* is a filterable and searchable database which contains results of over 1,000 past on-farm research studies, allowing users to find research that is relevant to their location and topic of interest. Third, the *Digital Ag Training Course* is an online course that covers the basics of utilizing common agricultural data management software to design and analyze geo-spatial on-farm research studies. Fourth, the *FarmStat* tool is a web application that enables users to conduct an ANOVA and mean-separation statistical analysis of their on-farm research study and obtain detailed output as well as simple and direct interpretations of the statistical output.

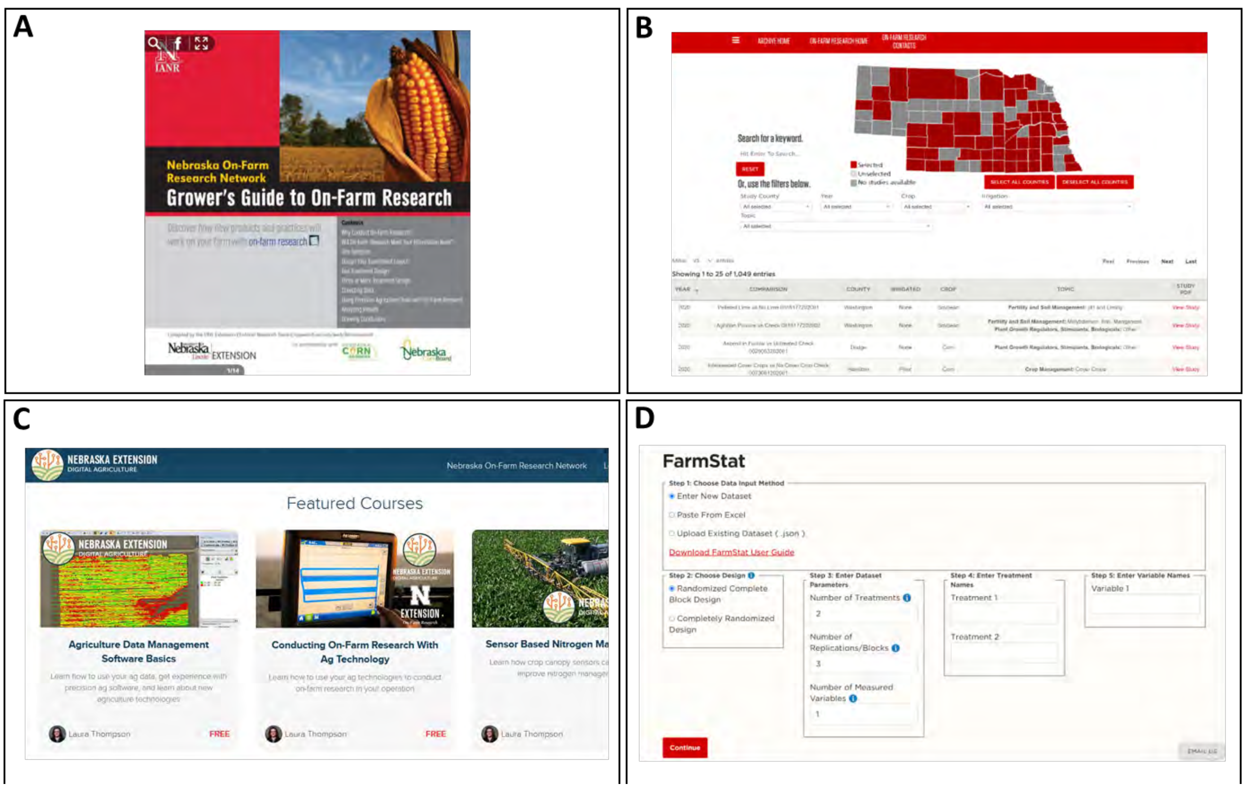

Figure 3. Tools to facilitate on-farm research provided by the Nebraska On-Farm Research Network. A) Grower's Guide to On-Farm Research, B) Results Finder searchable and filterable database, C) Digital Ag Training Course to learn to design and analyze on-farm research experiments, and D) FarmStat web tool for statistical analysis of research data.

Co-learning

Each year, participating farmers share their research results at the annual results update meetings which are open to the public. In this way, insights from on-farm research studies are valuable to non-participating farmers, expanding the reach of the program. These meetings are designed to be highly interactive with discussion about the research ideas and results. Annually, participants in the NOFRN results update meetings, rate the value of the knowledge they gain by attending at approximately $10 million. In 2022, attendee responses indicated that 93% learned new information about how to set up an on-farm research plot, 85% had a better understanding of cover crop management as a result of the programming, 79% learned new information about crop production practices, 86% learned new information about available ag technologies, and 96% have a better understanding of how ag technologies can be used to conduct on-farm research. Attendees noted that they liked the "variety of research done" and "networking around the state."

A highlight for many is hearing from their peers. Attendees noted that “I like farmers sharing experiences,” “at annual meetings we get to talk to others, share with others and without that, it would be half the value,” and “the on-farm research on my farm has allowed me to use less inputs and increase yields in the last 25 years…we learn a lot from each other.” The value of co-learning and social interaction in the program was documented through in-depth interviews which highlighted that the majority of people reported positive experiences from participating in the program were due to liking the university people they worked with and that they found value in the interactions at annual meetings (Thompson et al., 2019). This highlights the importance of co-learning and social interaction as part of an impactful on-farm research program.

Resources in this document can be found at https://onfarmresearch.unl.edu/.

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PRACTICAL FARMERS OF IOWA ON-FARM RESEARCH PROGRAM

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ABSTRACT

Practical Farmers of Iowa (PFI) has been leading and conducting on-farm research since 1987. The organization has staff scientists to help design experiments based on questions from participating farmers. Farmers are cooperators in research and they often collaborate with other farmers on the same project. Ideas for projects are considered at the annual Cooperators' Meeting in December each year. Cooperators describe what was done on their farm, why they did it, and what they found. They also make plans for future projects based on previous results and new questions raised. Farmers are responsible for planting, tending to animals, and taking measurements throughout the trial, based on experimental design and protocol developed with PFI staff. Summaries of results are also published each year.

INTRODUCTION

Since 1987, the Practical Farmers of Iowa (PFI) Cooperators' Program has helped direct curious farmers to conduct successful on-farm experiments that answer their production questions and guide their future decision-making. This program is unique in that farmers have always been at the helm – they are the ones brainstorming projects, setting on-farm research priorities and gathering the data on their farms.

DESCRIPTION OF PROGRAM

While PFI staff guide farmers through the process of setting up the on-farm trial, farmers are very much partners and leaders in the process. No prior research experience is necessary from the farmer, just their willingness to conduct the experiment. Most of the on-farm research trials take place on the farms of participating farmers. In addition, the Cooperators' Program research agenda is developed with the input of the farmers and the research is conducted by the same farmers.

In this program, the farmer-researchers are referred to and interacted with as cooperators because the first experiments in the program were done in cooperation with agricultural researchers, such as those from Iowa State University and USDA. Today, on-farm research trials are collaborative efforts between farmers and PFI staff scientists who guide the design of experiments based on questions posed by the participating farmers. On-farm research projects are also often collaborative endeavors among several farmers. So "cooperator" applies on many levels.

The farmer does not need a research or science-based background to participate. All that they require is an idea that they want to test on their farm and PFI's staff scientists help with the rest. That said, just like scientists, the farmers are making observations on their farm regularly through cropping season and they tend to make future decisions based on these observations and yield measurements. So many farmers function similar to scientists already. What the Cooperators' Program does is to increase the ability of farmers to answer pressing farm questions using simple yet rigorous tools of scientific research.

Each year, farmers who have conducted on-farm research and those interested in conducting on-farm research and communicate this to PFI are invited to the annual Cooperators' Meeting. Held in December, this gathering connects on-farm researchers as a community where results and observations from on-farm research performed over the past year are shared. During the meeting, cooperators are encouraged to describe what they did, why they did it and what they found. Cooperators also generate ideas and make plans for future projects based on previous results and new questions. Before the onset of spring, cooperators and PFI staff mutually agree on project plans and commitments. When the time comes to conduct the trials, farmers are ultimately responsible for planting seeds, tending to animals and taking measurements throughout a trial.

Participating farmer cooperators will gain:

- Experience and data from useful, reliable research that helps one understand what works and what doesn't on their farm.
- A connection with a community of curious farmers to exchange ideas and experiences, which can expand knowledge of what's possible with on-farm research.
- The chance to become a leader who inspires improvements to agriculture.

If someone cannot participate, but would rather just see the results of past on-farm results, the results of our Cooperators' Program research provide relevant, unbiased and science-based information that farmers can trust about new practices. The summaries of 2021 research and previous years' results are available at http://practicalfarmers.org/research .

To learn more about the Cooperators' Program, visit practicalfarmers.org/research. Have questions or want to get involved? Contact PFI through Stefan Gailans, senior research manager at (515) 232-5661 or email at stefan.gailans@practicalfarmers.org .

DESIGN, WRANGLING AND ANALYSIS OF AN ON-FARM STRIP TRIAL. IOWA SOYBEAN ASSOCIATION METHODOLGIES

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INTRODUCTION

Iowa Soybean Association (ISA) has conducted over 4,500 replicated on-farm trials over the past 15 years. During this time, we have developed our own methodologies and approaches to on-farm research. In this talk we review step by step ISA approaches to a replicated strip trial involving 5 nitrogen rates including trial design, data wrangling, data analysis and machine learning approaches. The talk concludes with discussion on some difficulties in on-farm research with an appeal to the science community to work on these gaps.

WHY CONDUCT ON-FARM RESEARCH?

While on-farm research is gaining acceptance among the scientific community, there remain many skeptics of on-farm research approaches to science. Most of these objection's stem from a lack of controlled environments where there is less confounding of experimental treatments with soil types, textures, landscape positions and other extraneous factors. Some major institutions still classify on-farm research as not research but "demonstrations". While these objections provide clear warnings to on-farm research approaches, we would argue that replicated strip trials can be sub-set in such a fashion that experimental units are as uniform as any small plot experiment, with the benefit that on-farm research can capture heterogeneous treatment responses across landscapes, yield levels and soil types, providing even more relevance to farmers.

The chart below lists what we believe are the most important benefits and limitations for on-farm research.

Benefits	Limitations
• Farmers find on-farm research more credible. • **Use Commercial Equipment.** • Insight into fertility by soil types and landscape position interactions. • Sometimes less expensive compared to small plots. • <u>Participatory Learning!</u>	• Designs must be simple and fit into logistics of commercial operation. • Analytics are different from small plot research.

While difficult to accept, much previous work has shown that farmers find results from on-farm research more credible than small-plot research from distant locations (Radatz, et. al, 2018; Baumgart-Getz et. al, 2012, Kyveryga, 2019). Farmers, being risk averse, want field-scale research results from their local geographies before they will implement improved practices. This does not imply that small-plot research is not an important aspect in the development of improved practices, but rather that small-plot research is not enough to drive adoption. On-farm research must be included as a companion or spoke of any program that seeks to drive adoption of improved practices.

A less appreciated advantage of on-farm research is that it utilizes commercial farming equipment. Over the past decade, farmers have made very large investments in planter, spraying, and harvesting technology. These investments usually far exceed small plot equipment at research stations providing more uniform stand establishment and treatment applications.

ON-FARM EXPERIMENT DESIGNS

Much too common in the industry is the use of split-field comparisons as "on-farm research". Split field designs are subject to sometimes extreme heterogeneity in experimental units due to different soils, landscape positions, pest incidence and base soil fertility. This heterogeneity in experimental units leads to spurious results and this practice should be discontinued immediately. The only exception being where it is logistically infeasible to conduct the experiment as a replicated strip trial and there are very competent statisticians available to mine the data.

In ISA research, we favor replicated strip trials where each treatment in the experiment is compared to the control in replicated strips across the field. In some cases, we use a "Two Blocks" design where the farmer will apply treatments to two large blocks in the field separated by untreated controls. This simplifies logistics for some tillage, manure, or cover crop experiments while maintaining more uniform experimental unit comparisons.

A growing on-farm research design is learning blocks where smaller experimental units are embedded in a variable rate application. The advantages of these learning block designs are that costs are reduced as the amount of land area dedicated to research is very much reduced. Further, it can sometimes be easier for a farmer to establish several treatments or rates compared to a replicated strip trial. However, in our experience in Iowa, it can sometimes to be difficult to find enough land area in uniform soils or yield potential to set up uniform experimental units. Further, since so much of ISA efforts are to understand heterogenous treatment responses, we prefer replicated strip trials whenever feasible.

DATA WRANGLING

A potential pitfall in on-farm research is the amount of data wrangling required. Practitioners of on-farm research must be equipped with specialized GIS software to read and map as-applied, as-planted, and yield monitor data. This data usually has outliers, and this data must be removed to reduce systematic noise in the experiments. Opinions on best approaches for removal of outliers in on-farm research data vary tremendously among scientists. There is a tremendous need for standardization in approaches to removal of outliers, especially with yield monitor data. Something that ISA urges is for academic and industry scientists to develop generally accepted protocols for outlier detection and removal. In the ISA approach, we use crop images to identify areas in the field where confounding factors such as wind damage, flooding or lodging have impacted the strips non-uniformly. Other than this, we don't generally remove any data from the analysis unless the data is not in the range of the yield monitor calibration.

HETEROGENOUS TREATMENT EFFECTS

The promise of precision agriculture is that farmers can improve profitability and stewardship via variable rate applications of inputs at the sub-field level. To date, this promise has largely not been fully achieved. Limiting this promise has been a lack of understanding of where and what rate to apply inputs. Replicated strip trials and on-farm research will be very important to the future of crop production as it is able to differentiate heterogeneous treatment effects such as how soils, yield levels and landscape positions interact with fertilizer rates. The data science community is making large progress in developing approaches and computer codes to understand and predict heterogeneous treatment effects through cubist and causal forest analysis. We foresee step change advances in agronomic science via the combination of on-farm research combined with recent advances in statistics and computing.

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THE AMMONIA RAINBOW

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Ammonia is a critical agricultural input either for direct soil application or as a precursor for other nitrogen and phosphorus fertilizers. Most of the world's ammonia supply is produced using the standard Haber-Bosch ammonia synthesis process and uses natural gas as a source of hydrogen and the energy for reaction. Haber-Bosch ammonia synthesis has come under criticism for the significant carbon footprint from use of natural gas as a feedstock. Development of hydrogen as a zero-carbon fuel and ammonia as a hydrogen carrier in these fuel systems has increased interest in alternative ammonia synthesis processes targeting reduced carbon footprint and use of renewable energy sources.

An ammonia "color palette" has been developed around these ammonia synthesis methods to distinguish the processes and carbon intensity. The most commonly mentioned "colors" are "grey" ammonia made by the traditional Haber-Bosch process, "blue" ammonia made by Haber-Bosch synthesis but employing carbon capture and storage, and "green" ammonia produced by water electrolysis using zero-carbon renewable energy (table next page).

The Ammonia Color Palette			
Type	Method	Carbon Intensity	Notes
Brown/ Black	Coal gasification to produce H_2, CO and CO_2. H_2 is separated.	Very high CO_2 emitted; CO release; high energy use	primarily China, least desirable
Grey	Steam reforming natural gas into H_2 + O_2	high CO_2 emitted, high energy use	most prevalent, 96% of global production
Blue	Steam reforming natural gas into H_2 & CO_2 followed by carbon capture and storage or reuse	Potential for lower carbon; 10-20% CO_2 not captured	CCS value is uncertain*
Green	Water electrolysis into H_2 + O_2 using renewable electricity source	Low/no CO_2 emission, higher energy use	Most desirable
Yellow	Water electrolysis into H_2 + O_2 using solar power or a mixture of renewable electricity sources	Low/no CO_2 emission, higher energy usage	Same as "green" ammonia but specifically using solar energy
Turquoise	High temp methane (natural gas) pyrolysis into H_2 + solid carbon	Low/no CO_2 emission, higher energy usage	Experimental
Pink	Water electrolysis into H_2 + O_2 using nuclear power electricity	Low/no CO_2 emission, higher energy usage; hazard waste generation.	Nuclear not considered sustainable energy source by some.

There is great interest in low- or zero-carbon ammonia, but there are still questions about costs and technology development. Some technologies are still experimental; others are in early stages of commercialization. Current cost estimates of green ammonia range from two to four times the cost of current Haber-Bosch production. It is expected costs should decrease as renewable energy sources become more available and their costs decrease but impacts on ammonia fertilizer prices remain an uncertainty. Some have proposed differential pricing schemes for fertilizer and fuel, but this seems impractical. Impacts of competing demands for ammonia as fuel and as fertilizer are not yet defined but could be at cross purposes in maintaining economical fertilizer supplies.

There are questions about the true carbon savings of carbon capture and storage (CCS; Howarth and Jacobsen, 2021). The carbon footprint of this process will be directly related to the efficacy of CCS. Using ammonia as a hydrogen fuel source seems to be building momentum but the fate of the nitrogen is not clear. Some have suggested conversion of marine transport from traditional diesel fuel and other fuel oils to ammonia could increase global ammonia demand from current demand of about 120 to 140 Tg/year to as much as almost 600 Tg/year. The environmental benefit of such a conversion would depend to large extent on the amount of leakage of reactive nitrogen from this system and combustion processes, which at present, seems a large risk (Wolfram et al, 2022).

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APPLICATION RATE STRATEGIES TO OPTIMIZE USE OF PELLETED LIME IN CORN AND SOYBEAN PRODUCTION

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ABSTRACT

Research has shown inconsistent results about the efficiency of pelleted lime at increasing soil pH or crop yield compared with aglime. Our previous Iowa research (2015-2016) showed that pelleted lime manufactured with limestone from northern Iowa quarries attained maximum soil pH with the same rate and at the same time than finely ground calcium carbonate, but more time was needed for aglime. However, there were no yield differences between the sources for corn-soybean rotations when one-time rates of 560 to 7,300 lb/acre of effective calcium carbonate equivalent (ECCE) were applied before corn. This new study (2020-2021) with corn-soybean rotations and 2-year trials at six locations was conducted with very low to high pelleted lime rates. Initial soil pH in fall 2019 was 5.1 to 5.9 across sites. Pelleted lime rates of 0, 100, 200, 400, 800, 1600 and 6400 lb/acre (89% ECCE) were applied in fall 2019 and were incorporated by disking for corn in 2020. After corn harvest each plot was divided into two halves to apply two sets of treatments for soybean in 2021. No pelleted lime was applied to one subplot to evaluate residual effects of the initial applications on soybean. The same initial rates were reapplied to the other subplot to evaluate effects of freshly applied lime, except that for the initial 6400-lb rate only a 1600-lb rate was applied. The freshly applied lime was not incorporated, and no-till soybean was planted. In 2020, soil samples were taken from all plots in March, June, and October after corn harvest. In 2021, soil samples were taken in March from all plots and in October only from the control and plots that received annual applications. On average across the six sites and by spring of 2021 soil pH for initial rates of 0, 100, 200, 400, 800, 1600 and 6400 was 5.53, 5.60, 5.65, 5.71, 5.78, 6.01, and 6.5, respectively. Soil pH for plots receiving annual applications was 5.63, 5.71, 5.82, 5.87, 6.15, and 6.59. Soil pH of 6.0 to 6.5 is considered optimum for corn and soybean in Iowa depending on the region. Maximum yield (means of replications) at each trial was 199 to 285 bu/acre for corn and 68 to 74 bu/acre for soybean. Grain yield increased exponentially to a maximum plateau for both crops. Relative yield increases across both crops to initial rates were 1.9, 2.5, 3.9, 6.2, 7.5, and 9.0% whereas for annual rates were 2.8, 3.5, 4.5, 7.2, 8.8, and 9.1%, respectively. Overall, the study showed that application of pelleted lime rates lower than needed to increase soil pH to 6.0 or 6.5 limited crop yield significantly at several sites.

INTRODUCTION

Pelleted lime was developed mainly to facilitate and improve uniformity of lime application, and typically is ground limestone granulated using a binding agent. Scarce research in other states from the middle 1980s until 2013 provided inconsistent results about the efficiency of pelleted lime at increasing soil pH or crop yield compared with aglime. Reasons for the inconsistent results of few field trials could not be identified mainly due to insufficient information about the pelleted lime manufacturing, such as chemical properties and fineness of the limestone used and final granule size. Additional research is needed because pelleted lime is more expensive than aglime and in recent years its offer to farmers has increased in Iowa and neighboring states.

A previous field study by our group in six Iowa sites showed that the efficiency at increasing soil pH and both corn and soybean yield of pelleted lime manufactured with limestone from Iowa quarries was similar to finely ground calcium carbonate and better than for calcitic aglime. However, the lowest application rate used was 2000 lb/acre of calcium carbonate equivalent (CCE). Therefore, the objective of this new field study was to develop application rate strategies for cost-effective use pelleted lime application for corn and soybean production by using very low to high rates of the same pelleted lime used before.

SUMMARY OF PROCEDURES

Six 2-year trials were established in fall 2019, with corn planted in 2020 and soybean planted in 2021. The trials were established at fields of Iowa State University research farms with contrasting soils located in different areas of the state, which were in the center (two trials) near Ames and near Boone, northeast near Nashua (NERF), northwest near Calumet (NWRF), southeast near Wyman (SERF), and southwest near Lewis (SWRF). Table 1 shows information about locations, soils, and soil-test results from samples collected in fall 2019 before treatments application. First-year plot size was 20 feet wide (for eight 30 inches corn rows) by 15 feet long and treatments replicated three times were pelleted lime rates of 0, 100, 200, 400, 800,1600, and 6400 lb/acre. After corn harvest in fall 2020, each plot was divided into two subplots, one did not receive lime to evaluate the residual effects on soybean and the other received similar rates except for 1600 lb/acre to plots with the highest first-year rate. Treatments were replicated four times.

Table 1. Locations, soils, and soil-test results (6-inch depth) in fall 2019 before treatment application for 2020.

Site	Nearest City	Soils†	Previous Crop	Soil-Test Results‡ pH	Ca	Mg	Na	OM
					----------- ppm	---------		%
1	Ames	Clarion loam	Soybean	5.8	8826	1269	12	2.9
2	Boone	Nicollet loam	Soybean	5.3	9013	1188	14	3.1
3	Nashua	Floyd loam	Corn	5.6	6566	879	11	2.7
4	Calumet	Galva SCL	Soybean	5.6	13450	2422	15	4.4
5	Wyman	Mahaska SCL	Corn	5.9	11039	2056	15	3.4
6	Lewis	Marshall SCL	Soybean	5.1	9791	1819	17	3.2

† SCL, silt clay loam; extractable Ca, Mg, and Na with ammonium-acetate; OM, organic matter.

The pelleted lime used (Calcium Products 98G pelletized limestone) is made from mined ground calcitic limestone from quarries near Gilmore City and Fort Dodge, Iowa. The pellets are manufactured by pan agglomeration using finely ground limestone (99% passing mesh 60, 90% passing mesh 100, and 75% passing mesh 200) and calcium lignosulfonate as the binding agent. Pellet diameter ranged from 2.0 to 4.0 mm. The lime was analyzed by methods required by the Iowa Department of Agriculture and Land Stewardship for sale of liming products. Pelleted lime CCE was 90.1% and effective CCE (ECCE) was 89%. In the first year, the pelleted lime was incorporated to a depth of 4 inches. In the second year, the new applied lime was not incorporated, and no-till soybean was planted. Soil (6 inches) was sampled for pH analysis in late March, June, and October 2020. All plots were sampled in March 2021 and only plots receiving the annual rates were sampled in October.

RESULTS AND DISCUSSION

First-year pelleted lime effects on soil pH

The overall pH levels and pelleted lime effects varied across sites and the three sampling dates (not shown). Large pH variation over time even without lime application often has been observed. Differences among sampling dates were probably due to weather and for the June sampling date the N application. The pH of unlimed soil in June was much more acidic than in fall 2019 or March 2021, being 4.7 to 5.6. At the Ames, Boone, and SWRF sites, soil pH levels were the highest for the October 2020 sampling date, the lowest for the early summer sampling date (about 5 weeks after the N application), and intermediate for the early spring sampling date. At the other sites there were no large or clear differences in overall soil pH among the three sampling dates. Also, by October 2020, one year after the initial applications, the 6400-lb rate increased soil pH above 6.5 at all sites. The second-high 1600-lb rate increased pH to 6.0 or above at the Ames, NERF, NWRF, and SERF sites but not at the Boone and SWRF sites. Optimum pH for corn and soybean in Iowa is 6.0 in the region of the Ames, Boone, NWRF, and SWRF sites (calcareous subsoil); and pH 6.5 in the region of the NERF and SERF sites (acidic subsoil). Pelleted lime rates of 100, 200, and 400 lb/acre increased soil pH by about 0.3 pH units or less.

Second-year pelleted lime effects on soil pH

The residual effects of the initial pelleted lime applications in fall 2019 and the annual applications on soil pH during 2021 (not shown). By March 2021, the residual effects on soil pH of the initial pelleted lime applications in fall 2019, were approximately maintained. The highest initial 6400-lb rate maintained soil pH near 6.5 or above at most sites with the exceptions of the NERF and SWRF sites where pH decreased to about pH 6.2 or 6.3. The second-high 1600-lb rate maintained pH near 6.0 or above only at the at the Ames and SERF sites, but not at the other four sites where pH decreased to about 5.6 to 6.8. Initial pelleted lime rates of 100, 200, and 400 lb/acre did not maintain soil pH above that of the control except at the Ames and NWRF sites.

The pelleted lime reapplications in fall 2020 before soybean did not have much effect by March 2021 and increased only slightly soil pH over values for the residual plots for most application rates. By October 2021, two years after the initial pelleted lime applications and one year after the second applications, only the two highest pelleted lime rates increased soil pH further than did in the March 2021 sampling date and only at the NERF, SERF, and SWRF sites.

Rates effect on soil pH across the two years

Figure 1 shows that on average across the six sites, soil pH for the control plots varied greatly over time, which has been often observed before, and ranged from 5.3 to about 5.6. During the first year and until the March 2021 sampling dates, soil pH increases over the control from initial pelleted lime applications of 100 and 200 lb/acre kept pH slightly higher than for the unlimed control but not much higher than the initial pH in October 2019. Soil pH was consistently at or above the optimum pH of 6.0 for Iowa soils in northcentral and western Iowa only for the two highest initial rates of 1600 and 6400 lb/acre. The reapplied (annual) rates for the second-year soybean increased soil pH in March 2021 compared with the pH for the residual plots only with the three highest annual rates. These effects were approximately maintained until the last sampling in October 2021.

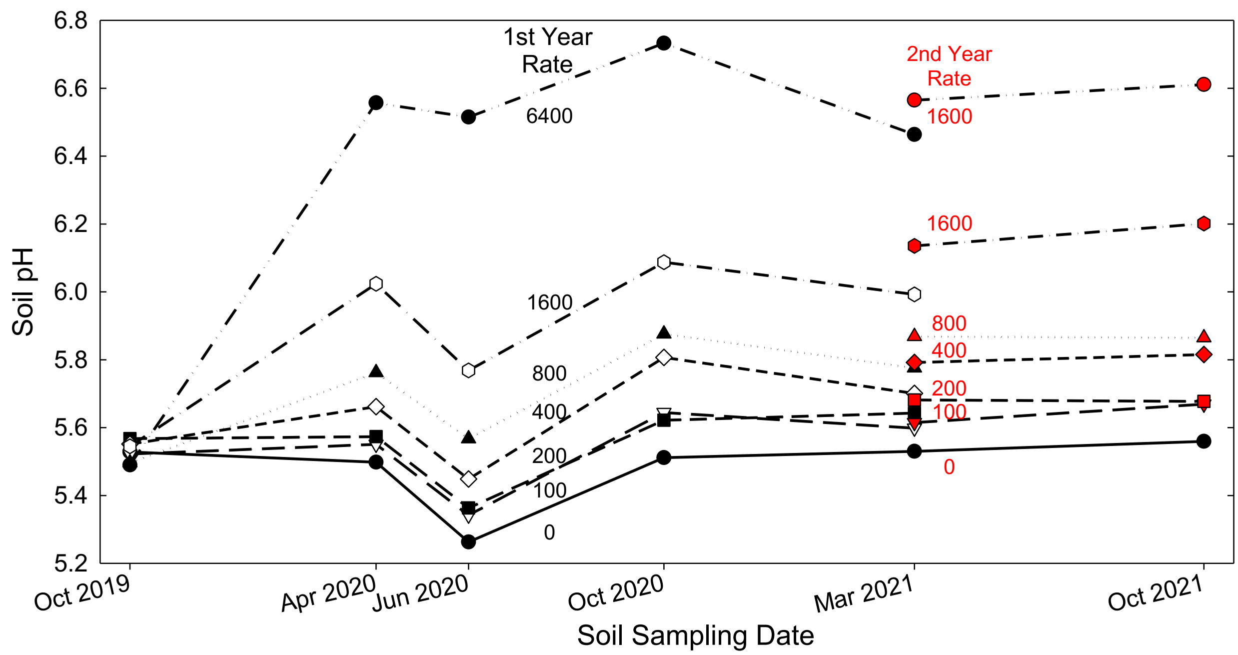

Figure 1. Pelleted lime effects on soil pH across the two years of the study.

Pelleted lime rate effect on corn yield

Figure 2 shows that there were corn grain yield responses to pelleted lime application at all six sites, which was expected because initial pH was acidic. Corn yield increased exponentially to maximum plateau at all sites. The magnitude of the responses and the differences among rates applied differed among sites. However, the two lowest pelleted lime rates of 100 and 200 lb/acre increased yield very little at all sites (5 to 16 bu/acre) when increases with higher rates was 32 to 46 bu/acre. The yield difference between the two highest rates was less than 6 bu/acre except at NERF and SWRF sites when was 10 and 11 bu/acre, respectively.

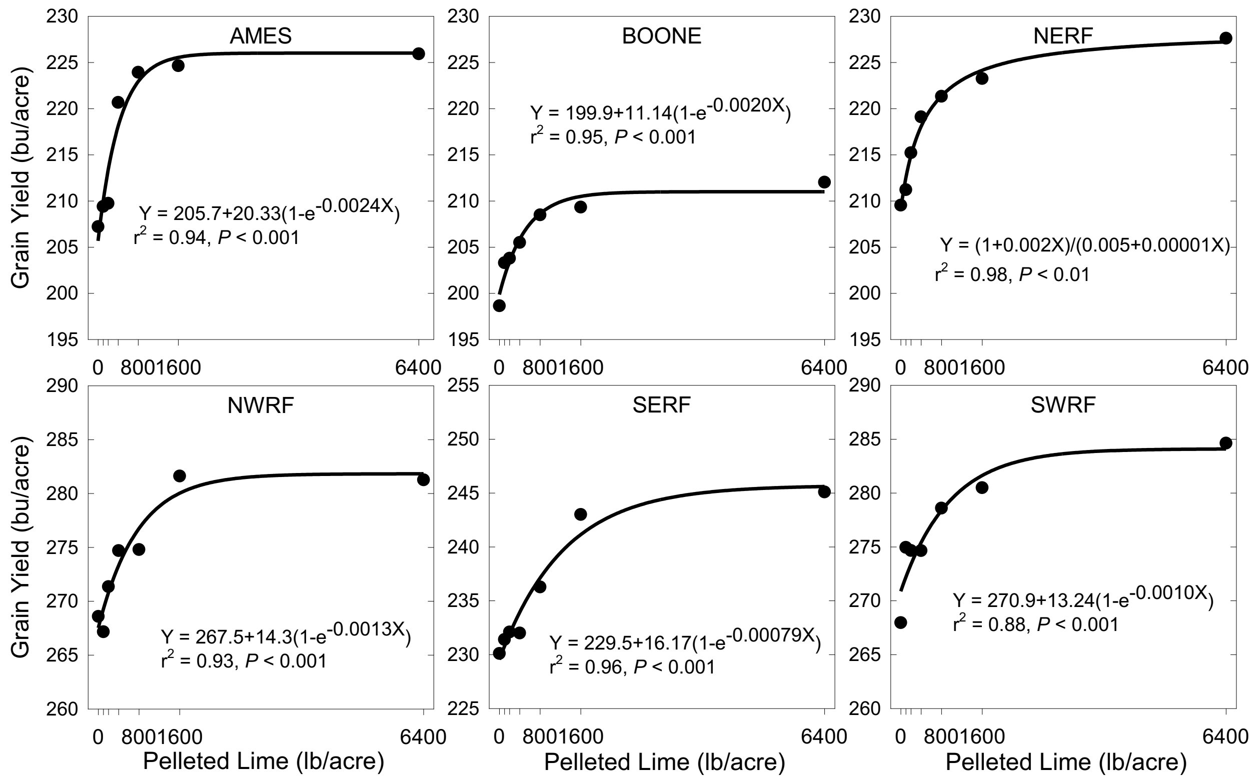

Figure 2. Effect of pelleted lime on corn grain yield in 2020.

Pelleted lime rate effect on soybean yield

Figure 3 shows that in the second year there were large soybean yield increases from the initial pelleted lime application at all sites. Yields increased exponentially with decreasing increments to a maximum plateau at most sites, except for NERF and SWRF where yield increased up to the highest initial rate used. These high residual effects were expected mainly for the higher two rates because initial pH was very acidic and these rates-maintained pH at pH 6.0 or 6.5 (optimum values for soybean in Iowa). However, we did not expect the clear residual effects of initial rates lower than 400 lb/acre, which increased yield over the unlimed control yield, although differences ranged only from 2 to 8 bu/acre. Single initial pelleted lime applications of less than the highest initial rate of 6400 lb/acre resulted in large yield losses at the SWRF site. Initial rates lower than the 1600 bu/acre resulted in large yield losses at the NERF, SERF, and SWRF sites.

Figure 3 also shows that the highest annual pelleted lime rates for second-year soybean did not increase yield over residual effects of the highest initial rates at any site, and no annual rate increased yield at the Ames, Boone, and NWRF sites. However, annual rates 3200 lb/acre (1600 lb/acre each year) significantly increased yield over the single initial rates at the NERF, SERF, and SWRF sites. On average across the six sites (not shown), yield for the reapplied (annual) rates was significantly higher than for residual effects of the initial applications except for the highest rate for which the difference was only 1 bu/acre. Therefore, although on average across sites annual applications of the 800-lb rate (1600 lb over two years) optimized second-year soybean yield, this rate resulted in large yield losses for the previous-year corn.

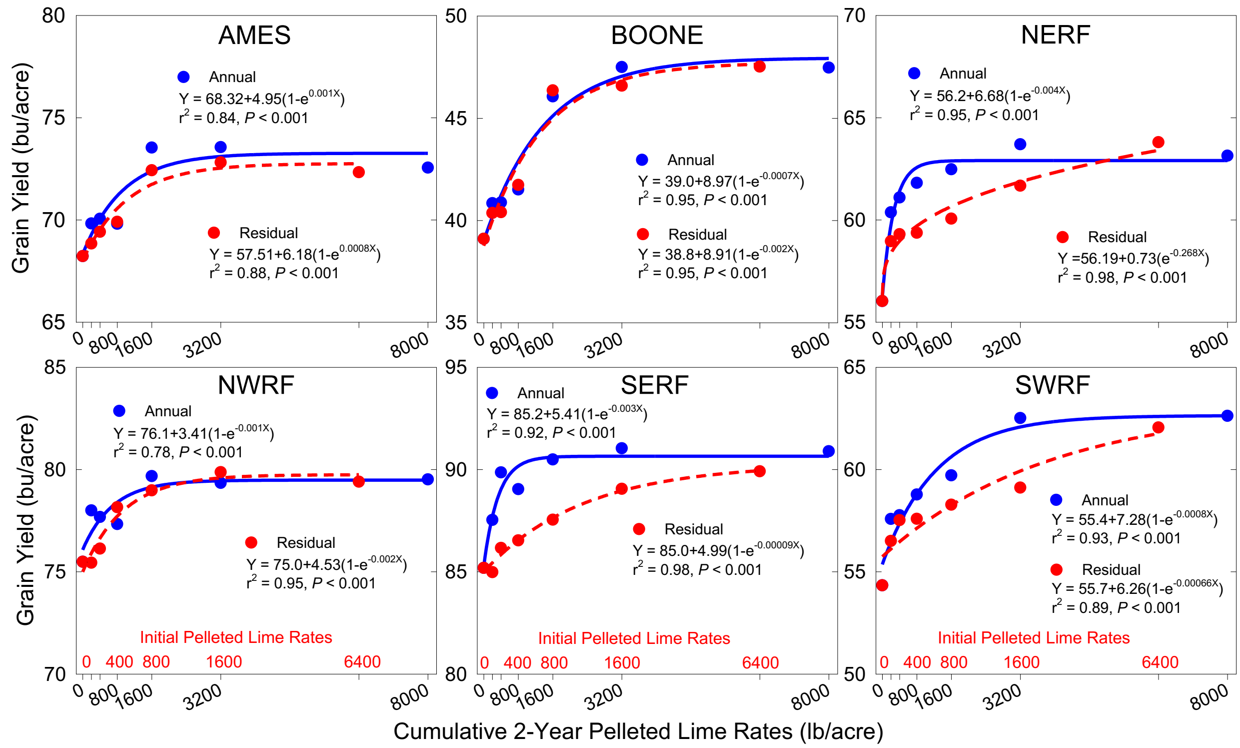

Figure 3. Effect of pelleted lime on soybean grain yield in 2021.

CONCLUSIONS

On average across six 2-year trials with corn-soybean rotations soil pH for the unlimed control varied from 5.3 to 5.6 over time. Over the two years, soil pH was at or above 6.5 only with the initial 6400-lb pelleted lime rate whereas was at or above pH 6.0 only with initial rates of 1600 and 6400 lb/acre. Soil pH increases from single initial rates of 100 and 200 lb/acre kept pH slightly higher than for the highly variable pH of the control but did not increase pH over the initial pH. Reapplied lime for the second year increased pH over the initial rates only with annual rates of 400 lb/acre or higher.

Unexpectedly, yields were slightly increased by the two lower pelleted lime rates (3 to 7 bu/acre for corn and 1 to 3 bu/acre for soybean across sites). Yield increases from a rate of 1600 lb/acre that increased pH to 6.0 and of 6400 lb/acre that increased pH to 6.5, were 13 to 16 bu/acre for corn and 5 to 6 bu/acre for soybean across sites. Relative yield increases across both crops to initial rates were 1.9, 2.5, 3.9, 6.2, 7.5, and 9.0% whereas for annual rates were 2.8, 3.5, 4.5, 7.2, 8.8, and 9.1%, respectively. Overall, the study showed that application of pelleted lime rates lower than needed to increase soil pH to 6.0 or 6.5 limited crop yield significantly at several sites.

ACKNOWLEDGEMENTS

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ADVANCING MODERN WHEAT NUTRITION TO SUSTAIN BOTH YIELD AND THE ECONOMICS OF PRODUCTION

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ABSTRACT

This work was intended to answer certain questions that result from the implementation of a multi-element wheat nutrition program. Nitrogen (N) rate is a fundamental driver of wheat yield and quality. However, the impact/value of sulfur (S) or the micronutrients, which are likely components of a more integrated wheat nutrient management program, was not clear. The main study design included four rates of N (40, 80, 120 and 160 lb N/acre), two rates of S (0 and 10 lb S/acre), and two rates of the micronutrient [boron (B) + zinc (Zn)] ‘package’ (0 and 1 lb B + 10 lb Zn/acre); in complete factorial combination to give a total of 16 (4x2x2) treatments. There were three sites in the 2019-20 season (one was lost to a spring freeze) and four sites in the 2020-21 season. Among the six sites the main effect of micronutrients on yield was significant ($P \leq 0.10$) at two, and the main effect of S on yield was also significant at two. At one site there was a significant S by N interaction on yield and at three sites there was a significant micronutrient by N interaction. All six sites gave a significant positive response to N rate, ranging from 18.3 to 54.7 bu/acre. All sites gave yield increases to 160 lb N/acre, over 120 lb N/acre, ranging from 2.8 to 14.9 bu/acre and averaging 6.7 bu/acre. No lodging was observed at any site. Yield increases to micronutrient addition were associated with significant and large increases in flag leaf tissue B and significant but smaller increases in flag leaf tissue Zn. The micronutrient by N interaction was interesting, as the yield increase to the micronutrients diminished as the N rate increased at all three sites. Soil test information for S and B were helpful but not definitive as regards predicting whether a significant response to those nutrient elements would occur. Plant tissue composition data may offer some opportunities as regards nutrient stress monitoring, but the sampling times will have to be earlier in the plant’s lifecycle in order to be of benefit to the crop growing in the field.

INTRODUCTION

There have been almost no significant advances in wheat nutrition since the start of the new century. There has been continuing work to understand the potential role(s) of new fertilizer sources, especially N sources, in wheat nutrition. There have been studies to advance the use of new technologies (chlorophyll meters, proximal sensors) in nutrient deficiency detection. There has been almost no work to examine the interactions, both agronomic and economic, that may be occurring with the use of a more integrated multi-nutritional element wheat nutrient management program. We believe that such research is needed if growers are to continue to sustainably produce wheat as a component of their grain rotations.

Our objective was to conduct field research that would look for, and then examine (both agronomically and economically), possible interactions between N, S and micronutrients [especially B and Zn]. Nitrogen rate is a fundamental driver of wheat yield and quality. But the impact/value of S or the micronutrients, which are likely components of a more integrated multi-nutritional element wheat nutrient management program, is not clear. Nitrogen can drive root exploration – does that mean S and the micros are less likely to be beneficial at higher N rates? Or, are S and the micros more likely to become yield/quality limiting with intensive wheat management at high N rates)? What are the economic consequences to the integrated multi-nutritional element wheat nutrient management program if there is or is not an interaction between N, S and the micronutrients? What are the economic impacts to the program if one of the nutrient additions fails to have a positive impact on the crop, diminishing returns to the program?

MATERIAL AND METHODS

The trial design consisted of four rates of N (40, 80, 120 and 160 lb N/acre), two rates of S (0 and 10 lb S/acre), and two rates of the micronutrient (B + Zn) 'package' (0 and 1 lb B + 10 lb Zn/acre); to give a total of 16 (4x2x2) treatments – the complete factorial combination of treatments needed to find any possible interaction among the nutritional elements. These were applied in four randomized complete blocks at each of seven study sites located in the heart of Kentucky's wheat production regions (Table 1). Fertilizer sources were SuperU, gypsum, Granubor and zinc oxysulfate, respectively.

Table 1. Site information for the two seasons.

Site Number	Site County – Site Name	Wheat Variety	Planting Date
3	Simpson – Walnut Grove Farm	AgriMAXX 454	24 Oct. 2019
5	Logan – Wheat Tech RBF	AgriMAXX 454	23 Oct. 2019
9a	Caldwell – UKREC/GFCE	Pembroke 2016	15 Oct. 2019
1	Caldwell – UKREC/GFCE	Pembroke 2021	17 Oct. 2020
6	Christian – Wheat Tech (CC)	AgriMAXX 454	20 Oct. 2020
8	Logan – Wheat Tech (RBF)	AgriMAXX 454	15 Oct. 2020
9b	Logan – Wheat Tech (OFF)	AgriMAXX 454	23 Oct. 2020

All trials were planted, without prior tillage, into the residues of a recently harvested corn crop. Planting was done in October of each year (Table 1). Weed control was excellent and diseases and insects were well controlled with the appropriate pesticides. Besides grain yield, we also took flag leaf tissue at early flowering, and soil samples (0-4 inches deep) in the early spring prior to S and micronutrient application, to assess whether analytical results from these tools would assist stress diagnosis.

RESULTS AND DISCUSSION

Site 9a was adversely effected by an April frost and was dropped from this analysis. For the remaining six sites, average site yield ranged from 90 to 125 bu/acre (Table 2). All six sites gave a significant positive yield response to N rates, and all six exhibited ‘diminishing returns’ with greater N rates (Table 2). The yield increase to 160 lb N/acre, relative to 40 lb N/acre, ranged from 18.3 to 54.7 bu/acre. Two sites gave a significant positive yield response (average of 2.5 bu/acre) to the B+Zn package and two sites gave a significant positive yield response (average of 3.5 bu/acre) to S addition (Table 2).

Table 2. Wheat Grain Yield Responses – By Site.

Treatment	Site 3	Site 5	Site 1	Site 6	Site 8	Site 9b
	------------------------------bu/acre------------------------------					
- B&Zn	106.0†	124.7†	92.1	101.2	103.2	128.4
+ B&Zn	108.5	127.2	89.9	103.2	101.1	126.1
- S	105.1†	125.5	89.7†	102.7	103.0	127.1
+ S	109.4	126.5	92.3	101.8	101.2	127.4
40 lb N/A	83.7†	115.3†	79.0†	72.3†	89.2†	107.4†
80 lb N/A	103.9	124.2	89.0	97.4	98.0	121.2
120 lb N/A	117.3	130.8	94.9	112.1	108.0	138.1
160 lb N/A	124.1	133.6	101.2	127.0	113.2	142.4
B&Zn by S	NS	NS	NS	NS	NS	NS
B&Zn by N	†	†	NS	†	NS	NS
S by N	NS	NS	NS	NS	NS	NS
B&Zn by S by N	NS	NS	NS	NS	NS	NS
Site Ave.	107.2	126.0	91.0	102.2	101.7	127.3

†Main or interaction effect, at a given site, is significant ($P \leq 0.10$). NS indicates not significant ($P > 0.10$).

A significant micronutrient by N rate interaction on yield was found at three sites (Table 2) and is detailed in Table 3. All three sites exhibited the same pattern to the yield response interaction, with micronutrient addition causing the greatest yield increase at the lowest N rate (40 lb N/acre) and little to no yield improvement at the highest N rate (160 lb N/acre). That greater N nutrition resulted in: a) greater root recovery of soil B or; b) improved internal efficiency in plant B efficiency could be speculated but is not known.

Table 3. Wheat Yield Response: The B&Zn by N Interaction.

Treatment	Site 3	Site 5	Site 6	All Sites Average
	---------------bu/acre---------------			
- B&Zn, 40 lb N	81.0	111.7	66.8	86.5
- B&Zn, 80 lb N	102.2	124.7	97.9	108.3
- B&Zn, 120 lb N	115.2	127.8	112.6	118.5
- B&Zn, 160 lb N	125.7	134.8	127.6	129.4
+ B&Zn, 40 lb N	86.4	118.9	77.8	94.4
+ B&Zn, 80 lb N	105.7	123.7	96.8	108.7
+ B&Zn, 120 lb N	119.4	133.9	111.7	121.7
+ B&Zn, 160 lb N	122.4	132.4	126.5	127.1

One other objective of our work was to gain additional clarity regarding soil test criterion for S, B and Zn applications with an expectation of a significant yield response. Site responses to S and micronutrient additions, and the associated initial soil test results, are compiled in Table 4.

Positive yield responses to S were associated with lower (10 to 17 lb S/acre) soil test S values, but only 40% (2 of 5 sites) of the time. Using soil test B, things were somewhat better, where sites with lower soil test B (0.33 to 0.53 lb B/acre) exhibiting a 60% (3 of 5 sites) positive response rate. Soil test Zn was entirely unhelpful, possibly because the range in observed values (3.7 to 6.6 lb Zn/acre) was narrow. Also, current University of Kentucky recommendations regarding Zn for corn would not have been triggered by the soil test Zn, soil test P and pH values observed at any of these sites.

Table 4. Site Responses to S, B&Zn – by Soil Test Result.†

Site	Meh III S lb/A	Response to S	Hot H_2O B lb/A	Meh III Zn lb/A	Response to B&Zn
2019-2020 Season					
3	10	yes, positive	0.53	4.7	yes, positive*
5	14	no	0.37	5.4	yes, positive*
2020-2021 Season					
1	17	yes, positive	0.44	3.7	no
6	16	no	0.51	6.6	trend, positive*
8	43	no	0.53	5.9	no
9b	14	no	0.77	6.2	no

†Soil test S and B from a 0-12 inch soil sample. Soil test Zn from a 0-4 inch sample.
*Exhibited a micronutrient by N rate interaction.

Table 5 is similar to Table 4, except that the flag leaf composition data for S, B and Zn are presented in lieu of soil test S, B and Zn. With S, the situation is quite similar to that with soil test S, and positive yield responses were associated with lower (0.25 to 0.28% S) flag leaf S values, but only 40% (2 of 5 sites) of the time. Leaf B and leaf Zn were similar to soil test Zn, entirely unhelpful. Perhaps for the same reason – that the range in values was narrow. Plant tissue composition data may offer a better opportunity as regards nutrient stress monitoring if an earlier sampling time (Feekes 3-4?) is used.

Table 5. Site Responses to S, B&Zn – by Leaf Analysis Result.†

Site	Leaf S %	Response to S	Leaf B ppm	Leaf Zn ppm	Response to B&Zn
2019-2020 Season					
3	0.28	yes, positive	2.8	18.2	yes, positive*
5	0.30	no	3.5	18.2	yes, positive*
2020-2021 Season					
1	0.27	yes, positive	3.1	13.4	no
6	0.25	no	2.3	13.6	trend, positive*
8	0.31	no	2.1	15.5	no
9b	0.28	no	2.8	12.8	no

AGRONOMIC MANAGEMENT OF NITROGEN TO REDUCE N_2O EMISSIONS IN MANITOBA

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INTRODUCTION

Nitrous oxide (N_2O) is recognized as a powerful greenhouse gas, with National Inventory values of N_2O-N emission set at 1% of applied N fertilizer. For a 100 lb N/ac application rate this loss is agronomically insignificant but environmentally is equivalent to 462 lb CO_2e/ac.The federal government has set a target to reduce 2020 N_2O emissions from fertilizer by 30% by 2030 and is currently offering a number of incentives for mitigating practices.

MATERIALS AND METHODS

University of Manitoba studies have documented emission reductions and yield impact of many of these practices. N_2O losses are measured in MB studies by 2 methods: Continuous measurement flux-gradient technique – from a permanent research site at University of Manitoba's Glenlea farm on heavy clay soil. The static vented chamber technique is used at off-station sites with sampling twice per week, generally amounting to 30 samples over the season.

In this article, summary details are presented, according to the management practice, displaying the cumulative reductions in N_2O and yield effect compared to a "standard practice". The reductions for nitrogen fertilizer practices are greater if considering only emissions from N fertilizer additions. This is because background N_2O that can occur without the addition of fertilizer are included. Surprising values are noted.

Practices that have been studied and shown impact on N_2O include the 4R Nutrient Stewardship components Rate, Source, Placement and Timing as well as cropping system factors of rotation with legumes, organic production and cover cropping.

RESULTS

N_2O release occurs in 2 main episodes in Manitoba (Figure 1): denitrification at spring thaw (usually amounting to 25-35% of cumulative emissions) and 1-4 weeks after N application coinciding with rainfall events and rapid nitrification through a nitrifier-denitrification process. Rapid nitrification appears to outpace diffusion of O_2, and with scarce O_2, denitrifiers reduce some NO_2^- to N_2O. N_2O may also be emitted during partial denitrification of nitrate under saturated soils, but usually denitrification is complete as N_2.

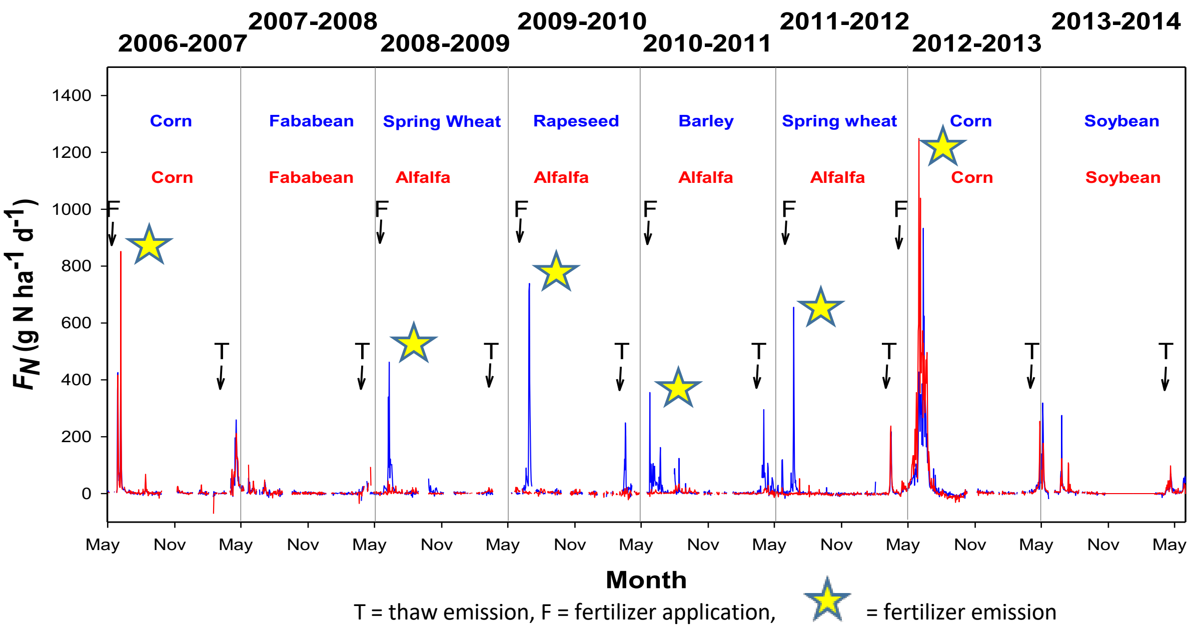

Figure 1. N_2O emissions in relation to thaw and fertilizer application events at Glenlea.[6]

FERTILIZER SOURCE

Table 1. Influence of polymer coated urea (ESN) and nitrification inhibitors on N_2O emission and crop yields.

Crop(s)	Site-yrs	Source	N_2O Reduction (%)	Yield difference (%)	Reference
HRS wheat, canola	2	ESN	48	-30*	1
HRS wheat	4	ESN	26	-2	2
Potato	3	ESN	15	0	3
HRS wheat	6	ESN	2	+3	11
corn	2	ESN	64	+8	6
Mean (ESN)	16		23	+2	
HRS wheat,	4	SuperU (DCD & NBPT)	29	-2	2
HRS wheat	6	SuperU (DCD & NBPT)	39	0	11
canola	6	SuperU (DCD & NBPT)	25	-1	9
HRS wheat	6	eNtrench (nitrapyrin)	33	0	11
Mean	22		32	-1	

* a spring application of ESN as 100% N source released too slowly for wheat and canola uptake. In practice, a blend of ESN with urea is applied.

FERTILIZER TIMING

Split Application

Table 2. Influence of Split N Application on N_2O emission and crop yields.

Crop(s)	Site-yrs	Treatment	N_2O Reduction (%)	Yield difference (%)	Reference
Potato	2	Split	59	0	3
Potato	2	Fertigation	49	0	3
Corn	3	Split	60	-5*	6
Canola	6	Split	38	-3	9
Mean	13		48	-2	

* Surface UAN split in corn was stranded in dry summers, but performed well in wet years.

Fall vs spring application

Table 3. Influence of Fall N Application on N_2O emission and crop yields.

Crop(s)	Site-yrs	Treatment	N_2O Reduction (%)	Yield difference (%)	Reference
Corn	1	Late fall	33	-8*	7
HRS wheat	6	Late fall	Increase 47**	0	11
Mean	22		36	-1	

* In the corn study, late fall banded NH_3 led to N_2O emissions during thaw the following year, but less than N_2O emissions following spring banded NH_3. Corn yield reduction was due to excessive wetness that delayed seeding, encouraged early weed growth and denitrification as N_2.
**In the hard red spring wheat studies, 2 sites had particularly high spring thaw N_2O emissions and higher cumulative emissions than spring applications. Both were heavy clay soils where high rainfall events caused saturated spring-thaw conditions.
When fall applications of N fertilizer convert to nitrate, high N_2O emissions occur during thaw the next spring, particularly on saturated clay soils

PLACEMENT

Table 4. Influence of banded N placement on N_2O emission and crop yields.

Crop(s)	Site-yrs	Treatment	N_2O Reduction (%)	Yield difference (%)	Reference
HRS wheat,	4	Deep sideband	14	2	2
HRS wheat	4	Deep mid row band	18	-4	2
potato	2	Deep band	9	0	3
canola	6	Deep band Shallow band**	Increase 16 increase 89	-2 -5	11
Mean	16	Deep band	3	-1	

RATE

N_2O emissions are proportional to N fertilizer application rates. An additional study of variable rate N application found high yield zones had the lowest emission levels despite receiving more fertilizer than field average target yields, suggesting more efficient crop N use in those areas with greater production potential.[5]

CROPPING SYSTEMS

Crop rotations, organic farming and cover crops

Table 5. Influence of previous legumes on N_2O emission and crop yields.

Crop(s)	Site-yrs	Treatment	N_2O Reduction (%)	Yield difference (%)	Reference
Wheat/soy	2	soybean	49	na	10
Field crops	11	Various legumes	65	na	8
HRS wheat	2	soybean	54	na	9
Mean			61		

Table 6. Influence of organic production and cover crops on N_2O emission and crop yields.

Crop(s)	Site-yrs	Treatment	N_2O Reduction (%)	Yield difference (%)	Reference
HRS wheat	2	Organic, alfalfa	17	-32	7
Canola, oat,soy	4	Rye cover crop	1	na	In progress

SUMMARY

Several practices result in considerable decreases in N_2O emissions from field crop production in Manitoba and likely the entire Prairies. The above individual studies are summarized in Table 7. Also noted is the current adoption level of practices used in wheat/canola and corn based on current Fertilizer Use surveys by Fertilizer Canada and crop commodity associations[9] and the level of confidence that N_2O emissions will be reduced.

Use of polymer coated urea and nitrification inhibitors (collectively called enhanced efficiency fertilizers) fertilizer N can well achieve N_2O emissions reduction targets of 30% from fertilizer N use by 2030. However, incentives may be necessary since yield responses are infrequent, they are more costly and they only make up some 10% of fertilizer use.

Split applications of N fertilizer, with some placed before or near seeding and the remainder during the growing season significantly reduces emissions. This may be a suitable strategy for long-season growing crops or those with delayed N uptake, such as corn and potato. Canola and cereals may also be considered for split application, but current adoption is low. Dry summer conditions risk stranding surface applications.

Table 7. Summary of production practices on N_2O emission and crop yields.

Management Practice	N_2O Reduction %	Yield Impact %	Current practice Wheat/ canola	Corn	Confidence
Polymer coated urea (ESN)	23	2	10%	11%	High
Nitrification inhibitors	32	-1	6%	8%	High
Split N Application	48	-2	1%	4-12%	Moderate
Banding depth - Deep (>2”)	3	-1	91%	63%	Low
Shallow (<2”)	Increase 89	-5			
Late fall application	Increase 36	-1	27-45%	41%	Moderate
N fixing legumes	61	NA	21-40%	40%	High
Organic Production	17	-32	-		Low
Cover crop	1		-		Low
Variable rate	yes	+	14%	14%	Low

Traditional studies have shown 20% greater efficiency with in-soil N banding than broadcast, indicating broadcast rates may need to be 20% greater to achieve similar yield. This efficiency is a direct reduction in N_2O emissions when application rates are adjusted accordingly, but in the reported studies, similar N rates were applied. Results were variable with deep banding N across a number of crops and placements. Shallow side-banding of N is common when seeding small seeded crops such as canola, but it can increase emissions and should be avoided.

N fixing legumes such as alfalfa, soybean, faba bean and field pea emit very little N_2O above what would occur without N fertilizer application. Organic production can result in a modest decrease in N_2O emissions however, yields are also lower. These organic yields will need to be increased if this system is to reduce emission for the same amount of food produced using conventional methods. High emissions can result when green manure crops leave high levels of overwintering nitrate. Cover crops do not increase N_2O emissions and to what extent they increase,soil C capture is unknown.

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UTILIZING FERTILIZER AND FUNGICIDE STRATEGIES TO ENHANCE WINTER WHEAT GRAIN AND STRAW PRODUCTION

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ABSTRACT

Improvement of winter wheat (*Triticum aestivum* L.) grain and straw yields have increased the adoption of intensive management. The objective of this study was to evaluate the effects of autumn-applied starter fertilizer, fungicide application timings, and late-season applied nitrogen on grain yield, straw production, and grain nutritive quality. Autumn starter and late-season applied nitrogen increased mean grain yield and when combined, improved straw yield. In absence of autumn starter, mean straw yield declined regardless of late-season N application. Autumn starter reduced grain nutrients and protein content implying partitioned photosynthates were diluted because of higher yield. Conversely, late-season applied N had a positive influence on grain protein. The lack of influence of fungicide indicates disease control was not necessary due to a low-disease pressure environment. Overall, autumn starter increased grain and straw yields while late-season applied N improved grain nutrients and protein content.

MATERIALS AND METHODS

Soft red winter wheat field trials were established on a non-irrigated wheat field following silage corn (*Zea mays* L.). Experiment was conducted on Conover loam soils (Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*). The experimental site consisted of twelve-row plots measuring 8 ft × 25 ft. Plots were planted with an Orbit-Air Granular Applicator with Disc Furrow Opener (Gandy Company Manufacturing, Owatonna, MN) at a rate of 1.8 million seeds A^{-1}. The short-statured, high-yielding variety of soft red winter wheat 'Wharf' (Michigan Crop Improvement Association, Okemos, MI) was planted on 20 September 2021.

Treatments were arranged as a full-factorial 2×5×2, randomized complete block design, with four replicates. Experimental factors included two levels of autumn starter (0 and 250 lbs. A^{-1}), five fungicide application timings (none, Feekes 7 and 10.5.1, Feekes 9 and 10.5.1, Feekes 10.5.1 individually, and Feekes 7, 9 and 10.5.1) and two levels of late-season applied nitrogen (0 and 30 lbs. A^{-1}) applied at Feekes 7. On 27 September 2021, autumn starter (12-40-0-10-1, N-P-K-S-Zn) (MicroEssentials® SZ® (MESZ) (Mosaic CO., Plymouth, MN) fertilizer was applied at a rate of 250 lbs. A^{-1} and topdressed using a handheld spreader. Blanket spring N was applied at 100 lbs N A^{-1} during Feekes 4 growth stage. Late N fertilizer was applied at a rate of 30 lbs N A^{-1} as UAN at Feekes 7. The five fungicide application timings evaluated included control (no fungicides applied), Feekes 10.5.1 individually (one spray), Feekes 5 – 7 and 10.5.1 (two-spray), Feekes 9 and 10.5.1 (two-spray), and Feekes 5 – 7, 9, and 10.5.1 (three-spray). Fungicide applications included 0.125% v/v of non-ionic surfactant and anti-foaming agent to improve fungicide coverage and efficacy. Fungicide was applied using a modified plot sprayer attachment (LeeAgra, Inc., Lubbock, TX; Kincaid Equipment Manufacturing Corporation, Haven, KS; Juniper Systems Inc., Logan, UT).

On 9 July 2022, plots were end-trimmed prior to harvest. Grain and straw yields were harvested from the central 3.9 ft of each plot utilizing a research combine (Kincaid Manufacturing, Haven, KS). Preliminary plot grain weight (lb), moisture (%), and test weight (lb bu^{-1}) data were collected and used to calculate grain yield expressed as bu A^{-1} and Mg ha^{-1} at a 13.5% moisture basis. Grain subsamples were acquired from each plot for nutrient concentration and nutritive quality. Straw yield was determined from the weights of total residue generated by combine output. The combine was set to 5.0" and weights were adjusted from total moisture content of gross harvest weight.

Data were analyzed with R using Analysis of Variance (α=0.10). Least square means were separated using Tukey's Honest Significant Difference (HSD) when ANOVA indicated a significant interaction. Means separation was calculated utilizing a single degree of freedom contrasts. Pearson correlation coefficient analyses were performed on the means of grain nutrients and protein content with grain and straw yields in SAS 9.4 (SAS Institute, 2012) using the PROC CORR procedure.

RESULTS AND DISCUSSION

Influence of weather on fungal disease development and fungicide effectivity.

Cumulative rainfall for May and June 2022 was 35% and 56% below average, respectively (data not shown). Mean temperature of April 2022 was also 5% lower than the 30-yr average which may have delayed the spring plant development and green-up (data not shown). In this study, the continuous cold and dry early- and mid-season months (March-May) eliminated the favorable environment for fungal disease development. Moist, cool conditions are most conducive for early fungal diseases such as Septoria leaf spot (*Zymoseptoria tritici*) and powdery mildew (*Blumeria graminis f. sp. tritici*) (Kelley, 2001). The absence of significant differences in grain yield (Table 1) and straw production (Fig. 1) across fungicide treatments indicates disease control was not necessary in a low-disease pressure environment.

Effects of autumn starter on grain yield, nutritive quality, and straw production.

The application of 250 lbs. A^{-1} of autumn starter increased the average grain yield 33 bu A^{-1} (Table 1). The positive correlation between grain yield, plant height, head count, and head length offers evidence for why autumn starter positively influenced grain production (Table 2). Increased yield through plant height, head count, and head length driven by autumn starter are justified by N fertilizer that exposes wheat to grow vigorously and increase tiller initiation (Zhang et al., 2020). Tiller population, a component of yield, determines potential head count. This aligns with Quinn and Steinke, (2019) study that both tiller production and head production increased from application of autumn starter in a low-input management system. Moreover, autumn starter supplied N and Zn, which may have increased the survival rate of productive tillers and developed into mature heads. Das et al., (2019), reported that the maximum number of tillers, grain, and straw yields was observed from 160 kg ha^{-1} N and 2 kg ha^{-1} Zn nutrient combination.

Head development is most rapid during stem elongation. When the wheat stem elongates, the “heading stage” is initiated (Simmons et al., 1985). This suggests that as stem extends, it offers greater opportunity for the head to stretch—producing a longer head. With longer head length comes more spikelets that will be filled with grains. According to Broeske et al., (2018), the number of spikes per head is determined at Feekes 5. Since autumn starter was applied in the early season, it provided more elongated stems relative to plants that did not receive autumn starter.

Grain yield was negatively correlated with grain nutrient concentrations (Table 2). Waldren and Flowerday (1979) found the translocation of dry matter from leaves to grain starts at the beginning of anthesis (Feekes 10.5.1) up to the grain-filling stage (Feekes 10.5.4). This aligns with the sufficient ranges of flag leaf nutrient concentrations at Feekes 9; since translocation has not yet started (data not shown). With the exception of grain K and Ca, autumn starter reduced grain N, P, and Mg by 13.1%, 5.0%, and 5.1%, respectively, and increased grain S by 9.6% (Table 1). At maturity, Waldren and Flowerday (1979) added that 70-75% of N and P are translocated when only 15% of K is present in grains. In this study, grain N, P, and Mg were reduced in autumn starter-treated plots (Table 1) suggesting that translocated grain N, P, and Mg were diluted from higher yield.

The application of autumn starter provided the highest mean straw yield when late-season N was not applied (1 ton A^{-1}) (Fig. 1). Conversely, the absence of autumn starter resulted in reduced straw yields, regardless of late-season applied N. The positive correlation between straw yield with plant height demonstrates the contribution of stem elongation during straw accumulation (Table 2). The active growing stage of wheat starts at Feekes 5 when leaf sheaths are fully elongated and pseudostems are strongly erected up to Feekes 10 when head is visible in the leaf sheath (Broeske et al., 2020). Rapid N uptake begins at Feekes 5 to 7 (Waldren & Flowerday, 1979). Since autumn starter was applied early in the season, it increased N uptake, which translated to improved stem elongation. Autumn starter increased plant height by 9.8% (data not shown). This demonstrates the potential for autumn starter to provide an advantageous start for mid-season environment, translating to improved straw production (Fig. 1).

Effects of late-season applied N in grain yield, nutrients, and protein content.

Late-season N at Feekes 7 increased grain yield, nutrient concentration, and protein content (Table 1). Late-season applied N improved grain yield by 5.0 bu. A^{-1}, as well as protein content, grain N, and P. Grain protein content was positively correlated with grain N (0.94) (Table 2). Previous studies have variable observations about the influence of late-season applied N on grain yield, nutrient concentration and quality. Topdressed spring N applications before stem elongation (Feekes 4 – 9) improved fertilizer N recovery, grain yield, and protein content (Sowers et al., 1994). This conflicts with De Oliveira Silva et al., (2021) who reported N applications at beginning of stem elongation (Feekes 5) did not increase the yield and nutrient uptake but enhanced the grain and vegetative components—an indicator of luxury consumption According to Waldren and Flowerday (1979), the N accumulation peaks at grain filling stage with 70% of N uptake goes into grains. It is possible that the late-season applied N underwent translocation into grains thereby promoting yield and increasing nutrient concentration.

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Table 1. Mean grain yield, protein content, and nutrient concentrations as influenced by autumn starter, fungicide timing, and late-season applied nitrogen in non-irrigated following silage corn, Lansing, MI, 2021-2022†.

Treatment	Yield	Protein Content‡	Grain nutrient concentration§ N	P	K	Ca	Mg	S
	--(bu A^{-1})--	--%--	------------%					------------
Autumn Starter								
0 lb A^{-1}	91.6 b	10.98 a	1.780 a	0.354 a	0.425	0.030	0.143 a	0.114 b
250 lb A^{-1}	124.6 a	9.70 b	1.574 b	0.337 b	0.421	0.030	0.136 b	0.125 a
p-value < 0.10	***	***	***	***	NS	NS	***	***
Fungicide Timing								
No fungicide	107.4	10.59 a	1.712	0.343	0.417	0.030	0.138 ab	0.115
Feekes 5-7, 10.5.1	107.8	10.15 ab	1.653	0.345	0.42	0.030	0.138 ab	0.121
Feekes 10.5.1	110.2	10.11 b	1.631	0.339	0.419	0.030	0.136 b	0.119
Feekes 9, 10.5.1	105.8	10.44 ab	1.684	0.346	0.429	0.030	0.139 ab	0.120
Feekes 5-7, 9, 10.5.1	109.2	10.42 ab	1.704	0.354	0.43	0.030	0.144 a	0.122
p-value < 0.10	NS	*	NS	NS	NS	NS	**	NS
Late-season Nitrogen								
0 lb A^{-1}	105.5 b	9.98 b	1.608 b	0.342 b	0.422	0.030	0.138	0.119
30 lb A^{-1}	110.6 a	10.71 a	1.745 a	0.349 a	0.424	0.030	0.141	0.120
p-value < 0.10	**	*	***	**	NS	NS	NS	NS
Nontreated check ††	45.9	9.66	1.505	0.36	0.453	0.03	0.145	0.123

† Treatments were compared per environment at 0.10 probability level, Tukey's HSD, where significant values * = 0.10, ** = 0.05, ***0.001.
†† Nontreated check, no fertilizer or fungicide applied.
‡ For nutrient concentration, 150 g. of grains was weighed and sent to the A&L Great Lakes Laboratories, Inc (Fort Wayne, Indiana).
§ For nutritive quality, near-infrared transmission (NIRS™ DS2500 L; FOSS Analytical, Hillerød, DK) was used.

Table 2. Correlations between agronomic and nutrient concentration with yield components and grain protein content in in non-irrigated following silage corn (SC), Lansing, MI, 2021-2022. †

	Agronomic ‡				Grain nutrient concentration					
	T	**PH**	**HC**	**HL**	**N**	**P**	**K**	**Ca**	**Mg**	**S**
Yield	0.19	0.84 ***	0.83 ***	0.67 ***	-0.34 **	-0.44 ***	-0.33 **	-0.06	-0.44 ***	0.48 ***
Straw	0.02	0.63 ***	0.6 ***	0.37 **	-0.28 *	-0.39 **	-0.16	0.06	-0.4 **	0.27
Grain Protein	-0.1	-0.16	-0.47 ***	-0.005	0.94 ***	0.46 ***	-0.04	-0.05	0.46 ***	-0.49 ***

† Peason correlation coefficient analysis using PROC CORR procedure, α = 0.05, where significant values * = 0.05, ** = 0.001, * < 0.001.**
‡ Agronomic parameters: T – tiller population, PH – plant height, HC – head count, HL – head length.

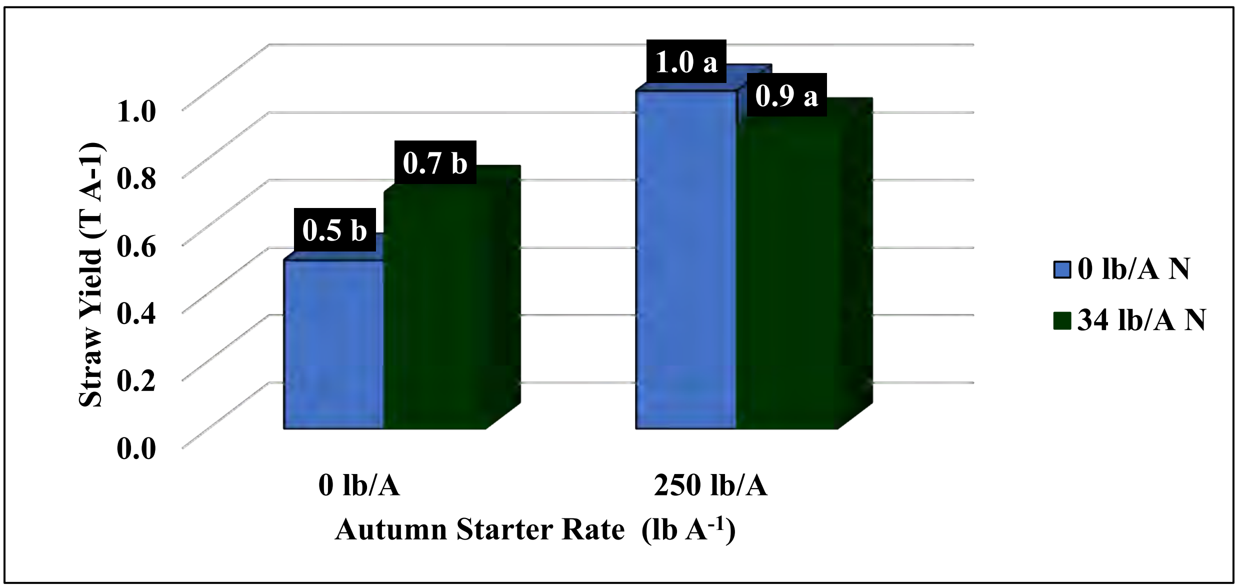

Figure 1. Interaction of autumn starter and late-season applied nitrogen on straw yield (T A^{-1}) in non-irrigated following silage corn (SC), Lansing, MI, 2021-2022. †
† Treatments were compared at 0.10 probability level, Tukey's HSD.

CARBON CREDIT AND SEQUESTRATION IN AGROECOSYSTEMS; LESSONS FROM TRIALS IN SOUTHERN ILLINOIS

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ABSTRACT

A carbon (C) credit is the attribution of net CO_2-C equivalent which can be used to decrease climate forcing through a given practice or farming system for a given unit time. Carbon credits allow industries to purchase C that is produced on a farm (i.e., offsets). Carbon can be captured in two ways; (i) by capturing and reducing greenhouse gasses (on a CO_2-C equivalent basis), and/or (ii) by increasing soil organic C stocks. Therefore, to enable C credits in the agricultural sector, we must measure and track CO_2-C equivalent flow in and out of the soil. Management practices that are in line with C increase in soil range from proper nitrogen (N) fertilization to a shift from tillage-based to no-till systems and increasing C inputs via cover crops (with different management scenarios like late termination), manure, etc. In Southern Illinois, results of a long-term tillage by fertility trial in a corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation indicates that a shift from tillage to no-till increases surface (0-5 cm) soil C, and provides protection for the sequestered C through increase in soil aggregation and aggregate stability but benefits do not go beyond 0-5 cm depth. Also, no-till benefits decrease significantly with no fertilization (control) reflecting lower C inputs by crop yields compared to tillage treatments. We observe a significant reduction in nitrous oxide (300 times more potent that CO_2) by no-till practice compared to a chisel-disk that could be considered for C capture. In a five-yr trial, adding cover crops into a corn-soybean rotation increased soil C stocks but only in 0-5 cm depth. Potentially, longer than five years of cover cropping is needed to build soil C stocks beyond topsoil. There are also tradeoffs in terms of greenhouse gas emissions with cover crop management practices. For example, in a winter wheat (*Triticum aestivum* L.)-corn trial, we observed significantly higher N_2O losses with wheat as a cover crop (especially when terminated late) than a no-cover crop reflecting increased soil volumetric water content during the corn growing season. Overall, based on our results, a first step is to ensure a continuous no-till practice in corn-soybean systems with proper N fertilization. Other practices require further assessments. Our results also indicate that quantifying CO_2-C equivalent inputs and outputs is difficult and tradeoffs between these must be considered for C credits. These results call for unified North Central trials to assess the effects of these diverse agricultural practices on soil C sequestration and C crediting and to find best solutions for mitigating climate change.

INTRODUCTION

A carbon (C) credit is the attribution of net CO_2-C equivalent which can be used to decrease climate forcing through a given practice or farming system for a given unit time. Carbon credits allow industries to purchase C that is produced on a farm (i.e., offsets). Carbon can be captured in two ways; (i) by capturing and reducing greenhouse gasses (on a CO_2-C equivalent basis), and/or (ii) by increasing soil organic C stocks[1]. Therefore, to enable C credits in the agricultural sector, we must measure and track CO_2-C equivalent flow in and out of the soil[2]. Management practices that are in line with C increase in soil range from proper nitrogen (N) fertilization to a shift from tillage-based to no-till systems and increasing C inputs via cover crops (with different management scenarios like late termination), manure, and many other sources.

An important approach to increase soil C is to increase net primary productivity (NPP)[2]. Optimizing cash crop growth and production requires proper N fertilization to ensure no N limitation[3]. In a long-term corn (*Zea mays* L.)-corn and corn-soybean (*Glycine max* L.) trial, Poffenbarger et al. found reported that at optimum N rate, SOC maximized which was mainly due to optimization of corn grain yield and returned crop residue[4]. In a recent 10-yr trial however, Bailey indicated that when soil N supplying capacity is high, at limited N rate, crop residue return could be similar to the optimum N rates and thus, SOC in the soil remained similar among N rates[5].

Shifting from tillage practices including moldboard plow and chisel-disk to no-till has been shown to increase SOC over time. This is mainly due to increase in soil C inputs than C outputs and thus, positive C balances[6]. Weidhuner et al.[7] reported an increase in soil SOC in a long-term tillage trial which was in line with a recent meta-analysis report by Liptzin et al.[8] suggesting decreased tillage increased SOC and such increase was more pronounced at sites with higher precipitation.

Cover crops especially in no-till systems have the potential to increase SOC over time. The increase in SOC by cover crops especially in no-till systems follows the similar greater N inputs than outputs scenario where no-till decreases C loss and cover crops increase the C inputs leading to positive net C balances. Liptzin et al.[8] suggested that SOC responded to integrating cover crops into cropping systems and that increase in soil C was higher in no-till systems. Literature suggests that a reasonable C input (0.9 tons ac^{-1}) from cover crops over at least a five-yr span is needed significantly increase SOC in top 12” of soil[9].

In this paper, we assessed trials in Southern Illinois and identified whether conservation practices could increase the SOC in long- and short-term trials and if nitrous oxide emissions could be decrease or increase in some of those studies which could influence C crediting scenarios.

MATERIALS AND METHODS

Several trials were conducted in Southern Illinois and ranged from short term studies (three to five years) to a long-term (49-50 years) tillage by fertility trial (currently in 52nd year).

Trial 1 (Tillage by Fertility Trial)

A long-term tillage by fertility trial field experiment was initiated in 1970 at the Belleville Research Center in Belleville, IL (38.519179° N, 89.843248° W). The randomized split-plot trial is located on a somewhat-poorly drained Bethalto silt loam (fine-silty, mixed, superactive, mesic Udollic Endoaqualf). Tillage treatments were laid out in a Randomized Complete Block Design. Four tillage treatments, applied at the same time were (i) MP using moldboard plow to 8-12"; (ii) CD using spring disking to 6" followed by chisel-point cultivator to 8"; (iii) AT which was 2-yr of no-till followed by a moldboard plow for 1 yr.; and (iv) continuous NT without disturbance of the soil excluding a standard planter. The main experimental design is split-plot with tillage as main plots (randomized strips) and five fertility treatments as subplots (randomized within tillage strips). Each tillage treatment was repeated four times. Soil samples were collected in 2019 (49 years into the trial) for soil C assessment. Protocols for the soil analysis are reported in Weidhuner et al.[7]. Soil nitrous oxide emission during the corn years was also assessed to calculate CO_2-C equivalent of nitrous oxide. The protocol for nitrous oxide measurement and analysis are reported in Weidhuner et al.[10].

Trial 2 (Manure by Winter Rye Double Crop)

A three-yr trial was conducted from 2019 to 2022 in a dairy farm located in Breese IL (38.60888° N, 89.9579706° W). The soil was Oconee-Darmstadt silt loam (fine, smectitic, mesic Udollic Endoaqualfs). Treatments were (1) corn for silage fertilized with 180 lbs UAN ac^{-1}; (2) phosphorus-removal-based liquid manure (12900 gal ac^{-1}) plus supplemental N fertilizer; (3) Nitrogen-based liquid manure (16500 gal ac^{-1}); (4) phosphorus-removal-based liquid manure (12900 gal ac^{-1}) plus supplemental N fertilizer and double cropping with winter rye (*Secale cereale* L.); (5) Nitrogen-based liquid manure (16500 gal ac^{-1}) double cropping with winter rye. The treatments were laid out in a Randomized Complete Block Design with four replicates. Soil samples were collected in 2019 and 2022 for soil C assessment. Protocols for the soil analysis are reported in Weidhuner et al.[7].

Trial 3 (Precision Cover Cropping in a Corn-Soybean Rotation)

A five-yr trial was conducted from 2016 to 2021 at a farm in Springerton, IL (38.16598° N, 88.41070° W). The soil was Edwardsville silt loam (fine-silty, mixed, superactive, mesic Aquic Argiudolls). The trial is in corn-soybean rotation with three treatments including (1) a no-cover crop control (NOCC); (2) NOCC on the corn row, vetch on the middle row, and winter rye on the side row (NOVR); and (3) Oat and radishes on the corn row, vetch on the middle row, and winter rye on the side row (ORVR). Figure 1 shows an example of precision planted cover crops. Similar soil indicators to Weidhuner et al.[7] including deep core (0-36") SOC and bulk density were collected and measured in 2021.

Figure 1. Example of a no-cover crop control (A), when corn row is skipped (B), and oat on the corn row with cover crop mixtures (C); Courtesy of John Pike.

Trial 4 (Wheat Cover Cropping in a Corn-Soybean Rotation)

A five-yr trial was conducted from 2017 to 2022 at the Agriculture Research Center (ARC) in Carbondale, IL (37.75° N, 89.06° W). The dominant soil type was Weir silt loam (fine, smectitic, mesic Typic Endoaqualfs). The trial lay out was split plot in a Randomized Complete Block Design with four replicates. Treatments were (1) a no-cover crop control (NOCC); (2) early termination of winter wheat as CC (ET); late-termination of wheat as CC (LT); and removing winter wheat residue (RR). During the corn years a split application of 130 lbs ac^{-1} at planting plus a sidedress rate of 100 lbs ac^{-1} was applied to corn (230 lbs N ac^{-1}). In this trial, we measured soil nitrous oxide emissions during the corn years (2019-2020) and (2020-2021). All sample handling and analyses were similar to those reported in Weidhuner et al.[10].

RESULTS and DISCUSSION

Trial 1 (Tillage by Fertility Trial)

Aggregate associated C and C by depth

Soil C in the NT system were higher in both large (2-4.75 mm) and small (0.25-2 mm) aggregate sizes than other tillage treatments. In small aggregates (0.25-2 mm) soil C was found to be 17.5 for NT, 12.9 for CD, 11.5 for AT, and 11.6 g kg^{-1} for MP (Fig. 2a).

In large aggregates soil C was 17.5 for NT, 11.7 for CD, 10.7 for AT, and 11.9 g kg^{-1} for MP (Fig. 3b). These results for AT indicate that disturbing the soil after two years of NT will reduce the soil C and N benefits that could be achieved by continuous NT practices. Less soil disturbance protects and accumulates C due to the formation of micro and macro-aggregates. There was a positive linear relation between C concentrations in dry small aggregates (0.25-2 mm) and C concentrations in water stable aggregates (r^2 = 0.57, $P \leq 0.01$) at 0.25-2 mm sizes (data not shown). Slower decomposition of crop residues in the surface of NT was likely the reason for greater percentage of water stable aggregates in NT. While water stable aggregates are related to the amount of SOC, greater C additions from increased crop residues increase the formation of soil aggregates.

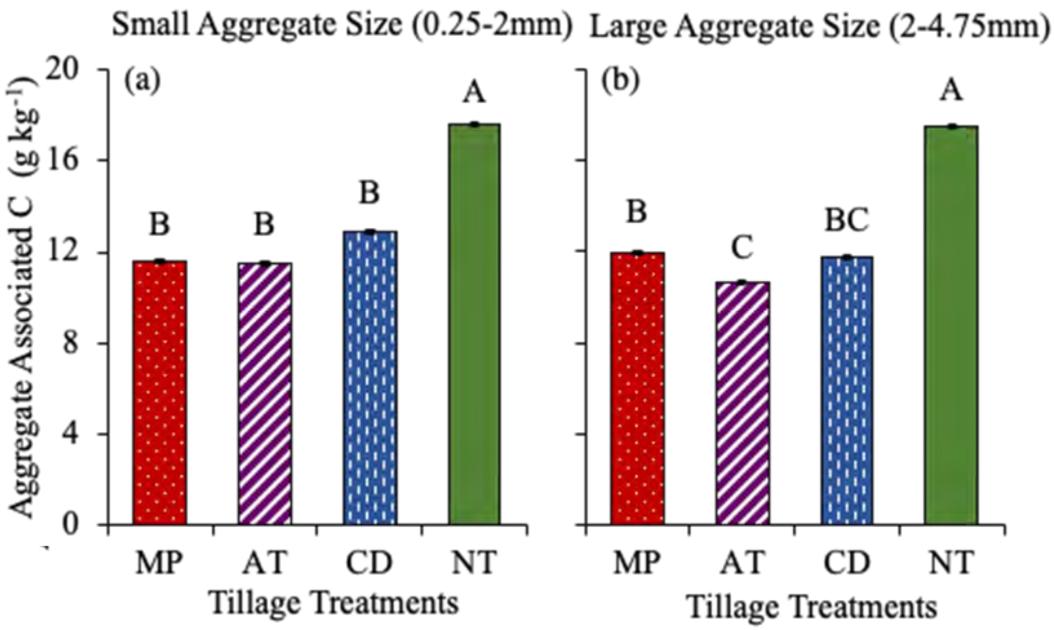

Figure 2. Tillage effect on dry, small (a) and large (b) aggregate associated C after 49 years. Yearly tillage treatments include: moldboard plow (MP); 2-yr no-till and 1 yr MP (AT); chisel-disk (CD); and no-till (NT). Similar letters indicate no statistical significance at 0.05.

Percent SOC by depth was much higher in the NT treatment at 0-2" (19.4 g kg^{-1}) than CD (12.3 g kg^{-1}), MP (10.7 g kg^{-1}) and AT (10.5 g kg^{-1}) (Fig. 3). This indicated that only two years of no-till followed by tillage (AT) does not benefit C build-up in the 0-2" depth compared to continuous MP treatment. All treatments had similar SOC beyond topsoil (0-2") which indicated that NT benefits of soil C were limited to the topsoil and additional practices such as inclusion of cover crops are needed to increase SOC.

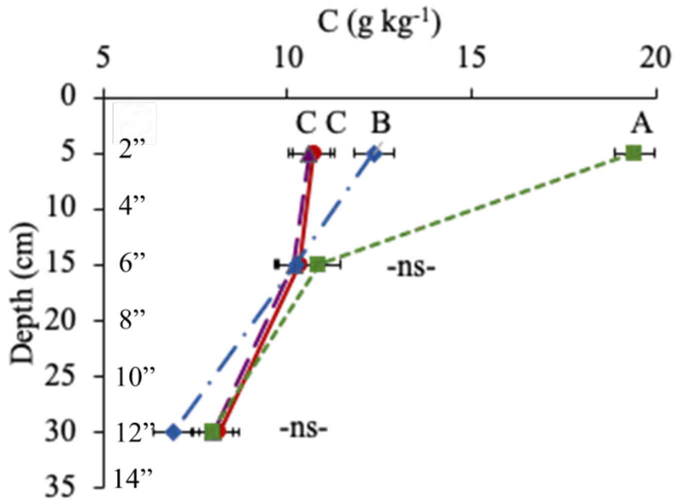

Figure 3. Tillage effect SOC in top 12” of soil after 49 years. Yearly tillage treatments include: moldboard plow (MP); 2-yr no-till and 1 yr MP (AT); chisel-disk (CD); and no-till (NT). Similar letters indicate no statistical significance at 0.05.

Trial 2 (Manure by Winter Rye Double Crop)

Coarse (> 0.25 mm) and light fractions of soil organic matter (0.053-0.25 mm) were higher in double cropped treatments (INJPCC and INJNCC) at 0-2” depth but at a depth beyond 0-2”, winter rye did not increase soil organic matter fractions (Figure 4) perhaps reflecting on C inputs that is higher in 0-2” than 2-8” (data not shown; Burkett et al. unpublished data).

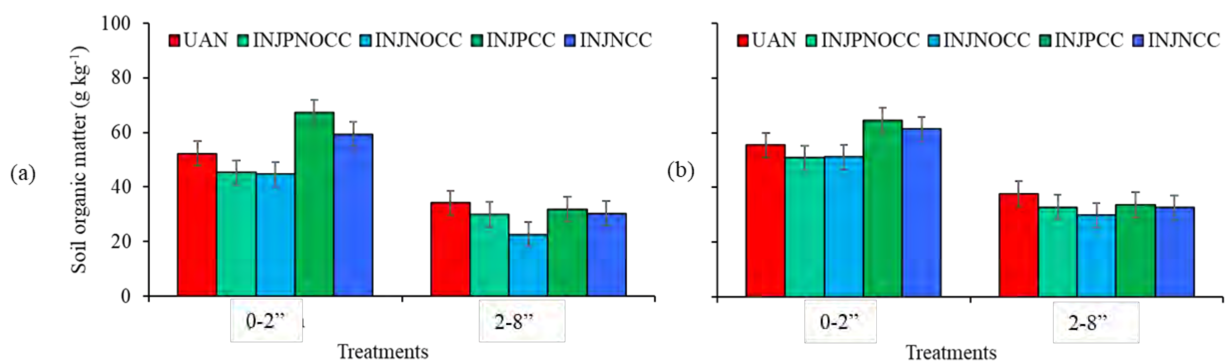

Figure 4. Effect of manure and fertilizer management on coarse (a) and light (b) soil organic matter fractions. (1) UAN: corn for silage fertilized with 180 lbs UAN ac^{-1}; (2) INJPNOCC: phosphorus-removal-based liquid manure (12900 gal ac^{-1}) plus supplemental N fertilizer; (3) INJNOCC: Nitrogen-based liquid manure (16500 gal ac^{-1}); (4) INJPCC: phosphorus-removal-based liquid manure (12900 gal ac^{-1}) plus supplemental N fertilizer and double cropping with winter rye (*Secale cereale* L.); (5) INJNCC: Nitrogen-based liquid manure (16500 gal ac^{-1}) double cropping with winter rye. Bars represent standard error.

Trial 3 (Precision Cover Cropping in a Corn-Soybean Rotation)

Results of a five-yr trial indicated that integrating NOVR and ORVR increased SOC stocks only in the top 2” of soil (data not shown). These findings are in line with our trial 2 that suggest greater root inputs are needed at lower soil depths to increase SOC concentration and stocks. Blaco-Canqui[9] suggested that delaying the termination of cover crops could accumulate more C and therefore, increase C inputs in agroecosystems. This led to our trial 4 to evaluate whether late termination of cover crops result in any tradeoffs in nitrous oxide emissions.

Trial 4 (Wheat Cover Cropping in a Corn-Soybean Rotation)

Assessing C inputs between early vs. late terminated wheat cover crop indicated that C accumulation is highly related to biomass accumulation and that early wheat termination (ET) had 2805 and 2661 lbs ac^{-1} less biomass than a late-terminated winter wheat treatment (LT) in 2020 and 2021, respectively (data not shown). Our data also suggest that inclusion of winter wheat and delaying the termination resulted in increased soil volumetric water content which played a key role in greater nitrous oxide loss in LT than the no-cover crop treatment. Averaged over the two-yrs, LT produced 825 lbs ac^{-1} more CO_2-C than the no-cover crop control (data not shown) suggesting a need to incorporate N_2O losses in the C crediting systems.

CONCLUSIONS

Overall, based on our results, we conclude that a first step is to ensure a continuous no-till practice in corn-soybean systems with proper N fertilization. Other practices require further assessments. Our results also indicate that quantifying CO_2-C equivalent inputs and outputs is difficult and tradeoffs between these must be considered for C credits. For example, a practice such as late termination of cover crops could add more C but increase nitrous oxide emissions and result in tradeoffs in gain and loss of C. These results call for unified North Central trials to assess the effects of these diverse agricultural practices on soil C sequestration and C crediting and to find best solutions for mitigating climate change.

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LANDSCAPE POSITION AFFECTS MANAGEMENT DECISIONS FOR CROP PRODUCTION

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ABSTRACT

Landscape positions influence crop growth and yield by impacting the water and nutrients movement in the soil. Previous studies have evaluated the impacts of topography, N management and hybrids on corn grain yield individually; however, limited information is available on the interaction of these factors on corn yield, N uptake and grain quality. The objectives of this study were to determine the effects of landscape positions, nitrogen rates, corn hybrids and seeding rates on corn grain yield. Additionally, in a separate study, we evaluated the performance of the nitrification inhibitor N-serve on corn grain yield at three landscape positions. The experiments were set up in a randomized block design with a split-split plot arrangement. Corn production data including harvest moisture, grain yield and grain quality were collected from the experiments. Corn grain yield was increased with an increase in seeding rate for DKC62-53 hybrid at the backslope position. No differences were observed in hybrids planted at three different seeding rates at the footslope position. Average over the years corn grain yield was highest 165 bu ac^{-1} at the backslope position with AA + N-Serve treatment followed by 163 bu ac^{-1} at the shoulder with AA + N-Serve treatment. Anhydrous ammonia when applied without any nitrification inhibitor at the footslope position had the lowest 144 bu ac^{-1} corn grain yield when average over the four years.

INTRODUCTION

Landscape attributes including topographic positions, slope, curvature, elevation, water flow direction, and water flow accumulation are well documented in the literature for their effects on crop productivity. Topography influences crop growth and yield by impacting water and nutrient movement in the soil. Under dryland crop production systems, water availability generally depends on topsoil depth, soil organic matter, and curvature of the micro-topography. To improve the overall productivity of a spatially diverse landscape, site-specific crop management practices have been advocated through the use of precision agriculture technology. However, on-farm adoption of site-specific crop management practices on landscape positions can be limited due to several reasons including the time needed to implement variable source technology when the spring planting window is shortened by wet springs, unavailability of reliable datasets providing recommendations for varying sources and rates applications, and limitation of equipment and skillset of the growers and consultants. Nitrogen (N) is one of the most important inputs that can maximize yields and economic returns if managed sensibly. Historically, a lot of research has been conducted on site-specific N management. Additionally, research on other inputs including seeding rates and hybrid selection has been conducted extensively. However, the interaction between input factors including N-rates, hybrid selection, and plant population has not been studied well in site-specific zones classified by landscape positions. In addition, there are minimal recommendations available for using nitrification inhibitors based on landscape positions for corn production. The overall goal is to understand variability due to landscape positions and develop general recommendations based on the selection of technology that improves crop productivity and returns on topographically diverse landscapes.

MATERIALS AND METHODS

To address the above goal two separate studies were set up in 2019 at the University of Missouri's Lee Greenley Jr. Research Center near Novelty, MO. The first study evaluated the performance of drought and flood-tolerant corn hybrids planted at three population densities and two N-rates at shoulder, backslope and footslope landscape positions (Figure 1). Landscape positions were classified according to Singh et al. (2016). Corn hybrids used in this study were DKC62-53 and DKC65-95 planted at 28,000, 33,000, and 38,000 seeds ac^{-1}. The DKC62-53 is a flood-tolerant hybrid whereas DKC65-95 is drought tolerant hybrid. The N-rates were 120 and 180 lbs N ac^{-1} applied as anhydrous ammonia with strip-tillage equipment in the fall. The experiment was set up as a randomized complete block design with a split based on landscape positions and nitrogen rates. Treatments were replicated three times across the landscape positions. Corn was planted at 30-inch row spacing with a cone planter on plots of 10 x 30 feet. Treatment plots were kept weed free. Agronomic production data including plant population, corn yields, test weights, and harvest moisture were collected from 2019 to 2022. Corn was harvested using a Wintersteiger plot combine equipped with a harvest master grain gauge. Corn grain was collected at the time of harvest and analyzed for grain quality including oil, protein and starch.

The second study evaluated the performance of a nitrification inhibitor, N-serve (nitrapyrin), applied with anhydrous ammonia in fall on corn grain yields and quality at three landscape positions (shoulder, backslope and footslope) for four years from 2019 to 2022. Anhydrous ammonia fertilizer was applied at 150 lbs N ac^{-1} with an 8-row strip-tillage implement equipped with a Raven rate control system. The treatments were set up as randomized completed block designs with either six or ten replicates. Real-time as-applied data for treatments were collected from the tractor controller. The as-applied data was used to make GIS-based plot maps for evaluating the treatment performed on the landscape scale field experiment. Plant population data was collected before harvest. Ten ear cobs were manually collected from each landscape position and nitrification inhibitor treatment combinations to test for grain quality. Corn was harvested using CASE-IH Axial-Flow 7250 commercial combine with an 8-row head equipped with a yield monitor. The yield monitor was calibrated each year before harvesting. Yield measurements were taken by grain sensors, with each measurement covering an area of about 5 by 20 ft (5 ft is an average forward distance traveled by a combine during 1 s, and 20 ft is the width of the combine header). Simultaneously, site coordinates were determined by a GPS unit of the combine. The moisture content for corn grain yield was adjusted to 15%. The collected point yield data was cleaned using yield editor software (Sudduth et al. 2012). After removing outliers, developed yield data sets were imported to ArcGis Pro software for extraction of landscape positions and yield features for 2019 to 2022 yield data that matched each yield point collected by the combine.

Datasets for both studies were analyzed for normality in SAS statistical software using the univariate procedure. The normalized datasets were subjected to ANOVA analysis using the glimmix procedure in SAS. For the first study, N rates were not significant therefore data were averaged over N rates for the analysis. The replications were treated as random factors. For the second study, yield points data having coordinated were set up as spatial and temporal covariate structures. The mean values were estimated using T-grouping at an alpha of <0.05.

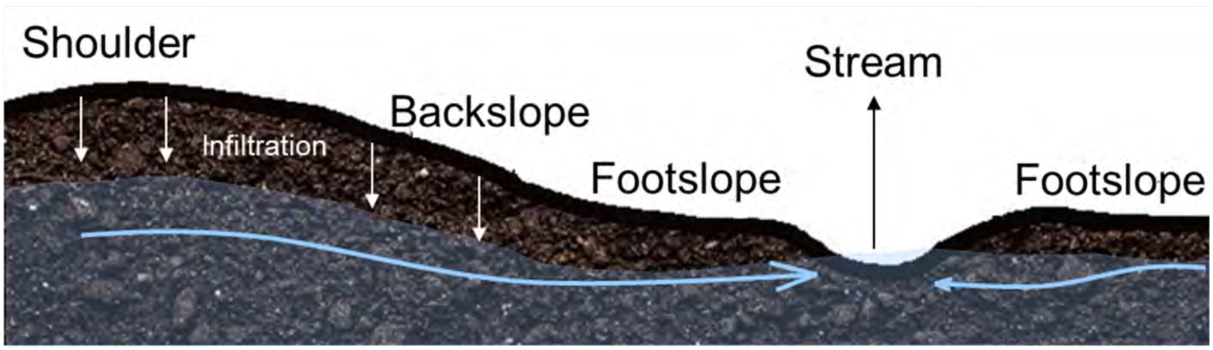

Figure 1. Common landscape position on a terraced field with a spacing of 120 ft of every terrace. Lidar data with a resolution of 9 sq ft/pixel was used to classify terraces in landscape positions using the Topographic Position Index Model.

RESULTS AND DISCUSSION

Corn grain yield was significantly affected by the landscape positions in all four years (P <0.0001). The corn grain yields were highest at the shoulder position followed by the backslope and footslope positions (Figure 2). In 2021, the corn grain yield was affected by the interaction of landscape position, hybrids, and seeding rate (P =0.047). At the shoulder position, corn grain yield was 18% greater with the 38,000 seeds ac^{-1} seeding rate than the 28,000 seeds ac^{-1} seeding rate for DKC65-95 hybrid (Figure 3). However, the 33,000 seeds ac^{-1} seeding rate performed better for yield production than the other two seeding rates for the same hybrid at the backslope position. Corn grain yield was increased with an increase in seeding rate for DKC62-53 hybrid at the backslope position. At a higher seeding rate of 38,000 seeds ac^{-1}, DKC65-95 had 19% higher yield than the DK62-53 hybrid at the shoulder position, whereas DK62-53 hybrid had 18% greater yield than DKC65-95 at the backslope position. No differences were observed for both hybrids due to seeding rates at the footslope position (Figure 3). N-uptake was significant in all four years for the main effects of landscape positions only (p<0.0001, data not shown). The grain quality data including oil protein and starch showed variable results for the main effects. The three-way interaction between landscape positions, hybrid, and seeding rates were not significant for grain quality parameters (p>0.05).

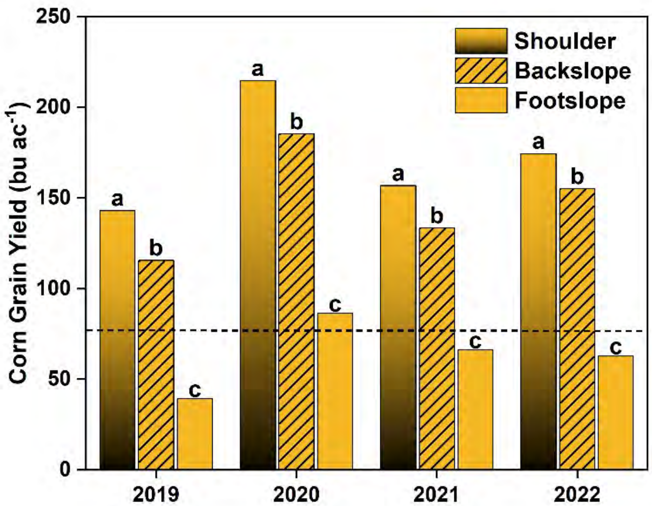

Figure 2. Corn grain yield determined by the main effects of landscape positions. Similar letters on the bars are not statistically different (α = 0.05). Grain yields were analyzed separately for years. The dashed verticle line indicates 75 bu ac^{-1}.

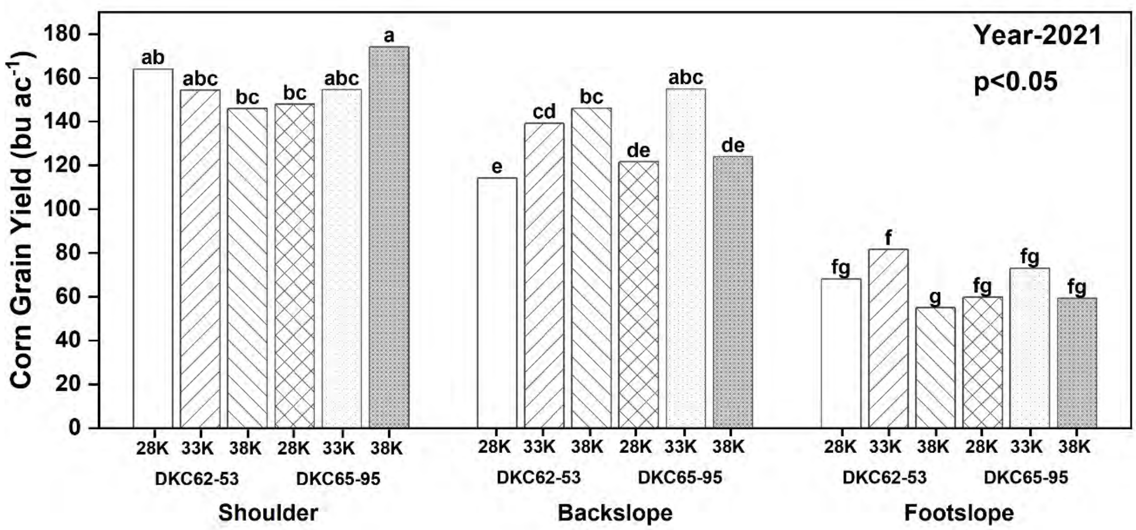

Figure 3. Corn grain yield determined by the three-way interaction of landscape positions, corn hybrids, and plant densities in 2021. Similar letters on the bars are not statistically different from each other (α = 0.05).

In the second study, corn grain harvest moisture and grain yields were significant for the two-way interaction of landscape positions and nitrification inhibitor treatments (Table 1). The highest grain moisture of 16.71% was observed for AA + N-Serve treatment at footslope compared to all other treatments. Within landscape positions, AA + N-Serve treatment had higher grain moisture compared to the control treatment (AA only). Average over the years corn grain yield was highest 165 bu ac^{-1} at the backslope position with AA + N-Serve treatment followed by 163 bu ac^{-1} at the shoulder with AA + N-Serve treatment. Anhydrous ammonia when applied alone without any nitrification inhibitor at the footslope position had the lowest 144 bu ac^{-1} corn grain yield. The nitrogen fertilizer was applied in the fall and environmental losses of nitrogen might have occurred during the winter and spring period contributing to lower N availability at the footslope positions.

In summary, precision management of inputs including seeding rate, nitrogen fertilizer application rate and timing, nitrogen stabilizers and hybrid selection is needed to increase production on the landscape positions. During four years of these studies, the footslope position yielded the lowest and is considered a marginal production ground when compared to the shoulder landscape position. At footslope position, N applied in fall has a greater chance of environmental loss, therefore best management practice could be to feed corn as per need. Hybrid selection and seeding rate should also be considered important factors when planning for production at landscape positions.

Table 1. Mean values of the harvest moisture and grain yields collected from three landscape positions from 2019 to 2022. Similar letters within a column are not significantly different from each other at p<0.05.

Landscape Positions (LP)	**Treatments (T)**	**Average Harvest Moisture (%) 2019-2022**	**Average Corn Grain Yield (bu ac^{-1}) 2019-2022**
Shouder		15.57c	159a
Backslope		15.93b	160a
Footslope		16.47a	151b
	Anhydrous Ammonia (AA)	15.81b	162a
	AA + N-Serve	16.18a	152b
Shoulder	AA	15.48d	156cd
Shoulder	AA + N-Serve	15.65c	163b
Backslope	AA	15.70c	154d
Backslope	AA + N-Serve	16.18b	165a
Footslope	AA	16.24b	144e
Footslope	AA + N-Serve	16.71a	158c
Source of Variation	**df**	**p-values**	
LP	1	<0.0001	<0.0001
T	2	<0.0001	<0.0001
LP x T	2	0.0011	0.0044

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ADVANCES IN NORTH DAKOTA SOIL FERTILITY 2022

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ABSTRACT

Following years of data accumulation from field studies using the GreenSeeker™ and Holland Scientific Crop Circle™ active optical sensors, algorithms for use in spring wheat to direct in-season N application for yield to determine the need for immediate-post-anthesis N application for protein enhancement have been developed. Both algorithms require an N non-limiting area as a standard. The algorithm for protein enhancement considers whether a cultivar has inherent high protein or lower protein characteristics than the industry standard 14% protein. Algorithms for use in determining N rate for in-season application to corn has also been modified and stream-lined.

Cover crops are becoming more common in North Dakota for use of excess moisture and to eliminate wind erosion. A summary of North Dakota studies indicated that:

1. it is difficult to produce more than 500 pounds per acre dry matter after corn or soybean, even if the cover crop is interseeded into a growing crop.
2. interseeding into corn does not produce yield drag, at least partially due to the dew that the cover crop attracts.
3. substantial cover crop dry matter (greater than 1,000 pounds per acre) is only consistently possible after short-season crops including barley, spring wheat and winter wheat.
4. N contained in cover crops is not released to the subsequent crop, even if there is a legume in a mix containing a small grain, small grain volunteers, or forage radish/turnip.
5. it is possible that the ammonium released immediately on decomposition is being ‘fixed’ by smectitic clays into a non-exchangeable ammonia fraction, which may be released several years after cover crop N accumulation.

INTRODUCTION

Active-optical sensors

In-season N application has been a part of NDSU corn fertilizer recommendations for at least 10 years. In-season N application, or side-dress, is not a state-wide recommendation although farmers across the state may choose to use the strategy for logistical help in managing their N inputs and spring help status. As in all Great Plains states, rainfall in North Dakota is greatest in the east, with decreasing rainfall the farther west one travels. In eastern ND, where spring rains may be in excess of crop needs, leaching on sandy loam and coarser soils, and denitrification on high clay soils is always a threat to the efficiency of crop N uptake. Therefore, side-dress is recommended on the soils with that history.

In dry springs, after using the ND N calculator to determine total seasonal N requirements based on residual soil nitrate to 2 feet, previous crop N credits and indicating whether the farm is in long-term (6 years or more continuous) no-till, if half of the N is applied pre-plant or at planting, the last portion can be applied by subtracting the initial N rate with the total recommended. However, in wet springs, loss of residual nitrate and the portion applied preplant/at-planting is highly possible on susceptible soils. Therefore, without some tool to indicate corn status, the N rate for side-dress is a guess. The use of an active-optical sensor was therefore investigated successfully to predict corn yield as a means to indicate side-dress N rate.

Oklahoma State University, led initially by Bill Raun and two Ag-Engineer colleagues, and now led by Brian Arnall, has maintained a website detailing the use of the GreenSeeker since the late 1990's. The initial research group developed the GreenSeeker for commercialization and correspondingly developed the science that makes its use and the use of other active-optical sensors practical (https://www.nue.okstate.edu/). Their website contains information on the development of the concept, first on Bermudagrass and winter wheat, and then on other crops.

Sensor research for application in spring wheat at NDSU was directed towards two different goals; first, to use the sensor to direct the rate of in-season N before mid-jointing to increase yield; second, to use the sensor at flag-leaf to determine whether or not a foliar N application should be applied immediately after anthesis (post-anthesis). Spring wheat in the Northern Plains of North Dakota, Montana, some portions of South Dakota and northwest Minnesota is considered a premium what by buyers interested in 'strong flour' with great gluten content. The industry standard is 14% protein. Selling hard red spring wheat with protein less than 14%, the farmer is subjected to a low protein dockage in most years (2021 excepted due to low supplies). In some years, particularly when TX, OK, KS wheat has low protein, the Northern Plains farmer may be offered a premium for spring wheat with protein greater than 14%. The dockage and premium value is always a guess until harvest time, but in some years the need for higher protein wheat is telegraphed to the farmer via news stories from the southern plains regarding their protein status and from other parts of the world. Agronomically, there is no non-sensor way to evaluated whether the farmer might reach or exceed 14% protein, thus the research effort.

Cover Crops

There is interest in North Dakota on cover crops to decrease wind erosion susceptibility in conventionally tilled systems, to reduce the loss of N at the end of growing seasons, and to reduce moisture in the spring to enable more timely planting and reduce acres lost to prevent planting. With greater corn and soybean acreage (8-10 million acres recently out of about 24 million total state acres), one challenge is establishing a meaningful cover crop after long season crops. Another question is when N is taken up by cover crops, when is it released.

METHODS

Active-Sensors

A series of N rate experiments were conducted from 2010 through 2021 on spring wheat (14 sites) and corn (58 sites). Each study was constructed as a randomized complete block design. Spring wheat sites were located in the eastern third of the state where spring rainfall might result in N loss, and where protein is more difficult to maintain market grade compared to western-grown wheat. The corn research was conducted across the state due to its longer season of N loss susceptibility and the newness of the crop in many areas of North Dakota. Each site consisted of 6 N rates from 0-200 pound N per acre in 40 pound N per acre increments with 4 replications. The GreenSeeker™ and Holland Scientific Crop Circle Sensor™ was applied at about V5 in spring wheat and V6 in corn.

Cover Crops

Cover crops were investigated from 2016 until the present year. Experiments were established near Rutland/Havana, ND on long-term (>40 years continuous) no-till fields and ENE of Gardner, ND on a transitional no-till field with high clay content. The experimental design on all experiments was a randomized complete split-plot, with cover crop and no-cover crop as main split, and N rates from 0 to 200 pounds N per acre in 40 pound per acre increments as the subplots). There were 3 replications. The study was conducted using a three-crop rotation of corn, soybean and spring wheat, in that order. There were 3 individual experiments in one larger field at Gardner, and there were 3 different fields with an experiment matching the rotation choice at Rutland/Havana. In corn, the cover crop (cereal rye + forage radish + camelina) were interseeded at about V6 using a prototype FargoAir™ (Amity Technologies, Fargo, ND) seeder. Cover crop following spring wheat included letting the spring wheat volunteers grow, seeding forage radish and camelina with a seed drill. Soybean preceded corn in this system, so interseeding in soybean was conducted usually in late August before leaves began to turn. The cover crop choice was oat, forage radish and camelina, broadcast applied by walking through the experiment in the cover crop main plots using a chest-style grass-seeder. Cover crop dry matter was determined from each main plot from 3, 1 foot by 2.5 feet areas by clipping the plants at the soil level. Radish roots were pulled and weighed separately when present. All plant samples were subjected to total N analysis by species.

RESULTS

Corn active-optical sensor algorithms

Algorithms are at https://www.ndsu.edu/fileadmin/snrs/Files/sf1176-5_0.pdf , which is a web-based publication. The algorithms support data gathered from a GreenSeeker Red NDVI sensor and from the Holland Scientific Crop Circle sensors for Red NDVI and Red-Edge NDVI if the sensor is used between V4 and V8. Readings are obtained from a preplant/at-planting N sufficient area, an area of farmer choice perhaps the width of the spring N applicator 100 feet or so long, with the full rate of recommended N plus 50 pounds N per acre more or less so that even if there is N loss due to spring rains there is enough N remaining to produce a crop supported by the soil/environment. The reading from this area are inserted into the algorithm to produce a yield prediction for N-nonlimiting corn growth. Readings from the rest of the field are compared to this value and if the field readings produce yield predictions lower than 95% of the non-limiting area yield, then a calculation of yield difference, the N content within the yield difference, divided by an efficiency factor (0.6 by default) of the N to be applied is made, producing the side-dress N rate. Details of the calculation are provided in the corn N algorithm circular indicated previously.

Spring wheat algorithms

The spring wheat algorithms for estimating top-dress N rates up to early tillering stage can be found at https://www.ndsu.edu/fileadmin/snrs/Files/sf1176-6.pdf .
The spring wheat algorithms for predicting agronomically practical immediate post-anthesis N application for protein enhancement can be found at
https://www.ndsu.edu/fileadmin/snrs/Files/sf1176-7__1_.pdf .
Implementation of the flag leaf sensor timing algorithm for protein enhancement requires knowledge of the inherent protein concentration characteristic of the cultivar. North Dakota State University published an annual report of yield and protein trials of many cultivars at all of the NDSU Research & Extension Centers in the state around the first of the year. High and low protein cultivars can be identified using the trial data.

Cover Crops

Cover crop biomass was much greater following winter wheat and spring wheat compared with cover crop interseeded into corn or soybean (Table 1). The greatest cover crop dry matter was less than 120 lb/acre, while seeding cover crop after short-season crop yielded dry matter from 695 to 5385 lb/acre.

Table 1. Dry matter yield of cover crop seeded following winter wheat or spring wheat, or interseeded into corn or soybean, Rutland and Gardner, 2016-2020.

	Crop before/during cover crop seeding			
	Winter wheat	Spring wheat	Corn	Soybean
Site Year	Pounds dry matter per acre			
Rutland 2016	3840	NA	40	NA
Rutland 2017	NA	4820	7	5
Gardner 2017	NA	22	NA	NA
Rutland 2018	NA	4500	13	48
Gardner 2018	NA	97	37	18
Rutland 2019	NA	5385	0	0
Gardner 2019	NA	18	117	101
Gardner 2020*	NA	695	65	0

*Rutland sites were abandoned after 2019 due to uncontrollable circumstances.

The growing seasons for 2017 through 2020 were relatively dry (Table 2). Despite interseeded cover crop at Gardner and Rutland, corn yield was not diminished by their growth (Table 3).

Table 2. Seasonal rainfall (May 1 through September 30) from nearest NDAWN weather station to site and departure from normal.

Site	Rainfall, in	Departure from normal, mm
Gardner 2017	14.1	-2.1
Rutland 2017	15.6	-0.1
Gardner 2018	13.7	-2.6
Rutland 2018	16.2	+0.6
Gardner 2020	14.6	-1.6

Table 3. Interseeded cover crop biomass and subsequent corn yields with interseeded cover crops 2017-2020. Differences between no cover crop and cover crop treatments were not significant (P<0.05) at any site.

Site Year	Interseed date	Covercrop Sampling date	CoverCrop Dry matter, lb/a	Yield No CoverCrop bu/a	Yield w/Cover Crop, bu/a
Gardner 2017	6/27	8/18	136	159	149
Rutland 2017	6/22	8/17	131	171	171
Gardner 2018	6/22	10/26	425	189	190
Rutland 2018	6/14	10/26	131	202	210
Gardner 2020	6/29	10/14	193	123	123

Leaf wetness sensors were installed at the Gardner location in 2019-2020 in cover crop and no-cover crop main plots at the 200 lb N/acre treatments in the corn studies. The mean number of days with dew, excluding days with rainfall were 40.5 with period of dew greater than 6 hours per event. In 2021, a small area (2 feet by 2 feet) was established with oat seeding in the Gardner corn study, in the 200 lb N per acre treatment (no cover crop was seeded in 2021). The oats emerged, and at 6 AM , August 30, the site was visited, and paper towel was used to blot the oat treatment for 30 seconds using a rubber-gloved hand. The mean weight of water from the blot was 0.5 g. The same technique was used to blot the crop residue with no growing cover crop in between the adjacent row, and 0 g water was collected on each replication. Although multiplying the water collected from the 30 second blot would amount to less than 0.2 inches of moisture during the period of interseeded cover crop growth, the blot does not consider the rest of the greater than 6 hours of dew collection experienced. The dew collected on the cover crop may be a reason for the lack of yield drag from cover crop interseeding.

The mean N concentration in cover collected in these studies was about 2%, with a C/N ratio of about 18. This would indicate some N release to the subsequent crop. However, N release was not seen in these studies. At Rutland for example (Figure 1), the cover crop following wheat contained about 100 lb N/acre, however, the N study in corn on this experiment indicated it required an N rate of about 100 lb/acre in the cover crop treatment to equal the 0 N rate in the no-cover crop treatment.

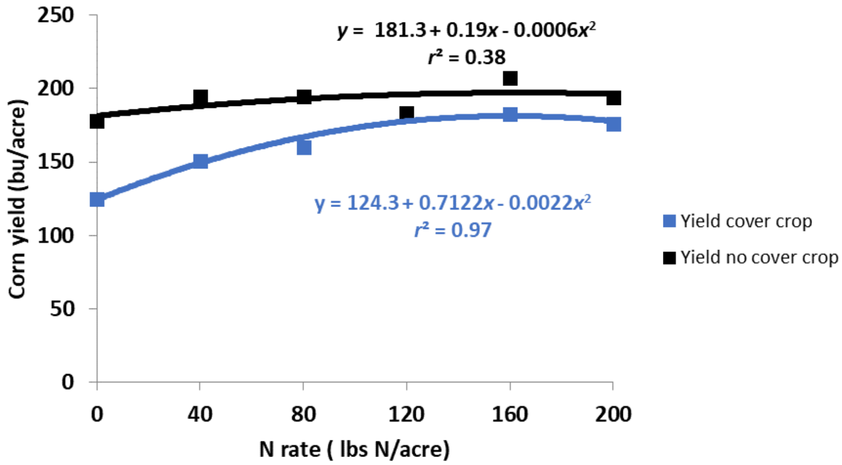

Figure 1. Corn yield response to N treatments, Rutland, 2018. Cover crop contained about 100 lb N/acre, which is about the rate of N necessary for cover crop yield to equal the yield of no cover crop at the 0 N rate.

To date, the N from the cover crop was not seen in the residual N soil tests at season end at any site. However, at some locations, the non-exchangeable ammonium content of the soil was greater with cover crop history than without (Table 4).

Table 4. Non-exchangeable ammonium, ppm at two sites in cover crop study.

	Non-exchangeable ammonium, ppm	
Site Year	**Cover Crop**	**No cover Crop**
Rutland 2018	60	41 sig $P < 0.10$
Gardner 2018	341	323 NS

Summary

Algorithms for use with active-optical sensors have been developed in North Dakota for use in corn and spring wheat. Cover crop establishment and total dry matter produced is much greater in the region after a short-season crop, such as winter wheat or spring wheat. The N taken up in the cover crop after short-season crop or interseeded into corn or soybean should not be subtracted from the N recommendation for the subsequent crop. Due to the dry seasons of these studies, it is unlikely that the N was 'lost' due to leaching or denitrification. It is possible that the ammonium is being held by the smectitic clays as non-exchangeable, although it has not been definitively established that this is its fate.

ACKNOWLEDGEMENTS

Funding for this work came from the North Dakota Wheat Commission, the North Dakota Corn Council, the SBARE committees for spring wheat and corn, and a USDA-NIFA grant Award no. 2016-69004-24784.

COVER CROPS, MANURE AND NITROGEN

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INTRODUCTION

Fall manure application following corn silage harvest in late August through late September is a common practice in Wisconsin. Grass cover crops planted after manure application has both soil and water conservation benefits as cover crops provide soil coverage after complete removal of corn biomass and trap nitrogen (N) applied via liquid dairy manure. So, the question remains if the cover crops are just trapping nitrogen that would be leached out of the root zone or if it taps into the nitrogen that would be available to the subsequent corn crop. To simplify, does the presence of a fall cover crop affect the fertilizer N equivalent of fall applied manure. The objective of this study was to assess how the species and biomass of fall seeded cover crops affect the optimum N rate of corn when fall manure is also applied.

MATERIALS AND METHODS

Field trials were conducted at the Arlington, Lancaster, and Marshfield Agricultural Research Stations between 2014-2017. At each location cover crops were planted in 2014, 2015, and 2016 and the N response to corn was evaluated in 2015, 2016, and 2017. New field sites were utilized in each site year at each location. The experimental design was a randomized complete block, split plot design with four replications. The whole plot factor was cover crop and the split plot factor was N rate. The whole plot treatments were: (i) no cover crop, (ii) spring barley (seeded at a rate 70 to 90 lb/ac), (iii) annual ryegrass (seeded at a rate of 15 lb/ac), and (iv) winter rye (seeded at a rate of 70 to 90 lb/ac). Cover crops were drill seeded following corn silage harvest and liquid dairy manure application. The total N applied varied per site; at Arlington and Lancaster the available N was 80 to 90 lb-N/ac and at Marshfield the available N was between 25-30 lb-N/ac (low solid content manure). Spring barley winter killed, annual ryegrass typically winterkilled, and winter rye was terminated with glyphosate. Cover crop biomass as collected in the fall prior to winter kill (spring barley and annual ryegrass) or in the spring prior to termination (winter rye). Corn harvested as grain was planted two weeks after termination of the winter rye and received 20-30 lb-N/ac as starter fertilizer. The split plot treatments were N rates between 0 to 360 lb-N/ac in 60 lb-N/ac intervals). Nitrogen was broadcast applied at V4-6 as urea coated with Agrotain®.

For each whole plot treatment, the response to N was determined as either non-responsive or with quadratic plateau. A bootstrapping technique was conducted on each cover crop-site-year to identify if the AONR and the yield plateau each cover crop was statistically different than the no cover crop treatment. If it was, the EONR was calculated for each treatment. The change in EONR (∆ EONR) and the change in yield plateau (∆ max yield) between each cover crop treatment and no cover crop treatment was calculated and regressed against total biomass.

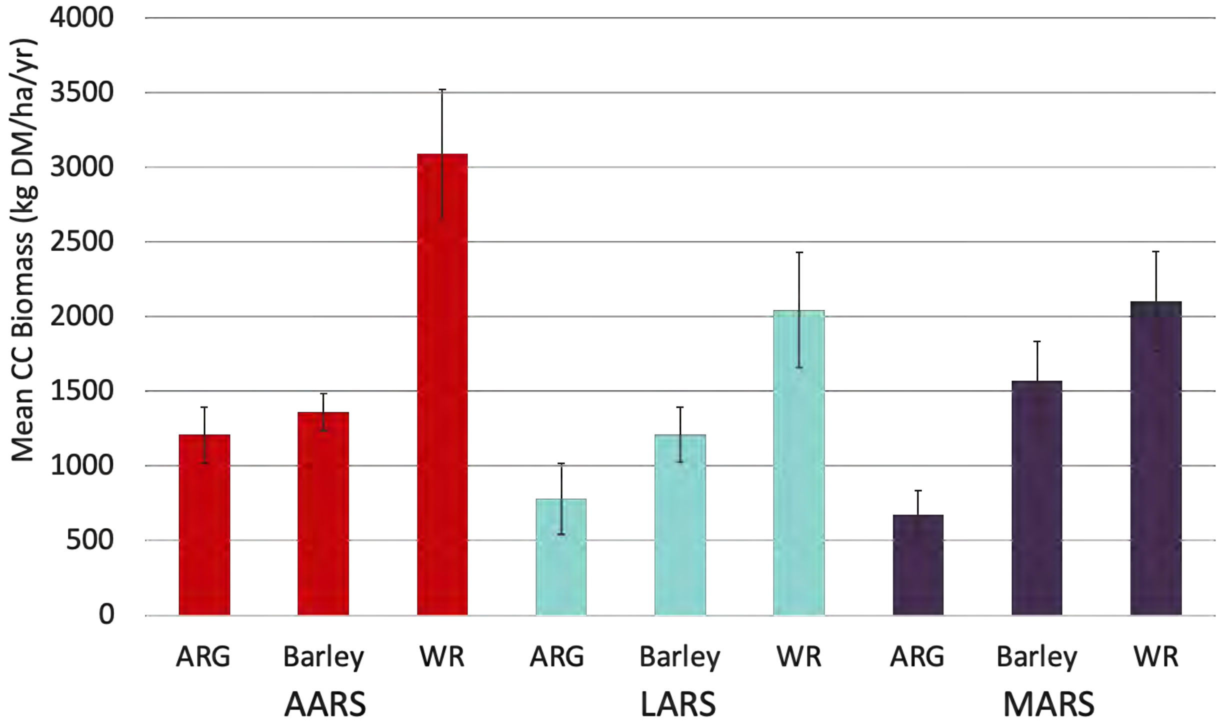

Figure 1. Cover crop dry matter biomass by site year. ARG=annual ryegrass, WR=winter rye

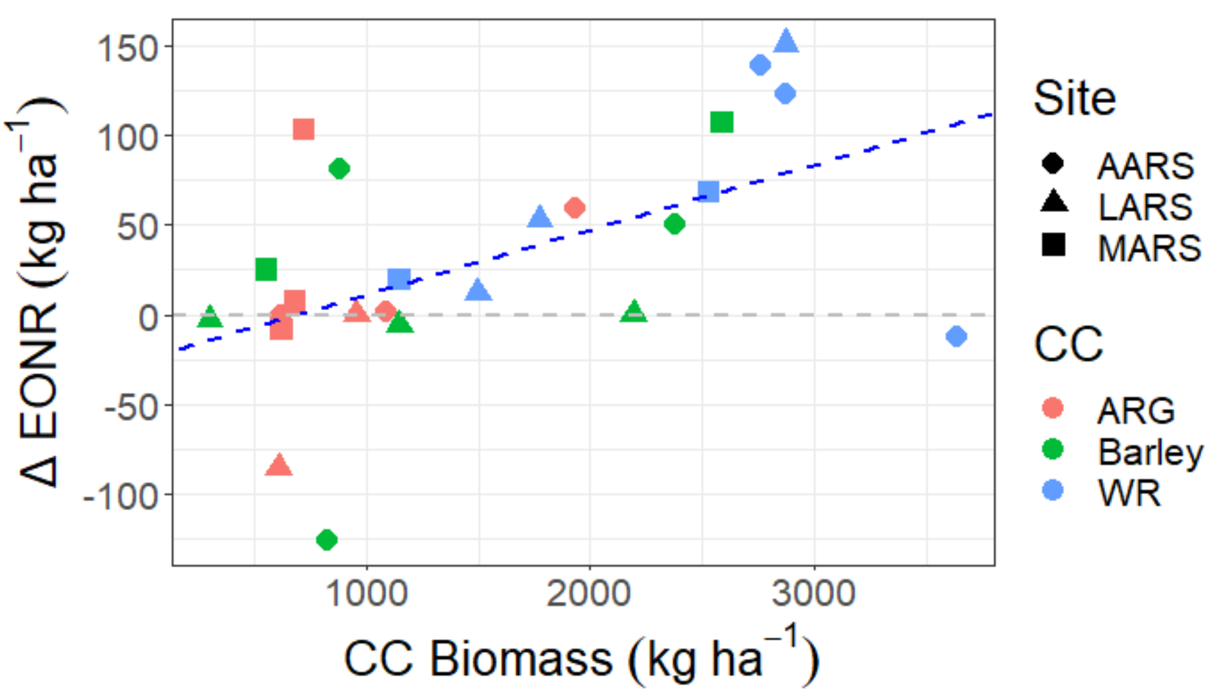

Figure 2. Linear regression between cover crop biomass and the change in EONR (compared to the no cover crop control). Regression equation y=0.036x-24.5; R^2=0.28.

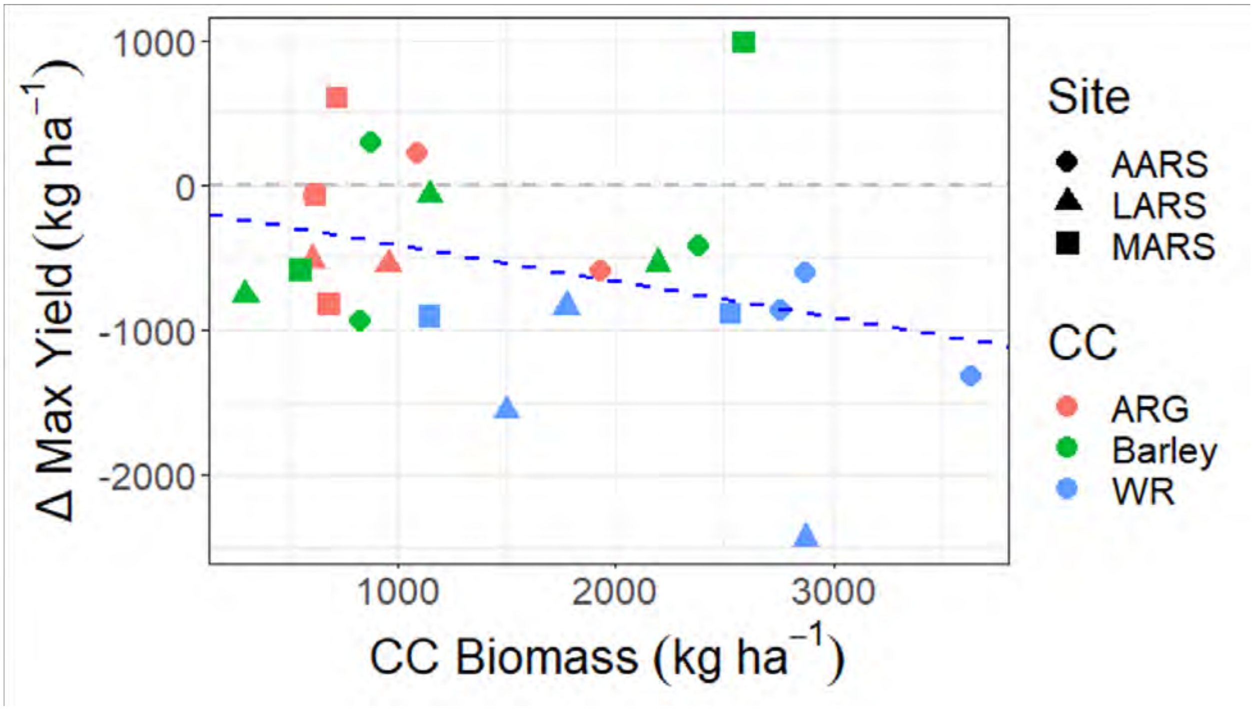

Figure 3. Linear regression between cover crop biomass and the change in maximum yield (compared to the no cover crop control). Regression equation y=-0.25x-168; R^2=0.11.

CONCLUSIONS

1. The greater the cover crop biomass, the greater amount of N needed to achieve economically optimum yield.
2. Corn yields were generally lower following cover crops, but biomass only explained 11% of the variation.

Nutrient management recommendations

This work, along with concurrent work support the following management recommendations:

1. Seed cover crops at a low of a rate as possible to minimize total biomass
2. Terminate cover crops as early in the spring as possible to minimize biomass
3. Based on regression analysis, additional N is needed (or more specifically, the manure N credit is less) once there is above 1,000 lb/ac of dry matter biomass.
4. If there is between 1,000 and 2,000 lb/ac of DM biomass, then 10 to 50 lb-N/ac more N is needed.
5. When greater than 2,200 lb/ac of dry matter biomass occurs, the entire manure-N credit was eliminated.

52nd Annual

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POSTER PROCEEDINGS

CONSIDERATION OF CLAY MINERALOGY FOR ENHANCED PREDICTION OF OPTIMAL CORN POTASSIUM FERTILIZER RATES

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ABSTRACT

Properly calibrated potassium (K) fertilizer recommendations (KFRs) are critical for improving crop yields and maintaining environmental stewardship. Recent innovations in soil and crop management suggest that certain soil factors, including clay mineralogy, can be used to predict optimal K requirements in corn. The objectives of this study include 1) correlate soil K levels to corn yield, 2) calibrate KFRs with clay mineralogy data, and 3) determine the relationships among clay mineralogy, K uptake, and fertilizer requirements. During the 2020-2021 growing seasons, 15 field trials were established across central and eastern South Dakota. The experimental design used was a randomized complete block design with four replications. Treatments of potash fertilizer were broadcast applied at 6 different rates: 0-150 lbs. K_2O ac.$^{-1}$ in 30 lb. increments. A linear plateau model correlating soil test potassium (STK) to relative yield suggested that South Dakota's K critical level could shift from 160 to 169 ppm. Calibrating K fertilizer rates to corn yield resulted in accurate prediction of optimal KFRs at 12 of the 15 sites. Initial results showed that including clay mineralogy in the calibration process could not confidently be used to predict corn yield response.

INTRODUCTION

Poorly managed potassium (K) fertilizer applications are costly. While under-applications of K fertilizer can reduce the ability of corn (*Zea mays* L.) to yield at optimal levels, over-applications of K fertilizer are just as inefficient, especially when soil test K (STK) levels are adequate. For example, applying K fertilizer in Ohio at twice the estimated crop removal rate was ineffective at building STK and resulted in infrequent corn yield responses over 9 years (Fulford and Culman, 2018). In Arkansas, correlation and calibration analyses conducted on K fertilizer recommendations found that corn yield responses to K fertilization gradually declined until reaching 0% at 140 ppm Mehlich-III K (Drescher et al., 2021). Furthermore, research by Oliver et al. (2022) concluded that the profit-maximizing fertilizer-K application rate is lower than the current agronomic recommendation for corn in Arkansas. These studies suggest that over-application of K fertilizer does not improve corn yields, fails to build STK, and is uneconomical. Moreover, they stress the need of thoroughly tested K fertilizer recommendations (KFRs).

One of the main difficulties in KFR research is addressing field-level variation, which has historically resulted in this research needing to be specific to a state or region. For example, K fertilizer rate verification research revealed the need for region-specific optimization of fertilizer recommendations to maximize economic yields and maintain sufficient STK levels, due to the fact that soils within the state of Tennessee differ considerably in yield potential, soil type, and nutrient supplying capacity (Singh et al., 2019). While traditional fertilizer recommendation and soil test correlation/calibration research has been conducted on a state-by-state basis, ongoing efforts to promote broad, multi-state collaborations for fertilizer recommendations are necessary and forthcoming (Lyons et al., 2021; Slaton et al., 2022; Zhang et al., 2021). Additionally, scientists are exploring the incorporation of additional soil measurements into fertilizer rate recommendation development. In Missouri, Svedin et al. (2022) offered insights for including soil health metrics into KFR development. In North Dakota, Breker et al. (2019) successfully improved corn yield response prediction when partitioning sample sites based on clay mineral content. These results provide evidence that incorporating other soil test parameters, notably clay mineralogy, into KFRs may improve their accuracy.

Current KFRs in South Dakota only incorporate STK and yield goals into the calculations. The current STK critical level is set to 160 ppm ammonium acetate-extractable K. Improvements in crop management practices over recent decades have led to higher yielding corn in South Dakota, which simultaneously suggests that more crop inputs are required. However, increasing K fertilizer rates to match the higher yielding demands of corn may not always be necessary. Research is needed to validate current KFRs in South Dakota. Therefore, the objectives of this project include 1) correlate STK levels to corn yield, 2) calibrate KFRs with clay mineralogy data, and 3) determine the relationships among clay mineralogy, K uptake, and fertilizer requirements.

MATERIALS AND METHODS

From 2020-2021, 15 field trials were conducted throughout central and eastern South Dakota (Table 1). Sites were conducted primarily on commercial operations, but also at three university research stations. Sites were chosen to encompass a broad range of soil types, climates, and management practices. The experimental design used within each site was a randomized complete block design with four replications. Six treatments (0 [control], 30, 60, 90, 120, and 150 lbs. K_2O ac.$^{-1}$) of potash fertilizer (0-0-60) were broadcast applied prior to corn emergence. Prior to treatment application, soil samples were collected within each replication at four depths: 0-4, 0-6, 6-12, and 12-24 in. Soil samples were dried and ground to pass through a 2 mm sieve, upon which they were sent to Ward Laboratories (Kearney, NE, USA) for fertility and health analysis, and Activation Laboratories (Ancaster, ON, Canada) for mineralogy analysis. Plots were harvested by hand or using a plot combine at physiological maturity. Statistical analyses were conducted using R. Yield data was transformed to percent of maximum yield, then correlated with STK using a linear plateau model. Quadratic plateau modeling was used to calibrate KFRs by plotting corn grain yield at responsive sites against K fertilizer treatments.

Table 1: Agronomic information for the 15 field trials in this study.

Site	Year	County	Soil Series	Soil Texture	Tillage	Previous Crop
1	2020	Tripp	Millboro	Silty Clay	No-Till	Wheat
2	2020	Tripp	Millboro	Silty Clay	No-Till	Wheat
3	2020	Potter	Agar	Silt Loam	No-Till	Wheat
4	2020	Kingsbury	Poinsett	Silty Clay Loam	No-Till	Soybean
5	2020	McCook	Clarno	Clay Loam	Reduced-Till	Soybean
6	2020	Clay	Egan	Silt Loam	No-Till	Soybean
7	2021	Yankton	Clarno	Clay Loam	No-Till	Wheat
8	2021	Roberts	Peever	Sandy Loam	Vertical-Till	Soybean
9	2021	Hutchinson	Hand	Loam	No-Till	Soybean
10	2021	Turner	Egan	Silty Clay Loam	Reduced-Till	Soybean
11	2021	Lincoln	Wentworth	Silty Clay Loam	Reduced-Till	Soybean
12	2021	Codington	Kranzburg	Silty Clay Loam	Conventional-Till	Soybean
13	2021	Minnehaha	Blendon	Sandy Loam	Conventional-Till	Corn
14	2021	Minnehaha	Moody	Silty Clay Loam	Conventional-Till	Corn
15	2021	Brookings	Brandt	Silty Clay Loam	Conventional-Till	Soybean

RESULTS AND DISCUSSION

Soil Test Potassium Correlations

Selected soil test parameters, including smectite and illite clay content, are reported in Table 2. Soil test K levels ranged from 132 to 735 ppm, with only sites 9, 10, and 12 reporting STK levels below 160 ppm. Figure 1 displays the linear plateau model for sites 5, 6, 9, 10, 12, 13, and 14, with STK ranging from 132 to 202 ppm. According to current KFRs in South Dakota, a yield response is unlikely to be observed in soils >160 ppm. In this study, the linear plateau model climbed past 160 ppm and plateaued at 169 ppm, suggesting that a higher percentage of maximum yield could be achieved by raising the K critical value to 169 ppm.

Potassium Fertilizer Recommendation Calibrations

Of the 15 field trials conducted, only two (sites 10 and 15) were observed to positively respond to K fertilizer treatments. To optimize corn yield, K fertilizer would need to be applied at rates of 60 and 37 lbs. K_2O ac.$^{-1}$ at sites 10 and 15, respectively. While the yield response was anticipated for site 10 (STK = 132 ppm), a yield response was not expected at site 15, where STK was exceptionally higher than the current 160 ppm K critical level (STK = 327 ppm). Although the agronomic optimum KFR was observed, neither site required K fertilizer to yield at economic optimal levels (assuming \$0.65 lb.$^{-1}$ K and \$6.00 bu.$^{-1}$ corn price), which is consistent with conclusions from Oliver et al. (2022).

Table 2: Select soil test data (0-6 in. sample depth) for the 15 field trials in this study.

Site	Soil Test Parameter†					
	pH	CEC	EC	K	Smectite	Illite
		meq 100 g^{-1}	mmhos cm^{-1}	ppm	--------- <2 µm fraction ---------	
1	7.5	40.3	0.50	634	55.3	34.3
2	7.7	39.2	0.59	735	48.5	39.3
3	6.2	21.6	0.25	501	41.8	48.0
4	5.9	29.5	0.22	322	77.5	16.3
5	6.1	25.6	0.19	200	76.3	18.3
6	5.3	24.1	0.16	202	36.3	52.0
7	6.8	13.7	0.13	241	51.5	38.8
8	6.0	17.2	0.11	287	34.8	51.5
9	6.1	14.3	0.11	132	43.5	44.8
10	7.2	22.7	0.31	143	80.8	13.0
11	8.0	29.3	0.40	436	54.0	36.8
12	6.1	22.2	0.44	155	39.8	47.0
13	6.4	14.1	0.22	161	19.0	65.0
14	5.3	21.9	0.16	170	41.0	45.3
15	6.1	18.7	0.21	327	14.3	70.8

† pH, 1:1 soil water; CEC, cation exchange capacity; EC, electrical conductivity; K, potassium, ammonium acetate-extractable

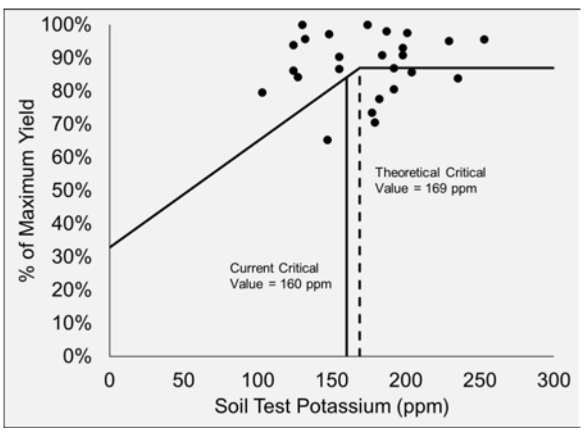

Figure 1: Linear plateau for correlation analysis.

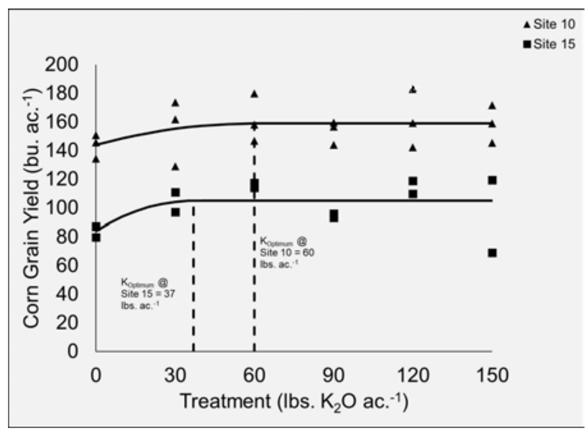

Figure 2: Quadratic plateau for calibration analysis.

Sites differed considerably in STK levels and mean maximum yields (MMY) (Table 3). However, only sites 10 and 15 showed positive yield responses to K fertilizer treatments. According to current South Dakota KFRs, using STK and MMY at each site, K fertilizer should be applied at 60 lbs. K_2O ac.$^{-1}$ at sites 9, 10, and 12 to optimize yield, while the remaining sites should not have any K fertilizer applied. Based on the observed yield responses, it was found that 60 lbs. K_2O ac.$^{-1}$ should be applied to site 10, and 37 lbs. K_2O ac.$^{-1}$ should be applied to site 15, while the remaining sites should have no K fertilizer applied. Therefore, when comparing current and optimum recommendations, KFRs were accurately predicted for 12 of the 15 sites. Over-applications of K fertilizer occurred at sites 9 and 12, while an under-application occurred at site 15.

Table 3: Soil test potassium, clay mineralogy, yields, and fertilizer recommendations.

Site	K	S:I†	MMY‡	Mean RY_0§	Yield Response⁋	Current KFR*	Optimum KFR††
			bu. ac.$^{-1}$	%		-------------lbs. K_2O ac.$^{-1}$-------------	
1	634	1.6	192	83	No	0	0
2	735	1.2	153	92	No	0	0
3	501	0.9	196	100	No	0	0
4	322	4.8	249	96	No	0	0
5	200	4.2	231	96	No	0	0
6	202	0.7	200	96	No	0	0
7	241	1.3	193	99	No	0	0
8	287	0.7	229	100	No	0	0
9	132	1.0	163	99	No	60	0
10	143	6.2	168	91	Yes	60	60
11	436	1.5	155	94	No	0	0
12	155	0.8	233	100	No	60	0
13	161	0.3	48	86	No	0	0
14	170	0.9	187	96	No	0	0
15	327	0.2	167	82	Yes	0	37

† S:I, smectite:illite ratio
‡ MMY, mean maximum yield, calculated as maximum yield from treatment means
§ Mean RY_0, mean relative yield from control treatment, calculated as yield of control plot divided by MMY
⁋ Significant quadratic plateau curve ($\alpha = 0.05$)
* Current South Dakota KFRs *Note*: 60 lbs. K_2O is minimum recommendation when STK <160 ppm
†† Theoretical optimum KFR obtained from quadratic plateau modeling

Integrating Clay Mineralogy

Clay mineralogy can impact the K fertilizer rate needed to optimize corn yield (Breker et al., 2019). It is theorized that a yield response to K fertilization may be observed, even if STK exceeds the soil test critical value, if there are more smectite than illite clays in the soil. Smectite clays are highly charged and exhibit shrink/swell dynamics, which hold onto K^+ ions tightly and temporarily fix K under dehydrated conditions. The K critical level in North Dakota was adjusted based on relative amounts of smectite and illite clays in the soil, in which soils containing 3.5 times or more smectites than illites increased the critical level to 200 ppm (Breker et al., 2019). Nitric acid-extractable K was found to be most exchangeable for kaolinitic soils, followed by mixed soils, and least exchangeable for smectitic soils (Sharpley, 1989). This finding may be a reason for observing a yield response to K at STK levels above the current critical soil test level, as demonstrated in Breker et al. (2019). In this study, the STK correlation findings demonstrated that the critical STK value for South Dakota may need to increase from 160 to 169 ppm (Figure 1). However, none of the sites in this study (1, 2, 4, 5, 7, and 11) that had STK levels >160 ppm and S:I >1.0 showed a yield response. While the STK level at site 15 was 327 ppm, the S:I value of 0.2 was the lowest of all sites, suggesting that clay mineralogy was not responsible for the yield response at that site. While clay mineralogy could not confidently be used as a prediction tool for KFRs in the first two years of this study, five additional field trials conducted in 2022 may provide further insights for this research.

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MANURE TOTAL NITROGEN VARIABILITY DUE TO ANALYTICAL METHOD AND TOTAL SOLIDS CONTENT

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ABSTRACT

Knowing the nutrient analysis of a fertilizer source is essential to ensure adequate nutrients are applied for crop growth, while not causing potential environmental impacts by overapplying nutrients. Using manure as a nutrient source can complicate matters as the nutrient content can be variable and the manure can come in a range of liquid to solid consistencies. There are multiple laboratory methods to determine different nutrient parameters and for manure total nitrogen (N) levels the most common methods are total Kjeldahl nitrogen (TKN) and nitrogen combustion (N-C). What laboratory method is the best suited for liquid or solid manure and is the least variable? The Minnesota Department of Agriculture (MDA) administers the Manure Analysis Proficiency (MAP) Program, which is the only manure proficiency program in North America where laboratories receive unknown manure samples to analyze. We used the MAP Program data back to 2003, which includes 6-9 unique sample exchanges with laboratories annually. We compared 4047 samples analyzed by the N-C method and 4536 samples analyzed by TKN method for total nitrogen. No significant difference in sample medians was found between analytical methods, however the N-C method was more variable than the TKN method for manure samples with less than 25% total solids. Being aware of the variability in these methods can help laboratories and nutrient management planners consider methods appropriate for their clients.

INTRODUCTION

When land applied, manure provides nutrients for growing crops. However, these nutrients can be variable depending on animal species, age, diet, management, housing, climate, and manure storage and handling. Knowing what nutrients are contained in a certain manure can assist farmers to better match manure application to field and crop needs. Laboratories have tested manure for many years but there was no coordinated effort for a laboratory proficiency program to ensure consistency across laboratories. Since 1996, the MDA has shipped prepared manure samples and collected data on these exchanges as a part of the MAP Program. From 2003-2006, MDA received Environmental Protection Agency (EPA) funding to create a nationwide manure proficiency program. The MDA currently continues this nationwide program and now includes Canadian laboratories as well. Laboratories participate in the MAP program to compare their laboratory's accuracy and precision to other laboratories and can become a MAP-certified laboratory annually. Laboratories receive feedback on items to improve upon and the certification process gives confidence to customers that they are receiving quality analyses. The MAP program data allows comparison of laboratory methods across labs and years.

With many nutrient management plans using N-based manure application rates, having confidence in the total N manure test results is important. Often there are multiple analytical methods for the parameters measured. The most common TN analytical methods are TKN and N-C. For N-C, a manure sample is combusted in an oxygen-containing environment and a thermal conductivity conductor quantifies the inorganic and organic N concentrations. The TKN method uses a Kjeldahl digestion with concentrated sulfuric acid, a metal catalyst, and salts to measure the organic N and NH_4-N concentrations. TKN does not measure nitrate or nitrate levels in manure, which manure contains little of. Near-Infrared Spectroscopy (NIR) can also be used to measure total N in poultry litter but is not used as often as TKN or N-C and thus is not included in this research. The TKN and N-C methods were compared going back to 2003. TKN was the most popular TN method in 2003 and is slowly declining in popularity and today N-C is the most common TN method as indicated by Figure 1.

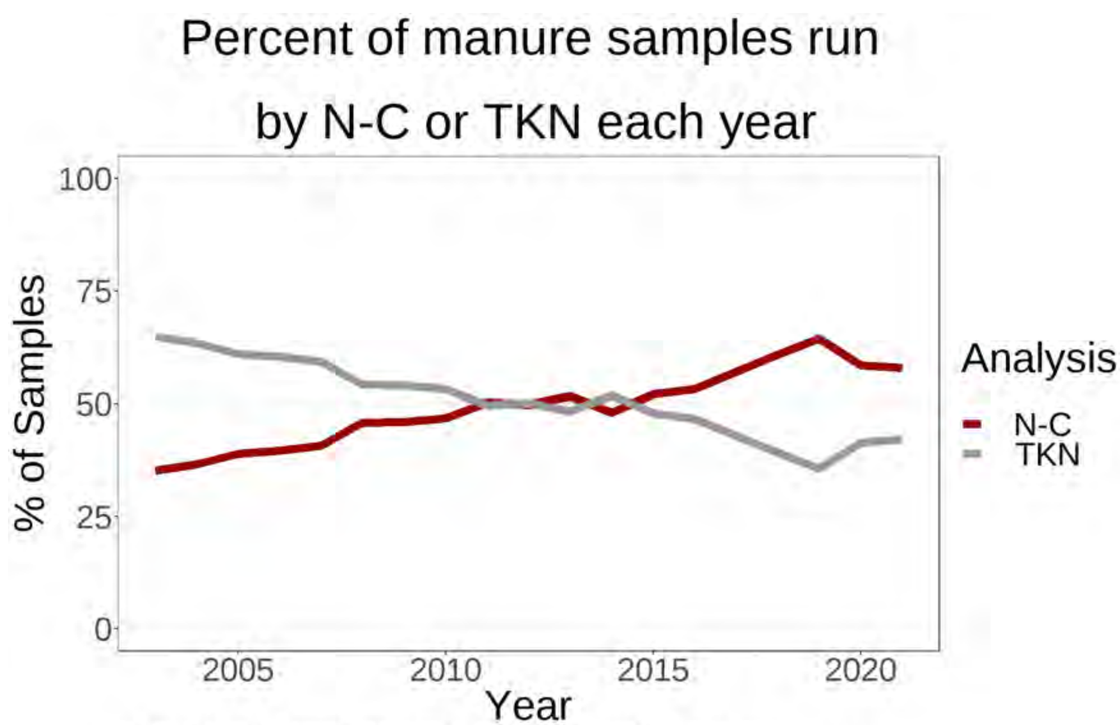

Figure 1. Trends in total nitrogen analytical methods used from 2003-2021.

MATERIALS AND METHODS

The MAP program has sent out manure sample exchanges two to three times per year since 2003 with an annual enrollment of 60 to 74 laboratories. Each exchange contained three manure samples in triplicate, for a total of nine bottles for each laboratory to analyze. The manure samples came from different animal types and a range (2-90%) of total solids (TS). Samples were considered liquid, slurry, or semi-solid when under 20% TS in the specially prepared MAP program samples. Central Lakes College (Staples, MN) specially ground, homogenized, and packaged the manure samples. Samples were mixed in a 60-quart Robot Coupe Vertical Cutter Mixer or in a 60-quart Robot Coupe Blixer to reduce particle size. A 12.5 cubic foot Imer cement mixer (Poggibonsi, Italy) mixed the solid manure samples. The exchange samples were frozen and shipped to program participants. Each laboratory submitted their analytical results on 12 test parameters on a standard template to MDA for statistical analysis.

This study compared 120 unique manure samples from 2003-2021 minus 2017 between the N-C to TKN methods. The 2017 data was not included as the MAP Program tried an experimental exchange method using 15 samples of freeze-dried manure with no replicates. The R programming language was used for statistical analysis (R Core Team, 2022). We calculated the lab mean for the triplicate samples, and then found the median for each sample across all labs for the TKN and N-C method each. We compared the medians values for the TKN and N-C samples using the unpaired (independent samples) t-test. We used median absolute deviation (MAD) to analyze the spread of the data without having exceptionally high or low values skew the results. MAD is calculated by finding the median of a data set, subtracting the median from each value in the dataset, and then finding the median from those calculations. Like a coefficient of variation, a Relative Median Deviation (RMD) is a dimensionless number that would indicate method precision in this case and is calculated by dividing the MAD by the median and multiplying by 100. Unpaired t-tests compared the RMDs between the two methods. The samples were divided into separate categories by TS percentages and RMDs were compared by method.

RESULTS AND DISCUSSION

The TKN and N-C sample TN% medians were not significantly different and the violin plots in Figure 2 show those median comparisons. When comparing the TN RMDs vs TS, there was not a significant difference between the precision of the two methods overall. However, when divided between distinct levels of TS, the RMDs were significantly different between TN methods for the manure samples with less than 25% TS, with the N-C having less precision compared to TKN for those samples. Figure 3 shows the TN RMDs compared to TS. The MAP Program helps minimize manure test variability and past MAP samples can answer some questions regarding method choice. Overall either method is still a recommended option for TN analysis and both are listed in the recently updated book, Recommended methods of manure analysis 2nd edition (Wilson & Cortus, 2022). Understanding there is some precision variability with samples with less solids can help laboratories and nutrient management planners consider methods appropriate to their clients.

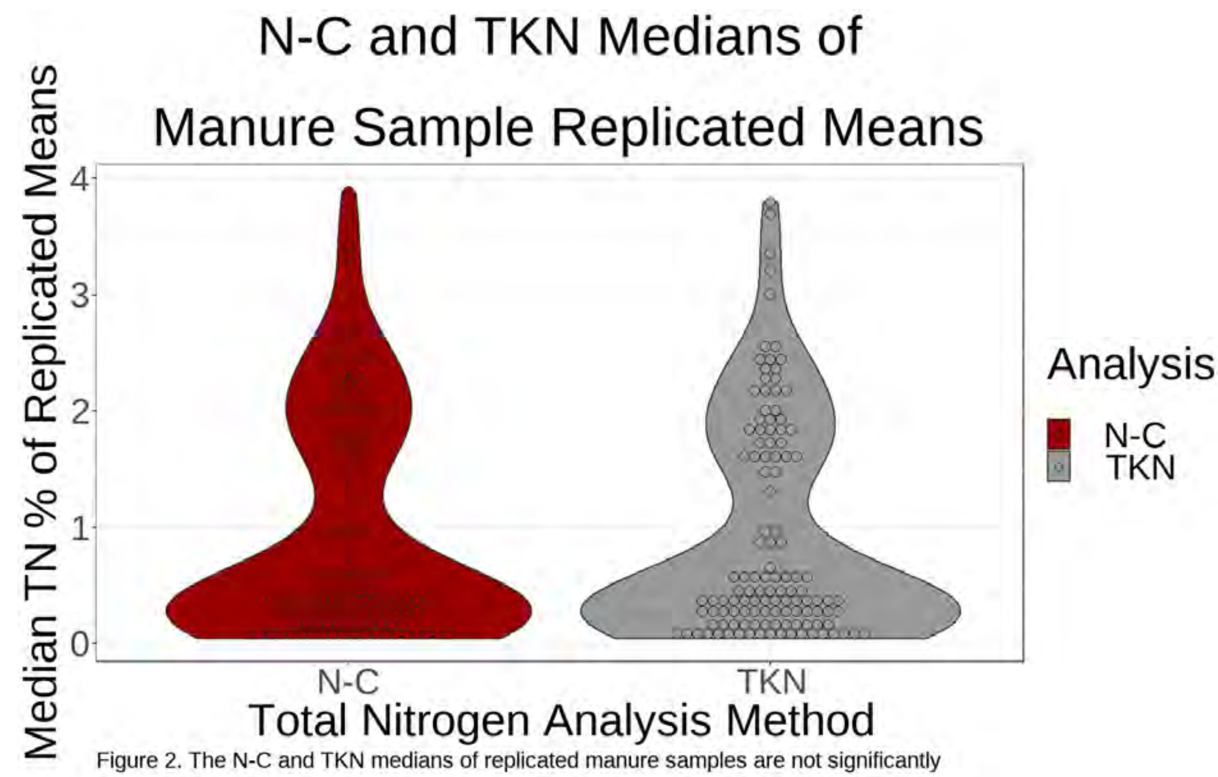

Figure 2. The N-C and TKN medians of replicated manure samples are not significantly different from each other.

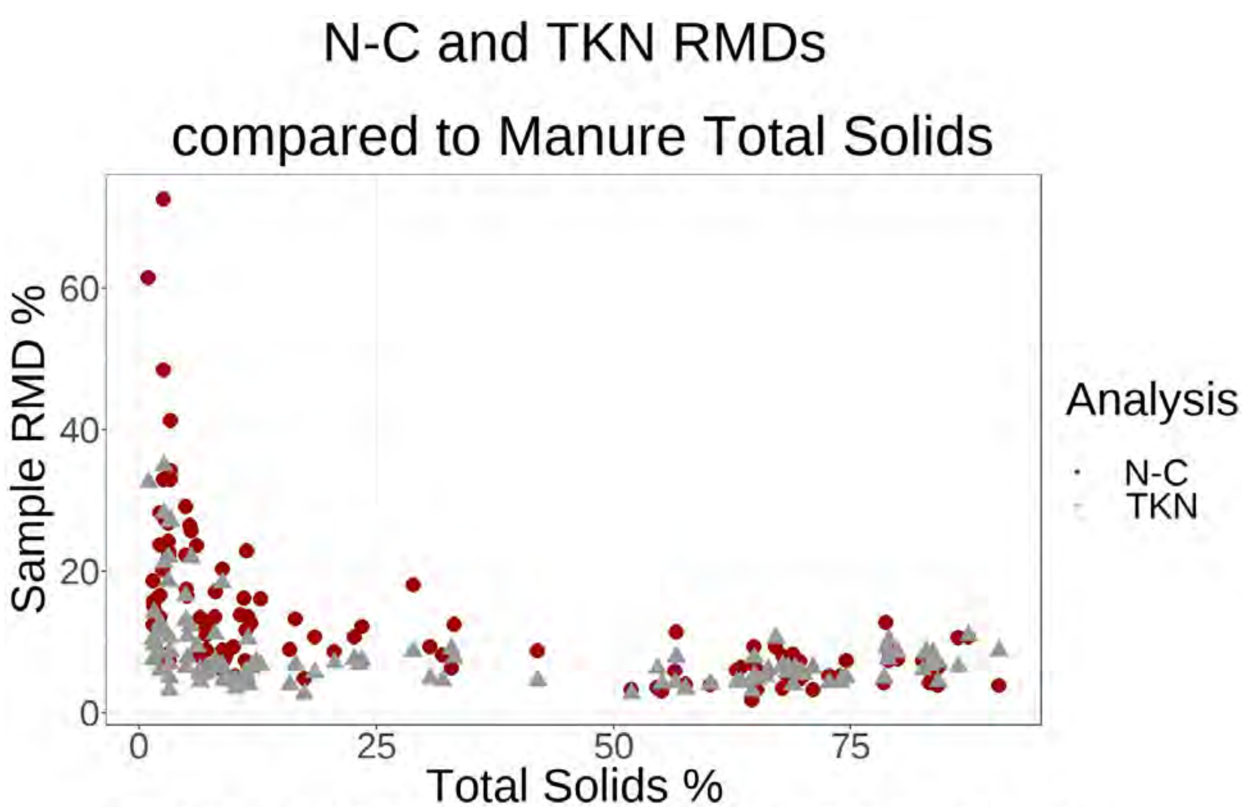

Figure 3. The RMDs are significantly different between methods when total solids are less than 25%.

ACKNOWLEDGEMENT

We appreciate the Minnesota Department of Agriculture sharing the MAP data.

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CORN RESPONSES TO SULFUR FERTILIZER IN INDIANA

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ABSTRACT

Corn yield increases in response to sulfur (S) applied as ammonium thiosulfate in liquid N (in sidedress and/or starter fertilizer applications) occurred in ~40% of 40 trials conducted between 2017 and 2021 and ranged from 4 to 24 bushels per acre on responsive sites. Increased grain yield with S fertilization occurred on soils ranging in texture from sandy loam to silty clay loam and soil organic matter concentrations from ~1 to 3%. Yield increases with S fertilization were not predicted by Mehlich-3 extractable sulfate-S in soil samples taken sometime between planting and sidedressing. The S concentration of plant samples taken just before sidedressing also did not correlate with responsive and non-responsive fields. Later in the season, earleaf S concentrations and nitrogen to S ratios (N:S) associated with sufficiency were >0.18% S and <16:1 N:S, respectively. Application of phosphorus fertilizers with incidental S content and potential carryover of S applied to the previous crop when grown on silt loam or heavier soils may need to be considered when attempting to predict S fertilization needs of the current crop.

MATERIALS AND METHODS

Corn response to S fertilization field trials were conducted on Purdue agricultural research farms and farmers' fields from 2017-2021. Sulfur treatments were applied with ammonium thiosulfate in liquid N (in sidedress and/or starter fertilizer) and the number of treatments and rates of S applied varied among trials – 1 to 5 rates (in addition to a zero S rate) and rates from 3 to 30 lb S/acre. Treatments were replicated from 3 to 18 times.

Whole plant and soil samples (0-8, 8-16, and 16-24" depth) shortly before sidedress treatments were applied and earleaves at silking were obtained from several trials. Plant samples were analyzed for N and S and soil samples for Mehlich3-extractable SO_4-S. Grain yield and moisture were obtained from calibrated yield monitors on commercial combines. Analysis of variance and single-degree of freedom contrasts (alpha=0.10) were used to compare treatments.

RESULTS AND DISCUSSION

Grain yield response to starter fertilizer containing S

The impact of starter and/or sidedress S on corn yield was evaluated in 9 trials. Sulfur rates ranged from 3-5 lb S/acre as starter and 12-25 lb S/acre as sidedress. Starter fertilizer did not increase grain yield in 8 of 9 trials (data not shown), compared to no S fertilizer, even though in 4 of the 8 trials supplying S at sidedressing increased yield 15-20 bu/acre. Applying S in both starter and sidedress had no greater effect on yield than applying S in sidedress alone.

Grain yield response to sidedress fertilizer containing S

The effect of sidedress S on corn grain yield was evaluated in 40 trials (including the 9 with starter S treatments). Multiple rates of sidedress S were utilized in 26 of the 40 trials, ranging from 5 to 30 lb S/acre and including a 0 lb S/acre treatment. Fourteen trials only had 2 S rates, 0 and 15 lb S/acre (mostly those conducted in 2021).

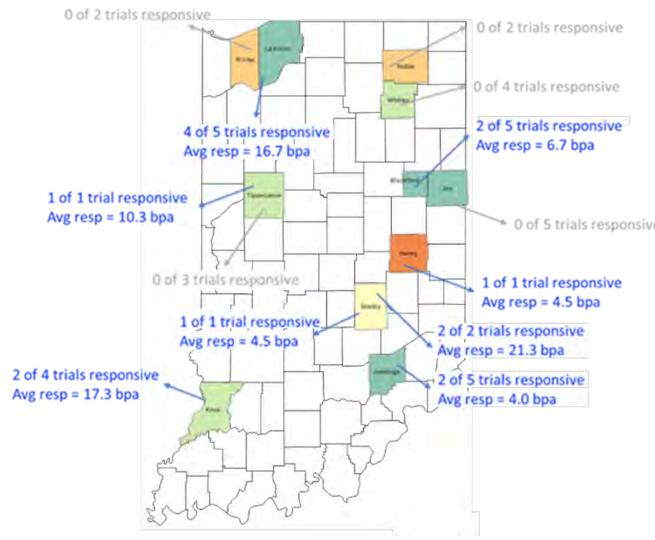

Figure 1. County of location for 40 corn response to sulfur fertilization trials conducted in Indiana from 2017-2021. The number of responsive trials and the average yield increase in responsive trials is shown.

Sidedress S increased yield in 15 of 40 trials (Fig. 1), ranging from 4 to 24 bu/acre averaged over the entire experimental area. In 7 trials where corn responded to multiple rates of sidedress S the lowest sidedress rate examined (ranging from 5 to 20 lb S/acre) was enough to maximize the yield response. Even at sites that had large yield increases with S fertilization in some years, no response occurred in other years (e.g. LaPorte and Knox Counties). Several sites were consistently unresponsive to S fertilization over several years of testing (e.g. Jay and Whitley County).

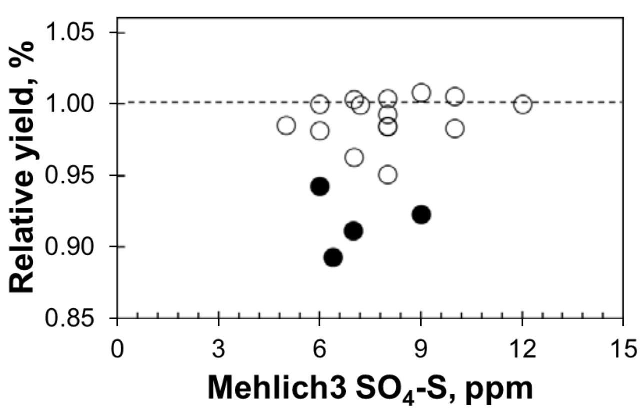

Figure 2. Relationship between Mehlich3-extractable SO_4-S in the upper 8 inches of soil sampled prior to sidedressing and relative yield (yield without S/yield with S). Solid circles denote sites where yield without S was lower than yield with S ($P \leq 0.10$) and open circles indicate non-significant effects of added S.

Mehlich3-extractable SO_4-S of the upper 8 inches of soil did not differentiate 4 sites where S fertilization increased yield from 14 non-responsive sites (Fig. 2). Including extractable SO_4-S from deeper depths, 8-16 and 16 to 24 inches, did not improve the relationship between soil SO_4-S and relative grain yield (data not shown).

Whole plant S concentration (Fig. 3) and N:S ratio (data not shown) at the V3-V7 growth stages prior to sidedressing did not separate 2 responsive sites from 11 non-responsive sites.

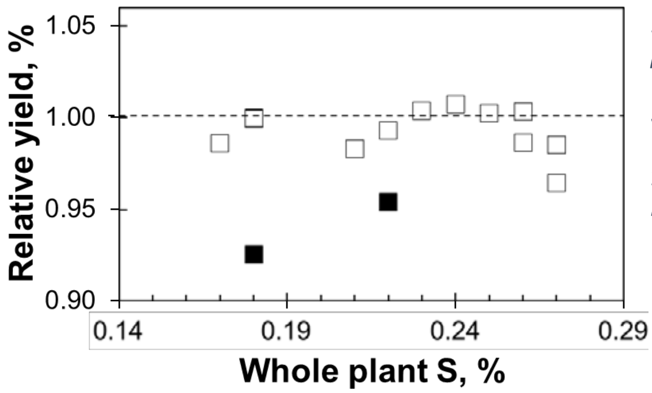

Figure 3. Relationship between whole plant S prior to sidedressing and relative yield (yield without S/yield with S). Solid squares denote sites where yield without S was lower than yield with S as determined by a single-degree-of-freedom contrast (P≤0.10) and open squares indicate non-significant effects of added S.

The earleaf S concentration and nitrogen to S ratio (N:S) at silking was reasonably well associated with sufficiency, separating responsive sites from non-responsive sites. Most sites where grain yield was lower without S fertilization had earleaf S ≤0.18% and N:S ratio ≥16:1.

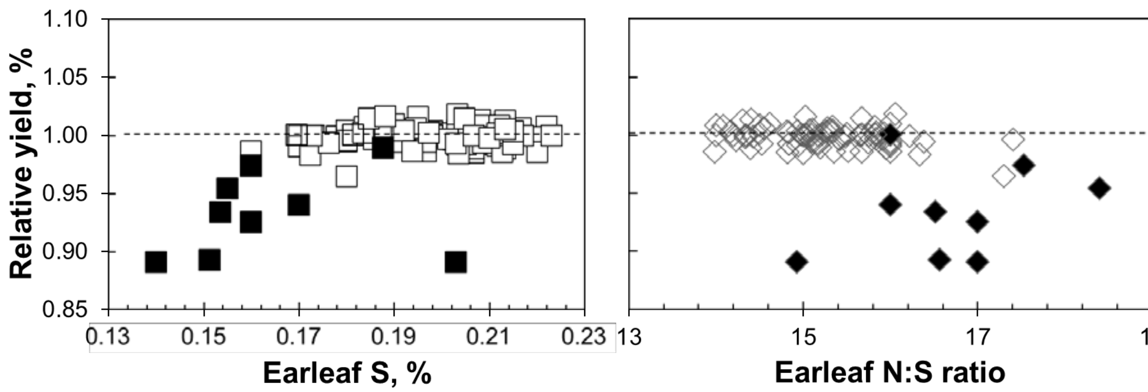

Figure 4. Relationship between earleaf S concentration and N:S ratio with relative grain yield. Relative yield was calculated as the mean of each treatment divided by the mean of all treatments receiving S. Solid symbols denote sites where yield with S was lower than yield with S as determined by a single-degree-of-freedom contrast (P≤0.10) and open symbols denote non-significant effects of added S. Data from 24 sites in 2018-2020.

Corn response to S occurred in ~40% of 40 trials conducted in Indiana from 2017-2021. Yield responses ranged from 4 to 24 bu/acre. Not surprisingly soil SO_4-S prior to sidedressing did not distinguish S responsive sites from non-responsive sites – nor did the %S or N:S ratio of plant tissue sampled at the same time. Earleaf %S and N:S ratio at silking was reasonably good at differentiating 7 of 9 responsive sites from 15 non-responsive sites, but of course this is not helpful for improving the yield of the current crop. Other factors that may impact corn response to S and should be investigated in future research are carryover of S applied to the previous crop, incidental S applied in phosphorus fertilizers, and the impact of drainage on mineralization of organic S.

BENCHMARKING NITROGEN RECOMMENDATION TOOLS FOR NEBRASKA WINTER WHEAT

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ABSTRACT

Winter wheat producers are challenged with achieving high yields, profits, and nitrogen (N) use efficiency (NUE). The use of site-specific N management and digital ag technologies has been demonstrated to increase NUE. During the 2020-2021 and 2021-2022 growing seasons, we conducted eighteen on-farm randomized strip trials comparing sensor-based variable-rate N tools versus grower's N management. Tools for sensor-based, variable-rate N management included commercially available active crop canopy sensors and satellite-based tools (SENSE). Nitrogen rate blocks were placed in the field to estimate the economic optimum N rate (EONR). A subset of five sites was included here. The objectives of this research were to (a) evaluate the performance of commercially available N tools for winter wheat on yield, NUE, and partial profit, (b) to compare them against the typical grower's typical N management strategy, and (c) benchmark tool performance using the University of Nebraska-Lincoln (UNL) N recommendation algorithm and the observed EONR. On average, the yield for SENSE and grower treatment were similar ~ 77 ± 13 bu ac^{-1}. Sensor-based N management applied 10% lower N rate compared to grower's traditional management. In addition, At all sites, SENSE N recommendations was closer to EONR than grower was to EONR. This resulted on higher N use efficiency with an average of 1.2 lb N bu^{-1} grain for SENSE. Further analysis will aim to investigate what factors influenced the performance of sensor-based N management in winter wheat and their performance at a site-specific level.

INTRODUCTION

Winter wheat (*Triticum aestivum*) production requires effective (N) fertilizer management to maximize yield and quality while reducing environmental impacts. Insufficient N fertilization may lead to significant yield and protein reductions (Fischer et al., 1993; Scharf et al., 2011). However, estimating the optimal N rate is challenging because soil available N and crop N demand are highly variable between years and across fields (Cassman et al., 2002). Therefore, N recommendations that account for soil characteristics, management, and weather factors could better estimate the economic optimum N rate (EONR) within fields and over the years (Puntel et al., 2016).

Several approaches exist to recommend N in winter wheat. For example, the University of Nebraska-Lincoln (UNL) developed a recommendation published in 2002 (Blumenthal and Sander, 2002) and revised it in 2009 (Hergert and Shaver, 2009). However, this recommendation method does not account for the year-to-year variability in weather conditions and the variation in soils. Sensor-based fertilization using active and passive sensors has been shown to effectively manage N in winter wheat, improve nitrogen use efficiency (NUE) and maintain yields (Raun et al., 2001; Li et al., 2009). This approach indirectly captures soil and weather variability through the N status of the crop

(Boyer et al., 2011). In addition, sensor-based technology can now be applied at a large scale using satellite images (Shou et al., 2007; Fabbri et al., 2020). Despite positive results from sensor-based N management in winter wheat, the adoption remains low. Thus, on-farm and hands-on experience with these tools could support adoption and improve yield, profit, and NUE in winter wheat.

Despite high yields, low protein values in winter wheat have reduced crop value (Baker et al., 2004) for producers. And, in the event of a high fertilizer price scenario, growers reduce N inputs to reduce costs. Reducing N applications to winter wheat typically results in low protein (Johansson et al., 2001) and low grain yield (Gastal et al., 2015). Thus, it is fundamental to promote adoption of N technologies that can better estimate the EONR site-specifically to maximize yield and protein content. Our objectives were to (a) evaluate the performance of commercially available N tools in winter wheat based on yield, NUE, and partial profit, and (b) to compare them against the grower's typical N management, observed EONR, and the UNL recommendation method.

MATERIALS AND METHODS

On-Farm Experimental sites

Eighteen on-farm research trials were conducted in winter wheat commercial dryland fields in Nebraska during the 2020-2021 and 2021-2022 growing seasons. Fields were distributed in the southeast (n= 4), east (n=4), northwest (n=3), and southwest (n=7) regions of Nebraska. Studies were focused on sensor-based technologies (herein SENSE N management), and five sites are discussed in this paper. The soil types, soil properties, and previous crops across sites are described in Table 1.

Treatments

In each site, two N management strategies were compared utilizing replicated and randomized field-length strips (Figure 1):

- *Grower's N management*: Traditional N rates varied among growers based on their preferences. The N rates varied from 73 to 115 lb N ac^{-1}. Timing of N applications occurred during fall (Feekes 2-3), spring (Feekes 4-6), or split (fall and spring) according to the grower's preference. Details about timing application between Grower's N and SENSE N management are provided in Table 1.
- *Sensor-based N management (SENSE):* Growers had access to two sensor-based N tools for SENSE N management. In 2020-2021, we tested the Ag Leader® OptRx sensor, and in the second year (2021-2022), we used data from Planet® SkySat satellite-based imagery and the handheld Trimble® GreenSeeker in the Ninja Ag platform. Both methods utilized either NDVI or NDRE and an algorithm to prescribe N recommendations. The fields were sensed, and variable-rate N was applied as UAN (32-0-0) (Figure 1).

Grain was harvested using the grower's combine, and yield values were obtained from yield monitors and used to analyze the difference between treatments. Site IV was hand harvested. Wheat phenological stages were defined based on the Feekes scale (Large, 1954).

Table 1. Average soil properties including pH, organic matter (OM), nitrate, cation exchange capacity (CEC), sand, silt, clay, and texture are reported by site. Grower N management, county, previous crop, and growing season in which the study occurred are reported for each site.

Site	pH	OM (%)	Nitrate N (ppm)	CEC me/100g	Sand (%)	Silt (%)	Clay (%)	Texture	Grower N (lb ac^{-1})	County	Previous crop	Growing season	Timing Grower | SENSE
I	6.2	3.6	5.9	13.4	19	61	20	Silt Loam	76	Nemaha	Soybean	2020/2021	Fall | Split
II	6.5	3.7	4.2	20.5	21	47	32	Clay Loam	112	Gage	Soybean	2020/2021	Spring | Spring
III	5.8	2.3	15.8	10.9	54	36	9	Sandy Loam	133	Perkins	Corn	2020/2021	Split | Split
IV	6.7	2.3	4	17.8	27	55	18	Silt Loam	140	Butler	Soybean	2021/2022	Split | Split
V	7.5	2.2	1.8	27.3	24	50	26	Silt Loam	103	Gage	Soybean	2021/2022	Split | Split

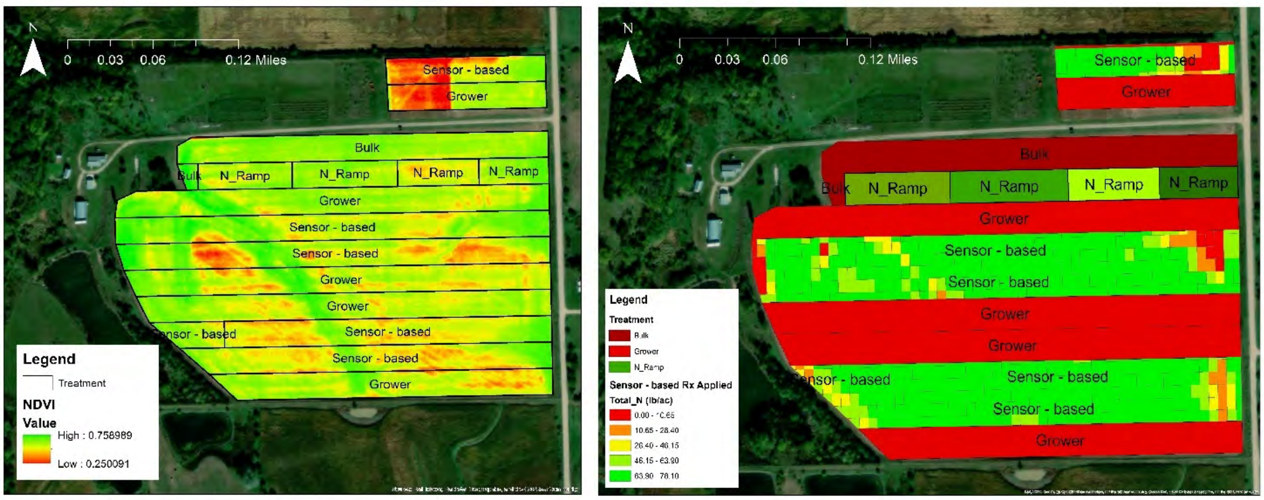

Figure 1. Example of a winter wheat nitrogen (N) treatment layout overlayed on the normalized difference vegetation index (NDVI) derived from Planet® SkySat satellite imagery (left) and a variable-rate N prescriptions from satellite-based N recommendation (right) applied on winter wheat at jointing (Feekes 6) at Butler County, Nebraska.

Economic optimal N rate (EONR)

Small blocks with a range of N rates were established in contrasting zones within each field using variable-rate N technology. Contrasting zones were established to capture variability due to differences in elevation (e.g., site II), soil N, apparent electrical conductivity (ECa), and soil properties (Table 1). In each site, four N rates were applied during the spring, with total N ranging from 30 to 117 lb N ac^{-1} (site I), 32 to 132 lb N ac^{-1} (site II), and 39 to 134 lb N ac^{-1} (site III), 19 to 106 lb ac^{-1} (site IV), and 23 to 120 lb ac^{-1} (site V). Yield data from these N rate blocks was used to calculate the EONR (ex-post) and benchmark the performance of grower and SENSE treatments. We also calculated the University of Nebraska-Lincoln (UNL) N recommendation (Blumenthal and Sander, 2002) for each site and compared it to the grower and SENSE treatments and EONR. This tool relies mainly on the soil residual nitrate test using soil test features as input to prescribe a N rate.

Data Analysis

One-way analysis of variance (ANOVA) was performed to determine significant differences between treatments (confidence interval of 95%) on yield, total N applied, and partial profit using the function *aov* (R Core Team, 2021). The relationship between yield and N rate was described with a quadratic function using R software (R Core Team, 2021). The EONR was calculated from the N response equations by setting the first derivative of the fitted response curve equal to the wheat and N fertilizer price ratio (US$ 9 bu ac^{-1} grain: US$ 0.56 lb N ac^{-1}).

RESULTS AND DISCUSSION

Across sites and treatments, winter wheat yield ranged from 63 bu ac^{-1} to 100 bu ac^{-1} with a mean of 77 bu ac^{-1}, and total N rates ranged from 61 lb ac^{-1} to 139 lb ac^{-1} with a mean of 95 lb ac^{-1} (Figure 2). On average, the yield for SENSE and grower treatment was similar (76±15 and 78±10 bu ac^{-1}, respectively, Table 2, Figure 3). Across sites, SENSE N management applied a 10% lower N rate than the grower's traditional management. This resulted on higher N use efficiency with an average of 1.2 lb N bu^{-1} grain for SENSE (Table 2). Across sites, profit varied between SENSE and grower. In site I, SENSE was more profitable than grower, while in Site V, grower had a higher profit compared to SENSE. For site V, the SENSE treatment was applied a month later than the grower. We also expect that a N base rate of 23 lb N ac^{-1} for the entire field was low for an application in May possibly due to low mineralization associated with dry conditions that could produce early N stress in the crop.

Table 22. Total nitrogen (N), economic optimal N rate (EONR), UNL N recommendation, grain yield, NUE, and partial profit between sites and treatments.

	Total N (lb N ac^{-1})		*Benchmarking rates (lb N ac^{-1})*		*Grain yield† (bu ac^{-1})*		*NUE (lb N bu $grain^{-1}$)*		*Partial profit‡ (US$ ac^{-1})*	
Site	Grower	SENSE	EONR	UNL	Grower	SENSE	Grower	SENSE	Grower	SENSE
I	61 a	73 a	121	92	65 b	71 a	0.9 a	1.0 a	550.8 b	598.1 a
II	89 b	115 a	121	90	91 a	100 a	1.0 a	1.1 a	769.2 a	835.6 a
III	106 a	95 b	93	59	82 a	82 a	1.3 a	1.1 b	679.2 a	684.8 a
IV	139 a	80 b	100	77	70 a	63 b	2.0 a	1.3 b	552.2 a	522.2 a
V	103 a	85 b	72	97	82 a	63 b	1.2 b	1.4 a	680.3 a	519.4 b

Values with the same letter are not significantly different at a 95% confidence level, comparisons run by site. ‡Partial profit based on $9/bu wheat. †Grain yield values are from weight wagon method. Bushels per acre corrected to 13.5% moisture.

The EONR ranged from 72 lb N ac^{-1} to 121 lb N ac^{-1} with a mean of 101 lb N ac^{-1}. At all sites, SENSE N recommendations was closer to EONR (18 lb N ac^{-1}) than grower was to EONR (35 lb N ac^{-1}). The estimated UNL N recommendation ranged from 59 lb ac^{-1} to 97 lb ac^{-1}, with a mean of 83 lb N ac^{-1}. The average difference between UNL recommendation with grower and SENSE treatments was 29 lb ac^{-1} and 19 lb ac^{-1}, respectively (Table 2). Average differences were calculated by subtracting the UNL recommendation from SENSE and grower N rate (Figure 2).

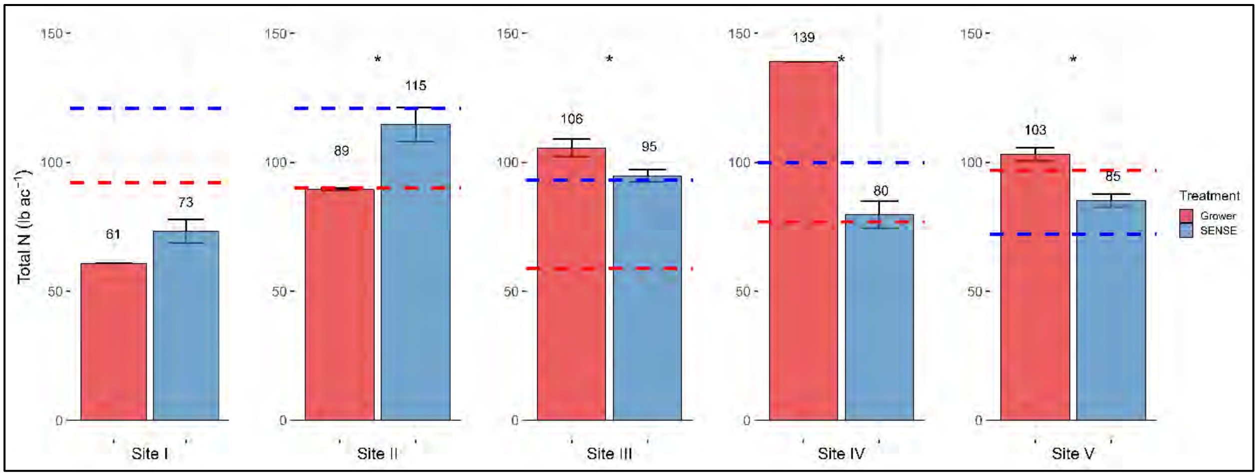

Figure 2. Average total nitrogen (N) between grower and sensor-based (SENSE) N management. Red and blue dashed lines represent the UNL and economic optimal N rate (EONR), respectively. Asterisk (*) indicates significant difference at 95% confidence level between treatment means at each site. Vertical bars represent the standard deviation of the mean.

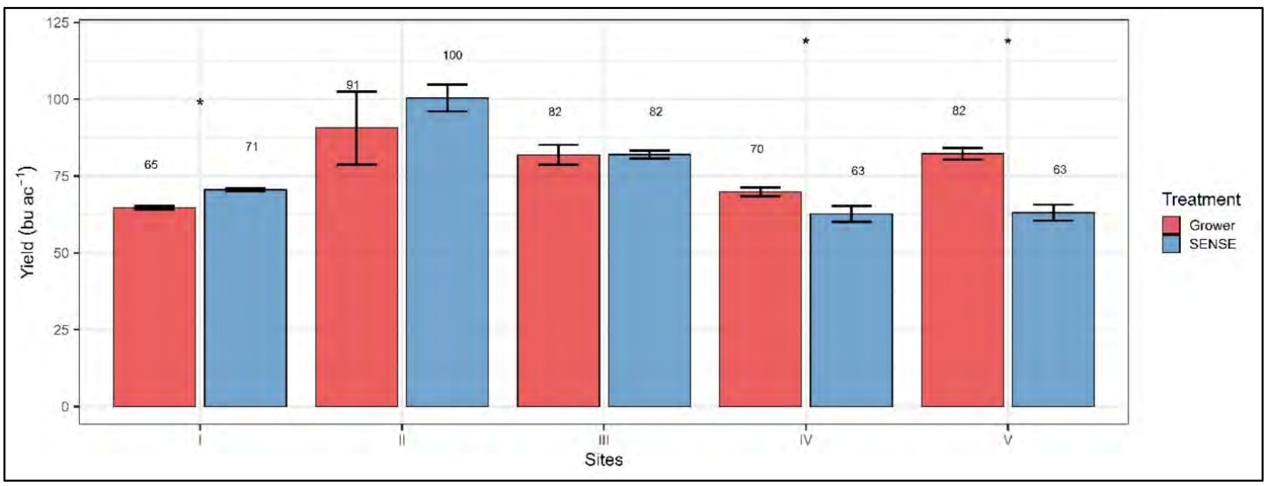

Figure 3. Average yield for Grower and sensor based (SENSE) N management. Asterisk (*) indicates significantly different at 95% confidence level. Yield values are from cleaned monitor data (except site IV) expressed at 13.5% moisture. Vertical bars represent the standard deviation of the mean.

CONCLUSIONS

The performance of SENSE N management for winter wheat varied between fields and growing seasons. On average, the SENSE and grower treatment yield was similar ~ 77 ± 13 bu ac^{-1}. Sensor-based N management applied 10% lower N rate compared to grower's traditional management. In addition, SENSE N recommendations was closer to EONR than grower was to EONR. This resulted in higher NUE with an average of 1.2 lb N bu^{-1} grain for SENSE. Despite some differences in yield, SENSE had similar profits than grower's management. The underperformance of sensor-based N recommendations could be related to the timing of the N application, the N base rate applied before the sidedress, and the method used to make the N recommendation (active vs. passive sensors). Further analysis will aim to investigate in-depth each of these factors affecting the performance of this technology and technology performance at a site-specific level.

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WHAT SOIL MEASUREMENTS RELATE BEST TO CORN ECONOMIC OPTIMAL N RATE?

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INTRODUCTION

The use of nitrogen (N) fertilizer is critical for optimizing corn (*Zea mays* L.) yield. However, improper applications can reduce fertilizer efficiency, create environmental issues, and reduce grower profits (Lawlor et al., 2008; Struffert et al., 2016; McCasland et al., 2020). One way to improve the accuracy of corn fertilizer-N rate guidelines is to improve soil testing and its use in making management decisions (Dinnes et al., 2002). To most effective in improving N rate guidelines, soil tests will likely need to account for both plant-available inorganic N and N that will be mineralized during the growing season.

To this point much research has been completed in using inorganic soil N to improve N rate guidelines accuracy (Vanotti and Bundy, 1994; Osterhaus et al., 2008; Sainz Rozas et al., 2008). Since 20% to 100% of N needed by corn to obtain optimal growth can be supplied by mineralization processes (Roberts et al., 2011; Yost et al., 2012; Morris et al., 2018), including biological soil tests along with inorganic N soil tests has the potential to improve upon current N rate guidelines. Recent research has shown that that improvements in soil biological health, improves corn yield potential (Wade et al., 2020). Soil tests that have shown some promise in being used to improve corn N rate guidelines include soil respiration or flush of CO_2 after rewetting soil (Yost et al., 2018; Bean et al., 2020; Franzluebbers, 2020). However, there are many other soil biological tests that may be able to be used in improving corn N rate guidelines (Karlen et al., 2019; Norris et al., 2020). Therefore, the inclusion of biological soil tests alone or in combination with other soil chemical and physical properties may enable us to improve the accuracy of corn N fertilizer needs to optimize yield. The objective of this study was to determine the relationship between EONR of corn and various soil chemical, physical, and biological properties.

MATERIALS AND METHODS

This study was conducted in 28 sites across central and eastern SD from 2018-2021 (Table 1). Sites varied in tillage practice, crop rotation, and soil type. The study was arranged as a randomized complete block design with four replications. Nitrogen fertilizer was applied at rates from zero to 200 lbs N ac^{-1} in 40 lb increments prior to planting. Urea (46%N) with N-(n-butyl) thiophosphoric triamide and dicyandiamide, SuperU) (Koch Fertilizer LLC) was broadcast on the soil surface.

Soil samples were collected prior to planting and fertilization from each replication using a 10-core composite sample for depths of 0-6 and 6-24 in. Soil samples were sieved through an 8-mm sieve and organic matter removed then air-

Table 1. Soil and management characteristics at each site.

Year	County	Nearest City	Soil Texture	Previous Crop	Tillage	Mean Nitrate-N 0-24 in., lbs ac^{-1}
2018	Brookings	Brookings	NA	NA	Conventional	51
2018	Codington	Southshore	NA	NA	Conventional	92
2018	Clay	Beresford	NA	NA	No-till	65
2018	Codington	Southshore	NA	NA	Conventional	49
2018	Brookings	Volga	NA	NA	Conventional	76
2018	Faulk	Chelsea	NA	NA	No-till	62
2018	Faulk	Chelsea	NA	NA	No-till	53
2019	Brookings	Aurora	NA	NA	Conventional	74
2019	Codington	Southshore	NA	NA	Conventional	75
2019	Clay	Beresford	NA	NA	Conventional	95
2019	Brookings	Volga	NA	NA	Conventional	63
2019	Edmunds	Ipswich	NA	NA	No-till	61
2019	Spink	Mansfield	NA	NA	No-till	56
2019	Brookings	Bushnell	NA	NA	Conventional	32
2019	Brookings	Bushnell	NA	NA	Conventional	26
2019	Minnehaha	Garretson	NA	NA	No-till	25
2019	Minnehaha	Garretson	NA	NA	No-till	78
2020	Brookings	Brookings	NA	NA	Conventional	52
2020	Clay	Beresford	NA	NA	No-till	53
2020	Codington	Southshore	NA	NA	Conventional	39
2020	McCook	Salem	Clay Loam	Soybean	Reduced till	30
2021	Roberts	Wilmot	Loam	Soybean	Reduced till	37
2021	Yankton	Yankton	Clay Loam	Wheat	No-till	26
2021	Brookings	Aurora	Clay Loam	Soybean	Conventional	30
2021	Roberts	Wilmot	Clay Loam	Soybean	Reduced till	28
2021	Aurora	Plankinton	Clay Loam	Sunflower	No-till	19
2021	Hutchinson	Freeman	Sandy Clay Loam	Soybean	No-till	30
2021	Turner	Freeman	Clay Loam	Soybean	Reduced till	27
2021	Lincoln	Lennox	Clay Loam	Soybean	Reduced till	36
2021	Codington	Southshore	Clay Loam	Soybean	Conventional	45
2021	Clay	Beresford	Clay Loam	Soybean	No-till	19
2021	Minnehaha	Renner	Sandy Loam	Corn	Conventional	30
2021	Minnehaha	Garretson	Silty Clay Loam	Corn	Conventional	32
2021	Brookings	Volga	Clay Loam	Soybean	Conventional	39

[a]NA, Not available.

dried, and ground through a 2-mm sieve. Soil samples were sent to Ward Laboratories (Kearney, NE) for soil analyses. Both the 0-6 and 6-24 in. samples were analyzed for NO_3^-–N and NH_4–N following recommended practices by the North Central Region (Nathan et al., 2015). The 0-6 in. depth was also analyzed for several other soil physical, chemical, and biological measurements along with their associated methods that are included in table 2.

Corn grain yield was determined by harvesting the center two rows of each plot and adjusting grain weight to 15.5% moisture. SAS software version 9.4 (SAS Institute Inc., Cary, NC) was used to complete all statistical analyses. The PROC REG and PROC NLIN procedures were used to evaluate the linear, quadratic, linear-plateau, and quadratic-plateau models for the corn N response to N fertilizer rate applications. A model averaging approach using both the linear- and quadratic-plateau model were used following the approach described by Miguez and Poffenbarger (2022) to calculate economic optimal N rate (N price = \$0.40 lb^{-1} and corn price = \$4.00 bu^{-1}), yield at economic optimal N rate, and yield without N fertilization. Sites were noted as nonresponsive and EONR set to 0 lbs N ac^{-1} when no plateau was reached. The EONR was noted as the maximum N rate applied (200 lbs N ac^{-1}) when no plateau was reached and a linear model best described the N response.

Table 2. Soil test measurements, methods, units, and primary references. All tests complete at Ward Laboratories in Kearney, NE.

Soil test	Brief method description	Units	Reference
Soil Health Test			
Permanganate oxidizable carbon	Oxidation with 0.2 M KMnO4 and shaken for 2 min at 240 oscillations per min with a 10 min settling time.	ppm	(Weil et al., 2003)
Soil respiration	24-hr incubation with KOH alkali trap	ppm C	(Zibilske, 1994)
Autoclaved citrate extractable protein	Autoclaved citrate extractable protein, 3 g soil with 24 ml Na3C6H5O7 buffer, autoclaved, and quantified with Bradford BCA	g kg^{-1}	(Moebius-Clune et al., 2016)
Arylsulfatase	p-nitrophenyl sulfate substrate addition with 1 h incubation at 36°C with PNP standard	ppm pNP g^{-1} soil h^{-1}	Klose et al. (2011)
β-Glucosidase	p-nitrophenyl-β-D-glucopyranoside substrate addition with 1 h incubation at 36°C with PNP standard	ppm pNP g^{-1} soil h^{-1}	Deng & Popova (2011)
N-Acetyl-β-Glucosaminidase		ppm pNP g^{-1} soil h^{-1}	Ward Laboratories
Soil Nitrogen Tests			
KCl NO3-N	KCl extraction of NO3-N	ppm	(Gelderman and Beegle, 2014)
KCl NH4-N	KCl extraction of NH4-N	ppm	Ward Laboratories
Total nitrogen	Measured via combustion on LECO TruMac C/N combustion analyzer (LECO Corp.).	ppm	(Nelson and Sommers, 1996)
Haney H2O NH4-N	Haney H2O extraction of NH4-N	ppm	Ward Laboratories
Haney H2O NO3-N	Haney H2O extraction of NO3-N	ppm	Ward Laboratories
Haney H2O Total N	Haney H2O extraction of Total N	ppm	Ward Laboratories
Haney H2O Organic N	Haney H2O Total N – (H2O NO3-N + NH4-N)	ppm	Ward Laboratories
Haney H3A NH4-N	Haney H3A extraction of NH4-N	ppm	(Haney et al., 2010)
Haney H3A NO3-N	Haney H3A extraction of NO3-N	ppm	(Haney et al., 2010)
Soil Carbon, Organic Matter, and Other Tests			
Total Carbon		%	(Nelson and Sommers, 1996)
Total organic carbon	Measured via combustion on LECO TruMac C/N combustion analyzer (LECO Corp.).	%	(Nelson and Sommers, 1996)
H2O extractable organic C			
Cation exchange capacity	Sum of base cations	me/100 g	(Soil Survey Staff, 2014)
Organic matter	Loss on ignition organic matter	%	(Nelson and Sommers, 1996)
pH water	Soil pH measured in water, with electrode (1:1 w/w)		(Peters et al., 2014)
Particle size	Hydrometer method	%	(Soil Survey Staff, 2014)

RESULTS AND DISCUSSION

EONR Related to Soil Health

The acid citrate extractable (ACE) protein test had the best relationship with EONR (R^2 = 0.34) (Table 3). All other soil health tests did not have a significant relationship with EONR. These results demonstrate that out of the six commonly used soil health measurements (POXC, soil respiration, ACE protein, and 3 enzymes: Arylsufatase, β-Glucosidase, N-acetyl-β-Glucosaminidase) evaluated in this study, the ACE protein test was the most likely test to help us further improve N rate guidelines. Although, these other tests do not relate well to EONR, they can still likely be used to evaluate general soil health and nutrient cycling.

Table 3. Relationship between corn economic optimal N rate (EONR) and various soil parameters.

Preplant Soil Test Measurement	Depth	P-Value	R^2
Soil Health			
Permanganate oxidizable C	0-6 in.	0.823	<0.01
Soil respiration	0-6 in.	0.149	0.06
ACE protein	0-6 in.	<0.001	0.34
Arylsulfase	0-6 in.	0.888	0.00
β-Glucosidase	0-6 in.	0.469	0.01
N-Acetyl-β-Glucosaminidase	0-6 in.	0.079	0.08
Soil Nitrogen Tests			
KCL NO3-N, lbs ac^{-1}	0-6 in.	0.399	0.01
KCL NO3-N, lbs ac^{-1}	0-24 in.	0.571	0.00
KCl NH4-N, lbs ac^{-1}	0-6 in.	0.26	0.03
KCl NH4-N, lbs ac^{-1}	0-24 in.	0.381	0.02
KCl NO3-N+NH4-N, lbs ac^{-1}	0-24 in.	0.554	0.01
Haney H2O NO3-N	0-6 in.	0.009	0.17
Haney H2O NH4-N	0-6 in.	0.377	0.02
Haney H3A NO3-N	0-6 in.	0.01	0.17
Haney H3A NH4-N	0-6 in.	0.192	0.05
Total nitrogen	0-6 in.	0.049	0.09
Haney H2O total N	0-6 in.	0.065	0.09
Haney H2O organic N	0-6 in.	0.087	0.08
Soil Carbon, Organic Matter, and Other Tests			
Total C	0-6 in.	0.007	0.16
total organic C	0-6 in.	0.004	0.19
H2O extractable Organic C	0-6 in.	0.004	0.20
Organic matter	0-6 in.	0.189	0.02
pH	0-6 in.	0.472	0.01
Cation exchange capacity	0-6 in.	0.961	<0.01
Sand	0-6 in.	0.049	0.09
Silt	0-6 in.	0.011	0.15
Clay	0-6 in.	0.987	<0.01
Silt:Sand	0-6 in.	0.004	0.19
Clay:Sand	0-6 in.	0.046	0.09
Clay:Silt	0-6 in.	0.027	0.11

Note: Units are the same as in table 1 unless otherwise noted.

EONR Related to Soil N Measurements

In areas in the US that are semi-arid to arid like that of South Dakota, the soil NO_3–N test is typically used to adjust N rate guidelines (Morris et al., 2018). However, the relationship between EONR and the traditionally used KCl extractable NO_3–N and NH_4–N from the top 6 or 24 inches never had a significant relationship ($P < 0.05$) with EONR (Table 3). This lack of relationship provides evidence to re-evaluate South Dakota's current N rate guidelines that use soil NO_3–N from the top 24 inches to adjust N rate recommendations. Also, important to note from these findings is that even though KCl extractable NO_3–N and NH_4–N did not relate to EONR, the H2O and H3A extractable NO_3–N tests from the top 6 inches had a relationship with EONR (R^2 = 0.17). Thus, providing evidence that H2O and H3A extractable N should be further evaluated for its ability to be used to improve current N rate guidelines. All other soil N tests evaluated in this study either had no relationship or a very weak relationship (R^2 < 0.10) with EONR.

EONR Related to C, Soil Texture, and Other Measurements

Similar to soil N tests, the various organic matter, C, and soil texture measurements also had at best marginal relationships with EONR ($R^2 \leq 0.20$) (Table 3). Of the C measurements, water extractable total C ($R^2 = 0.20$) had the strongest relationship followed by total organic C ($R^2 = 0.19$) and total C ($R^2 = 0.19$). When evaluating the components of soil texture (% sand, silt, and clay) and their ratios with each other, their relationships with EONR varied with R-squared results ranging between <0.01 (% clay) to 0.19 (silt:sand ratio). The best relationship alone of the three texture components was silt ($R^2 = 0.15$), sand ($R^2 = 0.09$), and lastly clay ($R^2 = < 0.01$). From these results, the various C measurements regardless of method and sand and silt percentage were the most likely to be able to be used to help improve current fertilizer-N rate guidelines.

Overall, the preliminary results from this study showed that the ACE protein test, C measurements, and the silt to sand ratio were the soil tests most likely to help us improve prediction of corn EONR. Continued evaluation of these soil tests relationship with EONR will continue for at least one more year at 12 locations throughout South Dakota.

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EVALUATION OF SOYBEAN RESPONSE TO SURFACE AND SUB-SURFACE PHOSPHORUS FERTILIZER PLACEMENT

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ABSTRACT

Phosphorus (P) fertilizer placement can affect P plant uptake during the growing season and yield at harvest; in addition, sub-surface placement of P fertilizer can provide environmental benefits by minimizing losses. The objective of this study was to evaluate the yield response and plant uptake to surface and sub-surface P fertilizer application in soybean. This study was conducted in 2022 at two locations (Scandia and Manhattan, Kansas). The average soil P level (Mehlich 3), was 17 ppm in Manhattan and 3 ppm in Scandia. Phosphorus fertilizer was applied before planting at 0, 40, 80, and 120 lbs P2O5 /acre. Two placements included surface broadcast and sub-surface with the drill (7.5 inches spacing). Rates and placement were arranged in a complete factorial combination of treatments. Measurements included P uptake at the V4 stage, trifoliate P concentration at the R3 stage, and seed yield. Statistical analysis was performed with the R software. In Manhattan, the early season P uptake (V4) showed a statistically significant response to rates and placement. Higher values were attained with sub-surface placement. In Scandia, soybean P uptake at V4 showed no significant response to placement, with a numerically higher value for the sub-surface placement. Trifoliate P concentration at the R3 stage showed a statistical difference for P rates in Scandia, with a higher P concentration for the high rates of P fertilizer of 80 and 120 lbs. P2O5 acre^{-1}. In Manhattan, with higher soil test P (17 ppm) there was a general trend for a clearer placement response in the early season; whereas in Scandia, with very low soil test P (3 ppm), there was a significant response to P fertilizer rates regardless of placement.

INTRODUCTION

Phosphorus fertilizer placement can influence the nutrient absorption by the plant and can change the dynamics and availability due to its interaction with the soil (Arruda Coelho et al., 2019). Phosphorus management can affect soybean yield by influencing plant nutrient uptake and, in some cases modifying plant root development (Hansel et al., 2017). Furthermore, Phosphorus placement is essential for improving nutrient use efficiency and reducing the risk of loss when applied in sub-surface (Preston et al., 2019).

Phosphorus placement via broadcast is the easiest method of applying phosphorus (Randall and Hoeft, 1988). However, applying subsurface phosphorus can have some advantages (Hansel et al., 2017b). The objective of this study was to evaluate the yield response and plant uptake to surface and sub-surface P fertilizer application in soybean.

MATERIALS AND METHODS

This study was conducted in 2022 at two locations (at the North Central Kansas Experiment field in Scandia, KS, and at the North Agronomy Farm in Manhattan, KS). The field in Scandia was irrigated while Manhattan was on dryland. In Manhattan, the soybean was planted into wheat residue, and in Sandia, it was planted into corn residue, both with no prior tillage. Before fertilizer application, soil samples were collected at a depth of 0 to 6 inches using a hand probe. The average soil P level (Mehlich 3), was 17 ppm in Manhattan and 3 ppm in Scandia.

Treatments included a control with no P application and three P rates of 40, 80, and 120 lbs P2O5 /acre, using mono-ammonium phosphate (MAP). The P rates had two different placements: surface broadcast and sub-surface with the drill (7.5 inches spacing). Rates and placement were arranged in a complete factorial combination of treatments.

Measurements included plant biomass at the V4 stage, P uptake at the V4 stage, trifoliate P concentration at the R3 stage, and seed yield at harvest. The plant tissue samples were digested using nitric-perchloric acid digestion and analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Statistical analysis was performed with the R software version 4.2.1.

RESULTS AND DISCUSSION

Early-season phosphorus uptake (V4) showed a significant response to the highest phosphorus rate when applied via sub-surface in Manhattan (Figure 1A). There were no statistically significant differences in Scandia as the P fertilizer rates were increased, but there were greater uptake values when the fertilizer was applied subsurface (Figure 2B). This increase in P uptake when the fertilizer was applied via sub-surface is perhaps due to the proximity of the nutrient and the root, improving P availability for the plants (Borkert and Barber 1985).

There was an increase in the trifoliate P concentration with higher fertilizer rates in Scandia, with no statistical difference between placements (Figure 2B). There was likely an increase in P uptake by the plant multiple days after fertilization (Comerford et al., 1987). Therefore, the increase in the concentration of P in the trifoliate when higher P rates are applied in Scandia is likely due to the lower soil test P value (3 ppm). Resulting in a greater P uptake when P fertilizer is applied. In Manhattan, with a higher soil test P value (17 ppm), there was no difference in trifoliate P concentration for both rates and placement (Figure 2A). Seed yield followed trends similar to P concentration in R3 for both Manhattan (Figure 3A) and Scandia (Figure 3B).

In Manhattan, with higher soil test P (17 ppm) there was a general trend for a placement response in the early season, whereas in Scandia, with very low soil test P (3 ppm), there was a significant response to P fertilizer rates regardless of placement.

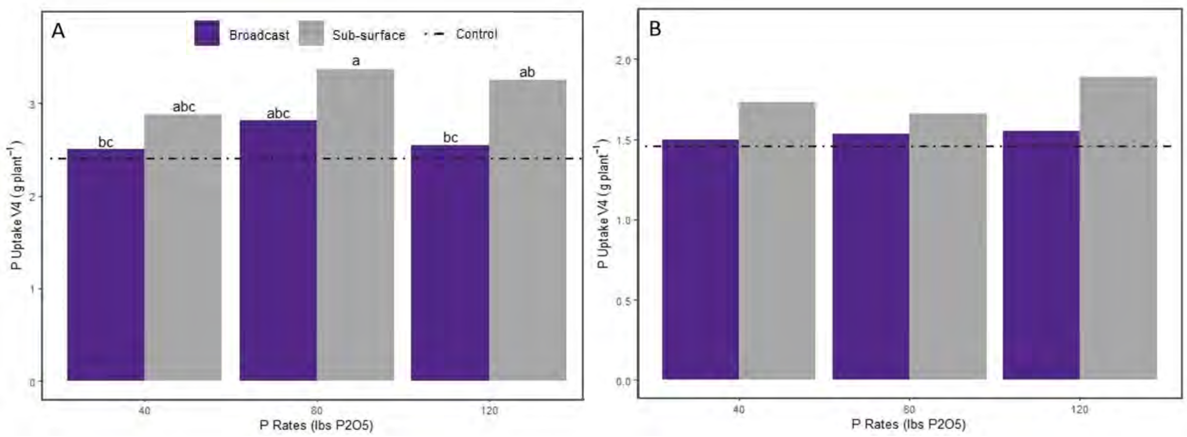

Figure 1: Phosphorus uptake (g plant^{-1}) as affected by different P placement and rates in Manhattan (A) and Scandia (B). Values followed by different letters indicate significant differences at the p≤ 0.05 probability level.

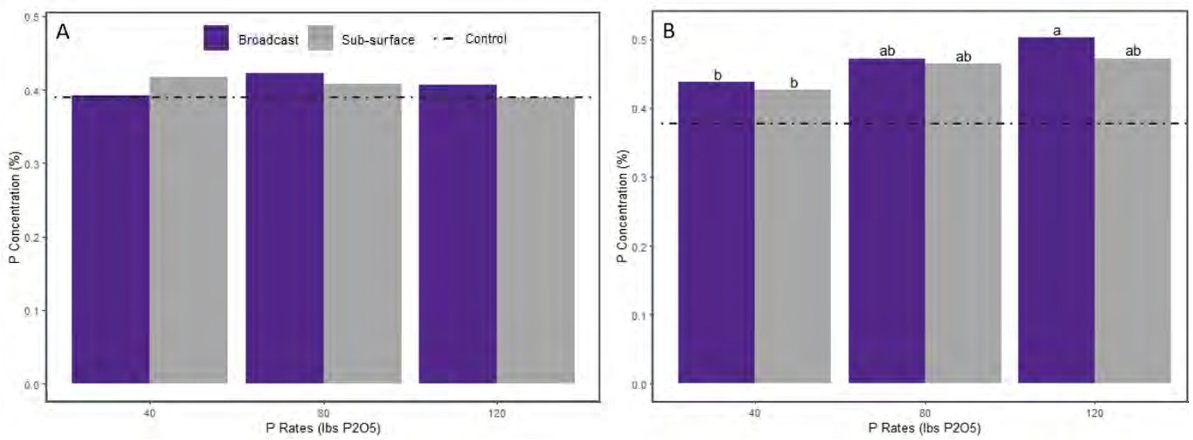

Figure 2: Phosphorus Concentration (%) as affected by different P placement and rates in Manhattan (A) and Scandia (B). Values followed by different letters indicate significant differences at the p≤ 0.05 probability level.

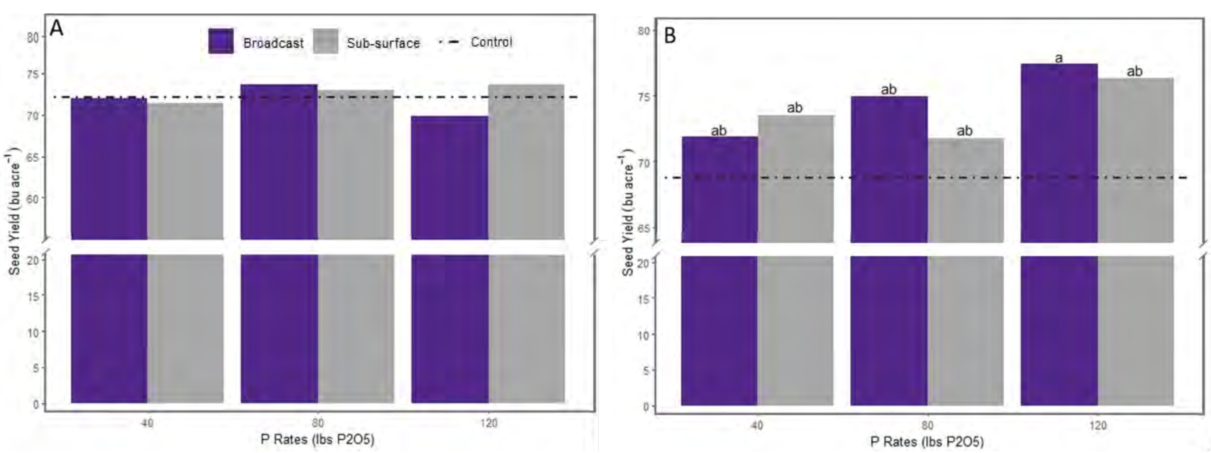

Figure 3: Seed yield (bushels acre^{-1}) as affected by different P placement and rates in Manhattan (A) and Scandia (B). Values followed by different letters indicate significant differences at the p≤ 0.05 probability level.

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IMPROVING DIGITAL SOIL MAPS FOR SITE-SPECIFIC SOIL FERTILITY MANAGEMENT USING FEATURE SELECTION

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ABSTRACT

In this study, the effectiveness of six types of FS methods from four categories (filter, wrapper, embedded, and hybrid) were compared. These FS algorithms chose relevant covariates from a set of 1049 environmental covariates for predicting five soil fertility properties in ten fields, in combination with ten different ML algorithms. The resulting model performance was compared by three different metrics (R^2 of 10-fold cross validation (CV), robustness ratio (RR; developed in this study), and independent validation with Lin's concordance correlation coefficient (IV-CCC)). Wrapper (BorutaShap) and embedded (Lasso-FS, Random forest-FS) methods with decision-tree based ML algorithms usually led to the optimal models. FS improved CV, RR, and IV-CCC compared to the models built without FS for most fields and soil properties. Wrapper (BorutaShap) and embedded (Lasso-FS, Random forest-FS) methods usually led to the optimal models. The filter-based ANOVA-FS method mostly led to overfit models, especially for fields with smaller sample quantities. Decision-tree based models were usually part of the optimal combination of FS and ML. Considering RR helped identify optimal combinations of FS and ML that can improve the performance of DSM compared to models produced from full covariate stacks. FS can assist building better predictive soil models to create better digital soil maps, which in return can improve the farm management (e.g., fertilization, liming, and manuring).

Introduction

Digital soil mapping (DSM) has been widely used to map various soil properties and classes for the last few decades [1]. A strategy for DSM is the process of using predictive statistical models (e.g., machine learning (ML)), utilizing the relationships between georeferenced soil lab data and environmental predictors (aka covariates) [2]. Performance of ML relies heavily on the covariates used to represent true soil-landscape relationships [3]. Thus, covariate (aka feature) selection is an important aspect for DSM. Objectives of FS, as a data pre-processing strategy, include building simpler models, reducing the effect of the curse-of-dimensionality, and improving prediction performance [4]. Previous studies on FS in DSM have focused on less dynamic and less heavily managed soil properties (e.g., soil classes and soil organic matter) [5, 6, 7] compared to soil fertility properties (e.g., soil-test-P and -K). In our study, the effectiveness of six types of FS methods from four categories (filter, wrapper, embedded, and hybrid) were compared. These FS methods chose relevant covariates from a set of 1049 environmental covariates for predicting five dynamic soil fertility properties in ten fields, in combination with ten different ML algorithms.

Methodology

Study Area and Input Datasets

The study sites were ten agricultural fields located within a research farm near Ames, Iowa, USA. A total of 992 soil samples, collected from a depth of 0–15 cm between 2018 and 2020 were used in this study. All samples from each field (A-J) were collected on a single date (Figure 1). Samples were analyzed for nitrate-nitrogen (NO_3^-), soil-test phosphorus (P), soil-test potassium (K), buffer pH (BpH), soil organic matter (SOM). The covariate set included 1049 spatial variables from digital terrain analysis (DTA) and spectral bands of RS (aerial and satellite imagery). Same covariates were used as in Ferhatoglu and Miller [8]. All covariates were resampled to 3 m spatial resolution and spatially aligned. Environmental covariate values were then paired with soil lab data at the sampling locations and transferred to a csv format for FS process. Selected covariates were used in ML algorithms to create predictive soil models.

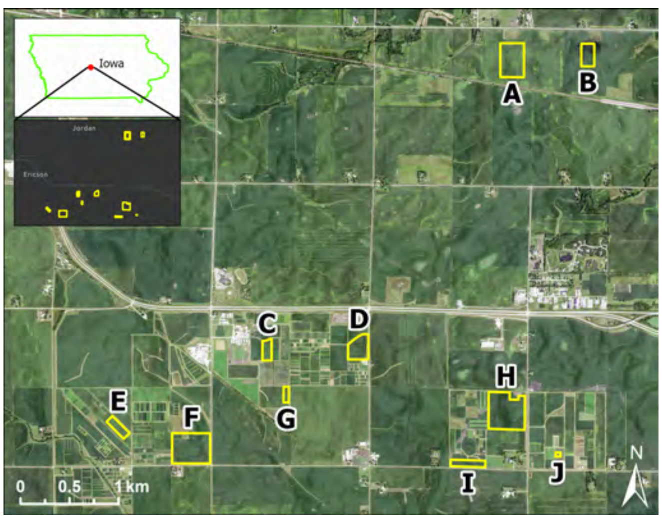


Figure 1. The study fields (A–J). The size of the fields ranged from 0.4 ha to 13.1 ha. Soil samples were collected from the fields with a grid-sampling design.

Feature Selection and Modelling

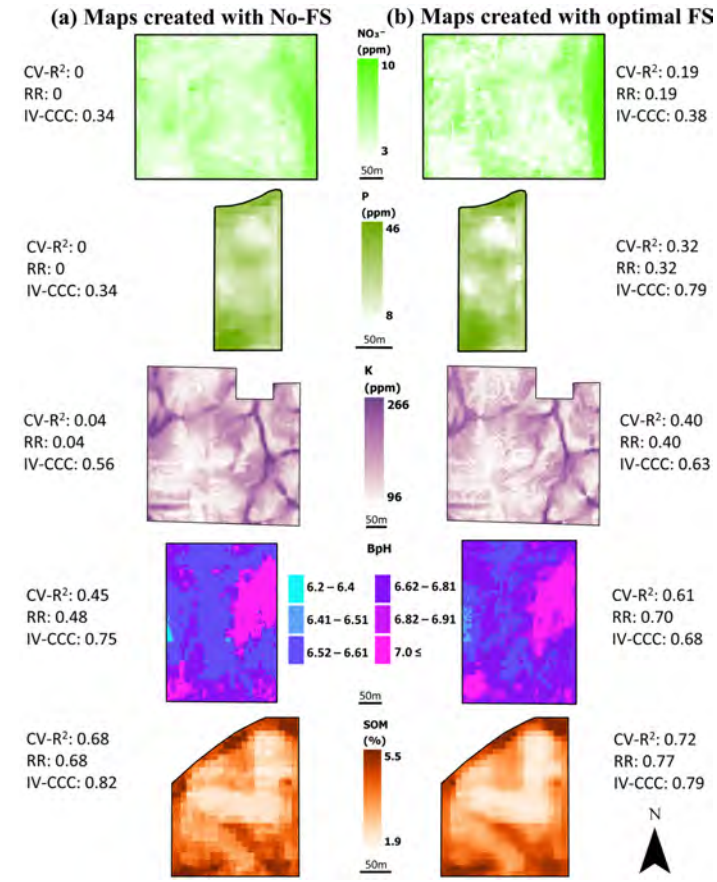
Six different FS methods were applied to identify relevant covariates: (1) Combined-filter-FS, (2) ANOVA-FS, (3) BorutaShap-FS, (4) Random Forest FS (RF-FS), (5) Lasso-FS, and (6) Hybrid-FS. Combined-filter-FS and ANOVA represented filter FS strategies while BorutaShap-FS, RF-FS, and Lasso-FS were embedded FS strategies. Hybrid-FS method represented hybrid FS strategy. More details about these FS methods can be found in in Ferhatoglu and Miller [8]. Using each covariates selected, ten ML algorithms (Lasso regressor, support vector regressor (SVR) with polynomial kernel, and multi-layer perceptron regressor (MLP), random forest (RF) regressor, extra-trees-regressor (ETR), CatBoost, AdaBoost, LightGBM, gradient boosting (GB), a voting regressor based on the nine ML algorithm above) from scikit-learn [9] with default parameters were used to model soil properties and compare FS methods by their interaction with ML algorithms. Voting regressor ranked predictions of the nine ML algorithms based on R^2 score on the validation set (IV: 20%) to weight respective model predictions in the final prediction.

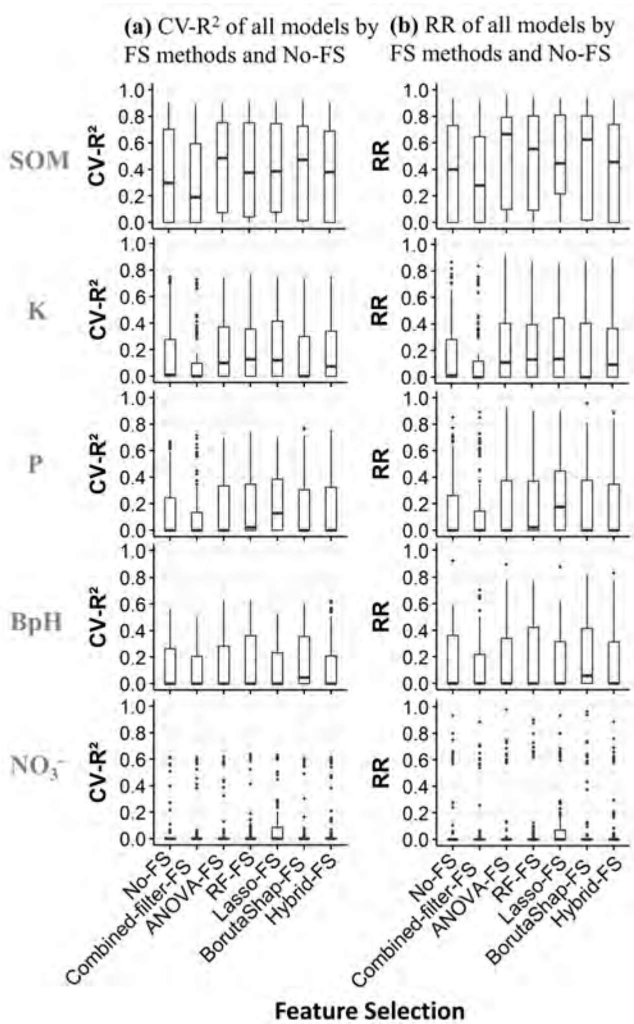
Experimental Design & Evaluation

Firstly, six FS methods were applied to the covariate stack for each target soil property and sample set (i.e., individual fields plus all fields combined. Full covariate stack was the control treatment. Models were then built from ten ML algorithms for each of those treatments, yielding 70 ML models per sample set and soil property. To simplify the evaluation process and interpretation of results, three stages of evaluation metrics were applied to identify the highest performing models. First, the models were evaluated by the R^2 of 10-fold cross-validation (CV). Ten models with the highest CV-R^2 score were selected for subsequent analysis based on a new metric introduced in this study to measure the robustness of the model (RR: R^2 of 10-fold CV/ R^2 of goodness-of-fit, which was 80% of samples). The five models exhibiting a likelihood to be robust were subsequently evaluated for prediction performance. The model with the highest CCC [10] based on IV was determined to be the optimal model for the respective field and soil property.

Results

Overall, FS methods consistently reduced the covariate stack to less than half of the original quantity. The largest to lowest reduction in covariate stack size was made by as follows: BorutaShap-FS > Lasso-FS ≈ Hybrid-FS > ANOVA-FS, Combined-filter-FS ≈ RF-FS. Models built from covariate stacks reduced by FS mostly performed better in CV than those built without FS for all properties (Figure 2A). NO_3^- was particularly challenging for producing predictive models, where the median CV-R^2 for No-FS and all FS methods was zero. Patterns between CV and RR were similar, which suggests stronger CV performance could be connected to RR performance (Figure 2A). In the second step of the evaluation, models from some FS methods remained competitive, while others were more often cut due to lower performance in terms of RR (data not shown). Although ANOVA-FS had the highest frequencies in the first step for K, BpH and NO_3^-, the difference between ANOVA-FS and other FS methods became smaller. Models produced from covariate stacks reduced by FS methods outperformed models built from covariate stacks without FS in most cases for independent validation (data not shown). IV-CCC scores for the final models were higher than full models for nine (SOM), eight (K), six (P), five (BpH), and all (NO_3^-) sample sets. BorutaShap-FS, ANOVA-FS, RF-FS, Lasso-FS were commonly optimal FS methods among the sample sets. Digital soil maps developed with the full covariate stack tended to be smoother than the maps created by using FS with exceptions in some fields (e.g., SOM map in field D) (Figure 2B). Despite differences observed in the evaluation of the models' prediction performance, all maps produced from covariate stacks reduced by FS had similar patterns to their No-FS counterparts. Figure 2B presents some examples comparing maps developed with and without FS.


(a) Maps created with No-FS
(b) Maps created with optimal FS
CV-R²: 0
RR: 0
IV-CCC: 0.34
CV-R²: 0.19
RR: 0.19
IV-CCC: 0.38
CV-R²: 0
RR: 0
IV-CCC: 0.34
CV-R²: 0.32
RR: 0.32
IV-CCC: 0.79
CV-R²: 0.04
RR: 0.04
IV-CCC: 0.56
CV-R²: 0.40
RR: 0.40
IV-CCC: 0.63
CV-R²: 0.45
RR: 0.48
IV-CCC: 0.75
CV-R²: 0.61
RR: 0.70
IV-CCC: 0.68
CV-R²: 0.68
RR: 0.68
IV-CCC: 0.82
CV-R²: 0.72
RR: 0.77
IV-CCC: 0.79
N


(a) CV-R² of all models by FS methods and No-FS
(b) RR of all models by FS methods and No-FS
SOM
K
P
BpH
NO3-
CV-R²
RR
No-FS
Combined-filter-FS
ANOVA-FS
RF-FS
Lasso-FS
BorutaShap-FS
Hybrid-FS
Feature Selection

(A) (B)

Figure 2. (A) Comparisons of performance for models produced from the different FS treatments, evaluated by (a) CV-R^2 and (b) RR. Except for Combined-filter-FS, FS methods consistently outperformed the No-FS treatment. For the most part, evaluation of models by RR followed similar patterns to those of CV-R^2, which suggests the higher CV-R^2 may also tend to have smaller differences between the goodness of fit R^2 and CV-R^2. (B) Examples of maps created by the optimal models built from covariate stacks with (a) No-FS and (b) FS. Applying FS generally led to less smooth maps compared to maps created with full covariate stacks. However, there were exceptions such as the SOM map shown in these examples. Maps shown reflect soil fertility levels present on the sampling dates: NO_3^- for field F (8 June 2019), P for field C (12 July 2019), K for field H (25 June 2018), BpH for field A (29 June 2020), and SOM for field D (16 July 2019).

Conclusions

Models produced from covariate stacks reduced by FS methods were less likely to be overfit and tended to have better performance in IV-CCC. Although there was no single optimal FS method among sample sets or soil properties, wrapper and embedded FS strategies produced the optimal model more frequently than the hybrid and filter FS strategies. Given the economic and environmental promise of precision agriculture, combined with the increasingly finer temporal resolution of remote sensing, there is an opportunity to apply these methods to provide farmers with better soil fertility maps.

ACKNOWLEDGMENTS

This work would not have been possible without the cooperation of several research groups within the Department of Agronomy at Iowa State University. Special thanks to the A.K. Singh Soybean Breeding and Genetics Group and the Geospatial Laboratory for Soil Informatics. Support for Caner Ferhatoglu was provided by the Department of Agronomy at Iowa State University.

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INDIVIDUAL LEAF SELECTION TO BEST REPRESENT WHOLE-PLANT NUTRIENT STATUS IN MODERN CORN CROPPING SYSTEMS

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ABSTRACT

In modern corn cropping systems, fertilization is often required to maintain plant health. Tissue sampling is commonly utilized to evaluate plant nutrient status and determine fertilizer treatment needs. Recommendations exist on which partition/leaf to select for accurate representation of the whole-plant. Recommendations change with growth stage, suggesting to sample the whole-plant at early-vegetative stages, the top-collared leaf at late-vegetative stages, and the ear-leaf during reproductive stages. The primary goal of this study was to explore the ability of various individual-leaf sample selections to accurately represent the whole-plant concentrations of nitrogen (N), phosphorous (P), potassium (K), and sulfur (S) across multiple growth stages and N rates. Research was conducted at the Agronomy Center for Research and Education (ACRE) near West Lafayette, IN during the 2021 and 2022 growing seasons. The experiment included three N rates (0, 135, and 215 lbs. N ac^{-1}) sidedress applied as UAN (28-0-0) at V5. At V8, the 8th leaf and whole-plant were sampled. At V12, the 8th leaf, 12th leaf, and whole-plant were sampled. Grain yields responded positively to N application, increasing from 124 bu ac^{-1} without N to 234 bu ac^{-1} under 135 lbs. N ac^{-1} and 270 bu ac^{-1} under 215 lbs. N ac^{-1}. At both V8 and V12, leaf and whole-plant N concentrations showed a strong response to N application, increasing ($P<0.05$) by up to 60%. At V12, 8th and 12th leaf P, in addition to 8th leaf and whole-plant S were increased by N application. Plant K was not significantly influenced by N rate or year at any stage. Whole-plant nutrient concentrations averaged 3.41% N, 0.41% P, 2.54% K, and 0.24% S at V8. At V8, whole-plant N was 13% lower than 8th leaf N, whole-plant S was 14% lower than 8th leaf S, whole-plant P was 13% higher than 8th leaf P, and whole-plant K was 24% higher than 8th leaf K. At V12, whole plant nutrient concentrations averaged 2.04% N, 0.25% P, 2.01% K, and 0.13% S. Relative to the 8th leaf at V12, whole-plant N was 38% lower, S was 80% lower, P was 5% higher, and K was 14% higher. Relative to the 12th leaf at V12, whole-plant N was 31% lower, S was 30% lower, P was 10% lower, and K was 6% higher. Individual-leaf N and S were most similar to whole-plant N and S when the 8th leaf was sampled at V8. Leaf P was most similar to whole-plant P at V12 (both 8th and 12th leaves), while leaf K was most similar to whole plant K in the 12th leaf sampled at V12. Preliminary results indicated that (1) leaf P and K were similar to whole-plant P and K, (2) leaf N and S differed from whole-plant N and S, and (3) from V8 to V12, nutrient dilution led to decreased nutrient concentrations. Further analysis will incorporate leaf comparisons at R1, and stover versus grain comparisons at R6 to determine how the trends already observed continue into the reproductive period.

MATERIALS AND METHODS

This experiment was conducted in West Lafayette, IN at the Agronomy Center for Research and Education (ACRE) for both the 2021 and 2022 growing seasons. The study was conducted in separate field areas for each of the growing seasons to maintain that the previous crop was soybean in both site-years. The experimental design was a randomized complete block design (RCBD) consisting of 4 to 6 replications within a larger 8-replication N study. This analysis focused on 3 of 6 sidedress N rates (0, 135, and 215 lbs. N acre^{-1}) included in the study. Pioneer hybrid 1359AM was grown at a density of 31,000 plants acre^{-1} (2021) and 34,000 plants acre^{-1} (2022). N fertilizer treatments were sidedressed as urea ammonium nitrate (UAN; 28-0-0) using coulter injection at the V5 growth stage. Sulfur was pre-plant broadcast applied as ammonium thiosulfate (ATS) (12-0-0-26(S)) to supply 20 lbs. SO_4 ac^{-1} to the entire trial area. The N supply from the ATS was approximately 9.2 lbs. N ac^{-1}. Plots were planted on April 28th (2021) and May 2nd (2022) using a six-row John Deere 1780 planter. Each plot consisted of six rows with 30-inch spacing for a total width of 15 feet and a length of 90 feet. Grain yield was determined by combine harvesting the central 2 rows of the 6-row plots for a harvest area of 450 ft^2 in each plot. Grain yields were adjusted to 15.5% moisture based on moisture readings from the combines.

Tissue samples were collected during the V8 and V12 growth stages. Individual-leaf and whole-plant samples came from the same 10 plant sample for each plot meaning leaves were removed from each of the 10 plants. At V8 this included separating the 8th leaf and whole-plant. At V12 the 8th leaf, 12th leaf, and whole-plant were separated. All tissue samples were dried at 60 C, weighed, and ground to a 1mm consistency before nutrient concentration could be determined. Samples were sent to Waypoint Analytical in Memphis, TN where the PT2 nutrient analysis was conducted. Upon receiving results, the weights and nutrient concentrations of individual leaves and their whole-plant counterparts were used to algebraically determine the true whole-plant nutrient concentrations, incorporating the leaves back into the whole-plant total. Prior to V8, aerosol spray paint was applied to the tip of the 7th leaf on each plant. This allowed researchers to distinguish specific leaf positions for accurate sampling as plants grew.

RESULTS AND DISCUSSION

It is important to consider nutrient sufficiency ranges and what partition these ranges are based upon. In Table 1, the V5 values are based upon a sample of the whole-plant. However, R1 samples are based upon just the ear-leaf. In many situations this may be a good representation of the whole-plant, but this study will investigate how this dynamic between a single leaf and the whole-plant can change with regard to growth stage, leaf position, soil N availability, and nutrient of interest. It is well documented in the literature that certain nutrients are mobile within the vasculature of a plant while others are not. Sulfur, for instance, is relatively immobile. Thus, once it is within the tissue of a

Table 1. Nutrient concentration sufficiency ranges in corn tissue during early vegetative (V5) and reproductive (R1) growth.

	Sufficiency Range (%)		
Nutrient	Whole Plant (~V5)	Ear Leaf (R1)	Mobility Within Plant
N	3.5-5.0	2.75-3.50	Mobile
P	0.3-0.5	0.25-0.45	Mobile
K	2.5-4.0	1.75-2.25	Mobile
S	0.2-0.5	0.15-0.50	Immobile

Adapted from "Plant analysis for testing nutrient levels in corn".

plant it is less likely to move to other areas if nutrient deficiency occurs. Alternatively, N, P, and K are relatively mobile.

In both years soil fertility samples were taken on an individual plot basis at planting to understand soil characteristics that could have implications on the plant tissue analysis to follow. Table 2 summarizes data from for both site-years to give averages of organic matter (OM), cation exchange capacity (CEC), P, K, and S levels. Results indicate a 10-ppm difference in P with lower phosphorous soil availability in 2021 compared to 2022. Inversely, soil levels of potassium were 10-ppm higher in the 2022 field site.

Table 2. Soil fertility characteristics measured at planting to a depth of 8" averaged across all plots for a given year

Year	OM (%)	CEC (meq/100g)	P (ppm)	K (ppm)	S (ppm)
2021	4.0	19.1	31	149	11
2022	3.7	18.9	41	139	11

Nitrogen

Nitrogen is often considered the "most" essential nutrient in corn production and is highly mobile within the plant (Table 1). During vegetative growth, N concentrations in the whole-plant decreased over time from 3.41% N to 2.04% N from V8 to V12 (Table 3). Similarly, the 8th leaf N concentration decreased from 3.85% N at V8 to 2.81% N at V12 (Table 3). At V8, the 8th leaf N concentration was 0.44% N higher than the whole-plant. Continuing with the idea of top-leaf versus whole-plant at the V12 growth stage, the 12th leaf averaged 2.68% N making it 0.64% N higher than the V12 whole-plant. At V12, the 8th leaf had a higher N concentration than the whole-plant with a concentration of 2.81% N in the 8th leaf compared to the 2.04% N in the whole-plant. Surprisingly, at V12 the N concentration of the 8th leaf was 0.13% N higher than the 12th leaf (Table 3). Overall, leaf N was higher than whole-plant N and grew as the season progressed.

Table 3. Nitrogen Concentration of Various Individual-Leaf and Whole-Plant Tissue Samples from V8 and V12 Growth Stages across Multiple N Application Rates and Years

	Vegetative Nitrogen Concentration (%)				
	V8 Growth Stage		V12 Growth Stage		
Nitrogen Rate lbs N acre^{-1}	8th Leaf	Whole Plant	8th Leaf	12th Leaf	Whole Plant
2021	3.90	3.22	2.87	2.76	2.26
0	3.68	2.90	2.44	2.32	1.76
135	4.00	3.38	3.07	2.93	2.61
215	4.01	3.38	3.10	3.03	2.42
2022	3.83	3.54	2.77	2.62	1.89
0	3.49	3.12	2.14	1.95	1.41
135	3.90	3.71	2.96	2.92	2.08
215	4.10	3.80	3.21	3.00	2.17
Mean	3.85	3.41	2.81	2.68	2.04
Significance Test[1]					
N Rate	**	**	**	**	**
Year	ns	**	ns	*	**
N Rate*Year	ns	ns	*	*	ns

[1]A mixed model was run using JMP Pro 9.1 with N rate and Year as main effects, block as a random effect, and block*year as a random effect. P-Values greater than 0.05 considered non-significant (ns). P-Values less than 0.05 (*), 0.01 (**), and 0.001 (***).

Nitrogen application rate significantly influenced N concentrations of all plant partitions, particularly at the later growth stage. Plants that did not receive additional N fertilization had the lowest N concentrations. Differences between the higher N rates were often small due to both rates being sufficient for plant growth at V12 (plant N requirements increase as the season progresses).

Nitrogen concentrations differed significantly from year to year, varying by 10% in V8 whole-plants, 18% in V12 whole-plants, and 5% in V12 12th leaves. At V8, whole-plant N was higher in 2022 than in 2021 whereas the opposite was true at V12. Furthermore, a significant interaction between N rate and year was detected in V12 8th and 12th leaves due to much stronger N concentration responses to N application observed in 2022 compared to 2021.

Sulfur

Sulfur is considered immobile within the plant, meaning S usually remains in older tissues even after other nutrients have been remobilized (Table 4). From V8 to V12 the whole-plant S concentration decreased from 0.24 to 0.13%. Being far less mobile than N, Table 4 suggests that the 8th leaf retains a substantial amount of S from V8 to V12, decreasing to a lesser extent in the leaves, from 0.27 to 0.23% S, than the whole-plant. At V8, 8th leaf S was just 0.03% S higher than whole-plant S, however by V12, 8th leaf S was 0.10% S higher than whole-plant S (Table 4). At V12, the 12th leaf also had a higher S concentration than the whole-plant.

Table 4. Sulfur Concentration of Various Individual-Leaf and Whole-Plant Tissue Samples from V8 and V12 Growth Stages across Multiple N Application Rates and Years

	Vegetative Sulfur Concentration (%)				
	V8 Growth Stage		V12 Growth Stage		
Nitrogen Rate lbs N acre-1	8th Leaf	Whole Plant	8th Leaf	12th leaf	Whole Plant
2021	0.27	0.22	0.19	0.16	0.14
0	0.28	0.21	0.20	0.15	0.12
135	0.26	0.22	0.19	0.17	0.15
215	0.28	0.22	0.19	0.18	0.14
2022	0.27	0.25	0.26	0.17	0.12
0	0.26	0.24	0.23	0.14	0.11
135	0.27	0.26	0.26	0.18	0.13
215	0.29	0.27	0.28	0.19	0.13
Mean	0.27	0.24	0.23	0.17	0.13
Significance Test[1]					
N Rate	ns	ns	ns	**	**
Year	ns	**	**	ns	**
N Rate*Year	ns	ns	*	ns	ns

[1]A mixed model was run using JMP Pro 9.1 with N rate and Year as main effects, block as a random effect, and block*year as a random effect. P-Values greater than 0.05 considered non-significant (ns). P-Values less than 0.05 (*), 0.01 (**), and 0.001 (***).

The average difference in S concentration between the 8th and 12th leaf at V12 was 0.06%, with the 8th leaf having the higher S concentration than the 12th leaf (Table 4). This trend, however, is not consistent between years with the 2022 data showing a larger difference than 2021. Furthermore, the 12th leaf was more similar to the whole-plant S status than the 8th leaf at V12. This means that at both V8 and V12 the top collared leaf was approximately 0.03% higher than the whole-plant (Table 4).

Nitrogen application rate affected V12 12th leaf and whole-plant S concentrations. When no N was applied, S concentrations were decreased by up to 36% relative to treatments receiving an N application (Table 4). Sulfur concentrations differed significantly from year to year, varying by 15% in V8 whole-plants, by 30% in V12 8th leaves, and by 13% in V12 whole-plant samples (Table 4). At V8, whole-plant S concentrations were higher in 2022, a trend also seen in the 8th leaf at V12. However, the V12 whole-plant had a lower S concentration in 2022 than in 2021. An interaction between N rate and year effects was detected from the V12 8th leaf due to S concentrations responding positively to N rates in 2022, yet remaining stable across N rates in 2021 (Table 4).

Phosphorous

Phosphorus is mobile within the plant despite being considered the most immobile nutrient in the soil. Table 5 illustrates that P concentration decreased from V8 to V12 in both the 8th leaf and whole-plant. The 8th leaf decreased from 0.35 to 0.24% P, but the decrease was more dramatic in 2021 (Table 5). The whole-plant P concentration also

Table 5. Phosphorous Concentration of Various Individual-Leaf and Whole-Plant Tissue Samples from V8 and V12 Growth Stages across Multiple N Application Rates and Years

	Vegetative Phosphorous Concentration (%)				
	V8 Growth Stage		V12 Growth Stage		
Nitrogen Rate lbs N acre-1	8th Leaf	Whole Plant	8th Leaf	12th Leaf	Whole Plant
2021	0.38	0.41	0.23	0.29	0.25
0	0.39	0.41	0.23	0.27	0.26
135	0.37	0.42	0.22	0.28	0.25
215	0.38	0.41	0.23	0.31	0.25
2022	0.33	0.40	0.25	0.27	0.25
0	0.31	0.38	0.21	0.25	0.25
135	0.34	0.40	0.26	0.28	0.25
215	0.36	0.42	0.27	0.28	0.25
Mean	0.35	0.41	0.24	0.28	0.25
Significance Test[1]					
N Rate	ns	ns	*	**	ns
Year	**	ns	*	ns	ns
N Rate*Year	ns	ns	**	ns	ns

[1]A mixed model was run using JMP Pro 9.1 with N rate and Year as main effects, block as a random effect, and block*year as a random effect. P-Values greater than 0.05 considered non-significant (ns). P-Values less than 0.05 (*), 0.01 (**), and 0.001 (***).

decreased from 0.41 to 0.25% P (Table 5). Whole-plant P trends over time were consistent across years with no major differences between N rate treatments.

At V8, 8th leaf P was 0.35% P which was lower than the 0.41% P measured in the whole-plant (Table 5). At V12,12th leaf P was slightly higher than both the 8th leaf and whole-plant status. The 8th leaf and whole-plant P concentrations were similar at V12.

Nitrogen application rate had a significant effect on both the 8th and 12th leaf at V12. In general, leaf P concentrations increased by up to 25% with N application. Phosphorus concentrations differed significantly from year to year, varying by 12% in the V8 8th leaf and 7% in the V12 8th leaf (Table 5). At V8, 8th leaf P concentrations were higher in 2021. However, at V12, 8th leaf P concentrations were higher in 2022. There was a significant interaction between year and N rate in the 8th leaf at V12 due to a positive P concentration response to N rate in 2022 but no response to N rate in 2021.

Potassium

Potassium demand peaks during the vegetative period and is mobile within the plant. From V8 to V12, K concentrations decreased in the whole-plant by about 0.6% K (Table 6). At V8, 8th leaf K decreased dramatically in 2021 from 2.16% to 1.72% but remained relatively stable during the same time period in 2022, only decreasing from 1.77 to 1.73% K (Table 6). Whole-plant K concentrations were consistently higher than individual-leaf concentrations.

Table 6. Potassium Concentration of Various Individual-Leaf and Whole-Plant Tissue Samples from V8 and V12 Growth Stages across Multiple N Application Rates and Years

	Vegetative Potassium Concentration (%)				
	V8 Growth Stage		V12 Growth Stage		
Nitrogen Rate lbs N acre-1	8th Leaf	Whole Plant	8th Leaf	12th Leaf	Whole Plant
2021	2.16	2.81	1.72	2.05	2.21
0	2.39	3.09	2.15	2.22	2.52
135	1.74	2.30	1.36	1.85	1.95
215	2.34	3.05	1.65	2.07	2.17
2022	1.77	2.35	1.73	1.79	1.87
0	1.82	2.33	1.94	2.01	2.16
135	1.66	2.15	1.56	1.66	1.72
215	1.85	2.58	1.70	1.70	1.74
Mean	1.93	2.54	1.73	1.89	2.01
Significance Test[1]					
N Rate	ns	ns	ns	ns	ns
Year	ns	ns	ns	ns	ns
N Rate*Year	ns	ns	ns	ns	ns

[1]A mixed model was run using JMP Pro 9.1 with N rate and Year as main effects, block as a random effect, and block*year as a random effect. P-Values greater than 0.05 considered non-significant (ns). P-Values less than 0.05 (*), 0.01 (**), and 0.001 (***).

Despite large year and N rate differences in treatment means shown in Table 6, significant N rate and year effects were not detected due to variable K concentration results. Still notable however, the 0 lbs. N ac^{-1} treatment had a K concentration in the 8th leaf, 12th leaf, and whole-plant. At both V8 and V12 the median N rate of 135 lbs. N ac^{-1} consistently had low mean K concentration values for all partitions across both years.

Grain yields in both 2021 and 2022 were above the Indiana state average. Grain yields responded positively to N application, increasing from 124 bu ac^{-1} without N to 234 bu ac^{-1} under 135 lbs. N ac^{-1} and 270 bu ac^{-1} under 215 lbs. N ac^{-1} (Table 7).

Table 7. Mean Grain Yield for N Rate Treatments

Grain Yield (bu. ac.-1)	N Rate (lbs. N ac-1)		
	0	135	215
2021	120	240	283
2022	127	227	257

CONCLUSIONS

The results of this study show that N, P, K, and S concentrations can vary depending upon growth stage and individual-leaf sample selection. In all nutrients measured, whole-plant and 8th leaf concentrations declined from V8 to V12. Leaf N and S concentrations exceeded whole-plant N and S by 13% and 11% at V8, respectively.

Leaf P concentrations were lower than whole-plant concentrations at V8, but were similar to or higher than whole-plant P at V12. Leaf K was always lower than whole-plant K. At V12, whole-plant N concentration was lower than both 8th and 12th leaf N concentration. The 8th and 12th leaf N concentrations were similar at V12. K and S concentrations in the V12 12th leaf showed strong similarity to their respective V12 whole-plant samples, while the V12 8th leaf was less similar to the V12 whole plant for K and S concentrations. For K, the 8th leaf concentration was lower than the whole-plant concentration at V12, but for S the 8th leaf had a higher concentration than the whole-plant at V12. P demonstrated that the 8th leaf, 12th leaf, and whole-plant were all similar at V12, but the 8th leaf may have been slightly more similar to the whole-plant. In both years of this study grain yield was increased with higher N rates. However, plant nutrient concentration response to N rate was variable depending upon the nutrient of interest and the growth stage. At V8, the only nutrient concentration affected by N rate was nitrogen. However, by V12 the S and P concentration of some partitions were affected by N rate. Plant nutrient concentrations varied by year for N, S, and P depending on sample selection and growth stage. Significant interactions between year and N rate, likely due to varying soil nutrient availability and plant growth rates caused by annual differences in temperature and precipitation trends. When tissue sampling it is important to acknowledge that last year's nutrient concentrations may not be a perfect benchmark. The unique mobility of N, P, K, and S within the plant influenced the relationships between individual leaves and whole-plant units. Special consideration must be given to immobile nutrients such as S, which may be overrepresented if older leaves are sampled. On the other hand, sampling newer or still-developing leaves may lead to higher-than-expected concentrations of mobile nutrients such as P. Interestingly, this study found that new leaves at V12 did not have higher N concentrations than older leaves. Preliminary results indicate that individual leaf sampling may be most effective at earlier vegetative growth stages, such as V8, due to increasing disparities between leaf and whole-plant nutrient concentrations as the season progresses.

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UPDATING SOIL-TEST PHOSPHORUS AND POTASSIUM CALIBRATIONS FOR WISCONSIN

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ABSTRACT

Effective soil-test interpretations and fertilizer recommendations require phosphorus (P) and potassium (K) soil test to be field correlated with crop yield response to fertilization and calibrated to identify response probabilities. Only the Bray-1 soil test is calibrated to provide P and K interpretation guidelines in Wisconsin, with supporting trials being over 30 years old. This study correlated the P extracted by the Bray-1 (BP), Mehlich-3, Olsen-P (OP), and H3A tests and K extracted by the Bray-1 (BK), Mehlich-3 (M3K), ammonium acetate (AAK), and H3A (H3AK) tests with corn and soybean grain yield response to fertilization at 10 Wisconsin sites for a total of 30 site-years. Phosphorus was determined by colorimetric and inductively coupled plasma emission spectroscopy for the Mehlich-3 (M3P-COL and M3P-ICP) and H3A (H3A-COL and H3A-ICP) tests. Sites included six soil series with silty clay loam to sand textures, pH acid to slightly alkaline (6-inch depth), managed with no-till or conventional tillage, and irrigation where required. Amounts of STP measured by BP, M3P-COL, M3P-ICP, OP, H3A-COL, and H3A-ICP were 1-128, 3-142, 8-161, 2-63, 1-76, and 5-94 ppm P, respectively. Amounts of STK measured by BK, M3K, AAK, and H3AK were 2-257, 51-296, 28-311, and 12-132 ppm K, respectively. The current, routine BP best correlated with M3P (R^2 = 0.98) and OP (R^2 = 0.90). The ratio of measured P for BP:M3P and BP:OP was 1.0 and 0.6, respectively.. Soils differing in texture and mineralogy (6-inch depth) showed different relationships between STK methods. Additionally, new STK methods for Wisconsin extracted and measured more or less K compared to the BK test depending on the study site. The M3K test had the strongest relationship with the BK test (R^2 = 0.95), however, it tended to extract more K. The ratio of BK to AAK or H3AK differed by site. Relationships between relative yield response and soil-test by each test and nutrient were described by fitting quadratic-plateau (QP) and linear-plateau (LP) segmented polynomials models. Soil-test CC ranges for both corn and soybean were identified using all models that had significant fit to the data ($P \leq 0.01$). Bray-1 CC range for P and K were 16-23 ppm and 78-116 ppm, which largely agree with current optimum STP and are slightly lower than optimum STK range in Wisconsin Fertilizer Guidelines. The OP, M3P-COL, and M3P-ICP CC ranges were 13-18, 16-24, and 30-43 ppm P, respectively. Ranges of CC for the M3K and AAK were 97-117 and 112-140 ppm K, respectively, and showed more variability than the BP test. For P and K, the H3A test showed high sensitivity to study site and poorer relationships with relative yield. These results are

initial phases in providing interpretation guidance for P and K soil tests, in addition to the Bray-1 test, for Wisconsin that can inform fertilization decisions.

INTRODUCTION

Fertilization guidelines that support crop production and abate nutrient losses require reliable and effective soil-test recommendations. As a diagnostic tool, soil testing provides the framework to which phosphorus (P) and potassium (K) fertilization should be based, and must be field correlated with crop yield response to fertilization and calibrated to identify response probabilities. The small fraction of total soil nutrient concentration measured by each soil test method can vary with soil properties. Each test can provide different interpretation, thus, needing to be individually calibrated when appropriate (Mallarino, 2009). Current P K fertilization guidelines in Wisconsin are solely based on soil-test P (STP) and K (STK) extracted with the Bray-1 solution (Laboski and Peters, 2012). Additionally, field and laboratory research supporting current recommendations are greater than three decades old and require reevaluation.

Private and public soil testing laboratories have moved to multi nutrient extracting solutions such as the Mehlich-3 test for P and K. From 2001 to 2020, the proportion of reported STP values as Mehlich-3 determined by inductively-coupled plasma spectrophotometry (ICP) across the conterminous U.S. has increased to 56% of soil P samples nationwide (Jones et al., 2021). Shifts to tests such as the M3P-ICP provide faster workflow times for soil sample submissions requesting P, K, Ca, Mg, Na, and micronutrients. However, performance of the Mehlich-3 test in certain situations, such as high pH soils (Rutter et al., 2021), has come into question. Additional tests such Olsen P (Olsen et al., 1954) and ammonium acetate K (Frank et al., 1998) have been calibrated in north central states to provide fertilizer recommendations. The Olsen P test is predominately used in regions with high pH soils and ammonium acetate K used nationwide. A soil P and K test component of a soil health assessment tool known as the “H3A test” has recently been used for fertilization decisions by farmers, agronomists, and organizations in the north central region (Hany et al., 2017). Though research in neighboring states have defined critical concentrations for H3A with P (Mallarino and Jones, 2018), there is no guidance for using the H3A method in Wisconsin.

Removal of nutrients during harvest represents the largest consistent mechanism for soil-test levels of P and K to decline below optimum ranges. Across the north central region, crop removal of P and K has increased from 2001 to 2020, with greater K removal than P (Jones et al., 2021). Grain concentration of P and K coupled with yield levels drive removal, but the relationships between soil-test level and increasing yields of corn and soybean on removal require attention. Maintaining optimum soil-test levels by applying removal rates can maximize yields (Mallarino and Prater, 2017) with consideration for grain content and yield level. It is uncertain how increasing or decreasing soil-test and yield levels affect P and k removal, thus, fertilizer needed to maintain optimum P and K levels.

Therefore, the objectives of this study were to: (1) compare the amount of P or K measured with additional tests compared to the routine Bray-1, (2) identify and compare critical soil-test concentrations for all P and K tests, and (3) examine the relationship between soil-test level, crop yield, and harvest grain removal of P and K.

SUMMARY OF METHODS

Field studies were conducted with corn and soybean at 10 Wisconsin sites with multi-year trials from 2021 to 2022. There were 30 site-years for both corn and soybean. Data for trials conducted from 2014 to 2020 are being summarized at this time. Trials included sites with six soil series with silty clay loam to sand textures, pH acid to slightly alkaline (6-inch depth), managed with no-till or conventional tillage, and irrigation where required. All sites included a randomized complete block design with a complete factorial treatment structure of several P (0 to 90 lb P2O5 ac^{-1}) and K (0 to 160 lb K2O ac^{-1}) rates replicated four times. Relative grain yield was calculated for each trial by expressing the mean yield (across replication) without fertilization as the percentage of the mean yield of treatments produced by the statistically maximum yield (the mean of all treatments, including the control, was used as maximum yield when there was no P or K response). This method of relative yield determination is termed "STATMAX" (Pearce et al., 2022). Grain samples were collected from each plot and analyzed for P and K concentration using (Zarcinas et al., 1987). Grain removal of nutrients with harvest was calculated by using the measured nutrient concentration multiplied by the plot-level grain yield and adjusted for consistent moisture.

Soil samples were analyzed for P by the Bray-1, Mehlich-3 (colorimetric), Mehlich-3 (ICP), and Olsen tests following the procedures suggested by the NCERA-13 north-central region soil testing committee (Frank et al., 1998). Soil samples were analyzed for K by the Bray-1, Mehlich-3, and ammonium acetate tests (Frank et al., 1998). Additionally, soil samples were analyzed by the H3A (colorimetric) and H3A (ICP) methods defined by Haney et al. (2017). Laboratory analysis was conducted at AGVISE Laboratories, Northwood, North Dakota.

Regression analysis was used to compare the amounts of P and K extracted by each test across all trials. Relationships between relative yield response and soil-test values for each method were studies across the response trials. Relationships between relative yield and soil-test concentration were studied for each P and K test and a range of critical concentrations for each method were determined by fitting the segmented polynomials linear-plateau (LP) and quadratic-plateau (QP) models. Using multiple models to identify a critical concentration range has been a well-documented method used for both soil nutrient and plant tissue nutrient concentration (Mallarino, 2003; Clover and Mallarino, 2013). Model selection was limited to those which provided a constant slope plateau when analysis of variance (ANOVA) indicated no statistical difference between treatments above the model joint point (the concentration at which the two portions of the LP and QP models join). The LP and QP models determine critical concentrations directly at a 100% sufficiency level. The two models were statistically significant for all methods ($P \leq 0.001$). Relationships between grain nutrient concentration of P and K and crop removal with soil-test level and crop yield were analyzed by fitting linear or curvilinear models. All statistical analysis, response model fits, and critical concentration identification was done in SAS ODA (SAS Institute, Cary, NC).

SUMMARY OF RESULTS

Relationships between Soil Tests

Correlations between the amounts of P measured with BP and other P tests are shown in Figure 1. Amounts of STP measured by BP, M3P-COL, M3P-ICP, OP, H3A-COL, and H3A-ICP were 1-128, 3-142, 8-161, 2-63, 1-76, and 5-94 ppm P, respectively. Study site soil properties (soil texture The BP and M3P-COL tests showed the strongest relationship ($r^2 = 0.98$) with a near 1-to-1 ratio (slope =1.04). This agrees with previous analysis of soil P tests (Mallarino and Jones, 2018), and supports why in other north central states the soil-test interpretations are the same for both BP and M3P-COL tests (Mallarino et al., 2013). The second best relationship ($r^2 = 0.9$) with BP was the OP test (Fig. 1). In general, the OP test extracted one half of the P measured by the BP test, and the relationship had greater variation compared to the M3P test. The relationship between both H3A-COL and H3A-ICP and BP was affected by study site. No effect of study year was observed on regressions between tests. Fine and coarse surface texture soils showed different relationships, with the H3A solution (determined by colorimetric or ICP methods) extracting less P in coarse texture soil (Fig. 1). Samples from coarse surface texture sites additionally had soil organic matter from 0.7 to 1.6% (6-inch), soil pH values of 5.0 to 6.1, and lower P buffering capacities (Laboski and Peters, 2013). The M3P-ICP test had the poorest relationship with the BP test (Fig. 1). Greater amounts of P were extracted by M3P-ICP compared to BP for sites with coarse surface texture. In fine texture soils, there was considerable variation between the ratio of BP to M3P-ICP at BP levels less than 60 ppm P. Figure 2 shows the correlations between all soil K tests investigated. Amounts of STK measured by BK, M3K, AAK, and H3AK were 2-257, 51-296, 28-311, and 12-132 ppm K, respectively. The BK and M3K tests had the strongest relationship across all site-years ($r^2 = 0.95$) with the M3K test extracting 1.2 times more soil K or 24 ppm K on average across the entire study. This ratio is within the range reported by Vitko et al. (2008) on central and eastern Wisconsin soils. Ammonium acetate K showed the poorest relationship with BK ($r^2 = 0.86$), and had a greater error at all BK levels. Relationships between all K tests and the H3AK were best described by separating the fine and coarse texture soils (Fig. 2). The H3AK test had a higher ratio compared to the BK, M3K, and AAK test for coarse soils and poorer for the fine soils.

Determination of Critical Concentrations

Soil-test critical concentrations (CC) are widely agreed to be the soil nutrient level above which crop yield response to fertilization is relatively low (Dahnke and Olsen, 1990).

Figure 4 shows the relationships between corn and soybean relative grain yield response to P with soil-test P measured by all P tests. Relative yield increased (response to fertilization decreased) with increasing soil-test P measured by all methods, but the goodness of fit for some specific models and soil-test methods were better than others. Bray-1 and M3P-COL tests showed similar CC ranges of 16-23 and 16-24 ppm P, respectively (Fig. 4). These ranges are similar to the current Wisconsin optimum interpretation class range for BP of 16-20 ppm P for corn and soybean (Laboski and Peters, 2012). The CC range for the M3P-ICP was 30-43 ppm P. Soil-test P determined with ICP is well reported to be greater than sing colorimetry (Mallarino, 2003), and M3P-ICP was shown to be 22 ppm P greater than M3P-COL in this study. Importantly, simply using the difference in amount of P extracted by the M3P-COL and M3P-ICP would not lead to correct identification of CC ranges and response model joint points. Thus, the need for field calibration studies that use direct laboratory measurements, and not mathematical regression inferences. The CC range defined here is similar to ranges found in Iowa (Mallarino, 2003; Mallarino et al., 2013). Olsen P CC range was 13-18 ppm P. The LP and QP models fit for relative yield and OP had the closest joint point, leading to a narrow CC range of 5 ppm. A more narrow range of CC for the OP test can be expected due to the lower amount of P extracted with the sodium bicarbonate used in the OP test. Lower measured soil-test P values will lead to condensed data points near the CC on a response curve graph (Fig. 4) like for the OP test. The H3A-COL and H3A-ICP test showed CC ranges of 10-17 and 23-29 ppm P, respectively. Recent field correlation studies in Iowa reported slightly lower values (9-13 ppm P) for the H3A-COL test (Jones, 2021). Although CC ranges only provide a point at which to determine to fertilizer or not, farmers and agronomists can use these ranges to guide decisions if only an H3A P test is returned in a soil sample result report.

Figure 5 shows the relationship of relative yield for corn and soybean with soil-test K for all K tests. Corn and soybean yield ranged from 34-285 and 20-111 bu ac^{-1}, respectively, across all site-years. Yield responses to K fertilization were greater and more consistent than responses to P. Potassium fertilization led to increases in corn and soybean yield of 0-260 and 0-48 bu ac^{-1}, respectively. Critical soil-test K concentrations for the BK, AAK, M3K, and H3AK tests were 78-116, 112-140, 97-117, and 30-37 ppm K, respectively (Fig. 5). Models fit for the BK, M3K, and H3AK had much better goodness of fit (R^2 0.83 to 0.97) than the AAK test (R^2 0.66 to 0.68). For all K tests, the QP model had a lower Akaike Information Criteria (AIC), lower values indicate a better likelihood of a good fit to the data, compared to the LP model. The CC determined for BK in this study is lower than the range of 100 to 130 ppm K used in current Wisconsin fertilization guidelines (Laboski and Peters, 2012). Reasons for the discrepancy between this study and current guidelines are complex. Root morphology, planting density, and residue decomposition rates have changed considerably since the original research work to build current guidelines (Kelling et al., 1990). Additionally, current Wisconsin guidelines consider the most limiting crop (requiring the highest STK CC) in a rotation that decide the recommended STK level and K fertilization rate (Laboski and Peters, 2012). The M3K CC range was 97-117 ppm K (Fig. 5). This range had a similar upper limit to the BK test, however, the lower limit of the CC was 18 ppm K lower for the M3K compared to the BK test. On average across the study, the M3K test measured 25 ppm K more than the BK test for a given sample, though as previously discussed the ratio of BK / M3K was smaller at lower STK levels, and decreased with increasing soil pH (Fig. 3), thus, assuming a constant ratio of BK / M3K may be incorrect. This partially explains why the lower CC limit of the M3K test is greater than the BK test, yet as both methods approach values near 100 ppm K or greater (the upper limit of the CC range), the two tests are near similar. The AAK test had the highest range of CC at 122-140 ppm K. Across all soils, the AAK test measured 22 ppm K more than the BK test. No discernable patterns between the ratio of BK / AAK were observed, however the relationship between the BK and AAK test was the weakest correlation of all K tests (Fig. 2). The AAK CC range is slightly higher than those reported in neighboring states like Minnesota () and Iowa () for fine-textured soils. Either model fit the AAK poorer than the other tests. The H3AK test had the narrowest CC range, owing to less K extracted with this method. No published recommendations have used the H3AK method for determining a CC range. The method of interpreting an H3AK soil-test value would not differ from the other K tests. Furthermore, both the LP and QP models best fit for the H3AK test compared to the others tests (R^2 = 0.98). For all K tests, response models well fit the data, allowing for clear determination of CC ranges, and can provide guidance of at what STK values a yield response to fertilization would not be expected.

Grain Concentration and Harvest Removal

Grain nutrient concentration and yield level determine the amount of nutrients removed with crop harvest. Current University of Wisconsin guidelines recommend applying crop removal of P and K when soil-test levels are in the Optimum category (in the CC range) and recommend applying on half of crop removal for the High interpretation class (Laboski and Peters, 2012). Figures 6 to 9 summarize the relationships between P and K grain concentration, removal, soil-test level (Bray-1 test only), and grain yield for corn and soybean separately. Figure 6 shows P grain concentration and removal as a function of BP. For corn and soybean, grain P increased rapidly from lower BP levels to a maximum near an asymptote (Fig. 6). Corn grain P reached an asymptote of 0.33 % at 41 ppm P, while soybean grain P leveled off at 0.7 and 70 ppm P. Removal of P (lb P_2O_5 ac^{-1}) showed varied relationships with BP. Figure 6 differentiates P removal values by STK levels (Bray-1 K). Lower STK levels led to a wider distribution of grain P removal, likely driven by yield response to STK, and demonstrates the need to consider STK levels when attempting to change STP levels. Figure 7 shows the relationships between grain K concentration, K removal, and STK (Bray-1 K). Corn grain K did not have any relationship with BK, however, soybean grain K increased to a plateau of 1.83% K at 101 ppm K (Fig. 7). This plateau BK level is near the center of the determined CC range of 78-116 ppm K, and reaffirms that range as allowing for optimal K supply to reach a maximum grain K content. Unsurprisingly, corn and soybean K removal both had significant relationships with BK (P < 0.01), albeit weak coefficients of determinations (r^2 0.23 to 0.28). Removal of K for corn and soybean plateaued at 104 and 93 ppm K, respectively, and was mostly driven by yield increase for corn but both grain K content and yield increases for soybean (Fig. 7).

Figure 8 shows the relationship of grain P and removal P in relation to crop yield. Neither corn or soybean grain P had a significant relationship with yield (Fig. 8), indicating higher or lower yield levels did not influence the P eventually located in the grain. Phosphorus removal showed a strong linear relationship with yield for both corn (r^2 = 0.9) and soybean (r^2 = 0.91). For all data in this study, corn removed 0.31 lb P_2O_5 per bushel yield and soybean removed 0.77 lb P_2O_5 per bushel yield. This indicated that at corn yield values of 100, 175, and 250 bu ac^{-1}, P removal would be 33, 56, and 79 lb P_2O_5 ac^{-1}. Soybean P removal for 50, 75, and 100 bu ac^{-1} yield are 37, 56, and 76 lb P_2O_5 ac^{-1}. Soil-test K level did not affect the relationship between P removal and corn or soybean yield, however the yield level of each crop did vary by STK. Figure 9 shows the relationship between grain K and K removal with yield. Yield level did not affect corn grain K, however, soybean grain K increased with increasing yield up to a plateau of 1.85 % K at 89 bu ac^{-1} soybean yield (Fig. 9). Corn and soybean K removal linearly increased with grain yield, however, soybean had a stronger relationship (r^2 = 0.98). These data suggest that soybean K removal not only increased with yield level due to a greater mass of grain being harvested, but also due to a higher grain K concentration (Fig. 9). Corn yield levels of 100, 175, and 250 bu ac^{-1} led to a K removal of 18, 30, and 42 lb K_2O ac^{-1}, respectively. Soybean yield levels of 50, 75, and 100 bu ac^{-1} led to K removal of 54, 85, and 117 lb K_2O ac^{-1}, respectively. Thus, corn grain removed 0.16 lb K_2O per bushel yield and soybean removed 1.26 lb K_2O per bushel yield (Fig. 9). In crop rotations where corn or soybean are achieving higher yield levels, priority should be given to concerning STK decline after a soybean crop.

CONCLUSIONS

Interpretation guidance for soil P and K test values other than the Bray-1 test have not been previously available in Wisconsin. Critical concentrations for corn and soybean identified using the BP, OP, M3P-COL, M3P-ICP, H3A-COL, and H3A-ICP were 16-23, 13-18, 16-24, 30-43, 10-17, and 23-29 ppm P, respectively. These ranges allow for decisions of at which soil-test P value yield response to P fertilization is expected. Bray-1 and M3P-COL tests had most similar amounts of P measured, and field calibration of CC ranges indicate both tests could inform fertilization decisions using the same interpretation classes currently available for the BP test in Wisconsin. To determine P fertilizer application rates using the M3P-ICP, OP, H3A-COL, or H3A-ICP, additional site-years are necessary and analyses of percent probability of response, which is currently ongoing. Potassium CC range of 78-116 ppm K for the BK test was slightly lower than current University of Wisconsin guidelines. This may indicate a need to refine guidelines to better match current cropping systems in Wisconsin compared to when historical data was collected. Critical STK ranges for the M3K and AAK tests were 97-117 and 112-140 ppm K, respectively. The differences in

M3K CC ranges compared to the BK range were attributed to the M3K test measuring for STK at lower STK levels and as soil pH increases.

Grain P and K content and removal drive fertilization decisions which aim to maintain an optimum soil-test P or K in the critical concentration range. Soybean grain P and K content increased with STP to reach maxima in this study, while only corn grain P content as STP increased. Only K removal showed a significant increasing trend to a maximum while STK increased to 93 and 104 ppm K for corn and soybean, respectively. Neither corn nor soybean grain P or corn grain K content showed a relationship with yield level. Soybean grain K content showed a strong relationship with yield, plateauing at 1.85 % K at 89 bu ac^{-1} yield. Removal of P with harvest linearly related to yield increase with removal values of 0.31 and 0.77 lb P_2O_5 bu^{-1}, for corn and soybean, respectively, with greater P removal generally occurring when STK levels were higher. Potassium removal increased with yield, with corn and soybean removing 0.16 and 1.26 lb K_2O bu^{-1}, respectively. These data suggest that as corn and soybean yields increase over time or with management decisions, increases in soybean yield can proportionally removal more K in a cropping system. Overall, these results provide interpretation guidance for soil-test methods in addition to currently used Bray-1 for P and K fertility management in Wisconsin or similar soils. Additional trials and site-years are currently being analyzed to supplement the data and processes presented.

Acknowledgements

The authors would like to thank Todd Andraski and Andrew Larson for their work and support in the trials discussed in this paper. This research is supported by the Wisconsin Fertilizer Research Council

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Tables and Figures

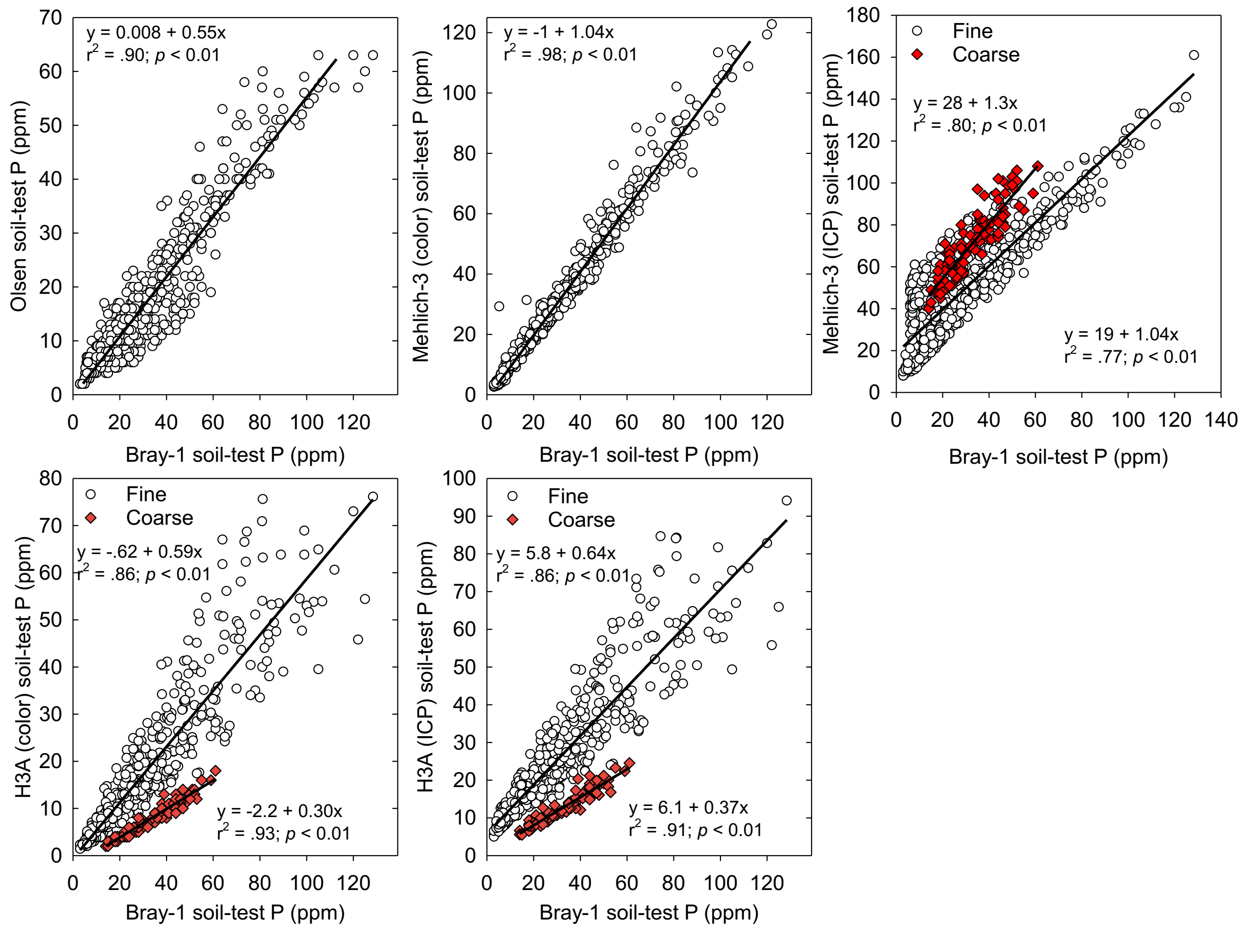

Figure 1. Correlations across all trials and years between the amounts of soil P extracted by the routine BP test and M3P-COL, M3P-ICP, OP, H3AP-COL, and H3AP-ICP methods (means across replications). When appropriate, data are segmented into soils with fine (loamy) and coarse (sandy) surface soil textures (6-inch).

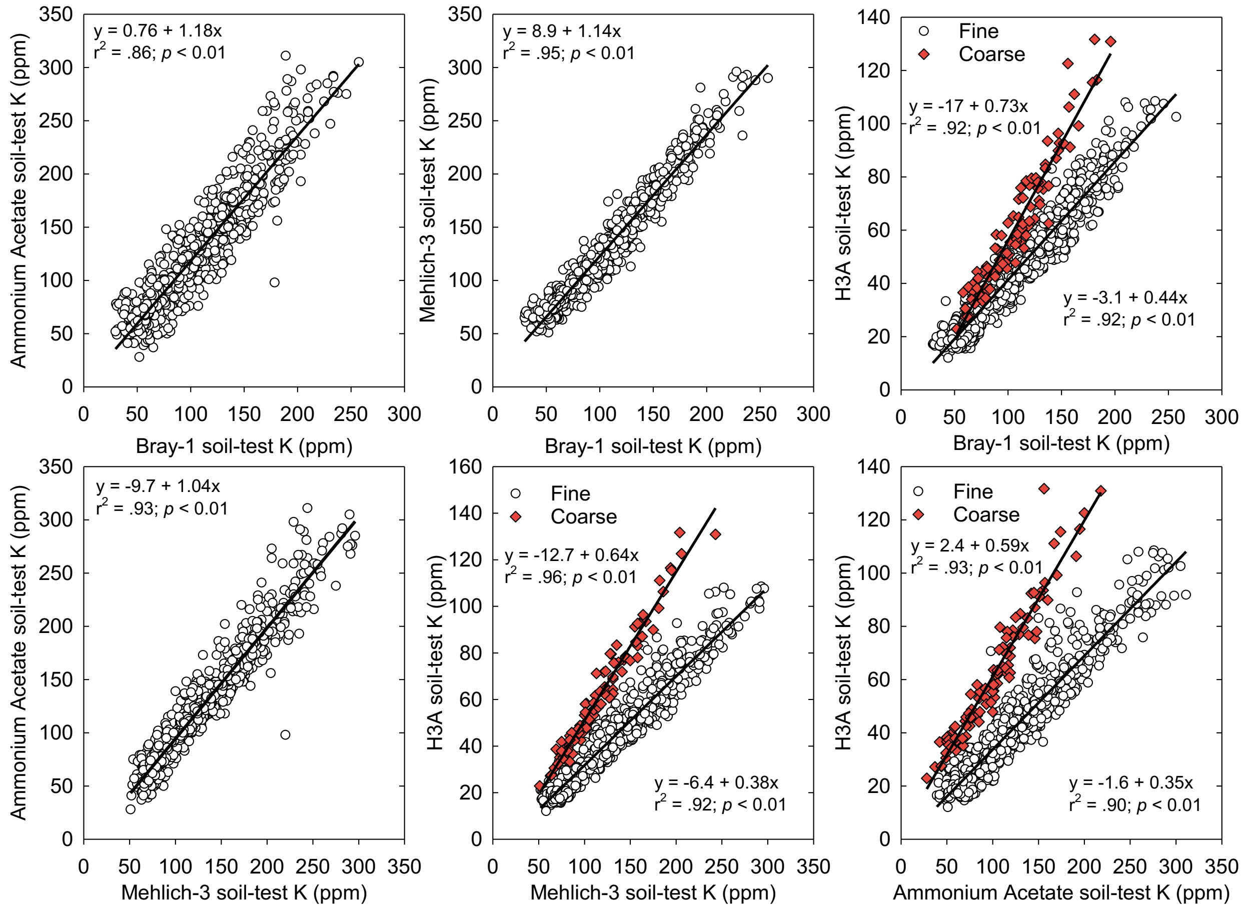

Figure 2. Correlations across all trials and years between the amounts of soil K extracted by the BP M3K, AAK, and H3AK methods (means across replications). When appropriate, data are segmented into soils with fine (loamy) and coarse (sandy) surface soil textures (6-inch).

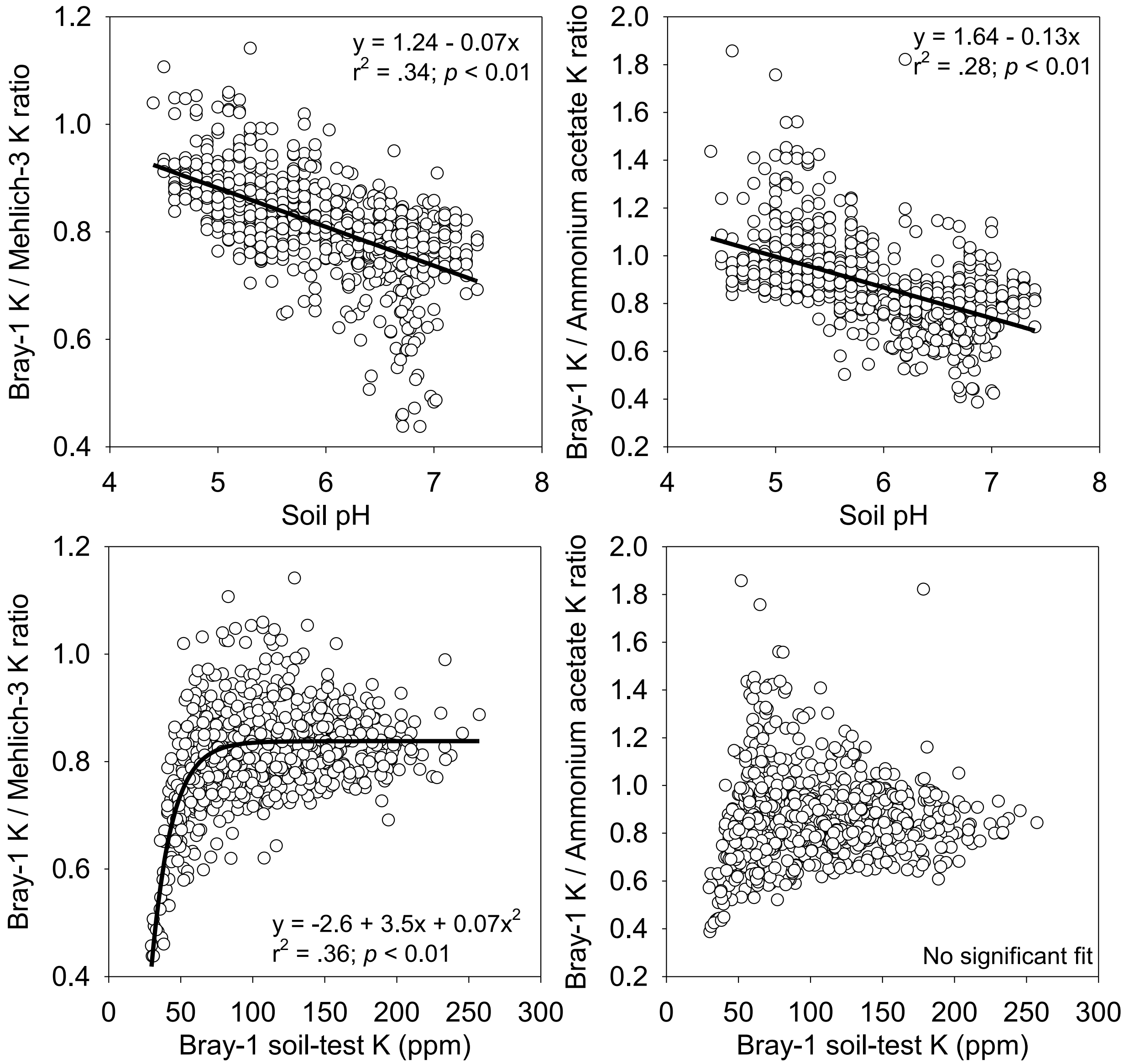

Figure 3. Ratio of Bray-1 to Mehlich-3 and ammonium acetate soil-test K with soil pH and soil-test Bray-1 K levels.

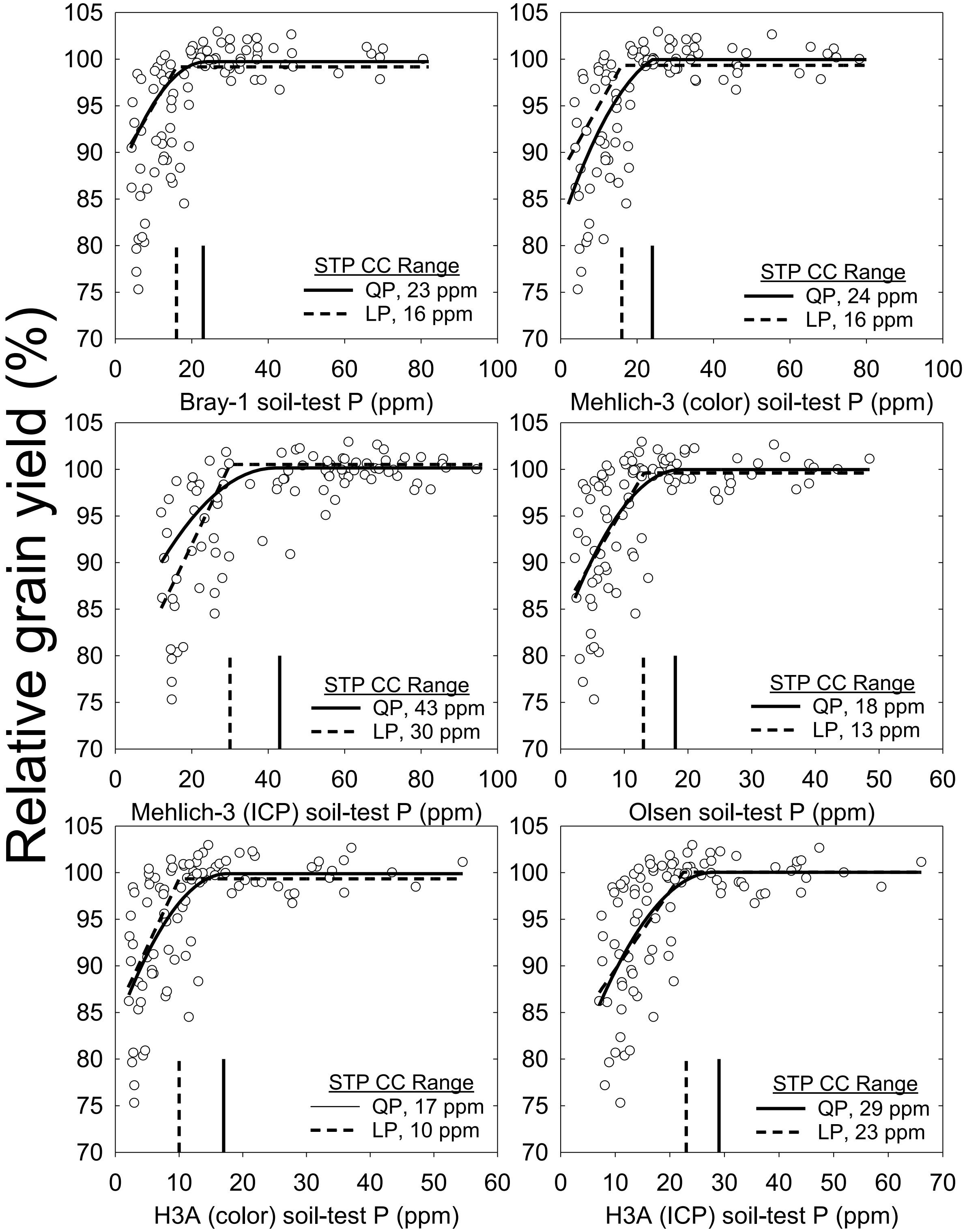

Figure 4. Relationship across all trials and years between corn and soybean yield response to P and soil-test P measured by the six methods. QP, quadratic-plateau model fit and its estimated critical concentration; LP, linear-plateau model fit and its estimated critical concentration.

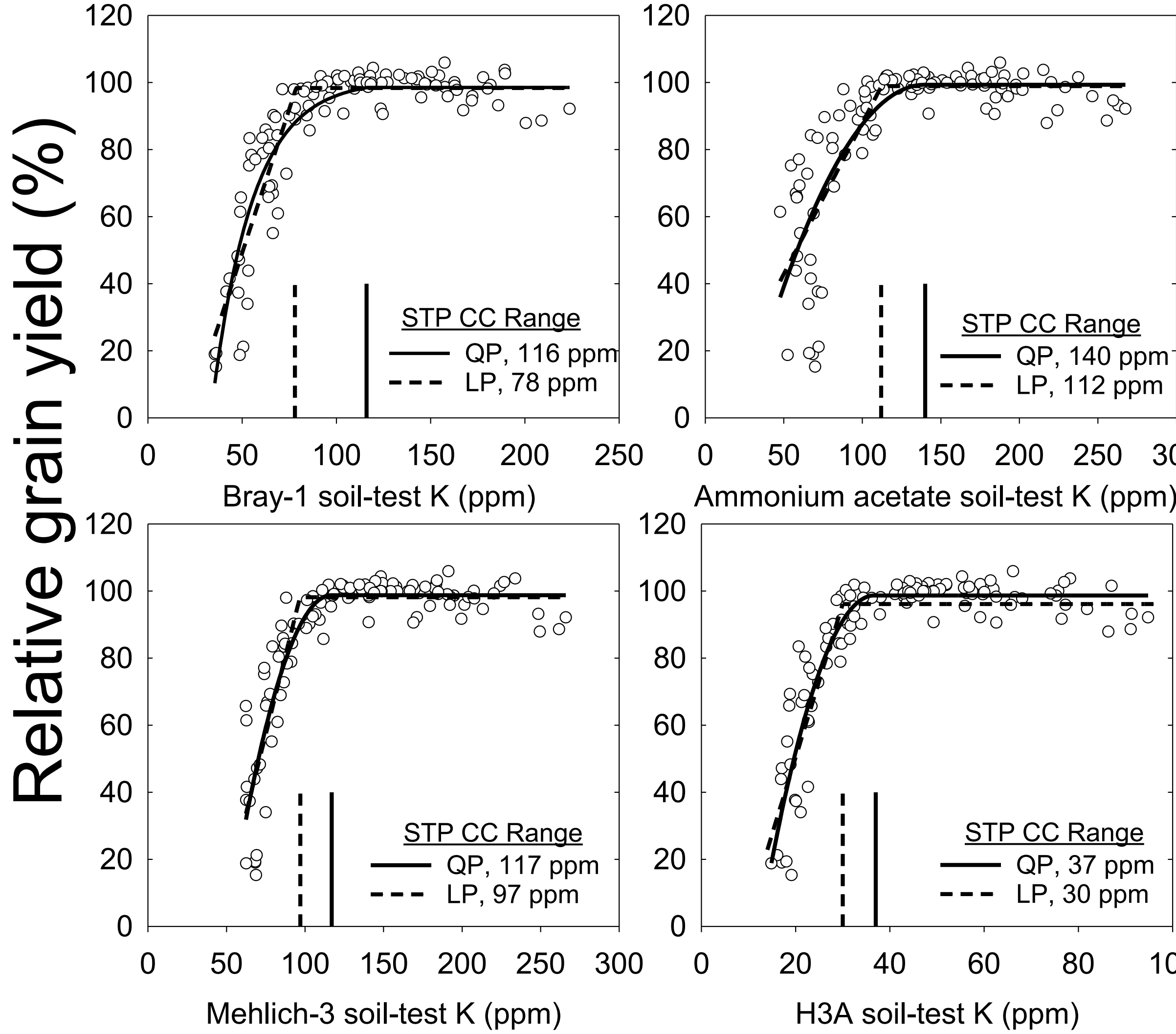

Figure 5. Relationship across all trials and years between corn and soybean yield response to K and soil-test K measured by the four methods. QP, quadratic-plateau model fit and its estimated critical concentration; LP, linear-plateau model fit and its estimated critical concentration.

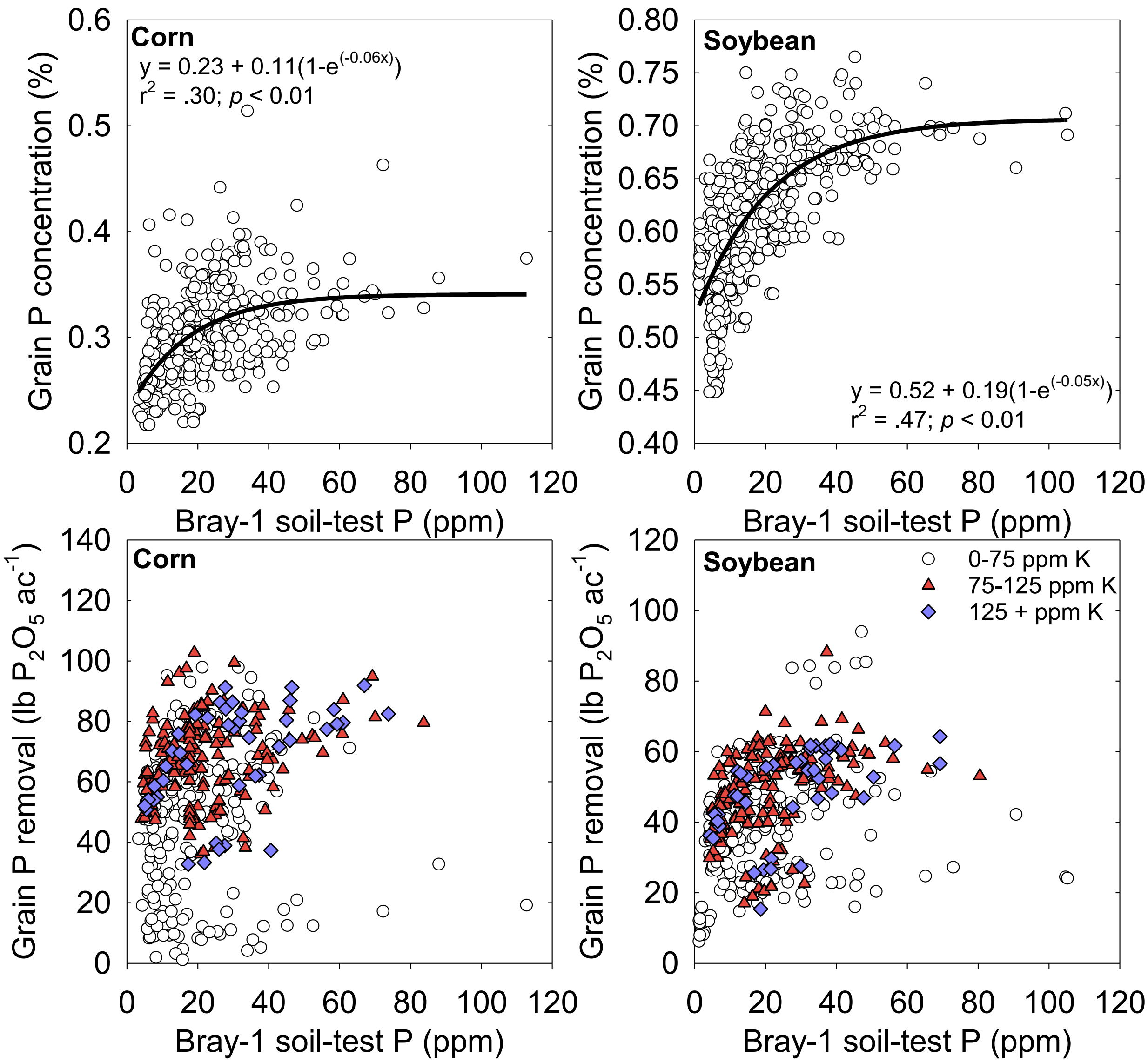

Figure 6. Relationships between Bray-1 soil-test P and grain P concentration and removal with harvest for corn and soybean.

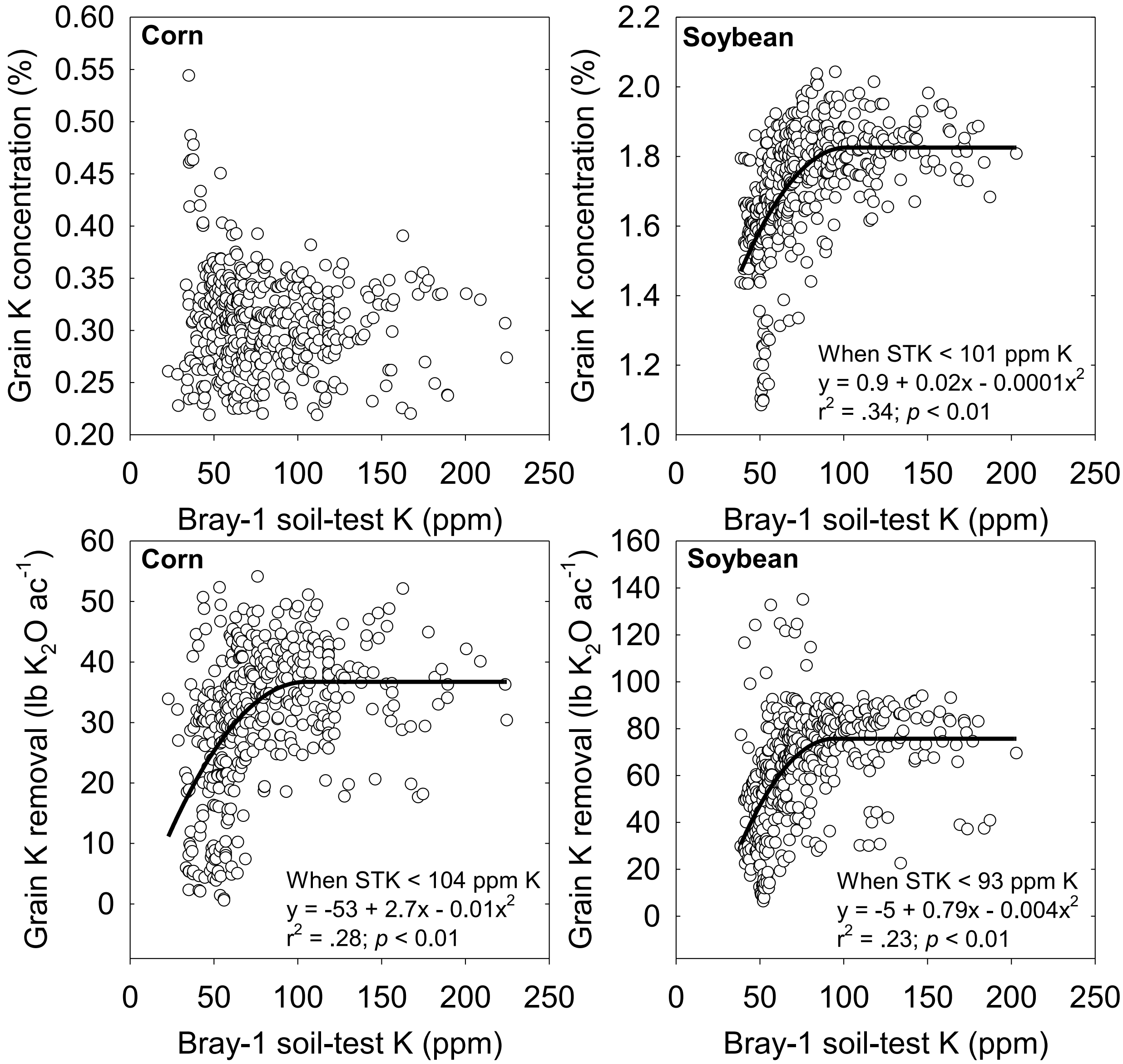

Figure 7. Relationships between Bray-1 soil-test K and grain K concentration and removal with harvest for corn and soybean.

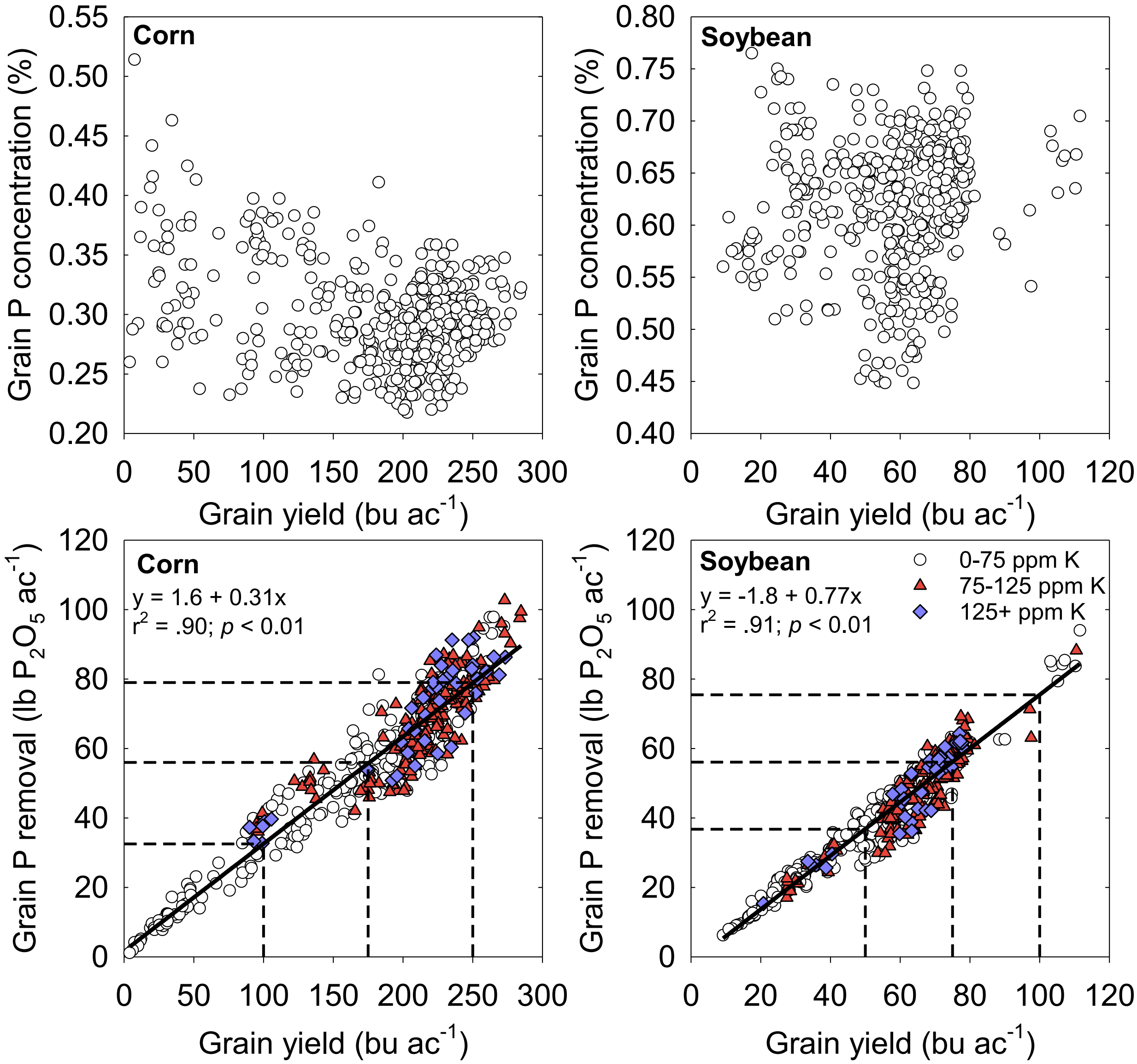

Figure 8. Relationship between corn and soybean grain yield and grain P concentration and removal with harvest.

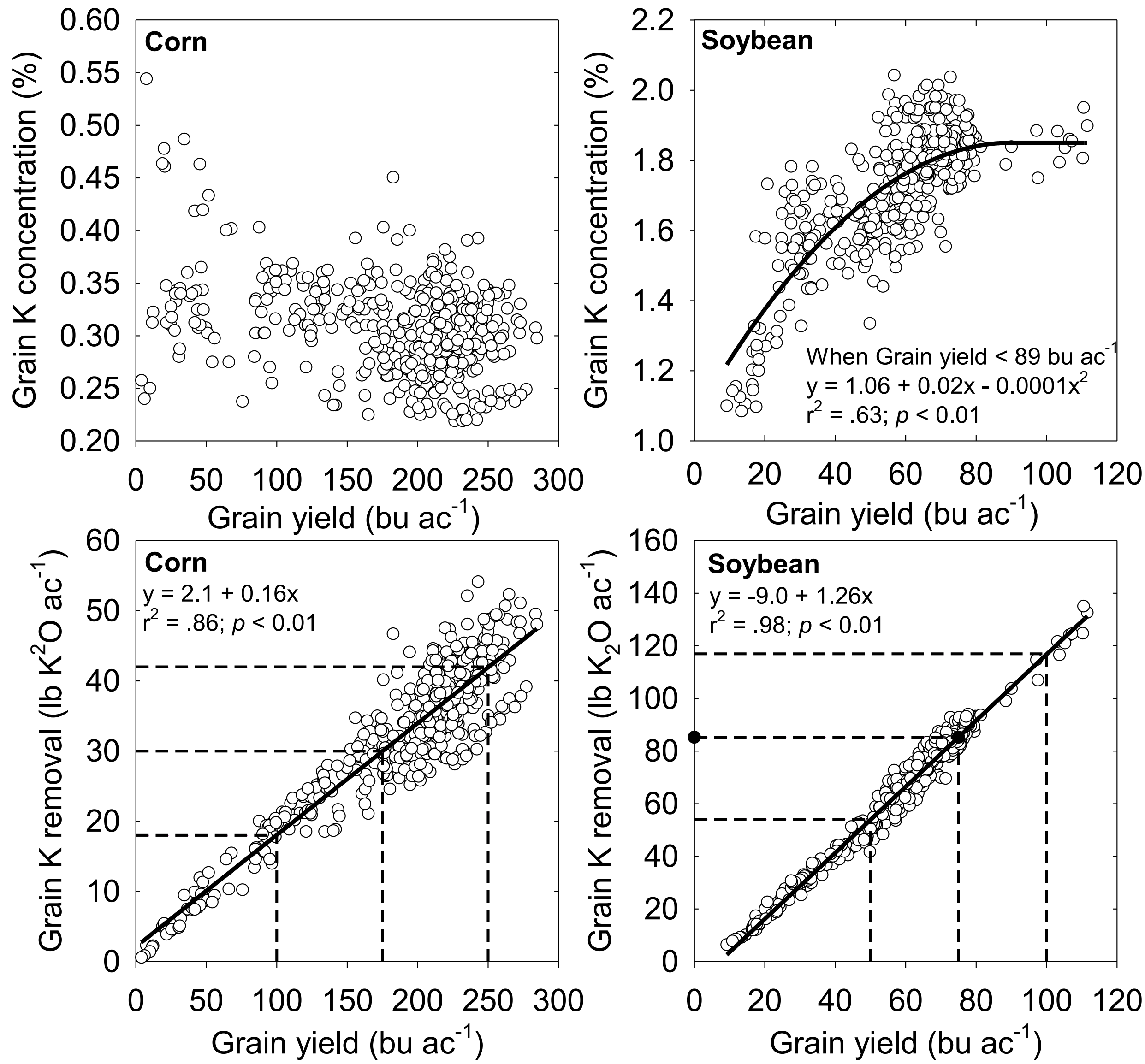

Figure 9. Relationship between corn and soybean grain yield and grain K concentration and removal with harvest

EVALUATION OF SOIL TEST POTASSIUM GUIDELINES IN MINNESOTA

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ABSTRACT

The objective of these experiments was to determine whether soil clay mineralogy impacts corn potassium (K) requirements. New and historica research trials were combined to correlate soil potassium concentration extracted by 1M ammonium acetate for samples collected at a six-inch sampling depth. Soil samples from current and historica studies were analyzed for clay species, specifically the relative abundance of illite and smectite. Soils were divided into groups with smectite:illite ratios above or below 3.5:1. Soils in central and western Minnesota tended to have a greater abundance of smectite in the clay fraction while illite abundance was greater in the southeastern and central areas of Minnesota dominated by silt loam or sandy textured soils. Critical soil test K concentration for soils with a ratio below 3.5:1 was 85 ppm which the critical soil K test was 106 ppm when the ratio of smectite:illite was 3.5 or greater. The data provided indicates a potential for different K guidelines for K based on the relative abundance of illite or smectite.

INTRODUCTION

Management of potassium in corn (*Zea mays* L.) can be challenging due to uncertainties in the availability of the nutrient. Potassium is present in the soil and is taken up by crops as a cation (K^+). While the chemistry of K in the soil is simple, the availability to crops is not due to the impacts of cation exchange capacity (CEC) and retention of the K^+ ion between layers of clay. In addition, drying of soil samples can result in over or under estimation of the availability of K to crops. Most soil testing labs dry samples as soon as they receive them to aid in throughput of the large number of samples. Past research in Iowa has shown a better prediction of the availability of K to corn and soybean based on extraction from moist soil (Barbagelata and Mallarino, 2013). Many labs are not set up to extract moist soils and most other nutrients tested are not impacted by drying of soil samples. Adoption of analysis of soils on a moist basis would be challenging to most labs and would increase the cost of soil tests.

Soil clays impact the ability to retain cations. Soils in Minnesota contain three major types of clays. Kaolinite which is a 1:1 clay with a low CEC, and illite and smectite which are both 2:1 clays. One major difference between illite and smectite is CEC which is greater for smectite than illite. Smectite also has a greater shrink-swell capacity but has less affinity to trap and retain K^+ ions in the clay interlayer spaces than illite. The radius of the K ion is the perfect size to fit within pockets in the outer layers of the tetrahedral sheet of 2:1 clay. Potassium ions in the interlayer space are often considered to be ‘fixed’ potassium. Illite tends to have a greater affinity to ‘fix’ potassium than smectite. It can be questioned whether K guidelines vary for soils dominated by illite compared to smectite.

Soil clay mineralogy has not been considered as an important factor in Minnesota to be used for generating K fertilizer guidelines (Kaiser et al., 2022). More recent work in North Dakota concluded that the ratio of smectite:illite can vary what the critical soil test level (the soil tests at which crop response to fertilizer ceases) is for corn (Breker et al., 2019). Current corn guidelines for North Dakota suggest that K fertilizer need vary for corn based on a smectite to illite ratio of above or below 3.5. In contrast, K fertilizer guidelines for Iowa have changed over the past ten years to account for the variability of K from soils dried before analysis. Work is ongoing in Minnesota comparing K extracted with 1*M* ammonium acetate solution on both field moist and air-dried soil samples. However, no extensive work has been done to study the variation in clay mineralogy across Minnesota. The objectives of this work were to 1) provide a survey of clay mineralogy for Minnesota; and 2) determine if clay species impact potassium requirements for corn.

MATERIALS AND METHODS

Table 1. Summary of field K response trials established in Minnesota from 2019 to 2021.

Year	Location	Trial[1]	STK	Optimal K Rate[2]
			--ppm--	-lb K_2O ac^{-1}-
2019	Mentor	FF	104	40
2020	Sauk Centre	FF	140	40
	Sauk Centre	FF	118	66
	Morris	FF	161	nr
	Marshall	FF	160	nr
	Granite Falls	FF	185	nr
	Benson	FF	123	79
	Lamberton	FF	171	nr
	Le Sueur	SP	138	93
	Rosemount	SP	81	107
2021	New Ulm	FF	151	71
	New Ulm	FF	113	nr
	Lakefield	FF	162	nr
	Eyota	FF	152	nr
	Belgrade	FF	192	nr
	Belgrade	FF	215	61
	Grand Forks	FF	211	nr
	Rochester	SP	98	78
	Becker	SP	99	66
	Lamberton	SP	109	37
	Rosemount	SP	90	nr

1/ FF, Farmer Field; SP, Small Plot.

2/ nr, no response

A total of 21 farmer field and small plot trials (Table 1) were established to gather K response data to be combined with previously collected data. Field trials consisted of five rates of K_2O per acre, 0, 40, 80, 120, and 160 lbs. Farmer field trials were established using a Latin square design with five replications. Small plot trials ranged from four to six replicates. Fertilizer potassium was applied at potash (0-0-60). Fertilizer was applied using commercial equipment by establishing blocks in each field where the fertilizer treatment structure was superimposed within fertilizer prescription maps. As applied maps were checked following application to verify fertilizer was applied correctly. Yield data from farmer field trials was collected using combines equipped with calibrated yield monitors.

Soil samples were collected from each replicate as a composite of 10 cores collected to a depth of six inches. Farmer field samples were collected from 0 K plots in June. Soil samples were collected from small plot trials as a composite across each replication before treatment application. Soil samples were dried at air temperature and ground to pass through a 2 mm sieve prior to analysis. Soil was analyzed for extractable potassium by the ammonium acetate procedure (Warncke and Brown, 2011). Semiquantitative mineral identification and clay speciation was conducted using the Rietveld method (Rietveld, 1969). Soil samples for mineralogical analysis were collected from the field trials outlined in Table 1 as well as additional non-trial locations located in areas of Minnesota to represent major landforms and soil associations.

RESULTS AND DISCUSSION

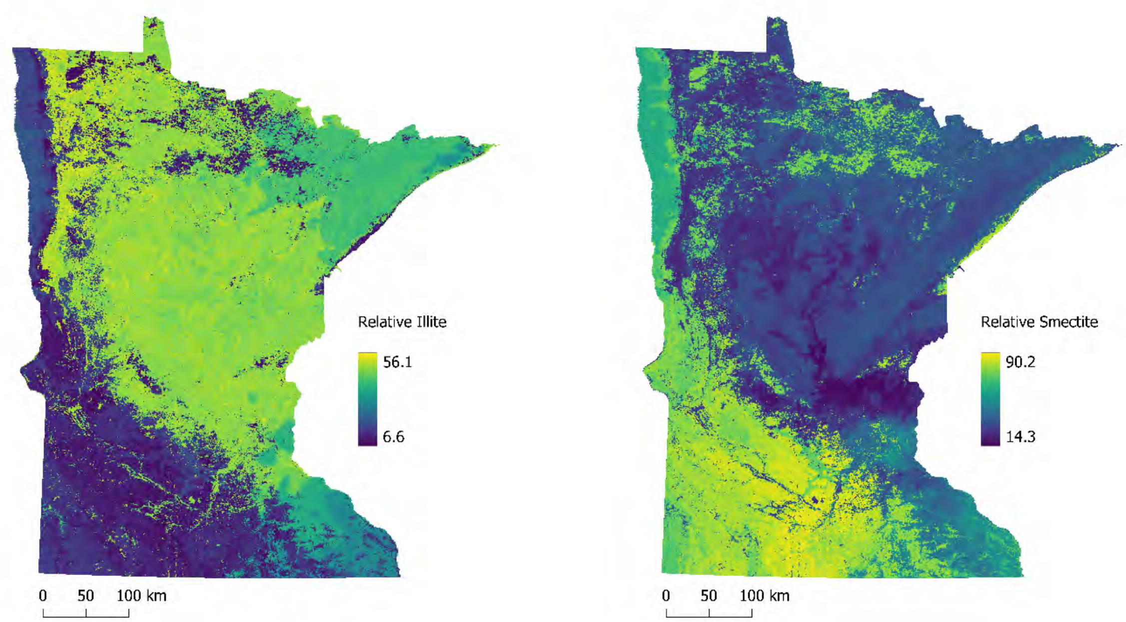

Figure 1. Semi-quantitative abundance of illite and smectite estimated for Minnesota soils.

The relative abundance of illite and smectite in soils is estimated across the state of Minnesota in Figure 1. Soils in the southern and western part of the state which are higher in clay tended to have relatively higher smectite concentrations which was expected. Illite abundance was greatest in the SE and the majority of north central Minnesota which corresponds to silt loam and sandy soils where crops historically have responded to K. Major inclusions higher in Illite in Central and Western MN were estimated around major rivers, the Minnesota river valley. Figure 2 summarizes the ratio of smectite:illite which was higher in Central and Western Minnesota and lower in the Southeastern and Central and Northcentral parts of the state.

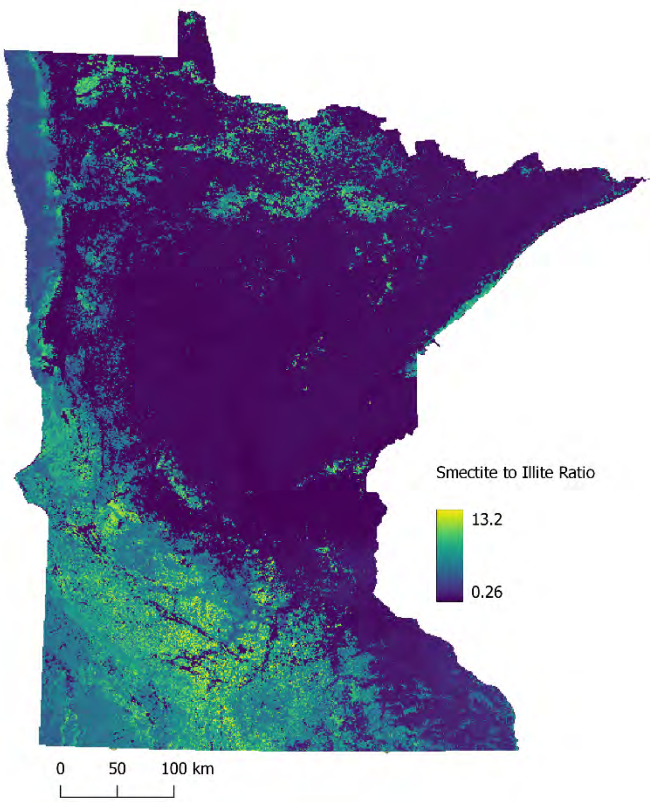

Figure 2. Ratio of smectite:illite for 0-6” soil sampling depth based on a semi-quantitative analysis.

A summery of the field trial response data is given in Table 1. Yield of individual treatments is not show for any of the trial locations. Table 1 contains the average soil test K (STK) and the rate of K that provided maximum yield at sites where a K response occurred. Corn grain yield was increased by K at 11 of the 21 locations. Corn grain yield responses occurred at sites ranging from 80 to 140 ppm with one exception, one site responded with a K test near 260 ppm. Corn grain yield was increased by 80-140 lb K_2O per acre.

Current trial data was combined with past research to form a database of K response (not shown). The ratio of smectite:illite was calculated for each location along with corn grain yield response. Figure 3 summarizing corn grain yield response for soils with a smectite:illite ratio of above or below 3.5. Data are summarized in Table 3. Overall, there was only a very small difference in where corn relative grain yield achieved maximum in both cases. The critical K concentration was determined after fitting a quadratic plateau curve and is defined as the soil test value where 95% of maximum yield was achieved. For soils with a smectite:illite ratio below 3.5, the critical soil K test was 85 ppm (or mg kg^{-1}). For ratios 3.5 or above the critical soil test K concentration was 106 ppm. The 85 ppm value corresponds the bottom of the previously used STK classification for the state of Minnesota. The STK classes were increased and for the new STK ranges the 106 ppm value is close to the bottom of the current STK class.

The data provided may indicate a lower critical level for soils with a greater abundance of illite. Anecdotally, many field trial locations in the Southeastern part of Minnesota and for irrigated sandy soils have not shown a strong response to K even for Low or Very Low K testing soils. A lower critical level may explain some of the differences that have been observed. It is unclear whether any differences would exist between silt loam versus sandy soils which comprise the bulk of the higher illite soils. This data provides a basis for revision of the corn K guidelines for Minnesota.

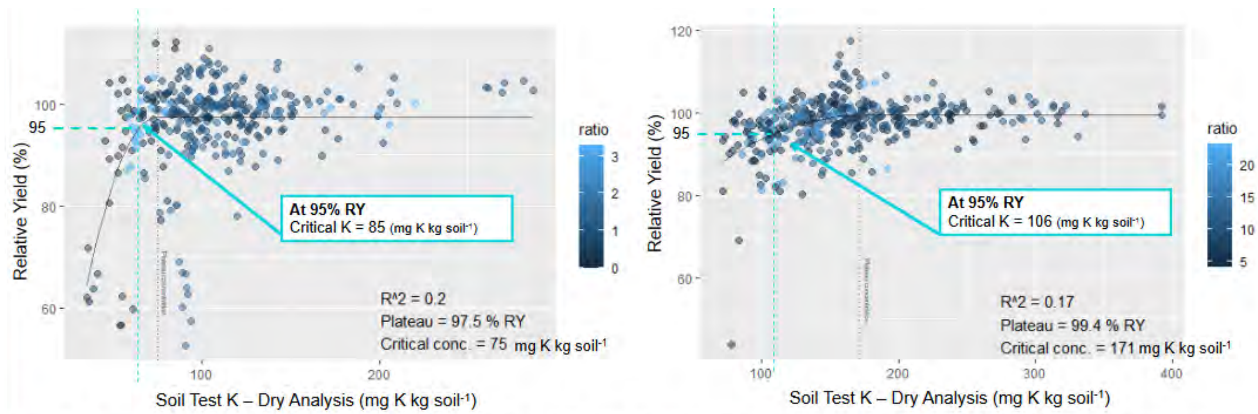

Figure 3. Relationship between relative corn grain yield and soil test potassium for a 0-6" soil sampling depth based on soils with a smectite:illite ratio of less than or greater than 3.5:1. Soil test K was made on dry samples and concentration is given at mg K kg^{-1} soil which directly equates to ppm.

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DRAINAGE AND NITROGEN MANAGEMENT AFFECTS SOIL HEALTH AND SOIL PROPERTIES

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ABSTRACT

The subsurface drainage and nitrogen (N) fertilizer management practices are known to improve crop yield in the Midwest U.S. However, the combined effect of fertilizer source and drainage system is uncertain in poorly drained claypan soils. A 5-year study in Missouri evaluated the impact of different N fertilizer management practices in free drained (FD) and non-drained (ND) soils on soil properties at 0-6-,6-12, 12-24-, and 24-36 in. soil depths. The N fertilizer treatments included Fall AA + Ns (fall applied 170 lbs N ac^{-1} anhydrous ammonia [AA] + nitrapyrin at 0.4 L ai ac^{-1}), spring AA (preplant AA at 170 lbs N ac^{-1}), TD urea [37 lbs N ac^{-1} SuperU plus 112 lbs N ac^{-1} as ESN at a 25:75% blend), and a NTC (non-treated control). In FD soils, application of TD urea and spring AA increased OM content 10% and 13%, respectively, compared to the NTC. Through increased crop production with FD, the N fertilizer application improved soil properties with increased soil OM and OC content. In this study, no adverse effects on soil properties were observed from N fertilizer application at different timings and different amounts. This study suggests that synergetic effect of N fertilization and soil drainage can improve soil fertility by increasing soil CEC, OM, and OC content.

INTRODUCTION

Midwestern United States farmers rely on key fertilizer inputs and management of soil drainage to maintain productivity and profitability. Subsurface tile drainage is used extensively throughout the Midwest U.S. to lower the water table and drain waterlogged soils. Installation of subsurface drainage enhance root growth and thus increase crop nutrient uptake which results in higher yield production. A number of studies in the Midwest U.S. reported an increase in corn (*Zea mays* L.) and soybean (*Glycine max*) yield (Kaur et al., 2022)

Saturated soil conditions influence soil N cycling due to higher environmental loss through leaching and N diffusion by denitrification. To improve nutrient use efficiency and sustainable crop production, best management practices such as 4R nutrient stewardship framework is being promoted in conjunction with drainage water management technology. The 4R nutrient stewardship framework promotes the application of nutrients using the right source at the right rate, right place and right time (Johnston & Bruulsema, 2014). In the Midwest U.S., crop productivity has been enhanced both through drainage water management (Nelson & Smoot 2012, Kaur et al., 2021) and N fertilization management (Nelson et al., 2009), which together may have different impacts on nutrient cycling and soil health. The objective of this research was to evaluate the impacts of N management systems on soil health indicators in drained and non-drained claypan soils.

METHODS

A 5-year (2017-2022) study was conducted at the University of Missouri Lee Greenley Jr. Memorial Research Center near Novelty, MO. The soil was a Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs), which contains a claypan subsurface layer at a depth of approximately 0.6 m (Nash et al., 2015). In this study, we evaluated the impacts of different N fertilizer management practices in free drained (FD) and non-drained (ND) soils on soil properties at 0-15,15-30, 30-60, and 60-90 cm soil depths. The fertilizer treatments included a fall AA + NI (fall applied 170 lbs N ac^{-1} anhydrous ammonia [AA] + nitrapyrin at 0.4 L ai ac^{-1}), spring AA (preplant anhydrous ammonia at 170 lbs N ac^{-1}), TD urea [topdressed urea included 37 lbs N ac^{-1} SuperU plus 112 lbs N ac^{-1} as ESN at a 25:75% blend), and a NTC (non-treated control). All fertilizer treatments were applied to ND and FD plots except the TD urea treatment that was only applied to the FD plots. The field was in corn-soybean rotation, with corn was planted in 2017, 2019, & 2021, and soybean was planted in 2018 and 2020.

In fall of 2017-2021, soil samples were collected at 0-6-, 6-12-, 12-24-, 24-36 inches soil depth using a Giddings probe (Windsor, CO). Collected soil samples were analyzed by the MU Soil and Plant Testing Lab using standard soil testing analytical procedures for Missouri (Nathan et al., 2006). The samples were analyzed for different soil fertility parameters including soil pH, calcium (Ca), magnesium (Mg), potassium (K), organic matter (OM), total carbon, total nitrogen (TN), and soil texture.

The effect of different fertilizer treatments and drainage management was evaluated using a generalized linear mixed model. The fertilizer source was analyzed as a nested factor in drainage, replication as a random effect, year and depth factor as a fixed effect. The P-values from analysis of variance are reported in Table 1.

RESULTS

Soil bulk density, pH, Ca, Mg, K, CEC, NO_3-N, Bray-I P, OM, TOC, TN, silt, and clay content varied significantly ($P < 0.0001$) with fertilizer source in different drainage systems. In ND soils, fertilizer application did not affect soil pH, Ca, Mg, Bray I P, OM, TOC, silt, or clay content. In FD soil, N fertilization increased soil pH, CEC, Ca, Mg, K, and Bray I P compared to the NTC (Table 2). Application of spring AA and TD urea increased soil pH due to hydrolysis of applied fertilizer. The soil pH was highest at 6–12-inch soil and lowest was observed ta 24-36 in soil depth. Soil test Ca increased and Mg was reduced with fertilizer application compared to the NTC (Table 2). This could be attributed to change in cation exchange sites with the addition of NH_4^+ in soil. In addition, different drainage management systems affect dry-wet alteration which affects fixing capacity of cations (Zhang et al., 2009). Drainage and nitrogen fertilization practices significantly affected the availability of soil Bray-I P (*P* =0.0003). Non-drained NTC plots had 34% higher soil P compared to the FD NTC plots (Table 2).

Improved soil aeration and increased plant growth with FD increased soil OM 10-13% in TD urea and spring AA fertilizer treatments compared to the NTC. The FD system improves the crop which resulted in higher amount of crop residue added to the soil. Similarly, TOC in the FD treatments increased 27% and 35% with TD urea and spring AA, respectively, compared to the NTC. At deeper soil depths soil OM and TOC reduced significantly in FD plots (Table 3). Increased aeration with rapid drainage in FD system accelerated mineralization of OM. Total N in soil was significantly higher with TD urea and spring AA application in FD plots (P = 0.0236) compared to other treatments and varied significantly with soil depth (P < 0.0001) and over years which changed at different soil depths (Table 3). Lower TN in ND treatments shows increased N loss through leaching or denitrification during flooded conditions.

The combination of different fertilizer source and drainage management affected soil texture with a significant change in silt and clay content (Table 3). The silt content was reduced by 7% in fall AA + NI in compared to the NTC in FD soils. Whereas, the clay content increased by 10-14 FD % compared to the NTC. The changes in soil texture were probability due to variation in soil cations with fertilizer application causing the dispersion of soil particles. Moreover, rapid wetting and drying of soil with FD system affects the structural stability of soil which resulted in variation in the soil texture over years.

CONCLUSION

In this study, installation of subsurface drainage with N fertilizer application has been shown to affect different soil properties. Overall, the FD and N fertilizer source effected the movement of cations and increased pH, Bray-I P, TOC, OM, and total N content in soil. There was no significant effect of N fertilizer source in ND soils. A significant depth and year effects showed significant seasonal variability in N fertilizer source and application timing. A future research work on soil microbial properties will help in understanding the management of 4R N management.

Table 1. Significance of the effects of experimental factors and their interactions on soil bulk density (BD), pH, cation exchange capacity (CEC), calcium (Ca), magnesium (Mg), potassium (K), phosphorus (Bray I P), nitrate (NO_3-N), organic matter (OM), total organic carbon (TOC), total nitrogen (TN), and soil texture in different soil layers over years as resulting from analysis of variance (ANOVA).

Source of Variation	DF	BD	pH	CEC	Ca	Mg	K	Bray 1 P	NO_3-N	OM	TOC	TN	Sand	Silt	Clay
		---------- *P*-values ----------													
Drainage(Fert)	6	0.1964	0.0229	0.0062	0.0023	0.0026	<0.0001	<0.0001	<0.0001	0.0017	<0.0001	0.0005	0.3342	0.0091	0.0117
Year	4	<0.0001	0.073	<0.0001	0.002	<0.0001	<0.0001	0.0191	<0.0001	<0.0001	0.5063	<0.0001	<0.0001	0.322	<0.0001
Depth	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Year x depth	12	<0.0001	0.3029	<0.0001	0.0038	<0.0001	0.2527	0.7758	<0.0001	0.4399	0.6971	0.0017	0.0241	0.5558	0.3277
Drainage(Fert)*Year	24	0.9831	0.9998	1	1	0.9992	0.9967	0.9973	<0.0001	0.7944	0.9978	0.7162	0.65	0.9804	0.9832
Drainage(Fert)*Depth	18	0.1751	0.0002	0.0211	0.0014	<0.0001	0.0244	0.0558	0.005	0.4458	0.0407	0.1587	0.3623	0.5533	0.2197
Drainage(Fert)*Year*Depth	84	0.9946	1	0.5655	0.9283	0.2318	1	1	0.1117	0.9995	1	0.5014	0.2933	1	1

Table 2. Mean soil pH, cation exchange capacity (CEC), calcium (Ca), magnesium (Mg), potassium (K), and bray I phosphorus (Bray I P) as influenced by drainage and fertilizer treatments, soil depths (0-6, 6-12, 12-24, 24-36 in.), and year (2017-2021) effect. Within a column means followed by same letters are not significantly different at α = 0.05.

Drainage†	Fertilizer‡	Sampling depth	Year	pH	CEC	Ca	Mg	K	Bray 1 P
		in			cmol kg^{-1}	--------------------kg ha^{-1}	--------------------		
FD	NTC			5.5 c	20 c	7007 b	1289 b	419 d	51 c
	TD urea			5.7 ab	22 ab	8100 a	1398 ab	575 a	81 a
	Fall AA+Ns			5.6 abc	22 ab	7790 a	1494 a	508 bc	65 bc
	Spring AA			5.7 a	21 bc	7719 a	1285 b	553 ab	80 a
ND	NTC			5.6 abc	20 c	8011 a	1454 ab	573 a	67 abc
	Fall AA+Ns			5.5 c	23 a	7684 a	1456 ab	542 abc	71 ab
	Spring AA			5.5 bc	22 ab	7572 ab	1443 ab	497 c	60 bc
p-value				0.0229	0.0062	0.0023	0.0026	<0.0001	<0.0001
		0-6		5.9 a	17 c	6098 d	663 d	684 a	133 a
		6-12		6.2 b	18 c	7081 c	860 c	429 d	60 b
		12-24		5.2 c	27 a	8233 b	1714 b	473 c	28 c
		24-36		5.1 c	25 b	9579 a	2372 a	533 b	54 b
		p-value		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
			2017	5.5 b	23.9 a	8220 a	1488 a	580 a	69 b
			2018	5.6 ab	21.2 c	7704 bc	1273 b	579 ab	80 a
			2019	5.5 b	22.7 b	7689 bc	1489 a	537 bc	65 b
			2020	5.6 ab	19.2 d	7302 c	1269 b	433 d	64 b
			2021	5.7 a	21.3 c	7825 ab	1491 a	520 c	70 b
			p-value	0.0703	< 0.0001	0.002	< 0.0001	< 0.0001	0.0191

† FD, free drainage; ND, no drainage

‡ NTC, non-treated control; TD urea, SuperU and ESN top dress application; Fall AA+Ns, fall anhydrous ammonia + nitrapyrin; spring AA, pre-plant anhydrous ammonia

Table 3. Mean soil organic matter (OM), total organic carbon (TOC), total nitrogen (TN), silt, clay, and bulk density (BD) as a function of drainage(fertilizer), depth, and year effect. Within a column, different letters indicate a significant difference at α = 0.05.

Treatment†	Fertilizer‡	Sampling depth	Year	OM	TOC	TN	Silt	Clay	BD
		in		------------------------	---------g kg^{-1} ---------	------------------------	------------------------	------------------------	mg cm^{-3}
FD	NTC			19.5 c	8.9 c	1 bc	559 a	309 c	1.4 ab
	TD urea			21.5 ab	11.3 a	1.1 a	540 abc	341 ab	1.4 a
	Fall AA+Ns			20.3 bc	9.3 bc	1.0 b	521 bc	353 ab	1.4 a
	Spring AA			22 a	12 a	1.1 a	550 ab	330 bc	1.41 ab
ND	NTC			20.4 bc	10 b	1 bc	523 bc	346 ab	1.4 a
	Fall AA+Ns			20.3 bc	9.5 bc	1 b	511 c	353 ab	1.3 b
	Spring AA			19.6 c	9.1 bc	1 b	517 c	359 a	1.3 b
p-value				0.0017	<0.0001	0.0005	0.0091	0.0117	0.0255
		0-6		27.8 a	16.2 a	1.5 a	628 a	231 d	1.3 c
		6-12		22.1 b	12.2 b	1.1 b	584 b	283 c	1.4 b
		12-24		20.2 c	8.2 c	0.9 c	431 d	444 a	1.3 b
		24-36		12.3 d	3.8 d	0.5 d	487 c	408 b	1.6 a
		p-value		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
			2017	20.5 bc	9.6	1.1 ab	533	379 a	1.36 c
			2018	21.5 ab	10.3	1.1 bc	534	347 b	1.4 b
			2019	19.6 cd	10.3	1.1 c	524	322 b	1.37 c
			2020	22.5 a	10.4	0.7 d	546	337 b	1.46 a
			2021	19 d	10	1.2 a	525	324 b	
			p-value	< 0.0001	0.5063	< 0.0001	0.3220	< 0.0001	< 0.0001

† FD, free drainage; ND, no drainage
‡ NTC, non-treated control; TD urea, SuperU and ESN top dress application; Fall AA+Ns, fall anhydrous ammonia + nitrapyrin; spring AA, pre-plant anhydrous ammonia

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DOES INTERSEEDED COVER CROPS COMPOSITION AFFECT CORN N FERTILIZER NEEDS IN CORN AND SOYBEAN YIELDS?

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ABSTRACT

Cover crops are often recommended as a valuable practice to develop more sustainable cropping systems. However, interseeding cover crops may change the amount and timing of nitrogen (N) provided to the crop from decomposition (mineralization), which may increase or decrease the N fertilizer required to optimize corn grain yield. This study aims at understanding the effect of cover crop composition (single and multispecies) on soil biological measurements, corn N requirements, and corn and soybean yield. A long-term corn-soybean rotation study was established in 2019 in Brookings and Beresford, South Dakota. Treatments consisted of three cover crop treatments (No cover crop, single grass species, and grass/broadleaf mixture) with 4 or 6 N rates for corn ranging from 0-250 lbs. ac^{-1}. Results from 2019 to 2021 indicate that corn with grass cover crop required anywhere from 40 lbs. ac^{-1} less to 25 lbs. ac^{-1} more N compared to when no cover crop was grown. In 2 of 4 N responsive site years including a grass/broadleaf cover crop reduced corn yield at EONR (Economical Optimum Nitrogen Rate) by 15-30 bu. ac^{-1} compared to the grass or no cover crop treatments. In two of three responsive site years. Including a grass cover crop significantly increased corn yield (15-30bu ac^{-1}) at EONR compared to the grass/broadleaf mix and no cover crop and required less N without any significant yield losses. For soybean, interseeding grass or a grass/broadleaf mixture had little to no influence on soybean yield. These results demonstrate that cover crops regardless of composition can be interseeded into soybean without negative yield results, but the effect of cover crop composition on yield and N requirements of corn has been inconsistent in the first three years of this study.

INTRODUCTION

Corn production and productivity have been on a steady rise in South Dakota. However, dependence on a small number of crops can reduce agricultural biodiversity. Rotating diverse crops improves productivity through enhanced soil biodiversity, nutrient availability, resource use efficiency, and increased soil organic matter(McDaniel et al., 2014; Tiemann et al., 2015). The inclusion of cover crops increases the diversity in corn (*Zea mays L.)* and soybean (*Glycine max L. Merr.*) rotations that are common in the US Midwest. The use of cover crops also affects a wide range of ecosystem services viz., improved soil quality, pest suppression, and biological N fixation(Schipanski et al., 2014).

Although the practice of planting cover crops has been around for many years recent gain in popularity can be largely credited to potential soil and water quality improvements (Thompson et al., 2021). Cover crops use in the US has increased by 50 percent between 2012 and 2017. Although this is a significant increase from the previous year's it only accounts for a small fraction of the total cultivated area. Current limitations to cover crop adoption are numerous, but seeding cost, return on investment, as well as a lack of breeding efforts and variety enhancement, were common culprits. Poor cover crop establishment was the most common factor limiting cover crop performance(Wayman et al., 2017). Furthermore, cover crop use tends to be lower in the northern Midwest likely due to the shorter growing season to establish a cover crop. Winter cereals are the only option for seeding a cover crop in northern climates following corn harvest; however, the establishment is still somewhat limited by the length of the growing season (Baker & Griffis, 2009). Currently, grasses are the most popular interseeded species, followed by clovers, and then Brassica species(*USDA ERS - Cover Crops*, n.d.). Researchers have examined interseeding several cover crop species including annual ryegrass (*Lolium multiflorum Lam.*) and crimson clover seeded as a single species and in mixtures.

Crop competition is a major concern associated with interseeding cover crops (Hall et al., 1992). The competitiveness of weeds in corn depends on the weed emergence time in relation to corn emergence, weed species, and weed density. Weeds were not competitive with corn when weeds emerged after V2, V4 (Travlos et al., 2011), and V5 corn stages. These results suggest that cover crops could be interseeded in corn as early as the V2 corn growth stage without reducing corn grain yield, but the competitiveness of cover crops, like weeds, may be dependent on species and density. Although cover crops do not compete with the corn plant after the V5 stage they can still influence the amount of N required to optimize corn yields. It is therefore important to understand the influence of different cove crop composition and their effect on the N rates in corn, and soybean yields. This study aims at understanding the effects of cover crop composition (single and multispecies) on soil biological measurements, corn N requirements, and yields in corn and soybeans.

MATERIALS AND METHODS

A long-term corn-soybean rotation study was established in 2019 in Brookings and Beresford, South Dakota. Treatments were laid out in a split-plot design with three cover crop treatments (No cover crop, single grass species, and grass/broadleaf mixture), and 4 or 6 N rates for corn ranging from 0-250 lbs. N ac^{-1}. Ammonium Nitrate or Super U were used as the N source. Pre-plant soil samples were taken from previous corn going into soybean at two depths (0-6" and 6-24"). Samples collected at 0-6" were analyzed for soil health and fertility and 6-24" samples were analyzed for ammonium, nitrate, and sulfur (Table1). All N rate treatments were applied 7-10 days after planting and cover crops were interseeded at V5 developmental stages in corn and soybean. In-season soil and plant samples were collected at V6, R1, and R6 developmental stages in corn and V5, R1, and R6 developmental stages in soybean. In-season soil samples were analyzed for soil health and fertility, and a complete nutrient analysis was done on plant samples (Table1). Grain samples were collected at harvest and tested for complete nutrient analysis. Post-harvest soil samples were collected at three depths (0-12",12-24", and 24-36"). These samples were analyzed for total nitrate N content remaining in the soil after harvest (Table1).

Table 1. Samples collected and tests run

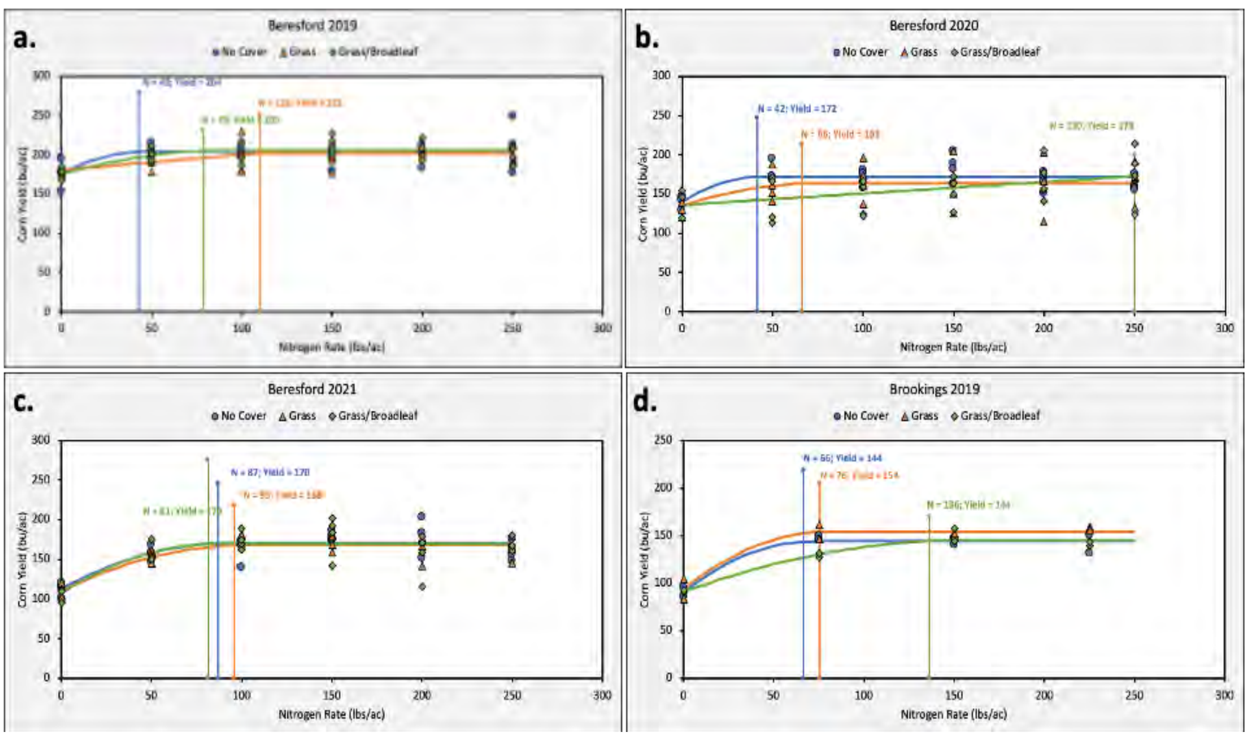
<table>
<tr><th>Sample type</th><th>Collection time/stage</th><th>Sampling depth/type</th><th>Tests run</th></tr>
<tr><td rowspan="2">Soil</td><td rowspan="2">Pre-plant</td><td>0-6”</td><td>Nitrate N
Ammonium N
Soil Organic matter
Organic Carbon
Active C
SHT-Soil health tests (NPK, SOM, CEC & S)
PMN (potentially mineralizable nitrogen)
Wet aggregate stability</td></tr>
<tr><td>6-24”</td><td>Ammonium N
Sub soil nitrate
Sub soil S</td></tr>
<tr><td>Soil</td><td>In-season</td><td>0-6”</td><td>Nitrate N
Ammonium N
Soil Organic matter
Organic Carbon
Active C
PMN (potentially mineralizable nitrogen)
Wet aggregate stability</td></tr>
<tr><td rowspan="3">Soil</td><td rowspan="3">Post- Harvest</td><td>0-12”</td><td rowspan="3">Nitrate N</td></tr>
<tr><td>12-24”</td></tr>
<tr><td>24-36”</td></tr>
<tr><td>Plant</td><td>V6,R1,R6</td><td>Corn Plant</td><td>Full nutrient analysis</td></tr>
<tr><td>Plant</td><td>V5,R1,R6</td><td>Soybean Plant</td><td>Full nutrient analysis</td></tr>
<tr><td>Grain</td><td>Harvest</td><td>Corn</td><td>Full nutrient analysis</td></tr>
</table>

RESULTS AND DISCUSSION

Corn yield response

Response in corn yields to N fertilization was observed in four of six site-years (Figure 1). The non-responsiveness of the other site years can be attributed to corn lodging from high winds and drought causing K deficiency in corn. Results from 2019 to 2021 indicate that corn with grass cover crop required anywhere from 40 lbs. ac^{-1} less to 25 lbs. ac^{-1} more N compared to when no cover crop was grown (Figure1a-d). In 2 of 4 N responsive site years, including a grass/broadleaf cover crop reduced corn yield at EONR (Economical Optimum Nitrogen Rate) by 15-30 bu. ac^{-1} compared to the grass or no cover crop treatments (Figure 2d). Including a grass cover crop significantly increased corn yield (15-30bu ac^{-1}) at EONR compared to the grass/broadleaf mix and no cover crop and required less N without any significant yield losses.

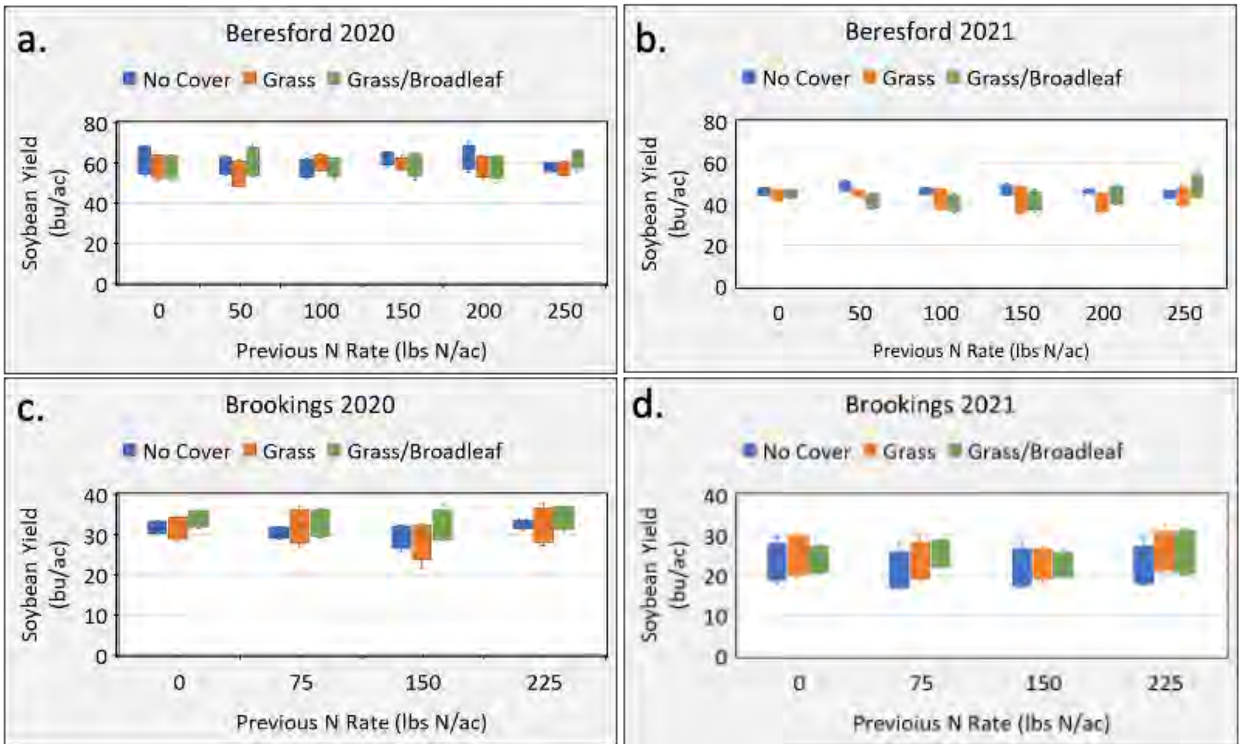
Figure 1. Corn responsive site years - yield vs. nitrogen rate



Soybean yield response

Regardless of the previous N rate applied, no significant difference was observed in mean soybean yields among the cover crop treatments with an exception at the Beresford site in 2021 (Figure2a-d). These results indicate that for soybean, interseeding grass or a grass/broadleaf mixture had little to no influence on soybean yield. Therefore, cover crops regardless of composition can be interseeded into soybean without impacting yield. In the Beresford 2021 site year, interseeded single or cover crop mixtures trended to reduce yield at the previous year's 50 and 100 lbs. N ac^{-1} rates (Figure2b). The drought conditions during 2021 may have contributed to this trend toward reduced yields where cover crops were planted. However, the 2021 Brookings site was also under drought conditions and cover crop inclusion did not influence soybean yield. As we get more site-years of data under various moisture conditions, our understanding of interseeded cover crop's effect on soybean yield will increase.

Figure 2. Soybean responsive site years – yield vs. previous N rate



CONCLUSIONS

Interseeding cover crops in the corn-soybean rotation can have several direct and indirect impacts on overall soil health and fertility without compromising yields. Single or multiple cover crop mixtures can be interseeded into soybean without negative yield. The effect of cover crop composition on yield and N requirements of corn has been inconsistent in the first three years of this study. Therefore, further data is required before solid conclusions about the effect of cover crop composition on N requirements and yield in corn can be determined.

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COVER CROP SPECIES AND PLANTING METHODS INFLUENCE ON CORN NITROGEN REQUIREMENT IN SOUTHERN ILLINOIS

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ABSTRACT

It is well established that planting cover crops prior to corn (*Zea mays* L.) can influence soil temperature, volumetric water content (VWC), and nitrogen (N) dynamics. These changes in soil along with the effects of cover crop on corn plant population can influence corn grain yield and N requirement. Two strategies to facilitate corn establishment and avoid N immobilization especially in winter cereal cover crops is by mixing legumes with winter cereals or skipping the corn row (precision planting). A randomized complete block design trial with split plot arrangement was conducted in 2020-2021 and replicated in the 2021-2022 growing season. The main plots were cover crop treatments including winter rye (*Secale cereale*), crimson clover (*Trifolium incarnatum*), their mixture, precision planted crimson clover, and precision planted crimson clover and winter rye in mixture. The subplot were six N rates (0 – 320 lbs N ac^{-1}). We measured cover crop performance, corn morphology and physiology, grain yield, N removal, N balance, and N use efficiency. In 2021 among cover crops, the precision planted mixture and winter rye had the largest cover crop biomass, 4.7 ton ac^{-1} and 4.6 ton ac^{-1}, respectively with a lower (C:N) at 26:1 compared to 31:1 in winter rye alone. Precision planted clover had similar biomass production to solid planted clover indicating lower clover seeding rate and skipping the corn row had no influence on clover performance but decrease cost of cover crop planting. Corn yield was similar among all cover crop treatments in 2021 and corn economic optimum rate of N (EORN) was 179 lb N ac^{-1}. Data for the year 2022 is continuing to be collected.

INTRODUCTION

In response to the growing algal blooms and eutrophication within the Mississippi River Basin, the state of Illinois is implementing the Nutrient Loss Reduction Strategy[1]. The goal of this strategy is to reduce the impact of N and phosphorus (P) loading in water bodies through the integration of best management practices[1]. Two of the strategies included are the selection of winter cover crops and the optimized use of N fertilizer[1]. It is known that winter rye offers a host of ecosystem services due to its ability to scavenge nutrients, reduce soil erosion, sequester carbon, lessen compaction, and suppress weeds[1,2]. While winter rye provides these benefits, it can negatively influence the following corn cash crop through several mechanisms [1,2]. Winter rye can immobilize

N, deplete soil water, interfere with corn establishment, decrease corn stand and therefore, decrease corn yield[2,3]. Solutions that can help alleviate the soil-N immobilization include the termination stage and integration of legumes, such as crimson clover, which can reduce the C:N below 25:1 where immobilization will no longer happen[3]. Previous studies have shown that a mixture of winter rye with crimson clover can decrease the negative effects of winter rye on the subsequent corn[4] and alter its N requirement. It is unclear how precision planting (skipping the corn row) or integrating precision planting into winter rye-crimson clover mixture can affect corn establishment, soil N, corn grain yield and N requirement. Therefore, the objectives were to explore the impact of cover crop selection and planting method on cover crop biomass, weed suppression, corn plant population (stand density), grain yield, and N requirement. We hypothesized that precision planting and including crimson clover could decrease N requirement of corn.

MATERIALS AND METHODS

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

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

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

We used several models (linear, quadratic, linear plateau, and quadratic plateau) and to identify the best fit for assessing economic optimum rate of N (EORN). Among those, linear plateau model was the best fit. Statistical analysis for cover crop biomass, percentage of weed biomass, and corn stand density was performed with SAS 9.4 (SAS Institute Cary, North Carolina) using a one-way ANOVA. Cover crops were considered as the fixed effect and block was the random effect. Statistical analysis for corn grain yield was performed using a two-way ANOVA with SAS 9.4 (SAS Institute Cary, North Carolina) using mixed models with cover crop and fertilizer set as fixed effects and block set as a random effect. When treatments were significant, mean separation was conducted using Least Square Means adjusted for Tukey.

RESULTS and DISCUSSION

Cover Crop Performance

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

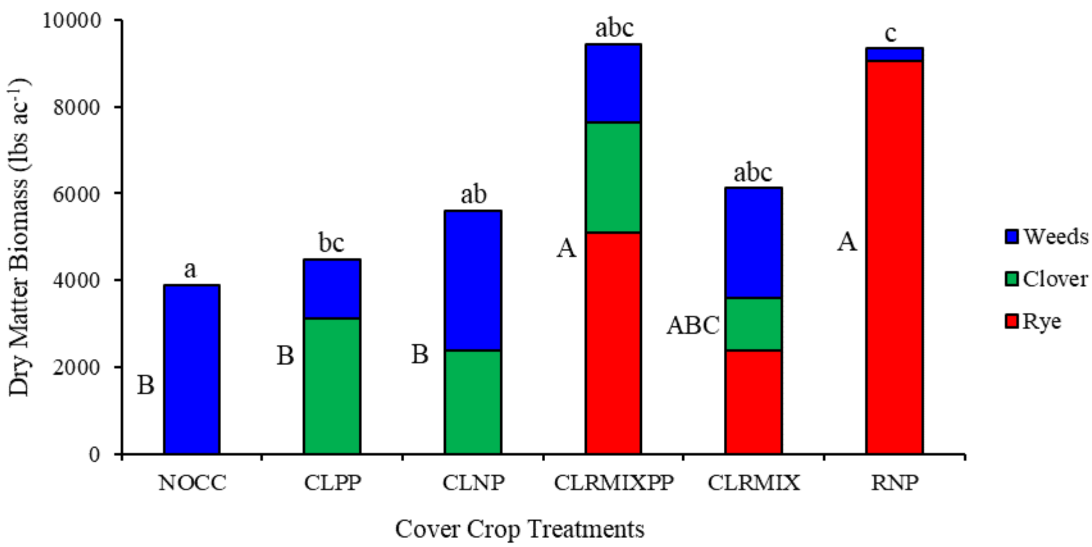

Figure 1. Cover crop (clover and rye) and weed dry matter biomass in each cover crop treatment. (lower case letters compare weed biomass and capital letters compare cover crop biomass) indicate significant difference (<0.05, Tukey). Treatments were no cover crop control (NOCC), crimson clover precision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

Corn population was only found significant between WCR and the control (NOCC), solid planted clover, PP clover, and PP mixture treatments (Figure 2). This indicated that the

WCR had interfered with corn establishment and resulted in corn stand density reduction further emphasizing the importance of precision planting of cover crops.

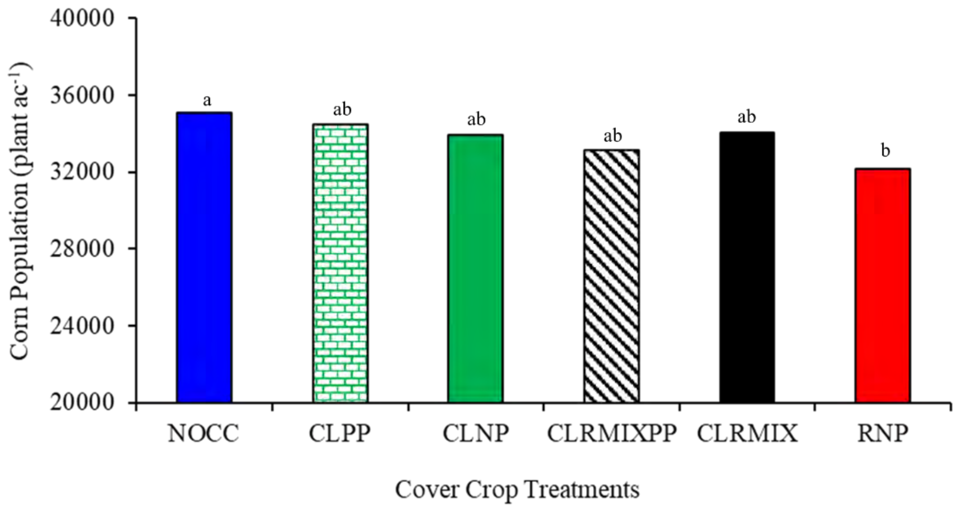

Figure 2. Corn plant population as influenced by cover crop treatments. (a, ab, b) indicate significant difference (<0.05, Tukey). Treatments were no cover crop control (NOCC), crimson clover precision planted (CLPP), crimson clover solid planted (CLNP), crimson clover on corn row winter rye (WCR) on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

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

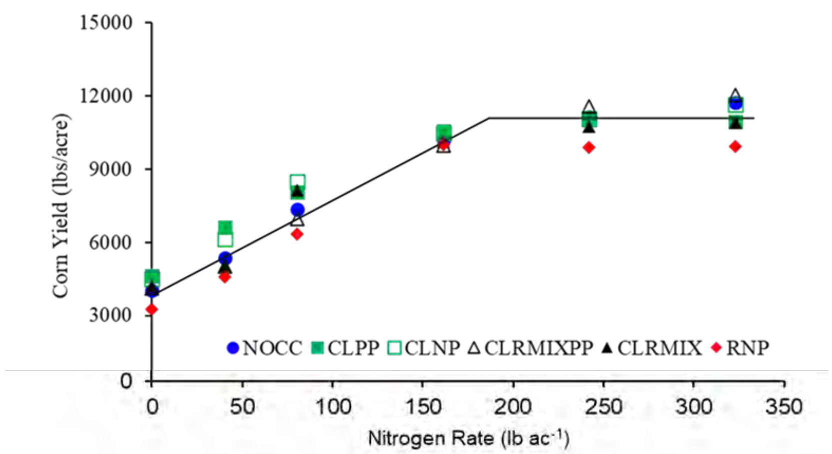

Figure 3. Response of corn grain yield to N fertilization rates and EORN for corn in 2021. Treatments were no cover crop control (NOCC), crimson clover precision planted (CLPP), crimson clover solid planted (CLNP), crimson clover on corn row winter rye (WCR) on middle rows (CLRMIXPP), crimson clover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

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UPDATING PHOSPHORUS RECOMMENDATIONS FOR ILLINOIS

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ABSTRACT

Phosphorus (P) is a key fertility input essential to maintain the high productivity of North Central cropping systems. An important aspect of fertilizer recommendations is knowing when soil tests indicate a profitable yield response to P fertilization. To this end, critical soil test values (CSTV) are essential to informing agronomic and economic optimum rates for crop production. To improve profitable use of P inputs, as well as to explain field-specific variation in CSTV that enable context-specific adjustment, soil P contribution to crop uptake is also necessary. Two sources of soil-derived P are inorganic P stocks, conceptualized as "soil P supply power", and organic P that can be mineralized to crop-available orthophosphate. Though no longer used by neighboring states, the Illinois Agronomy Handbook still recommends interpretation of CSTV based on subsoil P supply power, a qualitative (e.g., high vs low supply power regions) assessment based on loess thickness, loess age and drainage. Quantifying P stocks at fine spatial and their contribution P to crop uptake through on-farm trials will provide a basis for assessing the utility of the soil P supply power concept. Apart from inorganic P stocks, soils contain large reserves of P in organic forms, bound to carbon in organic matter. Like nitrogen, organic P in soil organic matter must first be mineralized via microbes, specifically from the catalytic action of enzymes known as phosphatases. Using radioisotopic dilution to estimate potentially mineralizable P, we find evidence for agronomically relevant magnitudes of potential P credits from soil organic matter. Active and forthcoming work on improving P recommendations for Illinois corn-soybean production systems are reviewed.

INTRODUCTION

<u>Updating P CSTV for Illinois</u>.

Soil tests are a simple but powerful approach to nutrient management: a soil sample is extracted using a chemical solution (e.g., Bray or Mehlich-3) that is calibrated to relative crop yield. The relationship between the increasing concentration of the nutrient extracted from the soil ("soil test" value) and relative yield (% of maximum obtainable) is then derived (Figure 1). Ensuring that soil tests are interpreted with correctly calibrated CSTV is essential to keep pace with agricultural management and soil testing practices that change over time.

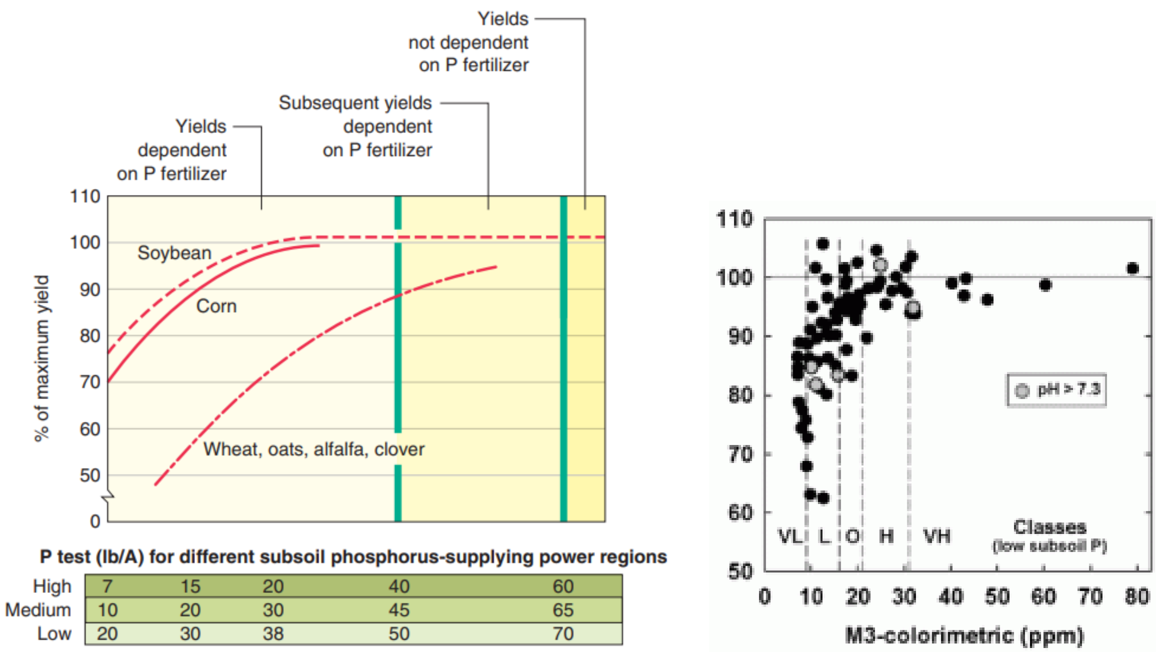
There are at least **<u>six reasons</u>** why the soil test P recommendations for Illinois agriculture are in need of updating:

1. Changes in how we test for soil P. Commercial labs have largely shifted from Bray for P to Mehlich-3 as a universal extractant [1]. Facilitated by inductively coupled plasma (ICP) optical emission spectroscopy (OES), which measures all nutrient elements except N in the same extract, Mehlich-3 ICP values are now the norm [2]. This is reflected in Mehlich-3 being the recommended soil test for P (and other macronutrients and micronutrients) in the North Central region according to the UDSA

NCERA-13 committee [3]. Due to the nature of extractants differing in chemical composition, soil test P values based on Bray or Mehlich-3 colorimetric values do not give the same numerical values as Mehlich-3 ICP that is used by most commercial soil labs. In other words, Illinois recommendations are out-of-date with the method of testing for soil P, and this can lead to misinterpretation of soil test results. In general, Mehlich-3 extracts more P than Bray, so using soil test P values based on Bray to interpret Mehlich-3 soil test results could lead to underapplication of P. However, universal conversions between soil tests are not possible, and require soil- or region-specific corrections.

2. Crop-specific needs. The Illinois Agronomy Handbook does not currently distinguish CSTV among crops (Figure 1), but it has been shown that corn or soybean vs wheat can have different CSTV for P [2, 4]. For example, wheat can have up 2x lower P Mehlich-3 CSTV compared to soybean [4].

Figure 1. Example of CSTV for P from (left) the Illinois Agronomy Handbook and (right) Iowa State University Extension CSTV, developed by Dr. Antonio Mallarino [5, 6].



High	7	15	20	40	60
Medium	10	20	30	45	65
Low	20	30	38	50	70

3. Changes in crop management. Higher plant populations, modern hybrids with changes in root systems, tillage practices, and fertilizer placement have all clearly changed in the >50 years since the Illinois CSTV were developed for P and K. However, these CSTV assume broadcast application with conventional tillage for full incorporation. Each of these changes could impact the CSTV based on crop uptake efficiencies, root densities, and nutrient stratification.

4. Changes in how we model the soil test data. Selecting a method for soil test correlations (i.e., model) to be used for determining CSTV is important because the model selected can change the resulting CSTV, even for the same dataset. Thus, it is important to evaluate multiple models for the same dataset. The Illinois Agronomy Handbook does not specify the original model(s) used to determine CSTV. Recent advances in CSTV calculation enable additional models to be evaluated for conference and for quantification of uncertainty inherent to CSTV estimations [7, 8].

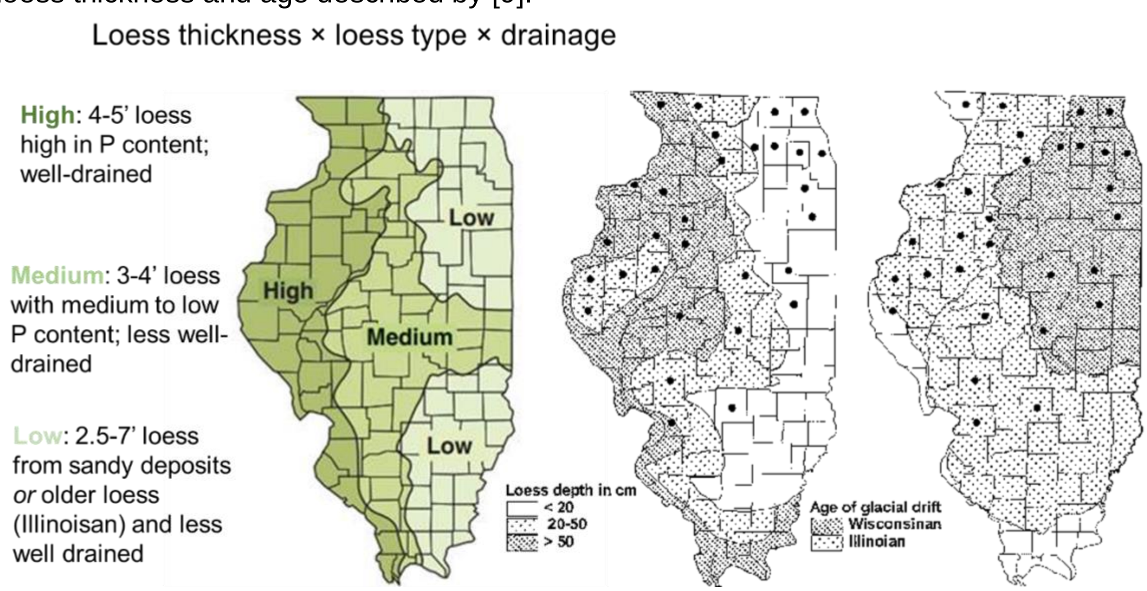
5. Changes in other North Central region and Corn Belt states. It is estimated that 80% of states have CSTV that are outdated by at least 20 years [7]. The economics of fertilizer and environmental stewardship pressures have led many states to update soil test P recommendations. For example, the Tri-States region of Indiana, Michigan and Ohio recently updated >25 year old CSTV for P for corn, soybean and wheat [2]. Nationally, the Fertilizer Recommendation Support Tool (FRST) effort is working to consolidate CSTV and soil testing recommendations across state borders [7, 8].

6. Transparency and open-access of data. To our knowledge, the original data and methods of modeling these for CSTV in Illinois are not available. The issue of transparency in CSTV can challenges users' interpretation of recommended CSTV [7].This lack of transparency should be addressed by making all data fully available *and* interactive, much like the North Central region's Mean Return to Nitrogen (MRTN) tool, and as exemplified by the FRST effort [7, 8].

Revisiting soil P supply power concept.

The concept of soil P supplying capacity that forms the basis of Illinois and many other Midwestern state recommendations on P management, including P application rates, are qualitative (e.g., low vs medium vs high) and not refined beyond broad regions (Figure 2). The Illinois Agronomy Handbook categorizes soils in Illinois and thus P application rates by "P supply power" (Figure 1) based on loess type and thickness, with soils developed on deeper and younger loess deposits considered to have higher P supply power. However, this is qualitative, and not useful at fine scales. Quantifying soil P stocks and test P to substantial depth (0-36") by loess region and soil types can help evaluate whether this concept can improve P application recommendations.

Figure 2. Phosphorus supply power regions in the Illinois Agronomy Handbook, compared to loess thickness and age described by [9].



Potentially mineralizable P as the basis for a soil P credit.

In constructing nitrogen (N) recommendations for farmers, N credits from organic matter mineralization are typically considered. These N credits are developed by combining the size of the soil organic matter “bank account” with inherent soil properties (e.g., clay content) to predict the total release of plant-available N. Currently, no such credit exits for P, though soils contain large reserves of P in organic matter. Though the amount of organic P stored in soils of Illinois or the US is largely unknown, like N it is likely to be substantial. Recent work by the Margenot Lab on soil P cycling at the Monmouth Research and Demonstration Center in northwestern Illinois reveal that at 0-6” depth alone, soils had 440 to 600 lb per acre of organic P that could be mineralized [10]. With recent advances in cost-effectiveness, instrumentation, and safety [11, 12], the use of radioisotopic (^{32}P or ^{33}P) pool dilution can provide an estimate of potentially mineralizable P (lbs/ac).

MATERIALS AND METHODS

Updating P CSTV for Illinois.

To determine P CSTV for corn, soybean and wheat and specific to Illinois regions and soil types, we are employing historical datasets from private commercial labs as well as an estimated n=80-90 on-farm trial locations for several years starting in the 2023 growing season. Specific objectives will be to (1) establish P CSTV for major soil types of Illinois, specific to corn, soybean and wheat; (2) account for (i) soil type, (ii) nutrient stratification by tillage management (conventional, strip, no-till) and (iii) soil sampling depth to fine-tune CSTV interpretations, as well as (iv) recent advances in modeling CSTV; and, (3) develop conversion factors among P tests to account for new tests being used in the 21st century (e.g., Bray P to Mehlich-3 P).

Revisiting soil P supply power concept.

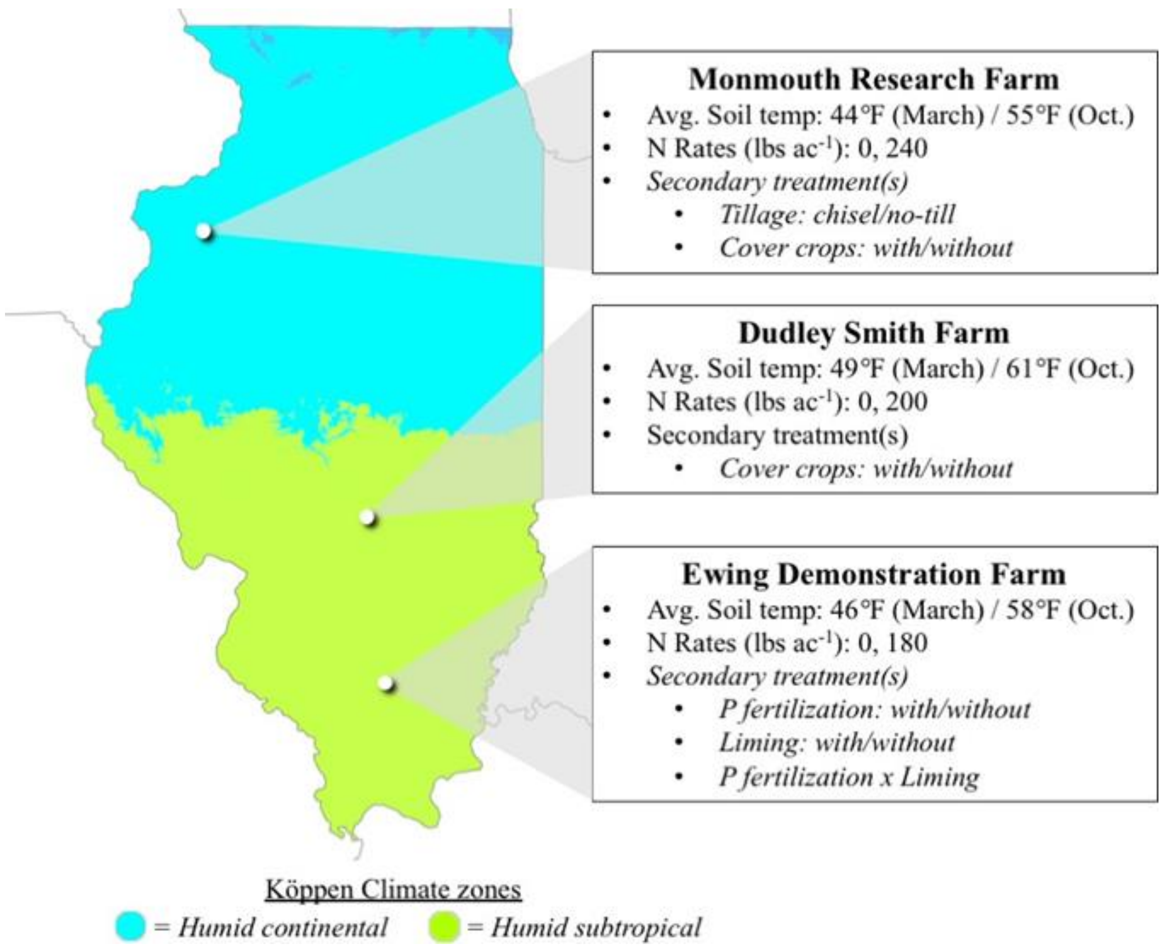
To verify the value of including the soil P supply power concept in interpretation of CSTV, soils from (1) an archive of pedons sampled in the Illinois state survey from 1904-2010 and (2) on-farm soil cores to 36” depth (n=1200 cores across n=140 fields) that capture geographic diversity of loess and soil types of the state are being analyzed for total P. A subset will be analyzed for available, potentially available (organic P, exchangeable P) and apatite P.

Potentially mineralizable P as the basis for a soil P credit.

Soil P mineralization rates at 5, 10, 15 and 20ºC were determined for n=18 soils [11, 13] encompassing soil-climate conditions of Illinois and agricultural mangaement treatments (Figure 3). Though complex and laboratory-intensive (hence the low sample size), this approach is the sole method in existence for estimating P mineralization rates in soil. Both gross and net (crop-available) P mineralization were quantified in a two-part experimental approach. First, a short-term (100 min) isotopic exchange kinetics (IEK) experiment was used to exclusively model physicochemical processes that must be controlled for in determining P mineralization. Second, a 28 d incubation experiment was performing to account for biological and/or biochemical processes. In both experiments, preincubated moist soil spiked with ^{33}P-phosphate tracer solution. Subsamples over the 28 d incubation were analyzed for radioactivity and water soluble

P. Data obtained from IEK was fit using empirical power function to extrapolate abiotic controls in 100 min over 28 d. The difference in the measured and extrapolated isotopically exchanged P was gross P mineralized. Microbial P uptake of mineralized P was corrected by fumigating the ^{33}P labeled soil. The specific radioactivity of the water extracts of fumigated soil and non-fumigated soil, together with the fumigant-labile P content, was measured to calculate the microbial P immobilization rates. By subtracting microbial P immobilization from gross P mineralization rates, net P mineralization rates were derived.

Figure 3. Subset of experimental sites and associated treatments being used to furnish soil samples with gradients of soil organic matter used to evaluate radioisotopic pool dilution based estimation of potentially mineralizable P. Soil temperatures indicate the 5 year-average (2014-2019). An additional site was included from contrast crop rotation and input treatments in year 145 of the Morrow Plots, and a forest and restored prairie, located in Urbana (Champaign Co.).



RESULTS & DISCUSSION

Updating P CSTV for Illinois.

Results are anticipated starting in early 2024, with project deliverables in 2027. A series of project updates will be delivered at future NCSFC and other outreach venues in Illinois and the North Central region.

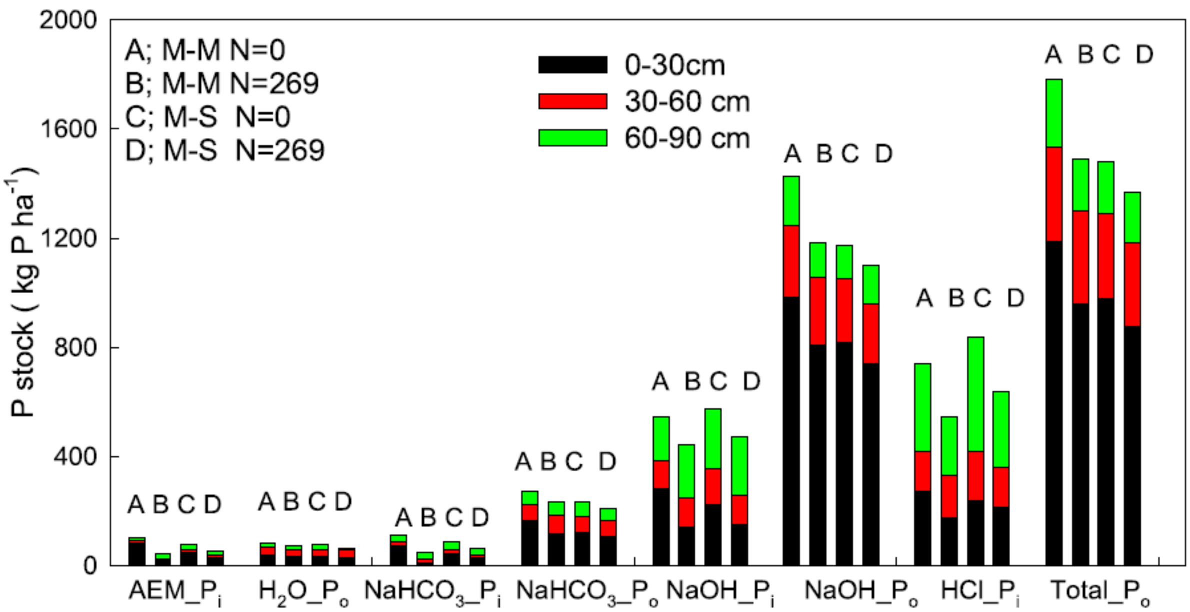
Revisiting soil P supply power concept.

Preliminary results on soil P stocks to depth indicate that the loess parent material of Illinois that blankets much of the North Central region contains appreciable P (250-400 mg/kg), which is largely in apatite forms of non-extractable forms (known as “occluded” or “residual”) that is not thought to be crop-available [14] (Figure 4). Thus, we find that there is substantial P stocked in subsoils developed on loess parent material. However, how much this subsurface P can contribute to crop P uptake remains unknown, and will be the subject of field trials (on-farm) that will initiated in the 2024 growing season. Additional results will be anticipated starting in early 2025, with assessments finalized in 2026. A series of project updates will be delivered at future NCSFC and other outreach venues in Illinois and the North Central region.

Potentially mineralizable P as a basis for a soil P credit.

Based on the diverse soils evaluated in Illinois, including Mollisols and Alfisols, there is reason to anticipate agronomically relevant P credits across the North Central region. Though the amount of organic P stored in soils of Illinois and the greater North Central region is largely unknown, it is thought to far exceed the pool of immediately available soil P that is proxied as “soil test” P [10]. At 0-6” depth alone, soils had 440 - 600 lb/ac of P in organic forms that could be mineralized, and at 0-36” depth contained 1,100 - 1,700 lb/ac [10] (Figure 4).

Figure 4. Stocks of soil P across operationally defined chemical fractions that correspond to pools of significant, including organic P (“Total P_o”) and apatite P from the loess parent material (“HCl P_i”). To convert from kg/ha to lb/ac, multiply by 0.892. From [10]. Additional fractions include crop available P (AEM-P_i), sub-fractions of organic P extractable by water (H_2O P_o), sodium bicarbonate ($NaHCO_3$ P_o) and sodium hydroxide (NaOH P_o), labile inorganic P extractable by sodium bicarbonate ($NaHCO_3$ P_i) and mineral-associated sodium hydroxide (NaOH P_i). Fractions are meant to *approximate* pools of varying availability [15, 16]. Different letters indicate significant differences among 36 year crop rotation treatments of corn-corn (M-M) vs corn-soybean (M-S), with or without N (269 kg/ha = 240 lb/ac) applied to corn.



The soils evaluated ranged widely in organic C from 1.0 – 5.9%, which entailed large variation in organic P of 190-1247 mg/kg, representing 59 – 94% of total P (Table 1). In soils under corn and soybean cropping, organic P ranged from 190 – 592 mg/kg, encompassing the same range of total P that was present as organic P.

Table 1. Properties of soils used to evaluate potentially mineralizable P across four agricultural trials (n=16 soils) and two non-agricultural soils used as a reference (n=2). Abbreviations: CC, cover crop.

Trial	Soil type	Treatment	Organic C (%)	C:N	pH	Total P (mg/kg)	Organic P	
							(mg/kg)	(% of total)
Ewing	Alfisol	No lime, - P	1.0	9.4	4.6	233	190	81
Ewing	Alfisol	No lime, +P	1.1	9.3	4.7	556	488	88
Ewing	Alfisol	Lime, - P	1.0	8.7	5.3	203	192	94
Ewing	Alfisol	Lime, +P	1.3	9.4	5.0	568	497	87
Dudley-Smith	Alfisol	- CC, +N	1.7	11.3	5.8	666	419	63
Dudley-Smith	Alfisol	+CC, +N	1.8	12.0	5.9	732	444	61
Dudley-Smith	Alfisol	-CC, -N	1.8	11.7	5.8	762	452	59
Dudley-Smith	Alfisol	Pasture	2.0	11.1	6.3	546	376	69
Morrow	Mollisol	Corn-corn, -NPK	1.5	11.7	6.2	530	411	78
Morrow	Mollisol	Corn-corn, +NPK	2.1	11.3	7.4	654	479	73
Morrow	Mollisol	Corn-soy, -NPK	2.0	12.5	6.5	486	430	88
Morrow	Mollisol	Corn-soy, +NPK	2.7	12.8	7.1	796	512	64
Monmouth	Mollisol	Till, +N	2.3	12.8	6.9	638	501	79
Monmouth	Mollisol	No-till, +N	2.5	12.4	5.5	629	592	94
Monmouth	Mollisol	corn-soy, -N	2.7	12.4	6.9	636	539	85
Monmouth	Mollisol	corn-soy, +N	2.3	13.5	7.2	603	446	74
n/a	Mollisol	Forest	5.9	13.7	7.3	1358	1247	92
n/a	Mollisol	Prairie	3.3	13.9	7.2	702	540	77

Interpreted as a pool of potentially mineralizable P (mg/kg or lb/ac), assessments support the hypothesis of a soil P credit that is agronomically appreciable.

At 0-6” depth, potentially mineralizable P ranged from 24 to 201 lb/ac in soils under agricultural management and up to 304 lb/ac in forest (Table 2). Notably, mineralizable P in prairie soils (94 lb/ac) was nearly the same as the average potentially mineralizable P in agricultural soils of 95 ± 43 lb/ac.

Assuming that half of this pool of potentially mineralizable P is actually mineralized in a growing season, this would entail a P credit of 12 to 100 lb/ac, which could meet from two-thirds to all the P needs of high-yielding corn and soybean [17, 18]. Clearly, how much P is actually mineralized – likely to depend on weather, as for N mineralization – will vary. Additionally, timing of P mineralization and synchrony of P release from organic matter with crop need will determine contributions of soil organic P to crop uptake.

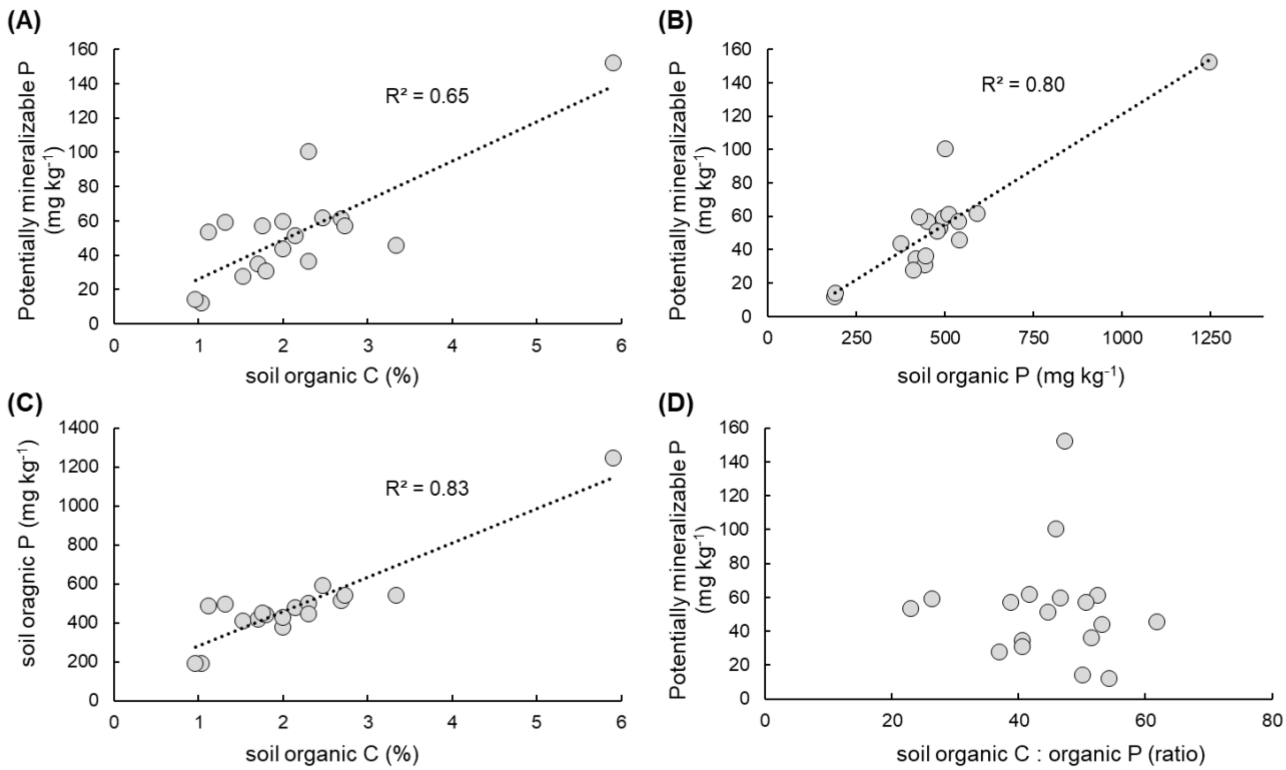
Table 2. Potentially mineralizable P at 0-6” depth across a range of agriculturally managed (n=16) and non-agriculturally managed (n=2) soils.

Trial	Soil type	Treatment	Potentially min. P (mg/kg)	(lb/ac)
Ewing	Alfisol	No lime, - P	12.1	24
Ewing	Alfisol	No lime, +P	53.3	107
Ewing	Alfisol	Lime, - P	14.1	28
Ewing	Alfisol	Lime, +P	59.2	118
Dudley-Smith	Alfisol	- CC, +N	34.8	70
Dudley-Smith	Alfisol	+CC, +N	30.9	62
Dudley-Smith	Alfisol	-CC, -N	56.9	114
Dudley-Smith	Alfisol	Pasture	43.9	88
Morrow	Mollisol	Corn-corn, -NPK	27.8	56
Morrow	Mollisol	Corn-corn, +NPK	51.2	102
Morrow	Mollisol	Corn-soy, -NPK	59.7	119
Morrow	Mollisol	Corn-soy, +NPK	61.3	123
Monmouth	Mollisol	Till, +N	100.6	201
Monmouth	Mollisol	No-till, +N	61.5	123
Monmouth	Mollisol	corn-soy, -N	57.0	114
Monmouth	Mollisol	corn-soy, +N	36.3	73
n/a	Mollisol	Forest	152.2	304
n/a	Mollisol	Prairie	45.8	92

Across soils and management treatments, potentially mineralizable P was 5- to 7-fold greater at 68°F vs 50-41°F soil temperatures, indicating that the temperature sensitivity of this process is robust across managements (data not shown).

Potentially mineralizable P was strongly related to total soil organic P and less so to total soil organic C (Figure 5), reflecting variation in organic C: organic P ratios from 23 to 62 (data not shown), well below the threshold of P immobilization of 200 [19, 20]. Potentially mineralizable P was unrelated to the organic C: organic P ratio.

Figure 5. Relationships of potentially mineralizable P at 0-6" depth in soils across a range of agriculturally managed (n=16) and non-agriculturally managed (n=2) soils. To convert from mg/kg to lb/ac, multiply by 2. To convert from lb P/ac to lb P_2O_5/ac, multiply by 2.29.



CONCLUSIONS

Updating P recommendations in Illinois requires revisiting current but multidecade-old recommendations in the Illinois Agronomy handbook, specifically CSTV and soil P supply power, while also considering a potential "soil P credit" to help refine application rates. A combination of on-farm field trials, soil archives, and lab-based assessments will continue through 2026 to provide much needed data to transparently update the basis for CSTV and soil P supply power thresholds and concepts, respectively, while also exploring the potential of crediting P from organic matter mineralization. Active and forthcoming work on improving P recommendations for Illinois corn-soybean production systems relevant to the greater North Central region will be presented at future NCSFC events.

ACKNOWLEDGEMENTS

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ASSESSING THE IMPACT OF THE 4R NUTRIENT MANAGEMENT ON NITROGEN USE EFFICIENCY IN CORN

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ABSTRACT

Determining the best management practices for nitrogen (N) fertilizer application to corn is crucial to achieving the objectives of the 4 r of nutrient stewardship. Although producers have a wide range of options regarding N fertilization, identifying the right rate, source, placement, and timing can significantly impact productivity and nitrogen use efficiency. Our objectives were to evaluate the nitrogen agronomic efficiency (NAE), and the corn grain yields as affected by different rates, sources, placements, and timing methods of N fertilizer application under rainfed and irrigated conditions in Kansas. Two rainfed locations in Riley and Republic counties and two irrigated locations in Republic and Shawnee counties were established in 2021. Increasing rates from 0 to 180 lbs N acre^{-1} in 30 lbs increments for rainfed locations and 0, 90, 120, 150, 180, 210, 240 lbs N acre^{-1} for irrigated locations applied at planting, as broadcast urea. Additionally, five different N management treatments were applied at the same rate of 90 and 120 lbs N acre^{-1} for rainfed and irrigated locations, respectively. The nitrogen application significantly impacted the grain yield for both irrigated and rainfed locations. Applying N fertilizer as UAN coulter-injected at planting and SUPERU at side-dress V6 growth stage increased grain yield and AE across locations when compared to the baseline of urea broadcast at planting.

INTRODUCTION

The “4r” references the four rights of nutrient management practices: right source, right rate, right time, and right place (Fixen, 2020). N fertilizer inputs are generally necessary for optimizing corn yields, but N is the most challenging plant nutrient to manage optimally (Ransom et al., 2020). Even if it is almost impossible to achieve total efficiency for N fertilizer use in any crop production system, there is significant opportunity for reducing N losses associated with management practices (Shanahan et al., 2008). Enhance N use efficiency is crucial to keep productivity and sustainability in agriculture. Ideal N management optimizes grain yield and N use efficiency (Shapiro and Wortmann, 2006). Our objectives were to evaluate the nitrogen agronomic efficiency (NAE), and the corn grain yields as affected by different rates, sources, placements, and timing methods of N fertilizer application under rainfed and irrigated conditions in Kansas.

MATERIALS AND METHODS

The study was conducted during the 2021 corn growing season across Kansas, two irrigated locations in Republic and Shawnee Counties and two rainfed locations in

Republic and Riley Counties were established under a randomized complete block design with five replications; plots were 10-ft width × 40-ft length. N fertilizer was applied at planting using urea as source, in the irrigated locations rates of 0, 90, 120, 150, 180, 210, and 240 lbs N acre^{-1}, and in the rainfed locations increasing rates from 0 to 180 lbs N acre^{-1} in 30 lbs increments were applied broadcasting the fertilizer. Additionally, five different N management treatments, broadcast Urea + NBPT, streamed UAN and UAN coulter-injected at planting, side-dress SUPERU and streamed UAN at V6 corn growth stage were applied at the same rate of 90 and 120 lbs N acre^{-1} for rainfed and irrigated locations, respectively. Before planting, soil composites samples were collected by block at 0 to 6 and 0 to 24 in. depth using hand probes. Corn was planted from April 25^{h} to May 5th. Plant and grain samples were collected from six plants from middle rows when corn reached R6 maturity growth stage; samples were dried at 140°F (60°C) and ground to 2mm. N content in the plant and grain were determined through dry combustion. Yields were determined harvesting the two middle rows from each plot and correcting grain moisture to 15.5%. Nitrogen Agronomic Efficiency (NAE) was calculated as:

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

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

Analysis of variance (ANOVA) and Fisher's least significant difference (LSD) pairwise comparisons at $\alpha < 0.01$ was performed using the RStudio 2022.07.2+576 software.

RESULTS AND DISCUSSION

Corn Grain Yield

There was a significant yield increase in grains due to the application of nitrogen across both irrigated (Figure 1A) and rainfed (Figure 1B) locations. The agronomic optimum nitrogen rate (AONR) was calculated for both irrigated and rainfed using the quadratic regression, for irrigated locations an AONR of 230 lbs of N acre^{-1} was obtained, and a value of 204 lbs of N acre^{-1} for rainfed locations. The nitrogen management treatments increase grain yields across rainfed locations (Figure 2B) compared to the urea baseline at planting. Across irrigated locations the UAN coulter-injected at planting and the SUPERU side-dress at V6 growth stage, increased significantly the grain yields ($P<0.07$) when compared to the baseline urea (Figure 2A).

Nitrogen Agronomic Efficiency

The higher rates of N fertilizer significantly decrease the NAE across both irrigated (Figure 3A) and rainfed (Figure 3B) locations. Nitrogen agronomic efficiency (NAE) decrease with N rate increase is expected, particularly for excessive N rates (Wortmann et al., 2011; Woli et al., 2016; Halvorson and Bartolo, 2014. The lowest NAE value was obtained with the highest rate of N ($P < 0.0001$). The UAN coulter-injected at planting and the SUPERU side-dress at V6 growth stage showed the highest NAE values when compared to the baseline of urea broadcast at planting across locations under irrigation

(Figure 4A). Across the rainfed locations the trends were similar, with the highest NAE attained with the the UAN streamed at planting (Figure 4B).

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

					0-6 in			0-24 in	
County	System	Planting Date	Hybrid	pH	OM	P	K	NO_3^-	NH_4^+
					%			lbs acre^{-1}	
Republic	Irrigated	5/5/2021	P1828AM	6.06	2.90			6.91	33.8
Shawnee	Irrigated	4/29/2021	P1185	6.78	2.34			18.14	27.36
Republic	Rainfed	5/5/2021	P1828AM	4.84	3.02			35.28	51.98
Riley	Rainfed	4/28/2021	P1151AM	5.90	2.15			58.9	33.8

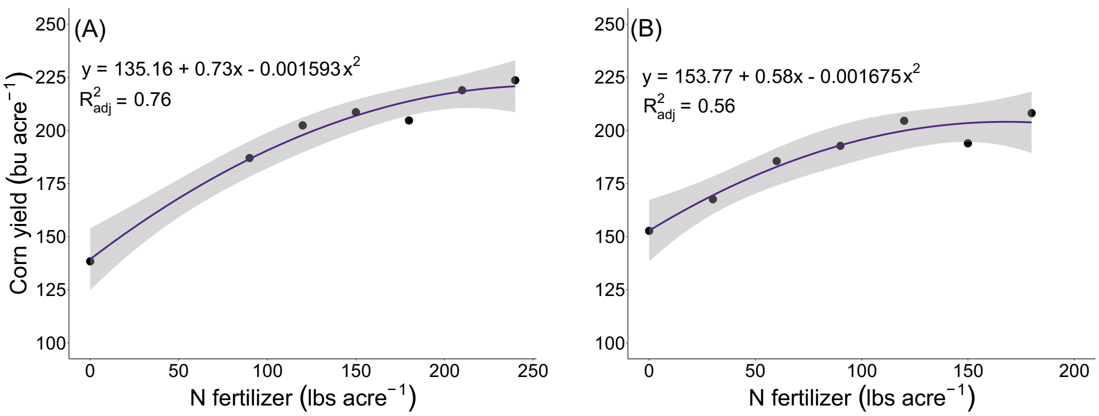

Figure 1. Average corn grain yield (bu acre^{-1}) as affected by the N rate treatments (lbs N acre^{-1}) across irrigated (A) and rainfed (B) locations.

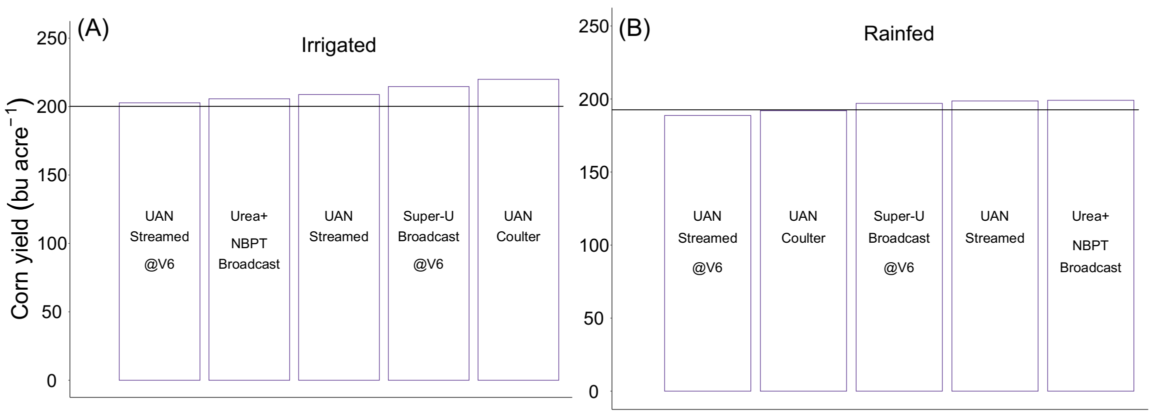

Figure 2. Average corn grain yield (bu acre^{-1}) as affected by N fertilizer managements treatments (lbs N acre^{-1}) across irrigated (A) and rainfed (B) locations. The horizontal line indicates the yield attained with the urea broadcast application method.

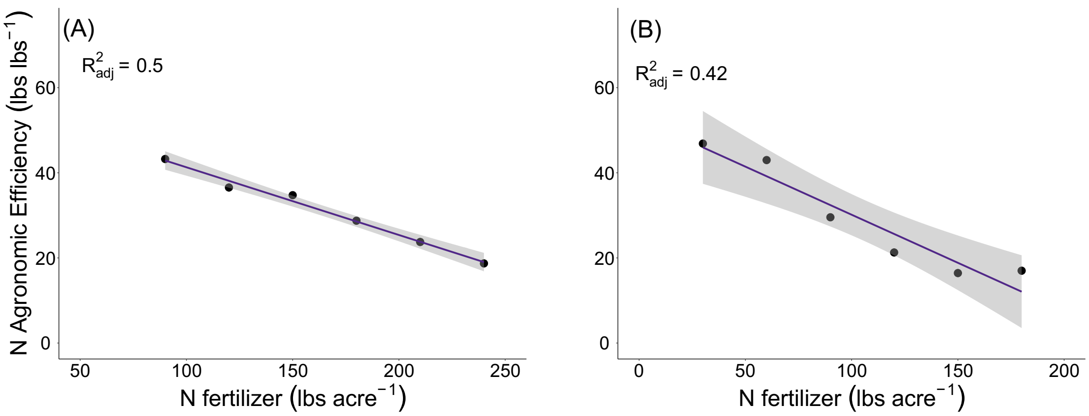

Figure 3. Average N agronomic efficiency (NAE) represented in lbs lbs^{-1} as affected by N fertilizer rate treatments (lbs N acre^{-1}) across irrigated (A) and rainfed (B) locations.

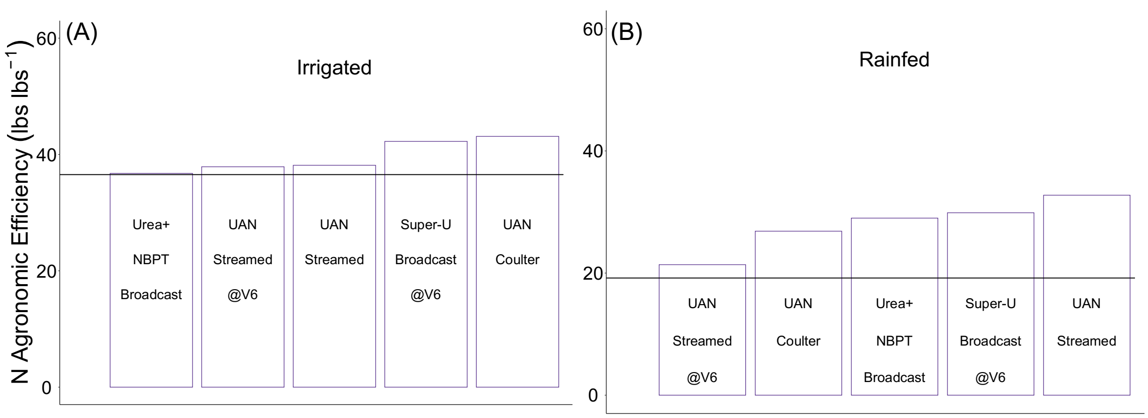

Figure 4. Average N agronomic efficiency (NAE) represented in lbs lbs^{-1} as affected by N fertilizer management treatments (lbs N acre^{-1}) across irrigated (A) and rainfed (B) locations. The horizontal line indicates the yield attained with the urea broadcast application method.

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

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ABSTRACT

Cereal rye (*Secale cereale* L.) is a popular cover crop before corn (*Zea mays* L.) due to its sizeable biomass production and superior nitrate uptake ability. Wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) are other winter cereals with similar fibrous root systems and may have comparable value as winter cover crops. A field study was conducted at the University of Kentucky North Farm in Lexington, KY, in 2022. This study aimed to determine if wheat and barley have a lower nitrogen penalty or provide similar soil benefits compared to rye as a winter cover crop for corn. The research design was a split-plot, randomized complete block with three replications. The cover crops treatments consisted of a no cover crop control, 'Somerset' barley, 'Pembroke' wheat, and 'Aroostook' rye. Liquid UAN (32-0-0) was surface applied at 40 lbs/ac to all plots at planting. The remaining nitrogen was accomplished with urea (46-0-0) that was broadcast to the soil surface at planting (AP) or at side-dress (SD) at rates of 0, 70, 170, 270, and 370 pounds lbs N/ac, totaling 40, 110, 210, 310 and 410 lbs N/ac. Cover crops were terminated two weeks before corn planting. At VT growth stage, nitrogen content was measured using a SPAD chlorophyll meter and ear leaf tissue samples from 5 randomized points in each plot. The grain yield, kernel number, kernel weight, and harvestable ears per plot data were collected at harvest. Cover crop did not affect corn SPAD readings at VT nor grain yield. A delayed December cover crop planting resulted in lower cover crop biomass. Corn yields were greatest for the three highest N rates (264 to 271 bu/ac), and the side-dress timing resulted in greater yields than the at planting timing. The 210 lbs/ac treatment with 40 pounds of Nitrogen at planting followed by 170 pounds of Nitrogen at sidedress was the optimum rate and timing since it used the smallest sufficient rate of fertilizer for the highest yield. This study will continue in the 2022-2023 growing season with two locations in Kentucky.

INTRODUCTION

Farmers use cover crops in Kentucky to prevent soil erosion and uptake residual nitrogen between cash crops' growing seasons. Winter cereals are often used for their establishment and value from planting in fall, winter durability, and regrowth in spring before a cash crop is planted. As a cover crop, rye has proven to produce higher biomass and total shoot nitrogen than wheat. Rye has a higher potential to limit corn yield to a more significant level than wheat (Kaspar & Bakker, 2015). Barley and wheat are cereal grains with fibrous root systems similar to rye and have the potential to serve as viable winter cover crops with potentially reduced grain yield risk. Adequate nitrogen levels are critical for a successful corn crop. There is an optimal nitrogen rate when yield is maximized, and the further rate increase will not significantly increase yield (Shapiro et al., 2016). Nitrogen fertilizer will also be volatile at a higher level once a soil nitrogen threshold is met (Ma, B. 2010). Nitrogen needs can vary based on location and soil type. This variability could be due to indigenous nitrogen supplies or soil nitrogen thresholds. A split or sidedress fertilizer application has been shown to reduce the rate needed significantly from single fertilization before planting (Davies et al., 2020). Various rates and timings could be used to determine if fertilization can assist in alleviating penalties from cover crops. Starter fertilizers did not assist in reducing the yield penalty associated with a rye cover crop (Quinn, 2021). The objectives of this study were to determine if wheat and barley had a lower nitrogen penalty and quantitatively measure their effectiveness compared to rye.

METHODS AND MATERIALS

Cover crops were planted on December 3rd, 2021, at the University of Kentucky North Farm in Lexington, KY, with a John Deere 750 no-till planter in 10-foot strips. The cover crops were planted into soybean residue since a corn/soybean rotation is typical for the region. The cover crops treatments consisted of a no cover crop control, Somerset barley, Pembroke wheat, and Aroostook rye. The soil type for all plots was predominately Lowell-Bluegrass Slit Loam. The following spring, cover crops were terminated on April 27th, 2022, with glyphosate herbicide (Roundup brand). Maize planting occurred two weeks later, on May 11th, to avoid potential yield penalties from the cover crops (Quinn, 2021). Dekalb hybrid (DKC 65-95RIB, 115-day maturity) was planted at a 2-inch depth at 38,000 seeds per acre in four 30-inch rows with a Wintersteiger pneumatic planter with a slotted disc system and cone seed delivery. The Kinze row units were fitted with Martin-Till row cleaners set to remove residue from the seed row, but not create a soil disturbance any deeper than ½-inch. Soil cores were collected at a 6-in depth before planting and after harvest to quantify soil organic matter and soil nitrates. Soil samples were analyzed at the University of Kentucky Regulatory Services.

The research design was a split-plot, randomized complete block with three replications. There were two fertilization timings with five nitrogen treatments All plots received 40 pounds of urea ammonium nitrate (32-0-0) per acre at planting. Both nitrogen timings used the same 40 lbs/ac control. The five nitrogen rates of 0, 70, 170, 270, and 370 lbs/ac were applied at planting (AP) or sidedress (SD) at the V3 growth stage with urea (46-0-0) as surface broadcast by hand. Total N applied was 40, 110, 210, 310 and 410 lbs/ac. In late June, around the V6 phenological stage for the plots, drip irrigation was installed to limit water stress. Drip lines were placed between rows 1/2 and 3/4 for each plot. Nitrogen Content was measured on five randomized corn leaves per plot with SPAD at the 10^{th} leaf and ear leaf for V10 and VT growth stages, respectively. Five randomized ear leaf tissue samples were collected per plot at VT. Disease ratings were taken throughout the early reproductive period, a low disease incidence was observed, and no fungicide was applied. Maize plots were harvested with a Wintersteiger Delta plot combine with a Geringhoff corn head and Juniper Weighing Systems HarvestMaster weigh bucket on October 3^{rd}, 2022. Grain yield, kernel number, kernel weight, and harvestable ears per plot data were collected at harvest. Preliminary data were analyzed with SAS statistical software at $p<0.10$ considered significant.

RESULTS AND DISCUSSION

Cover Crop Biomass

A late cover crop planting date resulted in reduced cover crop biomass growth. Wheat produced significantly more biomass than barley or rye (P=0.0523). Wheat averaged 775 lbs/ac compared to 562 lbs/ac for rye and 227 lbs/ac for barley. The cover crop did not affect corn yield response to N rate or timing. While cover crop planting date was late, it was consistent with private farms in the area, and thus, provides relevant data to the season experienced. Cover crops were planted in October of 2022 and should result in greater biomass yields, and potentially more N interactions, in spring of 2023.

Table 1. Nitrogen Rates /Timings and Cover Crops Effects on SPAD and Yields, Lexington, KY 2022.

Treatment		SPAD at R1 Chlorophyll Content		YIELD Bu/A	
Nitrogen Timing	**Total lbs N/ac**				
At Planting (AP)	40	41.3	e	174	e
	110	50.4	d	228	d
	210	56.2	b	242	cd
	310	56.7	ab	259	ab
	410	56.0	b	247	bc
Side-Dress (SD)	40	41.3	e	174	e
	110	52.1	c	232	d
	210	55.6	b	264	a
	310	57.9	a	271	a
	410	56.2	b	270	a
Cover Crop Effect					
None		54.3	a	246	a
Barley		53.7	a	245	a
Rye		53.2	a	240	a
Wheat		53.2	a	241	a
LSD (0.10) NR		*1.5542*		*14.58*	
LSD (0.10) CC		*1.0362*		*9.7176*	
P value NR		*<.0001*		*<.0001*	
P value CC		*0.2689*		*0.6315*	
P value NRxCC		*0.1177*		*0.2194*	

Means are compared within N Rate and Cover Crop.
Means in the same column with different letters are significantly different (p≤ 0.10).

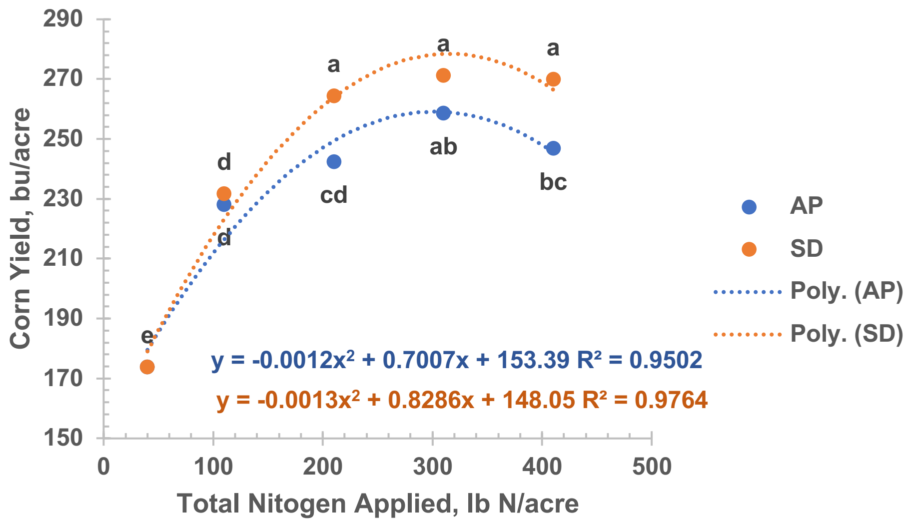

Figure 1: Corn Yields Averaged Across Cover Crops Response to N Rates, Lexington, KY 2022

SPAD Measurement at VT

The SPAD readings at VT growth stages were greatest for 310 lb N/ac at both timings (Table 1). SPAD readings for the 210 and 410 rates were less than the 310 rate but greater than the 40 and 110 N rates. Cover crop and N timing did not affect SPAD readings.

Corn Yields

Corn treated with 40 and 110 lbs N/ac yielded less than corn at the higher nitrogen rates (Table 1). Corn yields at 210, 310, and 410 lbs N/ac were similar to each other for each timing and ranged from 264 to 271 bu/ac averaged across all plots. At the three higher N rates, corn yielded greater with SD than AP timing. Corn receiving a total of 210 lb N/ac (40 AP and 170 SD) was the optimal N rate for this season and location.

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ELUCIDATING HOW N MANAGEMENT PRACTICES AND EXCESS WATER CONDITIONS AFFECT CORN N UPTAKE AND GRAIN YIELD

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ABSTRACT

Flooding and waterlogging events have been more frequent in the Midwest region, causing corn yield penalty and nitrogen losses through leaching and denitrification processes. Improving N fertilizer recommendations for areas prone to flood conditions is necessary to minimize N losses and optimize corn yield. This research aimed to determine how N application practices before and after waterlogging events impact corn growth and grain yield. A field experiment was initiated in 2021 in Custar, Ohio using a split-plot randomized complete block design with four replications. The whole plot factor was waterlogging regime implemented at the V4 corn growth stage: zero days (0-d), three days (term 1), or repeated waterlogged conditions (term 2; three days of water applied, followed by three days of drying and three additional days of water applied). The subplot factor was N treatment applied pre-plant with 0 or 100 lbs N ac^{-1}, and one of four rates applied post-waterlogging (0, 60, 120, and 180 lbs N ac^{-1}). Biomass and total soil inorganic N (nitrate-N and ammonium-N) were measured at zero, six, thirteen, and eighteen days after waterlogging initiation. Ear leaf N was measured at the R1 growth stage. Stalk nitrate and grain yield were measured at the R6 growth stage. Data were analyzed using mixed models (repeated measures and GLIMMIX procedures in SAS). Linear plateau regression analyses using PROC NLIN were performed using total soil inorganic N to predict ear leaf N content and yield. Biomass was reduced with term 2 waterlogging. Pre-plant and post-waterlogging applications of N increased biomass more rapidly after waterlogging was alleviated. Generated regressions using soil inorganic N to predict ear leaf N content resulted in R^2 of 0.14-0.50 and R^2 of 0.23-0.58 when predicting yield. Ear leaf N content was greatest when pre-plant with 120 or 180 lbs N ac^{-1} post-waterlogging was applied. Stalk nitrate levels did not indicate luxurious consumption of N in any treatment. Corn exposed to waterlogging had maximum yield production with pre-plant with 60, 120, or 180 lbs N ac^{-1} applied post-waterlogging. This trial will be repeated in 2022 and 2023 at more Ohio locations to ensure responsible N recommendations can be developed.

INTRODUCTION

Precipitation has been increasing in the Midwest (Dai et al., 2016). There is also an increase in extreme weather events in the region, potentially exacerbating the N-loss pathways (Iqbal et al., 2018). In the US, flooding and waterlogging were responsible for up to 34% of corn grain yield loss, which is comparable to the 37% loss from drought (Li et al., 2019). For the Midwest, in 2011, flooding caused an economic damage of $1.6 billion for corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] (Bailey-Serres et al., 2012). Waterlogging and flooding can also cause environmental impacts such as leaching in nitrate (NO_3^-) form and greenhouse gas emission as nitric oxide (NO) and nitrous oxide (N_2O) emissions due to denitrification (Motavalli et al., 2008; Bailey-Serres et al., 2012; Bowles et al., 2018).

The N management recommendations in the Midwest are derived from Maximum Return to Nitrogen (MRTN) approach, which is an economic tool that considers the fertilizer prices of nitrogen fertilizers and corn grain (ISU, 2020). However, the MRNT was not designed to account for split N application or excess soil water. Moreover, N application management in much of the Midwest consists of a single fall post-harvest application or spring pre-plant application (Gramig et al., 2017). Although this approach allows for N mineralization in NO_3^- form (Cassman et al., 2002), it also makes the N susceptible to environmental losses in case of flooding or waterlogging (Iqbal et al., 2018; Bowles et al., 2018). Adapting the N recommendations to account for waterlogging could reduce economic and environmental losses. This research aimed to determine how N application practices before and after waterlogging events impact corn growth and grain yield. The specific objective of this research was to measure soil inorganic, N uptake by plants, and corn yield following waterlogging conditions.

MATERIALS AND METHODS

Study site

This experiment was conducted at Northwest Agricultural Research Station (NWARS; 41° 12' 53" N, 83° 45' 34" W) in Custar, Ohio, in 2021. The NWARS soil type is Hoytville clay loam (Fine, illitic, mesic Mollic Epiaqualfs).

Experimental Design

The experimental design was a split-plot randomized complete block design with four repetitions (rep). The whole plot factor was waterlogging duration (WD): zero days of waterlogging (0-day); three days of waterlogging (term 1); and repeated waterlogging (term 2; three days of water applied, followed by three days of drying, and three additional days of applied water). Using overhead irrigation, waterlogging was imposed at the V4 corn growth stage to maintain soil saturation. The sub-plot consisted of two factors. The first factor was urea that was pre-plant incorporated at 0 or 100 lbs N ac^{-1}. The second factor was topdressed N applied post-waterlogging. The post-waterlogging rates were 0, 60, 120, and 180 lbs N ac^{-1}. The post waterlogging application was urea combined with N-(n-butyl) thiophosphoric triamide (NBPT) (N-save, PCT Sunrise). The NBTP is a urease inhibitor that prevents the urease enzyme's action, thus helping minimize ammonia volatilization and slow the conversion of ammonium to nitrate (Motavalli et al., 2008). Nitrogen was manually and evenly distributed in the subplots three days after the waterlogging event ended. Each subplot was 10 ft x 30 ft. There was a 20 ft buffer between waterlogging treatment in the same rep. Between reps, there was another buffer of 40 ft (Fig. 1). A commercial corn hybrid of common maturity for Ohio was used (DKALB DK C61-88) and seeded at 34,000 seeds ac^{-1} in 30-in rows.

Eight eight-inch depth soil cores were collected at 0, 6, 13, and 18 days after the first waterlogging initiation (DAWI) for NO_3-N and NH_4-N. A total of ten ear leaves from the middle row of each plot were collected at the R1 growth stage to quantify ear leaf N concentration. Six stalk segments were collected at R6 in the border rows of each subplot to quantify stalk nitrate. For ear leaf N and stalk nitrate, materials were dried using a conventional air drier (Blue M Electric, model DC-966RI-E, New Columbia, PA), grounded using a grinding mill (Thomas Scientific, model 3379-K05, Swedesboro, NJ), and sent to

A&L Great Lakes laboratory for analysis. Each subplot was harvested at the R6 growth stage and moisture was adjusted to 15%.

Statistical Analysis

The statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC). The ANOVA assumptions of normality of residuals distribution and equal variance (homogeneity of variance) were checked for all analyses. If the residuals were normally distributed, an ANOVA analysis was conducted with an alpha level of 0.05.

Plant biomass was analyzed using repeated measures. The MIXED procedure was used. The fixed factors were WD, N pre-planting, N post-waterlogging, and days after waterlogging initiation (DAWI). The random factors were rep and the interaction of rep with the fixed factors. DAWI was used for repeated measures statements. The covariance structure was chosen using the smallest Akaike information criterion (AIC). The means were calculated using LSMEANS. For soil sample at thirteen and eighteen DAWI, linear plateau regression analyses using PROC NLIN were performed using total soil inorganic N to predict ear leaf N content and yield. A mixed model's effect using GLIMMIX procedure was employed for ear leaf nitrogen, stalk nitrate, and yield. For GLIMMIX, the fixed factors were WD, N pre-plating, and N post-waterlogging, and the interaction between whole plot and sub-plot factors. The random factors were rep and the interaction of rep and WD. If the global F-test were significant, LSMEANS was used for means calculation, and pairwise means comparisons were performed using paired t-test. Letter separations were performed using the PDIFF statement.

RESULTS AND DISCUSSION

Biomass

Repeated waterlogging (term 2) negatively impacted plant growth, reducing biomass (data not shown). At 18 DAWI, term 2 had 45% less plant biomass than 0-day while term1 had 27% less biomass than 0-day (F-value =30.01; p-value = <0.0001). At 18 DAWI, the use of 100 lbs N ac^{-1} pre-planting increased biomass by 32% compared to no pre-planting across WD (F-value = 17.05; p-value = <0.0001). Dill et al. (2020) reported lower shoot biomass for 6, 4, and 2 days of flooding compared to no flooding. They also reported an increase in biomass with the application of N pre-planting. Kaur et al. (2019) reported lower shoot biomass for hybrids following 14 and 21 days of flooding compared to no flooding in a greenhouse experiment.

Inorganic N

The use of soil inorganic N at 18 DAWI resulted in greater R^2 values than those from 13 DAWI (Tables 1-2). The use of soil inorganic N was poorly correlated with ear leaf N (R^2 0.11 - 0.50) and yield (R^2 0.19 - 0.58).

Table 1. Soil inorganic N as a predictor of ear leaf N content (%). DAWI is days after first waterlogging initiation. WD is waterlogging duration.

DAWI	WD	a	b	joint	Plateau	R^2	F	Prob
13	0-day	1.85	0.04	25.99	2.76	0.11	1.52	0.238
13	Term 1	2.01	0.03	25.39	2.89	0.19	3.15	0.060
13	All	2.01	0.03	25.39	2.81	0.14	4.47	0.016
18	0-day	1.46	0.06	25.87	2.92	0.49	13.87	<0.001
18	Term 1	0.28	0.17	15.30	2.89	0.50	14.64	<0.001

18	Term 2	1.14	0.11	16.35	2.89	0.42	9.96	0.001
18	All	1.11	0.10	17.70	2.87	0.42	33.57	<0.001

Table 2. Soil inorganic N as a predictor of yield in bu ac^{-1}. DAWI is days after first waterlogging initiation. WD is waterlogging duration.

DAWI	WD	a	b	joint	Plateau	R^2	F	Prob
13	0-day	69.44	4.79	27.63	201.77	0.19	2.86	0.077
13	Term 1	107.13	3.09	29.97	199.86	0.23	3.80	0.036
13	all	115.19	2.49	35.97	204.85	0.21	6.93	0.002
18	0-day	-136.80	19.99	17.18	206.58	0.58	20.44	<0.001
18	Term 1	31.70	8.49	19.99	201.53	0.34	7.59	0.002
18	Term 2	15.18	9.93	18.67	200.67	0.49	13.43	<0.001
18	all	-0.67	11.12	18.18	201.41	0.49	43.87	<0.001

Ear Leaf Nitrogen and Stalk Nitrate

The pre-planting N application had a significant effect on ear leaf N content across WD (Fig. 1a). The application of pre-planting led to higher N concentration; however, it was below the sufficiency range of 2.9 to 3.5% (Vitosh et al., 1995). There was a significant interaction between WD and post-waterlogging applications across the pre-plant applications (Fig. 1b). Nitrogen post-waterlogging applications of 120 and 180 post-waterlogging irrespective of WD, were in the sufficiency range for ear leaf N content.

There was a triple interaction between the WD, N pre-plant, and N post-waterlogging for stalk nitrate content, though all treatments were below the optimum range (250 to 2000 ppm; Vitosh et al. 1995) (data not shown). The highest corn stalk nitrate concentration was observed at 0-day WD, with pre-plant, and 180 lbs N ac^{-1}, thus the treatment more likely to have consumed most of the available N available and have excess uptake (Zhang et al. 2013). The lower stalk nitrate across treatments can be attributed to the wet conditions posed by waterlogging, leading to lower availability of N and no surplus on N consumption (Varvel et al. 1997; Tao et al. 2018).

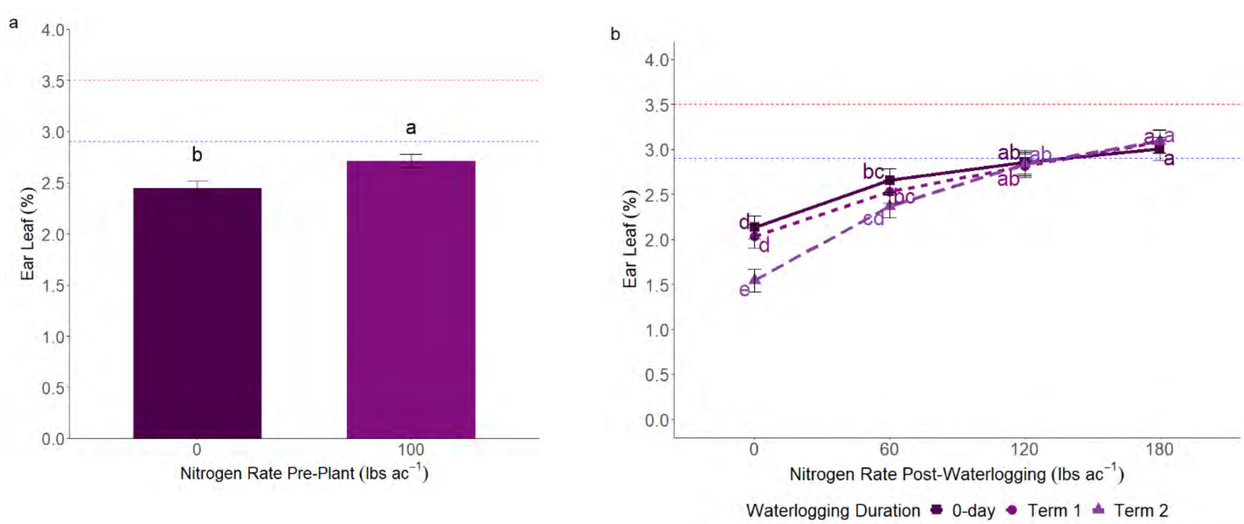

Figure 1. Mean and standard error for ear leaf N content. Blue and red dashed lines represent the optimum range for ear leaf N content according to Vitosh et al. (1995) **a.** Ear leaf N content across WD. Differences bar graphs represent different N pre-plant

rates. Different letters indicate treatment significant different at $p<0.05$ using paired t-test. **b.** Interaction between WD and N post-waterlogging. Different lines represent different WD. Different letters are significant different at $p<0.05$ using paired t-test.

Yield

There was a significant interaction between WD and N post-waterlogging across N-plant (Fig. 2a). The use of 180 lbs N ac^{-1} for all WD and 120 lbs N ac^{-1} for 0-day WD showed the highest yield. There was an interaction between pre-plant and post-waterlogging application across WD (Fig. 2b). The use of 180 lbs N ac^{-1} irrespective of pre-plant application and 120 lbs N ac^{-1} with pre-plant led to the highest yield (Fig. 2b). Other research studies also observed a positive response to N applying pre-planting or sidedress (Kaur et al. 2017; Dill et al. 2020). For this study, using 60 lbs N ac^{-1} did not result in higher yield for term 1 and 0-day, which differs from Dill et al. (2020), that showed a higher yield using 60 lbs N ac^{-1} as sidedress after 120 lbs N ac-1 was applied pre-plant incorporated. In Dill et.al study, yield for four days and six days of flooding were 207 bu ac^{-1} and 165 bu ac^{-1} compared to 246 bu ac^{-1} non-flooded. Kaur et al. (2018) showed that sidedress of 75 lbs N ac^{-1} only led to a higher yield for one season when comparing seven days of waterlogged and non-waterlogged treatments.

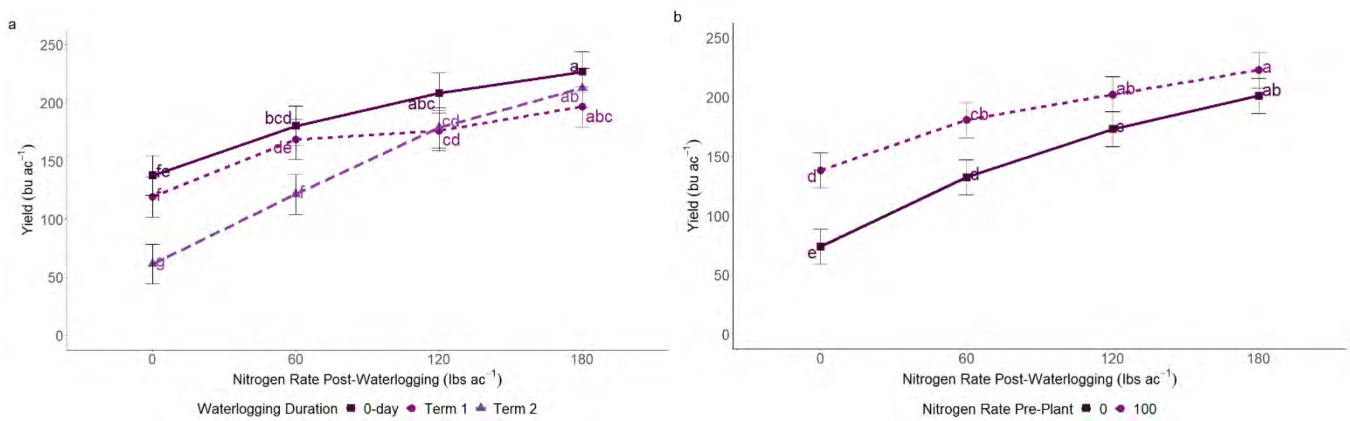

Figure 2. Mean and standard error of yield in bu ac^{-1}. **a.** Interaction between WD and N post-waterlogging application. Different lines represent different waterlogging treatments. Different letters indicate treatment significant different at $p<0.05$ using paired t-test. **b.** Interaction between nitrogen pre-plant and DAWI across WD. Different lines represent different nitrogen rate treatments. Different letters indicate treatment significant different at $p<0.05$ using paired t-test.

IMPLICATIONS

Pre-plant N application has a positive effect during early growth vegetative stages; however, post-waterlogging applications have a greater effect on yield. Repeated waterlogging causes a negative impact on corn growth. Nitrogen post-waterlogging can minimize the adverse effects of single flooding (term 1) or repeated flooding (term 2). For areas prone to waterlogging, it is recommended to use a post-waterlogging application (sidedress) at 180 lbs N ac^{-1} to maximize yield and reduce potential losses due to nitrate leaching. This research trial will be repeated in 2022 and 2023 at more Ohio locations to ensure responsible recommendations for farmers and growers in areas prone to soil water excess.

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BIOCHEMICAL SOIL HEALTH INDICATORS RELATED TO ECONOMIC OPTIMUM NITROGEN RATE IN CORN

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ABSTRACT

In corn production, nitrogen (N) fertilization is one of the main inputs to enhance yield. However, in the last few years, reducing N utilization has been a goal due to environmental concerns and production costs. Soil health tests have been studied to understand the relationship with N availability and its use to adjust N recommendation rates. The objective of this study was to evaluate the relationship of different soil tests with the economic optimum N rate (N) for corn in Wisconsin. Soil samples were analyzed from 24 sites in 2019 and 2020. Trials included treatments of corn yield response to different N rates. A total of six soil tests were conducted, total organic carbon (TOC), total carbon (TC), active carbon, soil respiration, ammonium content (NH4-N) at 0 and 7 days, and mineralizable N. Additionally, EONR and yield were determined for each site. Stepwise regression was used to select the best model to predict EONR across all sites. When evaluated alone, NH4-N at 0 days accounted for 64%, and soil respiration accounted for 40% of the variation in EONR across all sites. Stepwise regression selected the best model as the one that includes active carbon and NH4-N at 0 days, which accounts for 69% of the variation in EONR. The results of the regression models indicate ammonium content measured at 0 days to be a good predictor of EONR across the Wisconsin sites.

JUSTIFICATION

For farmers, it is important to decrease nitrogen use to maintain economic profit and avoid Nitrogen (N) leaching and contamination of the environment. Lately, there has been an interest in the use of soil health tests to predict N mineralization potential and further understand soil N availability.

The objective of this study was to evaluate bio/chemical soil health tests to predict economic optimum N rate (EONR) for corn in Wisconsin.

METHODS

In 2019 and 2020, 24 small plot field trials were conducted in 16 counties on private and university farms. Soil texture and drainage class, previous crop, use of cover crop, and manure history varied by site (Table 1). Corn grain yield response to sidedress N (0 to 224 kg N ha^{-1} in 40 kg N ha^{-1} increments at ~ V6; 4 replications) was evaluated. At each site, the EONR was calculated using a N: corn price ratio of 0.1 (eg. 0.4 $ per lb. N:4 $ per lb. grain) after fitting a model to the yield response data (quadratic plateau, linear plateau, or linear; best fit model chosen).

Soil samples (0-30 cm) were collected in the no N control plot within 3 days to planting. Samples were dried (32 °C) and ground (2mm) and analyzed for six bio/chemical soil tests: total organic carbon (TOC), total carbon (TC), and total N (TN) all analyzed on a LECO CN928 combustion analyzer; active carbon (permanganate oxidizable carbon, modified from Weil et al., 2003); soil respiration (CO_2 measured after 4 day incubation with sample rewet, CASH manual); initial NH_4 content (NH_4_0d) and NH_4 content after 7 days of anaerobic incubation at 40 °C (NH_4_7d), both extracted with 2M KCL and read with a spectrophotometer).

The relationship between EONR and soil tests were evaluated using correlation and forward stepwise regression analysis performed in R studio. The best model was selected using R^2 and adj R^2, BIC, AIC, and CP statistics.

Table 1. Twenty-one sites grouped by previous crop, texture, drainage, and manure history

Previous crop	Drainage Class	Texture	Manure	# Of sites
Soybean	W	Silt loam	No	2
			Swine	1
		Sandy loam	No	5
	MW	Silt loam	No	2
	SP	Silt loam	No	2
			Dairy	1
		Sandy loam	No	1
		Loam	Dairy	1
Corn	W	Silt loam	No	2
		Sandy loam	No	1
		Sandy	No	2

	MW	Loamy sand	No	1
Hemp	W	Silt loam	Turkey	1
Corn silage	MW	Silt loam	Dairy	1
Alfalfa	W	Silt loam	No	1

RESULTS

Three sites had NH_4 concentrations >13 ppm and appear to be outliers. At one site manure was applied a couple weeks prior to soil sampling, at another site banded N fertilizer was applied prior to sampling, and at the third site alfalfa was the previous crop. These conditions may have resulted in high NH_4 concentration and affected the correlation and model results.

Using stepwise regression with all data points, the best predictor was respiration with an Adj R^2=0.43 (Table 2), but when analyzed without the outliers the best predictor was NH_4 with and Adj R^2=0.64 (Table 3). The overall best predictor of EONR was the model that includes NH_4_0d and active carbon Adj R^2=0.68 (Table 3, Figure 1), when sites with >13 ppm NH_4 were removed**.**

Table 2. stepwise regression analysis using soil health tests to predict EONR 24 sites.

# Of Parameters	**Test combination**	**R^2**	**Adj R^2**	**AIC**	**BIC**	**Cp**	**RMSE**
1*	Respiration	0.45	0.43	259.5	261.8	-3.1	48.5
1	NH_4_7d	0.37	0.34	262.9	265.3	-0.4	52.1
1	TOC	0.36	0.33	263.3	265.6	-0.2	52.5
2	NH_4_0d+ TOC	0.48	0.43	261.3	263.9	-1.8	48.4
2	NH_4_0d + TC	0.47	0.43	261.3	263.9	-1.8	48.5
2	TOC + Respiration	0.47	0.42	261.4	263.9	-1.7	48.6
3	TOC + Respiration + TN	0.51	0.43	263.1	265.6	-0.8	48.2
3	TOC + TC + Respiration	0.50	0.43	263.3	265.9	-0.64	48.4
3	NH_4_0d + TOC+ Respiration	0.50	0.42	263.5	266.0	-0.5	48.6

*Indicates best model

Table 3. Stepwise regression analysis using soil health tests to predict EONR 21 sites

# Of Parameters	Test combination	R^2	Adj R^2	AIC	BIC	Cp	RMSE
1	NH_4_0d	0.64	0.62	220.4	222.1	1.3	40.5
1	Respiration	0.45	0.42	229.3	231.1	11.0	50.1
1	NH_4_7d	0.42	0.39	230.5	232.3	12.7	51.6
2*	NH_4_0d+ Active carbon	0.72	0.68	218.3	220.0	-0.67	36.8
2	NH_4_0d + respiration	0.70	0.67	219.3	221.0	0.02	37.7
2	NH_4_0d + TC	0.70	0.67	219.4	221.1	0.13	37.9
3	NH_4_0d + TC + ActiveC:TN	0.73	0.68	220.6	221.9	0.53	36.8
3	NH_4_0d + TOC + ActiveC:TN	0.72	0.68	221.1	222.3	0.82	37.2
3	NH_4_0d + TN + ActiveC:TN	0.72	0.67	221.3	222.6	1.00	37.5

*Indicates best model

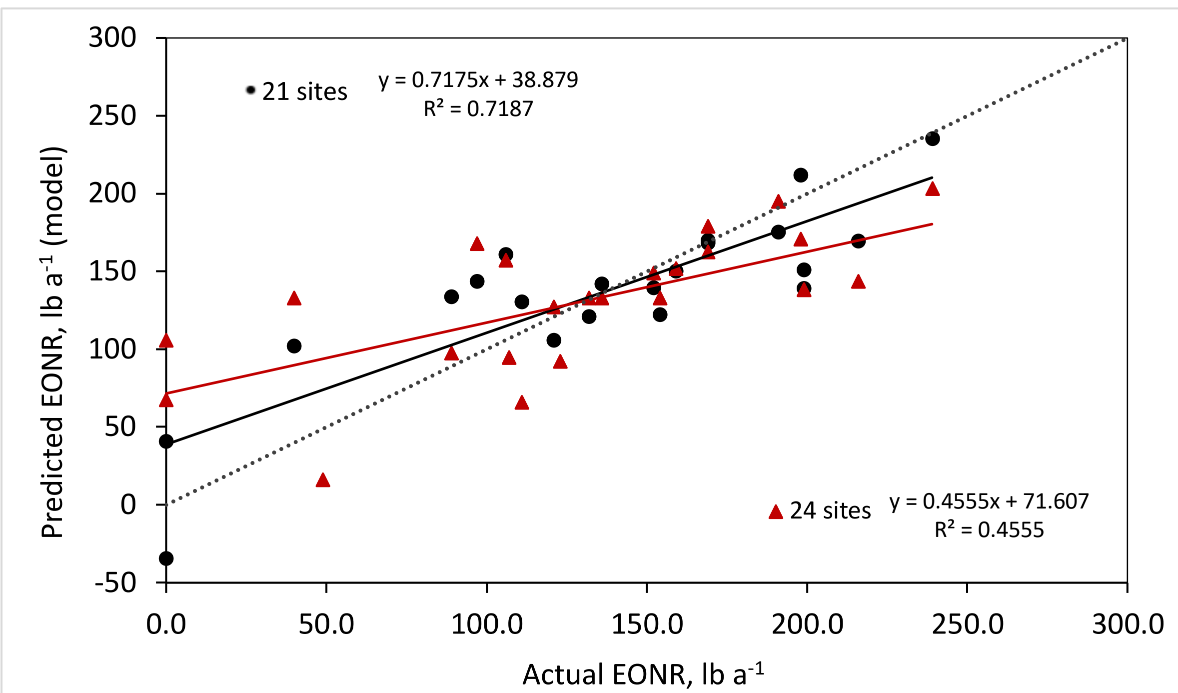

Figure 1. Actual EONR vs predicted EONR using outputs of the 21 sites model and 24 sites model.

CONCLUSION

The results from the stepwise regression analysis showed the best model to predict EONR is the one that uses NH^4 and active carbon soil tests since have the highest R^2 and Adj R^2, and the lowest AIC, BIC, and Cp statistics. This model can predict 68% variation in EONR, but it is important to highlight that this model has a modest increase in Adj R^2 compared to the prediction using only NH^4. According to the results, NH^4 is consistently present in most of the models that predict EONR better, so this can be an indication of how useful this soil test is to predict N availability in the soil. Additionally, it is important to notice that even when using more soil tests results the prediction of the models did not improve compared to the model with only one or two soil tests. These results show that N availability in soils can be assessed using fewer soil tests like NH^4, in combination with other soil health tests like active carbon and respiration. But the decision of which test to use could be based on the cost and the practicality of the test. For example, the soil respiration test is conducted using a four-day incubation, which could delay the results and not be useful to use in N recommendation adjustments.

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EFFECTS OF SILICATE SUPPLEMENTATION ON GROWTH AND SILICON ACCUMULATION IN TALL FESCUE (*Festuca arundinacea*) AND BENTGRASS (*Agrostis stolonifera*)

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ABSTRACT

We assessed the effect of silicon supplementation on biomass production and Si accumulation of tall fescue (*Festuca arundinacea*) and bentgrass (*Agrostis stolonifera*). Plants were grown in buffered Hoagland's media (pH 6) with four Na_2SiO_4 treatments (0, 0.5, 1, 2, 4 mM). The two species responded very differently to Si supplementation in terms of biomass. In bentgrass, biomass was enhanced by Si supplementation, but only significantly ($p < 0.05$) at the highest concentration (4 mM Si). Lower Si concentrations (0.5, 1 and 2 mM) significantly increased biomass in tall fescue, but there was no increase in biomass from 0.5 mM to 2 mM. We also analyzed tissue for Si concentrations after six weeks of growth using inductively coupled plasma optical emission spectrometry (ICP-OES). There was a positive linear relationship between Si concentration in media and Si concentrations in tissue. At 4mM Si, the Si concentrations in aboveground tissue of tall fescue and bentgrass averaged 24 and 30.5 g/kg dry mass, respectively. Epifluorescence microscopy of combusted leaf tissue showed that elevated silicon concentrations in growth media promoted formation of silica bodies. The highest Si rates (4 mM Si) resulted in the highest silica body areal coverage in leaves of both grasses. We observed two silica body morphologies (which we termed long and barbed). No silica bodies were observed in the 0 mM Si treatment for either species. These findings clearly indicate that in addition to being essential for Si body formation, supplying dissolved Si promotes growth of tall fescue and bentgrass. Typical natural background dissolved Si concentrations rarely exceed 0.6 mM. Our findings indicate that tall fescue is likely to benefit from Si supplementation when soil pore water dissolved Si is below 0.5 mM, but increases above this concentration are unlikely to increase biomass. In contrast, benefits in bentgrass may only be realized if dissolved Si in pore water is increased to 4 mM.

INTRODUCTION

Silicon (Si) is considered as a non-essential nutrient in agronomy, while plants take up significant amount of Si from soil every year (Guntzer, Keller, and Meunier, 2012). Soil contains 5-40% silicon by weight, primarily as silicon dioxide (Teixeira, Tokuda, and Yoko, 2009) and aluminosilicate minerals. However, Silicon is one of the most abundant elements in the Earth's crust (Fauteux et al., 2005). Soil solution only contains 0.1- 0.6 mmol/L of silicic acid, which is the dissolution product resulting from silicate mineral weathering (Orlov, 1985).

Plants take up Si in the form as silicic acid through rejective, passive, or active pathways depending on species (Mitani and Ma, 2005). Older tissues contain more Si than younger tissues (Blackman, 1968; Jones and Handreck, 1967; Sangster, 1970). Silicon can transport to different plant parts then plant silicification happens. Silicification occurs in cell walls, cell lumens, and intercellular spaces (Kumar, Soukup, and Elbaum, 2017). The Si deposits are called silica bodies (Sangster, 1970). Silica bodies appear as different sizes and shapes depending on plant species, and some of them perform green autofluorescence under fluorescence microscopy (Dabney et al., 2016).

The application of silicon fertilizers has a long history in agriculture, especially for rice cultivation. It has been reported that Si prevents rice lodging by increasing the thickness of the culm wall and the size of the vascular bundle (Shimoyama, 1958). It also decreases transpiration in rice leaves (Agarie et al., 1998). Potassium silicate (K_2SiO_3) was reported to increase grass biomass in an experiment on rhodes grass (*Chloris gayana*), timothy grass (*Phleum pratense*), sudan grass (*Sorghum sudanense*) and tall fescue (Eneji et al., 2008). Our objective for this study is to observe the differences in growth, development, and Si tissue distribution at different sodium silicate amendment rates in cool-season grasses (bentgrass and tall fescue).

MATERIALS AND METHODS

The experiment was conducted at University of Kentucky, Lexington, KY. Seeds of tall fescue [*Festuca arundinacea*, Hogan tall fescue blend (endophyte free)] and bentgrass (*Agrostis stolonifera*, Barracuda) were germinated in petri dishes on phytagel and then transplant in Hoagland solution in a growth chamber. The temperature was kept at 20°C with 16 h photoperiod. Plants were grown in buffered Hoagland's media (pH 6) with four Na_2SiO_4 treatments (0, 0.5, 1, 2, 4 mM). After four weeks of Si treatment, the grasses were harvested. Plant height, dry biomass and Si content of tissue were analyzed, and silica bodies in leaf ash were observed using epifluorescence microscope. Rstudio was used for data analysis.

RESULTS AND DISCUSSION

Our data showed tall fescue (at 0.5, 1 and 2 mM Si) and bentgrass (at 4 mM Si) both advantaged from Si supplementation in biomass compared to controls. Silicon concentrations in aboveground tissue had a positive linear relationship with Si concentrations in media for both grasses. The highest Si concentration in aboveground tissues was 24 (tall fescue) and 30.5 (bentgrass) g/kg dry biomass at 4mM Si (Fig.1). There were two silica body morphologies observed in leaf ash, and we called them long and barbed (Fig. 2). We only observed autofluorescence silica bodies in leaf tissue when Si was added in media. Taking together, Si supplementations can contribute to increasing aboveground biomass of tall fescue and bentgrass. Silicon supplementation could provide benefits when soil pore water dissolved Si below 0.5 and 4 mM for tall fescue and bentgrass, respectively.

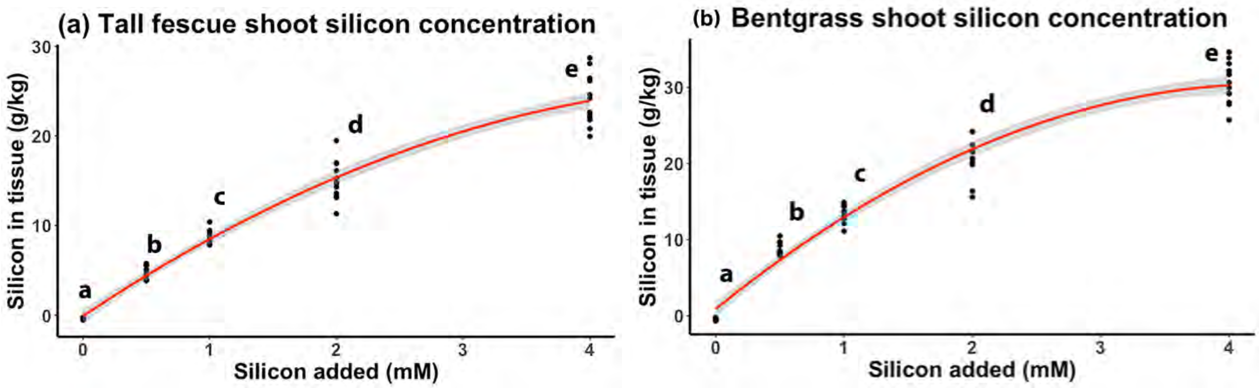

Figure 1. Effect of Si fertilization on tall fescue shoot (a), and bentgrass shoot (b) silicon concentrations (g kg^{-1} dry mass) at harvest. The solid lines represent linear regression through all data points. Shaded area indicates the 90% confidence interval for the regression line. Different lower-case letters indicate significant differences (p < 0.05) between different Si treatments in hydroponic culture, as determined by Tukey tests. The sample size n= 12 for each treatment.

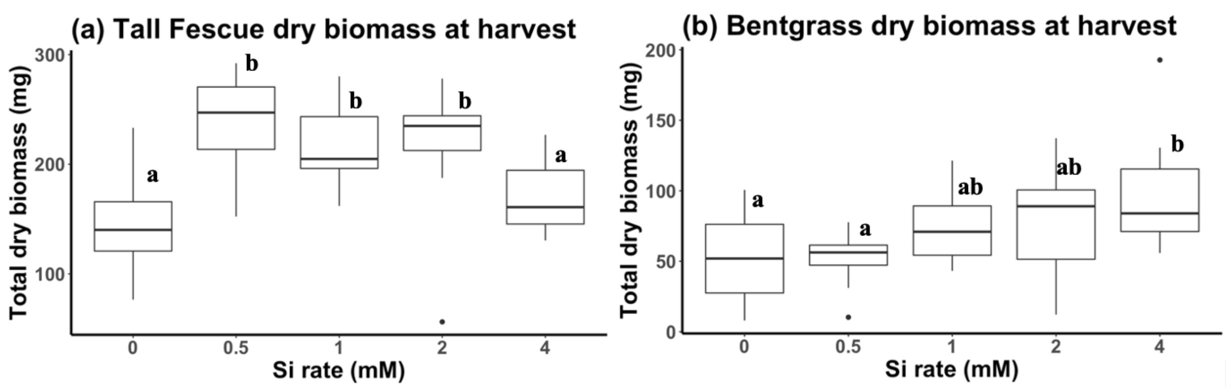

Figure 2. Boxplots representing whole plant dry biomass (mg) at harvest under the effect of silicon fertilization on (a) tall fescue and (b) bentgrass. The bold horizontal segments in the boxes represent the medians dry biomass of the treatment. The whiskers represent the 99% range, and the black dots represent the outliers. Different lower-case letters above boxes indicate significant differences ($p < 0.05$) between different silicon treatments in hydroponic culture, as determined by Tukey tests. The sample size n= 12 for each treatment..

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EVALUATION OF PLANT TISSUE ANALYSIS TO ASSESS PHOSPHORUS NUTRITIONAL STATUS IN CORN AND SOYBEAN

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ABSTRACT

Nutrient concentrations in plant tissue samples can be used to identify the nutritional status and response to phosphorus fertilization. This study aimed to determine critical P tissue concentration at different growing stages for corn and soybean. The experiment was conducted at 12 locations for corn in 2021 and 12 locations for soybean from 2017-2020 across Kansas. Tissue samples were collected from whole corn plants at the V6 stage, corn ear leaves at the R1 stage; and whole soybean plants at the V4 stage, and upper trifoliate leaves at the R2 soybean stage. Relationships between plant tissue P concentration and relative yield were investigated using data from plots that received no phosphorus fertilization. Linear-plateau models were used to identify the following critical values: whole corn plants at V4 = 0.41%, corn ear leaves at R1 stage = 0.24%, whole plant soybean at V4 = 0.34%, and trifoliate leaves at R2 stage = 0.39%. The relationship between the concentration at V6 and R1 for corn was moderately correlated with R^2= 0.69. For soybean, the relationship between the concentration of whole plants at V4 and trifoliate at R2 had an R^2 of 0.40.

INTRODUCTION

Phosphorus (P) is an essential macronutrient required in relatively large quantities for crops. Usually, the available fraction of the total soil phosphorus is low, and phosphorus fertilizer needs to meet crop phosphorus needs (Preston et al., 2019). Soil testing is the most used diagnostic tool to asses phosphorus nutrition. However, plant tissue analysis can also be used as a diagnostic tool to identify P deficiencies in crops and evaluate current P management programs (Reuter & Robinson, 1997). There has been relatively little research into the use of tissue analysis to asses phosphorus nutrition in corn and soybean in Kansas, particularly to identify critical values. The concentration of P in plants varies depending on the plant part and the growth stage. So, relationships between nutrient content and yield or yield response are needed for each part and growth stage. Critical values can be identified from these relationships by graphing the relative yield vs nutrient concentration (Munson & Nelson, 1990).

One downside of tissue testing is that it can only be performed in-season, while the crop is actively growing. As such, the time-window in which growers can take corrective actions is limited if deficiencies are found. Early season tissue sampling would be preferred, as this time window may be larger. Later in the growing season, the success of a correction practice for in-season P amendment is uncertain as it is considered immobile in both soil and plants. Even with those potential limitations, in-season tissue testing can be a helpful diagnostic tool to evaluate corn & soybean cropping systems. This study aims to determine critical P tissue concentration at different growing stages for corn and soybean to aid with the interpretation of tissue analysis in Kansas.

MATERIALS AND METHODS

Field experiments were conducted at 12 locations for corn in 2021 and 12 locations for soybean during 2017-2020 across the state of Kansas (Table 1). The experiment design was a randomized complete block design with four replications; plots were 10 ft width per 40 ft length. Tissue samples were collected as a whole plant in the V6 stage and ear leaf in the R1 stage in corn, whole plant in the V4 stage, and trifoliate in the R2 stage for soybean. Plant tissue samples were dried at 140 °F (60°C) and were ground to pass a 2-mm sieve. The plant tissue samples were digested using nitric-perchloric acid digestion and analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Corn and soybean were harvested, and the yield was calculated and corrected to 15.5% moisture for corn and 13% for soybean. Critical levels in corn were determined using the control's relative yield by blocks and plant tissue concentrations; this was achieved using linear plateau models. Critical levels in soybeans were determined from plots receiving no phosphorus fertilization and potassium fertilization ranging from 40 lbs to 120 lbs K_2O per acre. The relationships between P concentrations in different stages were evaluated using linear regression models. Data analyses were performed in R version 4.1. Linear plateau models were fit using nonlinear least square regression implemented using self-starting functions from the 'nlraa' R package.

RESULTS AND DISCUSSION

Critical Phosphorus Concentrations for Corn

The critical tissue P levels for the whole plant at the V6 growth stage were 0.41 %, and the model R^2 value was 0.27 (figure 1a), as determined by a linear plateau. The critical P levels for the ear leaf at the R1 stage were 0.24%, and the model R^2 value was 0.19 (Figure 1b). Both R^2 values are low, with the ear leaf at R1 having lower than the whole plant at V6. Stammer & Mallarino (2018) found a similar critical P concentration with a linear plateau for the whole plant at growth stage V6 of 0.48% and 0.25% for the ear leaf at the R1.

The relationship between the concentration in the whole plant at V6 and the ear leaf at R1 was moderately correlated with R^2 = 0.69 (Figure 3a). The P tissue concentrations ranged from 0.25% to 0.64% for V6 and 0.15% to 0.42% for R1. The tissue P concentrations at the V6 stage were higher than at the R1 stage; this suggests that the value of tissue testing to assess plant phosphorus nutritional status for corn may differ during the growing season.

Critical Phosphorus Concentrations for Soybean

The critical tissue P level for the whole plant at the V4 growth stage was 0.34%, and the model R2 value was 0.02 (Figure 2a), as determined by a linear plateau. The critical P levels for trifoliate leaves at the R2 stage were 0.39%, and the model R2 value was

0.08 (Figure 2b). The relationship between the concentration in the whole plant at V4 was moderately correlated with that measured from the trifoliate leaves at the R2 growth stage (R^2 = 0.40, Figure 3b). The P tissue concentrations ranged from 0.25% to 0.45% for V4 and 0.25% to 0.54% for R1.

While the critical values identified in this study were in agreement with those reported by Mills & Jones (1996) and Stammer & Mallarino (2018), the overall model fits were relatively poor for both maturity stages and plant parts. These results suggest that in-season tissue analysis can have value when used as a diagnostic tool for identifying nutrient deficiencies during the growing season, but it is important to recognize they are ranges and not specific values.

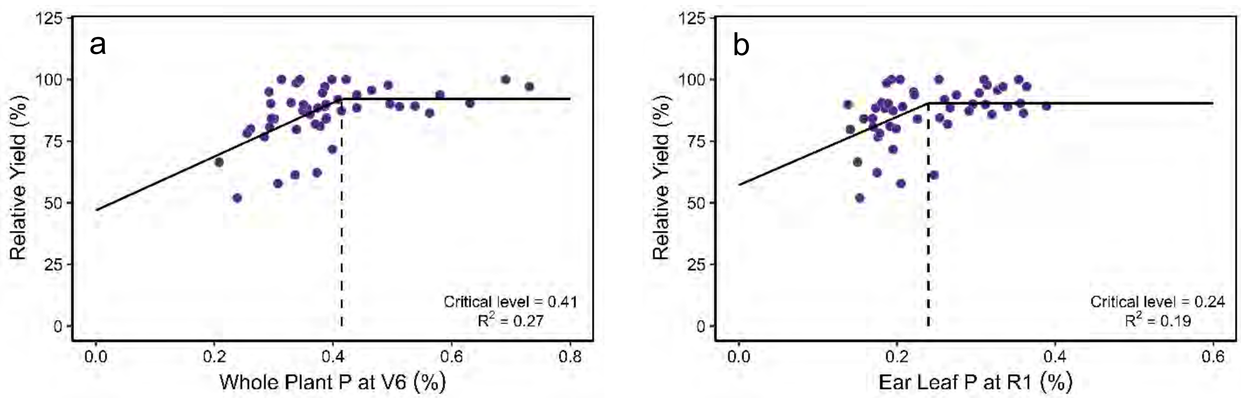

Figure 1. Relationship between relative yield and the P concentration of (a) whole plants at the V6 growth stage or (b) ear leaf blades at the R1 stage. Vertical lines indicate a critical P level with a linear plateau model.

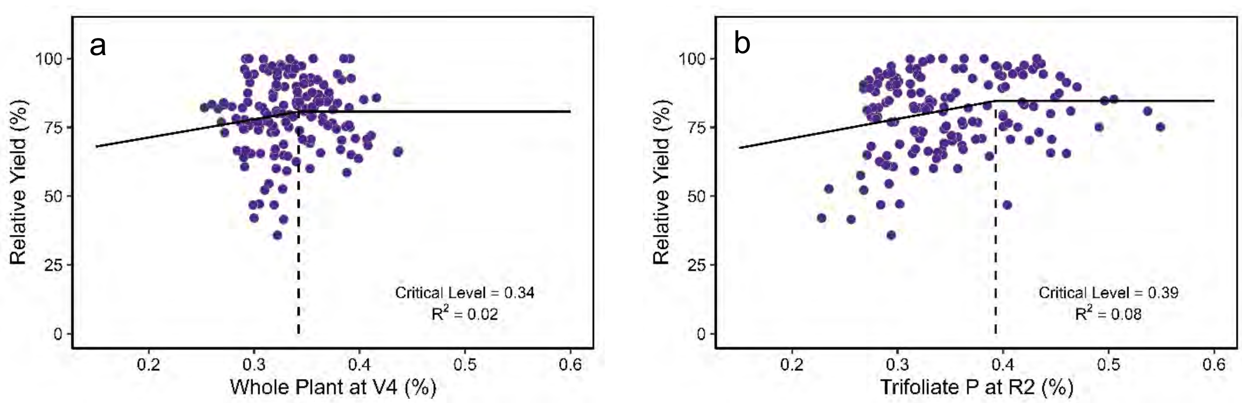

Figure 2. Relationship between relative yield and the P concentration of (a) whole plants at the V4 growth stage or (b) trifoliate at the R2 stage. Vertical lines indicate a critical P level identified with a linear plateau model.

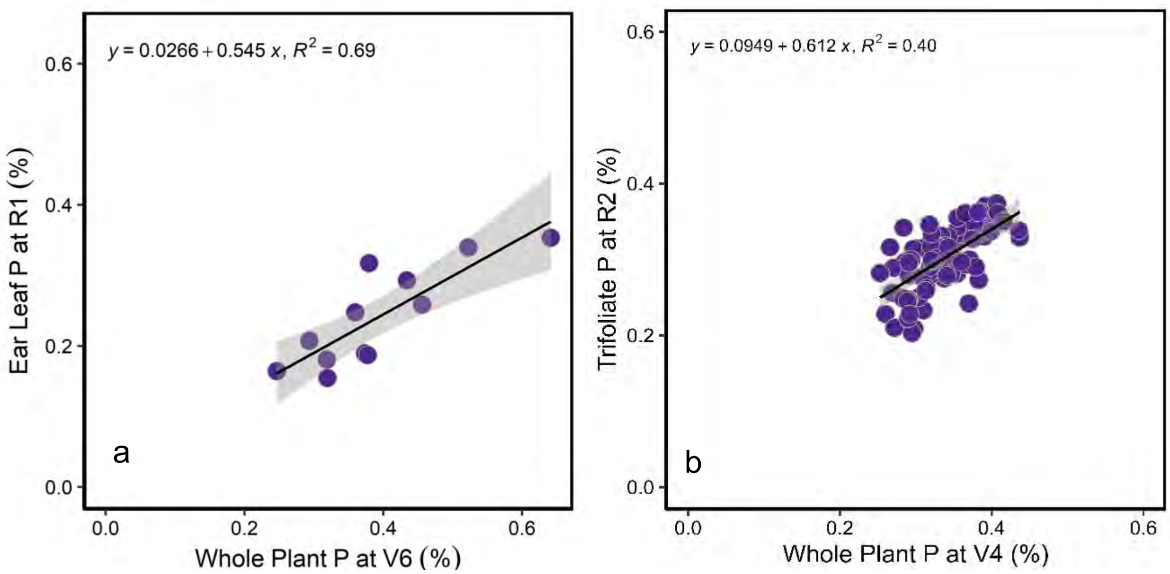

Figure 3. A) Relationship between P concentrations in the ear leaves of corn at the R1 stage and the whole plant at the V6 corn growth stage. B) Relationships between P content of whole plants at the V4 growth stage and trifoliates at the R2 growth stage.

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Table 1. Study sites, crops and soil properties. Samples were collected at 0- to 6-in. depth.

Location	County	Crop	pH	P	OM	CEC	Sand	Silt	Clay
				ppm			%		
1	Republic	Corn	6.5	5	3.3	13	28	57	15
2	Republic	Corn	6.1	7	2.7	13	20	61	19
3	Franklin	Corn	6.0	9	3.4	23	14	62	24
4	Dickinson	Corn	5.8	21	3.5	23	22	52	26
5	Shawnee	Corn	7.6	21	1.9	12	46	42	12
6	Gove	Corn	7.2	20	2.5	22	20	59	21
7	Logan	Corn	6.4	22	2.8	17	20	56	24
8	Gove	Corn	6.6	25	2.7	16	21	54	25
9	Gove	Corn	6.2	35	3.1	14	21	58	21
10	Salina	Corn	5.4	38	2.9	24	30	46	24
11	Riley	Corn	6.3	45	2.0	9	36	54	10
12	Brown	Corn	6.3	45	3.1	13	18	66	16
13	Franklin	Soybean	5.8	21	3.0	23	6	66	28
14	Mitchell	Soybean	5.3	70	2.8	20	18	56	26
15	Mitchell	Soybean	7.7	9	2.7	27	16	44	40
16	Shawnee	Soybean	6.6	12	1.7	11	30	60	10
17	McPherson	Soybean	7.9	65	1.8	14	30	56	14
18	Republic	Soybean	7.1	8	2.8	15	32	48	20
19	Clay	Soybean	5.8	28	3.1	18	30	47	23
20	Franklin	Soybean	6.2	15	2.9	23	14	62	24
21	Mitchell	Soybean	5.7	25	3.1	22	18	60	22
22	Mitchell	Soybean	4.8	35	3.5	21	22	48	30
23	Republic	Soybean	6.1	12	3.0	14	27	56	17
24	Shawnee	Soybean	6.8	31	1.8	12	45	44	11

MANAGING TRADE-OFFS OF WINTER RYE AS A COVER CROP

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ABSTRACT

Winter rye (Secal cereale L.) is a commonly used cover crop in Wisconsin due to its effectiveness in reducing soil erosion, scavenging nitrogen, and improving soil health. However, the potential trade-offs of using grass cover crops are decreases in corn yield driven by nitrogen uptake and immobilization. The study aims to determine the single year effect of rye seeding rate on rye biomass and optimum nitrogen rate of the subsequent corn (*Zea mays* L.) crop, while also evaluating the relationship between biomass and decomposition rate. Rye cover crop was planted in fall at five seeding rates (0, 30, 60, 90, 120 lb ac-1) following corn silage harvest and liquid dairy manure application at Arlington Agriculture Research Station in WI. Corn was planted following chemical termination of rye and fertilized with eight nitrogen rates (0, 40, 80, 120, 160, 200, 240, 320 lb-N ac-1). In contrast to previous research at this location, maximum corn yield was not affected by the rye. However, additional nitrogen fertilizer needed to be applied to reach optimum corn yield as rye biomass increased. Knowing how to accurately adjust nitrogen fertilization after a cover crop is critical to ensure optimum corn yield while still gaining the soil health and water quality benefits of winter rye.

INTRODUCTION

Cover crops are a common agricultural management practice used as living cover to protect the soil from erosion, prevent loss of nutrients, and build soil health (Kaspar & Singer, 2015; Sharma et al., 2018; Snapp & Surapur, 2018). The use of cover crops becomes increasingly important as environmental concerns with corn (*Zea mays L.)* production continue to increase . Corn silage is an integral crop to dairy production systems and is grown on about 10% of Wisconsin's crop production land (USDA NASS, 2017). However, this dairy production system has an environmental cost due to high in-season corn nitrogen requirements, lack of residue post-harvest, and fall manure application. Winter rye (*Secal cereale* L.) is an effective addition to this system due to its winter-hardiness and ability to scavenge soil nitrogen that could otherwise be leached from the system (West et al., 2020).

Potential trade-offs of using a grass cover crop are soil nitrogen immobilization and decreases in corn yield (Martinez-Feria et al., 2016; Pantoja et al., 2016). Rye biomass accumulates nitrogen that is then unavailable to the subsequent corn crop. However, the effects of this relationship between biomass accumulated and corn yield can be quite variable (Martinez-Feria et al., 2016). This study aims to better understand the relationship between winter rye biomass, soil nitrogen pools, and nitrogen requirements of the subsequent corn crop. The objectives of this study were to i) to determine how the seeding rate of winter rye effects root and shoot biomass, ii) to determine the effect of rye biomass on soil nitrogen pools, and iii) to determine the effect of rye cover crop biomass on subsequent corn yield and optimum nitrogen rate.

MATERIALS AND METHODS

The two-year field study was conducted at University of Wisconsin Arlington Research Station (43º18'9.47"N, 89 º 20'43.32"W) from 2020-2022 on a Plano silt loam (fine-silty, mixed, superactive, Mesic Typic Argiuodoll). Each year of the study was conducted at a different field site located within 5 km of one another. The experimental design was randomized complete block split-plot replicated five times. Whole block treatments were rye seeding rates of 0, 30, 60, 90, 120 lb ac^{-1} (15 ft x 320 ft, six corn rows wide). Split plot treatments were nitrogen fertilizer application rates of 0, 40, 80, 120, 160, 200, 240, 320 lb-N ac^{-1} (15 ft x 40 ft), surface applied at corn growth stage V3. Liquid dairy manure was surface applied after corn silage was harvested in fall, and winter rye was planted as a cover crop two weeks later. Rye was terminated in early spring and corn was planted two weeks later.

Soil samples for plant available nitrogen analysis were collected as a composite bulk sample of eight cores per plot at a depth of 0-1' and 1-2' in fall before the first hard frost and in spring at time of rye termination. Rye biomass was sampled from two 0.25-m^2 quadrats (three rye rows) per plot for carbon and nitrogen analysis. Rye root biomass was measured only in spring of year 2. In each plot, two 4.25" diameter soil cores were taken per plot to a depth of 2", one directly in a rye row and one between. Cores were stored in plastic sleeves until time of analysis when cores were soaked and roots were carefully separated from soil and organic matter using a sieve and tweezer. Biomass and soil samples were dried and ground before analysis.

RESULTS AND DISCUSSION

Winter rye biomass

Aboveground rye biomass increased as seeding rate increased, with more biomass accumulated in the second year (Figure 1). Carbon to nitrogen ratio of rye shoot biomass was low across all treatments but was least at the 30 lb ac^{-1} seeding rate. This difference in C:N was driven by %N in biomass, with greater values when rye seeding rates were low. With C:N ranging from 10-13, rye residue at all seeding rates is considered high quality and should not lead to additional nitrogen tie up throughout the growing season due to immobilization of plant available nitrogen (Table 1). Nitrogen

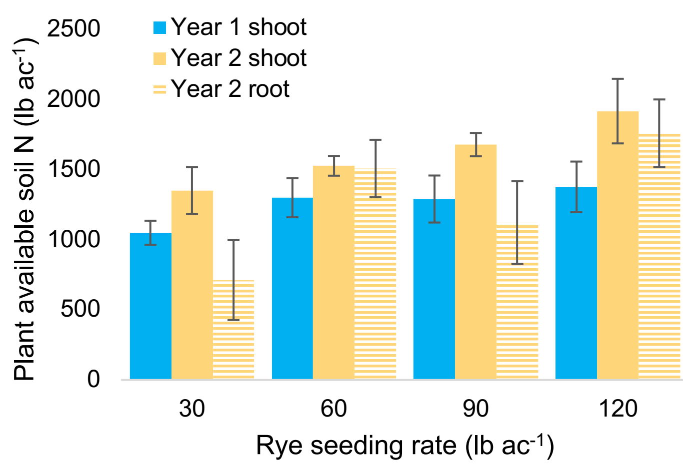

Figure 1. Winter rye cover crop shoot biomass in years 1 and 2. Root biomass was only sampled in year 2. Error bars represent standard deviation.

yield increased as seeding rate increased and was greater in year 2 when more rye biomass was accumulated.

Rye root biomass was sampled in year 2 only and followed the same trends as aboveground biomass (Figure 1). However, rye root biomass had a greater C:N ratio that could lead to potential immobilization throughout the growing season as rye roots decompose. Root biomass nearly doubles the amount of total plant biomass that is otherwise unaccounted for when only aboveground biomass is measured. This additional 12-26 lb ac^{-1} of N uptake caused by root biomass is important to account for in future nitrogen budgeting work when a nitrogen demanding crop is following a grass cover crop (Table 1).

Table 1. Summary of cover crop biomass nutrient content across rye seeding rate treatments in year 1 and 2. Root biomass was measured in year 2 only. ANOVA results as affected by seeding rate treatment are reported for each year. Within each column, means followed by the same letter are not significantly different at α=0.05.

Seeding rate	**Year 1**		**Year 2**				
	Shoot		Shoot		Root		Total
(lb ac^{-1})	C:N	N yield (lb ac^{-1})	C:N	N yield (lb ac^{-1})	C:N	N yield (lb ac^{-1})	N uptake (lb ac^{-1})
30	10b	41	10b	51b	24	12b	62b
60	12a	44	12a	53b	22	24a	73a
90	12a	43	12a	60ab	29	16b	76a
120	13a	44	13a	65a	27	26a	91a

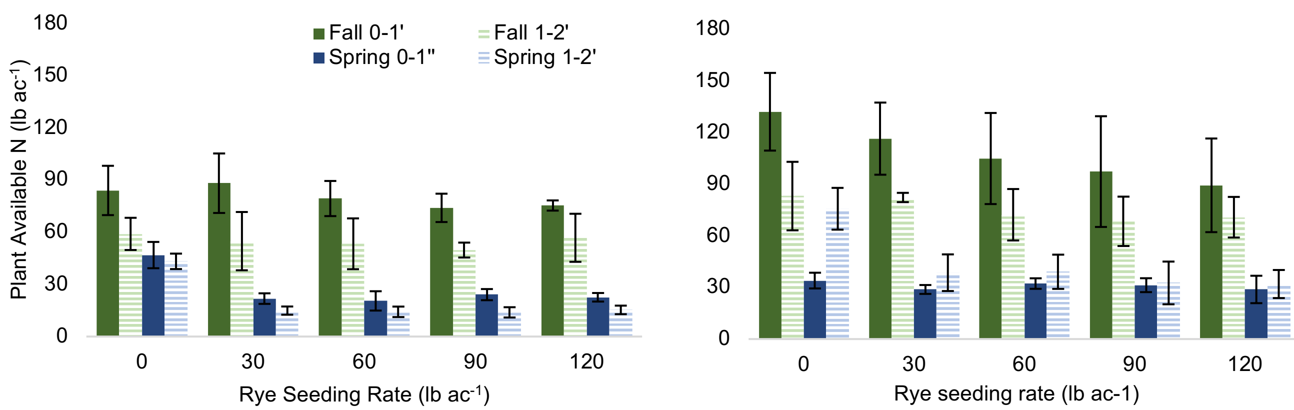

Figure 2. Plant available soil nitrogen (sum of nitrate-N and ammonium-N) in year 1 and 2 across rye seeding rate treatments. Solid bars indicate the sampling depth of 0-1’ and slotted bars indicate sampling depth of 1-2’. Error bars represent standard deviation.

Soil nitrogen

Fall soil nitrogen decreased in the 0-1’ depth as seeding rate increased, and this trend was more evident in year 2 due to a greater amount of rye biomass accumulated fall (Figure 2). In spring of year 1, all rye treatments had less plant available soil nitrogen in at both depths. The difference in soil nitrogen from fall to spring indicates that rye at all seeding rates was able to scavenge soil nitrogen that may have otherwise leached from the field. In spring of year 2 we see this same trend, but only in the 1-2’ depth. This difference is greatest where rye was not present, indicating that from fall to spring the nitrogen moved into the second foot, but the cover crop was still able to take up this nitrogen (Figure 2)

Corn yield response

Bootstrapped residuals of the quadratic plateau model for corn yield were used to calculate optimum nitrogen fertilizer rates and maximum yield. Based on the plateau, maximum corn yield for rye seeding rate treatments of 30 and 60 lb ac^{-1} were higher than the other treatments (Figure 3). The lowest corn yield occurred following rye seeding rate of 120 lb ac^{-1}, indicating that corn yield was not able to recover even at high nitrogen rates due to greater rye biomass accumulation. However, this yield was only 2 bu ac^{-1} different than the treatment without rye, so this difference is not economically significant (Table 2). More nitrogen was needed to reach maximum yield as seeding rate of rye increased, but this trend was not observed at the 60 lb ac^{-1} seeding rate which only required 104 lb ac^{-1} to reach maximum yield (Figure 4). This response is not expected because at the 60 lb ac^{-1} seeding rate rye accumulated a similar amount of biomass as the seeding rates of 90 and 120 lb ac^{-1}.

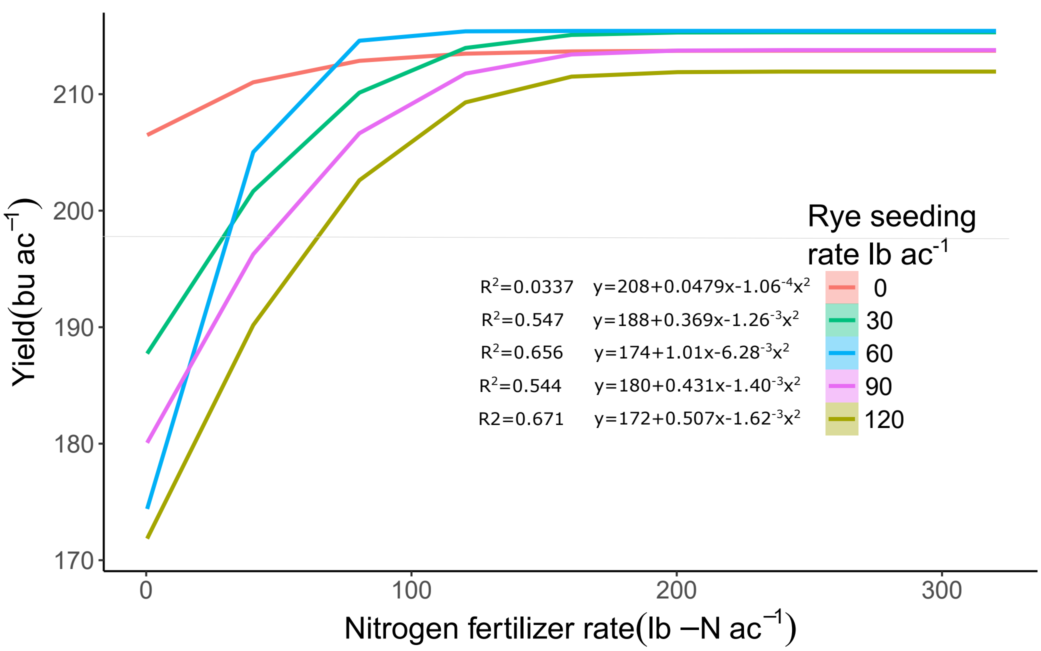

Figure 3. Year 1 corn yield fertilizer response curves determined by bootstrapping residuals of seeding rate treatments. Equations and R^2 represent fit of quadratic plateau model to the bootstrapped data.

Table 2. Year 1 economic and agronomic optimum corn grain yield and nitrogen rate following winter rye cover crop based on parameter estimates from quadratic plateau model of original data. Economic optimum values calculated using a nitrogen fertilizer to corn price ratio of 0.1.

	Economic optimum		Agronomic optimum	
Rye seeding rate	Nitrogen fertilizer rate	Corn yield	Nitrogen fertilizer rate	Corn yield
lb ac^{-1}	lb ac^{-1}	bu ac^{-1}	lb ac^{-1}	bu ac^{-1}
0	0	208	149	213
30	106	213	180	215
60	72.7	214	104	215
90	118	211	190	213
120	126	210	197	211

When corn was grown following the treatment without rye, grain yield was greatest at the 0 N fertilizer at 208 bu ac^{-1}, but did not plateau until N fertilizer rate of 149 lb ac^{-1} (Figure 3, Table 2). However, the economic optimum rate of nitrogen fertilizer is 0. This outcome indicates that corn yield was non-responsive to nitrogen fertilizer following the no rye treatment, and that starter fertilizer and plant available soil nitrogen provided enough nitrogen to the corn to reach the economically optimum grain yield.

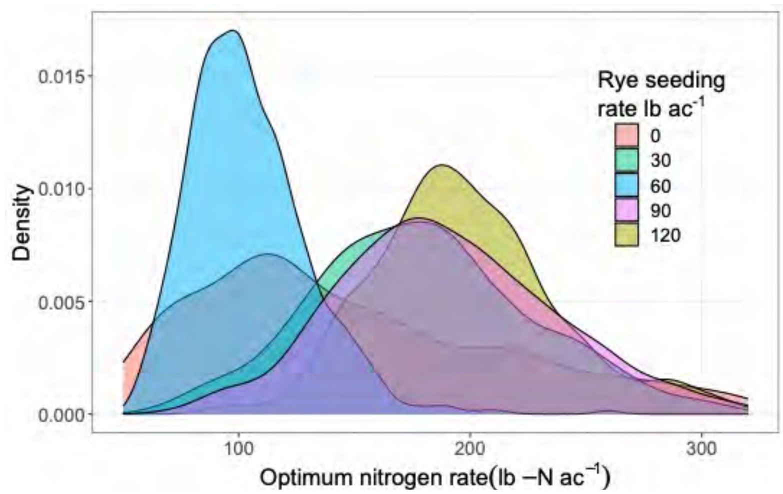

Figure 4. Density plot of optimum N fertilizer rate based on corn yield from year 1 of rye seeding rate treatments. The density plots are constructed with results from bootstrapping residuals with data resampled 1000 times.

CONCLUSION

When corn is grown following a winter rye cover crop, a lack in soil nitrogen leads to a yield decline at low nitrogen rates, but these yields recover upon additional nitrogen fertilizer application, and maximum grain yield was not negatively impacted. There appears to be little benefit to seeding rye at a rate above 60 lb/ac. Rye seeding rates of 30-60 lb ac^{-1} had less of a yield effect compared to rates of 90 and 120 lb ac^{-1}, and economic optimum yields recovered with the addition of 73-106 lb-N ac^{-1}. Even though we see a nitrogen effect occurring with corn following rye, all seeding rates of rye effectively scavenged nitrogen from the field and provided water quality benefits through nitrogen uptake. Thus, there is a clear tradeoff in-terms of nitrogen cycling with rye cover crop use with manure, as water quality benefits are obtained at the cost of agronomic benefit of the applied manure.

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SOYBEAN BIOLOGICAL NITROGEN FIXATION AND PRODUCTION AS AFFECTED BY FERTILIZER, NITROGEN APPLICATION, AND PLANTING DATE

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ABSTRACT

Michigan spring weather variabilities and earlier planting dates may provide opportunities for starter fertilizer to influence early season soybean (*Glycine max* L. Merr.) dry matter production while simultaneously decreasing the time interval for nutrient accumulation. However, potential fertilizer impacts on inhibition of biological N fixation (BNF) are not well understood. Field studies established near Lansing, MI examined soybean total dry matter accumulation (TDM), nodulation, ^{15}N content, grain yield, and net economic return as influenced by planting dates and fertilizer strategies in both irrigated and non-irrigated environments. Studies were arranged as a randomized complete block split-plot design containing four replications. Main plots consisted of two planting dates while sub-plots consisted of six fertilizer strategies. In 2021 grain yield of April and May planted soybean ranged from 82.3 to 78.0 bushels A^{-1} respectively, at the irrigated site, and 72.8 to 69.8 bushels A^{-1} respectively, at the non-irrigated site. Non-irrigated R4 mean nodule counts per plant showed a 36% reduction as planting date was delayed from April to May. All fertilizer treatments significantly reduced nodulation compared to the non-fertilized control except for the dry 2x2 starter strategy. Percent N derived from atmosphere (NDFA) interacted with planting date and fertilizer strategy at R2 but by R6 NDFA was different only between fertilizer treatments. Preliminary results suggest that starter fertilizer may be one tool to mitigate risk during early season planting without inhibiting biological N fixation.

INTRODUCTION

High input prices (i.e., seed, fertilizer, pesticides, etc.) have practitioners reevaluating soybean fertilizer management practices. Recent occurrences of spring weather variability combined with what has become cool, abnormally wet or dry Michigan spring planting conditions have increased interest in nutrient strategies that may influence early-season dry matter production and nutrient accumulation (i.e., reducing the lag-phase of soybean growth) but not adversely impact biological N fixation (BNF) 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.

Soybean production practices are often overlooked as many critical components of soybean yield potential are limited by the uncontrollable environment. Previous studies indicated plant density influences on total dry matter (TDM) accumulation may help facilitate nutrient uptake with greater pre-R5 dry matter associated with greater yields (Purucker & Steinke, 2020). As mean farm size continues to grow, earlier planting of soybeans has gained interest and may be another opportunity to influence TDM, grain yield, and oil content (Robinson et al, 2009). However, early spring soil conditions in

Michigan are unpredictable which may provide greater opportunity for starter fertilizer to influence plant establishment. Low rates of starter N fertilizer (< 25# A^{-1}) have been found to support increased V4 DM but yield and profitability were not consistent and effects on BNF unknown (Purucker & Steinke, 2020). Although low starter N rates have not decreased BNF, more data are needed regarding the influence of greater N rates and starter fertilizer practices not only TDM and grain yield but also BNF contributions to the plant (Salvagiotti et al, 2008).

MATERIALS AND METHODS

Field trials were conducted in Lansing, MI on irrigated and non-irrigated Capac loam soil in 2021 and 2022. All sites were previously cropped to corn (*Zea mays* L.) followed by autumn chisel plowing and spring field cultivation. Pre-plant soil samples (0–8-inch depth) indicated soil characteristics ranging from: 6.7-7.4 pH, 34-155 ppm P, 86-147 ppm K, and 8-17 ppm S across site years. Plots measured 15 ft. wide by 40 ft. in length with 30 in. row spacing. Trials were arranged as randomized complete block split-plot design with four replications to evaluate two plant timings (23 April, and 17 May 2021; 29 April, and 20 May 2022) as well as six fertilizer strategies: no fertilizer, 25 lb. N, 60 lb. P_2O_5, and 15 lb. S A^{-1} (12-40-0-10S mixed 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 mixed 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 growth stage V4, and 100 lb. N A^{-1} (28-0-0) band applied along each row at growth stage R2. Variety P24T35E, a 2.4MG soybean, was planted at both locations across years. At irrigated locations, 5 in. and 7.9 in. of supplemental water was supplied in 2021 and 2022 growing seasons, respectively, using a Micro-rain traveling irrigator (Micro Rain, Yukon, OK). Grain yield was harvested from middle two from each plot using a Kincaid 8xp small plot combine (Kincaid Equipment Manufacturing, Haven, KS) and adjusted to 13.5% moisture on 20 October 2021 and 5 October 2022.

A partial budget was used to calculate net economic return by subtracting fertilizer input cost from gross revenue (i.e., grain price multiplied by yield). Input cost included fertilizer and application costs obtained from local retail grain elevators and Michigan State University Extension Custom Machine and Work Rate Estimates. Application costs were US$2.98, $6.18, and $11.30 A^{-1} for subsurface 2x2 nutrient application, PPI broadcast application and incorporation, and surface banding, respectively (Farm Business Team, MSU, 2021). Fertilizer 2021 input costs were US$61.85, $74.78 $64.56, and $70.11 A^{-1} and in 2022 were US$104.60, $117.71 $124.97, and $131.11 A^{-1} for dry 2x2, liquid 2x2, PPI N, and V4/R2 N, respectively. Economic return was estimated by subtracting fertilizer and application cost from local cash prices of $12.02 and $13.24 Bu^{-1} in 2021 and 2022, respectively. Data were analyzed using SAS 9.4 (SAS Institute, 2012) using the GLIMMIX procedure at α=0.10.

PRELIMINARY RESULTS AND DISCUSSION

April and May 2021 precipitation was 58% and 77% below the 30-year mean with above average totals for the remainder of the growing season. High volume 24-hour rain events in late June and early July accounted for much of the above average rainfall. Under irrigation, 5 in. of supplemental water was provided to maintain field capacity. Growing degree day (GDD, base temp 50ºF) totals 28 days after April and May plant timings were 204 and 515, respectively. Soil temperatures did not permanently remain > 50ºF until 13 May. June and July 2022 precipitation was 56% and 40% below the 30-year mean, respectively. Soil temperatures remained >50ºF after 8 May, with 28 DAP GDD totals following April and May planting reaching 291 and 445, respectively. Supplemental irrigation provided 7.9 in of additional water at the 2022 irrigated location.

Irrigated 2021 results indicated no significant interactions between planting date and fertilizer strategy. April planting averaged 82.3 bu A^{-1} as compared to 78.0 bu A^{-1} for the May planting (Table 1). Yield data agreed with the Nelson (2021) observation of a four bushel per acre increase in April planted soybeans as compared to May. Biomass accumulation at V4, R2, and R8 was significantly greater with April as compared to May planting (Table 2). Although NDFA concentration was not impacted by planting date at R2 or R6 under irrigation, planting date and fertilizer strategy interacted to impact R2 NDFA at the non-irrigated location (Table 4). Nitrogen derived from atmosphere at R6 was influenced by fertilizer strategy at both locations with PPI and V4 N applications generating less N from BNF than liquid 2x2, dry 2x2, R2 N, and untreated treatments (Table 3). Relative abundance of ureides (data not shown) at R6 indicated total N accumulation in soybean plants was only reduced 1 to 4% across fertilizer strategies in the current study. At the non-irrigated 2021 location, April planted soybean averaged 72.8 bu A^{-1} as compared to 69.8 bu A^{-1} with the May planting date. Neither planting date or fertilizer strategy influenced grain yield (Table 1).

Non-irrigated 2022 grain yield was not influenced by planting date or fertilizer strategy. Grain yield decreased 9.32 and 8.64 bu A^{-1} for April and May planting dates, respectively, from non-irrigated in 2021. Grain yield reductions in 2022 were likely caused by a lack of moisture from June to mid-August which influenced the developmental (V4-R1) and grain fill (R4-R7) periods. Irrigated 2022 grain yields were affected by fertilizer strategy. Nitrogen application PPI was significantly greater than untreated indicating N supply via BNF may not have been sufficient for achieving maximum yield. Pending 2022 ^{15}N analysis data will help quantify the level to which BNF may have been impacted by early season N application.

In 2021, neither liquid or dry 2x2 starter fertilizer reduced nodulation at R4 or contributions from BNF at R2 or R6 at either location. The opposite occurred with PPI N applications at both locations where BNF contributions were reduced (Table 3). Starter fertilizer at 25 lb. N A^{-1} band applied did not appear to have a negative impact on N accumulation and may serve as a tool for reducing the “lag phase” of soybean nutrient uptake. In the above critical P and K concentration environments tested, data suggest that pre-plant and in season V4 N fertilizer applications may negatively impact biological N fixation without consistent changes in grain yield.

Table 1. Grain yield in bushels per acre of irrigated and non-irrigated soybeans, 2021 and 2022, Lansing, MI.

Site	Treatment	Irrigated 2021	Irrigated 2022	Non-irrigated 2021	Non-irrigated 2022
Irrigated	Planting Date	Bushel A^{-1}			
	April	82.3 a†	69.2 a	72.8 a	63.5 a
	May	78.0 b	68.3 a	69.8 a	61.2 a
	P > F	**0.07**	**0.81**	**0.19**	**0.55**
	Fertilizer				
	None	79.1 a	64.7 bc	72.6 a	61.3 a
	Dry 2x2	81.5 a	68.6 abc	75.7 a	64.5 a
	Liquid 2x2	78.1 a	64.1 c	70.7 a	61.4 a
	PPI N	82.2 a	72.8 a	68.9 a	63.0 a
	V4 N	78.4 a	71.0 abc	70.4 a	61.2 a
	R2 N	81.5 a	71.2 ab	69.5 a	62.5 a
	P > F	**0.18**	**< 0.01**	**0.20**	**0.90**

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

Table 2. Biomass accumulation at growth stages V4, R2 and R8 of irrigated 2021 soybeans.

Site	Treatment	V4 Biomass	R2 Biomass	R8 Biomass
Irrigated 2021	Planting Date	lb A^{-1}		
	April 23	255 a†	1652 a	8830 a
	May 17	158 b	1242 b	6381 b
	P > F	**0.02**	**0.09**	**0.05**
	Fertilizer			
	None	178 b	1096 b	7372 a
	Dry 2x2	257 a	1633 a	7189 a
	Liquid 2x2	206 ab	1622 a	7290 a
	PPI N	185 ab	1518 ab	8527 a
	V4 N	-- ‡	1366 ab	8211 a
	R2 N	--	--	7045 a
	P > F	**0.09**	**0.04**	**0.82**

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

‡ Treatment not in effect at time of sampling.

Table 3. Nodule count and percentage of nitrogen derived from atmosphere at R2 and R6 of irrigated and non-irrigated soybeans, Lansing, MI, 2021.

Site	Treatment	Nodules Plant^{-1}	% NDFA R2	% NDFA R6
Irrigated 21'	Planting Date			
	April 23	94 a†	25.13 a	56.57 a
	May 17	73 b	19.78 a	55.02 a
	P > F	**0.09**	**0.25**	**0.59**
	Fertilizer			
	None	86 a	28.30 a	57.67 a
	Dry 2x2	93 a	28.39 a	60.32 a
	Liquid 2x2	88 a	25.64 a	57.77 a
	PPI N	73 a	13.50 b	50.13 b
	V4 N	72 a	16.44 b	48.36 b
	R2 N	89 a	-- ‡	60.53 a
	P > F	**0.53**	**<0.001**	**<0.001**
Non-Irrigated 21'	Planting Date			
	April 23	88 a	§	36.73 a
	May 17	56 b		36.10 a
	P > F	**0.03**		**0.77**
	Fertilizer			
	None	94 a		41.40 a
	Dry 2x2	76 ab		47.94 a
	Liquid 2x2	69 ab		48.32 a
	PPI N	59 b		12.68 b
	V4 N	70 ab		19.68 b
	R2 N	65 ab		48.58 a
	P > F	**0.07**		**<0.001**

† Values followed by the same lowercase letter in the same column from the same site are not significantly different at α=0.1.
‡ Treatment not in effect at time of sampling.
§ See Table 3 for non-irrigated % NDFA R2 interaction.

Table 4. Interaction of planting date and fertilizer strategy on percentage of nitrogen derived from atmosphere at R2 of non-irrigated soybeans, Lansing, MI, 2021.

Site	Fertilizer	Planting Date		***P > F***
		23-Apr	17-May	
Non-irrigated 21'		—— % ——		
	None	37.53 a†A‡	30.86 aA	**0.3**
	Dry 2x2	31.20 aBA	37.70 aA	**0.31**
	Liquid 2x2	35.40 aA	39.47 aA	**0.52**
	PPI N	22.69 aB	7.50 bB	**0.05**
	V4 N	24.33 aB	34.31 aA	**0.12**
	R2 N	--*	--	**--**
	P > F	**0.044**	**<0.0015**	

* Treatment not in effect at time of sampling.

† Means in the same row followed by the same lowercase letter are not significantly different at α=0.10.

‡Means in the same column followed by the same uppercase letter are not significantly different at α=0.10.

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A MINNESOTA-WIDE ASSESSMENT OF CRITICAL PRE-PLANT AND IN-SEASON SOIL NITRATE FOR ADJUSTING NITROGEN RATE GUIDELINES

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ABSTRACT

Through a comprehensive statewide assessment of PPNT and PSNT data collected previously, we estimated and compared critical soil nitrate levels (CSNL) computed for various specific environmental and management condition as well as averaged across all the conditions (scenarios) present in the database. Preliminary results estimated as an average across all scenarios demonstrated that the PPNT has a lower CSNL for fields with soybean as the previous crop compared to corn as the previous crop and for sites with soil organic matter (SOM) < 4.6%, while a greater CSNL is required in fields with pH < 5.8 or with SOM > 4.8%. At pre-sidedress, CSNL requirement follows the same pattern as for PPNT, except that for fields with soil pH < 5.8 the CSNL was lower than for soils with higher pHs. While the results are preliminary, as currently only approximately 100 site years of data (approximately half of the site-years available) have been analyzed, the results indicate that soil conditions influence critical soil nitrate for both PPNT and PSNT.

INTRODUCTION

It is common to apply nitrogen (N) fertilizer prior to or at corn (*Zea mays* L.) planting in Minnesota. Residual soil nitrate testing can be used to quantify the amount of nitrate-nitrogen (N) present in the root zone and is an important nitrogen fertilizer management tool. It is among the practices recommended to be implemented under the Groundwater Protection Rule.

Pre-plant nitrate test (PPNT) and pre-sidedress nitrate test (PSNT) helps producers estimate if their fields have sufficient N to optimize yield. The PPNT provides an N credit for the N fertilizer rate and is determined based on soil testing performed prior to planting. The PSNT nitrate test is taken around V4 in mid-June at the 0- to 30-cm soil depth and helps determine if additional N is needed. Fields with soil test values (STV) less than 20-25 mg kg-1 are likely to respond but the PSNT does not provide an estimate of how much in-season fertilizer N should be applied.

The amount of residual nitrate in the soil depends on rainfall, soil texture and water holding capacity, organic matter, crop rotation, manure history and other factors. Since these factors varies regionally, the current BMPs from the University of Minnesota (U of M) has different recommendations across the state.

The current recommendations are based on research conducted nearly 40 years ago. They do not account for the generally wetter climate Minnesota is experiencing, advancements in fertilizer application technology including variable rate nitrogen fertilizer application, or in-season assessments of nitrogen needs including the use of in-season soil nitrate testing. They also do not align with the BMP regions used by the U of M for their other nitrogen fertilizer BMPs.

There is a need, therefore, to reevaluate the soil nitrate testing BMP recommendations to make them relevant and meaningful for current crop management practices and to establish an estimate of an in-season critical STV (CSTV) and the supplemental in-season N fertilizer rate that accounts for these unpredictable spring weather conditions is needed.

MATERIALS AND METHODS

The study inventory and assemble a dataset of existing corn grain yield responses to pre-and at-planting and in-season nitrogen fertilizer rates over contrasting spring weather conditions, soil textures, cropping rotations, and regions of Minnesota including data from University of Minnesota (U of M) research projects, Minnesota Department of Agriculture (MDA) nutrient management initiative, and other relevant studies. Based on the assembled data, it was evaluated the uses and applications of pre-plant soil nitrate test (PPNT) and pre-sidedress nitrate test (PSNT) for nitrogen rate adjustment.

Datasets contains:

- Site location
- Soil classification Previous crop
- N rate, source, application time and placement
- Soil sampling depth(s).
- Soil test method and the units reported.
- Soil sampling date and corn growth stage.
- Inclusion of multiple sampling dates, if measured, is desired (e.g. V4 and V8)
- Grain yield
- Data owner and custodian.

Additional Meta-data if available

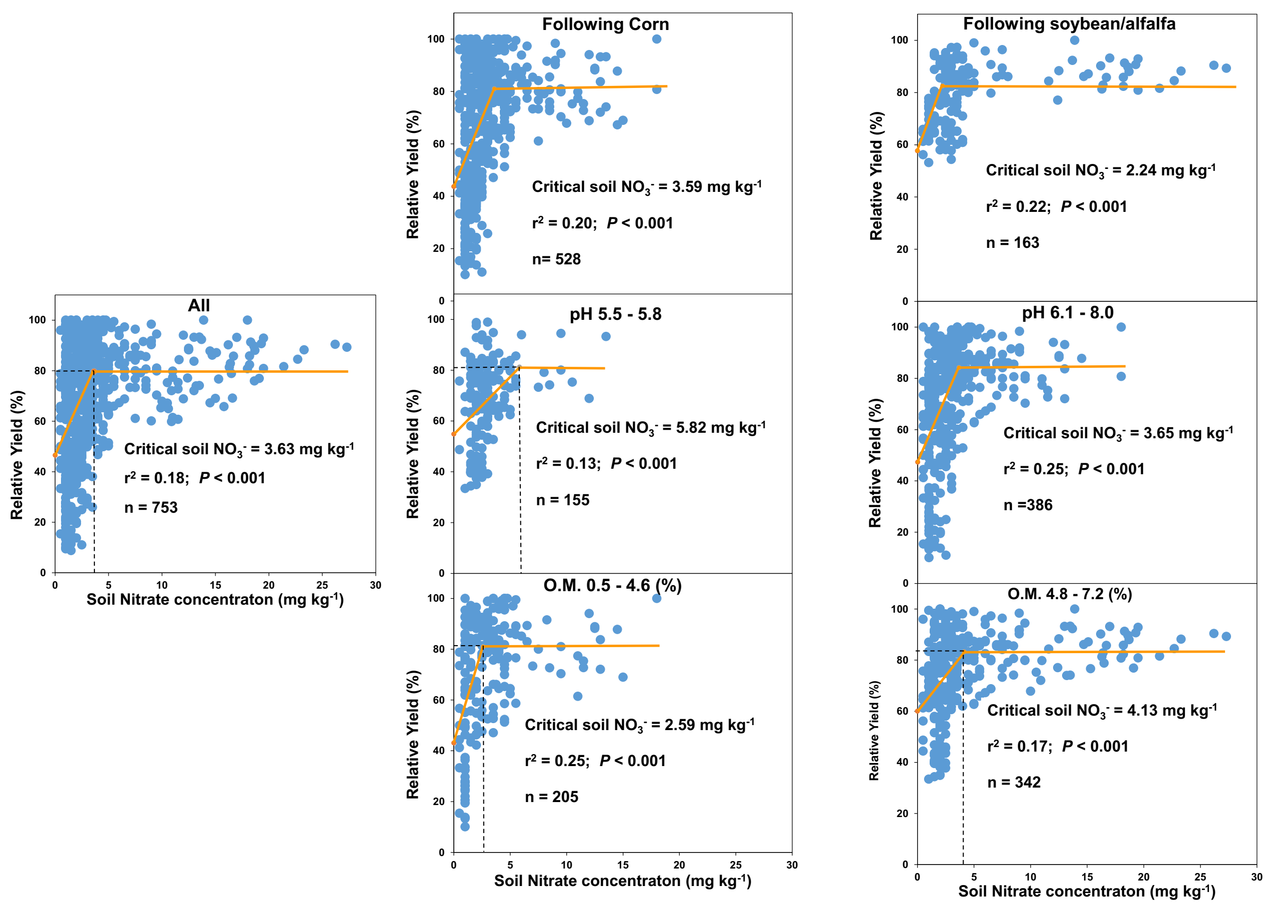
- Soil texture and soil attributes.
- Corn hybrid
- Tillage system
- Water regime
- Pre-plant soil test nitrate or 0-N check plot (depth, method, date)
- Aboveground plant N uptake at time of soil sampling
- Any publication details if previously published
- Field studies that include a pre-plant N rate response curve and in-season N rate response curve will be used for model validation

After screening and standardize units and variables, we estimated and compared critical soil nitrate levels (CSNL) computed for various specific environmental and management condition as well as averaged across all the conditions (scenarios) present in the database.

RESULTS

Preliminary results estimated as an average across all scenarios demonstrated that the PPNT has a lower CSNL for fields with soybean as the previous crop compared to corn as the previous crop and for sites with soil organic matter (SOM) < 4.6%, while a greater CSNL is required in fields with pH < 5.8 or with SOM > 4.8%. At pre-sidedress, CSNL requirement follows the same pattern as for PPNT, except that for fields with soil pH < 5.8 the CSNL was lower than for soils with higher pHs. While the results are preliminary, as currently only approximately 100 site years of data (approximately half of the site-years available) have been analyzed, the results indicate that soil conditions influence critical soil nitrate for both PPNT and PSNT.

- **Pre-plant critical nitrate**



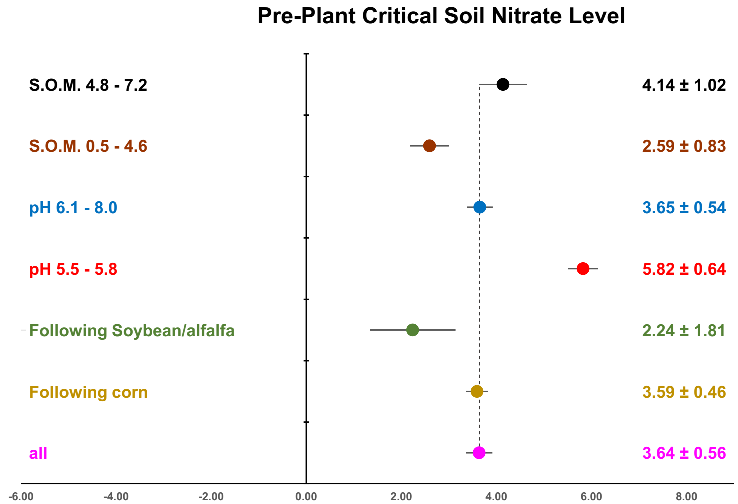
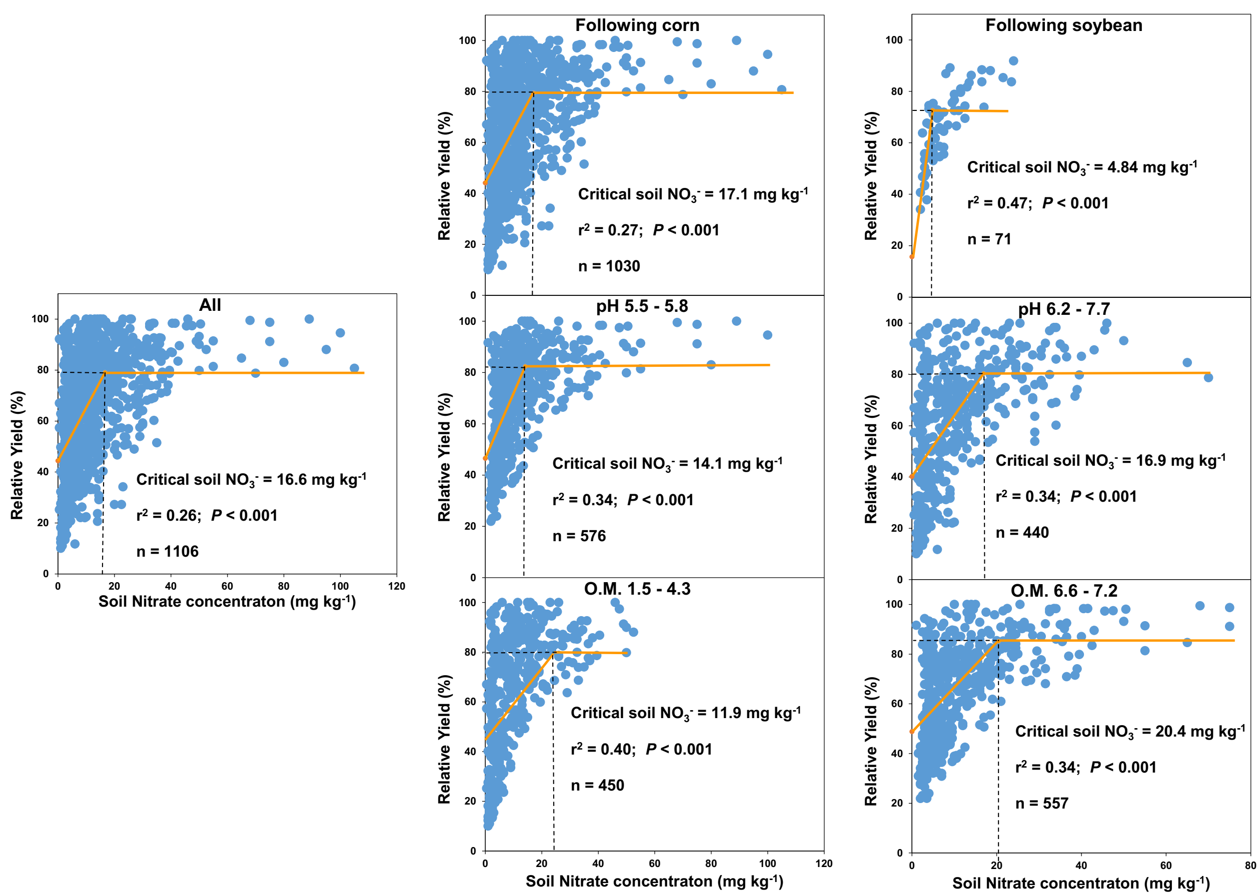
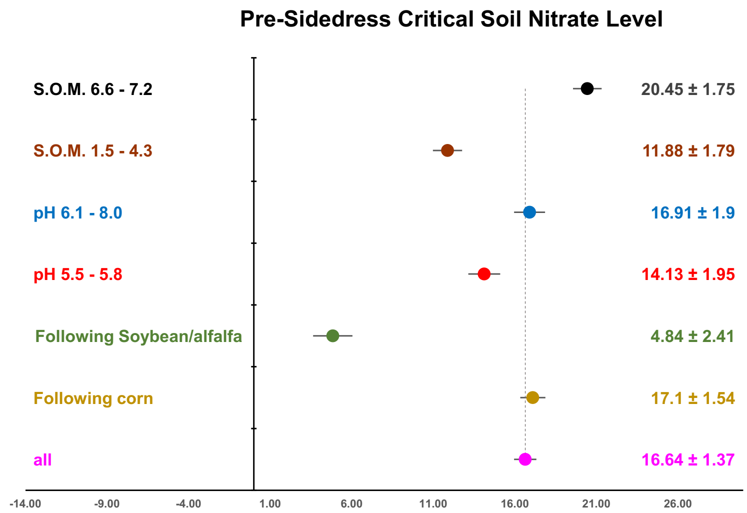


Fig. 2

- **Pre sidedress critical nitrate:**




Pre-Sidedress Critical Soil Nitrate Level
S.O.M. 6.6 - 7.2
S.O.M. 1.5 - 4.3
pH 6.1 - 8.0
pH 5.5 - 5.8
Following Soybean/alfalfa
Following corn
all
20.45 ± 1.75
11.88 ± 1.79
16.91 ± 1.9
14.13 ± 1.95
4.84 ± 2.41
17.1 ± 1.54
16.64 ± 1.37
-14.00
-9.00
-4.00
1.00
6.00
11.00
16.00
21.00
26.00

PROMOTING ADOPTION OF PRECISION NITROGEN MANAGEMENT TECHNOLOGIES THROUGH ON-FARM RESEARCH

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ABSTRACT

The Nebraska On-Farm Research Network helps farmers evaluate products and practices that impact the productivity, profitability, and sustainability of their operations. There are many technologies that have potential to increase nitrogen use efficiency (NUE) on corn and winter wheat but typically these technologies have low adoption. Concurrently, farmers have technologies such as GPS, yield monitors, and variable-rate application equipment on their farmers that enables them to easily conduct on-farm research to evaluate new technologies and products. Participating farmers evaluated commercially available nitrogen (N) management technologies across Nebraska and their impact on yield, profit, and NUE. We enabled farmer's hands-on experience with technologies that are relevant for their operation and promoted technology adoption. We also collected field data to validate and improve the technology tested. 40 trials are established each year in the three-year project. We utilized an innovative experimental design combining traditional strip trials with small N plots where all treatments are established with variable-rate fertilizer equipment on-the-go. An automated data processing tool was developed for data processing, analysis, and reporting. 98% of the experiments were successfully established in the first year of the study and 90% were analyzed using the automatic process. To measure impact, grower incremental changes in N management strategy and technology adoption were documented.

INTRODUCTION

Nitrogen (N) is critical for attaining higher crop yields; however, risks of environmental losses necessitate more precise fertilizer management. Predicting the economic optimum N rate (EONR) remains challenging due to spatial and temporal variability in crop yield, soil N supplying capacity, and N loss dynamics (Mamo et al., 2003). At the same time, there are an increasing number of technologies to improve N fertilizer efficiency by considering spatial and temporal variability (e.g., remote sensing and crop model-based tools), improving fertilizer efficiency (e.g., stabilizers, enhanced efficiency fertilizers, and inhibitors), or by relying on biological production of N (e.g., symbiotic N-fixing bacteria). These technologies provide paths for increasing NUE which is needed for more sustainable fertilizer management.

Despite the increase in available technologies, adoption of many of these technologies remains low (Lowenberg-Deboer and Erickson, 2019; Thompson et al., 2019a). On-farm research, where the farmer utilizes their equipment and land and plays a critical role in the research and discovery process, has been found to be a valuable means of technology transfer and important avenue to increasing adoption of technologies (Kyveryga, 2019; Thompson et al., 2019b; Lacoste et al., 2021). However, traditionally on-farm research has relied on field-length strips (often referred to as strip-trials) which while useful, have limited potential for testing spatial technologies and understanding site-specific, within-field technology performance (Kyveryga et al., 2018). Recently, the availability of precision ag technologies, including yield monitors and variable-rate application (VRA) equipment have made it possible to move beyond the traditional strip-trials used in on-farm research, greatly expanding the potential questions which can be addressed through on-farm research. Variable-rate application equipment is now being used to establish N rate blocks throughout farmer fields in whole-field "checkerboard" designs (Alesso et al., 2019; Bullock et al., 2019). Similarly, Scharf et al., 2005 established N rate blocks in contrasting field zones to determine the spatial variability of the EONR.

The Precision Nitrogen Project (PNP) was established to provide site-specific testing of N technologies and promote adoption by collaborating with farmers to inexpensively design and implement randomized agronomic field trials on whole commercial fields. From 2020 to 2022, the PNP project completed nearly 70 corn and wheat trials. In this work, we present a framework and procedures used by the multidisciplinary PNP team to implement on-farm precision experimentation (OFPE) to test N technologies. Specifically, we described (1) a farmer-centric, iterative, and tiered approach for N technology selection, (2) the use of a novel OFPE to benchmark and evaluate N technologies, (3) an automated OFPE data processing, management, analysis, and reporting system, and (4) the impact on cooperator management from three years of experimentation.

MATERIALS AND METHODS

Technology Selection

Cooperating farmers were engaged throughout the process by selecting the technology to test and by providing hands-on experience. Technologies were generally grouped as (1) crop model-based, (2) remote sensing-based, (3) enhanced efficiency fertilizers, and (4) biologicals (Figure 1). To guide this process, we utilized in-depth discussions with farmers, their crop advisors, extension educators, graduate students, and specialists to first understand the farmer's current N management and technology capabilities and then to guide the selection of technology. This customized, farmer-centric approach increases the potential for future adoption of the technology tested and allows farmers to incrementally increase the complexity of their N management. For example, a farmer with no in-season N application capability might be given options of testing enhanced efficiency fertilizers or soil and management zone-based tools to direct VRA. However, a farmer with in-season N application capabilities might be given options for testing remote-sensing and crop model-based tools, which are tools recommended to be used during the growing season.

To provide growers with access to a variety of N technologies, we established public-private partnerships with industry. Partnerships with industry played a critical role in ensuring that technologies were implemented correctly. Cooperating farmers were provided with financial compensation to negate the cost and risk, reducing the barriers of testing a new technology.

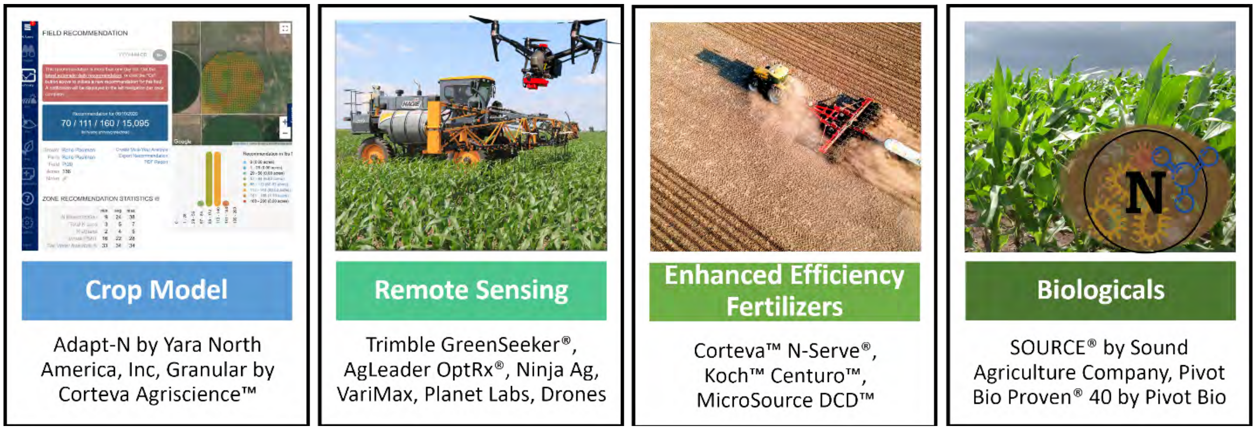

Figure 1. Nitrogen technology options for testing by cooperating farmers include crop model-based, remote sensing-based, enhanced efficiency fertilizers, and biologicals.

Novel On-Farm Precision Experimentation Design

Traditionally, on-farm research has used field-length strips to test differing products or practices. Recently, precision technologies such as yield monitors and VRA have enabled utilization of more diverse experimental designs in farmer fields, including placing smaller rate blocks throughout fields in a "checkerboard" design. In this work, we utilized a novel OFPE approach (Figure 2) which combines traditional strip-trials with small rate blocks allowing farmers to make a direct comparison of their approach to the new technology (through the strip-trials) while also benchmarking the technology performance (through small N blocks). The strip-trials were used to compare the farmers traditional management ("business-as-usual" N management) to the technology they are interested in ("next-level" N management). Nitrogen rate blocks are placed in contrasting zones of the field. For technologies that test different rates or timings (e.g., model-based and sensor-based N management) the technology was evaluated in field-length strips and N blocks were placed near the strip trials (Figure 2a). These rates for the strips and N blocks were assembled into a VRA that was implemented on-the-go using the farmer's VRA controller. Nitrogen rate blocks for the biologicals and enhanced efficiency fertilizers strip-trials were implemented in a split-plot design (Figure 2b). Technologies were changed manually (in the case of enhanced efficiency fertilizers) or applied with a "split-planter" approach (in the case of biologicals). Nitrogen rate blocks were implemented as a prescription via the farmers VRA controller.

Data collection

Before the implementation of the field trial, we performed a soil characterization by measuring organic matter (OM) and soil texture stratified by depths at contrasting yielding areas of the field. During the growing season, we measured soil moisture and temperature, soil nitrate, crop phenology, plant biomass, high-resolution imagery, and leaf area index (LAI). Farmers provided as-applied and yield monitor data for the field-scale trials.

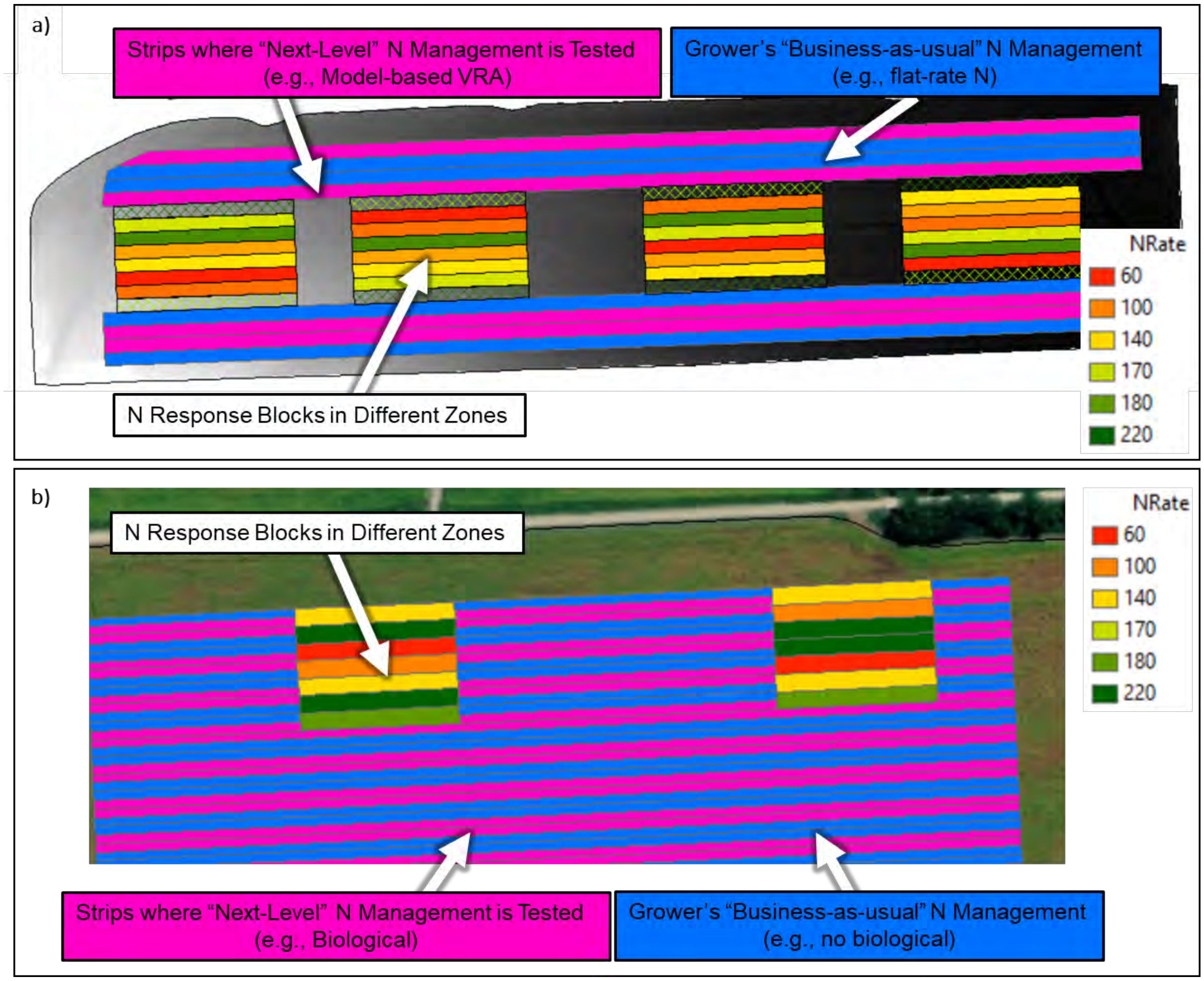

Figure 2. On-farm precision experimentation (OFPE) utilized to a) test technologies that adjust rate and/or timing (e.g., model-based and sensor-based) and benchmark the technologies using nitrogen (N) rate blocks and b) test technologies that use products (e.g., enhanced efficiency fertilizers and biologicals) and embed N rate blocks in a split-plot design to benchmark the technologies.

Automated Data Processing, Management, Analysis, and Reporting System

The farmer's business-as-usual N management was compared to the next-level technology selected. We evaluated total N used, yield, profit, and NUE. Economic optimum N rate (EONR) was estimated for each N rate block to spatially benchmark the technology tested and the farmer traditional management. The development of an automated OFPE data processing, management, analysis, and reporting system was critical in enabling robust and quick data processing. This system aggregates data layers from various sources and implements data quality control methods to check for overlapping, misalignment, or outliers within yield and as-applied data. The system does not eliminate yield observation, instead, they get flagged when issues were found.

Currently, a Shiny App is under development to interactively share in-season and end of season results to growers. This is a final critical piece of the PNP to facilitate conversations between agronomists and farmers, share results, and ensure adoption of N technologies evaluated.

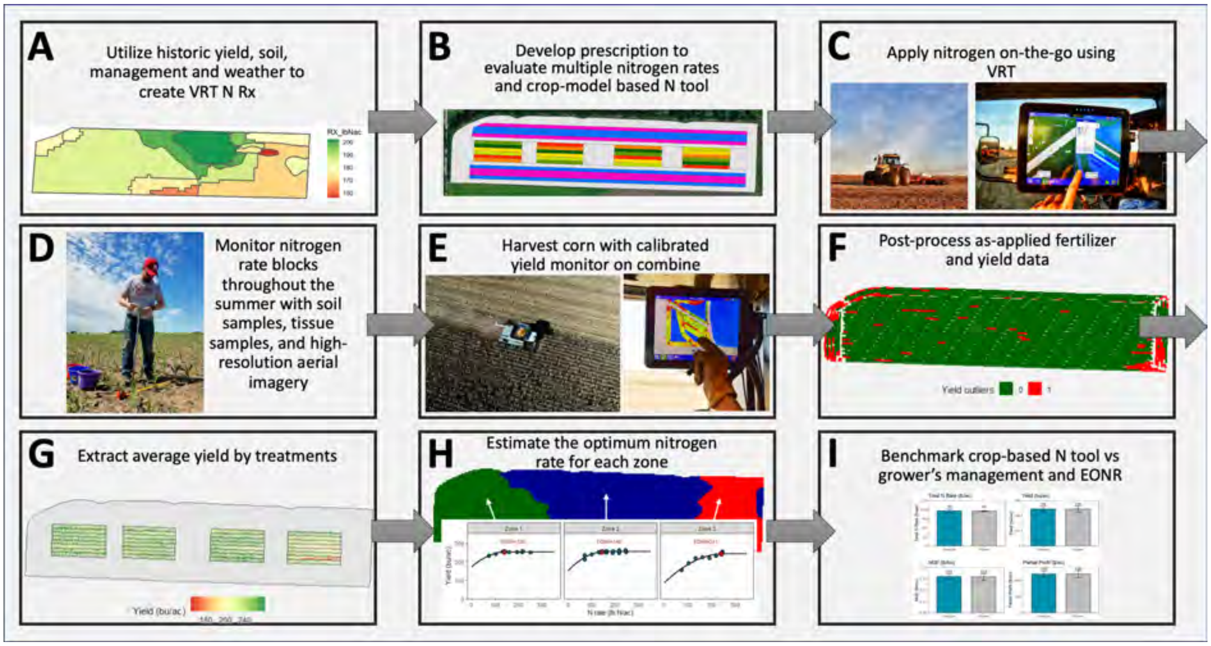

Figure 3. Precision nitrogen trial implementation workflow diagram: A) variable nitrogen rate prescriptions are created with the selected technology, B) trial layout is combined with the output of the technology and the nitrogen ramps , C) trials are applied on the go while the producers applies fertilizer, D) in-season data collection, E) end of season data collection, F) automatic data processing in R software, G) data summaries, H) analysis by zone, and I) data sharing.

RESULTS AND DISCUSSION

From 2020 to 2022, the PNP project completed nearly 70 trials in corn and wheat. Out of these trials, technologies selected were 39% crop model-based tools, 34% remote sensing-based, 21% enhanced efficiency fertilizers, and 6% biologicals. Biologicals were offered as an option for the first time in 2022 and we expect the interest in this N technology to increase in 2023. In 2021, 98% of the experiments were successfully established and 90% were analyzed using the automatic process and the reminder trials were analyzed manually due to issues in data quality. We expected to complete 120 trials by the end of year four of the PNP.

Due to this project, industry collaborations were established between academia and the growers. This facilitated technology transfer with expert input and allowed graduate students to be supported through industry collaborations. In addition, on-line workshop training sessions were organized to learn how to use some of these tools and allow growers to ask questions.

Results were shared with 200+ individuals annually through the on-farm research meetings and 12 presentations. Individual meetings were held to share results with the cooperating farmers. Farmer comments and stories revealed they were more comfortable using technology because of participating in this project. One producer noted, “I’ve had crop canopy sensors for years but didn’t feel confident using them. Now that I’ve seen the results, I will use them farm wide.” Growers also benefitted from seeing the results of the NUE analysis for their own management practices. One producer commented, “I’m shocked that our NUE is 1.1. I want to push the efficiency below 1. I was planning on purchasing some more fertilizer for the upcoming year, but now that I see these results, I think what I have is enough.”

Acknowledgements
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LOWER SOIL TEST P VALUES DO NOT AFFECT CROP YIELD VALUES WHEN UNDER CONSERVATION PRACTICES

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ABSTRACT

Sustainable P management in cropping systems is a challenge in modern agriculture. Phosphorus moving from agricultural fields to aquatic ecosystems resulting in eutrophication and other water quality problems continues to be a challenging issue for the agricultural community to solve. Despite the large amount of P in agricultural soils, most P is held within insoluble complexes, making this pool of P unavailable to plants. The implementation of conservation practices of no-till, retaining high levels of residue in the field, and diverse crop rotations have shown the potential of being able to lower the amount of soil test P required without reducing yield. At the Dakota Lakes Research Farm in Pierre, South Dakota soil test levels were drawn down to 5 ppm Olsen P in 2014. To create field areas with low, medium, or high soil test P levels within the field, P fertilizer rates of 0, 52, and 104 lbs P_2O_5 were applied in randomized strips across the field in 2014. These rates were again applied to the same treatment areas in 2017, 2019, and 2021 to maintain three distinct soil test levels. In 2022, the mean soil test P value of low, medium, and high areas at 0-6 inches were 12, 19, and 24 ppm, respectively. A five-year crop rotation was also started in this field in 2014 (soybean-wheat/cover crop-soybean-corn-corn). Each year approximately 26lbs P2O5 was applied to all treatments prior to planting in the soil three inches from the seed and at seed depth. After five years, regardless of the soil test P level there was no significant difference in yield response from P fertilization. This result indicates that soil test P levels and P application can be intentionally left at low levels, without a decrease in crop yield in long-term no-till plus high residue rotations. The relationship between arbuscular mycorrhizal fungi and soil test P levels were studied to determine if there was an increase in fungi activity in areas with lower soil test P values. Thus far, we have seen an increase in fungi numbers at the lower soil test P levels, indicating that these fungi populations may be assisting the plant in providing P during the growing season. Establishment of fungi and microbial communities in agricultural soils may be a key component in reducing the need of P fertilizers to optimize crop yield and the subsequent reduction of P fertilizers moving into aquatic ecosystems.

INTRODUCTION

Crop fertility is one of the most critical objectives of producers during the growing season. The fertility amendments that are most commonly applied are nitrogen, P, and potassium, all of which have important physiological benefits to plants. However, unlike nitrogen and potassium fertilizers that are synthesized in labs, P fertilizers are mined from the ground as phosphate rock (PR). This ultimately means this resource is nonrenewable, creating a sustainability problem. In fact, on a global scale, peak phosphate rock production is estimated to be reached as early as 2050 (Beardsley, 2011). The limited availability of this element in the future, and the rising prices of agricultural inputs in general have the potential to create significant problems in food scarcity and agricultural production. However, there are pools of phosphorus available in most agricultural soils, held as insoluble complexes. Using management systems like no-till, diverse cropping rotation, and high residue rotations, soil test P levels may be able to be left intentionally at low levels without reducing yield as has been noted at the Dakota Lakes Research farm in Pierre, SD. However, the mechanisms that allow lower soil test P levels to occur without yield reduction are unknown. Therefore, the objectives of this project are to compare the soil chemical, biological, and physical properties of a long-term P project where a low, medium, and high soil test P level has been established and evaluate crop nutrient content and crop yield responses to P fertilization.

MATERIALS AND METHODS

This study has been continuously conducted at Dakota Lakes Research Farm in Pierre, South Dakota since 2014. At the start of the experiment, soluble P concentrations were drained down to five ppm Olsen P. The study was arranged as randomized strips across the field with five replications. Since the initial depletion of soluble P, three distinct rates were applied in the field to create areas of low, medium, and high concentrations of soluble P measurements. Phosphorus fertilizer was applied at rates of 0, 52, and 104 lbs P_2O_5 ac^{-1} in 2014 as monoammonium phosphate (11-52-0), and again applied to the same treatment areas in 2017, 2019, and 2021 to maintain the low, medium, and high soil test P levels. A five-year crop rotation was initiated in 2014 as well, planted in succession as soybean-wheat/cover crop-soybean-corn-corn. The rotation was developed to maximize the amount of residue left in the field.

Soil samples were collected in the spring and fall periods of the year, once before planting and fertilization and once after harvesting. The samples were collected at depths of 0 to 3 and 3 to 6 inches. The 0 to 3-inch samples were collected using a spade in a cross-section pattern to include the banded and non-banded areas. The 3 to 6-inch samples were collected using a standard 0.75-inch soil sampler. These samples were analyzed for soil test P concentrations (Olsen P, Mehlich P, and Bray P-1) and Total P concentrations. Additionally, biological soil samples were collected using a standard soil core on June 14, 2022, and analyzed soil genetics measurements from, TRACE Genomics (Redwood City, CA) and for Phospholipid Fatty Acid (PLFA), and Autoclave centrifuge extraction (ACE) soil health assessment from Ward Laboratories (Kearney, NE) to determine if these biological indicators are affected by different soil test levels.

Tissue samples were collected at various stages of growth. For corn, samples were collected at the V3, V7, VT, and R6 growth stages. The V3 tissue was collected as whole plant samples, collecting four five-foot sections of corn in each treatment. The V7 tissue was collected by obtaining twenty uppermost collared leaves in each treatment. The VT samples were collected by obtaining twenty leaf samples in each treatment from the collared leaf below and opposite of the ear leaf. The R6 samples were collected as whole plants, collecting 10 plants in a row, and measuring the distance these 10 plants occupied in the row. These R6 samples were divided by transects, using the east and west sections of the field and then, combining the twenty plants collected in each treatment. All plant samples collected were dried and sent to Ward Labs (Kearney, NE) for analysis of elemental concentrations.

RESULTS AND DISCUSSION

Soil Testing:

Soluble P is the portion of P in the soil that is readily available for uptake by plants. The three categories of soluble P that have been studied in this project include Olsen, Bray, and Mehlich P. Preplant soil test results from 2022 show three distinct categories of available soluble P (Table 1). For example, using Olsen P the mean soil test levels in the low, medium, and high soil test level areas were 12, 19, and 24 ppm, respectively. According to the SDSU Fertilizer Recommendations, optimum soil test P values for Olsen is 16 ppm and Bray is 21(Gelderman et al., 2019). The low category of soil test P is below both these critical values, showing that our low level has been maintained since the start of the experiment in 2014. Using Bray P-1, these results show that our low, medium, and high soil testing levels are still in their correct category. However, when using Olsen P, the low testing soil fits in the medium category, the medium in the high category, and the high in the very high category. The differences in the placement of these categories may be due to the higher pH of this site (7.6) as the Bray P-1 soil test is less accurate in soils with pH above 7.2 (Antonio P, n.d.).

Table 1. Preplant soluble P levels and pH in low, medium, and high soil test P soil along with corn grain yield response to P fertilization.

Soil Test Level	Olsen P	Bray P-1	Mehlich P	pH	Yield
		ppm			bu/ac
Low	12	6	21	7.6	184
Medium	19	12	32	7.6	190
High	24	16	37	7.6	191

Water extractable C: N is commonly used to indicate microbial life in the soil that is evaluated. Carbon: N ratios have been shown to indicate mineralizable N content in soils along with microbial life from the C fraction. However, recent studies have shown that the relationship between soil microbial activity and water extractable C: N values are much stronger than that of traditional organic C:N ratios (Haney et al., 2012). In our study, the “Low” soil test P category had the highest average water extractable C:N ratio (Figure 1). This result provides evidence that in low testing P soils that there are more available C sources for the microbial community and that there is more microbial activity in lower soil test P soils.

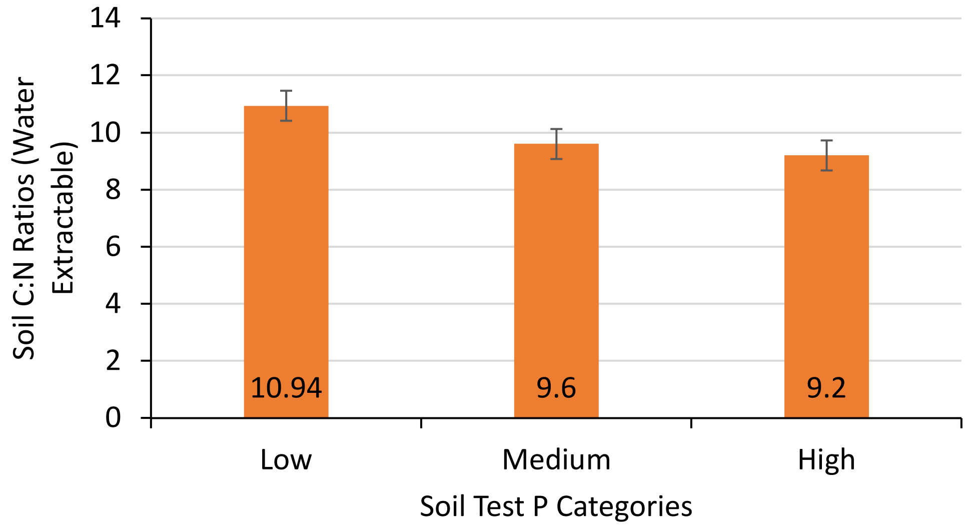

Figure 1. Average preplant water extractable C:N ratios in a low, medium, and high soil test P soil.

Tissue testing:

Leaf P content at V7 decreased marginally from the high (0.49%) to low (0.42%) in soil test P areas (Figure 2). These results indicate that there might be a slight decline in P percentage at the V7 growth stage in the low soil test category, suggesting there might be a decline in P translocation in these treatments. Nitrogen and K percentages show no significant difference between treatments.

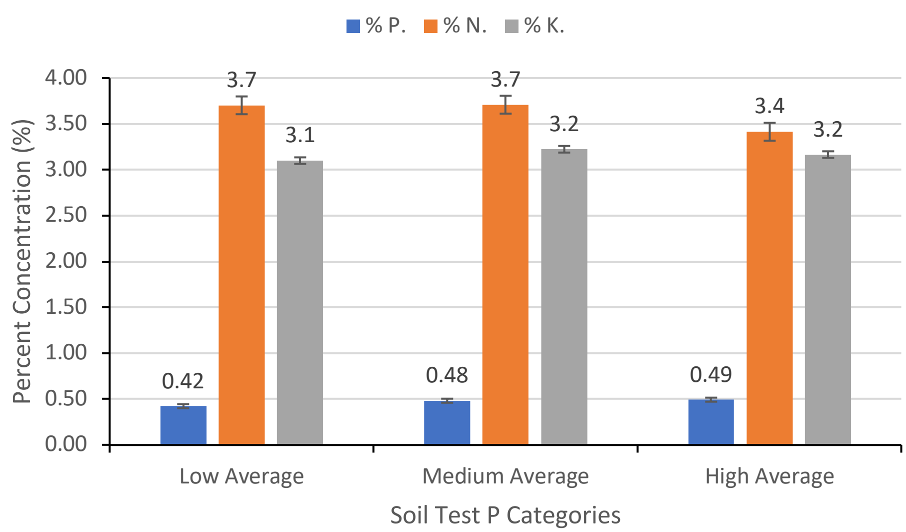

Figure 2. Average percent P, N, and K concentrations in V7 corn top-most collared leaf samples in low, medium, and high soil P testing soil treatments.

Leaf P content at VT decreased marginally from the high (0.52%) to low (0.40%) in soil test P areas (Figure 3). These results indicate that there might be a slight decline in P percentage at the VT growth stage in the low soil test category, suggesting there might be a decline in P transolcation in these treatments. Nitrogen and K perecentages show no significant difference between treatments.

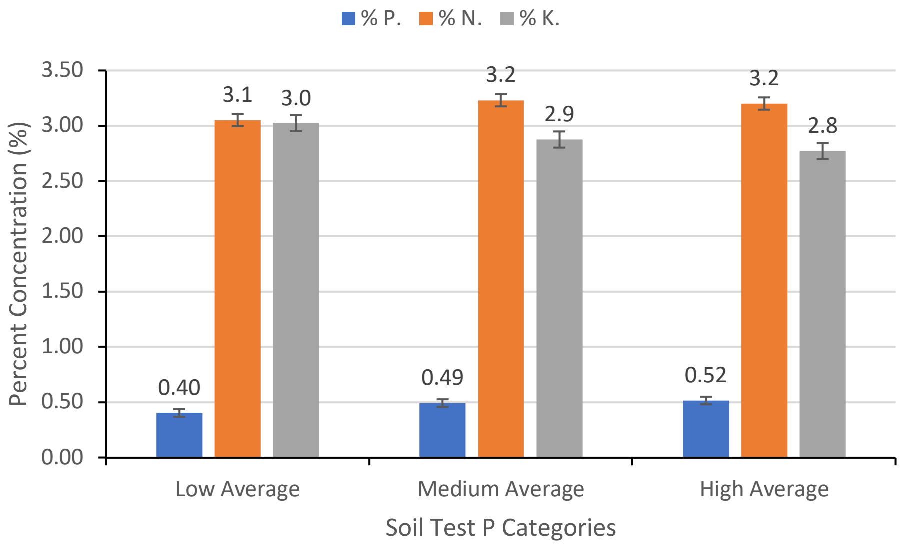

Figure 3. Average percent P, N, and K concentrations in VT corn ear leaf samples in low, medium, and high soil P testing soil treatments.

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VERSATILITY OF MYCORRHIZAL FUNGI APPLICATIONS TO INCREASE MAIZE PRODUCTIVITY

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ABSTRACT

With rising fertilizer prices and continual water contamination issues, it is vital to establish management factors that maximize productivity, while minimizing nutrient losses to the environment. One potential practice for improving nutrient use and grain yields includes utilizing mycorrhizal fungi. The objectives of this research were to determine the efficacy of various mycorrhiza applications on root colonization and the subsequent grain yield responses of maize (*Zea mays* L.). Three field trials were conducted at Champaign, IL in either 2018 or 2021. In all cases, soybean [*Glycine max* (L.) Merr.] was the previous crop and maize was grown at a stand density of 36,000 plants acre^{-1} with a sufficient amount of applied nitrogen fertilizer. A commercial mycorrhizal fungi product, *MycoApply EndoPrime SC* from Valent U.S.A. LLC (San Ramon, CA), was utilized in a variety of application methods. In 2018, mycorrhiza was applied in-furrow at planting with water as a carrier. In 2021, mycorrhiza was applied in-furrow at planting in combination with ammonium polyphosphate (APP; 10-34-0) starter fertilizer. Additionally, in 2021, mycorrhiza was impregnated with a slow-release polymer-coating [Pursell Agri-Tech (Sylacauga, AL)] on urea (46-0-0), which was applied in a pre-plant sub-surface band 6 inches directly below the crop row. In all three trials, mycorrhiza applications were compared to an untreated control. In the 2018 trial, the mycorrhiza treatment successfully generated mycorrhizal colonies on the treated maize roots compared to no fungal colonies on untreated plant roots and tended to increase yield by 2 bu acre^{-1}. Conversely, in 2021, supplying mycorrhiza in combination with slow-release urea or APP increased maize grain yields ($P \leq 0.10$) by 9 or 13 bu acre^{-1}, respectively, compared to the untreated controls. These findings demonstrate that supplying mycorrhizal fungi by multiple application methods can increase maize production, especially when paired with fertility.

INTRODUCTION

Phosphorus (P) is one of the most important mineral nutrients in maximizing maize production, with the second-greatest fertilizer demand in the world (FAO, 2019). Food production accounts for 90% of the global demand for P, totaling approximately 163 million tons of phosphate rock per year (Cordell et al., 2009). As the global population and food demand continue to increase, crop phosphorus (P) fertilizer requirements are predicted to increase by 50 to 100% by 2050 (Cordell et al., 2009). Inherent soil P levels are notably affected by increases in maize grain yield due to a large proportion of P removed with the grain (P harvest index). Of the essential mineral nutrients for maize, P has the highest harvest index of 79% (Bender et al., 2013).

Despite the importance of maintaining soil P levels, there are consequences of extensive fertilizer P applications, including increased eutrophication of water sources due to P loss from the soil. Phosphorus can be lost to the environment through soil erosion and runoff and is the leading source of river, stream, and lake contamination (Daniel et al., 1998), which ultimately leads to the intensification of the hypoxic zone in the Gulf of Mexico. Although projections are variable, rock phosphate is a finite resource and will ultimately become depleted (Vaccari, 2009; Van Kauwenbergh, 2013). Therefore, further research is vital to discover new grower practices that improve fertilizer use efficiency in efforts to minimize P loss and extend the lifespan of mineral P reserves.

Phosphorus fertilizer use efficiency is low in cereal crops with estimations of world P use efficiency of between 10-16% (Roberts & Johnston, 2015; Dhillon et al, 2017). Dobermann (2007) claimed that at best most agriculture crops recovered only 20 to 30% of applied P under favorable conditions. Phosphorus use efficiency is low because 75 to 90% of applied P fertilizer becomes unavailable to plants through precipitation with soil cations (Sharma et al., 2013). Phosphorus is abundant in agricultural soils; however, P is still a limiting nutrient for maize growth as it is present mainly in unavailable forms. In soils similar to Champaign, IL (silty clay loam with 3% organic matter and 18 CEC), there was a total of 1,200 lbs P $acre^{-1}$ in the top 6 inches of the soil profile. However, only a range of 0.01-0.1 lbs P $acre^{-1}$ was in plant-available forms (Gardner et al., 1985). The rest of the total P in the soil is either contained in the organic pool or in mineral complexes that have a wide range in solubility.

Organic P is a large constituent of the total P present in the soil and includes plant and animal residues, soil organic matter, and soil micro-organisms. Inorganic forms of P mainly exist as insoluble mineral complexes also called fixed P, and often occur following multiple fertilizer applications (Sharma et al., 2013). Soil P that is available for plant uptake is in the forms of $H_2PO_4^-$ and HPO_4^{2-} ions that are dissolved in the soil solution. Soil P cycling is a dynamic process where soluble P can move between organic and inorganic forms. Organic P is mineralized into readily available P for plant uptake and precipitated P forms can be solubilized into $H_2PO_4^-$ and HPO_4^{2-} ions in the soil solution. These processes are largely performed by native soil microorganisms and are crucial for sufficient plant-available P.

Challenges in P fertilizer management may be even greater in future years. Maize planting population in the United States has consistently increased each year since the 1960s (USDA-NASS, 2022). As planting densities increase, root biomass of each individual maize plant decreases, causing a smaller root surface area in contact with soil, and will ultimately cause issues with plant accumulation of immobile nutrients like P (Bernhard & Below, 2020).

The uncertainty of plant-available P, paired with the high P requirement for maize, indicates the need for improved management practices associated with P fertilization. Fortunately, there are a number of viable approaches to improve plant availability of P including placing fertilizer P near plant roots, increasing the surface area of roots, keeping fertilizer P from precipitating with soil cations, and promoting the cycling of P to plant-available forms either through mineralization (organic P forms) or solubilization (inorganic P forms).

One management strategy that can increase root surface area and enhance the uptake efficiency of fertilizer P is the utilization of arbuscular mycorrhizal fungi (AMF), which can form symbiotic associations with crop plants. These fungi colonize inside the root cortex, and the AMF grow hyphae outside the root. The plant provides carbohydrates as an energy source for the AMF, while the fungal hyphae act as an extension of the plant's root system, providing greater soil contact, and ultimately increasing plant accumulation of non-mobile nutrients such as P as well as water. Maize roots occupy only 1-3% of the soil volume in the top 0-8 inches, indicating a significant opportunity to improve nutrient use through greater root surface area (Barber, 1984). In addition, AMF can interact with unavailable soil P by releasing organic acids and phosphatase enzymes that solubilize inorganic forms or release organic forms of P in the soil. Organic acids can chelate cations that bind inorganic P complexes to promote the solubilization of plant-available P, while phosphatase enzymes are catalysts that enhance mineralization of organic P, by cleaving phosphate from the organic moiety. Thus, AMF inoculants can provide multiple modes of action to improve P fertilizer use efficiency through increasing root surface area and promoting levels of plant-available P in the rhizosphere.

MATERIALS AND METHODS

Field Characteristics and Cultural Practices

Three field trials were implemented at the Crop Sciences Research and Education Center at Champaign, IL in either 2018 or 2021. All fields were in a maize-soybean rotation with conventional tillage practices consisting of a deep ripping chisel plow in the fall followed by a field cultivator in the spring. All trials were planted with an ALMACO precision plot planter to achieve a density of 36,000 plants acre^{-1}. In 2018, the trial was planted on May 14, while in 2021 the two trials were both planted on May 1. All trials experienced average total rainfall and normal temperatures during the growing season.

Treatment Applications

To ensure adequate nitrogen (N) fertility, a base rate of 180 lbs N acre^{-1} as urea ammonium nitrate (UAN; 32-0-0) was pre-plant broadcast applied to all plots in 2018 and incorporated into the soil. Experimental treatments consisted of an uninoculated control or a commercial liquid mycorrhizal fungi inoculant, *MycoApply EndoPrime SC*, applied in-furrow at planting at a rate of 2 fluid ounces acre^{-1}. The inoculant was blended with water as a carrier for a total application volume of 12 gallons acre^{-1}.

In 2021, a base rate of 180 lbs N acre^{-1} as UAN was pre-plant broadcast applied at all plots to ensure adequate N availability and incorporated into the soil. Three treatments were implemented to test the compatibility of *MycoApply* with starter fertilizer. Ammonium polyphosphate (APP; 10-34-0) starter fertilizer was applied at 5 gallons acre^{-1}, supplying 20 lbs P_2O_5 acre^{-1}. Ammonium polyphosphate was applied with *MycoApply* at a product rate of 2 fluid ounces acre^{-1} or left uninoculated. These two treatments were compared to an untreated control with no in-furrow treatment. All in-furrow treatments were blended with water as a carrier for a total application volume of 12 gallons acre^{-1}. In a separate trial, *MycoApply* was impregnated with a slow-release polymer coating on urea (46-0-0), which was then applied in a pre-plant sub-surface band 6 inches directly below the crop row at a rate of 150 lbs N acre^{-1}. *MycoApply* was impregnated inside of the polymer coating on the urea prills at a rate of 2 fluid ounces acre^{-1} or left uninoculated. These two treatments were compared to an unfertilized control.

Measured Parameters

For the 2018 trial, root systems of four plants per plot were removed at the V8 growth stage from the outside rows using a shovel. Excess soil was gently removed by washing with a garden hose, leaving the rhizosheath soil that was directly in contact with the roots. The washed roots were sent to a third-party laboratory to be analyzed for abundance of mycorrhizal colonies.

Grain yield and harvest moisture were measured in all three trials by harvesting the center two rows of each plot with an ALMACO research plot combine and the subsequent grain yield values were standardized to 15.5% moisture. Subsamples of the harvested grain were evaluated for yield components of kernel number and average kernel weight. Kernel weights are presented at 0% moisture.

Experimental Design and Analysis

All trials were planted in a randomized complete block design with six replications. Experimental units were plots four rows wide and 37.5 feet in length with 30-inch row spacing. Statistical analysis was conducted using a linear mixed model approach using PROC MIXED in SAS (version 9.4; SAS Institute, Cary, NC). Treatment was considered a fixed effect, with replication as a random factor in the model. Treatment means were separated using Fisher's protected LSD test with significance declared at $P \leq 0.10$. Normality of the errors was conducted with PROC UNIVARIATE and the homogeneity of variance on the errors was assessed with PROC GLM.

RESULTS AND DISCUSSION

Effects of *MycoApply* in a Standard Management System

In the 2018 study, fungal colonies did not form on the untreated plant roots, but did in all plots receiving *MycoApply* in-furrow (Table 1). Although *MycoApply* led to mycorrhizal growth on maize roots, there was minimal effect of this inoculant on grain yield or yield components (Table 1).

Table 1. Influence of *MycoApply* application on V8 mycorrhizal fungi colony formation, grain yield, and yield components of maize grown at Champaign, IL in 2018.

Treatment	Mycorrhizal Colonies	Grain Yield†	Kernel Number	Kernel Weight††
		bu acre^{-1}	kernels m^{-2}	mg kernel^{-1}
UTC	0	238	4689	268
MycoApply	15	240	4702	273
LSD (0.10)	2	NS	NS	NS

†Grain yields reported at 15.5% moisture. †† Kernel weights reported at 0% moisture.

Synergies of *MycoApply* with P Fertility

In 2021, APP starter fertilizer tended to increase grain yield by 7 bushels acre^{-1} compared to the untreated control (Table 2). There was a synergistic effect of combining *MycoApply* with APP, resulting in a yield increase of 13 bushels acre^{-1} compared to the UTC (Table 2). Both applications of APP alone and APP + *MycoApply* promoted greater kernel production compared to the UTC, indicating either improved early-season growth leading to a greater ovule development or less kernel abortion (Table 2). In addition, *MycoApply* with APP tended to increase kernel number compared to APP alone (Table 2). Due to yield component compensation, the application of APP alone led to a lower kernel weight compared to the UTC. However, maize plants treated with APP + *MycoApply* produced a greater number of kernels with the same average kernel weight as the UTC (Table 2). This finding infers that applications of *MycoApply* had a season-long effect on P availability, resulting in late-season plant health during grain fill.

Table 2. Influence of *MycoApply* and ammonium polyphosphate starter fertilizer applications on grain yield and yield components of maize grown at Champaign, IL in 2021.

Treatment	Grain Yield†	Kernel Number	Kernel Weight††
	bu acre^{-1}	kernels m^{-2}	mg kernel^{-1}
UTC	270	5112	281
APP	277	5362	274
APP + *MycoApply*	283	5456	281
LSD (0.10)	12	194	NS

†Grain yields reported at 15.5% moisture. †† Kernel weights reported at 0% moisture.

New Potential *MycoApply* Application Method

Banded applications of slow-release urea (SR urea) significantly increased grain yield compared to the UTC; however, the addition of *MycoApply* in the polymer coating further increased yields compared to the uninoculated SR urea (Table 3). Grain yield benefits due to *MycoApply* application were a function of greater kernel production, with a similar average kernel weight (Table 3).

Table 3. Influence of *MycoApply* and slow-release urea fertilizer applications on grain yield and yield components of maize grown at Champaign, IL in 2021.

Treatment	Grain Yield†	Kernel Number	Kernel Weight††
	bu acre^{-1}	kernels m^{-2}	mg kernel^{-1}
UTC	148	3339	237
SR Urea	253	5303	255
SR Urea + *MycoApply*	262	5522	253
LSD (0.10)	9	426	NS

†Grain yields reported at 15.5% moisture. †† Kernel weights reported at 0% moisture.

CONCLUSIONS

The application of *MycoApply* alone, resulted in successful mycorrhizal colonization on maize roots, demonstrating the potential for greater root surface area and improved yield potential. However, grain yield benefits were not realized unless *MycoApply* was applied with concentrated fertilizer applications. When *MycoApply* was either combined with APP in-furrow or coated within a SR urea source in a pre-plant band, consistent grain yield increases were observed. The observed yield benefits from various application methods show the versatility of this mycorrhizal fungi inoculant. We conclude that *MycoApply* positively affects plant availability of fertilizer applied nutrients, especially when the fertilizer is concentrated in close proximity to the mycorrhizal fungi inoculant.

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