54th Annual

NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

November 20-21
2024

PROCEEDINGS

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UPDATING NITROGEN, PHOSPHATE AND POTASH RATE RECOMMENDATIONS (AGR-1) FOR KENTUCKY GRAIN GROWERS

J. Grove[1] and E. Ritchey[1]
University of Kentucky

ABSTRACT

For University of Kentucky (UK) soil test lab users, soil test phosphorus (P) and potassium (K) have been slowly declining for several decades, suggesting recommended ‘maintenance’ rates (initiated in 1992) were insufficient. Adjusting for modern grain P and K concentrations and increasing yield-driven nutrient removal, we raised corn, soybean and wheat maintenance rates by 10 to 20 lb P_2O_5 and 10 to 30 lb K_2O per acre, depending on the individual crop. Corn nitrogen (N) rate recommendations had not been deeply reexamined in 20 years. In response to a ‘data call’, 174 grain yield N response data sets/entries, from the 2013 to 2023 production seasons, were submitted by UK Plant and Soil Science faculty. Metadata for each entry (previous crop, tillage, soil drainage class, cover crop use, N loss inhibitor use, irrigation, manure use, N timing, N placement) were used to ‘bin’ the data in support of a meta-analysis. Several of the bins were insufficiently populated and unable to support meta-analysis. For 152 of the entries there were sufficient N rates (≥ 3) to determine the maximum yield (YAONR) and the corresponding agronomic optimum N rate (AONR), as well as the maximum economic yield (YEONR) and corresponding economic optimum yield (EONR). For the latter the partial factor productivity (PFP) was set to 0.1 bu/lb N. The AONR, YAONR, EONR and YEONR values were subject to the binning meta-analysis. Compared to the prior recommendations, some bin categories declined (e.g., soil drainage classes dropped from 3 to 2), and certain bin categories increased (e.g., previous crop categories rose from 3 to 4). New bin categories/scenarios were found to impact corn N response and resulted in new recommendations (e.g. without/with a cereal rye cover crop; without/with a N loss inhibitor). Current N rate recommendations, depending on the given scenario, are given as rate range. The new recommendations generally compress these rate ranges, usually by raising the low end of the rate range without greatly increasing the high end of that same range.

INTRODUCTION

Fertilizer P and K maintenance rate recommendations in AGR-1 (Ritchey and McGrath, 2020) have not been reexamined since inception - 1992. Others (G. Schwab, pers. comm.; B. Lee, pers. comm.) have reported that soil test P and K levels are declining in row-crop acres in some areas of Kentucky, even when AGR-1 (Ritchey and McGrath, 2020) fertilizer P and K rate recommendations are followed. This analysis was caused by those observations. The declines imply either that: a) that there has been an expansion in row crop acreage to areas with lower initial soil test P and K levels; or b) that P and K row crop maintenance rate recommendations are not adequate.

Additionally, there had been no substantial change to AGR-1 corn N management recommendations since the 2004-2005 version of the document.

Information about use of urease inhibitors was added at that time. Other N management recommendations last changed in the 2002-2003 edition, when text supporting use of management alternatives to surface urea application after May 1 were added. This does not mean that research results regarding corn N rate recommendations have not been considered. These later evaluations did not find enough evidence supporting the need to make a change. Corn producers and extension personnel voiced concern that current corn N management recommendations were not sufficiently modern = nuanced for more of the alternative practices available to producers.

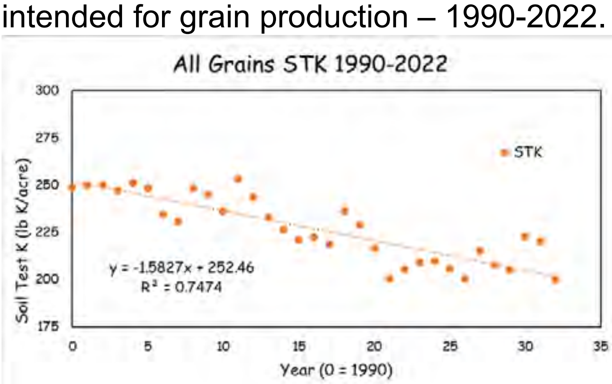
INFORMATION ANALYSES

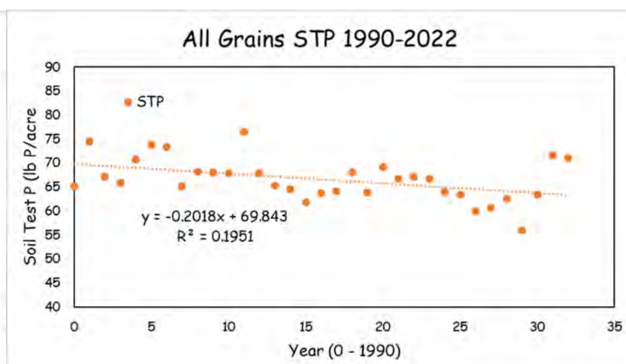
Soil Test P and K (Mehlich III) Values Over Time

There was a need to verify soil test P (STP) and/or K (STK) changes. The UK soil test lab provided STP and STK data for the 1990 to 2022 period. The data was sorted according to the commodity to be fertilized, as noted on the sample submission sheet, and then by year. Corn, soybean, and winter small grain (barley, canola, oat, rye, wheat) soil test data were separated from other soil test information. Annual sample numbers were around 9300, but considerable fluctuation was observed (not shown).

Across all grain commodities, STK has declined over the entire period (Figure 1a). The annual STK mean values were determined using all values remaining after removal of individual STK values greater than one standard deviation above the mean - to remove samples from manured fields or soils naturally high in STK. The fraction of samples removed, per year, ranged from 9.6 to 15.7%, averaging 12.4%. Annual average STK values fell with time, about 1.6 lb STK/acre/year. Over the past three decades, STK has fallen by about 47 lb STK/acre.

Figure 1. Annual average: a) soil test K (STK); and b) soil test P (STP) values from soils intended for grain production – 1990-2022.





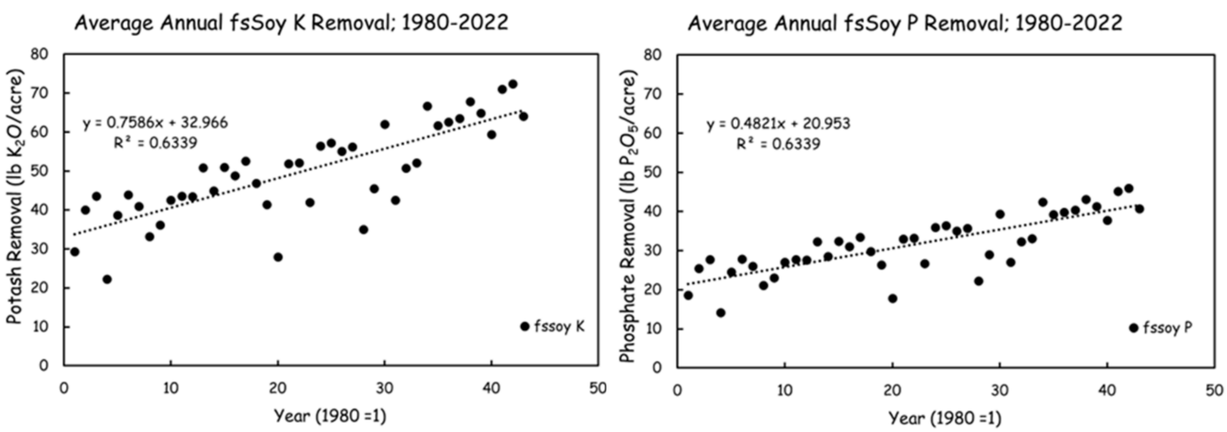
Across the grains, STP has hardly declined (Figure 1b). As was done for STK, the annual STP mean values were determined using all values remaining after removal of individual STP values greater than one standard deviation above the mean - to remove samples coming from manured fields or soils naturally high in STP. The fraction of samples removed, per year, ranged from 7.1 to 12.4%, averaging 9.8%. There was a modest decline, about 0.2 lb STP/acre/year. Over 33 years, STP has fallen by 7 lb STP/acre across this group of samples.

Grain P and K Removal

After a close look at the individual soil test data for corn and soybean, there was little support for the idea that soybean area expansion into less fertile fields caused the temporal decline in STP and STK values. This does not preclude the fact that recent expansion in both corn and soybean acreage has contributed to some of the decline in STP and STK values, but the amount of that contribution is not discernable.

It was known that soil test P and K declines could be related to increasing grain yield, and coincidently greater grain P and K removal. Kentucky's annual average corn, wheat, and soybean grain yield data for 1980 to 2022 were gathered from the National Agricultural Statistics Service (NASS, 2023). A recently published analysis of Illinois corn, soybean and wheat grain P and K composition by Villamil et al. (2019) was used with the annual yield data to compile annual average P and K removal for corn, full-season soybean, wheat and double crop soybean. Figure 2 illustrates that rising full-season soybean yield is driving P and K removal.

Figure 2. Average annual full-season soybean: a) potash; and b) phosphate removal – 1980-2022.



Maintenance P and K Rate Recommendations

Current AGR-1 grain crop P and K rate recommendations are shown in the three tables that constitute Figure 3. The maintenance portion of the recommendations is contained in the red boxes within each table. Mehlich III soil test values are in lb/acre.

Using the generated removal data, proposed grain crop P and K rate recommendations are shown in the three tables shown in Figure 4. The expanded maintenance portion of the recommendations is contained in the green boxes within each table. As in Table 3, Mehlich III soil test values are in lb/acre. Note that there is no proposed change to the Mehlich III soil test values at which no phosphate or no potash are recommended (60 lb STP/acre and 300 lb STK/acre, respectively). Rates below the proposed/expanded maintenance phosphate and potash rates also remain unchanged.

Figure 3. Current AGR-1 grain crop phosphate and potash rate recommendation tables.

Table 13. Phosphate and potash recommendations (lb/A), corn.

Category	Test Result: P	P_2O_5 Needed	Test Result: K	K_2O Needed
Very high			>420	0
High	>60	0	355 - 420	0
			336 - 354	0
			318 - 335	0
			301 - 317	0
Medium	46 - 60	30	282 - 300	30
	41 - 45	40	264 - 281	30
	37 - 40	50	242 - 263	30
	33 - 36	60	226 - 241	40
	28 - 32	70	209 - 225	50
			191 - 208	60
Low	23 - 27	80	173 - 190	70
	19 - 22	90	155 - 172	80
	14 - 18	100	136 - 154	90
	9 - 13	110	118 - 135	100
	6 - 8	120	100 - 117	110
Very low	1 - 5	200	<100	120

Table 18. Phosphate and potash recommendations (lb/A), small grains.

Category	Test Result: P	P_2O_5 Needed	Test Result: K	K_2O Needed
High	>60	0	>300	0
Medium	48 - 60	30	213 - 300	30
	45 - 47	40	187 - 212	40
	41 - 44	50		
	38 - 40	60		
	34 - 37	70		
	31 - 33	80		
Low	24 - 30	90	159 - 186	50
	17 - 23	100	132 - 158	60
	10 - 16	110	104 - 131	70
Very low	<10	120	<104	80

Table 15. Phosphate and potash recommendations (lb/A), soybean.

Category	Test Result: P	P_2O_5 Needed	Test Result: K	K_2O Needed
High	>60	0	>300	0
Medium	40 - 60	30	242 - 300	30
	34 - 39	40	226 - 241	40
	28 - 33	50	209 - 225	50
			191 - 208	60
Low	22 - 27	60	173 - 190	70
	16 - 21	70	155 - 172	80
	11 - 15	80	136 - 154	90
	9 - 10	90	118 - 135	100
	7 - 8	100	100 - 117	110
	6	110		
Very low	1 - 5	120	82 - 99	120
			64 - 81	130

Figure 4. New AGR-1 grain crop phosphate and potash rate recommendation tables.

Table 13. Phosphate and potash recommendations (lb/A), corn.

Category	Test Result: P	P_2O_5 Needed	Test Result: K	K_2O Needed
Very high			>420	0
High	>60	0	355 - 420	0
			336 - 354	0
			318 - 335	0
			301 - 317	0
Medium	46 - 60	50	282 - 300	50
	41 - 45	50	264 - 281	50
	37 - 40	50	242 - 263	50
	33 - 36	60	226 - 241	50
	28 - 32	70	209 - 225	50
			191 - 208	60
Low	23 - 27	80	173 - 190	70
	19 - 22	90	155 - 172	80
	14 - 18	100	136 - 154	90
	9 - 13	110	118 - 135	100
	6 - 8	120	100 - 117	110
Very low	1 - 5	200	<100	120

Table 18. Phosphate and potash recommendations (lb/A), small grains.

Category	Test Result: P	P_2O_5 Needed	Test Result: K	K_2O Needed
High	>60	0	>300	0
Medium	48 - 60	40	213 - 300	40
	45 - 47	40	187 - 212	40
	41 - 44	50		
	38 - 40	60		
	34 - 37	70		
	31 - 33	80		
Low	24 - 30	90	159 - 186	50
	17 - 23	100	132 - 158	60
	10 - 16	110	104 - 131	70
Very low	<10	120	<104	80

Table 15. Phosphate and potash recommendations (lb/A), soybean.

Category	Test Result: P	P_2O_5 Needed	Test Result: K	K_2O Needed
High	>60	0	>300	0
Medium	40 - 60	40	242 - 300	60
	34 - 39	40	226 - 241	60
	28 - 33	50	209 - 225	60
			191 - 208	60
Low	22 - 27	60	173 - 190	70
	16 - 21	70	155 - 172	80
	11 - 15	80	136 - 154	90
	9 - 10	90	118 - 135	100
	7 - 8	100	100 - 117	110
	6	110		
Very low	1 - 5	120	82 - 99	120
			64 - 81	130

Corn N Nutrition Research Data Sets

In response to a ‘data call’, 174 grain yield N response data sets/entries, from the 2013 to 2023 production seasons, were submitted by UK Plant and Soil Science faculty. Each entry consisted of two or more N rates and the same number of yield values and was accompanied by meta-data that permitted ‘binning’ of the data. Bins permit comparisons guided by existing AGR-1 N rate recommendations, but additional interesting comparisons were also done. Bins were related to soil drainage; tillage; previous crop; a cereal rye cover crop; manure use; irrigation use; N timing; N placement of the largest N fraction; N loss inhibitor use with largest N fraction; and location (grower farm vs. research farm).

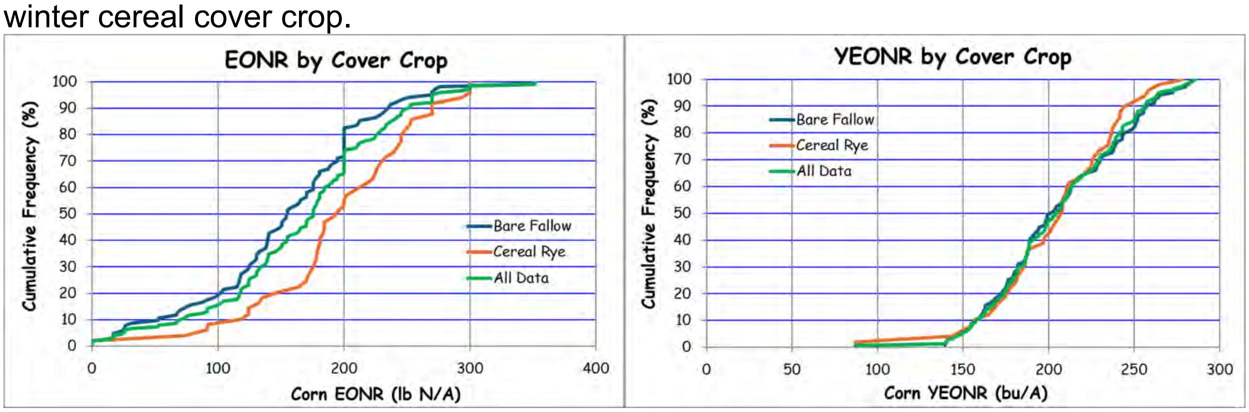
Each entry’s N rate and yield values were used to calculate a corn yield versus N production function, if possible. The quadratic-plateau function was favored, but some entries required linear-plateau, quadratic or linear functions. The production functions were used to determine the parameters that were binned: maximum yield (YAONR), the corresponding agronomic optimum N rate (AONR), the maximum economic yield (YEONR), and the corresponding economic optimum yield (EONR). For the latter the partial factor productivity (PFP) was set at 0.1 bu/lb N. There were enough N rates ($n \geq 3$) to determine production function parameters for 152 entries.

Once the parameters were binned, population analysis was done to evaluate differences in bin populations for a given parameter. First, the normality of each bin population was established using measures of skew and kurtosis. All bin populations were found to be normally distributed. Then, one-way ANOVA (PROC UNIVARIATE, PROC GLM) was used to evaluate bin population differences. Cumulative frequency distributions were developed to visualize the parameter bin populations.

Figure 5 illustrates the cumulative frequency distributions for EONR and YEONR depending upon whether a winter cereal cover crop (usually rye) was present ($n = 49$) or not ($n = 103$) prior to corn planting. In general, there was a greater spread in EONR values (0 to 352 lb N/acre) than in YEONR values (87 to 286 bu/acre). The EONR populations were significantly different with median values of 155 and 193 lb N/acre in the absence and presence of the cover crop, respectively. The YEONR populations were not significantly different, with median values of 201 and 207 bu/acre in the absence and presence of the cover crop, respectively.

The EONR and YEONR value distributions for the different previous cash crops

Figure 5. The EONR (a) and YEONR (b) value distributions as related to the use of a winter cereal cover crop.



(Figure 6) both exhibited some significant differences. Where corn was the previous crop (n = 49), median EONR was 186 lb N/acre but where either soybean (n = 90) or wheat/double crop soybean (n = 11) were grown previously the median EONR was 161 lb N/acre. The shapes of the EONR cumulative probability distributions differed, while those for YEONR were more similar. Mean YEONR values were not quite significantly different (p>F =0.1449), being 199 and 219 bu/acre where corn followed corn and wheat/double crop soybean, respectively. That said, yield differences were more pronounced at the higher end of the yield spectrum.

Figure 6. The EONR (a) and YEONR (b) value distributions as related to the previous cash crop.

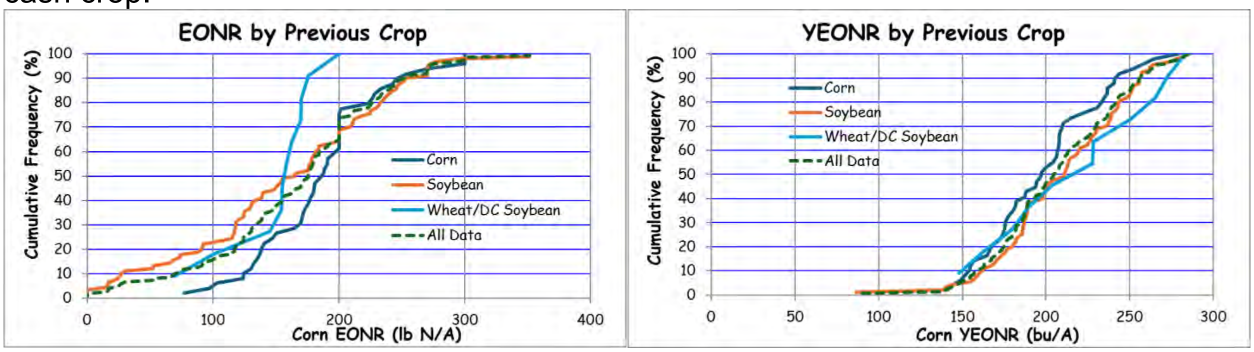
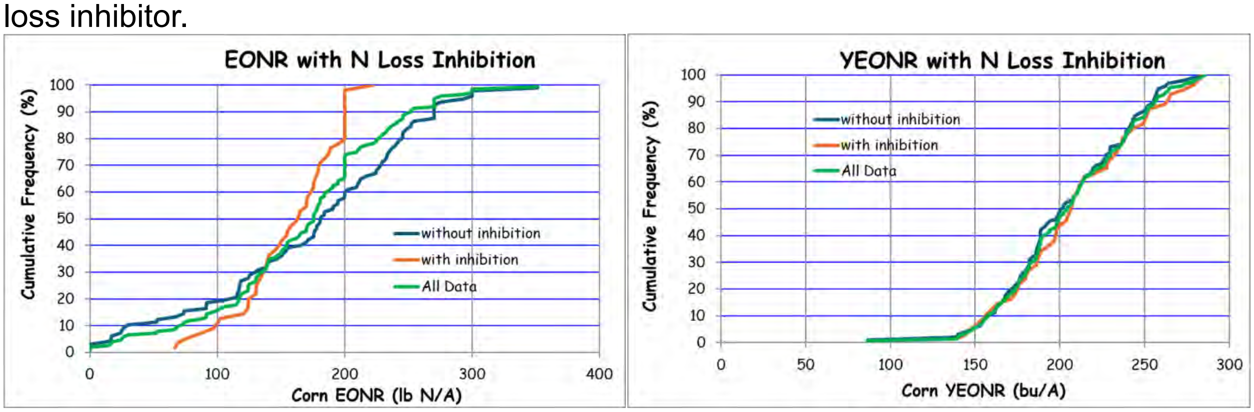


Figure 7 illustrates the impact of N loss inhibitor (usually urease inhibitor) use on EONR and YEONR value distributions. The YEONR values were similar across the distribution and averaged 201 bu/acre where no inhibitor was used (n = 97), and 207 bu/acre where an inhibitor was present (n = 55). The EONR value distributions were not similar, pulling away from each other when the situation required more N nutrition (at higher EONR values). In these cases, the use of the inhibitor reduced EONR values even more.

Figure 7. The EONR (a) and YEONR (b) value distributions as related to the use of an N loss inhibitor.



The previous corn N rate recommendations (Figure 8) were binned according to previous crop, tillage and soil drainage class. There were three previous crop categories (corn was lumped with the other grain crops), tillage differences were established according to the degree of residue cover, and soil drainage classes did not include the somewhat poorly drained class. Other N rate influencing factors are noted.

Figure 8. Current AGR-1 corn N rate recommendations.

Table 12. Recommended application of nitrogen (lb N/A), corn.[1]

Cover Crop	Tillage[3]	Soil Drainage Class[2]: Well-Drained	Soil Drainage Class[2]: Moderately Well-Drained[4]	Soil Drainage Class[2]: Poorly Drained
Corn, sorghum, soybean, small grain, fallow	Intensive	100 - 140	140 - 175	175 - 200
	Conservation	125 - 165	165 - 200	
Grass, grass-legume sod (4 years or less), winter annual legume cover	Intensive	75 - 115	115 - 150	150 - 175
	Conservation	100 - 140	140 - 175	
Grass, grass-legume sod (5 years or more)	Intensive	50 - 90	90 - 125	125 - 150
	Conservation	75 - 115	115 - 150	

1 Nitrogen rate for irrigated corn should be increased to 175 to 200 lb N/A.
2 Soil drainage class examples are given on Page 2.
3 Intensive tillage has less than 30% residue cover, and conservation tillage has more than 30% residue cover on the soil at planting.
4 Poorly drained soils that have been tile drained should be considered moderately well- drained.

New recommendations (Figure 9) separate corn/sorghum from other prior grown grain crops, simplify “Tillage” as no-till versus any tillage prior to planting, and split the four soil drainage classes into two bins. Table 12a assumes no inhibitor or rye cover crop use. Table 12b clarifies the impact of those two practices on the recommended N rate.

Figure 9. New AGR-1 corn N rate recommendations.

Table 12a. Recommended nitrogen application rate (lb N/A) for dryland corn.[1]

Previous Crop	Tillage[3]	Soil Drainage Class[2]: Well and Moderately Well Drained[4]	Soil Drainage Class[2]: Somewhat Poorly and Poorly Drained
Corn, Sorghum	No-Till	160-190	175-205
	Tilled	150-180	165-195
Soybean, Small Grain, Fallow	No-Till	140-170	155-185
	Tilled	130-160	145-175
Grass, Grass-Legume (≤ 4 years), Winter Annual Legume Cover Crop	No-Till	110-140	125-155
	Tilled	85-115	100-130
Grass, Grass-Legume (≥ 5 years)	No-Till	85-115	100-130
	Tilled	60-90	75-105

1 Assumes no cereal rye cover crop ahead of corn planting. Assumes no N loss inhibitor used.
2 Soil drainage class examples are given on Page 2.
3 No Till = no primary or secondary tillage, fall or spring, prior to planting the crop. Tilled = any primary or secondary tillage, fall or spring, prior to planting the crop.
4 Somewhat poorly or poorly drained soils that have been tile drained should be considered moderately well drained soils.

Table 12b. ***Cereal rye cover crop and/or urease inhibitor use:***[1] Recommended total nitrogen application rate (lb N/acre) for no-till dryland corn grown on well and moderately well drained soils and where two-thirds or more of the total N rate top/side-dressed with surface applied urea-containing fertilizer in the absence/presence of a cereal rye cover crop without/with use of a urease inhibitor.

Previous Crop	Cereal Rye Cover Crop[3]	Recommended Total N Rate (lb N/acre): No Inhibitor	Recommended Total N Rate (lb N/acre): With Inhibitor[2]
Corn, Sorghum	No	160-190	150-180
	Yes	185-215	165-195
Soybean, Small Grain, Fallow	No	140-170	135-165
	Yes	165-195	150-180

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Villamil, M.B., E. D. Nafziger, and G.D. Behnke. 2019. New grain P and K concentration values for Illinois field crops. Crop Forage Turfgrass Manage. 5:180090. doi:10.2134/cftm2018.11.0090

THE IOWA NITROGEN INITATIVE

S. Archontoulis[1], M. Miller[1], M. Baum[1], R. Osman[1], and M. Castellano[1]
Iowa State University

ABSTRACT

The Iowa Nitrogen Initiative (INI) aims to enhance nitrogen fertilizer recommendations for corn and provide Iowans with the best nitrogen science for the benefit of productivity, profitability, and environmental performance. We are working alongside agricultural service providers, farmers, and their advisors to design, execute, and interpret hundreds of coordinated on-farm, scientifically robust, replicated nitrogen rate trials every year. Since 2022, INI started, more than 700 N-trials have been conducted across the state. Data collection protocols include grain yield, plant and soil nitrogen, and drone imagery. Data analyses include statistical and process-based (APSIM) modeling. On-farm trial results and simulation outputs will be displayed on a website that is currently under development. Results from this project will help understand the interactions among genetics, weather, soil type, and management on N-fertilization rate for corn and update information about decision making for optimum nitrogen management across Iowa.

INTRODUCTION

Optimum nitrogen (N) fertilizer rates for corn production are variable and changing over the years (Baum et al., 2024). Monitoring the spatial and temporal variability as well as the variability introduced in the optimum N rate by management practices (King et al., 2024) will provide stakeholders with valuable data to make informed decisions about how genetics and agronomic management – including, but not limited to N-fertilizer management – can be manipulated to maximize productivity, profitability and environmental performance. The Iowa Nitrogen Initiative (INI) launched in 2022 for this reason. In this proceeding, we describe the methods used by the INI (on-farm trials, data analytics) and provide initial results.

MATERIALS AND METHODS

On-farm nitrogen trials

Iowa Nitrogen Initiative (INI) trials are conducted in cooperation with private farmers and custom applicators on Iowa farm fields. Farmers work with precision agronomists contracted by Iowa State University (ISU) to create a custom nitrogen (N) application prescription that works in their existing fertilizer program. Each trial (5 to 10 acre area of the field) has five replicates of each of five treatments (N rates), resulting in 25 plots (each 0.25 to 0.33 acres). Replicates are randomized throughout the trial area. The size of the trial is determined by factors such as width of applicator, planting, and harvest equipment, the topography of the field, and direction traveled. One field may contain more than one trial; location is selected using historic yield maps to identify stable, high-yielding areas of the field and variable, low-yielding areas of the field for comparison.

Trials are conducted using a variety of N-sources, primarily NH3, urea, urea + AMS, UAN, and UAN + ATS. The N type and time of application is decided by the farmer. The N-rate treatments vary from trial-to-trial and are selected with respect to the farmer's operation and are at least 30 lbs N /acre apart. The source and method of N application may influence trial N-rates due to equipment or logistical limitations.

Following N application, the farmer or their custom applicator sends ISU the as-applied N data to determine successful trial application. Following harvest, ISU receives spatial yield files, and from these data, constructs a corn-nitrogen response curve. Additional management data such as planting date, hybrid, cover crops, tillage, drainage, and manure history are also collected. In all INI trials, drone flights are collected in August to visually inspect N-trial quality. In trials with a zero N-rate treatment, pre-planting, V6-stage and post harvesting soil samples are collected to determine soil inorganic N levels.

As of November 2024, the INI has performed 787 N-trials. A pilot study in 2022 included 67 trials. In 2023, approximately 270 N-trials were conducted across the state. In 2024, over 450 N-trials were placed. Over three years, 126 farmers across the state have conducted at least one N-trial.

Data analysis

The yield response to N-rate per trial is statistically analysed to determine the optimum N rate, the yield at the optimum N-rate, the yield at the zero N and the lbs N per bushel corn at the optimum N rate. Our approach to determine these parameters differs from the approach used in the MRTN tool (Nafziger et al., 2022). Instead of analyzing the N-trials one-by-one, we analyze the data all-together, creating a general use model similar to that of King et al. (2024) where we use the general model to determine parameters per N-trial. This approach offers several benefits. It allows us to fit regression curves in N-trial datasets with narrow N-rates, avoids the use of linear models that bias parameter estimates, eliminates bias introduced by fitting different types of regression models (e.g., linear plateau vs quantratic), and includes the factor year as a covariate so we can keep track temporal patterns in optimum N-rates (Baum et al., 2024a). The R software is used to perfom the above statistical analysis.

In addition, the INI team uses the Agricutlural Production Systems sIMulator (APSIM), a cropping systems biophysical model. This model can simulate a range of management options (tile drainage, cover crops, plant date, etc.) and provide productivity and environmental outcomes (crop yield, water stress, N2O emissions, N leaching, etc) based on nearly infinite combinations of genetics, environment, and managment. Inputs to the model include soil, weather, agronomic management and cultivar. The model has been improved over the years for Iowa cropping systems (Archontoulis et al., 2020) and is routinely used in research and extension (Baum et al., 2023; Archontoulis et al., 2021). We use the APSIM model to get insight into factors determined high/low yield and optimum N-rates in the on-farm N-trails, and to perform simulation experiments to increase the inference of the INI project. More specifically, we ran simulations per county, per weather year (1984–2024), and selected management options (N-rate, planting date, residual soil N) to create a database to support benchmarking scenario analysis and educate stakeholders on N management.

Web-tool and information dissemination

Anonymized experimental data and model-based scenario data will be available through a public-facing web-based application currently in development. The information dissemination is built on major land resource area (MLRA), the USDA classification system for large areas of land with similar characteristics. This app is expected to launch Spring 2025.

RESULTS AND DISCUSSION

Analysis of the 2023 INI trials (n=270) indicated that the yield at the economic optimum N rate averaged 229 bu/acre with over 90% of the trials having an optimum yield greater than 200 bu/ac. The economic optimum N rate ranged from 100 to 337 lbs N/ac, with a mean of 190 lbs N/ac. The lbs of N per bushel of corn at the economic optimum N rate averaged 0.83 and ranged from 0.37 to 1.3 (Fig. 1). There values are comparable to Baum et al. (2024b) who reported lbs N per bushel by crop rotation and county in Iowa.

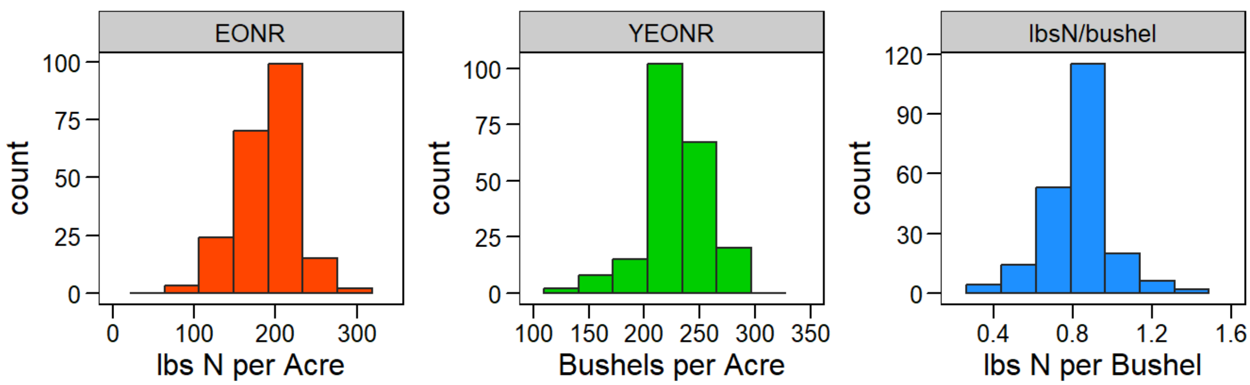

Fig. 1 Distribution of the economic optimum N rate (left), yield at the economic optimum N rate (middle) and lbs N per bushel (right) across all 2023 Iowa Nitrogen Initiative trials. On the y-axis, count refers to number of trials in each range data on the x-axis.

In 2023, we observed an east to west gradient in the economic optimum N rate (Fig. 2). This trend follows the historical precipitation patterns across the state. Within Northwest Iowa, and the Des Moines Lobe (top two MLRA's in terms of trial number) the mean economic optimum N rate was 182±50 and 203±28 lbs N per acre.

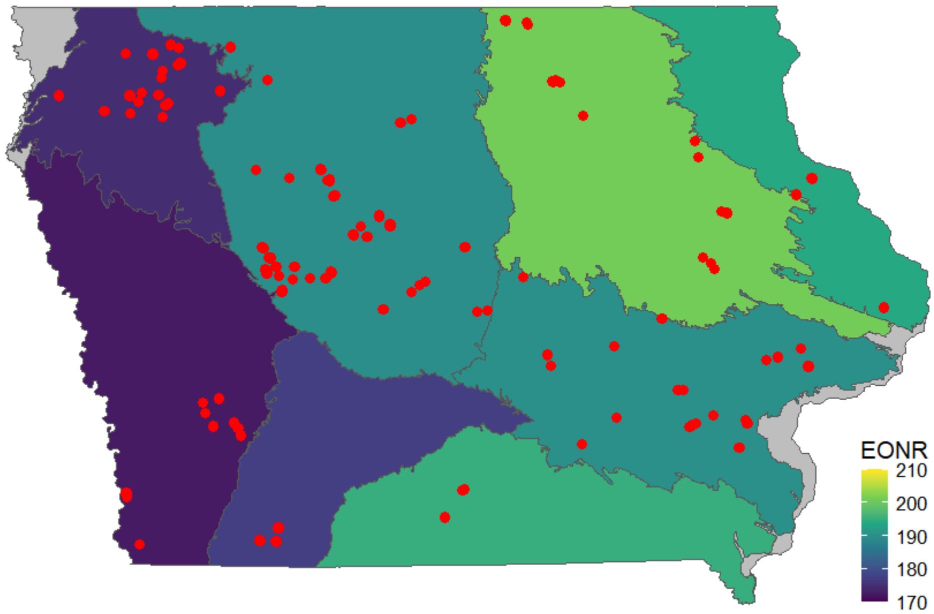

Fig. 2 Comparison of the mean economic optimum N rate per major land resource area (MLRA). Red points represent 2023 on-farm trials.

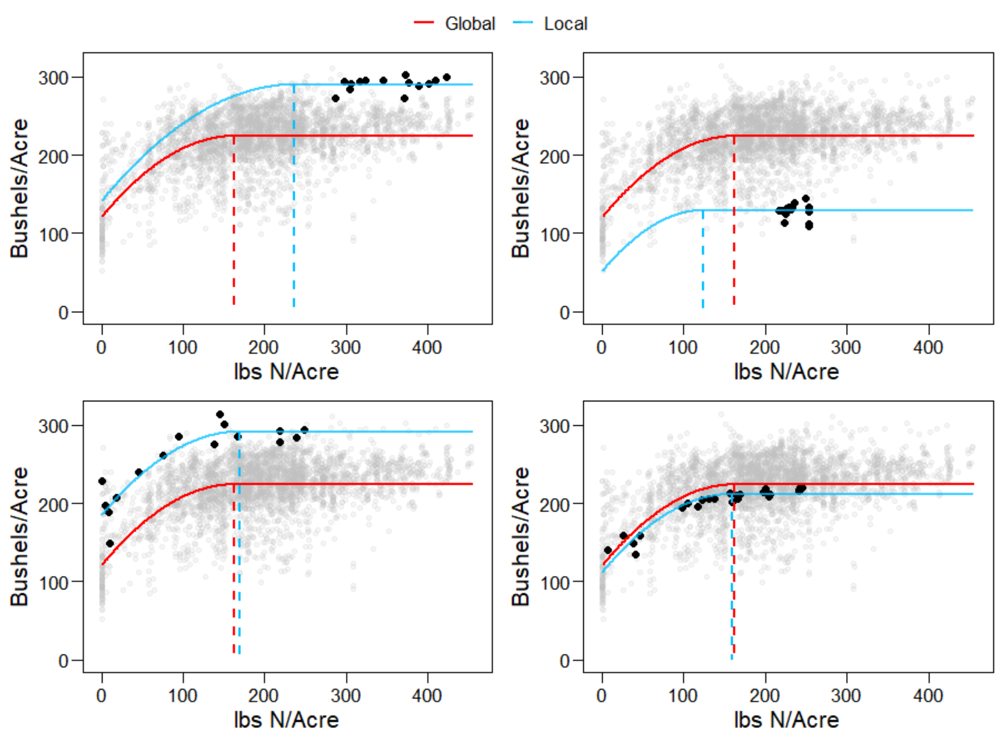

Fig 3 Yield response to N-fertilizer rate. Black points represent on-farm data for four different fields. Background grey points represent all the INI experimental datasets. Red line indicates the whole-dataset average statistical model (hereather global). The blue line indicates the on-farm specific fit of the global model (hereafter local). Vertical dotted lines indicate the economic optimum N rate.

A major innovation of the INI project is the way we analyze the data from the N-trials. Optimum N rate estimates per trial are derived using a mixed effect quadratic plateau model treating major land resource area, and crop rotation as fixed effects while each individual trial is treated as a random effect in the model. This approach allows for the global yield response curve to inform estimates from individual fields (Fig. 3). This is particularly useful in N-trials where the optimum N rate is outside of the applied N rate.

The APSIM model was capable of simulating the observed yield respose to N-rate (Fig. 4) and allowed us to get insight into the reasons for the observed responses. In addition to on-farm trials, we are testing the APSIM model capability in respresenting yield response to N rates by plant poppulation, corn relative maturity and other factors obtained in specialized INI experiments.

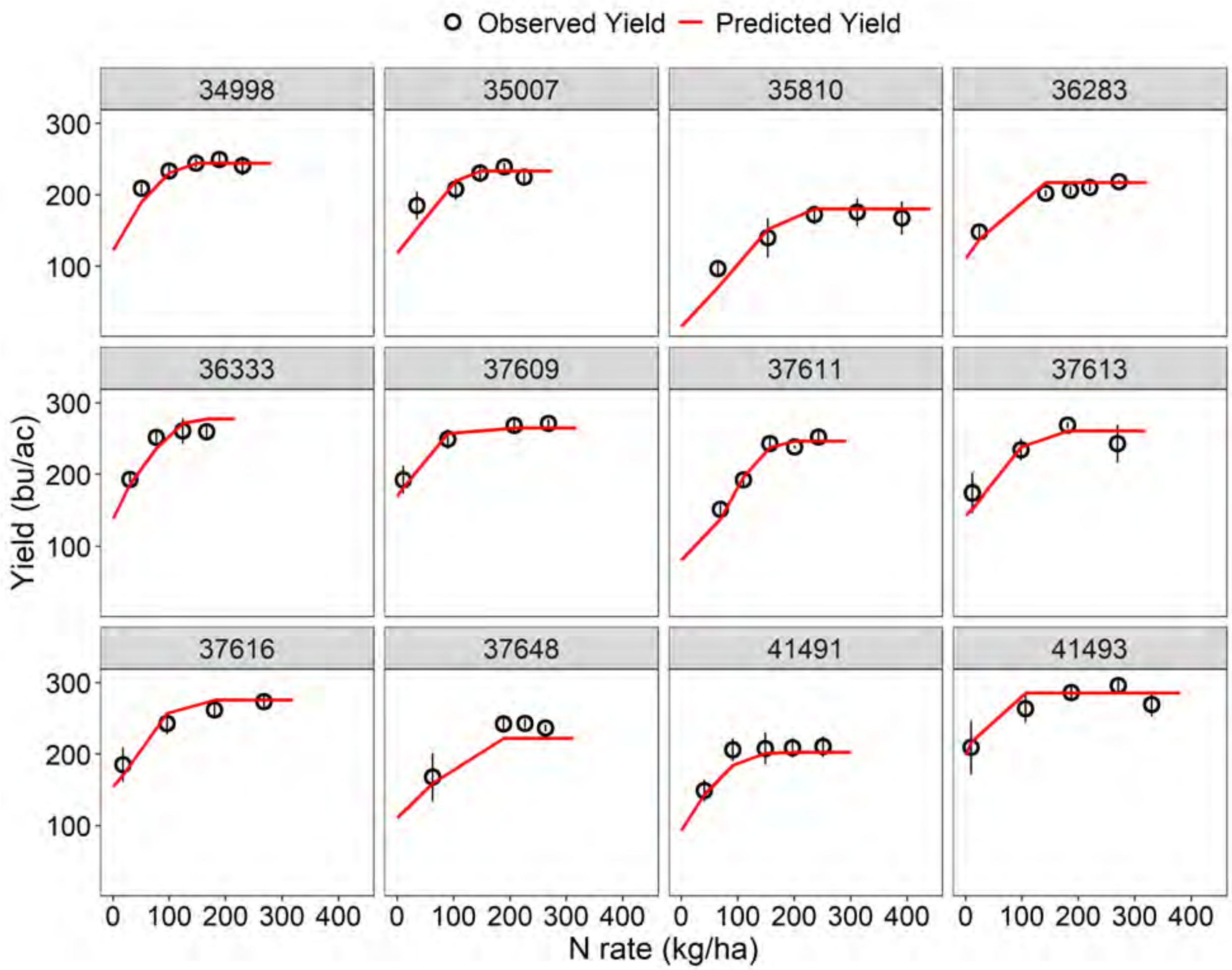

Fig. 4 Comparison of APSIM simulated (red line) and observed grain yield (open symbols) across various N fertilizer rates in a subset of the 2023 INI trials. Numerical acronyms refers to trial ID.

In summary, the INI has accumulated numerous N-trial datasets from farmers fields over the last 3 years (> 750 trials) and will continue to collect such data in the following years. In addition, the INI has deployed new methods in data analysis and uses a biophysical model to expand the inference of the project by capturing more regions, weather variability, and management practices towards developing a bechamarking tool to improve state level N-rate recommendations and educate stakeholders on N-fertilizer management. This new approach will provide genotype by environment by management information that will allows farmers to improve further nitrogen use efficiency. Result dissemination, through a publicly-available web-tool, will begin Spring 2025. This work is possible through partnerships with the Iowa Department of Agriculture and Land Stewardship and Iowa farmers.

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IS FIELD CROP CONTAMINATION WITH HEAVY MEATALS AN EMERGING CONCERN?

M. Kenneth Lane Suplito[1], Z. Hayden[1], and K. Steinke[1]
Michigan State University

ABSTRACT

Heavy metal contamination of food, particularly food consumed by infants and young children, with arsenic (As), cadmium (Cd), and lead (Pb), is a major food safety concern and is beginning to draw heightened regulatory scrutiny in the United States. Improved strategies, including fertilizer management, are needed to better understand and minimize the risks of heavy metal uptake. The objective was to: 1) evaluate the effectiveness of soil amendments in minimizing winter wheat (*Triticum aestivum* L.) uptake of heavy metals, and 2) visualize the spatial distribution of As, Cd, and Pb in winter wheat grain using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-TOF-MS). A randomized complete block design with four replications was established in Lansing, MI. Treatments investigated included: 1) control, 2) pre-plant agricultural lime (2 T A^{-1}), 3) pre-plant dairy compost (5 T A^{-1}), 4) pre-plant biochar (2 T A^{-1}), 5) pre-plant gypsum (1 T A^{-1}), 6) pre-plant granular $ZnSO_4$ (10 lbs. Zn A^{-1}) and foliar $ZnSO_4$ (1 pint A^{-2}) at Feekes (FK) 9, 7) low N (50 lbs. N A^{-1}) at FK 4, 8) moderate N (100 lbs. N A^{-1}) at FK 4, 9) high N (150 lbs. N A^{-1}) at FK 4, and 10) biodegradable chelating agent ethylenediaminedisuccinic acid (EDDS) sprays with a 2 mmol L^{-1} concentration applied at FK 5, FK 5 + 1 week, and FK 5 + 2 weeks. Autumn starter fertilizer was top-dressed to provide 15 lbs. N and 12.5 lbs. S A^{-1}, respectively, at planting. All treatments received a base green-up N application rate of 100 lbs. N A^{-1} of urea (46-0-0) except check and N fertilizer treatments. In both Feekes 4 and harvest soil samples, the order of heavy metal concentrations in soil was Pb > As > Cd. Across sample timings, the order of winter wheat stages with plant tissue Cd levels was Feekes 4 > Feekes 9 > grains at harvest; Feekes 9 > grains at harvest >> Feekes 4 for plant tissue As levels; and Feekes 4 = Feekes 9 > grains at harvest for plant tissue Pb levels.

MATERIALS AND METHODS

Field experiments were established in Lansing, MI (42°41'14.78"N, 84°29'10.15" W). Plots measured 12 rows wide (8.5 ft. width by 25 ft. length by 7.5 inch. row spacing) and planted using a Great Plains 3P600 drill (Great Plains Manufacturing, Salina, KS). Soft red winter wheat 'Wharf' was planted at 1.8 million A^{-1}. Pre-plant soil characteristics (0–8 in.) included 7.1 pH (1:1 soil/water) (Peters et al., 2015), 33 mg kg^{-1} P (Bray-P1) (Frank et al., 2015), 80 mg kg^{-1} K (ammonium acetate method) (Warncke& Brown, 2015), 23 g kg^{-1} soil organic matter (loss-on-ignition) (Combs & Nathan, 2015), and 3.4 mg kg^{-1} Zn (0.1 M HCl) (Whitney, 2015). Soil nitrate concentration (0-30 cm) was collected prior to planting with 3 mg NO_3-N kg^{-1} soil (nitrate electrode method) (Gelderman & Beegle, 2015).

Monthly growing season weather data was obtained from MSU Enviro-weather (https://enviroweather.msu.edu/, MSU, East Lansing, MI). A 30-year mean was compiled using National Oceanic and Atmospheric Administration data (NOAA, 2022). On 01 July 2024, the outer 5 ft. of plots were mowed prior to harvest. Grain yield was collected from the center 5 ft. by 20 ft. in each plot using a plot combine (Kincaid Equipment Manufacturing, Haven, KS). Grain weight, moisture, and test weight were measured to calculate grain yield expressed as bu. A^{-1} at 13.5% moisture.

Sample Preparation

Four random soil cores (0-8 in.) were sampled from each plot before planting, Feekes 4, and post-harvest, then air-dried for 72 hours, ground, and sieved through a 2 mm sieve. Tillers at Feekes 4 and Feekes 9 flag leaf were washed with tap water to remove soil particles followed by two washings with deionized water. At Feekes 4, tillers were separated into shoots and roots using a Teflon knife after air drying. The shoots were retained while the roots were discarded. Wheat shoots and flag leaves were dried at 158 °F for 72 hours before being ground to 1 mm (UDY Cyclone sample mill). Grain samples were manually cleaned by removing excess husk. Winter wheat grain (50g) was ground into a coarse powder using an electric coffee grinder (Hamilton Beach®, Richmond, VA) for 1 minute.

Microwave digestion and dilution

Due to differences in microwave digestion protocols, samples were digested in separate batches: (1) soil and (2) plant tissue (i.e., biomass at Feekes 4, flag leaf at Feekes 9, grains at harvest). Soil samples were digested using a microwave-assisted digestion method following EPA Method 3051 (U.S. EPA, 2007). Plant tissue samples and fertilizers were digested using EPA Method 3052 (U.S. EPA, 2007). Grains were digested at 200 °C (ramp time = 15 min., hold time = 15 min., 800 psi, power = 900-1,050 W).

Elemental analyses using ICP-QQQ-MS

The total Cd, As, and Pb concentrations were determined using Triple Quadrupole Inductively Coupled Plasma Mass Spectroscopy (ICP-QQQ-MS, 8900 Triple Quadrupole ICP-MS, Agilent Technologies, Santa Clara, CA). The isotopes used for each element followed the FDA Elemental Analysis Manual Section 4.7 ICP-MS Method. A certified reference material (NIST 1517a tomato leaves) from the National Institute of Standards and Technology (Gaithersburg, MD) and at least one blank run was used for quality control of plant tissue and grain analysis.

Translocation indicator

The plant uptake factor (PUF) indicates the plant's capacity to absorb a specific element. The PUF was calculated as the plant tissue elemental concentration divided by the soil elemental concentration, where w(plant) is the plant tissue elemental concentration (mg kg^{-1}) and w(soil) is the soil elemental concentration (mg kg^{-1}).

RESULTS

3.1 Weather

Compared to 30-year air temperature and precipitation averages, growing conditions in 2023-2024 had normal air temperatures (avg. 38.3-52.3 °F), wet early (Oct., + 49%) and dry late autumn (Nov., -52%). From December 2023 to March 2024, temperatures were warm (+ 5.4 °F) and moisture plentiful (+ 9%). April to May 2024 had warm temperatures (+2.7 °F) and dry spring conditons (-33%). June 2024 had normal air temperature (avg. 69.4 °F) but deficit precipitation (-10%) **(data not shown).**

3.2 Grain yield

Grain yield ranged from 18.2-109.2 bu. A^{-1} with a mean of 83.6 bu. A^{-1}. Low N decreased grain yield ($P < 0.0001$) by 19.1-35.8 bu. A^{-1} compared to the remaining soil amendments **(data not shown).**

3.3 Effects of soil amendments on bulk soil samples

The experimental site was established on a Conover loam soil (Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*) with a surface layer of 41.6% sand, 39.2% silt and 19.2% clay (National Cooperative Soil Survey, 2018). Prior to the field experiment, the average soil cadmium (Cd), arsenic (As), and lead (Pb) concentrations were 0.46, 5.50, and 13.46 mg kg^{-1} soil.

Bulk soil sampling of soil amendment treatments at Feekes 4 had comparable soil Cd, As, and Pb levels with check **(Table 3.1).** Soil Cd levels ranged from 0.13-0.36 mg kg^{-1} soil with a mean of 0.25 mg kg^{-1} soil. Soil As levels ranged from 2.58-3.89 mg kg^{-1} soil with a mean of 3.27 mg kg^{-1} soil greater than the statewide average of 2.50 mg kg^{-1} soil (State of Michigan, 2023). Soil Pb levels ranged from 8.52-25.37 mg kg^{-1} soil with a mean of 12.06 mg kg^{-1} soil.

Bulk soil sampling of soil amendment treatments at harvest had comparable soil As and Pb levels with check **(Table 3.1).** Among soil amendments, $ZnSO_4$ increased soil Cd level by 0.047 mg kg^{-1} soil. Soil Cd levels ranged from 0.15-0.43 mg kg^{-1} soil with a mean of 0.24 mg kg^{-1} soil. Soil As levels ranged from 1.56-3.99 mg kg^{-1} soil with a mean of 2.47 mg kg^{-1} soil. Soil Pb levels ranged from 7.76-12.11 mg kg^{-1} soil with a mean of 9.91 mg kg^{-1} soil. Soils were considered non-contaminated based on the Pb threshold of 39 mg kg^{-1} soil for gardening use of soils in Michigan (State of Michigan, 2023). Across both sampling periods, the order of heavy metal concentrations in soil was Pb > As > Cd. Further, Feekes 4 had greater As and Pb soil levels than at harvest while soil Cd levels remained comparable.

3.4 Effects of soil amendments on biomass and grain heavy metal concentrations

Cadmium, As, and Pb concentrations in winter wheat biomass at Feekes 4 and flag leaf at Feekes 9 were expressed in mg kg^{-1} of dry weight (dw) while grains at harvest were expressed in mg kg^{-1} of fresh weight (fw). At both Feekes 4 and 9, Pb was the most prevalent heavy metal followed by Cd and As. On the other hand, Cd was the most dominant heavy metal at harvest followed by Pb and As.

Wheat biomass from soil amendments at Feekes 4 and grain at harvest had comparable Cd levels with check **(Table 3.3).** Cadmium accumulation in biomass at Feekes 4 ranged from 0.22-0.60 mg kg^{-1} dw with a mean of 0.34 mg kg^{-1} dw. At Feekes

9, all soil amendments decreased flag leaf Cd level by 0.26-0.28 mg kg^{-1} with lime showing the greatest reduction compared to the control. Flag leaf total Cd levels ranged from 0.04-0.99 mg kg^{-1} dw with a mean of 0.15 mg kg^{-1} dw. Grain total Cd levels at harvest ranged from 0.019-0.053 mg kg^{-1} fw with a mean of 0.033 mg kg^{-1} fw. Across sampling, the order of winter wheat stages with plant tissue Cd levels was Feekes 4 > Feekes 9 > grains at harvest.

Biomass total As levels were below the detection limit (< 1.736 x 10^{-6} mg kg^{-1}) at Feekes 4. Arsenic accumulation began in the flag leaf at Feekes 9 ranging from 0.06-0.64 mg kg^{-1} dw with a mean of 0.16 mg kg^{-1} dw **(Table 3.3).** Soil amendments reduced flag leaf As levels by 18-24 mg kg^{-1} at Feekes 9 compared to the check plot. Grains at harvest had comparable As levels with check ranging from 0.002-0.006 mg kg^{-1} fw with an average of 0.003 mg kg^{-1} fw. Across sampling, the order of winter wheat stages with plant tissue As levels was Feekes 9 > grains at harvest >> Feekes 4.

Wheat Feekes 4 biomass and grain at harvest had comparable Pb levels with check **(Table 3.3).** Lead accumulation began in biomass at Feekes 4 ranging from 0.34-3.54 mg kg^{-1} dw with a mean of 1.33 mg kg^{-1} dw. At Feekes 9, the addition of $ZnSO_4$ decreased flag leaf Pb level by 2.90 mg kg^{-1} dw. Flag leaf total Pb levels ranged from 0.06-7.71 mg kg^{-1} dw with a mean of 1.57 mg kg^{-1} dw. Grain total Pb levels at harvest ranged from 0.003-0.073 mg kg^{-1} fw with a mean of 0.016 mg kg^{-1} fw. Among the mean grain Pb concentrations from soil amendments, lime (0.010 mg kg^{-1}) and gypsum (0.006 mg kg^{-1}) were within the allowable limit set by FDA (0.010 mg kg^{-1}). Across sampling, the order of winter wheat stages with plant tissue Pb levels was Feekes 4 = Feekes 9 > grains at harvest.

3.5 Effects of soil amendments on plant uptake factor of heavy metals

Plant uptake factor reflects the capacity of winter wheat to absorb heavy metals at certain crop stages. The PUF of heavy metals on biomass at Feekes 4 and grains at harvest showed that Cd was most absorbed followed by Pb and As **(Table 3.2).** Biomass exhibited greater PUF values for Cd accumulation than grains. Nonetheless, biomass Cd PUF values remained comparable with check (P = 0.3668). At harvest, all soil amendments, except for the high N rate and gypsum, were significantly different from the check (P = 0.0858). On the other hand, the addition of lime and biochar provided the lowest grain Cd PUF values. Grain As (P = 0.7903), biomass Pb (P = 0.5933) and grain Pb (P = 0.6133) PUF values remained comparable across treatments.

PRELIMINARY CONCLUSIONS

Initial results demonstrate the spatial distribution and temporal variation of Cd, As, and Pb in winter wheat. As plant growth progressed, As levels increased while Cd and Pb levels declined. Additionally, Cd was more readily transported from soil to grain compared to As and Pb. The potential of soil amendments to reduce heavy metal uptake was observed. Agricultural lime or biochar application resulted in lower grain Cd PUF values and Pb levels (< FDA action level 0.01 mg Pb kg^{-1}). The inherent properties of agricultural lime and biochar had a greater heavy metal immobilization impact than the other soil amendments.

Table 3.1 Cadmium, arsenic, and lead levels (mg kg^{-1}) in bulk soils at Feekes 4 and harvest. Mean Cd, As, and Pb levels of check plots were displayed. All other treatments display change in Cd, As, and Pb levels using Dunnett's test.

Treatment	Bulk soil at Feekes 4[a]			Bulk soil at harvest[b]		
	Cd	As	Pb	Cd	As	Pb
	mg kg^{-1} soil					
Check	0.25	3.29	12.48	0.22	2.56	9.77
Lime	-0.016^{ns}§	$+0.18^{ns}$	$+2.12^{ns}$	$+0.035^{ns}$	-0.20^{ns}	-0.19^{ns}
Dairy compost	$+0.019^{ns}$	$+0.10^{ns}$	-1.39^{ns}	$+0.031^{ns}$	$+0.42^{ns}$	$+0.61^{ns}$
Biochar	$+0.001^{ns}$	$+0.02^{ns}$	-1.26^{ns}	$+0.021^{ns}$	-0.24^{ns}	$+0.44^{ns}$
Gypsum	-0.016^{ns}	-0.16^{ns}	-0.55^{ns}	$+0.014^{ns}$	-0.36^{ns}	-0.03^{ns}
$ZnSO^4$	-0.040^{ns}	-0.26^{ns}	-0.96^{ns}	$+0.047^{*}$	-0.25^{ns}	$+0.54^{ns}$
Low N	NA ¶	NA	NA	$+0.028^{ns}$	0.37^{ns}	$+0.35^{ns}$
Moderate N	NA	NA	NA	$+0.017^{ns}$	-0.22^{ns}	$+0.26^{ns}$
High N	NA	NA	NA	-0.016^{ns}	-0.02^{ns}	-0.15^{ns}
EDDS	NA	NA	NA	-0.011^{ns}	-0.35^{ns}	-0.25^{ns}
Range	0.13-0.36	2.58-3.89	8.52-25.37	0.15-0.43	1.56-3.99	7.76-12.11
Overall mean	0.25	3.27	12.06	0.24	2.47	9.91

[a] Dunnett's test degrees of freedom = 18.

[b] Dunnett's test degrees of freedom = 27

§ Asterisks indicate thresholds of significance (NS, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001).

¶ NA - not applicable, treatments were excluded since they had not been applied before the Feekes 4 sampling.

Table 3.2 Plant uptake factor of heavy metals on biomass at Feekes 4 and grains at harvest as influenced by soil amendments.

Treatment	Biomass Feekes 4		Grains at harvest		
	Cd	Pb	Cd	As	Pb
Check	1.4	0.1	0.20 a	0.001	0.001
Lime	2.1	0.1	0.12 c	0.001	0.001
Dairy compost	1.3	0.1	0.16 abc	0.001	0.001
Biochar	2.0	0.1	0.12 c	0.001	0.003
Gypsum	1.5	0.1	0.17 ab	0.001	0.001
$ZnSO^4$	0.9	0.1	0.14 bc	0.001	0.001
Low N	¶ NA	NA	0.14 bc	0.001	0.003
Moderate N	NA	NA	0.15 bc	0.001	0.002
High N	NA	NA	0.19 a	0.001	0.002
EDDS	NA	NA	0.14 bc	0.001	0.002
P > F §	NS	NS	*	NS	NS

§.Asterisks indicate thresholds of significance (NS, P > 0.10; *, P < 0.10; **, P < 0.05;

***, P < 0.001). Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Values followed by the same lowercase letter are not significantly different.
¶ NA - not applicable, treatments were excluded since they had not been applied before the Feekes 4 sampling.

Table 3.3 Cadmium, arsenic, and lead levels (mg kg^{-1}) in winter wheat biomass at Feekes 4, flag leaf at Feekes 9, and grains at harvest. Mean As, and Pb levels of check plots were displayed. All other treatments display change in Cd, As, and Pb levels using Dunnett's test.

Treatment	Biomass Feekes 4[a]		Flag leaf Feekes 9[b]			Grains at harvest[c]		
	Cd	Pb	Cd	As	Pb	Cd	As	Pb
	——————————— mg kg^{-1} ———————————							
Check	0.32	1.06	0.39	0.36	3.16	0.041	0.003	0.010
Lime	-0.03^{ns} §	$+0.66^{ns}$	-0.28^{*}	-0.24^{**}	-1.06^{ns}	-0.012^{*}	-0.0006^{ns}	$+0.000^{ns}$
Dairy compost	-0.03^{ns}	$+0.01^{ns}$	-0.25^{*}	-0.21^{**}	-2.34^{ns}	-0.006^{ns}	-0.0006^{ns}	$+0.005^{ns}$
Biochar	-0.02^{ns}	$+0.73^{ns}$	-0.26^{*}	-0.23^{**}	-2.26^{ns}	-0.014^{*}	-0.0003^{ns}	$+0.017^{ns}$
Gypsum	$+0.11^{ns}$	$+0.41^{ns}$	-0.27^{*}	-0.21^{**}	-2.39^{ns}	-0.005^{ns}	-0.0004^{ns}	-0.003^{ns}
$ZnSO^4$	$+0.05^{ns}$	-0.29^{ns}	-0.26^{*}	-0.21^{**}	-2.90^{*}	-0.011*	-0.0004^{ns}	$+0.001^{ns}$
Low N	NA ¶	NA	-0.27^{*}	-0.18^{**}	-2.38^{ns}	-0.011^{*}	-0.0001^{ns}	$+0.017^{ns}$
Moderate N	NA	NA	-0.24^{*}	-0.21^{**}	-1.04^{ns}	-0.008^{ns}	$+0.0000^{ns}$	$+0.011^{ns}$
High N	NA	NA	-0.26^{*}	-0.20^{**}	-0.86^{ns}	-0.004^{ns}	$+0.0004^{ns}$	$+0.008^{ns}$
EDDS	NA	NA	-0.26^{*}	-0.19^{**}	-0.68^{ns}	-0.012^{*}	-0.0002^{ns}	$+0.007^{ns}$
Range	0.22-0.60	0.34-3.54	0.04-0.99	.06-0.64	0.06-7.71	0.019-0.053	0.002-0.006	0.003-0.073
Overall mean	0.34	1.33	0.15	0.16	1.57	0.033	0.003	0.016

[a] Dunnett's test degrees of freedom = 18.
[b] Dunnett's test degrees of freedom= 27.
[c] Dunnett's test degrees of freedom = 27
§.Asterisks indicate thresholds of significance (NS, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001)
¶ NA - not applicable, treatments were excluded since they had not been applied before the Feekes 4 sampling.

THE THREE-LEGGED STOOL: NITROGEN, ENVIRONMENT, AND CROP PRODUCTION

F. Fernández[1]
University of Minnesota

ABSTRACT

Nitrogen (N) loss reduces production and soil health. The objectives of this 3-yr continuous corn (Zea mays L.) US Midwest study were to evaluate traditional and advanced N management on corn N content, grain yield and economic returns; soil N content; and N losses [nitrate (NO_3^-), nitrous oxide (N_2O), and ammonia (NH_3)]. Treatments were: single pre-plant applications of 180 lb N ac^{-1} urea (U) or polymer coated urea ESN (E), and split with 60 lb N ac^{-1} pre-plant applications of either urea (U/U+) or ESN (E/U+) and 120 lb N ac^{-1} as urea+NBPT [N-(n-Butyl) thiophosphoric triamide] at V6. Split and E produced similar grain yield (177 bu ac^{-1} mean) and total N uptake (TNU) (140 lb N ac^{-1} mean) and were greater than treatment U (162 bu ac^{-1} and 119 lb N ac^{-1}). Net economic returns decreased: E/U+>U/U+>E>U, and splits and U had similar losses. The yearly mean sum of N_2O, NH_3, and NO_3^- was 47 to 49% lower with E vs. U, U/U+ and E/U+ (12.9 vs. 25.4, 24.2, and 24.6 lbs ac^{-1}, respectively). Consistent lower N losses for E and better grain yield than U or similar to split treatments indicate that E may be a valuable tool.

INTRODUCTION

Nitrogen, crop production, and environment are interrelated. Overemphasizing one component or underemphasis another creates instability, just like adding or cutting a piece of a leg in a three-legged stool. For brevity reasons, this proceedings article will focus on one particular study to illustrate points, but the oral presentation will discuss several projects aimed at finding where each of the three components (Nitrogen, crop production, and environment) are harmonized to produce a sustainable productive and environmentally-sound system. The results presented here are a summary of results published elsewhere (Menegaz et al., 2024).

The objectives of this continuous corn (*Zea mays* L.) US Midwest study over 3-yrs were to evaluate traditional and advanced N management on soil N content; N uptake, grain yield and economic returns of corn; and N losses as nitrate (NO_3^-), nitrous oxide (N_2O), and ammonia (NH_3).

MATERIALS AND METHODS

A field experiment was conducted from 2018 to 2020 in a continuous corn cropping system established in 2014 at the University of Minnesota Southwest Research and Outreach Center (SWROC) near Lamberton, MN (44°14’11.0” N 95°18’41.7” W), on a poorly drained Webster-Canisteo clay loam soil.

There were four treatments: single pre-plant applications of 180 lbs N ac^{-1} urea (U) or polymer coated urea ESN (E), and split with 60 lbs N ac^{-1} pre-plant applications of either urea (U/U+) or ESN (E/U+) and 120 lbs N ac^{-1} as urea+NBPT [N-(n-Butyl) thiophosphoric triamide] at V6.

Plant and soil samples were collected at various times during the growing season for nitrogen analysis. N losses were monitored throughout the growing season for nitrate (NO_3^-) and nitrous oxide (N_2O), and for approximately the first 60 days of the study for ammonia (NH_3).

Using local service supplier prices at the time the study, net economic return for the treatments was calculated by subtracting fertilizer and application costs from corn revenue. Corn revenue was calculated by multiplying corn yield by corn price of US$3.50 bu^{-1}. The following prices were used to calculate fertilizer costs: urea US$0.34 $lb\text{-}N^{-1}$, ESN US$0.54 $lb\text{-}N^{-1}$, and urea with Agrotain US$0.39 $lb\text{-}N^{-1}$. The pre-plant application cost was US$4.49 ac^{-1} and the side-dress application cost was US$11.01 ac^{-1}. All other costs were the same regardless of treatment and were not considered.

All the results were statistically analyzed. For more details on methodology, see Menegaz et al. (2024).

RESULTS AND DISCUSSION

Plant N uptake and grain yield

Total nitrogen uptake was lower for U compared to the other treatments in 2019, 2020 and for the 3-year mean, and a similar trend was observed in 2018 (Table 1). Averaged across years, TNU was 13 to 16% lower for U compared to the other treatments. The results highlight a clear advantage with the advanced N management practices, especially ESN combined with a side-dress application, to supply N during the entire growing season.

Although treatment differences in grain yield occurred only in 2020, all years showed consistently a similar trend, which was reflected in the differences observed for the 3-yr mean where the traditional treatment U resulted in lower yield (162 bu ac^{-1}) than the three advanced management treatments (Table 1). These results reflect the fact that advanced practices were better able to supply N through the season, as previously discussed for TNU. Further, net return calculations showed a clear advantage to using advanced management practices instead of a single pre-plant application with urea. Even though ESN is more expensive than urea, E instead of U increased net returns by US$18 ac^{-1} above the US$499 ac^{-1} revenue generated with U averaged across the three years of the study (Table 1). The split treatments were even more advantageous (despite the added cost of a side-dress application) generating an additional US$31 ac^{-1} (U/U+) and US$38 ac^{-1} (ESN/U+) compared to U.

Table 1. Mean plant total nitrogen uptake (TNU), grain yield, and net return from yield for 2018 to 2020 and 3-year mean as affected by treatment (Urea and ESN applied pre-plant at 180 lb N ac^{-1}; Urea/Urea+ and ESN/Urea applied pre-plant at 60 lb N ac^{-1}as urea or ESN followed by an application of 120 lb N ac^{-1} as Urea+NBPT [N-(n-Butyl) thiophosphoric triamide] at V6 corn development stage).

Year	Treatment	TNU‡	Grain Yield	Net Return§
		lb N ac^{-1}	bu ac^{-1}	US$ ac^{-1}
2018	Urea	129	147	447
	ESN	140	172	501
	Urea/Urea+	145	163	487
	ESN/Urea+	149	167	492
2019	Urea	107b†	163	503
	ESN	129a	167	484
	Urea/Urea+	131a	177	537
	ESN/Urea+	135a	179	531
2020	Urea	122b	175b	548
	ESN	143a	191a	568
	Urea/Urea+	142a	185ab	565
	ESN/Urea+	145a	194a	587
3-year Mean	Urea	119b	162b	499
	ESN	138a	177a	517
	Urea/Urea+	139a	175a	530
	ESN/Urea+	143a	180a	537

† Means within columns and year followed by different letters are significantly different ($P < 0.05$).

‡ Total nitrogen uptake (TNU) is the sum of plant N uptake at R6 and harvest grain N.

§ Calculated by subtracting fertilizer and application costs from corn revenue (corn price US$3.50 bu^{-1}; urea US$0.34 lb-N^{-1}; ESN US$0.54 lb-N^{-1}; urea with Agrotain US$0.39 lb-$N^{-1}$; pre-plant application US$4.49 ac^{-1}; split application US$11.01 ac^{-1}). All other costs were the same regardless of treatment and were not considered.

Nitrous oxide emissions

Although only the year total cumulative N_2O data are shown (Table 2), it is valuable to review some of the highlights of individual years, which are not presented here. The yearly fluxes averaged across treatments were greater in the wetter years, 2018 (40 µg N_2O-N m^2 h^{-1}) and 2019 (35 µg N_2O-N m^2 h^{-1}), than in the drier 2020 (23 µg N_2O-N m^2 h^{-1}), which highlight the large influence of weather conditions on environmental outcomes from N management strategies. While the magnitude of emissions varied between years and treatments, the temporal patterns of daily mean fluxes and resulting cumulative N_2O losses were generally similar across the growing seasons. Soil N_2O fluxes were low at the beginning of each season immediately before and after planting. Substantial emissions occurred within a few days after N application and continued for approximately 6 weeks during June and July. In fact, there were nine very high daily mean N_2O fluxes that occurred soon after the side-dress applications or after application of the U treatment in conjunction with precipitation events. Fluxes typically returned to baseline levels and remained low from August to October. These data support the finding that N fertilization is the primary contributor of N_2O in agriculture.

Table 2. Least square means and significance of F values for fixed sources of variation and their interactions for area scaled N_2O emissions (aN_2O) and yield-scaled N_2O emission (yN_2O) calculated by dividing aN_2O by grain yield.

	Direct aN_2O emission	yN_2O
	lb N ac^{-1}	lb N bu^{-1}
Year (Y)		
2018	2.7	0.015
2019	2.6	0.013
2020	1.8	0.009
Treatment (T)†		
Urea	3.4	0.022
ESN	1.4	0.008
Urea/Urea+	2.3	0.013
ESN/Urea+	2.2	0.013
Interaction		
Y*T	<0.05	<0.05

† Treatments were Urea and ESN applied pre-plant at 180 lb N ac^{-1}; Urea/Urea+ and ESN/Urea applied pre-plant at 60 lb N ac^{-1} as urea or ESN followed by an application of 120 lb N ac^{-1} of Urea+NBPT [N-(n-Butyl) thiophosphoric triamide] at V6 corn development stage.

The significant year by treatment interaction for aN_2O and yN_2O (Table 2) illustrates that N_2O emissions were impacted by the amount and distribution of precipitation after fertilizer application regardless of when it was applied (pre-plant or V6). Potential for N_2O loss was high for both application times in 2018 and pre-plant in 2019 and was low for both applications in 2020 and side-dress time in 2019. The interaction for aN_2O and yN_2O was explained by ESN substantially lowering emissions relative to treatments with urea during wet conditions soon after the pre-plant application (2018 and 2019) while no differences occurred when it was drier than normal in 2020, though a trend for more loss with U was also observed. Within 30 days after the pre-plant fertilizer application there were 16 days with 7.4 inches of precipitation in 2018 and 14 days with 4.7 inches in 2019, whereas there were only 9 days with 3.1 inches in 2020. Further, the year by treatment interaction clearly showed that split treatments might produce no benefit relative to U if substantial precipitation follows the side-dress application, as was the case in 2018 but not in 2019 and 2020. Within 30 days after the side-dress application, there were 15 days with 8.9 inches of precipitation in 2018, compared to only 10 days with 3.8 inches in 2019 and 10 days with 4.4 inches in 2020. Even closer to the time of application, within 7 days, it was observed that 5 days of precipitation totaling 2.8 inches in 2018 was sufficient to induce greater N_2O loss relative to 2019 (0.7 inches over 3 days of precipitation) and 2020 (0.8 inches during 1 day of precipitation). While logistically in commercial farming it is not always possible to side-dress at the best time, guiding the application based on a 5-to-7-day weather forecast can be an effective management strategy. Although E was not as profitable as the split treatments (U/U+ and ESN/U+) (Table 1), the fact that E consistently had low N_2O emissions regardless of weather conditions indicates that this management strategy could be viable for environmental-stewardship incentive programs. Further, since E maintained high grain yield levels, this management represents a win-win situation in the context of protecting the environment while maintaining agricultural productivity to meet the demands of a growing global population.

Ammonia volatilization

As with N_2O, although only the year total cumulative NH_3 data are shown (Table 3), it is valuable to review some of the highlights of individual years, which are not presented here. Ammonia emissions followed a similar temporal pattern between 2019 and 2020, but the magnitude was greater in 2019 likely due to differences in weather conditions that favored loss (Table 3). Compared to 2020, in 2019 the air temperature was 57°F warmer between days 1 to 5 and 45°F warmer between days 6 to 10 after the pre-plant application. Also, in 2019, 0.4 inches of precipitation three days after side-dress applications was likely sufficient to solubilize but not incorporate the fertilizer into the soil, thus increasing substantially the potential for NH_3 fluxes and cumulative loss. Whereas in 2020, 0.8 inches of precipitation five days after side-dress likely solubilized and incorporated the fertilizer deep enough in the soil to minimize NH_3 volatilization.

Table 3. Cumulative NH_3 loss for two 28-day periods after pre-plant and side-dress fertilizer applications and as a total across measurement periods for 2019, 2020, and the 2-year mean as affected by treatment (Urea and ESN applied pre-plant at 180 lb N ac^{-1}; Urea/Urea+ and ESN/Urea applied pre-plant at 60 lb N ac^{-1}as urea or ESN followed by an application of 120 lb N ac^{-1} as Urea+NBPT [N-(n-Butyl) thiophosphoric triamide] at V6 corn development stage).

Treatment	28 days after pre-plant application			28 days after split application			Total NH_3†		
	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
	---lb ac^{-1}---								
Urea	1.61a‡	1.16a	1.43a	0.09b	0.09b	0.09b	1.96b	1.16a	1.43a
ESN	0.45b	0.09b	0.27b	0.09b	0.09b	0.09b	0.63b	0.18b	0.27b
Urea/Urea+	0.27b	0.18b	0.18b	4.73a	0.89a	2.05a	5.18a	1.07a	2.32a
ESN/Urea+	0.27b	0.09b	0.09b	5.80a	1.07a	2.50a	6.07a	1.07a	2.59a

† Total NH_3 is the sum of cumulative emissions collected during the two sampling periods. In 2019, the final sampling was 30 days after side-dress application.
‡ Means within columns followed by different letters are significantly different ($P < 0.05$).

In 2019 and 2020, cumulative NH_3 emissions for U increased rapidly after fertilizer application for approximately 28 days until they plateaued. On the other hand, the full N fertilization rate with E showed a small amount of NH_3 accumulation, similar to the split treatments that had received only one-third of the fertilizer N. At 28 days after the pre-plant application, compared to U, the advanced treatments (E, U/U+, and E/U+) lowered cumulative NH_3 loss by approximately 80% in 2019 and 90% in 2020 (Table 3). After the side-dress application, although the magnitude was greater in 2019, both years displayed a rapid increase in cumulative NH_3 emissions during the entire sampling period for split treatments (U/U+ and E/U+), but little accumulation occurred for U and E. The cumulative NH_3 loss during the 58 days of measurement were on average 4.3 times greater for the split treatments (U/U+ and E/U+) than the single pre-plant treatments (U and E) in 2019, and in 2020 U and the split treatments produced 6 to 6.5 times greater loss than E (Table 3). As explained earlier, different weather conditions in the two years resulted in distinct treatment outcomes.

While only in 2020 U resulted in greater total NH_3 emissions than E, 2019 showed a similar trend with approximately the same difference between the treatments (Table 3). Further, the combined analysis across the years clearly shows that E lowered NH_3 emissions by 81% compared to the traditional practice (U). In addition, E was consistently superior in lowering total NH_3 emissions by 88 to 90% compared to the advanced practice of split applications (Table 3). Further, over the two years, the split treatments produced no advantage compared to U, and in 2019, split treatments actually significantly increased emissions. Agronomists often view split applications as superior to pre-plant applications to lower the risk of N loss in typical wet springs. These results clearly show that, while the N loss is nominal in agronomic terms (only a few pounds) and not reflected in grain yield (Table 1), the negative environmental impact of surface applications in-season can be substantial when there is insufficient precipitation to incorporate fertilizer in the soil. This is true even when applying a urease inhibitor as a recommended best management practice. These results highlight how challenging it is to manage N in the field under unpredictable weather conditions. However, these findings also point out, as described for N_2O, that E can be a viable alternative to meet both agricultural productivity- and environmental protection-goals.

Nitrate leaching

Nitrate loads were lower for E than the other treatments in 2019, and a similar trend was observed in 2018 during the two above-normal precipitation years of the study (Table 4). Conversely, loads were similar between all treatments and much lower during the drier-than-normal 2020 growing season that produced only a few episodic N loss events (Data not shown). As already discussed for N_2O and NH_3, E also shows promise as a management strategy to lower NO_3^- loading and mitigate the environmental footprint of N fertilizers in agriculture, especially when adverse weather conditions increase N loss potential. Unfortunately, the advanced N management practice of split applications showed no benefit compared to the traditional U application.

Drainage amounts as well as daily nitrate loads (data not shown) were greatly influenced by precipitation amounts and distribution, but there were no drainage differences due to treatment. However, during 2019, the wettest year of the study where daily NO_3^- loads were as high as 13 lb N ac^{-1}, there was a trend for less drainage with E (Table 4). Because NO_3^- load is greatly influenced by drainage amounts, flow-weighted NO_3^- concentration, are often used to account for differences in drainage. While there were no treatment differences for flow-weighted NO_3^- concentration, the trend for lower concentrations with E during the wet years as well as the average across years was consistent with the load data already discussed. The lack of treatment difference could be the result of compounded variability as drainage and concentration measurements, each with their inherent variability, were combined in the calculation. This is a common challenge for these kinds of studies. Furthermore, NO_3^- concentrations were below the maximum drinking water standard of 10 mg L^{-1} set by USEPA. Since the N rate used was within the MRTN rate recommended by university guidelines, these results highlight that when the right rate of N is applied, other N management practices, such as source or time of application, might provide limited additional benefit to lower NO_3^- concentrations in drainage water.

Table 4. Mean annual sub-surface drainage water, NO_3^- load leached, and flow-weighted NO_3^- concentration for 2018 to 2020 and 3-year mean as affected by treatment (Urea and ESN applied pre-plant at 180 lb N ac^{-1}; Urea/Urea+ and ESN/Urea applied pre-plant at 60 lb N ac^{-1}as urea or ESN followed by an application of 120 lb N ac^{-1} as Urea+NBPT [N-(n-Butyl) thiophosphoric triamide] at V6 corn development stage).

Treatment	NO_3^- Load				Drainage				Flow-weighted			
	2018	2019	2020	Mean	2018	2019	2020	Mean	2018	2019	2020	Mean
	-------------lb ac^{-1}-------------				-------------inch-------------				-------------mg L^{-1}-------------			
Urea	18	29a†	5	17a	8.8	20.3	2.7	9.7	8.8	6.3	8.0	7.8
ESN	13	16b	4	11b	8.9	13.0	1.8	7.4	6.9	5.9	8.6	7.2
Urea/Urea+	20	31a	4	16a	10.6	18.0	1.9	9.2	8.4	8.1	8.2	8.2
ESN/Urea+	20	29a	5	16a	11.0	17.1	2.8	10.1	8.1	7.4	6.6	7.4

† Means within columns followed by different letters are significantly different ($P < 0.05$).

CONCLUSIONS

Finding N management tools that increase or at least maintain crop productivity and profitability while improving N utilization and lower of N loss is fundamental to meeting the growing global demand for agricultural products in an environmentally minded way. Field conditions are challenging to meet these goals as our ability to forecast weather accurately, especially precipitation, extends only a few days into the future. Split applications, which in theory are considered best management practices to address both production and environmental protection goals, only produced crop production benefits without lowering N loss compared to the traditional U application. Clearly, one of the biggest challenges in lowering N loss is related to weather conditions following N fertilization regardless of when the application is done. While it might not be possible to obtain the full benefit of a given practice every year, favoring practices that have a higher frequency of producing gains, or at least not resulting in drawback, is appropriate given the uncertainty of growing season conditions that extend past the time of fertilization. Application of E can be a robust tool because it consistently maintained high productivity and net economic benefits while protecting against the different N loss pathways throughout the growing season regardless of different weather conditions. The combined direct measurements of aN_2O, NH_3, and NO_3^- showed an annual loss of

N that was 47 to 49% lower with E (12.9 lb ac^{-1}) than U, U/U+ and E/U+ (25.4, 24.2, and 24.6 lb ac^{-1}, respectively). While E represents a more complete solution because it meets both goals to maintain productivity and profitability and lower N loss to the environment, there are still costs with this practice. There is an added cost in the form of lower net returns compared to the most profitable production strategy tested, and N losses are lowered but not eliminated, which highlights the fact that even when using the best available practices there is an environmental cost to agricultural production. While profitability is key to farmers, incentive programs that pay for loss of revenue due to lower grain yields are often met with greater resistance than if the incentive is to pay for the implementation of an improved management practice that maintains or increases grain yield. As a management practice, E has a high potential for implementation success. This is because it does not require fundamental changes in equipment or logistics for farmers, and the difference in net profit compared to the most profitable scenario is relatively simple to calculate for compensatory measures given that the costs are related to inputs (fertilizer and application costs) and not do to reduction in grain yield. Although these results are promising, this study is limited to a single location and three years. Additional studies are needed before broad adoption of these results can be encouraged beyond the local conditions of this study.

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CORN GRAIN YIELD RESPONSE TO NITROGEN RATE TIMING, SOURCE, AND NITRIFICATION INHIBITOR IN MISSOURI

G. Singh[1], K.A. Nelson, P. Pal[1], C. Roberts[1], J. Lory[1], M. Davis[1], J. Chlapecka[1], L. Abendroth[2], J.C. Ransom[2], J. Calhoun[1], W. Bradley[1], H. Naumann[1], and G. Kaur

[1]Division of Plant Science & Technology, University of Missouri, Columbia, MO
[2]Cropping Systems and Water Quality Research, USDA-ARS, Columbia, MO
[1]Division of Animal Sciences, University of Missouri, Columbia, MO
[4]School of Natural Resources, University of Missouri, Columbia, MO

ABSTRACT

Nitrogen response depends on several factors including weather conditions, soil N supply capacity, previous crop in the rotation, plant population, and fertilizer management practices. Fertilizer management practices include fertilizer rate, source, application timing, placement, and use of nitrogen stabilizer. In Missouri, the nitrogen fertilizer rate recommendations for corn are based on a yield goal equation. This equation includes the target plant population, pounds of nitrogen removed per thousand plants, and a product of yield goal with pounds of nitrogen per yield unit. This equation has a soil health adjustment factor that is based on the organic matter content of the soil. The organic matter adjustment factor is based on soil texture and cation exchange capacity which provides a soil N credit in pounds of nitrogen per acre. The parameters used in the yield goal equation were updated in the 1980's. The yield goal equation does not integrate new practices such as cover crops, bio-stimulants, and nitrogen stabilizers. Moreover, the nitrogen recommendations do not incorporate variations in nitrogen supply across the landscape for different productivity zones. Therefore, a multi-site project funded by the Missouri Fertilizer Control Board began in 2023 to address these gaps, add new practices, and help update nitrogen fertilizer recommendations for Missouri. The specific objectives are to evaluate biological input products; cover crops; nitrification inhibitors and other biological management technologies for improving nitrogen use efficiencies; evaluate soil health indicators as yield predictors; evaluate the effect of landscape position and soil conditions on productivity and soil nitrogen supply; calibrate the integration of soil health measurements into fertilizer nitrogen recommendations and improve calibrations of in-season nitrogen prediction tools. Three-year results indicate that the factor for the internal N requirement of the corn plants was 1.06, which is 0.17 units more than the current factor. Nitrogen removal for 1000 corn plants was calculated to be 3.88 lb N ac^{-1} which indicates that the newer corn hybrids are more efficient in assimilating N in their biomass.

INTRODUCTION

The corn nitrogen (N) recommendation system for Missouri is a yield goal-based system. Most yield goal systems adopted in the US states are derived from Stanford's equation (Stanford, 1966). The derived yield goal equation is oversimplified where the N application rate (N_r) to corn is a factor of the internal N requirement of the corn plant (n) and expected yield from a field also called as yield goal (Morris et al., 2018). The n, internal N requirement of corn plants, is the maximum attainable yield developed from the rate response curves and varies from state to state (0.8 to 1.5 lbs N bu^{-1}). This approach overestimates the N recommendation in most cases and the oversimplification of this equation ignores several management practices which are known to affect the recovery efficiency of N by corn plants. The recovery efficiency (RE_N) is calculated based on the yield from the non-fertilized plot subtracted from the yield of the fertilized plot and divided by the N application rate (Cassman et al., 2002). It has been well documented that the RE_N varies with changes in management practices like fertilizer source, timing of application, placement of application, and use of enhanced efficiency products like nitrification or urea inhibitors in addition to the weather and temperature conditions (Hermelink, 2018).

In Missouri, the internal N requirement of corn plants is estimated based on the assumed plant population required for a given yield goal (Brown et al., 2004). For a corn stand of 1000 plants ac^{-1}, a total of 4 lb N ac^{-1} is added to the base recommendation which is 0.9 lb N ac^{-1} multiplied by the yield goal. Additionally, this equation is balanced by crediting N from soil texture and organic matter. The N credit system that was developed is a simplified table with three broad soil textural classes sand-sandy loam, silt loam-loam, and clay loam-clay. The soil N credit is further split into three organic matter classes within each soil textural class which varies from 20 lbs N ac^{-1} for sandy-sandy loam soil to 80 lbs N ac^{-1} for a silt loam to loam textural class. The approach of using an organic matter correction factor and adjustment to corn stand is unique to Missouri. The organic matter with a corresponding N credit which is probably related to the potentially mineralizable nitrogen are soil health indicators that are used in the N rate recommendation calculator for Missouri. The introduction of new technologies and new traits in corn hybrids with higher yield potential requires an updated N recommendation which should be tailored towards incorporating the complex dynamics of N functions in the soil geared towards improving RE_N and lowering environmental and economic loss of N fertilizer. To address this goal, the Missouri Fertilizer Control Board funded a multi-year multi-site project with specific objectives to evaluate biological input products; cover crops; nitrification inhibitors and other biological management technologies for improving N use efficiencies; evaluate soil health indicators as yield predictors; evaluate the effect of landscape position and soil conditions on productivity and soil N supply; calibrate the integration of soil health measurements into fertilizer N recommendations; and improve calibrations of in-season N prediction tools.

MATERIALS AND METHODS

This project involves soil and crop scientists working throughout the state located at Fisher Delta Research Center (FDRC), Bradford Research Center (BRC), Greenley Research Center (GRC), Forage Systems Research Center (FSRC), and USDA-ARS. The cropping systems in Missouri are different from Bootheelof Missouri to central Missouri and upstate Missouri. The seven counties in the Missouri Delta region also have cotton and rice as major crops. The cropping system is different from the rest of the state do to extensive flood irrigation. More than 90% of the cropland in central and upstate Missouri which includes 60 and 70% of the soybean and corn production in the state is under dryland production whereas it's more than 90% irrigated in the Bootheel. During

2023 and 2024, a total of 18 locations were established with the following projects evaluating N rate response in corn managed with different cultural practices.

Greenley Research Center (GRC):

1. Nitrogen timing (3) X Inhibitor (2) X N rate (5) - Corn. Evaluate N response with and without the inhibitor Centuro in fall with anhydrous, at preplant with anhydrous, and at V6 with UAN.
2. Landscape (3) X Inhibitor (3) X N rate (5) – Corn. Evaluate N response in three slope positions down a slope testing the inhibitors Centuro and N-serve at 120 and 180 lbs. N/acre.
3. Biological (3) X N rate (5) - Corn. Evaluate N response with three biologicals (Biological 1, Envita, and UtrishaN) with an untreated control.

In Upstate Missouri (GRC), corn response to N fertilizer rate, source, and timing was evaluated in the first study. The N rates selected for the study were 0, 60, 120, 180, and 240 lbs N ac^{-1}. Anhydrous ammonia with and without Centuro (nitrification inhibitor) was applied in the fall and as spring pre-plant. Additionally, UAN with and without Centuro at the same rates as anhydrous ammonia was applied at the V6 corn growth stage as a single application timing. In the second study, three landscape positions were classified using a topographic position model using LiDAR data in ArcGIS (Esri). Nitrogen rate responses of corn were evaluated for anhydrous ammonia applied as spring pre-plant at 0, 60, 120, 180, and 240 lbs N ac^{-1} rate. Additionally, 120 and 180 lbs N ac^{-1} with nitrification inhibitors (Centuro and N-serve) were also included as treatments. In the third-rate response trial, we evaluated three biological products applied at 0, 60, 120, 180, and 240 lbs N ac^{-1} N rates. Urea ammonium nitrate (32%) was used as an N-source applied at the V6 growth stage. Weather data were collected from the Missouri Mesonet at the GRC (Figure 1).

Bradford Research Center (BRC):

1. Landscape (2) X Cover Crop (2) X N rate (6) – Corn. Evaluate N response with and without cover crop at two landscape positions.
2. Cover crop (2) X N rate (6) – Corn. Evaluate N response with and without a cover crop.

In Central Missouri at the BRC, corn response to N was evaluated at two landscape positions with and without a winter rye cover crop with N applied at 0, 90, 120, 150, 180, and 210 lbs N ac^{-1} as UAN. The experiment was replicated at two locations. The second trial evaluated corn response to cover crops and no cover crops at two locations with N application rates of 0, 90, 120, 150, 180, and 210 lbs N ac^{-1} as UAN.

Fisher Delta Research Center: Biological (2) X N rate (7) – Corn. Evaluate N response with and without a biological.

At the Fisher Delta Research Center, N rates evaluated were 90, 120, 150, 180, 210, 240, and 270 lbs N ac^{-1} applied as UAN with or without a biological product applied as in-furrow liquid treatment. Throughout the year soil and tissue samples were collected as well as drone imagery. At the end of the season, the center two rows of each plot were harvested to calculate grain yield from grain weight and harvest moisture.

Statistical analysis:

The statistical analysis was performed using R-studio, SAS, and graphs were developed in Sigmplot or Origin Pro software.

RESULTS AND DISCUSSION

The 22-year average precipitation at the GRC location was 38.9 inches (Figure 1). Precipitation received in 2022, 2023, and 2024 was 30.5, 24.5, and 29.3 inches, respectively. The agronomically optimum nitrogen rates (AONR) and economically optimum nitrogen rates (EONR) were calculated for all data irrespective of the nitrogen sources, placement, timing, and use of nitrogen stabilizers (Figure 2). The AONR for 16 site-years of data was 212 lbs N/ac whereas EONR was 168 lbs N/ac. Nitrogen rate response curves were split based on the year. In 2022, the observed AONR was 196 lbs N/ac and EONR was 178 lbs N/ac. During a drought year (2023), lower overall corn grain yields were observed due to lower moisture availability during the growing season (Figure 2). The AONR in 2023 was 109 lbs N/ac and EONR was 152 lbs N/ac. In 2024, rainfall during the growing season was well-distributed which resulted in the highest corn grain yield among all years of the study. The AONR for 2024 was 235 lbs N/ac whereas EONR was 177 lbs N/ac.

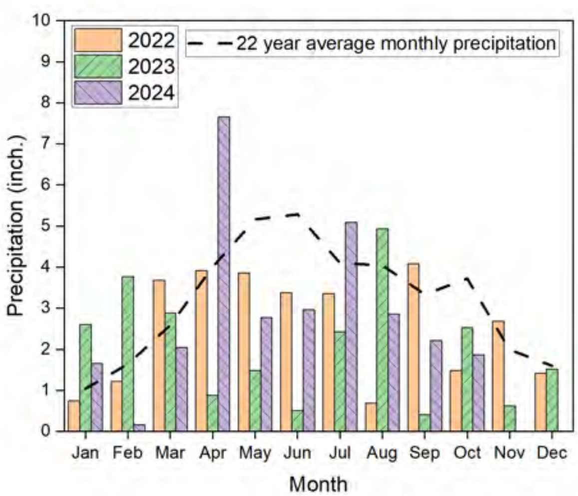

Figure 1. Precipitation received during 2022, 2023, and 2024 at the Novelty location in Northeast Missouri. The dashed line is the 22-years historic monthly precipitation.

At the Central Missouri location, reductions in corn grain yields were observed in the presence of cover crops (a difference of 11 bushels/acre; Figure 4. Although yield differences appeared, there were fewer differences among in-season corn plant measurements (e.g., color and biomass; Figure 4). The decrease in yield was likely due to early and mid-season water stress when the number of kernels per row was set (data still pending review). Treatments that had cover crops likely had less soil water and exhibited additional water stress (soil moisture measurements were not recorded). While treatment differences were observed, nitrogen response was similar (Figure 4). The 2023 drought conditions led to more water stress than nitrogen stress which minimized any large difference that we were expecting to observe from these studies.

Evaluating soil health parameters' and the correlation with yield at different nitrogen fertility levels revealed weak relationships for certain variables (Figure 5). The yield results with no additional nitrogenshowed pH, neutralizable acidity, and water aggregate stability were significant, but they were weakly correlated. More variables were correlated with yield from plots that received an excessive amount of nitrogen. These included pH, neutralizable acidity, active carbon (POXC), potential mineralizable nitrogen, and soil respiration. However, not all indicators were positively correlated (i.e., the more of the test value the higher the yield). This is a promising initial finding that needs to be revisited with data from non-drought years.

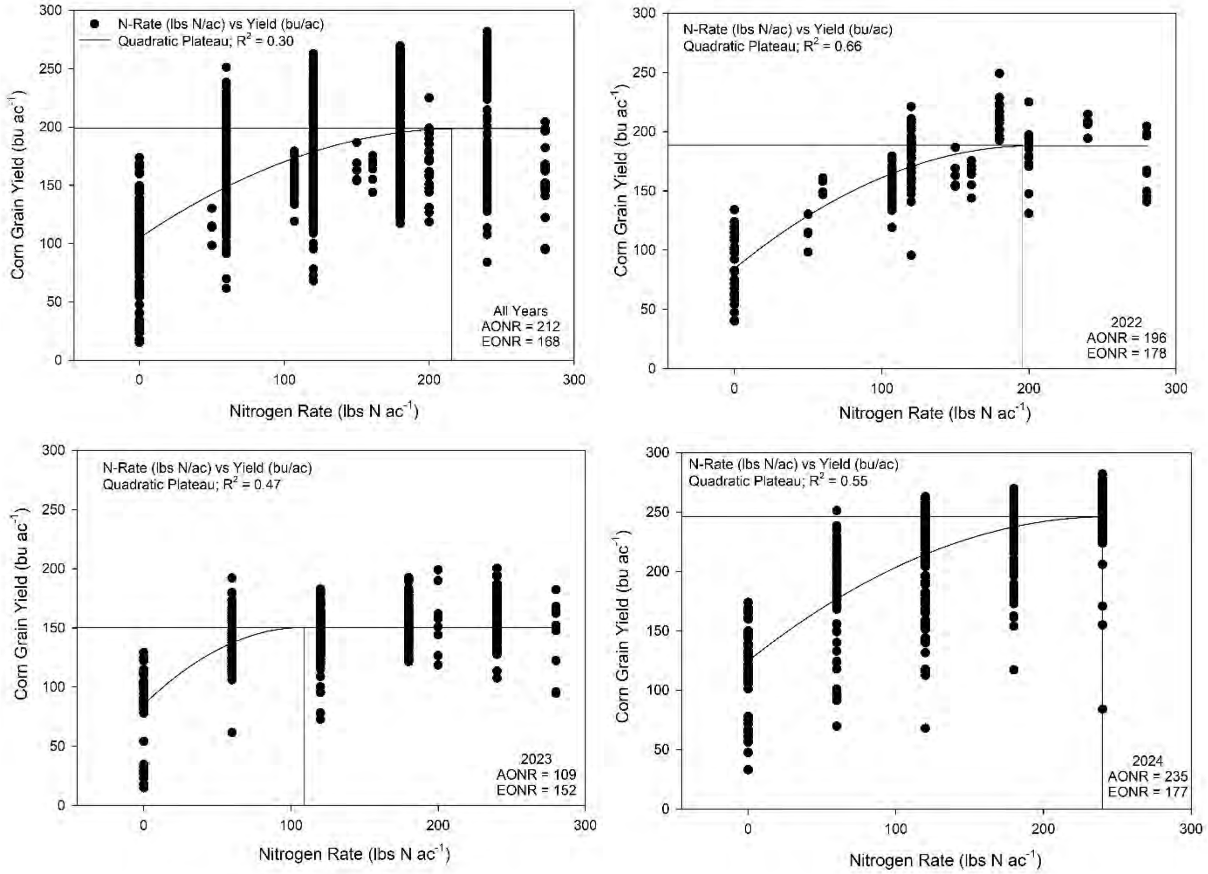

Figure 2. Nitrogen rate response curves from 16 site-years of data produced in Northeast Missouri at the Greenley Research Center.

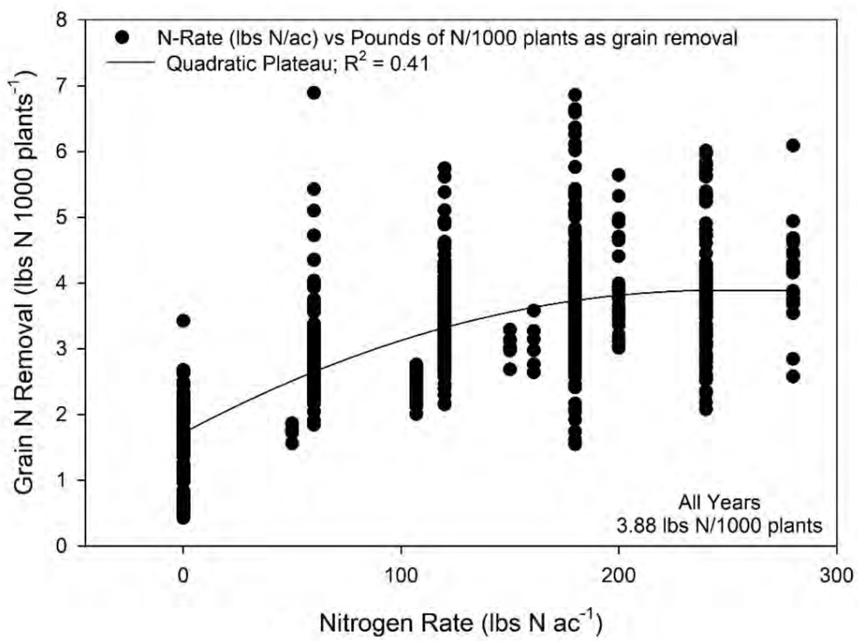

Figure 3. Grain nitrogen removal for 1000 corn plants at 16 site-years of data in Northeast Missouri Greenley Research Center.

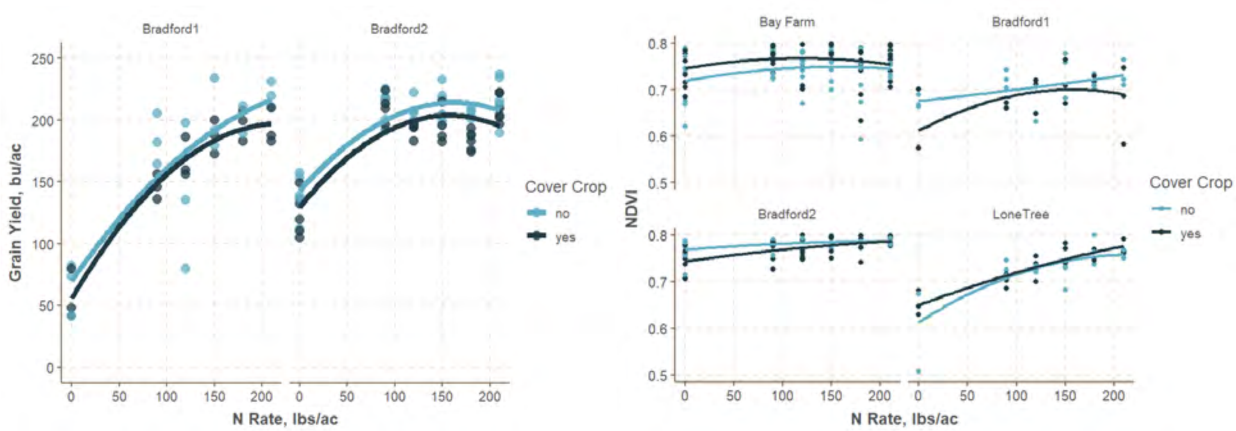

Figure 4. Corn grain yield response to nitrogen fertilization with and without a cereal rye cover crop in 2023. Corn plant greenness and biomass using normalized difference vegetative index (NDVI) for treatments with and without a cover crop in 2023.

Figure 5. Initial correlation coefficients of soil health (physical, chemical, and biological) indicators at two N rates. The closer the values are to 1 or -1 indicates a strong correlation to yield. Yields at two different fertility levels (0 lbs N/acre and 210 lbs N/acre applied) are shown.

At the Fisher Delta location, results indicated that biological products had no significant effect on N response in 2023 (Figure 6.). Only N rates significantly impacted corn yield. Generally, as the N rate increased, corn yield also increased under the irrigated growing conditions.

CONCLUSION

The factor for the internal N requirement of the corn plants based on the three years and 16 site-years of data was 1.06, which is 0.17 units more than the current factor. Nitrogen removal for 1000 corn plants was calculated to be 3.88 lb N ac^{-1} which indicates that newer corn hybrids are more efficient in assimilating N in their biomass. The preliminary analysis of soil health indicators showed some weak correlations with corn grain yield. For Missouri's corn N calculation equation, a credit is given based on the organic matter in the soil which varies from 20 lbs N ac^{-1} for sandy-sandy loam soil to 80 lbs N ac^{-1} for silt loam to loam. Data from soil health indicators will be further explored for their role in providing N credits and may help modify the existing corn N calculator equation.

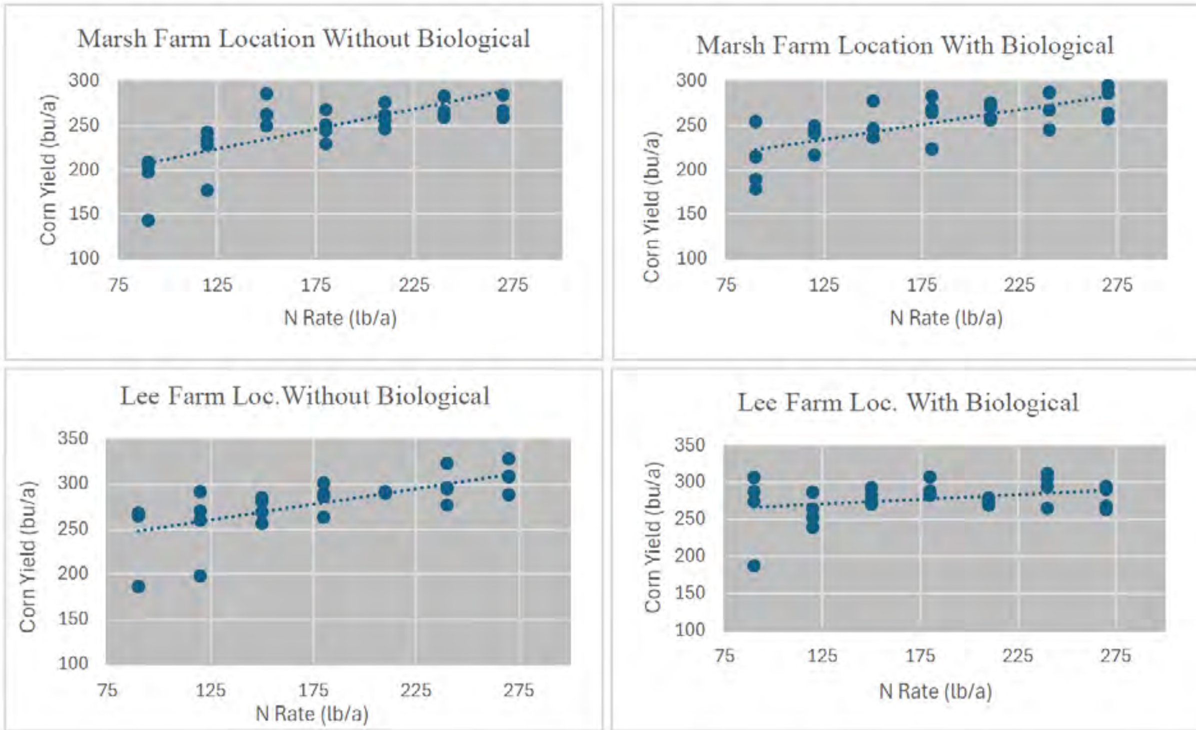

Figure 6. Corn grain yield response to nitrogen rates applied with and without a biological product at the Lee and Marsh farms in 2023.

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COVER CROPS AND N CYCLING IN NORTH DAKOTA CROPPING SYSTEMS

B. Goettl and D. Franzen
North Dakota State University

ABSTRACT

Cover crops have proven effective in reducing wind and water erosion, improving soil health, and capturing excess N in the fall to prevent leaching. Although the benefits of cover crops to soil health are widely reported, their impact on the yield of the following crops is not clear. The purpose of this North Dakota study was to determine the impact cover crops have on the yield of following corn (*Zea Mays L.*) and wheat (*Triticum aestivum L.*) crops along with quantifying nitrogen pools in the soil. Following barley (*Hordeum vulgare L.),* cover crops were no-till seeded at three eastern North Dakota sites in 2021 and 2022. Prior to frost termination, above-ground cover crop biomass ranged from 660 to 2,600 lb ac^{-1} across locations. The following spring, corn grain was planted into cover crop and no-cover crop treatments and fertilized with five N rates (0 to 160 lb N ac^{-1}) in a randomized complete block design with a split-plot arrangement. The following year, wheat was planted on these sites and fertilized with the same N rates. After corn and wheat harvest, grain yield was determined and soil samples were taken to a depth of 2 ft and analyzed for NO_3-N, NH_4-N, and non-exchangeable NH_4-N. The cover crop had no significant impact on corn or wheat yield; however, it did appear the cover crop had an impact on the wheat yield response to N. The total known available N (TKAN, sum of preplant soil NO_3-N, N credits, and fertilizer N) needed to reach maximum yield in the no cover crop treatments was greater than the amount of N needed in the wheat grown two seasons following the cover crop, indicating a potential second-year credit from cover crops may be attainable in these environments.

INTRODUCTION

Cover crops provide environmental benefits by reducing N leaching and may also provide productivity and economic benefits if retained N becomes available to subsequent cash crops (Hughes and Langemeier, 2020). However, studies relating the use of cover crops to following crop yield have had highly variable results. Some studies show the use of cover crops improve the following crop yield (Reinbott et al., 2004; Andraski and Bundy, 2005; Blanco-Canqui et al., 2012), while other studies show the opposite, mixed, or neutral effects (Kuo and Jellum, 2000; O'Reilly et al., 2012; Berti et al., 2017; Ruark et al., 2018; Andersen et al., 2020; Leiva, 2020; Franzen et al., 2023). The impact of cover crops on yield of the following crop is not clear, indicating N from cover crop biomass does not consistently become available the following growing season. The purpose of this study was to determine the impact fall cover crops have on the yield of the subsequent crops of corn and wheat and soil NO_3-N, NH_4-N, and non-exchangeable NH_4-N.

MATERIALS AND METHODS

Site Description and Experimental Design

This experiment was conducted from 2021 to 2023 at three non-irrigated locations in eastern North Dakota, near Valley City (46.880486N, 97.913760W), Logan Center (47.791001N, 74 97.775661W), and Gardner (47.175694N, 96.920118W). The sites were all managed under no-tillage practices and were planted with a cover crop following small grains the year prior to the establishment of this project. Gardner and VC had been under no-till management for >6 years at the inception of this study, LC <6 years.

Two of the locations in this study were a continuation of a two-row malting barley N rate experiment established in the spring of 2021 at VC and LC (Goettl et al., 2024). The barley study consisted of five N fertilizer rates ranging from 0 to 160 lbs N ac^{-1}. An additional site, Gardner, was included in the analysis for this study. Wheat was grown at the Gardner site in 2022, prior to cover crop establishment, and fertilized with 80 lbs N ac^{-1}. Following small grain harvest at each site, a mixed species cover crop was seeded. The cover crop mix consisted of 2 lbs ac^{-1} forage radish, 2 lbs ac^{-1} brown flax, and 30 lbs ac^{-1} faba bean at LC and VC. At the Gardner site 30 lbs ac^{-1} oat, 2 lbs ac^{-1} forage radish, and 2 lbs ac^{-1} brown flax was planted. Following the cover crop, corn was planted the subsequent spring with wheat following the second year. Cover crop above-ground biomass was collected in the fall prior to the first killing frost averaging 1,123, 2,877, and 1,912 lbs ac^{-1}, Gardner, LC, and VC site respectively.

The experiments were arranged as a randomized complete block design with a split-plot arrangement. Cover crop versus no cover crop was the main-plot treatment and N rate was the sub-plot treatment. Blocks were replicated three times at Gardner and five at VC and LC. Nitrogen fertilizer treatments applied to the subsequent corn and wheat crops were 0, 40, 80, 120, and 160 lbs N ac^{-1}.

Crop Management

At all of the three locations, corn was no-till planted in 30-in rows. Wheat was sown the cropping year following corn in 7.5-in rows at LC and VC. Seeding rates, cultivars, starter fertilizer, and pest management were determined and executed by the cooperating farmers in accordance with local production practices.

At the time of planting, N fertilizer was hand-broadcast applied to the N treatments using SUPERU as the fertilizer N source. SUPERU is a urea-based (46% N) fertilizer treated with *dicyandiamide* and *N-(n-butyl) thiophosphoric triamide*. (Koch Agronomic Services LLC, 2019)

Data Collection and Analysis

After harvest, corn grain weights were adjusted to the standard moisture content of 15.5% and wheat to 13.5% for yield calculations. Soil samples were collected from the 0-24 in depth in the spring prior to corn and wheat planting and fertilization, and again following crop harvest. These samples were immediately air dried before being analyzed for NO_3-N, NH_4-N, and non-exchangeable NH_4-N. NO_3-N and NH_4-N analyses were carried out by Agvise Laboratories (Northwood, ND). Non-exchangeable NH_4-N was determined using a modified sodium tetraphenylboron method (Cox et al., 1996; J. Breker, personal communication, July 7, 2022).

Data analysis was performed using JMP Pro 17 (SAS Institute, Cary, NC). Analysis of variance (ANOVA) was carried out as a randomized complete block design with a split-plot arrangement. Regression analysis was performed using JMP Pro 17 Nonlinear Modeling. Corn and wheat response to N was determined using total known available N (TKAN) (Franzen, 2023; Goettl et al., 2024) and maximum return to N methods (Sawyer and Nafziger, 2005). TKAN is calculated as the sum of preplant soil NO_3-N, prior crop N credits, no-tillage N credits, and amount of fertilizer N applied. Tillage and prior crop N credits were assessed as reported in Franzen (2023). To compare yield response to TKAN relative yield was used; relative yield was calculated by dividing the maximum yielding experimental unit at each site by yield of each experimental unit (Raun et al., 2011; Franzen et al., 2021; Goettl et al., 2024). Mean separation was performed using Student's T for comparing two means or Tukey's Procedure for comparing three or more. Analysis of wheat yield and N data during the wheat year at the Gardner site is not included in this manuscript. Data in this study was considered statistically significant at p=.05.

RESULTS AND DISCUSSION

Grain Yield and Quality

In the first cropping season following the cover crop, corn grain yield was not impacted by the presence of the cover crop (Table 1). However, corn yield did show a significant response to N fertilizer rate, as expected. When also considering TKAN and relative yield (Figure 1a), yield response was not significantly different between the cover crop treatments. The similarity of yield response to TKAN in both the cover crop and no cover crop treatment indicates no contribution or detraction of crop available N impacting corn yield following a cover crop, which is not unexpected based on previous research (Pantoja et al., 2015; Andersen et al., 2020; Leiva, 2020). Without a differing relationship between following corn yield and TKAN between previous cover crop and no cover crop in this study, it appears N sequestered in cover crop biomass is not becoming available to the subsequent crop in this environment, as also noted by (Andersen et al., 2020; Leiva, 2020).

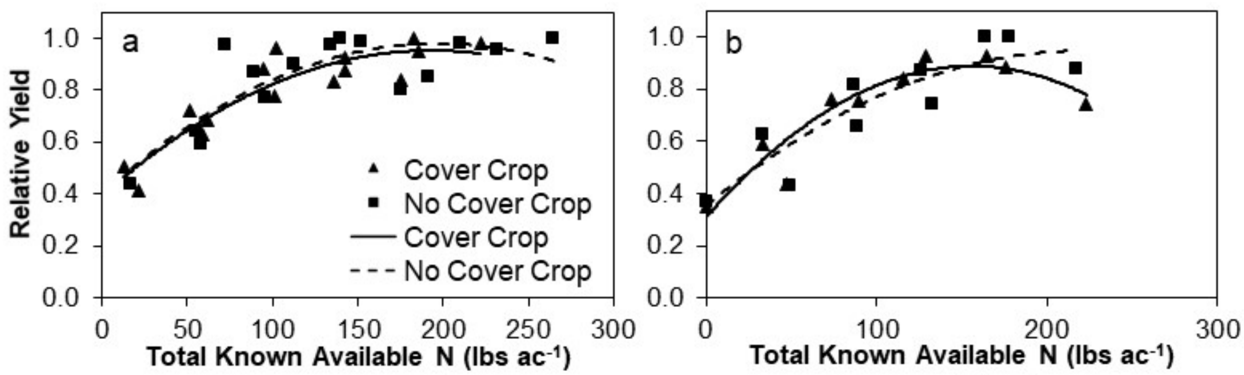
Similar to the corn yield response, wheat planted two crop years following a fall cover crop showed a significant response to N fertilizer rate, but no response to cover crop treatment at the LC and VC sites (Table 1). With increasing N fertilizer rate, not only did yield increase, but grain protein content showed a positive response (Table 1).

Unlike the corn relative yield response to TKAN (Figure 1a) where response curves for both cover crop and no-cover crop treatments follow similar quadratic shapes and have similar agronomic N rates, the wheat response to TKAN indicates differing responses to cover crop treatments (Figure 1b). Whereas maximum wheat yield for the cover crop treatments was attained at 162 lbs N ac^{-1}, maximum yield on the non-cover crop treatment was attained at 235 lbs ac^{-1}, based on the quadratic regression. North Dakota N rate studies carried out from 1969-2019 indicate the TKAN needed to attain maximum yield averages 220 lbs ac^{-1} across all productivity levels and varying management practices in eastern North Dakota.

Table 1. Mean corn grain yield following fall-seeded cover crops and wheat yield and protein content planted following the corn in eastern North Dakota.

		Corn[a]	Wheat[b]	
Effect	**Variable**	**Yield**	**Yield**	**Grain Protein**
		lbs ac^{-1}	lbs ac^{-1}	%
Cover Crop	No Cover Crop	110 a	50 a	14.2 a
	Cover Crop	101 a	49 a	13.7 a
N-Rate (lbs ac^{-1})	160	117 a	61 a	16.4 a
	120	118 a	61 a	15.4 a
	80	112 a	55 a	14.1 ab
	40	101 ab	44 ab	12.3 b
	0	80 b	26 b	11.4 b

[a]Sites were located near Logan Center, Valley City, and Gardner, North Dakota.
[b]Sites were located near Logan Center and Valley City, North Dakota.
Note: Means with the same letter within the same effect are not significantly different at the .05 probability level.



	Corn		Wheat	
Treatment	**Equation**	**r^2**	**Equation**	**r^2**
Cover Crop	$y=0.400+0.005x-1.156\times10^{-5}x^2$	0.84	$y=0.307+0.007x-1.927\times10^{-5}x^2$	0.89
No Cover Crop	$y=0.398+0.005x-1.185\times10^{-5}x^2$	0.67	$y=0.354+0.005x-9.487\times10^{-6}x^2$	0.81

Figure 1. Relative corn grain yield (a) following fall cover crop and no cover crop treatments and subsequent wheat yield (b) following the corn compared to total known available soil N at sites in eastern North Dakota.

Based on the historical wheat response to N in North Dakota and current recommendations, the TKAN rate for maximum yield on non-cover cropped treatments is near what is expected. The cover cropped treatment, however, appears to demand a lower TKAN rate to attain maximum yield (Figure 1b) indicating a potential contribution of N from the to the system not recognized in the constituents of TKAN calculation or by N fertilizer rate alone. The contribution of N is only recognized two years following cover crop growth and termination, a phenomenon also noted in North Dakota by Franzen, (2022). Additionally, the yield contribution may be from non-N-related cover crop benefits, such as increased snow capture during the winter prior to wheat planting, which was not measured in this study.

Nitrogen Pools

Soil N concentrations in the fall following cover crop termination showed a significant decrease in NO_3-N in the cover cropped treatments at two of the three sites (50 lbs N ac^{-1} lower in LC and 17 lbs N ac^{-1} lower in Gardner), NH_4-N and non-exchangeable NH_4-N showed no significant change, however. Soil samples collected in the fall following corn harvest and the spring prior to wheat harvest indicated no statistical differences in concentration of NO_3-N, NH_4-N, or non-exchangeable NH_4-N for either cover crop treatment at all sites. Soil NO_3-N levels did show a significant interaction with applied N fertilizer rate in the fall following corn and again following wheat cultivation.

CONCLUSION

Although cover crops were shown to decrease residual NO_3-N in soil thereby decreasing the risk of leaching, the results of this study align with previous work indicating N sequestered in cover crop biomass does not become available the subsequent cropping season. Although a yield benefit from the cover crop was not seen, it is important to note a decrease in yield was not noted, either. Planting a cover crop for soil health and environmental-service benefits did not come at a detriment to the following corn crop. In the second year following cover cropping practices, no yield benefit was realized; however, it does appear the cover crop has an impact on N response two cropping seasons following its growth. The lower N demand of the crop two years following a cover crop indicates a potential second-year credit from cover crops may be attained. Although the source of the N credit cannot be determined by the present study, future long-term studies should be carried out to determine the magnitude of this occurrence.

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WISCONSIN'S NITROGEN OPTIMIZATION PILOT PROGRAM: HIGHLIGHTS AND SUCCESSES OF ON-FARM RESEARCH

M. Schauer and M. Ruark
University of Madison Wisconsin, Madison, WI

ABSTRACT

Accurately determining nitrogen (N) fertilizer requirements for crops is challenging due to the wide variability introduced by management practices and environmental conditions. Over-application reduces profits and negatively affects water quality, while under-application can prevent yield targets from being reached. Conducting field-scale, on-farm research is a practical approach to better estimating optimum N rates on a field by field basis. In 2023, Wisconsin's Department of Agriculture, Trade and Consumer Protection established the Nitrogen Optimization Pilot Program (NOPP) to provide funding for farmers to conduct their own N rate trials, in collaboration with UW-Madison. So far, the program has supported 37 projects, conducting trials on 71 Wisconsin farms, which has led to valuable insights into management and region-specific N needs. These trials address producer and partner driven research questions, ranging from evaluating alternative N sources and timings, determining if optimum N rates varied by landscape position, and assessing the optimum N rate following a cover crop. Here, we highlighted the most interesting case studies to showcase how on-farm trials have shaped producer-driven decisions and demonstrate the potential of on-farm research to influence the future of nutrient management.

INTRODUCTION

Accurately predicting the N fertilizer needed for corn (*Zea mays* L.) during the growing season is an ongoing challenge in Wisconsin. Managing N fertilization effectively is critical to optimizing corn yield while minimizing environmental impacts and improving producers' bottom line. Current N recommendation tools provide an estimate of crop N need, but farm and field specific management may affect the accuracy of those estimates (Morris et al., 2018). Factors such as N source, timing, and placement coupled with other uncontrollable factors such as soil type, temperature, and precipitation, make it difficult to develop state or regional recommendations that are consistently reliable in the absence of long-term N rate trial data (Puntel et al., 2016). To improve the precision and accuracy of future optimum N rate models, N rate studies need to be carried out on a variety of management and soil conditions.

To address these issues regarding N demand of crops in Wisconsin, replicated N rate studies were conducted on-farm under a variety of management conditions. Wisconsin's Department of Agriculture, Trade and Consumer Protection established the Nitrogen Optimization Pilot Program to provide grants for farmers to conduct research projects aimed at answering specific N-related questions on their farms.

Under 92.14(16), Stats., grant recipients shall collaborate with UW-Madison to implement a project that optimizes the application of commercial N and is carried out for at least two growing seasons. The objectives of these trials were to i) assess the value of early spring soil testing in accounting for available soil N, ii) to determine the economic and agronomic optimum N rate of corn, and iii) to determine the effect of a specific field variable (i.e., tillage, n-fixing product, cover crops, or zone management) on subsequent corn yield and optimum N rate.

MATERIALS AND METHODS

On-farm N rate trials were conducted in Wisconsin in 2023 across 33 counties. Here, we will focus on three of these trials that took place in Jefferson, Green, and Lafayette counties. Site 1 used an N rate trial to explore the N requirement of corn on two soil types. The experimental design was a randomized complete block design with six N rates and 4 replications in a low area of the field with finer textured soil and duplicated in a high area of the field with coarse textured soil. Site 2 used an N rate trial (six rates) to explore N need of corn, planted green following a rye cover crop. The experimental design was a randomized complete block, split plot design with four replications. The whole plot factor was a rye cover crop and the split plot factor was N rate. Site 2 used an N rate trial (eight rates) to explore a biological product that claims to fix N. The experimental design was a randomized complete block, split plot design with four replications. The whole plot factor was use of the biological product and the split plot factor was N rate.

At all sites, soil nitrate samples were collected pre-plant as a composite bulk sample of 8-12 cores per block at a depth of 0-1' and 1-2'. Routine soil samples at a depth of 0-6" were also collected at this time. Site 2 collected cover crop biomass in fall before the first hard frost and in spring before termination to be analyzed for C:N. Yield was measured on a plot basis using a weigh wagon for sites 1 and 3 while a yield monitor was used for site 2. Nitrogen response curves were chosen based on the best fitting model according to RMSE and adjusted R^2. The economic optimum nitrogen rate (EONR) was derived from the parameters of the best fitting model using a nitrogen to corn price ratio of 0.1.

RESULTS

Site 1- Soil comparison

The fine textured field area had about 4% greater organic matter (Table 1) and greater preplant soil nitrate than the field with a coarse texture (Table 2). The coarse textured field reached EONR at 190 lb-N/ac while the response curve of fine textured field area did not plateau or reach EONR (Figure 1). Yield was consistently greater in the fine textured field area than the coarse across all N rates.

Table 1. Site 1 baseline soil analysis sampled pre-plant by field soil texture area at a depth of 0-6" prior to any nitrogen application.

	pH	OM	CEC	P	K	Ca	Mg

		%		- - - - - - - ppm - - - - - - -			
Coarse	7	1.9	8.7	77	129	1313	180
Fine	7.5	6.2	29	23	91	3920	665

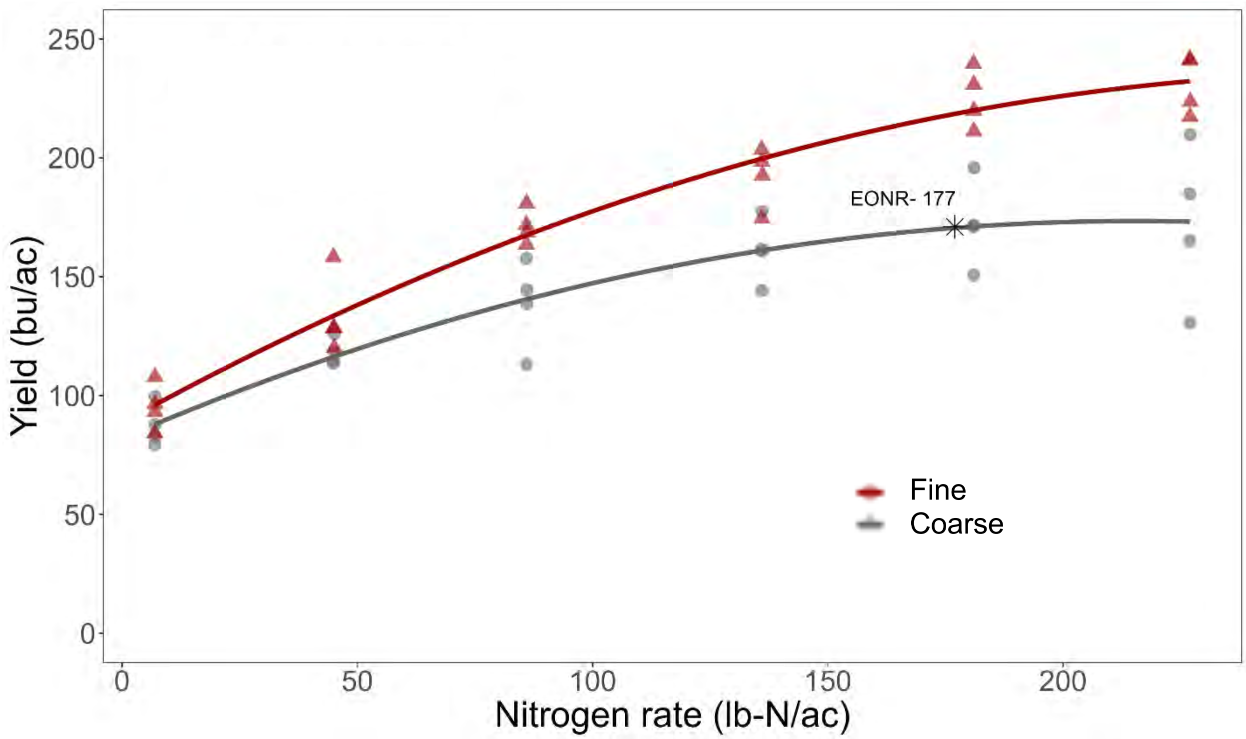

Figure 1. Quadratic nitrogen rate yield response curve of coarse and fine textured soil field area across six nitrogen rates. EONR was calculated using the parameters of the curve and a nitrogen to corn price ratio of 0.1.

Site 2- Biological product

Site 2 had the greatest soil nitrate of any of the sites, with nearly as much nitrate in the second foot as the first (Table 2). The use of the biological product did not lead to an increase of yield at any nitrogen rate. The quadratic curve was the best fit for both the control and biological treatment. In the biological treatment EONR was reached at 121 lb-N/ac while the control reached EONR at 124 lb-N/ac (Figure 2).

Table 2. Pre-plant soil nitrate for all sites at the depth of 0-1' and 1-2'.

		Pre-plant soil nitrate (NO_3-N)		
		0-1'	1-2'	Total
		- - - - - -	lb/ac	- - - - - -
Site 1	Coarse	7.7	2.6	10.3
	Fine	29.4	12.4	41.8
Site 2	-	35.0	31.0	66.0
Site 3	Rye	8.9	6.1	15.0
	No cover	23.6	21.0	44.6

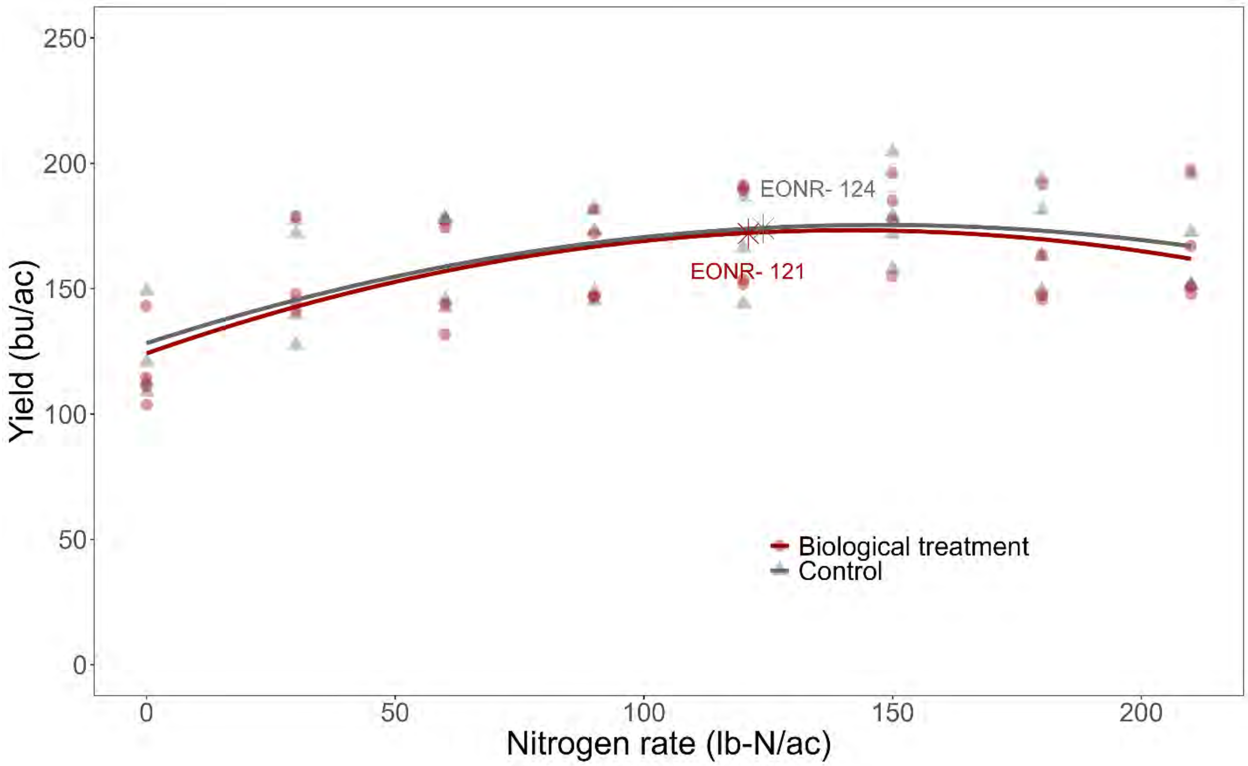

Figure 2. Quadratic nitrogen rate yield response curve of biological product treatment and control across eight nitrogen rates. EONR was calculated using the parameters of the curve and a nitrogen to corn price ratio of 0.1.

Site 3- Rye cover crop

Total biomass of the rye cover crop was 2355 lb/ac across the field, with a C:N of 22 and total nitrogen uptake of 48 lb/ac. The no cover control treatment had greater soil nitrate than the rye cover crop at both soil depths (Table 2), an indication of the nitrogen uptake by the cover crop. Quadratic plateau was the best fit curve for both the rye cover crop and no cover control. Corn yield was consistently lower following a cover crop than no cover, with the largest difference at lower N rates (Figure 3). EONR was 182 lb-N/ac following the cover crop and 154 lb-N/ac without cover.

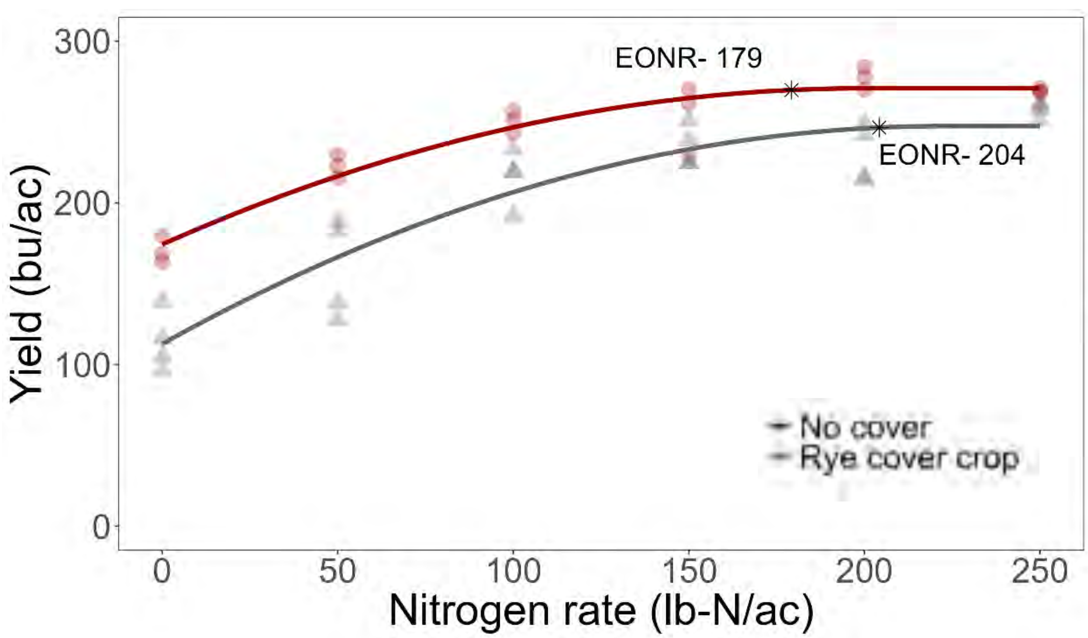

Figure 3. Quadratic plateau nitrogen rate yield response curve of corn following a cover crop treatment and bare control across six nitrogen rates. EONR was calculated using the parameters of the curve and a nitrogen to corn price ratio of 0.1.

CONCLUSION

The added field variables studied in each of these specific sites highlighted the importance of farm specific nitrogen rate studies. Site 1 demonstrated the importance of managing areas of the field separately, considering yield potential and nitrogen need may differ greatly based on soil variability. Site 2 proved the importance of testing the efficacy of nitrogen supplying products before making changes to nitrogen management or investing in products across the farm. Site 3 highlighted the benefit in rye as a cover crop in terms of scavenging nitrogen, but proved that some additional nitrogen is sometimes needed to maintain yields, and even then, yield loss may occur. All of these results are based on only one season of data, so management decisions should not be made until more data is accrued, although previous research in Wisconsin would support all of these findings.

These three case studies demonstrate the importance of providing farmers with the tools to conduct their own trials to gain practical knowledge on nitrogen management on their farm. Participating in on-farm nitrogen rate trials gave agronomic insight and provided value for university researchers, farmers, and other project partners. Data from these on-farm studies have generated interest from local farmers as the data continues to be shared at field days and webinars. On-farm trials continue to highlight variability across the Wisconsin landscape and farming systems, proving the need for more local farmer generated data.

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

A. Sadeghpour[1&2], C. Kula[1], G. Guzel[1]
[1]School of Agricultural Sciences, Southern Illinois University
[2]Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West

ABSTRACT

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

INTRODUCTION

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

MATERIALS AND METHODS

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

Cover crops were planted on Sept. 23rd, 2020 with a John Deere 450 series grain drill (John Deere, Moline, IL, USA) and terminated via burndown on April 13th, 2021. Prior to termination cover crops were sampled from a 7.2 ft^2 area using grass shears. Cover crops were oven dried at 60 ◦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.

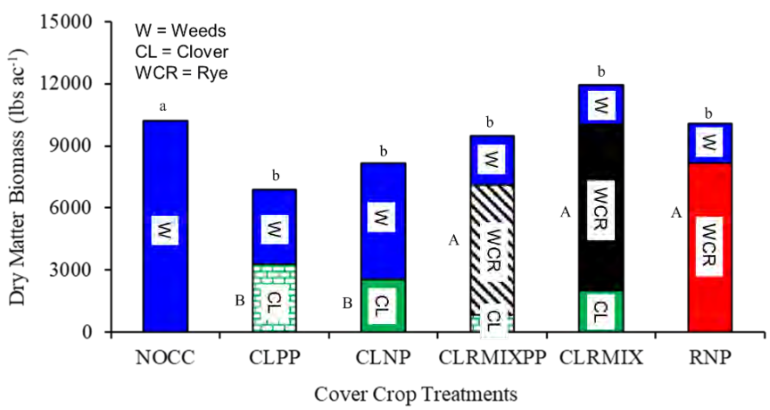

Figure 1. Cover crop (clover and rye) and weed dry matter biomass in each cover crop treatment. (lower case letters compare weed biomass and capital letters compare cover crop biomass) indicate significant difference (<0.05, Tukey). Treatments were no cover crop control (NOCC), crimson clover precision 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.

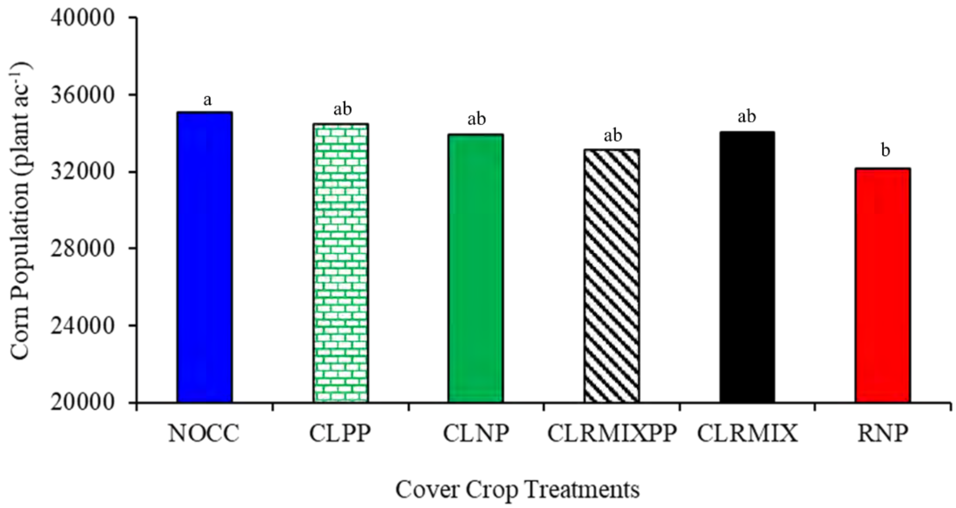

Figure 2. Corn plant population as influenced by cover crop treatments. (a, ab, b) indicate significant difference (<0.05, Tukey). Treatments were no cover crop control (NOCC), crimson clover precision planted (CLPP), crimson clover solid planted (CLNP), crimson clover on corn row winter rye (WCR) on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

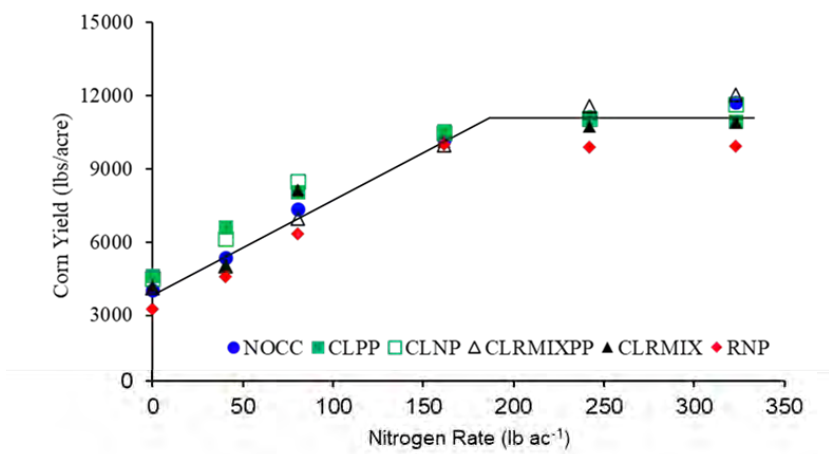

Figure 3. Response of corn grain yield to N fertilization rates and EORN for corn in 2021. Treatments were no cover crop control (NOCC), crimson clover precision planted (CLPP), crimson clover solid planted (CLNP), crimson clover on corn row winter rye (WCR) on middle rows (CLRMIXPP), crimson clover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

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IMPACT OF NITROGEN APPLICATION TIMING ON CORN YIELD AND FARM PROFITABILITY IN DIFFERENT WHEAT COVER CROPPING SYSTEMS

F. Adeyemi[1], O. Adeyemi[1] J. McGrath[2], S. Armstrong[3], A. Sadeghpour[1&4]
[1]School of Agricultural Sciences, Southern Illinois University
[2]Office of National Programs, USDA-ARS
[3]Department of Agronomy, Purdue University
[4]Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West

ABSTRACT

The continuous increase in the concentrations of nitrogen (N) and phosphorus (P) in the Upper Mississippi River Basin (UMRB), has led to the introduction of mitigation strategies with the use of winter cereal cover crop such as winter wheat (*Triticum aestivum*). The understanding of the use of these winter cereal cover crops in relation to soil N and its impact on corn yield is imperative. The study investigates the impact of cover crop and N application timing on corn production over two years. The experimental design was a Randomized Complete Block Design with four treatments and four replicates in Agronomy Research Center, Carbondale, IL between two growing seasons. The Main plots were cover crop treatments and subplots were the subplots five N fertilizer application timings (ranging from all N fertilizer upfront to all N applied at sidedress timing). Corn yield was higher in 2018 than 2019 reflecting more timely precipitation in that year. In 2018, grain yield declined by 12.6% following the wheat cover crop compared to no cover crop control, indicating a yield penalty when corn was preceded with a wheat cover crop. In 2018, a year with timely and sufficient rainfall, there were no yield differences among N treatments and N balances were near zero. In 2019, delaying the N addition to sidedress timing resulted in high yields. Split application of N (50-100 lbs/acre or 50-150 lbs/acre) was consistently most productive in both years suggesting that there is an advantage to sidedressing than upfront N application in cover crop systems.

INTRODUCTION

Illinois is evaluating management practices to reduce N losses to the Upper Mississippi River Basin (UMRB) (Lacey et al., 2020). Based on Illinois Nutrient Loss Reduction Strategy (INLRS, 2017), winter cereal cover crops are the best on-farm practices to reduce N loss in corn–corn or corn–soybean (*Glycine max* L.) cropping systems. Therefore, planting winter cereal cover crops has been encouraged to effectively reduce nitrate-N in the tile drainage. Planting a winter cereal cover crop before corn could decrease corn yield as a result of reduced N availability in spring due to N immobilization caused by high C:N ratio of cover crop residue or soil moisture depletion by the winter cereal early in the spring (Singh et al., 2020). There have been studies on cover crop N release potentially happening simultaneously with cash crop N demand, but results have shown a decrease in cash crop N uptake (Ruffatti et al., 2018). The literature suggests corn N need increases or corn yield potential decreases when rye (*Secale cereal* L.) is planted prior to corn (Pantoja et al., 2015). Unlike cereal rye, studies on wheat as a cover crop prior to corn are scant in Illinois. Wheat is a low-cost and versatile cover crop and growers are often familiar with wheat management. Our objective was to evaluate whether split N application to corn changes corn N need and NUE in no-cover crop compared to following an early terminated wheat cover crop.

MATERIALS AND METHODS

Experimental Site and Weather Conditions

A field trial was conducted at the Agronomy Research Center in Carbondale, IL (37.75° N, 89.06° W) during 2017–2018 and 2018–2019 growing seasons. From this point forward, to simplify presenting our results, 2017–2018 is referred to 2018 and 2018–2019 is referred to 2019. In 2018, soil was classified as Weir silt loam (fine, smectitic, mesic Typic Endoaqualfs) and in 2019, the soil was classified as Stoy silt loam (fine-silty, mixed, superactive, mesic Fragiaquic Hapludalfs).

Mean air temperature during the growing season (May–November) was close to the 30-year average in Carbondale, IL (data not shown). The cumulative growing season precipitation (May–November) was 844.80 mm (33.2 inches) in 2018 and 852.42 mm (33.5 inches) in 2019, while the 30-year average precipitation during May–November amounted to 718.82 mm (28.3 inches). These data indicate that both 2018 and 2019 were wetter than the 30-year average and that differences from year-to-year were mainly due to temporal distribution rather than total precipitation. Precipitation in May 2018 was close to 30-year average but lower than 2019, indicating more suitable growing conditions for timely corn planting and corn establishment in 2018 than 2019.

Experimental Design and Treatments

The experiment was conducted as a randomized complete block design with split plot arrangement and four replicates. The main plots were two cover crop treatments: no cover crop (control) and a cover crop (wheat) terminated four weeks (at stem elongation stage) prior to corn planting and the subplots were five N timing applied to the subsequent corn. All N treatments received a total amount of 150 lbs N/acre at a various combination of preplant and post-plant sidedress as: (1) 150 lbs N/acre applied at planting; (2) 50 lbs N/acre applied at planting plus 100 lbs N/acre applied at sidedress; (3) 100 lbs N/acre applied at planting plus 50 lbs N/acre applied at sidedress timing; and (4) 150 lbs N/acre applied at sidedress timing. A zero-N control treatment was also included in the study forming 10 treatments in total.

Cultural Management Practices

Wheat Establishment

Wheat (cv. “Agrimaxx 446”) was planted with a grain drill on 26 October 2017 and 15 November 2018 at a rate of 1.5 million seeds/acre.

Corn Planting and Management

Plots were 33 ft long and 10 ft wide. A no-till drill was used to plant corn (Dekalb “DKC64-35RIB”) at 30,000 seeds/acre on 25 May 2018 and 24 May 2019. Preplant N was applied at planting in the form of liquid urea ammonium nitrate (UAN; 28%). The sidedress N was applied at corn V5 stage (18 June 2018 and 1 July 2019) using

UAN (28%). Later sidedress timing in 2019 reflects the challenging year with excessive rainfall in 2019.

Data Collection

Wheat Sampling

Tissue samples were collected four weeks before corn planting date on 20 April 2018 and 23 April 2019 when wheat plants were at the stem elongation stage (Feekes 7). Samples were then dried at 60 °C until constant dry weight. The oven-dried samples were then ground to 0.6 mm particle size and analyzed for N and C content using dry combustion (Flash 2000 Elemental Analyzer, Thermo Scientific, Cambridge, UK).

Corn Sampling

The corn was machine-harvested on 13 November 2018 and 10 October 2019. A grain subsample was taken from each plot for measuring N concentration using wet chemistry. Nitrogen removal by stalks and leaves was estimated at 45% of the grain N removal (Otte et al., 2019). Sum of N content in grain and N content in stalks was used for NUE calculation.

Nitrogen Balance and N Use Efficiency

Nitrogen balance for each treatment was calculated by subtracting N removed by grain harvesting (lbs grain yield/acre × % N in the grain) from N applied for each fertilizer treatment in each year (Sadeghpour et al., 2017). Since corn stover remained in the field, N content of corn stover was not included in N removal calculation.

The NUE (lbs DM lbs N) was determined as (lbs DM at Nx - lbs DM at N0)/lbs of applied N where Nx = N rate > 0, and N0 = no N application (Ketterings et al., 2007).

Statistical Analysis

Data were analyzed using Proc Mixed of SAS. The fixed effect in the model was year, cover crops, and N treatments and block was a random effect. When treatment effects were significant, mean separation was performed using least significant difference (LSD).

RESULTS AND DISCUSSION

Wheat Biomass and N Uptake

Wheat produced 0.71 tons/acre biomass (dry matter basis) by the time of termination in 2018 which was four-fold higher than in 2019 reflecting: (i) earlier planting in 2018; and (ii) less favorable growing conditions in 2019. Nitrogen uptake by wheat cover crop in 2018 was 21 lbs N/acre, which was more than three-fold higher than 2019. This indicates the importance of timely planting of wheat to establish and perform well in spring.

Corn Grain Yield, N removal, Balances, and NUE

Grain yield was influenced by year, cover crop, N application, and year × N application. Mean grain yield was notably greater in 2018 (9813.9 lbs/acre) than in 2019 (5263.9 lbs/acre), reflecting the effect of precipitation on year-to-year yield variation (Table 1). While 2018 received even and timely precipitation, 2019 was a very wet year in Carbondale, IL contributing to substantial N loss and thus lower grain yields. Maximum corn grain yield in cover crop treatment was 14% lower compared to the maximum yield in no cover crop control confirming that N immobilization could most likely have caused yield reduction (Weidhuner et al., 2019). In 2018, a year with timely precipitation, there were no corn yield differences among N application treatments (Table 1). In 2019, an extremely wet year, corn grain yield increased by delaying N application from planting to sidedress timing indicating that later application of N possibly decreased N losses (leaching or nitrous oxide emissions) in heavy soils of southern Illinois (Table 1). This highlights the importance of timely application of N fertilizer to meet corn N demands after the V4 stage.

Corn N removal was influenced by year, cover crop, year × cover crop, N application, and year × N application. Mean N removal (112 lbs/acre) was greater in 2018 than N removal (46 lbs/acre) in 2019 due to much lower grain produced in that year. Excluding the zero-N control, N removal was 124.9 lbs/acre in 2018 vs. 50.8 lbs/acre N removal in 2019. In 2018, N removal by corn after wheat cover crop was 20% lower compared to the control treatment without cover crop (data not shown). In 2019, N removal was similar between the two cover crop treatments (data not shown). This indicates that, in the year with a favorable condition (2018), corn had decent growth and required N. Thus, wheat presence, using some of the available N, in addition to N immobilization resulted in a significant difference between no cover crop and cover crop treatments. In 2019, a wet growing season impacted corn growth resulting in lower N removal.

Nitrogen balance was affected by year, cover crop, year × cover crop, N application, and year × N application. Excluding the zero-N control, N balance was 2.6 lbs/acre in no cover crop control and 26.5 lbs/acre in wheat cover crop, suggesting more N was needed when wheat was the preceding cover crop to corn compared to no cover crop control.

All N application treatments had slightly positive N balance (13.3 lbs/acre; average of N treatments) with no difference among the N treatments. In 2019, N balance was lower in all sidedress treatments followed by split application of 50 lbs N/acre at planting plus 100 lbs N/acre at sidedress timing, indicating lower yield, and possibly greater N loss with early N application timing in a very wet year.

Nitrogen use efficiency was affected by year, cover crop, year × cover crop, and year × N application. The NUE was higher in 2018 than 2019 in line with slight positive N balances, and overall greater yield in that year.

Table 1. Corn grain yield and nitrogen (N) concentration, N balance and removal, partial factor productivity (PFP), and N use efficiency (NUE) as affected by different N rates in 2018 and 2019 growing seasons.

		Grain Yield	Grain N Concentration	N Removal	N Balance	NUE
	N treatments †	(lbs/acre)	(%)	(lbs/acre)	(lbs/acre)	lbs yield/lbs N
2018	N0	6156 [b]	1.052 [b]	64.2 [b]	-64.7 [b]	
	N150U	10795 [a]	1.136 [a]	122.7 [a]	16.4 [a]	28.5 [a]
	N100U50S	11241 [a]	1.147 [a]	129.4 [a]	9.7 [a]	30.0 [a]
	N50U100S	10349 [a]	1.173 [a]	121.8 [a]	17.3 [a]	25.0 [a]
	N150S	10884 [a]	1.164 [a]	126.1 [a]	13.0 [a]	29.0 [a]
2019	N0	2854 [c]	1.010 [a]	29.0 [b]	-29.0 [c]	
	N150U	3390 [c]	0.950 [a]	31.2 [b]	107.9 [a]	3.6 [c]
	N100U50S	5085 [b]	0.949 [a]	41.6 [b]	97.6 [a]	15.8 [b]
	N50U100S	6066 [a.b]	1.060 [a]	64.5 [a]	76.6 [b]	24.2 [a]
	N150S	6423 [a]	1.026 [a]	66.1 [a]	73.1 [b]	25.5 [a]

Numbers within columns followed by different letters indicate significant difference at $p \leq 0.05$. † N0, zero-N control; N150U, 150 lbs N/acre applied at planting; N100U50S, 100 150 lbs N/acre applied at planting plus 50 150 lbs N/acre applied at sidedress timing; N50U100S, 50 150 lbs N/acre applied at planting plus 150 lbs N/acre applied at sidedress; N150S, 150 lbs N/acre applied at sidedress timing.

CONCLUSIONS

Our results indicate weather conditions, especially temporal distribution and amount of rainfall, impact the effectiveness of split N application. In 2018, a year with timely and sufficient rainfall, there were no differences among N treatments except for zero-N control. In a wet growing season, delaying N addition improved NUE and corn grain yield indicating N losses were substantial early in the season and that later N fertilization allows for better utilization of applied N. Wheat cover crop effect on corn N requirement was also weather dependent. In 2018, wheat decreased corn yield potential possibly due to N immobilization, which indicates a need for revisiting corn N rate recommendations and fine-tuning N application timing following wheat cover crop. In 2019, due to excessive rainfall, corn yields were lower than average and cover crop effects on corn yield were not detectable. Overall, inclusion of crediting system for cover crops could help current N management systems in Illinois.

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NITROGEN APPLICATION TIMINGS IN NO-TILL DRYLAND CORN PRODUCTION SYSTEM

N. Adotey, R. Blair, R. Adotey, and N. Montgomery
University of Tennessee

ABSTRACT

Right timing of nitrogen application is one of the practices of the 4 R nutrient stewardship. Three independent trials using a randomized complete block with 4 replications were conducted to determine the optimal (1) split rate, (2) proportion and (3) timing for sidedress N application in non-irrigated corn. In trial 1 (13-site years), five N rates were examined: 60, 120, 180, 240, and 300 lb N/A, which were applied at two split-applications. Split-applications included single- and split-application. In trial 2 (2 years), the N proportions evaluated included 180/0, 120/60, 60/120, 90/90,40/100/40, 0/180 lb N/A. The proportion of N was applied at planting and/or at sidedress) for a total of 180 lb N/A. In trial 3 (2 years), the sidedress N timing evaluated included V6, V8, V12, V14 growth stage. Split-applications increased corn yield over single-applications at the 120 lb N/A and beyond except in 2023. There was no significant yield difference at the 180 lb N/A rates and the rates beyond for split-application. The optimal spilt proportion of N fertilizers was 60/120 lb N/A. In 2022, there was at least 15% yield penalty when 2/3 or more of the total recommended N was applied at planting. The optimal sidedress N application time was between V6 and V8. A 15-40% yield reduction were observed when N was delayed until the V14, respectively. Split application is recommended when N rates are greater than 120 lb N/A. If split application is recommended, then split apply 1/3 at planting and sidedress the remaining around V6 growth stage.

HARVESTING TIME BASED ON GROWING DEGREE DAYS INFLUENCED WINTER CEREAL RYE MORPHOLOGICAL TRAITS, FORAGE YEILDS, QUALITY, AND FARM PROFIT IN POORLY DRAINED ALFISOLS

G. Burkett[1], S. Babaei[1], K. Vaughn[1], O. Adeyemi[1], O.M. Zandvakili[1], M.L. Battaglia[2], J. Nair[3], S. Still[1], A. Sadeghpour[1&4]

[1] School of Agricultural Sciences, Crop, Soil, and Environmental Program, Southern Illinois University
[2] School of Agricultural Sciences, Animal Science Program, Southern Illinois University
[3] Department of Animal Science, Cornell University
[4] Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West

ABSTRACT

Winter cereal rye (*Secale cereale* L.) (WCR) is often double-cropped with maize for silage (*Zea mays* L.) to increase forage supply and farm profit. Spring nitrogen (N) fertilization of WCR can influence production and quality at various harvesting times. The experiment was conducted over the 2019–2021 growing seasons to evaluate the effects of harvesting time (late March to end of April based on growth stage) and spring N fertilization (0 and 47 kg N ha^{-1}) on WCR morphology, forage yield, nutrient removal, quality, and farm profit. A quadratic model best described the increase in WCR dry matter (DM) yield with growing degree day (GDD) accumulation ($R^2 = 0.81$). As GDD increased, WCR relative forage quality (RFQ) declined linearly. Benchmarking RFQ at 150 for dairy milk production indicated WCR should be harvested at a GDD of 543, at which plant height was 31.8 cm and DM yield was 0.77 Mg ha^{-1}. Harvesting at a GDD of 668, where RFQ was suitable for heifer production, produced a plant height of 71 cm and DM yield of 2.25 Mg ha^{-1}. If harvesting WCR occurs early at GDDs lower than 744, no N fertilizer in spring is required. If the goal is to maximize DM yield and forage quality is less critical, then N fertilization is needed to increase DM yield at later harvesting times (GDDs > 744). Therefore, N need of WCR depends on the harvesting time or growth stage.

INTRODUCTION

Dairy farmers must balance profitability, animal nutrition, and environmental sustainability. In corn silage–alfalfa rotations, Illinois growers often “double crop” winter cereal rye (WCR) with corn silage, benefiting soil health, nutrient cycling, and forage supply (Nair & Ngouajio, 2012; Lyons et al., 2019). Profitability in this system depends on managing WCR nitrogen (N) and harvest timing (Mirsky et al., 2017), with high-quality forage generally harvested from boot to early heading stages (Zadoks et al., 1974). Later stages increase yield but often reduce forage quality (Collar & Askland, 2001). Studies show that as WCR matures, acid detergent fiber (ADF), neutral detergent fiber (NDF), and lignin increase, while crude protein (CP), total digestible nutrients (TDN), and relative forage quality (RFQ) decrease.

Understanding WCR's N requirements is essential to maximizing profit and minimizing environmental impacts. N is a significant cost, and optimal rates vary based on factors like manure history, soil organic matter (SOM), and harvest timing; fields with high SOM may require minimal N (Lyons et al., 2019). On farms with manure history, it is critical to assess if high-SOM soils respond to spring N fertilization to improve sustainability and profitability, given forage quality influences price (Halopka, 2023). Nitrogen application can improve WCR dry matter (DM) yield, CP, dry matter digestibility (DMD), TDN, and RFQ (Delevatti et al., 2019). However, excessive N may reduce fiber digestibility and unbalance livestock diets, impacting economic returns.

This study aimed to assess the effect of harvest timing, based on growth stage, and N addition on WCR's (i) morphophysiological traits; (ii) forage yield and quality parameters (e.g., CP, TDN, RFQ); (iii) N requirements; and (iv) farm profit. We hypothesized that in soils with high SOM (>30 g kg^{-1}) and fall-applied manure, no spring N might be required for WCR optimum production.

MATERIALS AND METHODS

Field experiments took place near Breese, IL, from October 2019 to April 2021. Initial soil samples were taken to 20 cm for physical and chemical analysis. The trial followed a randomized complete block design with five replicates, conducted over two years (2019–2020 and 2020–2021), with 3.3 m x 5 m plots. Treatments consisted of five WCR harvest times from late March to late April, based on Feekes and Zadoks scales (Large, 1954; Zadoks et al., 1974), and two N rates (0 and 47 kg N ha^{-1}). WCR plots were fertilized with liquid dairy manure at 34 kL ha^{-1}, seeded at 90 kg ha^{-1} following corn silage in October, and top-dressed with urea in March (Vaughn et al., 2024). Plant height, leaf area index (LAI), and biomass were measured weekly from late March to late April. Biomass samples were collected from a 0.675 m^2 area within each plot, dried at 48°C for 72 hours for dry matter (DM) yield, and then ground for forage quality analysis (Weidhuner et al., 2019).

Forage quality indices, determined using near-infrared reflectance spectroscopy (NIRS), included CP, ADF, NDF, NDFD, NFC, fat, ash, and lignin. Calculations were made for total digestible nutrients, dry matter digestibility (DMD), in vitro dry matter digestibility (IVDMD), dry matter intake (DMI), relative forage quality (RFQ), net energy gain (NEG), lactation (NEL), maintenance (NEM), N removal, partial factor productivity (PFP), apparent N fertilizer recovery (ANFR), and nitrogen use efficiency (NUE) (Vaughn et al., 2024).

The economic analysis evaluated forage yield and quality responses to harvest timing (GDD) and N rates, incorporating costs for urea, operations, forage prices, and RFQ levels. Sensitivity analysis considered average forage prices and adjustments at 80% and 120%, accounting for N operational, urea, and fixed costs as inputs. Yield and quality impact forage price (Vaughn et al., 2024).

Data were analyzed using PROC MIXED. In this split-plot design, N rate was assigned to main plots and harvest timing to subplots. For significant interactions, regression against growing degree days (GDD) by year employed linear, quadratic, and exponential models (JMP Pro 14). Model selection was based on p-values, R^2, and root mean square error (RMSE). Fisher's LSD test and contrast analysis were applied for mean separation (P ≤ 0.05).

RESULTS AND DISCUSSION

Winter cereal rye plant height was significantly affected by year, N rate, harvesting time, and year x harvesting time interaction (P ≤ 0.05). Averaged across GDDs, plants were taller in 2021 (84.9 cm) than in 2020 (59.5 cm), due to higher GDDs in 2021. Plants were taller in 2021 at each sampling date (Fig. 1A). Leaf area index (LAI) was influenced by N rate, harvesting time, and their interaction. At the fertilized rate of 47 kg N ha^{-1} (N47), LAI reached its maximum at 744 GDD, suggesting that fertilized WCR maintained maximum LAI up to the heading stage (Fig. 1B). For the unfertilized control (N0), LAI was maximized at 620 GDD. WCR dry matter (DM) yield was impacted by year, harvesting time, and interactions between year × harvesting time and N rate × harvesting time. DM yield was lower in 2020 (1.79 Mg ha^{-1}) compared to 2021 (2.93 Mg ha^{-1}). Harvesting time affected DM accumulation differently each year (Fig. 1C&D).

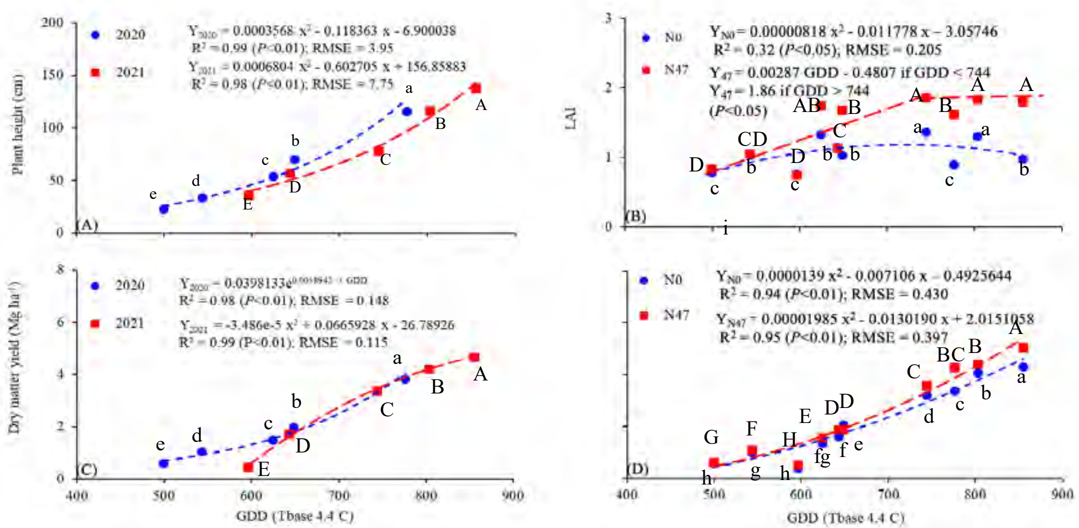

Fig. 1. The year × growing degree day (GDD) interaction for winter cereal rye plant height (A) and dry matter (DM) yield (C), and N rate × GDD interaction for leaf area index (LAI) (B), and DM yield (D) at Breese, IL USA

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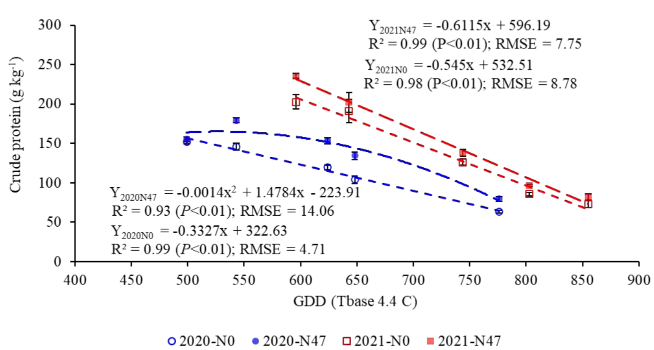

Fig. 2. The year × N rate × GDD interaction for WCR CP concentration at Breese, IL USA. Values are the means of five replicates. RMSE= Root means square error. The bars indicated as standard error. N0 = zero-N; N47 = 47 kg N ha^{-1}.

For forage quality indicators, CP was influenced by year, N rate, harvesting time, year × harvesting time, and year × N rate × harvesting time interaction. At the initial harvesting time, CP was higher in N47 than N0 in 2021 but similar in 2020, both higher in 2021 (Fig. 2). Acid detergent fiber (ADF), NDF, lignin, fat, NEL, NEM, NEG, and TDN were all influenced by year, harvesting time, and year × harvesting time interaction ($P \leq 0.05$). An increase in ADF, NDF, and lignin with an increase in GDD accumulation means WCR fat, NEL, NEM, NEG, and TDN decreased by delaying the harvesting time. Dry matter digestibility (DMD), DMI, IVDMD, and NDFD were all influenced by year, harvesting time, and year × harvesting time interaction ($P \leq 0.05$). Dry matter intake potential was higher in the first four harvesting times in 2021 than in 2020, indicating higher quality forage as reflected by the lower NDF and higher TDN in 2021 than in 2020 in these sampling dates. The DMI potential (16.6 g kg^{-1} averaged over the two years) was similar between the two years only in the final harvesting time when WCR was headed. Neutral detergent fiber digestibility (NDFD) was also higher on all harvesting times in 2021 than in 2020. Relative forage quality was only affected by harvesting time and year × harvesting time interaction ($P \leq 0.05$). Relative forage quality was similar in the initial sampling dates between the two years. The RFQ was 6 and 15% higher in sampling dates 2 and 3, respectively, in 2021 (Fig. 3).

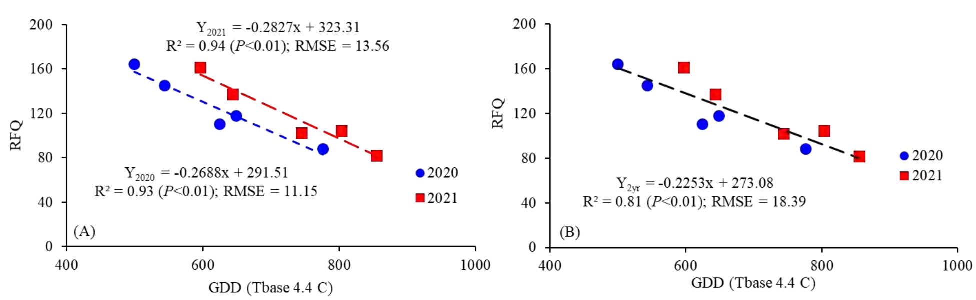

Fig 3. The year × growing degree day (GDD) interaction and linear model relation for WCR RFQ (A) and averaged over the two years (B) at Breese, IL USA. Values are two N rates and five replicates. RMSE = root mean square error.

Our results indicated that regardless of GDD, at every sampling date, profit decreased by N fertilization. In 2021, the highest profit occurred at GDD of 744-803 for both N0 vs. fertilized treatments. Similar to 2020, adding N fertilizer decreased profit at every sampling date, in line with our hypothesis that spring N addition at early harvest for high RFQ is not economical in soils with high SOM with previous manure history. Additionally, there was a harvest reduction at all harvesting dates, therefore, growers must evaluate their field history of manure management and soil capacity to deliver N in spring when fall manure is applied.

If harvesting WCR occurs early at GDDs lower than 744, no N fertilizer in spring is required. If the goal is to maximize DM yield and forage quality is less critical, then N fertilization is needed to increase DM yield at later harvesting times (GDDs > 744). To produce high-quality forage for milking cows (RFQ > 150), WCR should be harvested at 31.8 cm height when DM yield is at 0.77 Mg ha^{-1}. If the goal is to produce a lower quality for heifer/beef production, an RFQ of 125-30 is desirable. To achieve an RFQ of 125, WCR should be harvested at 71 cm height, at which the forage DM yield is 2.25 Mg ha^{-1}. Higher forage value prices had a higher effect on increasing profit than lower fertilizer and operation costs. Thus, under high forage quality and increased forage value, fertilizing may benefit growers, but as the value of forage decreases or fertilizer price increases, it does not pay off, even with increased yields. Such results have sustainability implications because adding N in spring means increased farmer costs, and not capturing the N benefit means higher unused N in the soil system, which could lead to more significant N losses.

CONCLUSIONS

A critical decision for growers in the Midwest USA managing WCR double-cropped with corn silage is finding best management practices. Our results indicated that harvest should occur at a growing degree day (GDD) of 543 to achieve a desirable relative forage quality (RFQ) of 150 with 0.77 Mg DM ha^{-1}. However, economic analysis showed that an RFQ of 125 at a GDD of 668 with a 2.25 Mg DM ha^{-1} yield was more profitable than the higher-quality forage. In determining whether WCR requires N fertilizer, we concluded that high-quality, low-yielding WCR does not require fertilization, while lower-quality, high-yielding WCR could benefit from 47 kg N ha^{-1}. Future research should evaluate harvesting time and N fertilization rates (in fall vs. spring) to determine the optimum N requirement of WCR for maximizing profit while minimizing the environmental footprint.

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SOYBEAN RESPONSE TO PHOSPHORUS FERTILIZER AND VOER CROP COMBINATION IN KANSAS

J. Demarco and D. Ruiz Diaz
Kansas State University

ABSTRACT

Phosphorus (P) plays a critical role in supporting plant growth and maximizing crop yields, but its availability is often limited in agricultural soils. Cover crops (CC), widely used to improve soil health, can also influence nutrient availability and moisture dynamics. This study investigates the effects of P fertilization and CC on soybean P uptake, soil moisture, and grain yield in Kansas. Field trials were conducted across multiple sites in 2022 and 2023, using a randomized complete block design with a 2x2 factorial treatment structure involving oat and triticale CC and P fertilization of 0 and 45 kg ha-1 of P2O5. The goal was to enhance soybean P uptake, improve grain yield, and evaluate the effect on soil moisture. Results indicated that triticale, with its longer growing season, produced more biomass than oat, contributing to greater P uptake. However, CC reduced soil moisture at soybean planting and temporarily limited P uptake in the early season. At later growth stages, P fertilization significantly increased the soybean P uptake, but the addition of CC did not further enhance P uptake or yield. Additionally, a critical CC biomass threshold of 2465 kg ha-1 was identified, beyond which soybean grain yield began to decline. Despite the potential benefits of CC for soil health and erosion control, careful management of CC biomass and termination timing is crucial to avoid negative impacts on soil moisture and yield. This research highlights the importance of balanced P fertilization and adaptive CC management to optimize soybean production in Kansas.

POLYMER COATED UREA AND TIME OF APPLICATION FOR CORN PRODUCTION IN MINNESOTA

F. Fernández, K. Fabrizzi, J. Vetsch, and W. Lazarus
University of Minnesota

ABSTRACT

Managing N for corn (Zea mays L.) production is a key to minimizing N losses. Excessively wet spring conditions resulting from ongoing climate change exacerbate the potential loss of early spring N applications. Also, a shift with less anhydrous ammonia and more urea availability in certain regions calls for an extensive evaluation of other N sources across different soil conditions to update the current N best management practices. The objectives of this research are to evaluate various urea, polymer-coated urea (PCU), and PCU-urea blends and N application timing strategies in corn production and determine the agronomic and economic optimum N rate and grain yield, N use efficiency and indirectly the potential for N loss to the environment, and their cost-benefit relationship. Nitrogen sources and application time were evaluated in a 3-yr study corn study grown in a corn-soybean rotation under irrigation in well to excessively well drained soils at Rosemount and Becker, MN and in dryland conditions in poorly to somewhat poorly drained soils in Waseca and Lamberton, MN. Grain yield, the economic optimum N rate (EONR), net return, and residual inorganic soil N at post-harvest were measured at each site/year. For the dryland soils, grain yield was significantly affected by N source in only 2 of 3 years at Waseca with no differences at Lamberton. However, the use of PCU-Urea blends resulted in lower EONRs than Urea or PCU in dryland soils for the three growing seasons, and PCU had lower EONRs than Urea in 2023 at Lamberton. In irrigated corn, grain yield was significantly affected by N source only in Rosemount 2021. Also, the split application of PCU-Urea blend had lower EONR but not necessarily greater economic net return than Urea in these sandy soils. Drought years, particularly 2021, resulted in greater soil TIN after harvest especially at the highest N rates.

INTRODUCTION

Nitrogen (N) fertilization is essential for corn production, but N loss can diminish environmental health and farmers' profitability. Excessively wet spring conditions resulting from ongoing climate change can exacerbate loss potential of early spring N applications in Minnesota. At the same time, anhydrous ammonia is being rapidly replaced by urea as the major N source, which poses concerns. Because of volatilization issues, urea applications are done early so urea can be incorporated into the soil by tillage before planting. Because urea nitrifies quicker than anhydrous ammonia, this can lead to more N loss potential. Alternatively, in-season application can reduce N loss in wet springs, but driving in wet fields can be logistically impossible. In addition, in-season urea applications add cost and need to be incorporated quickly by rain or irrigation, or a urease inhibitor is needed to mitigate volatilization loss. Irrigating when unnecessary, simply to incorporate fertilizer, results in added cost and increased N loss potential if followed by substantial precipitation. One way to circumvent these issues is to use controlled release fertilizers, such as polymer-coated urea (PCU), or PCU-urea blends in tandem with application timing management. The goals are to evaluate various urea, PCU, and PCU-urea blends and N application timing strategies in corn production across four locations in Minnesota and determine 1) the agronomic and economic optimum N rate and grain yield, 2) N use efficiency and indirectly the potential for N loss to the environment, and 3) their cost-benefit relationship.

MATERIALS AND METHODS

A 3-yr (2021-2023) corn study grown in a corn-soybean rotation was conducted under irrigation in well- to excessively well-drained soils at Rosemount and Becker, MN and in dryland conditions in poorly- to somewhat poorly-drained soils in Waseca and Lamberton, MN.

Each study consisted of five N rates that cover the range of corn grain yield response to nitrogen (below, at, and above optimal). For dryland (non-irrigated) soils, N rate response curves for pre-plant only applications included blend of Urea (46-0-0, N-P-K) and PCU [ESN (44-0-0, N-P-K)] that varied by one-third increments from 100% Urea to 100% PCU (Table 1) with total N rates of 0, 60, 120, 180, and 240 lb N ac^{-1}. In these soils with corn after soybean, corn grain yield is normally optimized around 130 lb N/a. For irrigated soils N rate response curves were developed with various combinations of source and time of application with applications done in three splits with equal amounts of N at V2, V6, and V8/V10 (Table 1) with total N rates of 0, 80, 160, 240, and 320 lb N ac^{-1}. Urea was applied with a urease N inhibitor Agrotain (N-(n-Butyl) thiophosphoric triamide, NBPT) to minimize volatilization losses, but were incorporated by rain or irrigation within 24 hrs. of application. For irrigated soils with corn after soybean, corn grain yield is normally optimized around 180 lb N/a.

Although we are not presenting it here, we also evaluated a set of different N source/N time combinations at a single total rate (120 or 160 lb N ac^{-1} for dryland and irrigated soils, respectively). Timings were pre-plant (PP) or split at PP and at V6 corn stage in dryland soils, and split in various combinations at V2, V6, and V10 corn stage for the irrigated soils.

Table 1. N rates and N sources for dryland and irrigated corn.

Dryland corn (Lamberton- Waseca)		**Irrigated corn (Becker- Rosemount)**	
N rate lb N ac^{-1}	**N source**	**N rate lb N ac^{-1}**	**N source**
0	100% Urea	0	1/3V2(Urea)-1/3V6(Urea)-1/3V10(Urea)
60	1/3 PCU-2/3Urea	80	1/3V2(PCU)-1/3V6(Urea)-1/3V10(Urea)
120	2/3 PCU-1/3 Urea	160	1/3V2(PCU)-1/3V6(PCU)-1/3V10(Urea)
180	100% PCU	240	1/3V2(1U:2PCU)-1/3V6(2U:1PCU)-1/3V10(Urea)
240		320	

Corn yield and grain N content was measured at harvest. Corn economic optimum N rate (EONR) was calculated at a fertilizer to corn price ratio of 0.1 (US$0.50

lb^{-1} N; and \$5.00 bushel^{-1} of corn). Fall 2023 prices were used to calculate net return: Urea US\$0.70 lb^{-1} N fertilizer, ESN \$0.93 lb^{-1} N fertilizer; Corn \$4.7 bushel^{-1}.

After harvest, soil samples were collected from each plot using a 40-mm inside diameter soil core sampler (Giddings Machine Co., Fort Collins, CO) at the 0-12, 12-24, and 24-36-inch depth increments and analyzed for NH_4^+-N and NO_3^--N, and the sum of both was calculated to determine residual soil total inorganic N (TIN).

An in-situ incubation of PCU fertilizer was performed and N release curves were evaluated at 4 sites during each growing season at planting (AP) or V2, V6 and V10 corn development stages. Data presented correspond to the 2021 growing season.

The experimental design was a randomized complete block with four replications. Statistical analysis was performed using the SAS software. Mean differences were consider significant at P=0.05.

Table 2. Mean monthly precipitation (inches for the 30-yr normal and the 2021, 2022, 2023 growing season at each experimental site.

Location	Year	April	May	June	July	Aug.	Sept.	Apr.-Sept. cumulative
						--inches --		
Becker	Normal (1991-2020)	**2.8**	**4.1**	**4.1**	**4.0**	**4.0**	**3.2**	**22.1**
	2021	2.7	3.1	1.3	1.2	3.7	2.8	14.8
	2022	3.3	6.7	2.3	1.9	5.8	2.9	22.9
	2023	5.0	1.1	1.2	3.1	4.2	3.9	18.4
Rosemount	Normal (1991-2020)	**3.0**	**4.4**	**5.1**	**4.4**	**4.6**	**3.4**	**24.9**
	2021	2.0	3.2	1.8	1.3	4.9	2.8	16.0
	2022	3.7	4.1	0.9	2.1	6.3	0.4	17.3
	2023	3.5	2.4	2.2	3.8	1.6	4.4	17.9
Waseca	Normal (1991-2020)	**3.3**	**4.5**	**5.4**	**4.9**	**4.8**	**4.1**	**27.0**
	2021	0.6	2.7	2.0	2.7	4.8	1.9	14.8
	2022	3.8	4.7	4.4	4.6	5.5	0.8	23.7
	2023	3.7	6.5	1.6	1.6	3.3	2.2	18.8
Lamberton	Normal (1961-2020)	**2.8**	**3.5**	**4.0**	**3.7**	**3.2**	**3.2**	**20.5**
	2021	1.4	2.7	0.5	1.2	4.8	5.0	15.6
	2022	3.6	3.9	1.1	1.6	3.0	0.7	13.9
	2023	3.9	7.1	2.9	1.0	2.0	0.6	17.4

RESULTS AND DISCUSSION

Overall, the three growing seasons were dry, ranging from 3.1 to 12.2 inches below normal, except Becker 2022 where precipitation was 0.8 inches above normal (Table 2).

For dryland soils, there was a positive response to N application on grain yield at both locations (Table 3). The current MRTN guidelines indicate 131 lb N ac^{-1} and a range of 118 to 144 lb N ac^{-1} for corn-soybean cropping systems. The EONRs in our study were within or close to the range except for Waseca 2022 and 2023 and Lamberton 2021 where EONRs were higher than the MRTN (Table 3). Across N rate, grain yield was significantly affected by N source in 2 of 3 years at SROC with no differences at SWROC. However, when all the N source/timing were compared at the same N rate (120 lb N ac^{-1}) differences were observed only in 2022 at SROC, and 2021 at SWROC (data not shown).

For irrigated soils, there was a positive response to N application on grain yield at both locations (Table 4). The current MRTN guidelines for irrigated corn indicate 179 lb N ac^{-1} with a range of 162 to 195 lb N ac^{-1} for corn-soybean cropping systems. The EONRs in our study were lower than the MRTN, ranging from 21 to 66 lb N ac^{-1} lower than the MRTN, except Becker 2021 which was 6 lb N ac^{-1} above the MRTN but within the acceptable range. Since the effect of drought could be managed by irrigation, lower EONRs with relatively high yields represent high N use efficiency and likely reflect the fact that N losses were low during these growing seasons. Further, while nitrate concentrations in irrigation water are low for these sites, greater irrigation amounts than normal also contributed to more than normal N application through irrigation than normal, which likely contributed in a small degree to lowering the EONR. Across N rate, grain yield was significantly affected by N source in 1 of 3 years at Rosemount with no differences at Becker. However, when all the N source/timing were compared at the same N rate (160 lb N ac^{-1}) differences were observed in 2022 for SPRF, and 2021 and 2022 for RROC (data not shown).

Across years and N rates, the highest net return was for 1/3PCU PP-2/3Urea in Waseca (Table 5). The use of PCU-Urea blends resulted in lower EONRs than Urea or PCU. At Lamberton, PCU-Urea blends resulted in lower EONRs than Urea however N returns were lower than Urea (Table 5). For irrigated soils, EORNs were lower for the 1/3 PCU-2/3 Urea treatment in 2021, and the Urea+PCU blend in Becker (Table 4). At Rosemount, the EONRs were lower for all treatments with PCU compared to Urea. For both sites, however the overall net return was higher for Urea treatments (Table 6).

Though there were differences due to soil type, in all situations residual soil N at post-harvest was greater when N was applied over the EONR (Fig.1). The 2021 growing season showed greater residual total inorganic N after harvest regardless of N rate especially at Lamberton and Becker. The higher residual N is likely related to substantial drought during the 2021 growing season (Fig. 1).

Overall, N released from in-situ PCU incubations followed similar pattern across sites and time of application (Fig. 2), however dry conditions typically created further delays in the N release, especially at Lamberton where it was dry after the application, unlike Waseca that received precipitation after V10. These release curves showed that early application of PCU will ensure greater N availability and synchronization with crops need compared to late applications.

Summary

For dryland soils, the PCU-Urea blends showed lower EONRs than Urea at most sites/years, but responses were likely smaller in magnitude due to the dry conditions and low potential for N loss.

For irrigated soils, the split application of blends of PCU and Urea had lower EONRs but not necessarily a greater net return than Urea alone.

N release curves showed the importance of early application of PCU fertilizer to maximize N availability for crop uptake.

Drought years, particularly 2021, resulted in greater soil TIN after harvest especially at N rates above the EONR.

Table 3. Corn grain yield for the dryland sites from 2021 to 2023 growing seasons.

	Corn Grain Yield (bu ac^{-1})					
	Waseca			Lamberton		
N rate (lb N ac^{-1})	2021	2022	2023	2021	2022	2023
0	110 d	130 d	106 d	92 d	120 c	75 c
60	148 c	183 c	138 c	117 c	158 b	132 b
120	160 b	215 b	160 b	128 b	183 a	161 a
180	164 ab	230 a	179 a	134 b	184 a	159 a
240	168 a	232 a	184 a	144 a	191 a	171 a
EONR (lb N ac^{-1})	132	178	220	194	149	143
Yield$_{EONR}$ (bu ac^{-1})	164	230	183	139	187	164
MRTN (lb N ac^{-1})	131 (118-144)					

Table 4. Corn grain yield for the irrigated sites from 2021 to 2023 growing seasons.

	Corn Grain Yield (bu ac^{-1})					
	Becker			Rosemount		
N rate (lb N ac^{-1})	2021	2022	2023	2021	2022	2023
0	117 d	89 c	84 c	155 c	139 d	148 c
80	187 c	193 b	169 b	230 b	199 c	184 b
160	210 b	224 a	192 a	243 a	211 b	189 ab
240	219 ab	231 a	198 a	244 a	219 ab	196 a
320	225 a	224 a	202 a	245 a	225 a	189 ab
EONR (lb N ac^{-1})	185	149	150	123	158	113
Yield$_{EONR}$ (bu ac^{-1})	220	226	197	243	219	190
MRTN (lb N ac^{-1})	179 (162-195)					

Table 5. Economic optimum N rate (EONR, lb N ac^{-1}), grain yield (bu ac^{-1}) at the EONR, and net return for Waseca and Lamberton across N rates and years.

	Waseca			Lamberton		
--Nitrogen Blend--	**EONR**	**Yield**	**Net return**	**EONR**	**Yield**	**Net return**
Preplant	**lb N ac^{-1}**	**bu ac^{-1}**	**\$ ac^{-1}**	**lb N ac^{-1}**	**bu ac^{-1}**	**\$ ac^{-1}**
Urea	181	194	867	201	186	751
1/3 PCU - 2/3 Urea	168	193	868	117	157	714
2/3 PCU - 1/3 Urea	165	192	863	127	159	703
PCU	185	193	838	187	178	696

Prices: Urea 0.54, 1.03, 0.85 $/lbN; **PCU** 0.76, 1.25, 1.07 $/lbN; **Corn** $5.22, 6.64, 4.9$/bu for 2021,2022, and 2023 respectively.

Table 6. Economic optimum N rate (EONR, lb N ac^{-1}), grain yield (bu ac^{-1}) at the EONR, and net return for Becker and Rosemount across N rate and years.

			Becker			Rosemount		
------Nitrogen Blend------			**EONR**	**Yield**	**Net return**	**EONR**	**Yield**	**Net return**
V2	**V6**	**V10**	**lb N ac^{-1}**	**bu ac^{-1}**	**\$ ac^{-1}**	**lb N ac^{-1}**	**bu ac^{-1}**	**\$ ac^{-1}**
1/3-Urea	**1/3-Urea**	**1/3-Urea**	165	217	962	154	222	1010
1/3-PCU	**1/3-Urea**	**1/3-Urea**	141	210	931	149	218	975
1/3-PCU	**1/3-PCU**	**1/3-Urea**	198	220	925	132	214	949
1/3(1Urea:2PCU)	**1/3(2Urea:1PCU)**	**1/3-Urea**	138	211	935	108	217	985

Prices: Urea 0.54, 1.03, 0.85 $/lbN; **PCU** 0.76, 1.25, 1.07 $/lbN; **Corn** $5.22, 6.64, 4.9$/bu for 2021,2022, and 2023 respectively.

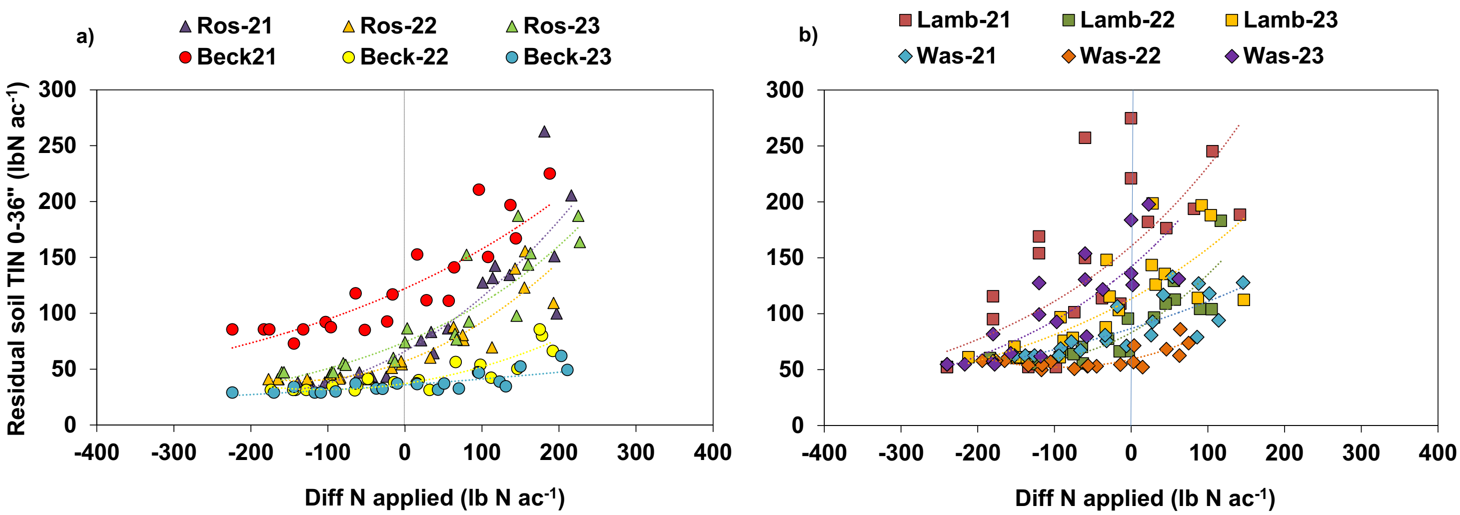

Figure 1. Residual soil Total Inorganic N (TIN) (lb N ac^{-1}) at 0-36 inches soil depth and the difference between N rate and EONR (Diff N applied, lb N ac^{-1}) for Rosemount and Becker (a) (irrigated soils) and Lamberton and Waseca (b) (dryland soils) for 2021, 2022, 2023 growing seasons.

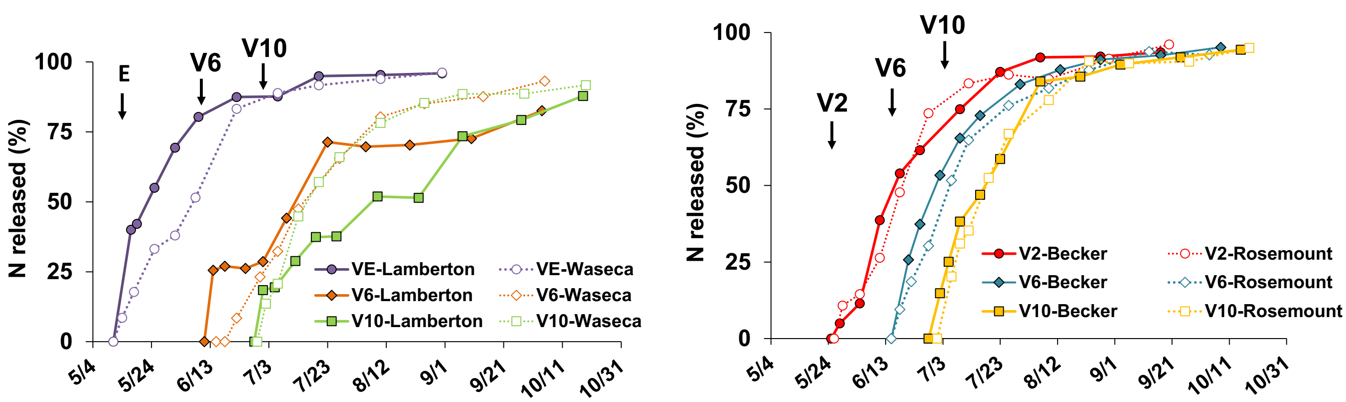

Figure 2. N released curve from PCU fertilizer in fine-textured and sandy soils. 2021 growing season

FINDING THE "SWEET SPOT": NITROGEN STRATEGIES FOR VARIABLE SUGARBEET HARVEST TIMINGS

S. Fleming and K. Steinke
Michigan State University

ABSTRACT

Early sugarbeet (*Beta vulgaris L.*) harvest is a new challenge facing the Michigan sugarbeet industry. Few data indicate how early or how late N can be applied and the subsequent effects on sugar quality. The objective was to evaluate the influence of harvest timing, planter-applied starter fertilizer, and in-season N fertilizer strategies on root yield, sugar quality, and in-season plant growth and development. Studies were blocked by harvest date with treatments arranged in a randomized complete block factorial design with four replications. The main plot factor was harvest date (early and conventional (conv.)). Fertilizer strategy was the subplot factor and split into 1) two rates of starter N fertilizer (0, and 60 lbs. N/acre applied 2x2), and 2) seven in-season N fertilizer strategies consisting of either low (60 lbs. N/acre) or high (100 lbs. N/acre) applied in either early Jun, July, or August. Conv. harvest 2023 increased root yield +17.9 Tons A^{-1} compared to early harvest with root yield increasing on average +1.9 Tons A^{-1} week^{-1}. Starter fertilizer did not influence early harvest root yield, but results were influenced by deficit precipitation (-48%, April- June). Conv. harvest increased root sucrose content +4.3% compared to early harvest. For early harvest, applying nitrogen 1 August as compared to 1 June decreased mean sucrose content -0.5% when starter fertilizer was not utilized. For early harvest 2024 starter N increased root yield +4.4 Tons A^{-1} but had no effect on sugar content. June SD resulted in the greatest yield amongst all the low-rate N treatments increasing root yield +3.5 and +6.2 Tons A^{-1} compared to July and August SD, respectively. Data for 2024 conv. harvest was not completed by this report.

INTRODUCTION

Functioning as a non-sucrose impurity within the beet root, late-applied N decreases sugarbeet sugar content (Campbell, 2002). Therefore, growers tend to apply N earlier in the growing season to decrease the chance of non-sucrose N impurities remaining in the beet root at harvest. Due to sugar processing capacity limitations, earlier sugarbeet harvest is necessary to ensure beet processing is complete by mid- to late-March. Nitrogen strategies for an earlier sugarbeet harvest may differ from a conventional harvest. Although differing each year, the early harvest interval for Michigan often ranges between late Aug. through early October while conventional harvest will initiate mid-Oct. and last until beets are harvested or the piling grounds are at capacity. Harvest date timings are determined by the Michigan Sugar Company which continuously sample throughout the growing season to factor in potential root yield and sugar quality. The optimal N strategy for sugarbeet would be to maximize sugar quality while retaining moderate root yields.

MATERIALS AND METHODS

Field trials were initiated in Richville, MI on a Tappan-Londo-loam soil following corn on 27 April 2023 and 25 April 2024. Soil properties included: 7.7- 8.1 soil pH, 2.1% - 2.5% SOM, 14 – 17 CEC, 14-18 ppm Olsen P, 141-166 ppm K. Main plots were blocked by harvest date (early and conventional). Treatments were arranged in a randomized complete block factorial design with four replications. Fertilizer strategy was split into two rates of starter fertilizer (0 or 60 lbs. N/acre applied 2x2) and seven in-season N fertilizer strategies consisting of either low (60 lbs. N/acre) or high (100 lbs. N/acre) applied in June, July, or August plus a nontreated check. Nitrogen fertilizer treatments included urea ammonium nitrate (28-0-0) for both the starter and side dress treatments. The Jun sidedress treatment was applied via coulter disk injection while the July and August sidedress treatments were applied via Y-drop applicator blended with a urease inhibitor (NBPT). Research plots were 15 ft. wide by 35 ft. long and planted to six rows on 30-inch row spacing with the center two rows acting as the harvest rows. Beet population was 52,000 seeds/acre, and the variety CG049 (i.e., a high tonnage, moderate sugar variety). Composite soil samples were collected at 0-8” prior to planting. Aboveground foliar tissue was sampled prior to applying the Jun sidedress, July sidedress, and the Aug. sidedress. Dry weights were recorded with subsamples analyzed for total N concentration. Preharvest foliar biomass fresh weight was recorded and analyzed for N concentration. Data collection also included normalized difference vegetation index (NDVI), and row fill (%) recorded every two weeks from emergence through row closure. Harvest data included root yield (tons/acre), sugar content (%), recoverable white sugar per ton (lbs./ton), recoverable white sugar per acre (lbs./acre), and economic profitability.

Table 1. Mean monthly and 30-yr. precipitation, Richville, MI, 2023 and 2024

Year	April	May	Jun	Jul	Aug	Sep	Oct
				inches			
2023	3.06	0.98	1.51	5.49	5.91	1.32	2.6
30-yr ‡	3.61	3.59	3.48	3.36	3.49	2.68	2.93
% Change	-15.2	-72.7	-56.6	+63.3	+69.3	-50.7	-11.2
2024	2.76	4.14	3.88	4.27	3.38	1.51	1.85*
30-yr §	3.61	3.59	3.48	3.36	3.49	2.68	2.93
% Change	-23.5	+15.3	+11.5	+27	+3.1	-43.6	-36.8*

RESULTS AND DISCUSSION

The early 2023 growing season was dry with May precipitation at 0.97 inches (72% below the 30-year average) (Table 1). The early season rainfall drought impacted beet establishment and growth. Plants receiving 60 lbs. N/acre starter had a 22% size reduction at growth stage 6-8 LF compared to the plants not receiving any starter fertilizer. Biomass reductions may have been due to saltation from the 2x2 applied starter fertilizer. Saltation symptoms diminished once consistent precipitation began in mid-July with precipitation increasing +63% above the 30-year average. In 2023, harvest date significantly impacted sugarbeet root yield and sugar content (Table 2).

Conventional harvest date yielded +17.9 Tons A^{-1} greater than early harvest and also resulted in a +4.3 % greater sugar content when compared to early harvest. The additional 64 days between harvest dates resulted in a net gain of +1.9 tons A^{-1} and +0.47% sugar $week^{-1}$. Reduced root yields and sugar content are expected outcomes from early harvest sugarbeets in Michigan thus a premium is paid out for early harvest acres.

Table 2. Main effects of harvest date on sugarbeet root yield and sugar content. Richville, 2023

Treatment	Root Yield	Sugar
	—— Tons/acre ——	——— % ———
Harvest Date		
Early $_{21\text{-}Aug}$	14.4 b	13.8 b
Conv $_{24\text{-}Oct}$	32.3 a	18.1 a
P > F†	**<0.0001**	**0.0002**

An interaction between starter fertilizer and N SD strategy affected early harvest root yield in 2023 (Table 3A). Without starter application, N SD strategies were similar. However with starter N application, Aug SD low and no SD both decreased root yield compared to remaining treatments. The Aug SD low rate decreased root yield -3 and -3.4 Tons A^{-1} from the June and July low-rate SD treatments, respectively. The August SD low rate was comparable to avoiding a sidedress application altogether. Wet August field conditions may have resulted in some degree of denitrification causing yield reduction with the low August SD treatment as compared to the Aug SD high rate. Across SD strategies, starter fertilizer had little impact on root yield presumably due to lack of early season moisture impacting both growth and N uptake.

Table 3A. Interaction between starter fertilizer and sidedress N strategy on early harvest root yield, Richville, MI 2023.

Early Harvest 2023	Starter N		
	No Starter	60 lbs. N	
	Root Yield		**P>F‡**
Side Dress N	———Tons/acre———		
June SD $_{low}$	13.9 aA	15.3 aA	**NS**
June SD $_{high}$	14.2 aA	16.4 aA	**NS**
July SD $_{low}$	15.6 aA	15.7 aA	**NS**
July SD $_{high}$	15.3 aA	14.7 abA	**NS**
August SD $_{low}$	12.7 aA	12.3 bA	**NS**
August SD $_{high}$	15.2 aA	15.3 aA	**NS**
No SD	12.2 aA	12.8 bA	**NS**
P>F†	**[a]NS**	**0.0808**	

[a] ns, not significant.
† Means in the same column followed by the same lowercase letter are not significantly different at α=0.10.
‡ Means in the same row followed by the same uppercase letter are not significantly different at α=0.10.

An interaction between starter fertilizer and N SD strategy affected conventional harvest root yield in 2023 (Table 3B). Without starter fertilizer, the June SD timing or high rate of July SD timing optimized yield. The August SD timing without starter significantly reduced yield but it is important to note that this SD timing produced greater yield than no SD at all indicating August was not too late to still recover some yield potential. With starter N application, few yield differences occurred amongst N SD strategies indicating starter N effectively minimized yield variability under these environmental conditions regardless of SD timing. This result may impact future N strategies given the year-to-year climate variabilities sugarbeet growers now encounter. Starter N also significantly increased root yield for the low-rate July SD, both rates of August SD, and the no SD treatments. In general, without starter fertilizer SD strategy played a much greater influence on yield potential during the conventional harvest window.

Table 3B. Interaction between starter fertilizer and sidedress N strategy on conventional harvest root yield, Richville, MI 2023.

Conventional Harvest 2023	Starter N		
	No Starter	60 lbs. N	
	Root Yield		**P>F‡**
Side Dress N	———Tons/acre———		
June SD $_{low}$	33.1 abA	35.8 aA	**NS**
June SD $_{high}$	36.9 aA	36.4 aA	**NS**
July SD $_{low}$	29.9 bcB	35.5 aA	**0.0316**
July SD $_{high}$	34.1 abA	34.0 aA	**NS**
August SD $_{low}$	28.6 cB	33.9 aA	**0.0440**
August SD $_{high}$	27.6 cB	33.9 aA	**0.0173**
No SD	22.9 dB	29.8 aA	**0.0104**
P>F†	**<0.0001**	**[a]NS**	

[a] ns, not significant.
† Means in the same column followed by the same lowercase letter are not significantly different at α=0.10.
‡ Means in the same row followed by the same uppercase letter are not significantly different at α=0.10.

Early harvest 2023 sugar quality was also affected by a starter N and SD N strategy interaction (Table 4). Starter decreased sugar content -0.55 and -0.57% for the Jun SD low and No SD treatments, respectively. Without starter application, later applied N decreased sugar content as expected. August SD treatments reduced sugar % compared to June and July SD timings with Aug SD low-rate reducing sugar -0.72 and -0.71% compared to June and July SD low-rate SD strategies, respectively, while Aug SD high-rate reduced sugar -0.22 and -0.21% compared to the June and July high-rate SD strategies, respectively. With starter N application, low-rate July SD increased sugar % compared to remaining treatments. Starter N decreased variability across SD treatments as compared to no starter N possibly due to ~15% greater biomass production resulting in greater tonnage. Late-applied N, especially with early harvest, may not have sufficient time to be translocated and utilized by the plant.

Table 4. Interaction between starter fertilizer and sidedress N strategy on early harvest sugar quality, Richville, MI 2023.

Early Harvest 2023	Starter N		
	No Starter	60 lbs. N	
	Sugar Content		P>F‡
Side Dress N	———%———		
June SD low	14.03 bA	13.48 bB	**0.0360**
June SD high	13.73 bcA	13.69 bA	**[a]NS**
July SD low	14.02 bA	14.24 aA	**NS**
July SD high	13.72 bcA	13.56 bA	**NS**
August SD low	13.31 dA	13.63 bA	**NS**
August SD high	13.51 cdA	13.67 bA	**NS**
No SD	14.81 aA	14.24 aB	**0.0210**
P>F†	**<0.0001**	**0.0077**	

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

No significant interactions or main effects occurred on sugar quality for conventional harvest 2023 with sugars ranging between 17.75 – 18.80%.

For the early harvest 2024 season, starter N increased root yield +4.4 Tons A^{-1}, with no impact on sugar content (Table 5). June SD N strategies produced greatest yield with reductions occurring for both July and August SD timings. June and July SD timings produced similar sugar %'s with reductions in sugar quality occurring with August SD timings. Coventional harvest 2024 data were not available at time of this report. The 2024 growing season was excessively wet May through August resulting in greater root yields but reduced sugar quality as compared to early harvest 2023.

Table 5. Main effects of fertilizer strategy for early harvest sugarbeet root yield and sugar content. Richville, 2024.

Treatment	**Early Harvest (August 29, 2024)**	
	Root Yield	**Sugar**
	— Tons/acre —	—— % ——
Starter N		
None	24.5 b	12.9 a
Starter	28.9 a	13.1 a
P > F†	**0.0001**	**[a]NS**
Side Dress N		
No SD	23.3 e	13.49 a
June SD low	30.3 ab	13.31 ab
June SD high	32.3 a	13.03 ab
July SD low	26.8 cd	13.05 ab
July SD high	29.0 bc	13.01 ab
August SD low	24.1 de	12.91 bc
August SD high	21.5 e	12.42 c
P > F	**<0.0001**	**0.0698**

[a] ns, not significant.
† Means in the same column followed by the same lowercase letter are not significantly different at α=0.10.

PRELIMINARY CONCLUSIONS

Vastly different growing conditions impacted N utilization during the first two years of this study and highlight the variability and unpredictability that growers must try to account for each season. The first half of the 2023 growing season (April-June) was extremely dry while the last half (July-August) was extremely wet. The 2024 growing season was opposite to 2023 with a wet early season (April-July) and dry autumn (August-September) soil conditions. Starter N fertilizer was able to reduce some yield variabilities with conventional harvest but also resulted in some degree of additional variability with early harvest 2023 but not 2024. Growers need to have a plan in place at planting time whether acres will be targeted for early or conventional harvest otherwise reductions in sugar quality and losses in revenue from residual N may occur. Results are not intended to highlight the downside or benefit from any single N management practice but rather to gather more data that will allow growers to remain flexible with N management and adjust in-season practices based on variable climate scenarios.

NITROGEN DYNAMICS AND AGRONOMIC-ENVIRONMENTAL IMPACTS OF ANNUAL VS. PERENNIAL COVER CROPS IN IRRIGATED CORN-SOYBEAN SYSTEMS ON SANDY SOILS

E. Garay, F. Fernández, J. Grossman, V. Sharma, and R. Venterea
University of Minnesota – Saint Paul, Minnesota

ABSTRACT

Irrigated sandy soils can be highly productive yet vulnerable to Nitrogen (N) losses. Kura Clover (*Trifolium ambiguum*) living mulch offers an alternative mitigation strategy. However, there is limited research aiming to holistically compare the effect of annual vs. perennial cover crops on season-long N dynamics and agronomic-environmental impacts on corn (*Zea Mays* L.)-soybean [*Glycine max* (L.) Merr.] cropping systems. This 2-yr study assessed rye (*Secale cereale)* and Kura effects on corn and soybean grain yield, season-long N availability and uptake, nitrate (NO_3^--N) leaching, ammonia (NH_3-N) volatilization, and nitrous oxide (N_2O-N) emissions in continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) cropping systems on irrigated sandy soil. Treatments included 3 cover strategies (no cover, annual rye, and Kura clover living mulch) paired with five N rates (0-270 lb N ac^{-1} in CC and CSb) for no cover and rye, and two N rates (0 and 180 lb N ha^{-1} in CSb or 225 lb N ha^{-1} in CC) for Kura. Rye and no cover showed similar yield and N uptake across cropping systems. Kura decreased CSb yield by 28% and impacted N uptake. In CC, wetter conditions during grain filling diluted Kura's yield penalties and had no impact on N uptake throughout. N availability up to V6 impacted corn the most, exacerbating CSb sensitivity due to Kura's competition for soybean N credits. Kura reduced NO_3^--N losses by 42% compared to rye and no cover. Contrastingly, Kura increased NH_3-N volatilization by 13 and 20% in CSb and SbC, respectively. Both cover crops had no effect on N_2O-N emissions. Kura clover in CC demonstrated a promising agronomic performance while offering synergistic agroecosystem services.

INTRODUCTION

The State of Minnesota has approximately 240,000 acres of irrigated sandy soils which are predominantly under corn and soybean cultivation. A critical aspect to ensure productivity optimization of these soils is through the efficient supply of nitrogen. However, N recovery from the corn plant typically ranges between 30-50% in the Midwest region, suggesting significant N losses via NO_3^--N leaching, NH_3-N volatilization, N_2O-N emissions or soil immobilization/fixation. One mitigation practice that has gained traction is the use of cover crops, often promoted as a signature tool for achieving sustainable cropping systems. Due to the need of winter-hardy species in the Upper Midwest and its relatively easy integration to corn and soybean systems, rye is considered the staple cover crop in the region. Nonetheless, unperceived or antagonistic results have been observed from the use of rye. Within the US Midwest, another factor hindering adoption rates is the narrow window between fall harvest and winter, along with the added cost of annually planting a second crop. Thus, living mulches are being considered as an alternative to rye cover crop systems. Kura has been recently promoted as a potentially viable living mulch due to its winter hardiness, spreading habit, and N fixation capability.

Variable outcomes from implementing Kura clover suggest attractive environmental benefits, but variable impacts on productivity. Cover crops influence soil N availability for the main crop, which can significantly impact the agronomical and environmental output of a system. There is a critical need of holistically understanding how Kura clover living mulch affects N dynamics throughout the growing season compared to the commonly used annual rye cover crop. These insights can facilitate both productive and environmentally optimized N management strategies in irrigated sandy soils. Therefore, the objectives of this study were to determine the effects of annual rye cover crop and Kura clover living mulch on N dynamics and its impact on the agronomic and environmental performance of CC, CSb, and SbC cropping systems.

MATERIALS AND METHODS

The study was located at the Rosholt Research Farm in Westport, MN and was conducted from September 2019 to October 2022. The site was divided into three adjacent blocks to accommodate three cropping systems: one block with CC and two blocks that alternated a CSb and a SbC rotation, with both crops present each year. Each of the cropping systems allocated a randomized complete block design with 12 treatments replicated 4 times. Irrigation was applied uniformly with a linear movement system and was planned via the checkbook scheduling method. Treatments factorially combined 3 cover management approaches (no cover, spring-terminated rye, and Kura clover as a living mulch) with 5 N rates for no cover and rye, and 2 N rates for Kura clover. No cover and rye included 0, 90, 180, 225, and 270 lb N ac^{-1} rates in both CC and CSb, whereas Kura clover received 0 and 225 lb N ac^{-1} in CC, and 0 and 180 lb N ha^{-1} in CSb. The SbC rotation did not receive any nitrogen. Urea (46-0-0) with Agrotain [N-(n-butyl) triophosphoric tiramide] was used as the fertilizer source. The N fertilizer was broadcast in the no cover and rye plots and banded by the corn row in Kura plots to minimize N uptake by kura. The fertilization was completed in 3 split-applied events when the corn reached the V2, V6, and V10 growth stages with a corresponding 25, 25, and 50% of the total N rate for each treatment.

Cover crops were sampled for aboveground biomass prior to corn and soybean planting. A whole plant sampling was performed on the corn and soybean when they reached R6. Subsequently, the dried plant biomass was analyzed to determine total N concentration via dry combustion. Corn grain collected at the R6 stage was added to the weight of the combine-harvested dataset for calculation of total grain yield. Four pairs of Plant Root Simulator (PRS) probes were inserted into the soil at a depth of 6 in for 3-week intervals, during seven measurement periods to quantify season-long N fluxes. A total of 216 permanently installed lysimeters facilitated weekly water sampling to determine NO_3^--N concentrations. Drainage was calculated via the water balance equation using parameters established by the FAO Irrigation and Drainage paper 56. The product of both was used to calculate NO_3^--N loads. Nitrous oxide emissions were measured weekly at a decreasing frequency as the season progressed using a portable high-accuracy AERIS N_2O/CO gas analyzer. An open chamber with PTFE moisture barrier acid trap was used to quantify NH_3-N volatilization 1, 4, 7, 14, 21, and 28 days after each split-fertilization event. An ANOVA and mean separation (when applicable) were conducted for all variables in SAS 9.4, while N_2O-N fluxes were calculated in R studio.

RESULTS AND DISCUSSION

Only 2021 depicted significant differences for both cover crop biomass and N content. These interactions were mainly driven by a consistent decrease in rye biomass at the N fertilized rate. This antagonistic response was explained by the residue source and accumulation intensity from the previous year which impacted the subsequent cover crop growth and development. This pattern is evidenced with CSb (rye planted on soybean stubble) resulting in approximately 3x more biomass accumulation across cover crops compared to CC and SbC (Table 1).

Table 1. Cover crop biomass and N content from continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) as affected by Cover and N rates.

		2021			2022		
Cover Crop	**N Rate**	**CC**	**CSb**	**SbC**	**CC**	**CSb**	**SbC**
				Biomass			
	lb N acre		------------------------ **lb acre^{-1}** ------------------------				
Kura	0	67 A	233 AB	64 A	164	246	318
Kura	180/225	94 AB	349 A	56 A	203	208	343
Rye	0	122 B	292 AB	151 B	222	177	235
Rye	180/225	64 A	152 B	70 A	182	262	274
				N Content			
			------------------------ **lb acre^{-1}** ------------------------				
Kura	0	1.94 A	7.38	1.95	5.72	7.53	10.51
Kura	180/225	2.87 B	11.40	2.24	8.10	7.98	11.22
Rye	0	2.21 A	5.32	2.56	3.64	3.47	4.37
Rye	180/225	1.18 A	3.37	1.53	4.22	6.05	3.37

Means within a year and column followed by the same letter are not significantly different ($P<0.05$). 180/225: In the CC system a 225 lb N acre^{-1} rate was applied whereas in CSb a 180 lb N acre^{-1} was applied.

Rye consistently resulted in similar grain yields than no cover across N rates in both corn rotations and years. Conversely, in CSb Kura clover led to an average yield decrease of 28% across N rates. The negative effect of Kura clover on CSb grain yield had a lesser impact on CC, as evidenced on a lack of significant differences by cover in 2021 and an interaction of the main effects in 2022, were Kura decreased corn grain yield only when fertilized. The grain yield response observed in CC is likely the combined effect from yearly precipitation variability with a reduced competition from Kura clover. Moreover, for SbC the cover main effect was significant only in 2022, indicating a 21% yield decrease caused by Kura compared to no cover and rye (Table 2). As expected, N uptake across cropping systems and years had a similar response to grain yield. More importantly, the lack of differences by cover in CC also suggests that it is possible to synergistically implement Kura clover living mulch within this production system without compromising corn N uptake.

Table 2. Grain yield and N uptake averaged across Cover and N rate main effects from continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) cropping systems.

Main Effects	2021			2022		
	CC	CSb	SbC	CC	CSb	SbC
			Grain Yield			
Cover Effect			------------------------ bu acre^{-1} ------------------------			
No Cover	104	144 A	59	100	126 A	65 A
Rye	101	143 A	55	99	135 A	61 AB
Kura	104	103 B	61	81	94 B	50 B
N Rate Effect						
0	51	86	57	51	79	57
180/225	155	174	60	136	157	60
			N Uptake			
Cover Effect			------------------------ lb acre^{-1} ------------------------			
No Cover	90	109 A	399	92	101 A	346 A
Rye	84	103 A	408	93	103 A	337 A
Kura	85	82 B	415	82	84 B	263 B
N Rate Effect						
0	39	58 A	389	47	58	311
180/225	134	139 B	425	131	134	319

Means within a year and column followed by the same letter are not significantly different (P<0.05). 180/225: In the CC system a 225 lb N acre^{-1} rate was applied whereas in CSb a 180 lb N acre^{-1} was applied.

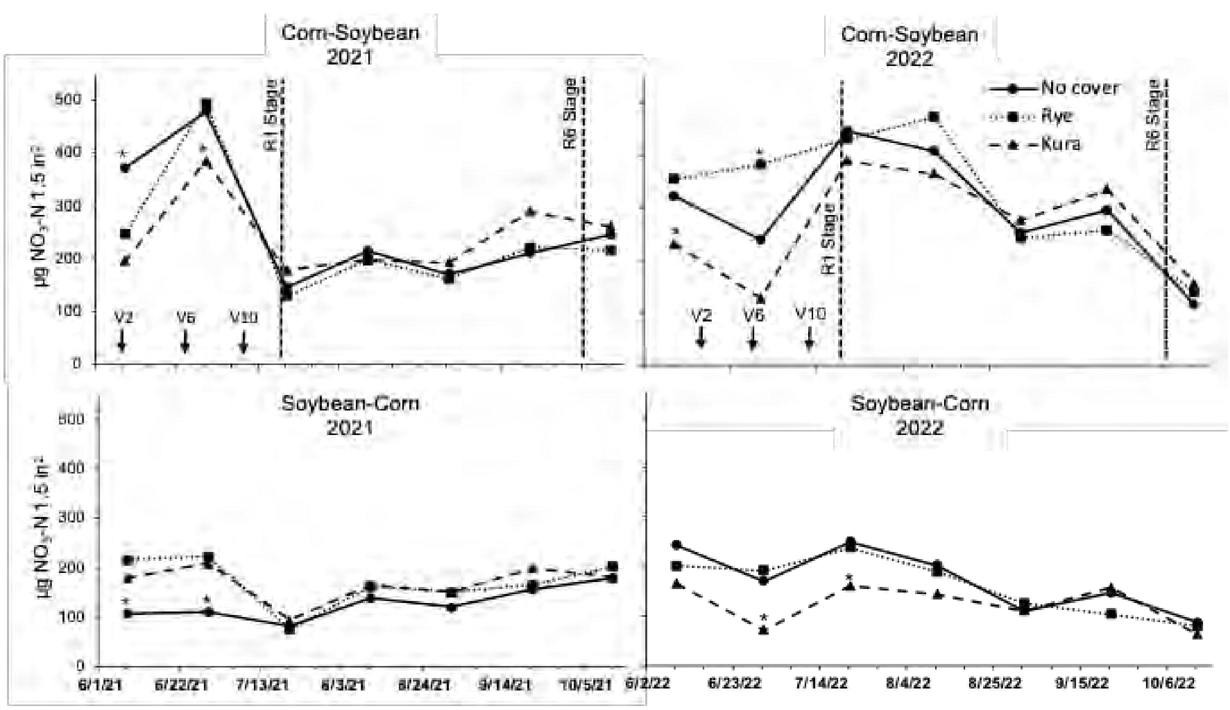

Figure 1. Mean bioavailable NO_3^--N measured by PRS probes showing the season-long Cover effect for CSb and SbC cropping systems averaged across N rates. Asterisks indicate significant differences between treatments at a time interval ($P<0.05$). Arrows indicate timing of the split-fertilization events at corresponding corn development stages.

The CSb rotation resulted in a similar response during both years showing cover crops differences only in the first 2 PRS timings were Kura had the lowest NO_3^--N fluxes compared to no cover and rye. Contrastingly, the absence of differences between covers throughout timings 3 to 7 indicate that the Kura Clover yield penalty in CSb was mainly caused by a decrease of early-season N availability. Earlier stages of SbC development were also more sensitive to soil N availability reductions from Kura, as evidenced in the yield performance in 2022 (Figure 1).

The major environmental loss observed was via NO_3^--N leaching. Although differences were not as evident on the concentration between cover crops, factoring in the drainage facilitated an improved understanding of the system. Kura tended to reduce losses in most scenarios, particularly when fertilized. However, this effect was only significant in 2022 on the corn systems were Kura reduced NO_3^--N load by 42% on average compared to rye and no cover (Table 3). There is also a potential under-quantification of Kura's benefits in 2021 due to current limitations on inter-cropping water usage modeling particularly as the growing season progresses. In addition, the three cropping systems depicted a significant response to N fertilizer ($P<0.05$).

Table 3. Season long NO_3^--N concentrations and cumulative load from continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) as affected by Cover and N rates.

Crop	N Rate	2021			2022		
		No Cover	Rye	Kura	No Cover	Rye	Kura
		Season-long Nitrate Concentration					
	lb N acre	------------------------ mg NO_3^--N L^{-1} ------------------------					
CC	0	5	6	9	5	6	11
	225	27	29	34	24	23	25
CSb	0	11	13	13	16 A	19 B	13 A
	180	18	20	24	17 A	23 B	18 A
SbC	0	13	13	12	11	11	10
	180	25	27	27	30	27	27
		Cumulative Nitrate Load					
		------------------------ lb NO_3^--N $acre^{-1}$ ------------------------					
CC	0	16	25	31	16 A	16 A	22 A
	225	64	68	44	35 B	27 B	19 C
CSb	0	38	45	34	44 A	42 A	24 B
	180	44	43	46	25 A	26 A	13 B
SbC	0	51	55	38	24	20	12
	180	93	97	80	56	52	36

Means within a year and row followed by the same letter are not significantly different. 180/225: In the CC system a 225 lb N acre^{-1} rate was applied whereas in CSb a 180 lb N acre^{-1} was applied.

The smaller fraction of environmental losses corresponded to gas emissions where CC was unaffected by cover crops. Further, Kura increased cumulative NH_3-N volatilization by 13 and 20% in CSb and SbC, respectively. This can likely be a result of the growing conditions derived from the living mulch growing system, such as greater moisture retention or changes in soil pH due to N_2 fixation leading to higher volatilization activity. Cover crops did not significantly affect cumulative N_2O-N emissions although effect trends were observed from Kura but were likely negligible due to the high variability of N_2O-N measurements.

Table 4. Cumulative NH_3-N volatilization and N_2O-N emissions from continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) as affected by Cover and N rates.

Rotation		2021			2022		
	N Rate	No Cover	Rye	Kura	No Cover	Rye	Kura
		Cumulative Ammonia VolatilizationΨ					
	lb N acre	~~~~~~~lb NH_3-N acre^{-1}~~~~~~~					
CC	0	1.29	1.42	1.56	1.61	1.74	1.85
	225	1.53	1.56	1.37	1.66	1.59	1.86
CSb	0	1.17 A	1.11 A	1.30 B	1.54	1.13	1.78
	180	1.20 A	1.04 A	1.30 B	1.50	1.36	1.41
SbC	0	1.18 A	1.11 A	1.40 B	1.66 A	1.36 A	1.29 A
	180	1.27 A	1.25 A	1.10 A	1.38 A	1.34 A	1.84 B
		Cumulative Nitrous Oxide Emissions					
	lb N acre	~~~~~~~lb N_2O-N acre^{-1}~~~~~~~					
CC	0	0.42	0.21	0.35	0.16	0.12	0.10
	225	0.49	0.84	0.52	0.69	0.65	0.67
CSb	0	0.24	0.37	0.08	0.07	0.32	0.28
	180	0.77	0.67	0.26	0.74	0.94	1.40
SbC	180	0.30	0.22	0.17	0.12	0.07	0.16

180/225 In the CC system, a 225 lb N acre^{-1} rate was applied whereas in CSb a 180 lb N acre^{-1} was applied.

Ψ Cumulative NH_3-N was a period of 77 and 84 days for 2021 and 2022, respectively.

ASSESSING THE EFFECTIVENESS OF GREEN-SEEKER ALGORITHM IN MINIMIZING NITROGEN LOSS IN CORN PRODUCTION

O. Guzel[1], J. McGrath[2], O. Adeyemi[1], B. Arnall[5], A. Sadeghpour[1,3]
[1]School of Agricultural Sciences, Crop, Soil, and Environmental Program, Southern Illinois University
2 Office of National Programs, USDA-ARS
3 Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West
[4]OCP North America
[5]Oklahoma State University

ABSTRACT

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

INTRODUCTION

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

MATERIALS AND METHODS

Experimental Site, Design, and Treatments

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

Measurements

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

RESULTS AND DISCUSSION

Corn Grain Yield

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

Soil nitrate-N trends

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

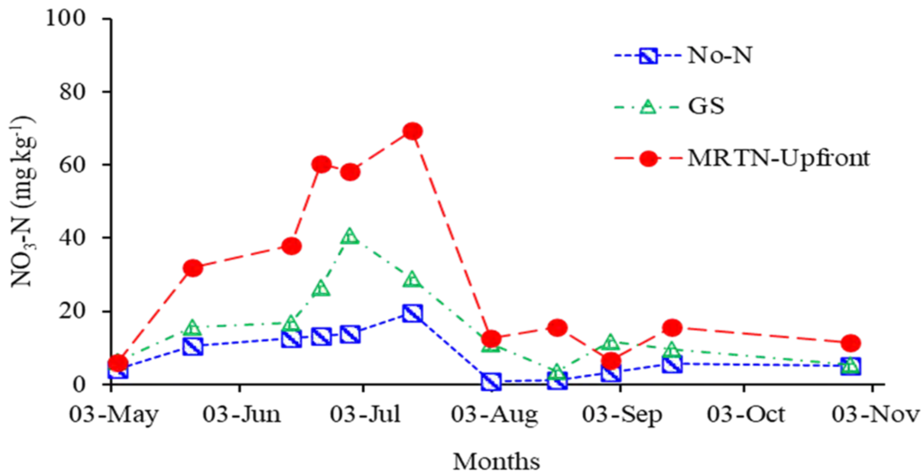

Fig. 1. Soil NO_3-N as influenced by N management in 2022. No-N is no fertilizer control, GS indicates GreenSeeker-based N rate and MRTN-Upfront is 203 lbs N ac^{-1} at planting.

Cumulative N_2O-N emissions

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

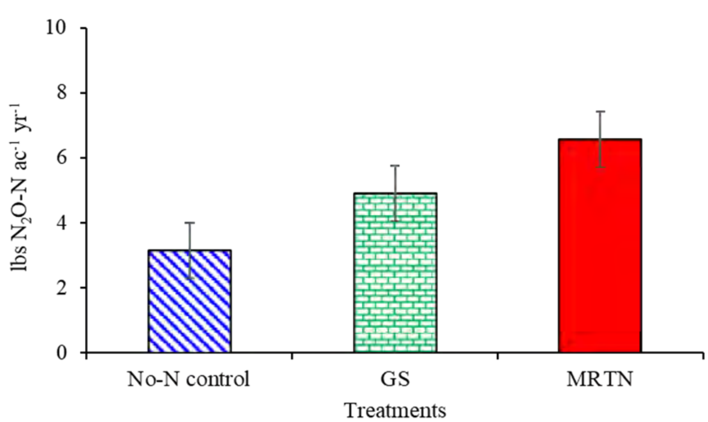

Fig. 2. Cumulative N_2O-N emissions during the corn growing season as influenced by N management in 2022. No-N is no fertilizer control, GS indicates GreenSeeker-based N rate and MRTN-Upfront is 203 lbs N ac^{-1} at planting.

Nitrate-N leaching

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

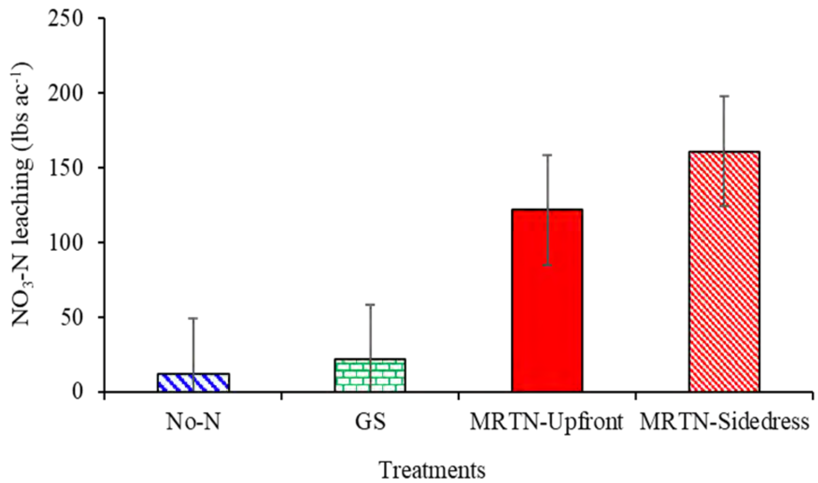

Fig. 3. Nitrate-N leaching during the corn growing season as influenced by N management in 2022. No-N is no fertilizer control, GS indicates GreenSeeker-based N rate and MRTN-Upfront is 203 lbs N ac^{-1} at planting and MRTN-sidedress is 203 lbs N ac^{-1} that was applied as 55 lbs N ac^{-1} at planting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

PRELIMINARY CONCLUSION

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

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CAN CRP SERVE AS A SOIL HEALTH BENCHMARK: A MINNESOTA CASE STUDY UTILIZING SMAF

O. Hoffman[1], C. Chorpenning[2], C. Buchanan[2], T. Trimarco[2], N. Carr[3], and J. Ippolito[1]

The Ohio State University[1], Colorado State University[2], Faribault County Soil and Water Conservation District[3]

ABSTRACT

Soil health is an important concept relating to sustainable agriculture and food security. However, the absence of a universally accepted benchmark for soil health complicates its application as a tool to measure soil functional capabilities. Here we propose the use of Conservation Reserve Program (CRP) soils as a potential benchmark for soil health in Southern Minnesota. The Soil Management Assessment Framework (SMAF) was used to evaluate soil health indicators and quantify the soil health gap (SHG) between corn-based agricultural and CRP systems. This case study featured three paired systems consisting of 22-year CRP tall grass prairie adjacent to long-term corn-based agriculture (AP). Soil samples were collected at a depth of 0-15cm, and SMAF scores were assigned to various soil health indicators. Results showed either greater soil health overall scores or trending towards greater soil health scores in CRP as compared to AP, primarily driven by soil biological indicators ($p < 0.001$). The CRP sites were statistically indicative or trended towards potentially being used as a benchmark for soil health, yet some data appeared to show limitations of SMAF as tool to characterize soil health at CRP sites. This suggests that more data is required and perhaps SMAF scoring functions need to be updated to more accurately reflect the conditions present in “benchmark” CRP locations.

INTRODUCTION

Agriculture plays a critical role in the production of food, feed, and fiber to meet the needs of a growing population. However, innovations in agricultural production in the early and mid-20th century have compromised environmental sustainability (Melsted., 1954). Over recent decades, the connection between agricultural production and environmental protection has gained significant scientific attention, with soil health emerging as a promising tool (Karlen et al., 2019). While soil health is recognized as a tool to bridge crop production and environmental stewardship, the scientific foundation of the topic is lagging behind the widespread implementation.

One prominent knowledge gap regarding soil health is a universally accepted benchmark to serve as a comparative tool for agricultural lands. Maharjan et al. (2020) proposed the concept of the soil health gap (SHG) as a way to understand the difference between untouched native soils and a test soil (benchmark soil – test soil = SHG). Native ecosystem soils were proposed as a reference point for soil health, but due to extensive conversion to agricultural and urban uses specifically in the Corn Belt region of the US, identifying representative native soils is a challenge. An alternative to using native soils as a benchmark could be soils within Conservation Reserve Program (CRP) locations, as they can be found extensively across the US with their aim to conserve environmentally sensitive land by restoring a semi-native ecosystem (Stubbs., 2014). Here we assess the use of CRP as a soil health benchmark in Faribault County, Minnesota, and quantified soil health using the Soil Management Assessment Framework (SMAF).

MATERIALS AND METHODS

Three agricultural production (AP) fields adjacent to three CRP sites were identified in Faribault County, Minnesota (farms H, E, and S). All CRP fields had been enrolled in the program for 22 years and managed as outlined by the NRCS county office. AP sites utilized different management systems, but all revolved around a corn-soybean rotation. In August of 2023, soil samples were collected from the top 15cm at each paired site and tested for the Soil Management Assessment Framework (SMAF) indicators. SMAF is a soil health quantification tool developed jointly by the USDA-NRCS and USDA-ARS at the Laboratory for Agriculture and the Environment in Ames, IA (Andrews et al., 2004). SMAF indicators included soil organic carbon (Nelson and Sommers., 1996;Sherrod et al., 2002), microbial biomass C (Beck et al., 1997), betaglucosidase activity (Green et al., 2007), mineralizable nitrogen (Mulvaney., 1996 and Curtain; McCallum., 2004), water stable aggregation (Kemper and Rosenau., 1986), bulk density, texture (Ashworth et al., 2001), pH (Thomas., 1996), electrical conductivity (Thomas., 1996), and plant-available P and K (Mehlich., 1984). SMAF then interprets the measured values using on-site characteristics to produce indicator scores and soil health scores ranging from 0 to 1 (0 being poor, and 1 being optimal). Pairwise comparisons from AP to CRP with each farm combined were performed utilizing the Mann-Whitney test while individual farm pairwise comparisons from AP to CRP were performed using the Kruskal-Wallis test. Significance levels were determined with an α of 0.05.

RESULTS AND DISCUSSION

The average soil health gap (SHG; presented in figure 1), calculated using SMAF overall scores, was 0.12 and proved significant. Notably, Farm H exhibited the largest and only significant SHG of 0.18, primarily driven by biological and physical indicators, all of which were significant. Farm S, although not significant, had a SHG of 0.09, trending towards the CRP sites having higher overall SMAF score, and was similarly influenced by biological and physical indicators. Interestingly, farm E had the smallest SHG of 0.01, likely a result of acidic pH conditions stressing the soil microbiome and reducing soil biological activity, a finding supported by previous research (Malik et al., 2018).

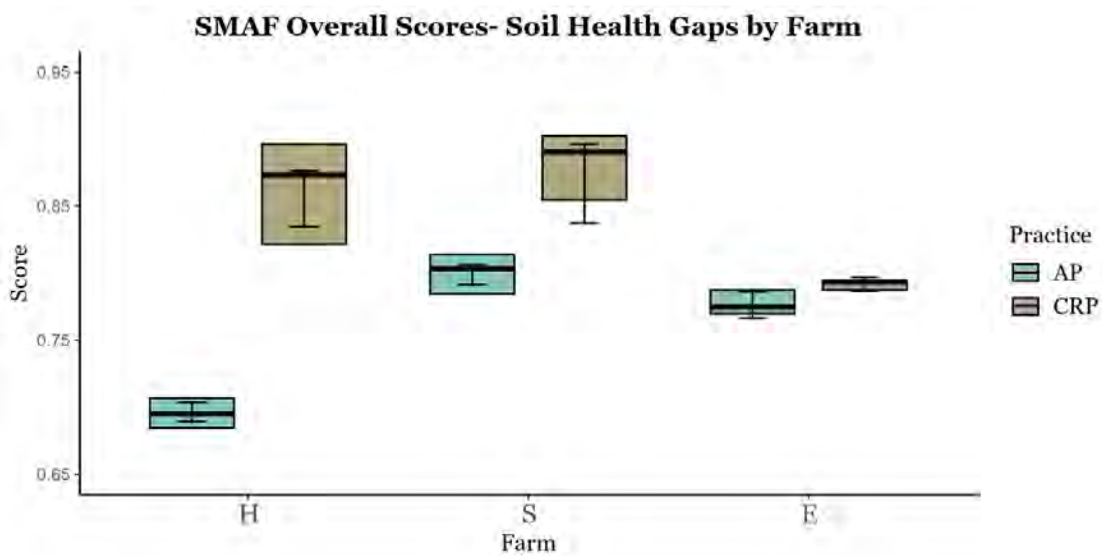

Figure 1: Average SMAF overall scores by individual farms comparing agricultural production (AP) site to Conservation Reserve Program (CRP) site.

The effect of pH on the soil microbiome was more pronounced in CRP sites and within SMAF biological indicators. This was likely because natural systems pH is a direct product of the environment while in AP sites, lime is often applied to manage for pH. Given that SMAF biological indicators were a significant driver of the overall soil health score, this pH effect likely drives the relatively small SHG found at farm E (figure 1). Specifically soil organic carbon (SOC), microbial biomass carbon (MBC), and betaglucosidase activity (BG) scores, and thus biological and overall soil health were impacted the most by pH (figure 2).

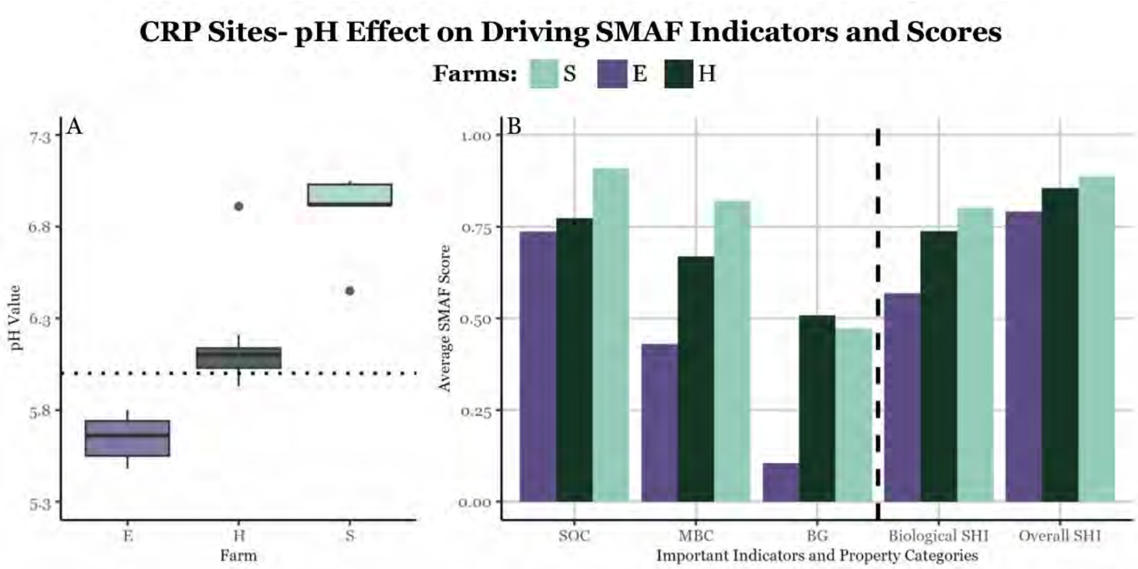

Figure 2: The influence of pH on SMAF biological indicator scores, biological soil health index (SHI) and overall SHI in CRP sites only. A) pH values for each individual farm

CRP site. B) Soil organic carbon (SOC), microbial biomass carbon (MBC), betaglucosidase activity (BG), biological SHI, and overall SHI by farm and only for CRP sites.

To better understand the effect of pH on biological indicators, diving into measured values is prudent. For the CRP sites, farm H had an average pH value of 6.2 while farm S was 6.9 (figure 2), both within neutral range minimizing the effects of pH on the soil microbiome. Whereas at farm E, the measured pH value for the CRP site was 5.6. When combining sites H-CRP and S-CRP for betaglucosidase activity (BG), the average measured value was 288 mg PNP/kg/hr while at site E-CRP the average BG measured value was 115 mg PNP/kg/hr, a 60% reduction in C cycling enzyme activity (figure 3). Similarly, microbial biomass carbon (MBC) was reduced by 42% and potentially mineralizable nitrogen (PMN) was reduced by 49% (figure 3). These results for biological indicators support our observation of acidic pH impacting C and N cycling in these soils.

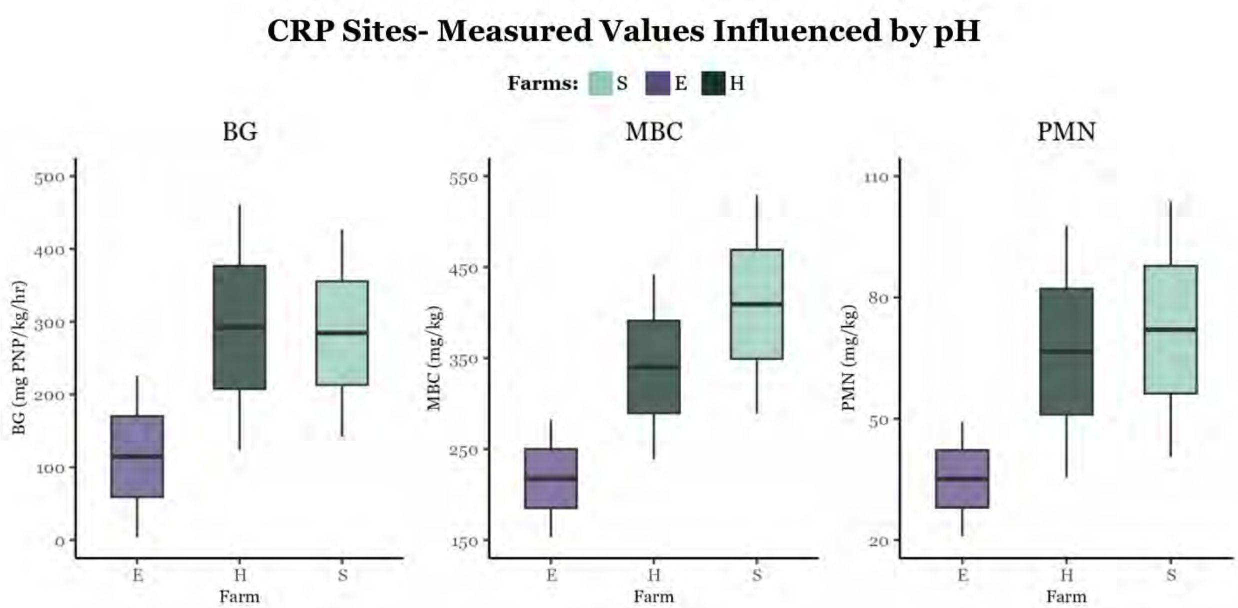

Figure 3: Raw values by individual farm for only the CRP sites. BG: betaglucosidase activity (mg PNP/kg/hr). MBC: microbial biomass carbon (mg/kg). PMN: potentially mineralizable nitrogen (mg/kg).

The observed effect of pH on soil biological indicators raises concerns regarding the applicability of SMAF within natural systems. For agricultural systems, where the goal is to produce commodity crops, soil pH is managed with lime to maintain optimal levels of nutrient availability. However, in natural systems, pH is a direct result of environmental conditions and therefore becomes an inherent soil factor. Within SMAF, pH is treated as a manageable indicator with a direct score given, yet it seems more apropos to be treated as a factor class influencing soil biological interpretations for natural systems. Despite the effects of pH on SMAF scores and the SHG, CRP does appear to show potential as a benchmark for soil health. Farms H and S are examples of this, an informative SHG was derived and differences in the SHG appear to be tied to agricultural management strategies.

CONCLUSIONS

The need for a soil health benchmark remains, however this case study identified facets of soil health that must be understood before a true benchmark can be implemented. Specifically, the mechanisms by which SMAF and soil health frameworks in general interpret pH when assessing natural systems. CRP does show promise to serve as a nation-wide soil health benchmark and appears to have elevated biological activity and physical structure. Results from this project suggest future work assess the potential of CRP on a larger scale and the updating of soil health frameworks to more accurately reflect natural systems. Data from a larger scale project can potentially inform what agricultural management practices have the greatest potential to decrease the soil health gap and increase regional agricultural sustainability.

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ASSESSING FALL APPLIED PHOSPHORUS SOURCES AND WHEAT COVER CROP ON THE FOLLOWING SOYBEAN PERFORMANCE

M. Javid[1], J. McGrath[2], S. Babaei[1], F. Sheikhi Shahrivar[1], A. Sadeghpour[1&3]

[1] School of Agricultural Sciences, Crop, Soil, and Environmental Program, Southern Illinois University
[2] Office of National Programs, USDA-ARS
[3] Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West

ABSTRACT

Growers often maintain soil test phosphorus (STP) using ammonium phosphate fertilizers, such as diammonium phosphate (DAP, 18-46-0) or monoammonium phosphate (MAP, 11-52-0) and employ fall application to avoid competition for time and wet field conditions, both prevalent in the spring. However, fall application of nitrogen (N) with these P fertilizers presents a risk of N loss over the fallow period. One source that could minimize N loss during the fallow period is triple superphosphate (TSP; 0-46-0). This experiment evaluates wheat (*Triticum aestivum* L.) cover crop use of fall-applied P sources and the following soybean (*Glycine max* L.) yield and yield component in rotation to evaluate the response of soybean to wheat as a cover crop in different P management scenarios in the fall. Treatments are arranged in split plot design with cover crops as the main effects (with and without) and four fertilizer treatments [three P sources (DAP, MAP, and TSP) a no-P control] as subplots. Our results indicated that wheat biomass was similar among all treatments in an April sampling date but greater in DAP than other treatments when sampled in May, reflecting greater N use and demand as these cover crops grow during the spring period. Soybean yields were higher in the cover crop treatments than the no-cover crop control which could be explained by moisture preservation during the dry July and August in that year. More study years are needed to conclude the best fall-applied fertilizer practices in soybean seasons.

INTRODUCTION

According to the U.S. Department of Agriculture's National Agricultural Statistical Service (USDA-NASS), Illinois is the largest producer of soybean (*Glycine max* (L.) Merr.) in the United States. However, Studies in Illinois have shown that after the corn (*Zea mays* L.) and soybean harvests, there is a significant amount of nitrate-N leaching, which concerns the environment, especially the water quality. The Illinois Nutrient Loss Reduction Strategy (INLRS) suggests winter cereal cover crops (WCCC) as a management strategy that may effectively minimize nutrient loss and protect Illinois waters and the Gulf of Mexico (Sadeghpour et al., 2021). In Illinois, wheat is a common WCCC that offers several agronomic benefits. In addition to helping control weeds, it protects soil, reduces erosion, and minimizes nitrate-N leaching (Adeyemi et al., 2020). Farmers often use ammonium phosphate sources, such as diammonium phosphate (DAP) and monoammonium phosphate (MAP), to apply P fertilizers in the fall to meet their phosphorus (P) requirements. However, nitrogen (N), also present in these fertilizers, is vulnerable to leaching and denitrification during late fall and early spring fallow periods, which might result in environmental losses. When combined with various P sources, this study examines how these cover crops affect future soybean production and yield components and assesses whether a wheat (*Triticum aestivum* L.) cover crop can efficiently use N from fall-applied P sources.

MATERIALS AND METHODS

The experimental design was a randomized complete block design with split plot arrangements and four replicates in 2022-2023. The Main plots were cover crop treatments (wheat cover crop vs. a no-cover crop control). The subplots were four fertility treatments, including a no-fertilizer control, diammonium phosphate (DAP), mono ammonium phosphate (MAP), and triple superphosphate (TSP).

Wheat was planted in mid-October in fall 2022. The seeding rate for wheat was 1.6 million plant ac^{-1} with a row spacing of 7.5 inches. The wheat cover crop was terminated in mid-May 2023 before soybean planting. The plots were 10 ft wide and 40 ft long. In mid-May, a no-till drill was used to plant soybeans at 100,000 seeds ac^{-1}. The P fertilizer application occurred in the fall of 2022 when wheat was established. All plots, excluding the no-fertilizer control, received 200 lbs P2O5 ac^{-1}. This means that DAP and MAP treatments received 78 and 42 lbs of N ac^{-1}, respectively. The soybean was harvested on October 20^{th,} and at that time, plant population and yield components were measured. Data were evaluated for normality of the residuals and then analyzed with SAS statistical software at $p<0.05$, considered significant.

RESULTS AND DISCUSSION

Wheat Cover Crop Biomass and Nitrogen Uptake

Wheat cover crop biomass was similar among fertility treatments in April sampling (Fig. 1). Wheat cover crop termination timing is important for nitrogen (N) absorption. There was no statistically significant difference in wheat biomass between the fertilizer treatments when the wheat was terminated early in April, indicating that the wheat did not uptake sufficient nitrogen. Compared to other treatments, a significant increase in biomass was observed in the DAP-treated plots when termination was postponed until May. The difference could be explained by the fact that DAP has a higher N content than MAP, allowing wheat in DAP-treated plots to uptake more N as it grows. Delaying termination allowed the wheat cover crops in DAP plots to use the available N better, producing higher biomass than other treatments.

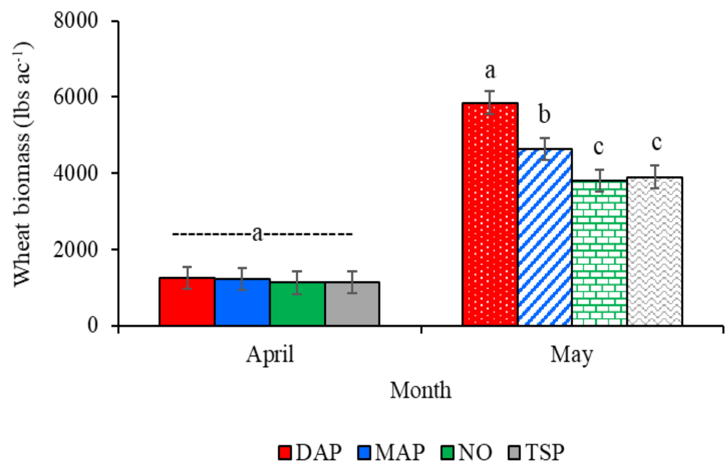

Fig 1. Wheat response to different fertility treatments in April and May (prior to planting soybeans). Bars are standard error, and similar letters indicate no statistical differences (Tukey ≤ 0.05).

Soybean Biological Yield, Grain Yield, and Harvest Index

Soybean biological yield (aboveground biomass including grain and plant parts) was influenced by cover crop treatment in which fallow had higher soybean biological yield than the wheat cover crop treatment (Fig. 2).

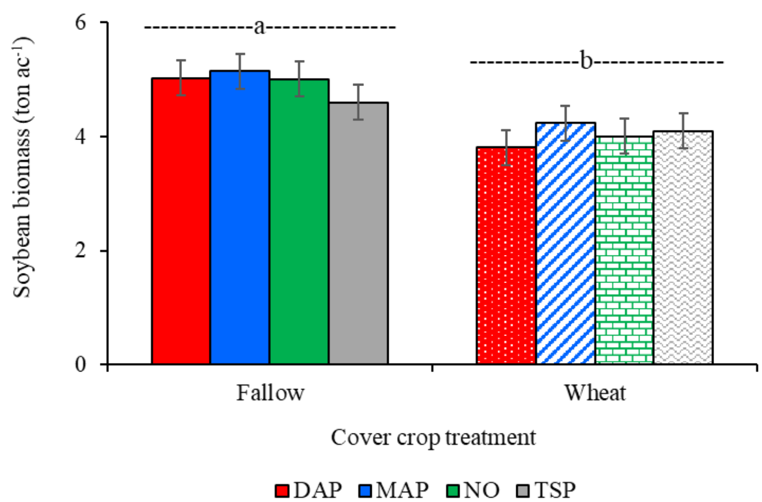

Fig 2. Soybean biological yield as influenced by cover crop and fertility treatments. Bars are standard error, and similar letters indicate no statistical differences (Tukey ≤ 0.05).

Soybean grain yield was higher in wheat treatments than the fallow treatments, but there was no fertility effect in each cover crop treatment (Fig. 3).

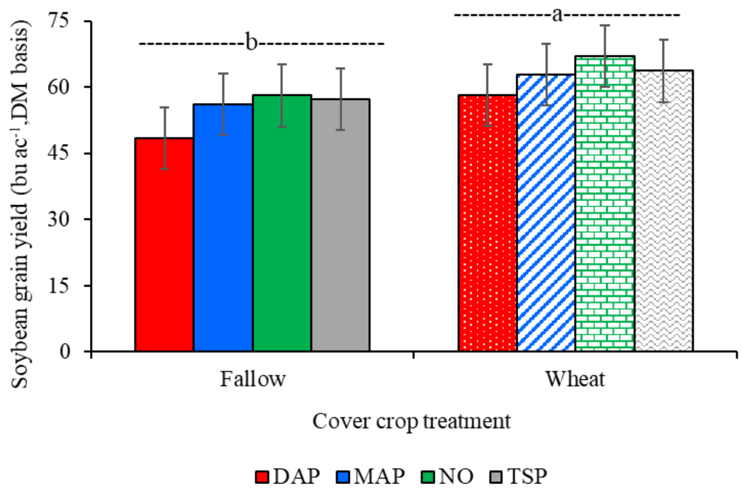

Fig. 3. Soybean grain yield (dry matter basis) as influenced by cover crop and fertility treatments. Bars are standard error, and similar letters indicate no statistical differences (Tukey ≤ 0.05).

Harvest index

Harvest index (%) affected by cover crop and fertility treatments. The harvest index was in the typical range for soybeans, with lower HI in fallow than wheat cover crop treatment (Fig. 4).

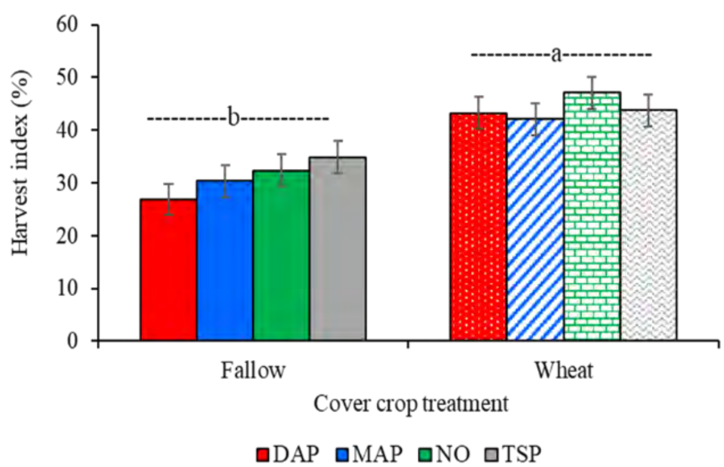

Fig. 4. Harvest index (%) affected by cover crop and fertility treatments. Bars are standard error, and similar letters indicate no statistical differences (Tukey ≤ 0.05).

Wheat Cover Crop Biomass and Nitrogen Uptake

Our results showed that wheat cover crop biomass was significantly higher in plots treated with ammonium phosphate fertilizers (DAP and MAP) than in those receiving TSP or no fertilizer. This suggests that the wheat cover crop used some of the N available in DAP and MAP, reducing the risk of nitrate leaching by capturing N during the fallow period. Additionally, N uptake by wheat was greatest in DAP-treated plots due to its higher N content relative to MAP. These findings emphasize the wheat cover crops' role in N maintenance, supporting its use as a winter cover to mitigate N losses.

Soybean Biological Yield, Grain Yield, and Harvest Index

Soybean biological and grain yields were higher in wheat cover crop treatment than the fallow control, particularly in treatments that received DAP and MAP. This finding suggests that cover crops help keep N during the fallow period and support following crop performance by preserving soil moisture and enhancing soil structure. The higher harvest index (HI) in plots with wheat cover-crop shows that a greater proportion of aboveground biomass was allocated to grain production, underscoring the potential of cover crops to improve resource use efficiency and yield outcomes in following cash crops.

Comparison with Previous Studies

Our findings align with those of Sadeghpour et al. (2021), who reported the benefits of winter cereal cover crops in reducing nutrient losses in Illinois, particularly in no-till systems where N holding is important for the following crop. Similarly, Adeyemi et al. (2020) noted that wheat cover crops help decrease nitrate-N leaching and promote soil conservation, consistent with the observed N uptake in this study. Vaughn et al. (2022) emphasized that cover crops mitigate N loss but may not reduce N leaching risks associated with fall-applied N. Our results support this, showing that although wheat cover crops reduce N loss, their effect is maximized when paired with high-N sources like DAP.

The soybean yield responses in this study align with Fernández et al. (2010), who verified positive yield impacts of ammoniated phosphates, particularly when N loss was managed effectively through cover crop integration. The higher harvest index in cover-cropped plots shows that wheat may contribute to better yield components by retaining soil N and moisture, at last supporting the cash crop's productivity.

CONCLUSION

This study highlights the role of winter wheat cover crops in reducing N loss from fall-applied phosphorus fertilizers and enhancing soybean yield. Our findings show that ammonium phosphate fertilizers (DAP and MAP) used with wheat cover crops help retain N and reduce nitrate-N leaching. Notably, soybean grain yield, biomass, and harvest index were enhanced by cover crop presence, reflecting improved resource efficiency and environmental sustainability.

These results support the integration of winter cover crops with fall-applied phosphorus fertilizers, particularly in systems utilizing ammonium phosphates, to mitigate N loss, especially during the fall and spring periods. Future research should further explore the long-term effects of different phosphorus sources on N dynamics and crop performance to refine sustainable nutrient management practices in soybean systems.

ACKNOWLEDGMENT

This research was funded by OCP North America and the Illinois Nutrient Research Education Council (NREC). The authors thank Randy Lange and Chris Vick for their invaluable technical support throughout the study. Special thanks to the field crew at Southern Illinois University for their assistance in data collection.

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A DIRECT APPROACH TO MEASURE COVER CROP NITROGEN UPTAKE FROM DAIRY MANURE VIA ^{15}N ENRICHMENT

T. Judd, M.Ruark, and Z. Freedman
Department of Soil and Environmental Sciences, University of Wisconsin-Madison

ABSTRACT

Fall manure applications are a standard practice across Wisconsin, primarily due to manure storage constraints and unpredictable spring field conditions. Unfortunately, manure derived nitrogen (N) is at risk for runoff and leaching into groundwater without an appropriate mechanism for N retention. Fall-planted grass cover crops can serve as N scavengers, reducing losses of manure N to the environment, especially post-silage harvest, however potential tradeoffs between sufficient N uptake and spring termination must be considered between winter-killed and overwintering varieties. This study aims to directly quantify manure N in fall-planted cover crops utilizing ^{15}N labeled dairy manure to directly determine differences in N uptake between winter-killed and overwintering varieties, while also tracking manure N in the soil profile. Spring Barley, spring oats, winter wheat, and winter rye were drill-seeded in the fall at 60 lb ac^{-1}, in addition to a no cover crop treatment, following semi-solid manure application and incorporation at approximately 220 lb total N ac^{-1} at the Arlington Agricultural Research Station (Arlington, WI). Main plots received unlabeled manure (control) and microplots within the main plots received ^{15}N labeled manure. Cover crop root and shoot samples and soil samples were taken in December and April to measure Total N/^{15}N of plant and soil. Presented results will directly quantify the amount of manure N in cover crop biomass with a stable isotope informed approach of ^{15}N manure labeling. These results will illuminate our knowledge regarding the fate of fall applied manure N when cover crops are utilized in the North Central US.

INTRODUCTION

In Wisconsin, cover crops are a promising management strategy for addressing environmental and producer concerns pertinent to manure applications. Nitrate is the greatest contaminant concern for groundwater in the state of Wisconsin, and nitrate pollution continues to increase statewide (WDNR, 2022). Runoff from applied nutrients, including manure, accounts for nearly 90% of groundwater nitrate (WDNR, 2022), which also equates to an economic loss for producers. Nearly 63% of Wisconsin acres grown for corn received dairy manure in 2010, and almost 56% of it was fall applied, according to a study done by Mitchell et al. (2021). Storage constraints and unpredictable spring weather make fall manure applications ideal, however, no growing crop is typically in place by manure application time. Non-leguminous, fall-planted cover crops can potentially utilize a significant amount of manure-derived nitrogen (N), but increased producer confidence for practice adoption is still needed in the state. This study aims to better describe manure N availability in-field under cover crop utilization, and the success of different grass cover crop varieties as N scavengers. The objectives of this study were to i) compare root and shoot biomass between winterkilled and overwintering cover crop varieties in fall and spring prior to termination, ii) measure manure-N uptake across cover crop varieties, iii) determine residual manure-N in soil following cover crop termination and when no cover crops were planted.

MATERIALS AND METHODS

Experimental design and field setup: This two-year study is being conducted from Fall 2023- Spring 2025 at the University of Wisconsin Arlington Agricultural Research Station (Arlington, WI) (43º18'9.47"N, 89 º 20'43.32"W). The soil is Plano silt loam (fine-silty, mixed, superactive, mesic Typic Argiudoll, US Department of Agriculture [USDA] Soil Taxonomy) with 6% sand, 72% silt, and 22% clay. 20- 9×12ft field plots were established in a pseudo-replicated block design with 3×3ft microplots installed within each field plot that received labeled ^{15}N manure. The remaining outside area of the main received unlabeled manure (control). Four cover crop varieties, two overwintering (winter wheat and winter rye) and two winter-killed (barley and oats) were planted in the four block reps of the experiment. Additionally, a no cover crop treatment was established that only received manure. Cover crops were drill-seeded in early October 2023 at a seeding rate of 60 lb acre^{-1}. Prior to planting, both unlabeled and labeled manure were spread and incorporated into the soil at an approximate rate of (220 lb total N acre^{-1} or ~60 lb available N acre^{-1}). Refer to table 1 for a timeline of research activities related to this project.

Timeline	Summer 2023/2024	Fall 2023/2024	Spring 2024/2025
Plans/ measurements	Installation of microplots, labeled/unlabeled manure production.	Manure application, plant cover crops. Baseline soil samples for TN/^{15}N. TN/^{15}N of plant biomass in late fall.	Cover crop termination, yield data, TN/^{15}N of plant biomass and soil. End Field Experiment

Table 1. Project timeline outlining years 1 and 2 of field and lab setup/sampling.

Production of unlabeled and ^{15}N labeled manure: The protocol described has been approved by UW-Madison Institutional Animal Care and Use Committee (IACUC) prior to the start of the experiment. Two cannulated mid-lactation dairy cows from the UW-Madison Dairy Cattle Center were utilized to produce both labeled and unlabeled manure (feces + urine). Over a 12-day period, cows were bedded on mattresses in a tie-stall barn. No additional wood or hay bedding was used to better control the C:N of manure between collection periods.

Cow feeding regimes were normal daily herd total mixed rations (TMR), but urea N was supplemented by direct addition into the rumen of the cannulated cows. Pharmaceutical grade unlabeled urea was fed to both cows on days 1-8 to produce enough unlabeled (control) manure in a timely manner. On days 9-11, reagent grade (>99% purity) ^{15}N urea @ 98at% was mixed with unlabeled urea to achieve ^{15}N urea @ 10at%, which amounted to ~5g of reagent grade ^{15}N urea in the total 50g fed daily. ^{15}N urea was only fed to one cow due to the lower amount of manure needed for microplots and expense of ^{15}N urea. To allow for animal adaptation to a nonprotein nitrogen source, unlabeled urea was supplemented through the cannula in increasing increments of 10g per day, up to 50g of urea per day by day 5 (table 2). All urea was dissolved in 100mL of distilled water to evenly apply over rumen contents. By day 12, both cows were returned to their daily TMR with no urea supplementation.

Day	**Feed amount/type**	**Fecal Collection (Feces + Urine)**
1	10g unlabeled urea	None
2	20g unlabeled urea	Unlabeled manure collection
3	30g unlabeled urea	Unlabeled manure collection
4	40g unlabeled urea	Unlabeled manure collection
5	50g unlabeled urea	Unlabeled manure collection
6	50g unlabeled urea	Unlabeled manure collection
7	50g unlabeled urea	Unlabeled manure collection
8	50g unlabeled urea	Unlabeled manure collection
9	50g labeled urea (10at% ^{15}N) (1 cow)	^{15}N labeled manure collection
10	50g labeled urea (10at% ^{15}N) (1 cow)	^{15}N labeled manure collection
11	50g labeled urea (10at% ^{15}N) (1 cow)	^{15}N labeled manure collection
12	Normal TMR	^{15}N labeled manure collection

Table 2. Daily unlabeled and labeled urea feeding and manure collection schedule.

Manure (feces + urine) was collected twice daily in pans below the gutter grates that allow cows to defecate normally. Manure was stored in 5-gallon buckets at 4°C for < 2 weeks to minimize chemical decomposition of manure beyond a single day to accommodate the logistics of field application. The manure was sub-sampled after being mixed with a paint mixer prior to storage and air-dried at 40°C or frozen at -20°C to conduct isotopic and routine analysis of the manure. Prior to field application, both unlabeled and labeled manure was mixed and subsampled again for isotopic and routine manure analysis. For labeled manure, digested ^{15}N urea takes between 32-96 hours to evenly label between urine and feces (urine and endogenous fecal N pools), so manure collected on days 11 and 12 (days 3 and 4 of ^{15}N feeding) were prioritized for microplot application. A minimum ^{15}N at% of 10% over natural abundance can be used for short-term (1-2 year) crop N cycling studies (Powell et al., 2004).

Soil and Plant Sampling: Soil sampling occurred prior to planting and manure application for baseline soil ^{15}N/TN, in late fall after spring barley and oat winterkill, and in the spring following winter wheat and rye termination. Within each plot, five cores were taken using a hand probe and divided between 0-20cm and 20-40cm, then homogenized by depth and plot, yielding two homogenized soil samples per plot (control ^{15}N). Microplot sampling followed the same protocol except 2 cores were taken (sample ^{15}N). Soils were air-dried, passed through a 2mm sieve, and prepared for ^{15}N/total N analysis. Whole plant biomass sampling occurred for all four cover crops within the field plots (control ^{15}N) and microplots (sample ^{15}N) in late fall once the winter-killed varieties began to winterkill, and immediately prior to chemical termination of overwintering varieties. 5 individual plants from the main and microplots were dug up to encompass the root mass, then roots were soaked in water to remove all soil prior to separating from shoot and drying. Plant samples were oven dried @ 60°C, weighed, and ground for ^{15}N/total N analysis. Winter wheat and rye aboveground biomass were sampled from a $3ft^2$ quadrat (three rye rows).

TN/^{15}N analysis: Soil and plant material were prepared for IRMS analysis according to protocols set forth by the Freedman Lab Core at UW-Madison.

RESULTS AND DISCUSSION

Dairy manure enrichment: ^{15}N dairy manure produced in August 2023 was successfully labeled >10% of natural abundance (0.37at%)(fig. 1). Within 72 hours after the initial ^{15}N urea feeding, isotopic enrichment increased by almost 50%, peaking at 0.57at% at 4am on day four of collection. These results indicate that the approach used for ^{15}N labeling of dairy manure was successful, and we would expect that the isotopic signal is strong enough to trace ^{15}N manure into both the cover crops and soil profile.

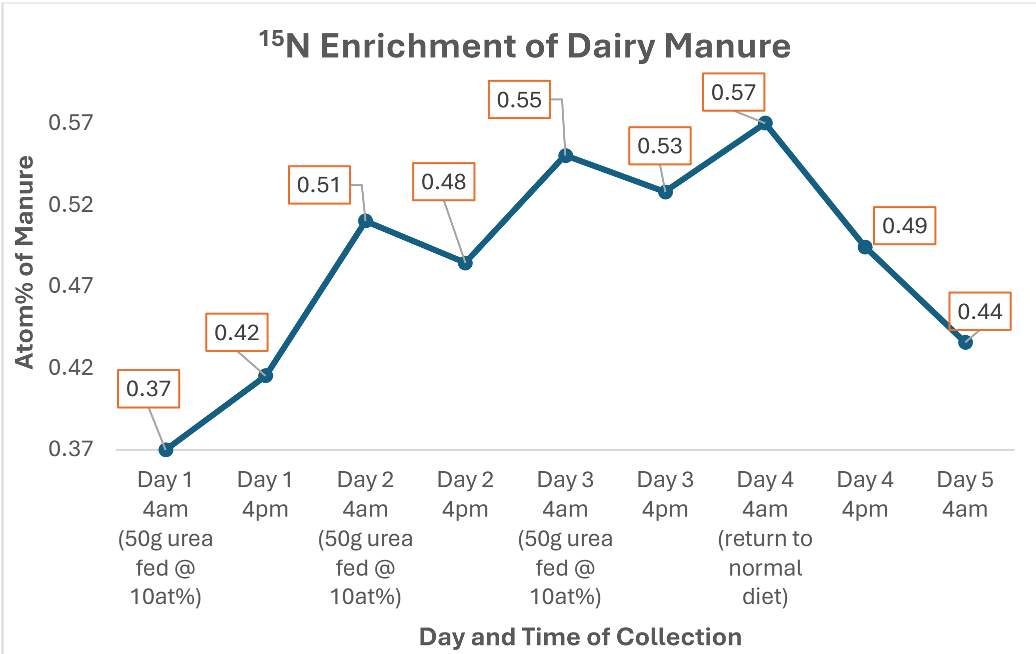

Fig. 1. Change in 15N at% of collected manure across three days of feeding with two manure collections daily.

Cover Crop Biomass: In Fall 2023, cover crop growth was limited by a late September seeding date and early snowfall. All four cover crop varieties successfully established in the plots (fig. 2), however spring barley and oats unlikely obtained enough growth to retain an environmentally relevant amount of manure N. At Fall plant sampling, shoot biomass made up >60% of the total biomass on average in winter rye, winter wheat, and barley (fig. 3). By spring sampling, shoot biomass still accounted for >50% of total biomass in winter rye and winter wheat, however root biomass accounted for nearly 40% of the total biomass (fig. 4). Calculated yield for winter rye and winter wheat were approximately 2000lb acre^{-1} and 1500lb acre^{-1}, respectively.

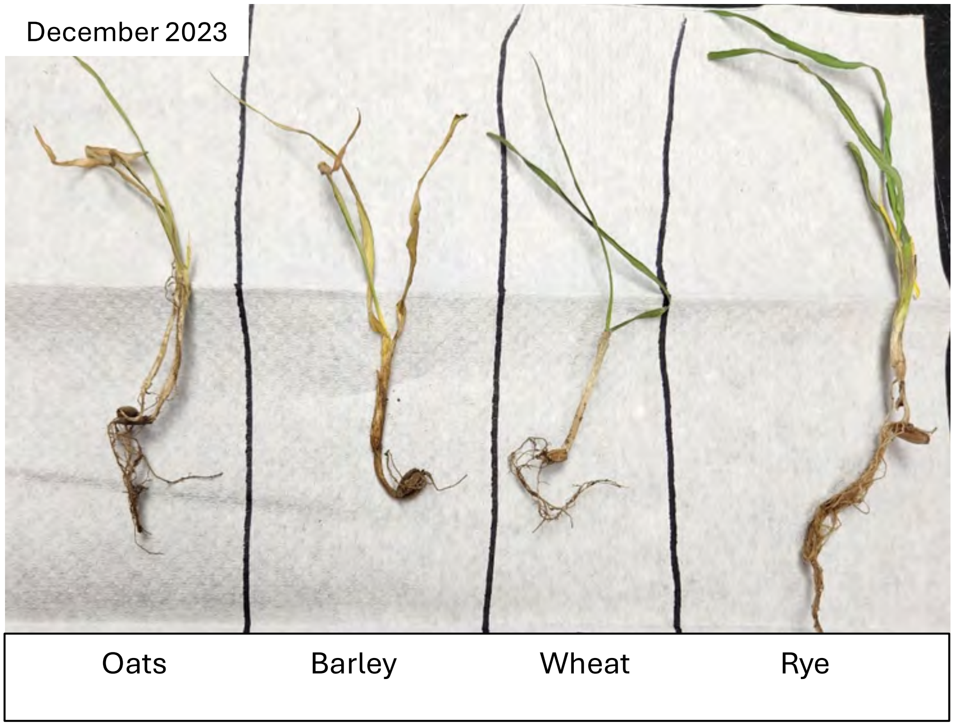

Fig. 2. Spring oats, spring, barley, winter wheat and winter rye sampled in December 2023

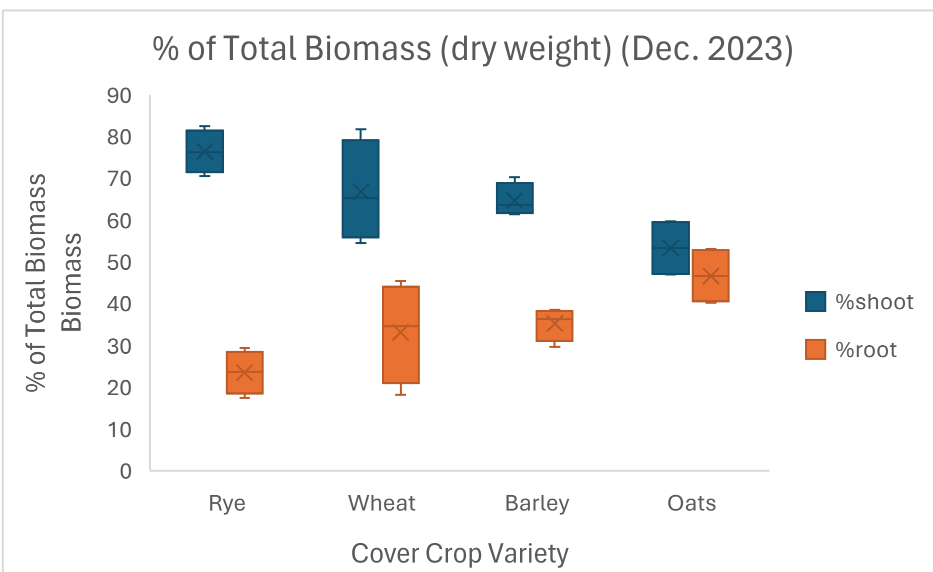

Fig. 3. % of total biomass attributed to root or shoot between four cover crop varieties samples in December 2023 following winterkill of spring barley and oats.

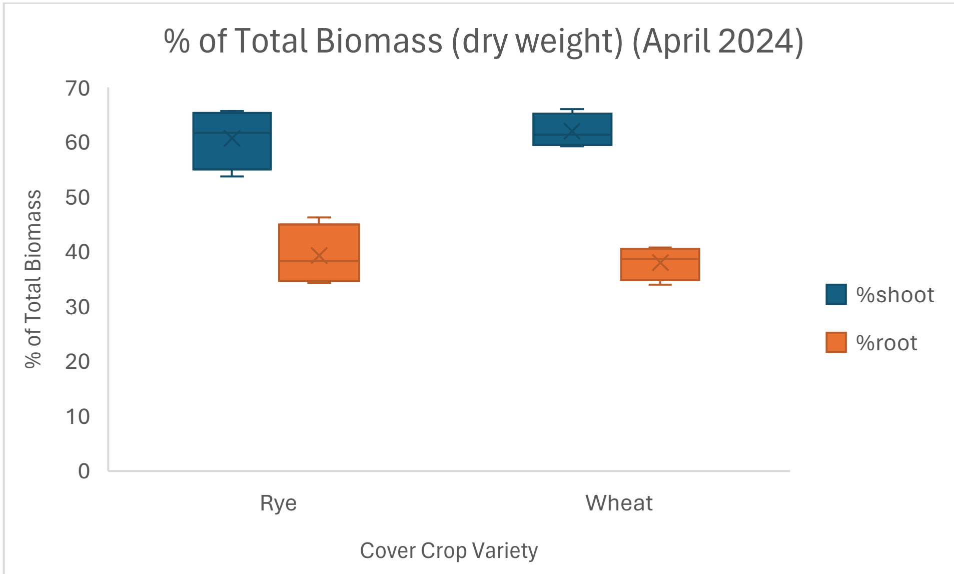

Fig. 4. % of total biomass attributed to root or shoot between four cover crop varieties samples in April 2024 following winterkill of spring barley and oats.

Manure N uptake by cover crops: Cover crop samples are still being analyzed via IRMS for ^{15}N/TN but will be presented at the conference. We expect that all four cover crop varieties sampled in late fall to have a similar amount of manure N uptake given their growth. From Spring sampling, we expect that winter rye will retain more manure N than winter wheat, but winter wheat still served as an effective N scavenger. We expect to see that spring-sampled winter rye and winter wheat will have a significant amount of their total N stored in their root biomass.

CONCLUSION

^{15}N labeled urea fed to dairy cattle successfully produced dairy manure with an isotopic label between 10-50% above natural abundance, likely sufficient for 1–2 year N cycling studies in-field. In study year 1 (Fall 2023- Spring 2024), winterkilled varieties were likely not planted early enough to obtain sufficient biomass to serve as effective N scavengers, however all varieties did establish. Winter rye obtained the greatest biomass prior to spring termination, and we expect it also retained the greatest amount of manure N.

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COVER CROP COMPOSITION: IMPLICATIONS FOR CROP YIELDS, NITROGEN USE AND SOIL HEALTH IN CORN-SOYBEAN ROTATIONS

S. Kodali, J.D. Clark, P. Kovacs, P. Sexton, S. Osborne
South Dakota State University

ABSTRACT

Cover crops can improve agricultural sustainability by influencing N (N) use, enhancing soil health, and optimizing crop yields. However, their effects may vary based on species composition. This study evaluated how different cover crop compositions impact crop yields, N requirements, and soil health in corn-soybean rotations. Field experiments were conducted at Brookings and Beresford, South Dakota. Three cover crops (none, single grass, and multi-species) were interseeded at the V6 stage in corn and V5 in soybean. Six N rates ranging from 0 to 250 $lb.ac^{-1}$ were applied 10 days after planting in corn. Soil samples collected from the 0-6" depth at V6, R1, and R6 stages were analyzed for active carbon, aggregate stability, organic carbon, organic matter, potentially mineralizable N (PMN), NO3 – N, and NH4 – N. On average, interseeding cover crops in corn required 10-15 $lb.ac^{-1}$ more N than no cover crop, with the grass cover crop requiring ~10 $lb.ac^{-1}$ more N than the mixed species. At the economic optimal N rate, yield differences were minimal; the grass cover crop increased yield by only ~0.03 $bu.ac^{-1}$ and mixed species reduced yield by ~0.08 $bu.ac^{-1}$ compared to the control. These results suggest that interseeding cover crops in corn slightly alters yields but remains feasible with proper N management, while soybean yields remain unaffected, supporting interseeding as a viable practice. Interseeding cover crops had minimal impact on measured soil health parameters, likely due to insufficient biomass production. Conversely, higher N rates enhanced PMN, NO3 – N, and NH4 – N, reflecting increased nutrient availability. Sample timing influenced organic matter, active carbon, and aggregate stability. Overall, this study shows that cover crops regardless of composition can be interseeded into soybean without yield effect, but corn requires more N to sustain yields. Further, four years of interseeding cover crops into corn and soybean was not sufficient to find measurable differences in the selected soil health measurements.

INTRODUCTION

Corn-soybean rotations dominate agriculture in the U.S. Midwest, but this narrow crop diversity can limit biodiversity and compromise long-term soil health. To address these issues, cover crops are increasingly incorporated to enhance sustainability through greater species diversity, improved soil quality, and more efficient nutrient cycling. Cover crops can boost N use efficiency, soil health, and crop productivity, although the benefits depend on factors like species selection, timing, and management practices (McDaniel et al., 2014; Tiemann et al., 2015). However, widespread adoption is limited by high costs, return-on-investment concerns, and challenges with establishment, especially in areas with shorter growing seasons (Wayman et al., 2017).

Despite these obstacles, cover crop use has surged recently, with U.S. adoption growing 50% between 2012 and 2017, though they still occupy a small fraction of farmland (Thompson et al., 2021). In the northern Midwest, shorter growing seasons pose additional constraints, favoring winter cereals as cover crops despite challenges with their establishment timing (Baker & Griffis, 2009). Commonly interseeded species include grasses, clovers, and Brassicas (USDA ERS - Cover Crops, 2021). Combinations like annual ryegrass and crimson clover, both individually and in multispecies mixes, are being explored to find options that balance environmental benefits with crop productivity.

A primary concern with interseeding cover crops in corn is potential competition, particularly for N, which could impact corn yields (Hall et al., 1992). Studies by Travlos et al., 2011 indicate that competition with corn is minimal when weeds emerge after growth stages V2 to V5, suggesting that cover crops interseeded as early as V2 may not affect corn yields. However, the competitiveness of cover crops varies by species and density, influencing N needs for optimal yields. This study examines how single and multispecies cover crops, impact soil health, N requirements, and yields in corn-soybean rotations.

MATERIALS AND METHODS

In 2019, a long-term study was initiated in Brookings and Beresford, South Dakota utilizing a corn-soybean rotation. The study employed a split-plot design within each crop area. The main plot consisted of three cover crop treatments: no cover crop, a single grass species, and a mixture of grass and broadleaf species. The subplots included N fertilizer rates, with four or six levels ranging from 0 to 250 $lb\text{-}N.ac^{-1}$, applied 7–10 days after planting. Ammonium nitrate or Super U served as the N source, and cover crops were interseeded at the V5 developmental stage of both corn and soybean.

Soil, plant and grain sampling

Soil samples were collected before planting from plots previously under corn and transitioning to soybeans, at depths of 0–6” and 6–24”. The 0–6” soil samples were analyzed for soil health and fertility, while the 6–24” samples were tested for ammonium-N, nitrate-N, and sulfur content (Table 1). In-season soil samples were collected at key developmental stages: V6, R1, and R6 for corn, and V5, R1, and R6 for soybean. These samples were analyzed for soil health and fertility indicators (Table 1). Post-harvest, soil samples were taken at depths of 0–12”, 12–24”, and 24–36” to assess residual nitrate-N levels following the growing season (Table 1).

Plant samples were collected at specific developmental stages: V6, R1, and R6 for corn, and V5, R1, and R6 for soybean. For corn, six plants were sampled at each stage, while soybean samples were collected from a 1 m^2 area. At harvest, grain samples were taken and analyzed for complete nutrient content.

Table 1. Summary of soil sampling stages, depths, and parameters analyzed.

Sample Type	Collection Time	Sampling Depth	Measurements
Soil	Pre-plant	0-6”	Nitrate-N, Ammonium-N, Soil Organic Matter, Organic Carbon, Active C, PMN, Wet Aggregate Stability
		6-24”	Ammonium-N, Nitrate-N, Sulfur (S)
Soil	In-season	0-6”	Nitrate-N, Ammonium-N, Soil Organic Matter, Organic Carbon, Active C, PMN, Wet Aggregate Stability
Soil	Post-Harvest	0-12”	Nitrate-N
		12-24”	
		24-36”	

RESULTS AND DISCUSSION

Corn Yield Response and N requirements

Corn yields and N requirements varied across cover crop treatments at the Beresford and Brookings locations. At Beresford, the grass cover crop consistently had the highest EONR of up to 113 lb.ac^{-1}, while the no cover and mix treatments had lower N requirements, averaging around 47–78 lb.ac^{-1}. Despite increased N needs, the grass treatment maintained stable yields at EONR, averaging 165–199 bu.ac^{-1}, while the no cover treatment showed consistently higher yields of 176–206 bu.ac^{-1} with less N, indicating more efficient N use. The mix treatment demonstrated intermediate N needs, with EONRs around 77 lb.ac^{-1} and slightly lower yields averaging 204 bu.ac^{-1}. At Brookings, the grass treatment also required higher N inputs, with EONR reaching about 120 lb.ac^{-1} in 2019, while no cover and mix treatments required lower EONR values of around 45–85 lb.ac^{-1}. Yields at EONR were stable across treatments at Brookings, with the no cover treatment averaging 175–200 bu.ac^{-1}, and grass yielding slightly less, around 160–190 bu.ac^{-1}.

Overall, these results emphasize the importance of aligning cover crop selection with N management goals in corn. The grass treatment, while more N-intensive, may enhance sustainability by providing stable yields and potentially benefiting soil health through increased organic matter and labile carbon. Conversely, the no cover treatment's efficiency could support reduced input strategies, particularly in regions where minimizing N application is economically or environmentally advantageous. These insights contribute to the broader understanding of how cover crop choices can impact N optimization and yield outcomes, providing valuable guidance for designing efficient and sustainable corn-soybean rotation systems.

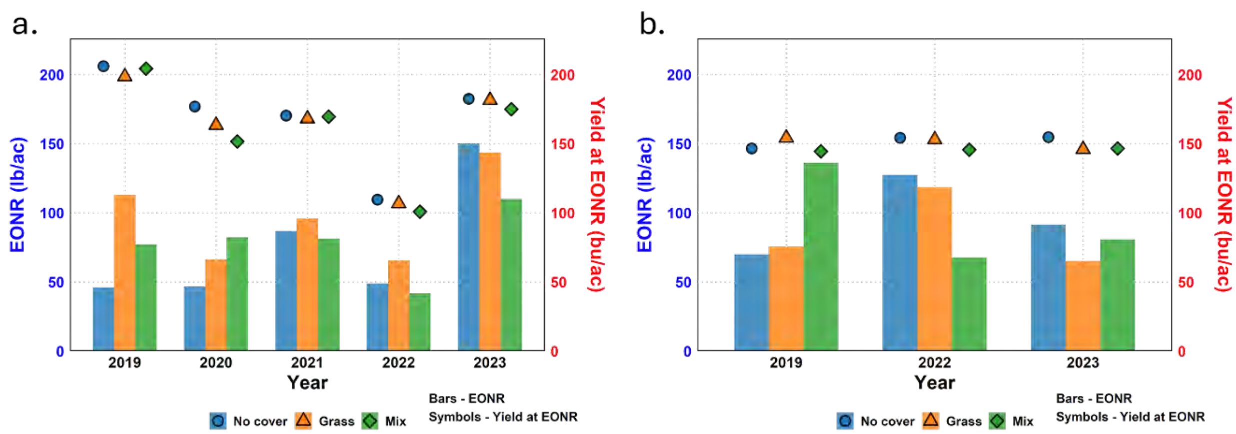

Figure 1. Economic Optimum Nitrogen Rate (EONR) and Corn Yield at EONR Across Years and Cover Crop Treatments at a) Beresford and b) Brookings

Soybean Yield Response

Soybean yields across cover crop treatments showed minor variations but generally stable trends at both the Beresford and Brookings locations (Figure 2). At Beresford, the grass and mix treatments produced slightly lower yields, averaging around 45 bu/ac, while the no cover treatment yielded slightly higher, with an average close to 46 bu/ac. At Brookings, similar patterns were observed, with all treatments yielding consistently over the years. Despite minor fluctuations, particularly with the mix treatment, there were no substantial differences among treatments, suggesting that the use of cover crops (grass or mix) did not significantly impact overall soybean productivity compared to the no cover treatment.

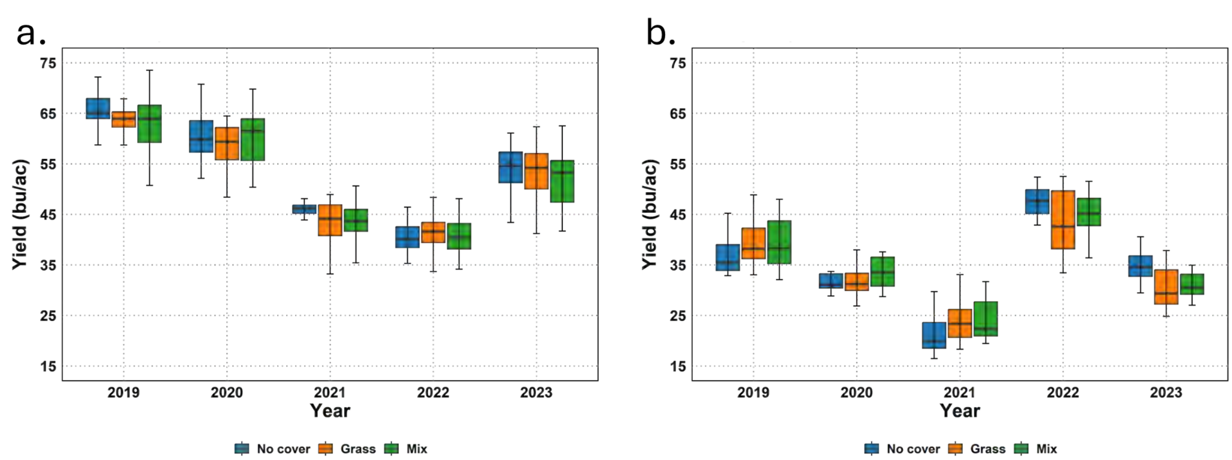

Figure 2. Soybean Yield Across Years and Cover Crop Treatments at a) Beresford and b) Brookings.

Soil health responses

The analysis of soil health variables, though initially revealing trends across cover crops, N rates, and sample timing, showed no statistically significant differences for any cover crop treatment across all measured soil health metrics. Organic Matter (OM) and Organic Carbon (OC) levels remained stable across treatments, with slight increases observed in plots with higher N rates, reaching up to 3.8% for OM and 2.2%

for OC, suggesting that while cover crops and N application may support organic content, these changes were not statistically significant. Active Carbon (Active C) displayed higher values in cover-cropped plots, particularly with single-species covers, reaching around 400 ppm. Variations in Active C over the season (dropping to around 250 ppm later in the season) point to progressive carbon utilization, yet again without significant distinctions across treatments.

Potentially Mineralizable Nitrogen (PMN) levels tended to increase in higher N rate plots, particularly early in the season, with values reaching up to 70 ppm, suggesting boosted microbial activity from N inputs, although cover crop treatment effects remained statistically nonsignificant. Similarly, Aggregate Stability (Agg Stab) showed slight improvements with cover crops and higher N rates, ranging between 13% and 21%, but with no statistically significant effect from cover cropping. Nitrate-N and Ammonium-N concentrations were also most responsive to elevated N rates, reaching 20 ppm and 15 ppm respectively at early sample timings, but these results did not show significant differences among cover crop treatments. Overall, these results suggest that while cover crops and N applications appear to influence soil health trends, no significant differences were detected, indicating that longer-term studies may be needed to observe measurable effects from cover cropping on soil health.

CONCLUSIONS

This study underscores the nuanced role of cover crops and N management in shaping both crop yield and soil health within a corn-soybean rotation system. Although cover crops like grass species require slightly higher N inputs for optimal corn yields, they offer stable productivity and support soil health by enhancing labile carbon and improving soil structure. The minimal impact of cover crops on soybean yield suggests that soybean may be a resilient crop choice within rotational systems using cover crops, as its productivity remains consistent across site-years.

The findings also highlight the importance of sample timing on soil measurements, as early-season N applications contribute significantly to nutrient availability and microbial activity, with decreasing levels as the season progresses. Overall, this work emphasizes that efficient N use, and targeted cover crop choice can align with sustainable agricultural practices, allowing for productivity without compromising soil quality. As agricultural systems move toward more sustainable models, these insights can inform decisions that balance productivity goals with long-term soil health, offering a framework for resilient and resource-efficient cropping systems in the Midwest.

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ASSESSING DIFFERENT SOURCES OF PHOSPHORUS FERTILIZER ON NITRATE LEACHING IN THE FALL PERIOD AND ITS EFFECT ON THE FOLLOWING CORN

S. Koduru[1], M. Javid[1], R. Keshavarz Afshar[2], A. Margenot[3], A. Sadeghpour[1&4]
[1]School of Agricultural Sciences, Southern Illinois University
[2]Dairy Management Inc.
[3]Department of Crop Sciences, University of Illinois Urbana-Champaign
[4]Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West

ABSTRACT

Illinois nutrient loss reduction strategy is questing to reduce nitrate and phosphorus (P) loss by 25 and 15% by 2025. Fall applied ammonium-based P fertilizers could result in both nitrate and phosphate loss during the fallow period. Two ways to minimize these losses are by utilizing urease and nitrification inhibitors and also assessing other sources of P including triple superphosphate (TSP) and dissolved air flotation (DAF) that separates solids from liquid manure. A four-times replicated experiment was initiated in fall 2023 with Randomized Complete Block Design and five treatments in Agronomy Research Center, Carbondale, IL. Treatments were fertilizers [Control, TSP, DAF (Dissolved Air Flotation), MAP, & MAPI (MAP + urease and nitrification Inhibitor)], timing (fall & spring) and application type (surface & tilled). Data on nitrous oxide emissions, nitrate leaching, soil test phosphorous (STP), and total N were recorded during fall and spring prior to planting of corn (*Zea mays* L.) and agronomic observations (plant height, LAI & NDVI) were also recorded for corn. Our results indicated that DAF increased STP more than MAP when surface applied. Over winter and spring, nitrate form of N availability and leaching losses were less under DAF and TSP compared to MAP or MAPI, suggesting that inhibitor did not reduce N availability and leaching from MAP source when applied in fall. Corn growth was slightly higher under DAF compared to other fertility treatments indicating it can be as a potential replacement source to the synthetic P fertilizers.

INTRODUCTION

Effective nutrient management is crucial for reducing environmental impacts in agriculture, especially with the growing concerns around phosphorus (P) and nitrogen (N) losses. Fall-applied ammonium-based P fertilizers are known to contribute to nitrate leaching and phosphate runoff during fallow periods, posing risks to water quality and soil health (Duncan et al., 2017; Eghball and Power, 1999; Kleinman et al., 2002). To address these challenges, strategies such as the use of urease and nitrification inhibitors have been developed to slow N transformations and reduce losses. Additionally, innovative technologies like Dissolved Air Flotation (DAF), which separates solids from liquid manure, offer potential to reduce P and N losses by concentrating nutrients in the solid fraction. This study aims to explore the potential of DAF-separated solids as a replacement for conventional phosphorus sources, while assessing their impact on crop yield and soil health. By investigating these alternatives, we seek to contribute to more sustainable nutrient management practices in agriculture.

MATERIALS AND METHODS

In 2023, a field experiment was initiated at Southern Illinois University Agronomy Research Center in Carbondale, IL by employing a randomized complete block design replicated four times. Treatments were fertilizers [Control, TSP, DAF, MAP, & MAPI (MAP + urease and nitrification Inhibitor)], timing (fall & spring) and application type (surface & tilled).

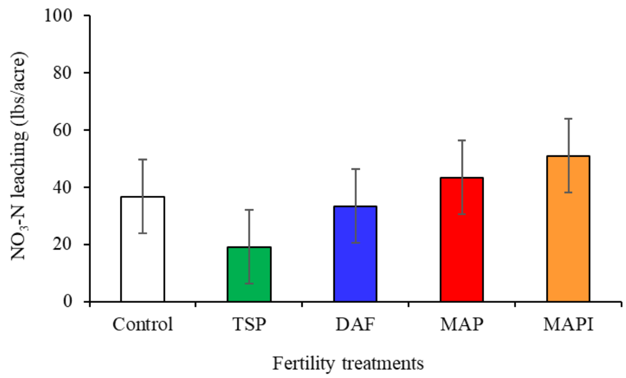
Soil samples were collected in mid-November at 0-2- and 2-6-inch depth. Ion exchange resin lysimeters were then placed in 20 ft wide by 40 ft long plots. Following this, fall treatments were applied. Surface application treatments included closed vented aluminum chambers to estimate nitrous oxide emissions and resin lysimeters to measure N and P leaching losses during the fallow period. Gas samples were collected 14 times during the fallow period using syringes at 0, 15, 30, and 45 minutes on each sampling day. These samples were analyzed for N_2O using gas chromatography. Resin lysimeters were harvested before spring application and analyzed for nitrate-N concentrations using OI analytical flow solution. Throughout the fallow period (November-May), monthly soil samples were collected from 0–6-inch depth and analyzed for total N (nitrate-N and ammonium-N) and soil test phosphorus (STP). Spring treatments were applied on May 28, 2024, prior to corn planting on May 30, 2024.

During the corn growing period, regular agronomic observations were made at different growth stages (V3, V6, V9, R1, R3, and R6). These included measurements of plant height, leaf area index (LAI), and normalized difference vegetation index (NDVI) up to the V9 stage. Data were evaluated for normality of residuals and analyzed using SAS statistical software. Results with $p < 0.05$ were considered significant.

RESULTS & DISCUSSION

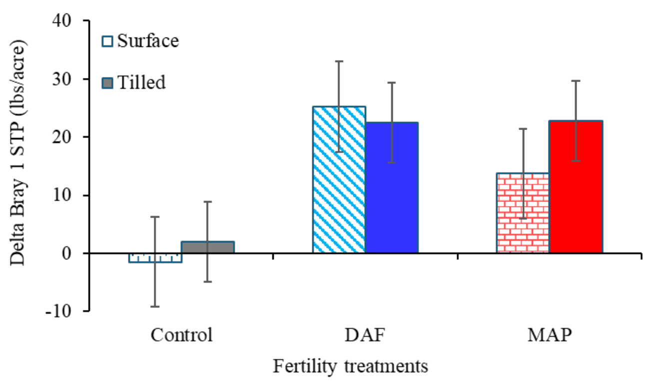
Nitrate Leaching

Although not statistically significant, the treatments TSP (56% and 63%, respectively) and DAF (23% and 34%, respectively) showed lower NO_3-N leaching compared to MAP and MAPI, this shows that inhibitor did not reduce NO_3-N leaching from the MAP source, in this site-year, indicating a relative advantage of DAF or TSP as a potential substitute for water-soluble phosphate fertilizers like MAP in lowering N losses (Leon et al., 2023).



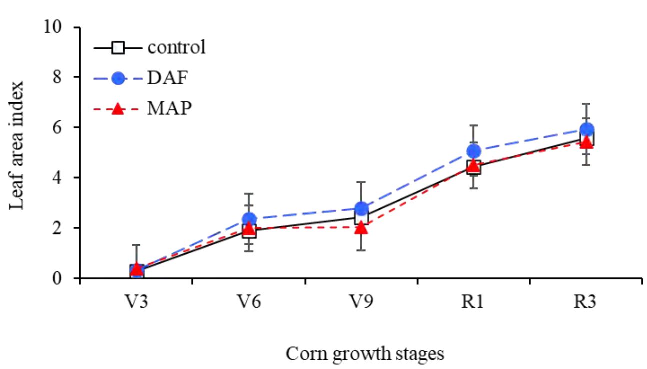
Soil Test Phosphorus

According to the Illinois Agronomy Handbook recommendations, 9 lbs acre^{-1} of P_2O_5 increases STP by 1 lb acre^{-1}. However, this is not consistent with our results, as DAF built more STP than MAP, suggesting less P fixation with DAF.



Fall Applied P fertilizers on Corn Growth

Corn growth was slightly higher ($P = 0.06$) with DAF and MAP treatments compared to the control. This suggests that DAF and MAP provided sustained N availability throughout the corn growth period.



Preliminary Conclusion

In this preliminary trail, we observed that nitrate-N leaching can be reduced during the fall period by 50% and 13%when TSP and DAF were used as the source of fertilizer compared to control. Using inhibitors in this site-year did not reduce nitrate-N leaching as compared to MAP. In this site-year, we observed slightly quicker corn growth with DAF compared to the other treatments, but this quicker growth was minimal. Multiple site-years are required to draw a firm conclusion on P fertilizer source in corn cropping systems.

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LANDSCAPE POSITIONS AND NITRIFICATION INHIBITORS AFFECT CORN PRODUCTIVITY ON CLAYPAN SOILS

P. Kadari, G. Singh, K. Nelson, and G. Kaur
Northern Missouri Research, Extension, and Education Center, University of Missouri

ABSTRACT

Corn nitrogen (N) management in claypan soils is highly influenced by spatial and temporal variability caused by complex soil and water interaction within a landscape. This study investigated the impact of N application rates and nitrification inhibitors (nitrapyrin and pronitridine) on corn productivity across three topographic positions (shoulder, backslope, and footslope) in claypan soils at the Lee Greenley Jr. Memorial Research Farm, Novelty, Missouri, during 2023 (dry year) and 2024 (wet year). The experimental design was a split-plot design having topographic positions as main factors and N rates (0, 60, 120, 180, and 240 lb N ac^{-1}) and nitrification inhibitors (120 and 180 lb N ac^{-1} with nitrapyrin or pronitridine) as split factors. Results showed significant yield differences across topographic positions and years, with higher yields generally observed in 2024 due to higher precipitation during the cropping season. In 2023, 180 lb N ac^{-1} + nitrapyrin produced the highest yield (148 bu ac^{-1}) at the footslope, while in 2024, 180 lb N ac^{-1} + nitrapyrin reached 178 bu ac^{-1} at the footslope. Applying nitrification inhibitors at 180 lbs N ac^{-1} at the backslope and footslope topographic positions improved yields compared to N application at 180 N ac^{-1} without nitrification inhibitors in both years. Nitrification inhibitors enhanced corn yield, especially in wet conditions, suggesting reduced N losses through leaching and denitrification. This research highlights the importance of optimizing N management strategies and nitrification inhibitor technology to maximize corn yields in variable soil moisture conditions typical of claypan landscapes. It also reiterates the importance of using site-specific variable source technology on these landscapes.

INTRODUCTION

Nitrogen (N) management in corn production is challenging due to varying soil conditions, particularly in claypan soils characterized by poor drainage (Nash et al., 2012). Topographic positions significantly affect N dynamics, with higher yields typically observed in well-drained upper slopes and lower yields at footslope due to water accumulation (Halvorson & Doll, 1991; Miao et al., 2006; Singh., 2022). However, lower positions like the footslope can outperform upper slopes during dry years, because of increased moisture retention particularly on claypan soils (Gentry et al., 2009).

Nitrification inhibitors like nitrapyrin and pronitridine can address yield disparity by enhancing N use efficiency and reducing losses across slope positions under varying climatic conditions (Steusloff et al., 2019; Singh et al., 2019). Studies have shown that applying nitrapyrin with anhydrous ammonia on claypan soils can reduce N losses by 20 to 55% and increase corn yields by 10 to 68 bu ac^{-1} under various conditions (Nash et al., 2013; Nelson et al., 2017). Despite these benefits, the interaction between topography and nitrification inhibitors on N dynamics and corn productivity in claypan soils remains underexplored. This warrants further investigation. This research determined the optimum nitrogen (N) application rate and evaluated the efficacy of nitrification inhibitors, nitrapyrin (N-serve) and pronitridine (Centuro), on corn productivity across three different topographic positions (i.e., shoulder, backslope, and footslope).

MATERIALS AND METHODS

A field experiment was conducted in 2023 and 2024 at the Lee Greenley Jr. Memorial Research Farm (40.02328°N, 92.19179°W) near Novelty, MO. The soil series of the experimental field is classified as Kilwinning silt loam (Fine, smectitic, mesic Vertic Epiaqualfs) and Putnam silt loam (Fine, smectitic, mesic Vertic Albaqualfs) with a saturated hydraulic conductivity of <0.01 μm s^{-1}. The experiment layout was a split-plot design with four replications. The main plots were three topographic positions: shoulder, backslope, and footslope classified similarly to Singh et al. (2020) using the Topographic Positioning Index (TPI) model. The sub-plots were N application rate treatments applied as anhydrous ammonia (AA) at 60 lb N ac^{-1} (60 N), 120 lb N ac^{-1} (120 N), 180 lb N ac^{-1} (180 N), and 240 lb N ac^{-1} (240 N), along with combinations of 120 lb N ac^{-1} + Pronitridine (120 N + Pronitridine), 120 lb N ac^{-1} + nitrapyrin (120 N + Nitrapyrin), 180 lb N ac^{-1} + Pronitridine (180 N + Pronitridine), and 180 lb N ac^{-1} + nitrapyrin (180 N + Nitrapyrin) along with a non-treated control (0 N; NTC). The plot size was 10 ft wide and varied based on the modeled topographic position layout. Corn was planted using a Kinzee planter at a row spacing of 30 inches wide rows and at a seeding rate of 35,000 seeds ac^{-1}.

Corn was harvested using a commercial combine equipped with a yield monitor calibrated for weight accuracy. The yield monitor was set to collect point yield data every second, capturing parameters such as duration, swath width, distance, track degree, moisture content, and mass flow. The collected point yield data were processed using Ag Leader SMS software, and further prepared for analysis in ArcGIS Pro v3.1. Quality control measures were applied to eliminate likely erroneous data points based on the following criteria: duration <0.99 s or >1.01 s, swath width ≠10 ft, distance <3 ft, track degree >10° & <170° or 90° & <350°, moisture >22%, and yield >300 bu ac^{-1}. The cleaned data were then overlayed with topographic positions and nitrogen treatments to extract the respective yield points. Corn grain yield was adjusted to 15% moisture content before data analysis. The GLIMMIX procedure in SAS was used to compare the means at $p=0.05$.

RESULTS

Rainfall varied significantly between the two site years, with very (597mm) rainfall in 2023 (270 mm), compared to the 2024 cropping season (597 mm). Following the rainfall patterns, grain yields at all three topographic positions varied significantly across N rate treatments in 2023 and 2024 at $p < 0.05$.

Shoulder (SH) Position: On the SH 2023, 180 N treatment recorded the highest grain yield, producing 144 bu ac^{-1}, significantly greater than NTC (96 bu ac^{-1}) on SH. Yields of 120 N + Nitrapyrin were statistically similar to 180 N at 146 bu ac^{-1}. The 240 N treatment achieved 135 bu ac^{-1}, comparable to 180 N + Pronitridine (138 bu ac^{-1}) and 180 N + Nitrapyrin (135 bu ac^{-1}), indicating a NI's effectiveness in lowering the N application rate.

In 2024, the 240 N treatment had the highest yield 234 bu ac⁻¹ which significantly outperformed all other treatments. The 180 N treatment produced 214 bu ac⁻¹, while the 180 N + Pronitridine and 180 N + Nitrapyrin had similar yields (209 bu ac⁻¹ and 203 bu ac⁻¹ respectively). Treatments receiving no N had the lowest yield (71 bu ac⁻¹) which highlights the substantial benefits of applying N to the crop (Table 1).

Backslope (BS) Position: In 2023, the highest grain yield was observed with 180 N + Nitrapyrin which produced 152 bu ac⁻¹, followed by 180 N at 150 bu ac⁻¹. Both treatments 240 N and 180 N + Pronitridine resulted in 145 bu ac⁻¹ yield which was 58 bu ac⁻¹ higher than the NTC. In 2024, the 240 N treatment had significantly greater yields at 230 bu ac⁻¹ while 180 N + Pronitridine and 180 N + Nitrapyrin yielded 5 to 9 bu ac⁻¹ higher in grain yield compared to 180 N (Table 1).

Footslope (FS) Position: During 2023**,** 180 N + Nitrapyrin (148 bu ac⁻¹) had the highest grain yields, which was 10 bu ac⁻¹ higher to the yields of 180 N + Pronitridine (Table 1). Grain yields for the N rate treatments, 120 N and 120 N + Pronitridine were similar at 134 bu ac⁻¹ and 133 bu ac⁻¹, respectively. In 2024, 180 N + Nitrapyrin. had 178 bu ac⁻¹ grain yields that were 4 to 8 bu ac⁻¹ higher than 180 N+ Pronitridine and 240 N. The lowest yields were recorded with no N application, showing the continued benefits of a nitrogen application at the FS.

Table. 1. Corn grain yields at Shoulder, Backslope, and Footslope topographic positions in 2023 and 2024. Means followed by similar letters within a column are not significantly different at $p<0.05$.

	Shoulder		Backslope		Footslope	
N-rate treatment	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
lb ac^{-1}	-----------------------------------bu ac^{-1}-----------------------------------					
0 N†	96 d	71 i	87 e	61 i	94 g	57 i
60 N	122 c	110 h	123 d	110 h	119 f	89 h
120 N	135 b	162 f	144 c	165 f	134 cd	138 f
180 N	144 a	214 b	150 ab	202 d	141 b	162 d
240 N	135 b	234 a	145 c	230 a	126 e	168 c
120 N + Pronitridine	126 c	157 g	143 c	168 e	133 d	153 e
120 N + Nitrapyrin	146 a	177 e	143 c	158 g	127 e	126 g
180 N + Pronitridine	138 b	209 c	145 bc	211 b	138 bc	174 b
180 N + Nitrapyrin	135 b	203 d	152 a	207 c	148 a	178 a
p-value	<0.0001	<0.0001	<0.000	<0.0001	<0.0001	<0.0001

†non-treated control with no nitrogen and nitrification inhibitor, 0 N; 60 lbs N ac^{-1} with no nitrification inhibitor, 60 N; 120 lbs N ac^{-1} with no nitrification inhibitor, 120 N;180 lbs N ac^{-1} with no nitrification inhibitor, 180 N; 240 lbs N ac^{-1} with no nitrification inhibitor, 240 N; 120 lbs N ac^{-1} with Centuro, 120 N + Pronitridine; 120 lbs N ac^{-1} with N-Serve, 120 N+ Nitrapyrin; 180 lbs N ac^{-1} with Centuro, 180 N+ Pronitridine; 180 lbs N ac^{-1} with N-Serve, 180 N+ Nitrapyrin.

CONCLUSION

Corn grain yields were higher in the wet year (2024) across all topographic positions. The 240 lb N ac^{-1} treatment achieved the greatest yields. Particularly at the shoulder (234 bu ac^{-1}) and backslope (230 bu ac^{-1}) positions. In contrast, the dry year (2023) had more comparable yields across various N treatments. This indicated limited benefits from higher N rates under moisture-limited conditions. Nitrification inhibitors like nitrapyrin and pronitridine had substantial yield increases in 2024, especially at the FS, highlighting their effectiveness in reducing nitrogen losses during wetter conditions. The non-treated control consistently had the lowest yields, with a significant decline in the wet year. This showed the importance of nitrogen applications for optimal production. Overall, nitrogen management strategies showed varied effectiveness depending on the year's moisture conditions, with higher N rates and inhibitors proving more beneficial during wet conditions across the topographic positions.

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EFFECT OF PHOSPHORUS AND POTASSIUM APPLICATION ON THE GROWTH AND YIELD OF A 14-YEAR-OLD MISCANTHUS X GIGANTEUS STAND

A. Larson, E. Heaton, N. Boersma, J. Studt, S. Emran, and A. VanLoocke
Iowa State University, Ames, IA

ABSTRACT

Miscanthus x giganteus (miscanthus) is a perennial C4 grass grown for renewable bioenergy and bioproducts. Despite its known low nutrient requirements, the specific fertilization needs of miscanthus remain poorly constrained, especially for older stands. This study aims to guide nutrient management practices for miscanthus by determining the demand for phosphorus (P) and potassium (K) fertilization and identifying the soil testing values at which these nutrients optimize yields. To address this aim, we conducted an experiment in a 14-year-old miscanthus stand in central Iowa, which had no prior fertilization history. The experiment followed a randomized complete block design with four blocks, each containing seven plots (one for each treatment and four controls), each measuring 800 ft². Baseline measurements of soil fertility indicated low soil test values for P (5-13 ppm) and K (73-181 ppm) were common in most plots. Stem height, density, yield and soil testing were also recorded prior to treatment. There were positive correlations between pre-treatment soil nutrient levels and yield, with K showing a slightly stronger relationship than P. Following harvest, treatments of P (100 lb/a), K (130 lb/a), and P+K (100 lb/a P + 130 lb/a K) were applied, with all plots receiving nitrogen (N) at 200 lb/a. Throughout the following growing season (May to October), canopy height, staging, and leaf area index (LAI) were taken. Preliminary results from the season prior to treatment indicate a positive correlation between height and yield that we applied to predict yield in advance of the post-treatment harvest. Averaged predicted yields indicated increases in the control, P, and P+K treatments, with P+K treated plots showing the greatest increase. In contrast, K-treated plots exhibited no yield change. At the end of the growing season, we will measure final stem height, stem density, yield, and soil nutrient levels for comparison with baseline data. This work will enhance our understanding of miscanthus's nutrient requirements, contributing to more informed fertilization recommendations.

INTRODUCTION

Compared to other crops, miscanthus has been shown to have high nutrient uptake and nutrient use efficiency and low nutrient input requirements due to the ability to translocate nutrients to and from its rhizomes (Cadoux et al., 2012). While its nutrient needs are not fully understood, current research suggests that potassium (K) may be of higher importance than phosphorus (P). The significance of K is due to miscanthus requiring a higher concentration of K to maintain optimal growth, a larger percentage of P re-mobilized back to the rhizome by the end of the growing season, and a greater concentration of K removed at harvest (Beale et al., 1997; Himken et al., 1997). The ongoing development of nutrient recommendations is largely driven by the need to offset these nutrient removals, which is to be applied on an annual basis (Cadoux et al., 2012). Even so, yield response to P and K fertilization appear to be dependent on initial soil test values, which are often quite variable, indicating critical soil nutrient values remain unclear (Clifton-Brown et al., 2007; Haines et al., 2014, Shield et al., 2014). Because of the uncertainties in the literature, this study's primary goals are to determine whether P and K fertilization is essential for optimal yields and identify precise soil testing values at which fertilization becomes necessary. In this research, we applied nutrient treatments to a 14-year-old miscanthus stand, including combinations of nitrogen (N), P, and K at rates determined to surpass its needs. This approach ensures plants are not nutrient-limited. The outcomes will contribute to more precise fertilization guidelines, potentially increasing yields and profitability for miscanthus growers. In addition, the findings are a step towards the development of fertilization rate recommendation

MATERIALS AND METHODS

In 2024, an experiment was conducted at Sorenson Farm near Ames, Iowa (42° 0' 43.2504" N, - 93° 44' 40.9092" W) in a 14-year-old stand of sterile, triploid clone *Miscantus x giganteus* (Greef et. Deu. ex. Hodkinson et Revoize; 3n=57) clone "Freedom", provided by AGgrow Tech, High Point NC USA. The soil types included Webster clay loam (Fine-loamy, mixed, superactive, mesic Typic Endoaquolls), Clarion loam (Fine-loamy, mixed, superactive, mesic Typic Hapludolls), and Canisteo clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls). The experiment was set up in a randomized complete block design with four replicates. Each block contained seven plots: one plot each for a P treatment, a K treatment, and a P+K treatment, and four control plots. Each plot measured 800 ft^2. To address pre-existing variability in the stand, this study aimed to ensure a yield response was due to applied fertilizer rather than prior variability. Predicted yields obtained from satellite imagery from the 2021 growing season were used to calculate average yields for each treatment group (Emran et al., in preparation). An ANOVA was then performed to confirm no significant difference among treatments prior to fertilizer application (Excel, Version 16.0.10415.20025, 64-bit, Microsoft Corp.). Fertilizer treatments were broadcast applied on May 3, 2024 for P and K, and on June 4, 2024 for N. The N, P, and K fertilizers were applied as follows: N was applied using polymer-coated sulfur-coated urea (43-0-0) at a rate of 200 lb/a N, applied to all plots; P was applied using triple super phosphate (0-46-0) at a rate of 100 lb/a P; and K was applied as potassium chloride (0-0-62) at a rate of 130 lb/a K.

Baseline measurements for stem height, stem density, and yield were taken in each plot before fertilization at the end of the growing season. Soil cores were collected from each plot at depths of 0-6 inches and 6-12 inches for nutrient analysis. Throughout the growing season following fertilization (May to October), above-ground measurements of canopy height, leaf area index (LAI), and staging were measured two to four times per month. A linear regression model of the relationship between the pre-fertilization stem height and yield, along with this season's maximum canopy height, was applied to predict the current year's yields (R stats package, version 4.4.1). Moving forward, baseline measurements will be remeasured and directly compared to those that were initially taken.

RESULTS AND DISCUSSION

Pre-Fertilization Results

In the top 6 inches of soil, soil test P levels across the 28 plots ranged from 5-13 ppm, with a mean of 8.7 ± 0.5 ppm, while soil test K levels ranged from 73-181 ppm, with a mean of 118.7 ± 5.5 ppm. Slight positive correlations were found between both soil test P and K and yields, suggesting some potential for yield response with increased soil nutrient levels (figure 1). However, the relationships were relatively weak, with R^2 values of 0.14 for P and 0.16 for K, indicating that additional factors likely influence yield. Stem density showed very little correlation with yield, while stem height demonstrated a positive correlation. Therefore, if a yield change is recorded, the response may be primarily in the form of taller plants rather than increased stem density.

Post-Fertilization Results

Using pre-fertilization and predicted post-fertilization yields, we estimated the average relative yield change for each treatment (figure 2). The control plots increased in yields with a relative difference of 7.7%. The P-treated plots exhibited a relative difference of 16.3%, followed by the P+K-treated plots at 18.4%, showing the greatest yield increase. The K-treated plots did not change, indicating that P fertilization may be more critical than K in this stand. This suggests that baseline soil test P levels were insufficient for optimal growth, while K levels were already adequate. Final yield data from the chopper harvest at the end of the season will provide further insights, as a yield response may come in other forms beyond height, such as stem density. Throughout the season, no significant differences were observed in height, staging, or LAI among treatments.

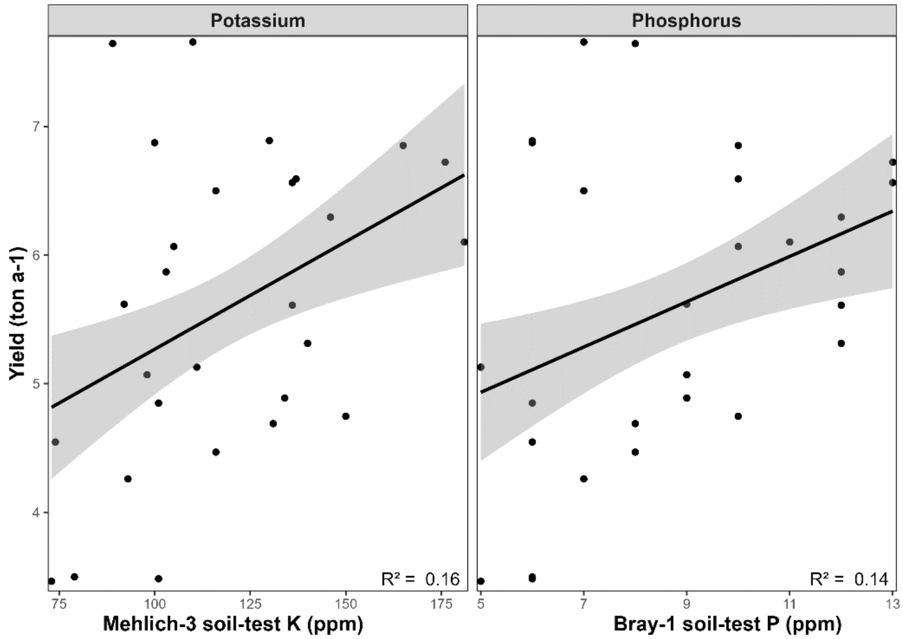

Figure 1. Relationship between 2023 pre-fertilization yield and soil test phosphorus (P) and potassium (K) levels. Miscanthus yield was mechanically harvested in March 2024 and soil was sampled in April 2024.

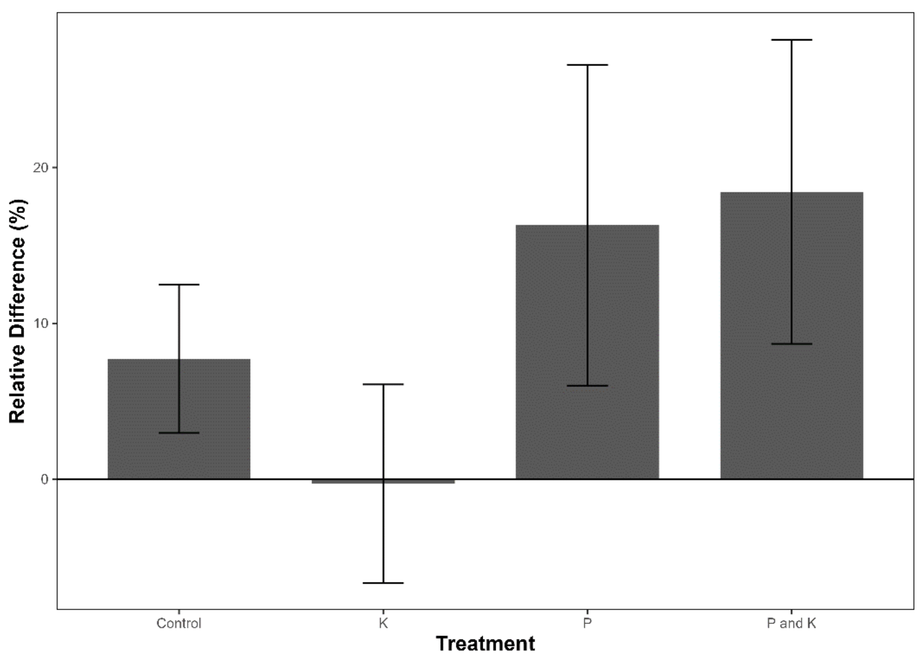

Figure 2. Relative difference (post fertilization minus pre-fertilization) in predicted yields for each treatment. Pre-fertilization yields are from the 2023 mechanical harvest, while 2024 post-fertilization yields are predicted based on heights (see methods). Fertilized plots included P, K, and P+K treatments (n=4 respectively), while unfertilized control plots (n=16) were also analyzed. Error bars indicate standard error.

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CAN MULTI-YEAR FERTILIZER APPLICATIONS IMPROVE PRODUCTIVITY IN A CORN AND SOYBEAN ROTATION?

S. Leskanich, C. Sible, and F. Below
University of Illinois

ABSTRACT

Corn (*Zea mays* L.) yield responses to fertilizer are often greater when the fertilizer is applied in the same year, while soybean [*Glycine max* (L.) Merr.] yields are typically equivalent or higher when fertilizer was applied in a previous year. Thus, a common fertilization practice in the Midwest is to apply two-crop amounts of phosphorus (P), potassium (K), and sulfur (S) fertilizers during the corn phase of a corn-soybean rotation. However, with rising fertilizer costs, it is important to purchase and apply fertilizer when prices are low, so the objective of this study was to assess the effects of single versus multi-year fertilizer applications on soil nutrient availability and the consequent productivity of corn and soybean. Fertilizer treatments were initiated in the spring of 2021 at Champaign, IL, and consisted of: 1) an untreated control (UTC); 2) an annual application to either crop; 3) a biennial corn-only amount; 4) a biennial two-crop application amount; and 5) a single four-crop amount. All corn treatments were balanced for N (180 lbs/acre), and monoammonium phosphate (11-52-0), muriate of potash (0-0-60), and polyhalite (POLY4, 0-0-14-19S-11.4Ca-3.6Mg), which, in total, provided corn equivalents of 70, 60, and 25 lbs/acre, and soybean equivalents of 30, 60, and 15 lbs/acre of P_2O_5, K_2O, and S, respectively. Although not statistically significant, all fertilized treatments increased year-one corn yields by 4-8 bushels/acre, but the annual application supplied in year two did not increase soybean yield. Differences in soil S levels from the initial 2021 fertilizer applications were no longer detected two years later. All previous or current fertilized treatments of year three increased corn yields, and the two-crop application resulted in the highest yields across each of the first three years, likely due to greater soil P, K, and S availability, which was detected in the root zone postharvest. In year four, all fertilized treatments produced 4-5 bushels/acre more soybean. These findings suggest that farmers could apply nutrients biennially before corn with sufficient nutrient availability for both crops in a standard corn-soybean rotation.

INTRODUCTION

Phosphorus, K, and S are essential macronutrients that are often limiting in corn and soybean production and, thus, are the most applied. In 2021, 75% of corn acres in the U.S. received phosphate fertilizer, averaging 64 lbs/acre and totaling 2.05 million tons. There were 2.15 million tons of potash applied to 65% of U.S. corn acres, averaging 77 lbs/acre. Sulfur applications averaged 19 lbs/acre across 34% of corn acres, totaling 0.25 million tons (USDA-NASS, 2022). For the 2023 U.S. soybean crop, 44% of acres received phosphate (57 lbs/acre; 1.02 million tons), 46% received potash (88 lbs/acre; 1.64 million tons), and 14% received S (20 lbs/acre; 115 thousand tons) (USDA-NASS, 2024). A typical Midwest fertilization strategy is to apply enough fertilizer before planting corn to meet the nutrient needs of both the corn and soybean crops.

As yields have increased, more nutrients are removed from the soil, increasing the demand for fertilizer application (Bender et al., 2013). Optimizing the timing and rate of these nutrients is crucial to be more efficient, as nutrients can become unavailable for crop uptake if applied too early. Soybean has often yielded similarly or greater when fertilizer is applied in previous years, while corn responded more consistently to same-year fertilization (Boring et al., 2018). Rising demand for corn and soybean has driven the need for higher yields and more fertilizer, resulting in increased fertilizer prices (Jones & Nti, 2022). Thus, farmers have questioned whether they should apply fertilizer each year or if they should apply multi-year rates when prices are relatively low to reduce input costs. The objective of this research was to quantify the effects of different allocations of multi-year fertilizer applications on yield and soil nutrient availability in a corn and soybean rotation over a four-year period.

MATERIALS AND METHODS

The trial was initiated in 2021 at the Crop Sciences Research and Education Center at Champaign, IL with first-year corn and continued through 2024 in a corn-soybean rotation. Prior to trial implementation, a composite soil sample was taken to determine initial fertility levels and consisted of 10 cores at a depth of 0–6 inches sampled in a grid pattern across the trial area and analyzed by A&L Great Lakes Laboratories, Inc. (Fort Wayne, IN) using Mehlich III-extraction. The selected site was a Drummer silty clay loam (fine-silty, mixed, superactive, mesic typic endoaquolls) with initial levels of 3.8% soil organic matter, a pH of 6.7, and P, K, and S levels of 62, 198, and 6 ppm, respectively.

Experimental units were four-row plots in 30-inch row spacing and were 37.5 feet in length for the corn phase and 36 feet long for soybean. Treatments were arranged in a randomized complete block experimental design with six replications (30 total plots), with the plot arrangement being static over the four years.

For both crops and all years, conventional tillage was done with a disk-ripper in the fall and a soil finisher in the spring, and consistent weed control was maintained throughout the trial period. A SeedPro 360 research plot planter (ALMACO, Nevada, IA) was used for planting in all four years. The corn hybrid DKC64-64 (Bayer Crop Science, Research Triangle Park, NC) was planted on 7 April 2021 and 6 May 2023 at 36,000 plants/acre density, with Force 6.5G applied in-furrow at a rate of 2.3 oz/1000 ft to ensure control against soil-dwelling insects. Due to seed availability, different soybean varieties were used, with AG37XF2 (Bayer Crop Science) being planted on 10 May 2022 and AG38XF3 (Bayer Crop Science) planted on 22 April 2024, both at a density of 140,000 plants/acre.

Fertilizer blends of polyhalite (POLY4; 0-0-14-19S-11.4Ca-3.6Mg; Anglo American Crop Nutrients LTD., U.K.), monoammonium phosphate (MAP, 11-52-0), muriate of potash (MOP, 0-0-60), and urea (46-0-0) were mixed and applied preplant at three different rates calculated by seasonal nutrient needs of corn and soybean (Bender et al., 2013; Bender et al., 2015). Treatments initiated in the spring of 2021 for the four-year duration were: 1) an untreated control (UTC), 2) a biennial corn-only amount consisting of a 1-year blend applied in study year one and repeated in year three (Corn-Only), 3) an annual application consisting of 1-year blends fertilizing either corn or soybean in each year (Annual), 4) a biennial two-crop application consisting of blends fertilizing the corn in study years one and three with presumably enough nutrition for the following year's soybean crop in the respective years of two and four (Two-Crop), and 5) a single four-crop application in the first year with presumably enough nutrition for growing both corn and soybean over the next four seasons (Four-Crop). All four fertilized treatments were broadcasted with a hand spreader and lightly incorporated with a harrow in the spring before corn planting in 2021, and in 2023, the corn-only, the annual, and the two-crop amounts were reapplied broadcast. In 2022 and 2024, only the annual application was broadcast-applied before soybean and left unincorporated. First-year and four-year total nutrient rates are summarized in Table 1, and the soybean nutritional rates were 30, 60, 15, 9, and 3 lbs/acre of P_2O_5, K_2O, S, Ca, and Mg, respectively. In the two years of the corn phase of the rotation, plots received supplemental urea-nitrogen applications across all treatments for a total balanced nitrogen (N) rate of 180 lbs/acre each season.

Table 1. The nutrient amounts supplied in the first year and the total of a four-year study by five fertilization treatments to evaluate the effect of fertilizer blends applied to a corn-soybean rotation at Champaign, IL in 2021-2024. All corn plots were balanced for 180 lbs N/acre.

	First-Year Rates					Four-Year Total				
Fertilization	P_2O_5	K_2O	S	Ca	Mg	P_2O_5	K_2O	S	Ca	Mg
	lbs/acre									
UTC	0	0	0	0	0	0	0	0	0	0
Corn-Only	70	60	25	15	5	140	120	50	30	9
Annual	70	60	25	15	5	200	240	80	48	15
Two-Crop	100	120	40	24	8	200	240	80	48	15
Four-Crop	200	240	80	48	15	200	240	80	48	15

The center two rows of each plot were mechanically harvested using a rotary combine (R1, ALMACO, Nevada, IA) at physiological maturity for grain yield and standardized to bushels per acre at 15.5% moisture for corn and 13% moisture for soybean. Preplant and postharvest soil samples consisting of six cores per plot were taken between 0-6-inch depths, and the composite sample was analyzed for mineral nutrient compositions using Mehlich III extraction by A&L Great Lakes Laboratories, Inc.

Parameters were analyzed with the software SAS (version 9.4; SAS Institute, Cary, NC) using the PROC MIXED package. The homogeneity of variance of the residuals were assessed with the Brown-Forsythe modification of the Levene test while their normality of were determined with the Shapiro-Wilk test, QQ-plots, and histograms using the UNIVARIATE and GLM packages in SAS. An outlier analysis was conducted based on visual diagnostics and Pearson residuals to remove any data points that could skew the data. Means were separated using Fisher's protected LSD test, and significance was declared at the $P \leq 0.1$ level.

RESULTS AND DISCUSSION

Although initial soil tests did not indicate a need to apply P or K fertilizer, all fertilizer treatments tended to increase corn grain yield over the UTC by 4-8 bushels/acre in 2021, suggesting that the increase may have been due to the S application (Table 2). Despite the four-crop amount having the most applied nutrition through the first two years, it did not result in the highest yield in either year. In 2022, the prior-year fertilizer applications increased soybean yield by 2-5 bushels/acre, while the annual application (the only fertility applied in 2022) slightly decreased yield, indicating potential benefit of multi-year fertilization on the two-crop rotation. In 2023, although the four-crop application was applied two years prior, residual fertility effects were still present, generating yields of only 4 bushels/acre less than the two-crop fertilization treatment, but 2 and 4 bushels/acre more than the corn-only and annual treatments, respectively. Fertilizing for two crops produced the greatest yields each year except in 2024, where all applied fertility treatments produced similar soybean yields of 94-95 bushels/acre, exceeding the UTC by 4-5 bushels/acre. These high yields suggest that the two-crop amount applied before corn may be optimal to maximize production.

Table 2. Effect of multi-year fertilizer treatments on corn and soybean grain yield expressed at 15.5% or 13% moisture, for corn and soybean, respectively, at Champaign, IL from 2021-2024.

Treatment	2021 Corn	2022 Soybean	2023 Corn	2024 Soybean
	bushels/acre			
UTC	258	78	262	90
Corn-Only	264	82	270	95
Annual	262	77	269	95
Two-Crop	266	83	276	94
Four-Crop	262	80	272	94
p-value	0.3155	0.2344	0.0002	0.0228
LSD (α = 0.10)	ns	ns	4	3

Phosphorus and K soil nutrient levels followed similar patterns, increasing with applications of the annual, the corn-only, the two-crop blend, and even more so by the four-crop blend at postharvest in the first year [Figures 1(a) and 1(b)]. After the annual treatment application in 2022, fall P and K soil test values rose to the level of the equivalent fertilizer amount of the two-crop treatment applied in 2021, but with numerically higher values for the annual treatment due to less time for nutrients to be bound to the soil. The 2022 preplant and postharvest soil test levels of the plots that had received the four-year blend in 2021 remained the highest for both P and K, but the annual treatment supplied in 2021 and again in 2022 increased P to the same level after the soybean harvest. By fall 2023, after corn, the plots receiving the corn-only, annual, and four-crop treatments had similar soil test P values greater than the UTC, with the two-crop treatment having the highest P levels due to more fertility applied that season. Potassium levels of the two-crop and the four-crop treated plots were the greatest after corn harvest in 2023, while the corn-only and the annual treatments produced lower and similar K levels.

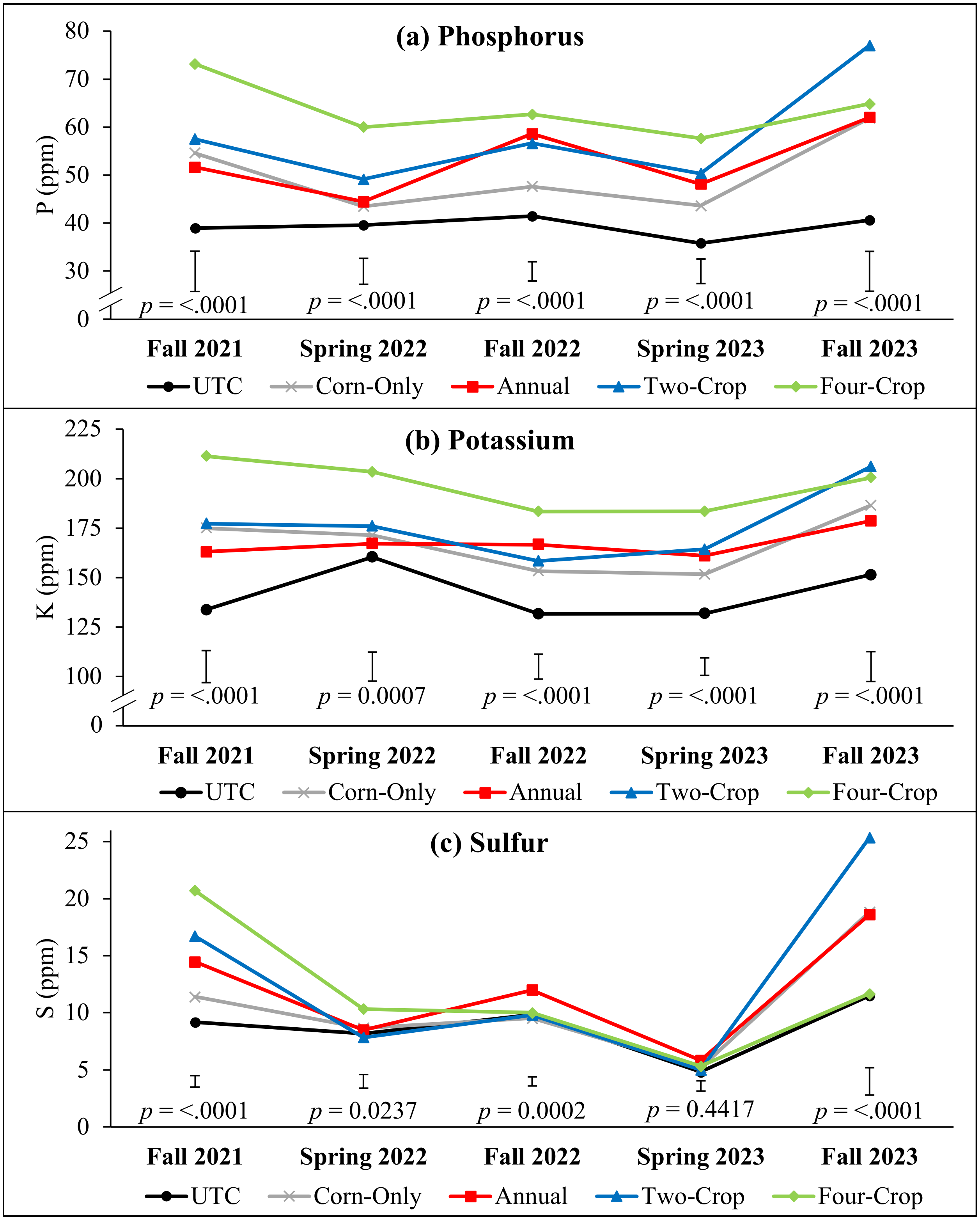

Figure 1. Effect of fertilizer treatments on soil nutrient levels (a) P, (b) K, and (c) S at 0-6 inch depth at Champaign, IL during 2021-2024. Corn was planted in 2021 and 2023, and soybean in 2022 and 2024. Vertical bars represent the least significant difference within a sample timing using the Fisher test at p = 0.1.

In the fall after trial initiation, as S rates were increased with the multi-year blends, the soil test value also increased [Figure 1(c)]. However, in the spring of 2022, S had likely been immobilized or leached from the rooting zone since the corn-only, annual, and two-crop amounts had levels similar to the UTC. Soil test S values were highest in the four-crop treatment plots at this time, likely due to the greater POLY4 application at the time of sampling, as well as POLY4's sustained release properties where it has not yet been wholly leached out of the soil sampling depth, immobilized, or taken up by the crop. At postharvest in 2022, the annual fertilizer application resulted in the highest S level, while the four-year application fell to the level of the other treatments, likely due to the application timing, as the annual fertilizer application was the only treatment applied that year. By spring 2023, all S levels were similar, but after application of the corn-only, annual, and two-crop amounts, fall soil test S values were increased, with the two-crop treatment plots exhibiting the greatest increase, attributed to this blend's greater S application rate that season.

This study suggests farmers could apply nutrients biennially before corn with sufficient nutrient availability for soybean in a corn-soybean rotation, as it consistently produced the highest yields, and its timing and rate provided better residual fertility over four years. While other applications provided "short-term" benefits, they generally resulted in lower yields or inconsistent nutrient availability throughout the trial period.

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COUNTY-LEVEL PHOSPHORUS BALANCES FOR 2017 IN ILLINOIS

X. Liu[1], O. ZandVakili[1], M. Guzel[1], S. Xu[2], A. Margenot[2], A. Sadeghpour[1&3]
[1]School of Agricultural Sciences, Southern Illinois University
[2]Department of Crop Sciences, University of Illinois Urbana-Champaign
[3]Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West

ABSTRACT

Cropland phosphorus (P) balances (manure and fertilizer P minus crop P removal) are great sustainability tools to assess long-term managements at farm, county, and state levels. Our objectives were to estimate county, regional, and state-level cropland P balances for Illinois in 2017. Based on the census data in 2017, Illinois county P balance ranged from -16.188 to 38.322 lbs/acre/yr. Overall, Illinois had a negative P balance at about -3.312 lbs/acre/yr. About 76% of counties had a negative P balance, ranging from −0.443 to −16.188 lbs/acre/yr, representing P outputs exceeded P inputs. This could reflect on increased crop yields over time and therefore, greater P removal than expected suggesting modification in P fertilization is required in areas with low P supplying power to sustain P levels at maintenance levels. Future research should focus on evaluating the trends of P balances over the last decade to understand P balance effect on legacy P and P losses in Illinois.

INTRODUCTION

As an essential nutrient to plant growth, Phosphorus (P) has played a critical role in improving crop productivity throughout the last century (Hopkins & Hansen, 2019; Pedersen et al., 2023). Due to its essential agronomic significance in crop production and its underlying harm to the environment when used in excess amount, much research has been conducted on P nutrient balances (Godber et al., 2024). In the last 15 years, there were several studies published on P balances at the US county and state levels (Khanal et al., 2014; Leytem et al., 2021; Peterson et al., 2017). As agriculture dominates land use in Illinois, assessment of P balances will be important for land management and policy development. This study aims to calculate and evaluate the annual P balances (harvested crop P removal subsets P supply with manure and fertilizer) in Illinois at county-level for 2017.

MATERIALS AND METHODS

Data collection and calculation for annual manure P

The inventory of major animals at county level in the state has been considered into calculation for annual manure P. The following categories were used (Mekken et al., 2006): (1) cattle and calves (including beef cows, milk cows, and other cattle), (2) poultry (layers, pullets, broilers, and turkeys), (3) sheep and lambs, (4) horses and ponies, (5) hogs and pigs, and (6) goats. All animal inventory data were extracted from USDA National Agricultural Statistics Service (NASS) Census of Agriculture (2017 Census data). The coefficients for excreted and recovered P were based on Mekken et al. (2006). The annual manure P was calculated as follows (Mekken et al., 2006):

Annual manure P = inventory * P excreted * recoverable P fraction

Where the inventory was the number of animals at county level, and P excreted represented the amount of P in the manure, and recoverable P was defined by the fraction of the total manure P pool which can be managed on the farm (Mekken et al., 2006).

Data collection and calculation for fertilizer P

Fertilizer data were collected from Illinois Department of Agriculture Fertilizer Reports. The amount of fertilizer P at county level was calculated, after the separation of non-farm and farm fertilizer usage, as follows:

Fertilizer P = US ton fertilizer * P_2O_5 *0.437 * 2000

Crop P removal calculation

Data for all crop yields (harvested acres and quantity) at county level were extracted from USDA NASS (2017 Census data). Crops used in this study include corn (*Zea mays* L.), soybeans (*Glycine max* L.), wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.), sorghum (*Sorghum bicolor* L.), alfalfa hay (*Medicago sativa* L.), corn silage, haylage, and other hay exclude alfalfa. Phosphorus grain concentrations for main cash crops (including corn, soybean, and wheat) and crop values (weight per yield unit, dry matter, and P content per yield unit) were extracted from Godber et al. (2024) and Mekken et al. (2006). The crop removal P can be calculated as follows:

P removal in crops = Crop yield * P removed per yield unit

Phosphorus balance calculations

P balance was calculated by subtracting sum of cash crop removal from sum of manure and fertilizer P as follows (Mekken et al., 2006):

P balance (lbs/acre) = [Manure P (lbs/acre) + Fertilizer P (lbs/acre)] - Crop P Removal (lbs/acre)

RESULTS AND DISCUSSIONS

Manure P application

After normalizing data based on the total cropland per county, DuPage, DeKalb, Mercer, Adams, Cumberland, Effingham, Jasper and Clinton County had the highest manure P contribution with 10.511, 10.113, 11.360, 12.952, 11.052,13.589,14.461, and 13.945 lbs/acre, respectively (Figure 1A).

Fertilizer P application

The following counties DuPage, Lasalle, Kankakee, Peoria, Tazewell, McLean, Hancock, Brown, Cass, Montgomery, Clinton, and Edwards had the highest fertilizer P contribution, ranging from 23.717 to 49.014 lbs/acre (Figure 1B). Fertilizer P was applied at higher rates in central crop reporting district, reflecting higher yield potential and thus higher maintenance rates in those counties of central crop reporting district due to greater soil organic matter and tile drainage. P application in the Southwest and

Southeast of Illinois was mostly lower than 10 lbs/acre, reflecting lower expected yields in those areas.

Crop P removal

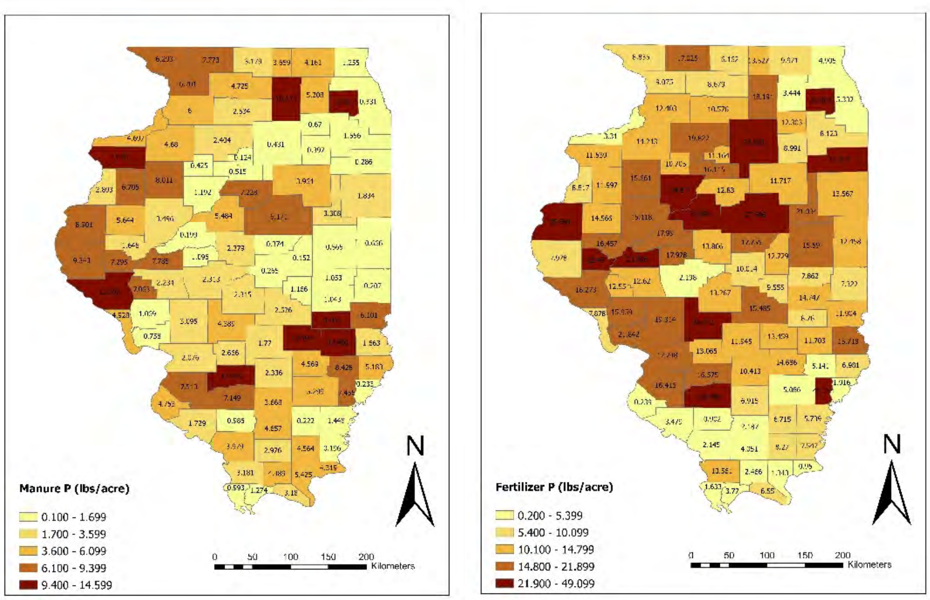
Crop P removal in 2017 at county level ranged from 10.311 to 27.127 lbs/acre (Figure 2A). In general, crop P removal was higher in counties located in Northwest, West, and Central of Illinois than those in other areas, especially in Southwest and Southeast. We assumed that P fertilization in Illinois was related to the yield and maintenance phase of P management, but soil test P data are required to better make sense of P fertilization decisions by growers in Illinois.

County-level P balances

The results showed that P balances of Illinois at county-level ranged from -16.188 to 38.322 lbs/acre/yr (Figure 2B). Overall, Illinois had a negative P balance at -3.312 lbs/acre/yr. About 76% of counties had a negative P balance, ranging from −0.443 to −16.188 lbs/acre/yr, demonstrating P outputs exceeded P inputs. This could reflect on increased crop yields over time. Further, greater P removal than expected suggests a modification in P fertilization may be required in certain areas to maintain agronomic productivity.

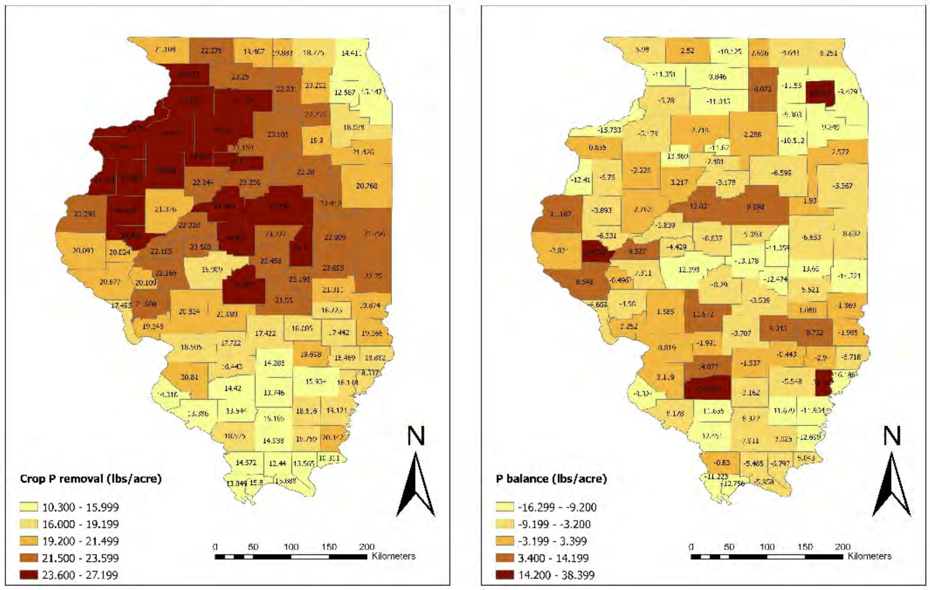
CONCLUSIONS

In 2017, P balances at county-level ranged from -16.188 to 38.322 lbs/acre/yr in Illinois. About 76% of counties had a negative P balance, ranging from −0.443 to −16.188 lbs/acre/yr, indicating less fertilizer compared to the crop P removals was used or higher crop yields are removing more P than expected. Future research should focus on assessing P balances over several years and link those to legacy P to improve sustainable P management practices.



(A) (B)

Figure 1: Total county-level P applied from manure (A) and fertilizer (B) based on USDA-NASS 2017 Census data for Illinois.



(A) (B)

Figure 2: County-level crop P removal (A) and P balance (B) based on USDA-NASS 2017 Census data for Illinois.

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EFFECT OF BARLEY AND WINTER PEA COVER CROPS ON NITROGEN AVAILABILITY IN NO-TILL CORN

E. Marsh and C. Lee
University of Kentucky

ABSTRACT

Cover crops are known to have positive effects on soil health and reduce erosion. However, popular cereal grains used as cover crops, such as rye (*Secale cereales*), wheat (*Triticum aestivum*), and barley (*Hordeum vulgare*) can negatively affect nitrogen availability for the subsequent corn crop. Legumes, such as winter peas (*Pisum sativum*) could reduce competition for nitrogen between the cereal cover crop and the summer corn crop. This study's objective is to determine if barley as a cover crop will be less competitive for nitrogen when mixed with a legume and how cover crop termination timing affects nitrogen availability for the subsequent corn crop. This study is located at the University of Kentucky's Spindletop Farm in Lexington, KY and at a private farm near Glendale, KY. The study design is a split-plot randomized complete block. Treatments for the cover crop include no cover crop control, barley alone, and an Austrian winter pea (plus barley mix. Cover crops were terminated at either five weeks or two weeks before planting. Five nitrogen rates of 40, 170, 215, 260, and 349 lb/A were applied, with 40 lb/A applied at planting, and the remaining nitrogen applied as side dress to V3 corn. Cover crop biomass and nutrient content were assessed. Soil cores were taken prior to V10 to determine nitrate levels. SPAD chlorophyll readings were taken at V10 and R1. Ear leaves were pulled at R1 for nutrient analysis. Grain yield is also being analyzed. Preliminary findings show that early termination of the cover crops can lead to an increase in corn nitrogen content during the growing season.

UNDERSTANDING COVER CROP EFFECTS ON WATER QUALITY UNDER INTENSE PRECIPITATION

S. Moylan, N. Nelson, G. Kluitenberg, A. Sheshukov, K. Bigham, P. Tomlinson, K. Roozeboom, D. Presley, and G. Hettiarachchi
Kansas State University

ABSTRACT

Climate change is expected to increase the frequency of extreme precipitation events, which could also increase runoff, erosion nutrient loss, and flooding. Cover crops are a best management practice for cropping systems that are vulnerable to soil erosion. The objective of this research was to analyze the effects of cover crops and precipitation intensity on surface runoff and water quality under natural precipitation events. Edge-of-field runoff and water quality data were collected from 2015 -2022 in a corn (*Zea mays*) - soybean (*Glycine max)* cropping rotation with two levels of cover crop use (with cover crops and without cover crops) and two levels of phosphorus fertilizer (no phosphorus and with phosphorus). Water samples were analyzed for total phosphorus, dissolved reactive phosphorus, and total suspended solids. Runoff hydrographs were used to compute runoff volume, peak flowrate, time to peak flowrate, and time to runoff initiation. Runoff events were placed into five categories based on maximum 30-minute precipitation intensity. Cover crops increased the time to peak flowrate under the highest intensity precipitation events by an average of 12 minutes. Increasing precipitation intensity increased erosion for the no-cover crop treatment over 3 times more than for the with cover crop treatment. Total phosphorus loss increased with increasing precipitation intensity for all treatments except the combination of cover crops and no P fertilizer application. These results indicate that cover crops may be a promising best management practice to reduce runoff intensity and sediment loss under high intensity precipitation events.

INTRODUCTION

With precipitation events predicted to increase in intensity due to climate change (USGCRP, 2023), farmers will need to know if their current management practices will change in effectiveness. These extreme events are predicted to exacerbate issues already linked to surface runoff such as sedimentation of lakes and reservoirs and eutrophication due to nutrient concentrations in the runoff and sediment (Sondergaard et al, 2001; EPA, 2024). Precipitation amount and intensity are drivers of the production of surface runoff. Surface runoff carries sediment and nutrients that can have detrimental effects on the environment in which they are deposited, leading to sedimentation and eutrophication (Correll, 1998; Dodds et al., 1992). Sedimentation of reservoirs reduces storage capacity for freshwater and impacts flood management ability. Solutions to this problem involve costly operations to remove the sediment, which can then end up farther downstream creating new problems. Eutrophication of waterbodies leads to deadly algal blooms that can impact humans as well as the fresh and saltwater species living in them. These additional nutrients increase algal production, blocking sunlight from reaching benthic plant species, thereby interrupting photosynthesis and reducing oxygen in the environment (hypoxia). Cover crops are a conservation practice option for fields at high risk of soil erosion and runoff. Studies have shown that cover crops can increase infiltration rate and reduce soil erosion (Folorunso et al., 1992; Siller et al., 2016; Steele et al., 2012). Reducing runoff, soil erosion, and nutrient loss also benefits the farmer. The loss of topsoil can impact several different aspects of crop growth and development including soil moisture capacity, root penetration, and emergence. The objective of this research was to determine if increasing precipitation intensity would influence the effects of cover crop use on surface runoff and water quality.

MATERIALS AND METHODS

Site Description

This study was conducted at the Kansas Agricultural Watershed (KAW) field laboratory in Ashland Bottoms, KS. The KAW field lab consists of 18 small watersheds (about 0.5 ha each) separated by terraces, each with equipment for monitoring edge-of-field runoff. Soils are mapped as Smolan silty clay loam with 3-7% slopes. The cropping system was a no-till corn (*Zea mays*) - soybean (*Glycine max)* rotation. The experimental design is a 2x3 factorial, with two levels of cover crop (with cover crop [CC] and without cover crop [NC]) and three levels of phosphorus fertilizer management. However, for this study we only used two levels of P fertilizer management (0 P fertilizer addition and spring injected P fertilizer placement) because those treatments remained relatively unchanged for the duration of the study (Oct. 2015 through Sept. 2022).

Data Collection

Each plot outlet had a 0.45 m H-flume paired with a 730 Bubbler Module and a 6712/6700 ISCO Auto Sampler. Water depth was recorded each minute with the bubbler module. Runoff event sampling occurred once the depth in the flume exceeded the 0.015 m enable level. After the enable level was reached, a 200 ml sample was collected for each 1 mm of runoff and composited in a 10 L bottle. Once the event was complete, samples were collected within 24 hours and stored at 4 C until analysis for total suspended solids (TSS) and total phosphorus (TP). One-minute runoff data was downloaded from the ISCO sampler. Precipitation was measured on one-minute intervals with 4 tipping bucket rain gauges distributed across the experimental site.

Data Analysis

One-minute flume depth measurements (h_a) were used to calculate runoff volume (m^3/s) using the equation from Bos (1989), where A, B, and C equal 0.0238, 2.5473, and 0.2540 respectively for a 0.45-m H-flume.

$$\text{Log } Q = A + B \log h_a + C [\log h_a]^2$$

Runoff characteristic variables such as runoff volume, peak flow, time to initiation of runoff, time to peak runoff were computed from runoff event hydrographs. There were 96 runoff events during the 7-year monitoring period. Runoff events without sufficient water quality data for analysis were removed from the dataset (primarily events with less than 2 mm of average runoff), leaving 71 events used for statistical analysis. Precipitation events were categorized based on maximum 30-minute precipitation intensity with category “a” being the least intense and category “e” being the most intense (Table 1). Runoff, sediment losses, and phosphorus losses were summed within each category and divided by the total precipitation that occurred for that category to normalized the data based on precipitation depth. Three-way ANOVA with fixed effects of cover crop, P fertilization, precipitation category, and all interactions was used to determine treatment effects on water quality variables and hydrograph characteristics.

Table 1. Precipitation intensity categories used to separate runoff events for statistical analysis.

Category	Range for 30-min maximum precipitation intensity (mm/hr)
a	0 to 13.2
b	13.21 to 26.4
c	26.41 to 39.6
d	39.61 to 52.8
e	>52.8

RESULTS AND DISCUSSION

Runoff Characteristics

Peak flow rate increased with increasing precipitation intensity. The increase tended to be greater for the no-cover crop management compared to the with cover management (Figure 1). Categories c and d maintained the same peak flowrate despite the increased precipitation intensity. The time to peak flowrate (TTP) was affected by cover crop treatment and intensity category. Cover crop use increased the TTP by an average of 14 min for the most intense precipitation events (category e; Figure 2).

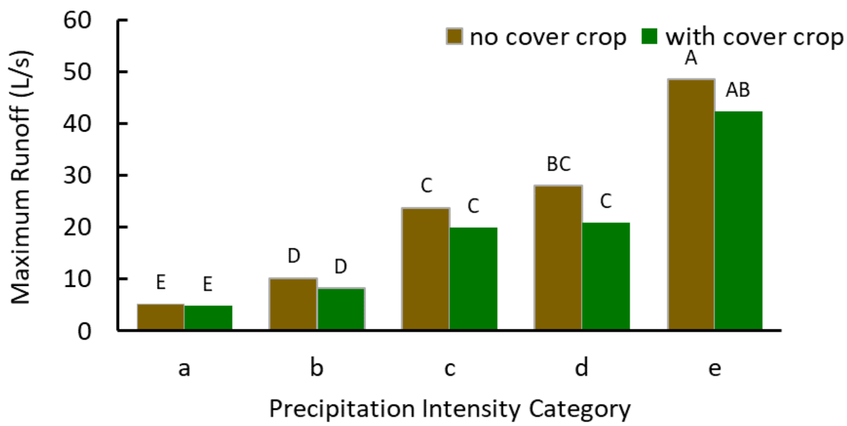

Figure 1. Peak flow rate from a no-till corn-soybean rotation without a cover crop (NC) and with a cover crop (CC) for different precipitation intensities (Table 1).

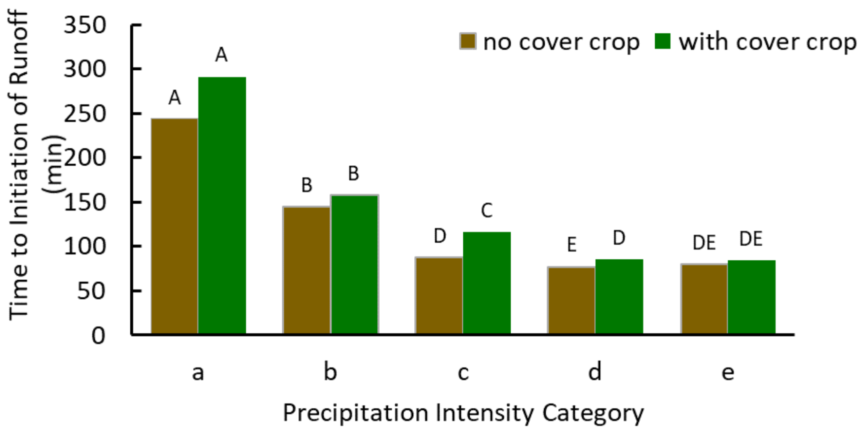

Figure 2. Average time from the beginning of a precipitation event to the peak flowrate of surface runoff from a no-till corn-soybean rotation without a cover crop (NC) and with a cover crop (CC) for different precipitation intensities (Table 1).

Water Quality

Total suspended solids loss was reduced by cover crop use, with larger reductions observed for the highest precipitation intensities (categories d and e) (Figure 3). The TSS loss for NC plots increased by 1.1 kg/ha/mm from category c to d, whereas there was no difference in TSS loss for precipitation categories c, d, and e for the CC plots.

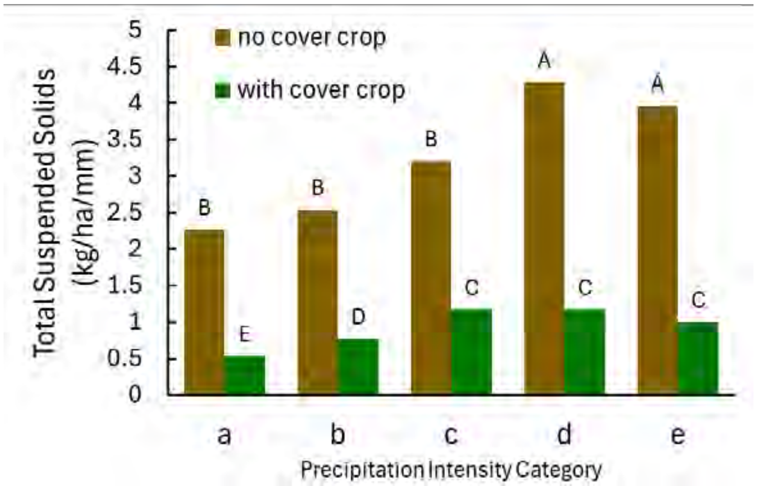

Figure 3. Average total suspended solids loss (kg/ha/mm) in surface runoff from no-till corn-soybean rotation without a cover crop (NC) and with a cover crop (CC) for different precipitation intensities (Table 1).

Total phosphorus loss was impacted by the interaction of cover crops and P fertilizer (Figure 4). The CC plots with no P fertilizer applied did not show a significant difference in TP loss as precipitation intensity increased and had the least TP loss overall. For plots without CC, the TP loss increased with increasing precipitation intensity. The TP loss also increased with increasing precipitation intensity for CC plots that received P fertilizer. Although cover crops decreased sediment loss, this same effect was not observed for total P loss because cover crops increased dissolved P reactive P loss (data not shown).

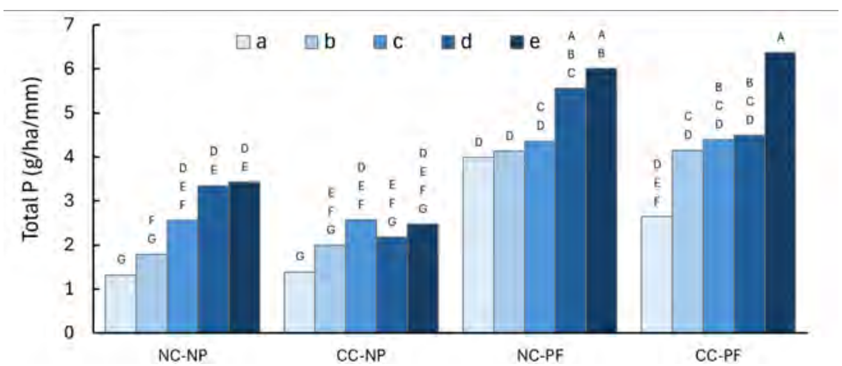

Figure 4. Effect of precipitation intensity category (Table 1), cover crop, and P fertilizer addition on average total phosphorus loss from a no-till corn-soybean rotation (NC-NP=no cover crop and no P fertilizer; CC-NP= with cover crop and no P fertilizer; NC-PF= no cover crop and with P fertilizer; CC-PF= with cover crop and with P fertilizer).

Under intense precipitation events cover crops maintain a reduction in sediment loss compared to no cover treatments. Cover crops also tended to maintain a peak flow reduction as precipitation intensity increased. However, cover crops paired with phosphorus fertilizer did have the most phosphorus loss out of the treatments. With these results it is promising that cover crops will continue to reduce soil erosion and runoff intensity under intense precipitation events, but without other BMPs may not improve water quality.

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CORN RESPONSE TO NITROGEN RATE AT THREE TOPOGRAPHIC POSITIONS WITHIN A TERRACED LANDFORM

M. Muhammad Aslam[a], G. Singh[a*], K. Nelson[a], and G. Kaur[b]
[a]Division of Plant Science and Technology, College of Agriculture, Food and Natural Resources, University of Missouri
[b]School of Natural Resources, College of Agriculture, Food and Natural Resources, University of Missouri

ABSTRACT

Nitrogen (N) application and topographic positions (TPs) are critical factors affecting corn (Zea mays L.) grain yield and quality, particularly in regions with diverse terrain like Northern Missouri. A field experiment was conducted in Northern Missouri in 2022 and 2023 to evaluate the effects of four nitrogen rates (0, 120, 200, and 280 lb N ac-1) and three TPs (shoulder, backslope, and footslope) on corn yield and quality. Corn grain yield increased with N application rates than non-treated check (NTC; 0 N), with significant variability across TPs and years. In 2022, corn yield at the shoulder position increased by 194, 190, and 168% at 120, 200, and 280 lb N ac-1 compared to the control. The backslope position showed the highest yield increase of 231%, particularly at 200 lb N ac-1, while the footslope position also exhibited significant increases of 178 and 179% for 200 and 280 lb N ac-1. In 2023, the shoulder position produced yield increase of 359, 427, and 423% at 120, 200, and 280 lb N ac-1, respectively, compared to NTC. The backslope position had the highest yield at 200 lb N ac-1 with a 448% increase, while the footslope position showed a 637% increase at 200 lb N ac-1 than the NTC. Protein levels significantly increased in 2022, particularly in the shoulder position reaching 8.64% and 9.10% at 200 and 280 lb N ac-1, respectively. The footslope position also showed an increased protein content of 8.45% with 280 lb N ac-1, compared to 6.05% with NTC, with similar but lower trends in 2023. Oil content was not significantly affected by TPs or N rates. These findings indicate the importance of site-specific N management strategies to enhance corn yield and quality in heterogeneous landscapes.

Keywords: Nitrogen rates, Topography, Yield quality, Corn, Sustainable agriculture

INDUSTRIAL HEMP RESPONSE TO NITROGEN APPLICATION

A. Nain[1], G. Kaur[1], K. Nelson[2], J. Miller[3] and G. Singh[2]

[1] School of Natural Resources, College of Agriculture, Food and Natural Resources, University of Missouri

[2]Division of Plant Science and Technology, College of Agriculture, Food and Natural Resources, University of Missouri

[3]Hundley-Whaley Extension and Education Center, Albany, University of Missouri,

ABSTRACT

With the increasing interest in industrial hemp (*Cannabis sativa L*.) as a versatile crop for both fiber and grain production, optimizing nitrogen (N) management has become critical for maximizing its productivity. Field experiments were conducted at two locations (Novelty, Albany) in northern Missouri to evaluate the effects of N application rates on industrial hemp growth, biomass, and grain yield. The experiment was set as a randomized complete block design with a split-plot arrangement and four replications. Main plots included four varieties (Puma, Yuma, Futura 83, Orion 33) and subplots were five N rates (0, 45, 90, 134, and 179 kg N ha^{-1}). The plant biomass yield, grain yield, height, plant stand, and stem diameter were recorded to assess industrial hemp growth and production under different N rates. Pre-plant soil samples were collected from two depths (0–15 and 15-30 cm) to determine baseline soil N content. Post-harvest soil samples will be collected to assess residual N levels, allowing for evaluation of nitrogen-use efficiency and the environmental impact of N fertilization. The results from these field experiments will be presented at the NCSF conference.

THE EFFECT OF NITROGEN MANAGEMENT IN WINTER WHEAT ON NITROUS OXIDE EMISSIONS IN A WHEAT-SOYBEAN DOUBLE CROPPING SYSTEM

Oluwaseun Ola[1], Osman Guzel[1], Karla L. Gage[1], Karl W.J. Williard[2], Jon E. Schoonover[2], Steffen Mueller[3], Amir Sadeghpour[1&4]
[1]School of Agricultural Sciences, Crop, Soil, and Environmental Program, Southern Illinois University
[2]School of Agricultural Sciences, Forestry and Horticulture Program, Southern Illinois University
[3]Energy Resources Center, University of Illinois Chicago
[4]Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West

ABSTRACT

Nitrogen fertilizer management plays a critical role in emissions of nitrous oxide (N_2O) in agricultural production systems. This study investigated the impact of nitrogen application in a winter wheat (*Triticum aestivum* L.)-soybean (*Glycine max* L.) double cropping system on winter wheat biomass production, grain yield, and N_2O emissions. The experiment was conducted at the Agronomy Research Center (ARC), Carbondale in Southern Illinois University, IL using a Randomized Complete Block Design (RCBD) with treatments representing varying nitrogen input levels (low, medium, and high) in double cropping systems. Results indicated that nitrogen application in the medium-input treatment did not significantly affect winter wheat biomass, grain yield, and cumulative N_2O fluxes compared to the high-input treatment, which included a fall fertilizer application. Similar results were observed in soybeans concerning grain yield and cumulative N_2O fluxes. While the total nitrogen applied in both the medium and high treatments was the same, the removal of fall fertilization is beneficial in reducing N_2O fluxes without compromising yield or environmental performance. Soil N_2O fluxes varied significantly across sampling dates, but no significant treatment-by-sampling dates interaction was observed. These findings suggest that fall nitrogen application may not be necessary for optimizing winter wheat yield in this site, offering an effective nitrogen management strategy for winter wheat-based cropping systems. This research serves as evidence in supporting the refinement of nitrogen application timing to enhance environmental sustainability in agricultural systems. Future studies shall continue to explore the impact of these treatments and the economic implications on nitrous gas emissions in the long term.

INTRODUCTION

Nitrous oxide (N_2O) is the most potent greenhouse gas playing a significant role in climate change, with agricultural crop production being a primary source of concern. The USEPA reports that agricultural soil management practices are the main contributor to total N_2O emissions in the USA (USEPA, 2024). Therefore, reducing N_2O emissions through sustainable management strategies and processes is essential to minimize environmental impact.

The emission of N_2O from soil is primarily driven by microbial processes, specifically nitrification and denitrification. These processes involve the conversion of nitrate-N (NO_3-N) into various nitrogen gases, including nitrogen oxide (NO), nitrous oxide (N_2O), and nitrogen (N_2) gases (Meisinger et al., 2008; Sadeghpour et al., 2017).Thus, moist soils with warm temperatures, NO_3-N availability, and soils rich in labile carbon (C) serving as energy reservoirs are some of the factors that enhance the emissions of N_2O through the processes of nitrification and denitrification (Butterbach-Bahl et al., 2013). This study examined the impact of cultivating winter wheat (WW) as a double crop to soybeans and the timing/rate of nitrogen (N) management in WW phase on its dry biomass, yield, and N_2O emissions. We hypothesize that cultivating WW as a double crop in soybeans could increase N_2O emissions due to addition of N as fertilizer to WW and low nitrogen use efficiency (NUE) of N fertilizers.

MATERIALS AND METHODS

Experimental site, design, and treatments

The study was laid out in a Randomized Complete Block Design (RCBD) with four replicates at the Agronomy Research Center (ARC), Carbondale, and Belleville Research Center (BRC), IL. The eight treatments, applied at the same time were (1) corn-soybean rotation with no-CC (control), (2) corn-rye-soybean-rye rotation (maximum nitrate-N reduction control), (3) corn-wheat (low input)-soybean-no-CC, (4) corn-wheat (medium input)-soybean-no-CC, (5) corn-wheat (high input; NREC growers suggestions)-soybean-no-CC, (6) corn-wheat (low input)-soybean-rye CC, (7) corn-wheat (medium input)-soybean-rye CC, and (8) corn-wheat (high input; NREC growers suggestions)-soybean-rye CC. However, N_2O emissions were measured in the following treatment plots: (1) corn-soybean rotation with no-CC (control), (6) corn-wheat (low input)-soybean-rye CC, (7) corn-wheat (medium input)-soybean-rye CC, and (8) corn-wheat (high input; NREC growers suggestions)-soybean-rye CC.

Nitrogen management for winter wheat

The low input treatments (3 and 6) were subjected to a nitrogen (N) application regimen, wherein 40 lbs of N ac^{-1} was administered as Urea Ammonium Nitrate (UAN) both at the tillering stage and during the jointing stage. In contrast, the medium input treatments (4 and 7) received a total of 70 lbs of N ac^{-1} of UAN, with applications taking place at the tillering and jointing stages. Conversely, the high input treatments (5 and 8) had a distinct N application strategy. These treatments involved the application of 27 lbs of N ac^{-1} of Diammonium Phosphate (DAP) during the fall season, in addition to 70 lbs of N ac^{-1} in the form of UAN, administered at both tillering and jointing stages (Table 1).

Winter wheat, soybean, and cereal rye establishment

A no-till drill was used to plant WW (var. AgriMaxx 495) and cereal rye (CR) Guardian VNS (variety not specified) at 125 lbs ac^{-1} and 78 lbs ac^{-1}, respectively in October 2021. CR was terminated in May 2022 while WW was harvested in June 2022. Soybeans (var. Asgrow 47xF0) were planted after the termination of CR and harvesting of WW in May (single season) and June 2022 (double crop). Soybean was harvested and CR was planted on October 2022.

Data collection

Before WW harvest, 7.26 ft^2 (3 frames of 2.42 ft^2) of fresh biomass in each plot were sampled using the grass shears at about 2 inches above the ground surface. The fresh biomass was oven-dried at 140 degrees Fahrenheit for 72 hours and weighed for dry biomass. Plant heights were measured using a graduated ruler from the ground to the canopy top. The Normalized Difference Vegetation Index (NDVI) for each treatment was measured using the GreenSeeker Handheld Crop Sensor HCS 100 (Trimble Ltd., Sunnyvale, CA) device. This was done by passing the device over the full length of the two rows of crops at the middle of each plot. The AccuPAR (LP–80; METER Group, Pullman, USA) ceptometer was used to measure the leaf area index (LAI). This device measured the above and below photosynthetically active radiation (PAR) in the crop canopy in each treatment plot.

N_2O emissions measurement

According to Sistani et al. (2011), vented chambers with lids were built. The closed vented chambers were installed between the soybean rows (2.5 feet wide and 30 feet long) immediately after planting. During the sampling time, a 30 mL syringe and needle were used to obtain air samples from the closed vented chamber at 0, 15, 30, and 45-minute intervals (Sadeghpour et al. 2018). The air sample was immediately dispensed into an exetainer vial of 12 mL obtained from Labco Ltd., Lampeter, United Kingdom. Air samples obtained were 16 times in WW 2021-2022 however, in soybeans, it was 18 times for a single season and 12 times for a double crop in 2022, respectively. Air sampling was carried out intensively two times per week following fertilizer application in the winter wheat phase and during intensive rainfall occurrence.
The concentration of N_2O emissions in air samples stored in the exetainers was quantified using a Shimadzu Gas Chromatograph (GC-2014; Shimadzu Scientific Instruments, Inc., Columbia, MD). Air samples were automatically transferred from the exetainer vials to the GC machine by a Multifunctional AOC-6000 autosampler (Shimadzu Scientific). A 1 mL air sample was withdrawn from the exetainer vials with a N_2-purged glass syringe and injected into the GC machine for analyses.

Table 1: N Application Rates for WW Growth Stages in Fall and Spring 2021-2022.

	FALL lbs ac^{-1}	SPRING lbs ac^{-1}				TOTAL lbs ac^{-1}
		Tillering		Jointing		
	DAP	DAP	UAN	DAP	UAN	
Low	-	27	40	-	40	107
Medium	-	27	70	-	70	167
High	27	-	70	-	70	167

Soil N_2O emission rates were calculated by linearly regressing N_2O concentrations against time after chamber closure. If a non-linear response was observed for N_2O concentrations across the sampling time, linear regressions were derived by randomly selecting three measurements. Sampling dates where high N_2O emissions were recorded typically demonstrated a strong linear regression fit (R^2 > 0.90), which was used to calculate N_2O fluxes. Total and monthly cumulative N_2O emissions were calculated through interpolating between sampling periods and according to the USDA-ARS GraceNet protocol (Parkin and Venterea, 2010). Data on dry biomass, grain yield, and total cumulative of N_2O were analyzed using the mixed model in SAS (SAS Institute, 9.4, 2024). However, data on sampling dates and monthly cumulative for N_2O were analyzed as repeated measures using mixed models in SAS. Mean separation was done using Tukey's Honestly Significant Difference (HSD) test at .05 level of significance.

RESULTS AND DISCUSSION

The WW biomass and grain yield were similar among all treatments at both research sites (Figure 1). The soybean grain yield showed statistically significant differences across all treatments. Grain yields were higher in the single-season soybean compared to the double-season system. (Figure 2). The low yield in the double-cropped soybeans were probably due to the smaller plant size, shorter flowering period, pod set, and seed filling caused by delayed planting.

Soil N_2O fluxes were affected by date of sampling during the WW growing season. High N_2O fluxes were observed during the periods of freeze–thaw cycles and following N fertilizer application due to the response of nitrifying and denitrifying microbial activities to shifts in environmental conditions and N addition. Nevertheless, soil N_2O fluxes were similar among treatments across the different sampling dates (Figure 3).

Calculated monthly cumulative N_2O fluxes were affected by sampling months and treatment effects but not their interaction. The N_2O fluxes were higher in the high-input fertilizer treatment plots when compared to those that received low-input fertilizer. This increase suggests that surplus nitrogen in the high-input plots served as an additional substrate, thereby enhancing N_2O production through microbial nitrification and denitrification pathways. Furthermore, N_2O fluxes peaked in February and March, likely attributable to warming temperatures and increased soil moisture, which stimulated microbial activity and accelerated nitrification and denitrification processes.

Soil N_2O emissions during the soybean season were affected by sampling dates, treatments, and their interactions (Figure 4). The observed N_2O fluxes were due to temperature and soil moisture increase, which enhanced activities of microorganisms and accelerated the nitrification and denitrification processes. The monthly cumulative of N_2O fluxes showed that month and treatments were statistically significant. However, the interaction between month and treatment was not statistically significant. The HW treatment had the highest N_2O fluxes when compared to the single season soybean approach. The MW and LW treatments were similar to the single season soybean treatment and HW (Figure 4). The total cumulative analysis was not statistically significant.

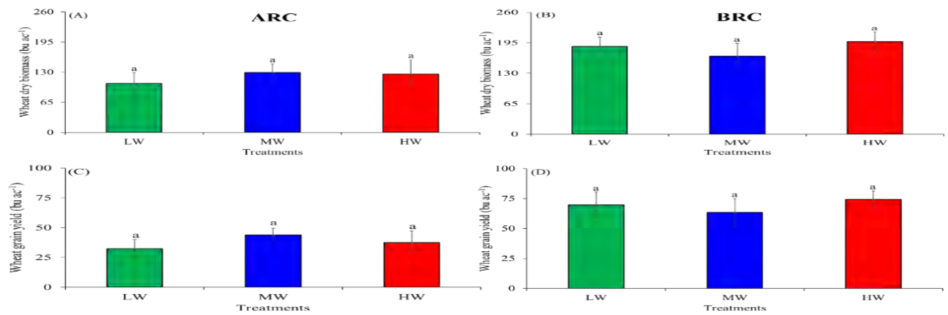

Fig. 1. Response of WW biomass (A-B) and grain yield (C-D) to varying N fertility management intensities. Identical letters indicate no significant difference (Tukey $p \leq .05$ level). Abbreviation: NOCC = No cover crop, LW = low fertilizer rate, MW = medium fertilizer rate, and HW = high fertilizer rate for WW.

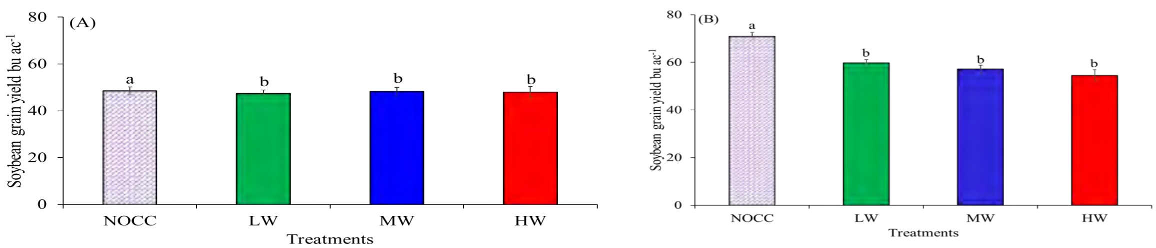

Fig. 2. Soybeans grain yield at ARC (A) and BRC (B) as influenced by WW double crop and different N fertility management intensities in 2022. Identical letters indicatee no significant difference (Tukey $p \leq .05$ level). Abbreviation: see Table 1.

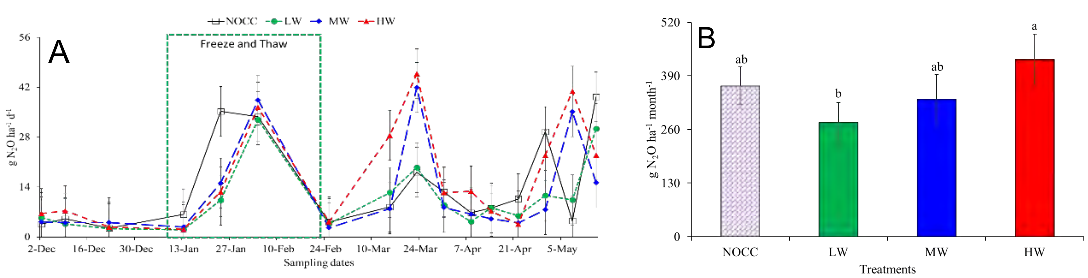

Fig. 3. N_2O flux trends (A) and monthly cumulative N_2O fluxes (B) across fertilizer treatments during WW growth in 2022. Identical letters indicate no significant difference (Tukey $p \leq .05$ level). Abbreviation: see Table 1.

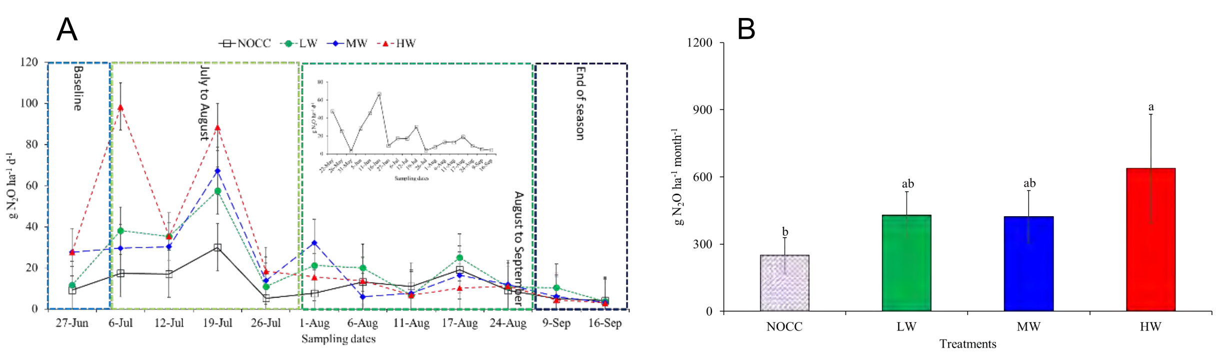

Fig. 4. N_2O flux trends (A) and monthly cumulative N_2O fluxes (B) across fertilizer treatments during soybeans in 2022. Identical letters indicate no significant difference (Tukey $p \leq .05$ level). Abbreviation: see Table 1.

PRELIMINARY CONCLUSION

This study assessed the impact of N fertilizer management on N_2O emissions, biomass, and yield in a wheat-soybean double-cropping system. Our results showed that eliminating the fall nitrogen application in the medium-input treatment does not significantly affect wheat biomass, grain yield, or N_2O emissions when compared to the high-input treatment, which includes fall fertilization. While the total N applied in both treatments remains the same, the absence of fall fertilization presents an opportunity to reduce N_2O fluxes without sacrificing crop productivity. These findings have practical implications for optimizing nitrogen application timing, particularly for farmers looking to improve environmental stewardship. The that fall nitrogen applications might not be essential for attaining high yields or reducing nitrous oxide emissions. However, additional site-years of data are needed to solidify this conclusion, which would support the development of more effective fertilizer management strategies.

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SHORT-STATURE AND FULL-STATURE CORN HYBRID RESPONSE TO NITROGEN RATE AND PLANT POPULATION

E. Oliva, S. Casteel, and D. Quinn
Purdue University

ABSTRACT

The recent introduction of short-stature corn (*Zea mays* L.) hybrids (5-7 ft height) suggests agronomic management recommendations need to be reassessed and updated in comparison to modern full-stature hybrids. Short-stature hybrids target to increase overall Midwest corn production and agronomic efficiency by reducing lodging potential under higher plant populations through improved wind tolerance, stalk strength, and plant standability. However, the optimal combination of nitrogen rate and plant population for short-stature corn has yet to be determined. The objective of this research trial is to compare short-stature and full-stature corn performance across diverse nitrogen rates and plant populations to determine optimal nitrogen rates and plant population recommendations for future use. This research study utilizes a factorial, randomized complete block design with four replications to assess grain yield, yield components, leaf area index (LAI), plant standability, ear height, and plant height responses of two short-stature corn hybrids (PR111-20SSC, PR112-20SSC), and two full-stature corn hybrids (DKC61-41RIB, DKC62-70RIB; Bayer Crop Science, St Louis MO.) across four nitrogen rates (160, 200, 240, 280 lbs. N/ac), and three plant populations (32,000; 38,000 and 44,000 plants/ac). Small-plot (15 ft wide x 40 ft long) studies were conducted at The Agronomy Center for Research and Education (ACRE) in West Lafayette, IN. Preliminary data observed interactions between hybrid type and optimum seeding rate, but not nitrogen rate. Across all examined treatments, full-stature hybrids yielded higher than short-stature hybrids by 10-20 bu/ac. On average, short-stature corn requires a higher optimum seeding rate as compared to full-stature hybrids.

MATERIALS AND METHODS

A field trial was established at the Purdue Agronomy Center for Research and Education (ACRE) in Tippecanoe County, Indiana. The research trial examined corn yield response to different short and full-size corn hybrids, nitrogen, and seeding rates. This research study utilizes a factorial, randomized complete block design with forty-eight treatments and four replications. Individual plots measured 15 feet wide (6, 30-inch corn rows) by 40 feet long, and the center 2 rows were harvested with a small-plot combine and adjusted to 15.5% moisture for yield analysis. The trial factors included both short-stature hybrids (PR111-20SSC and PR112-20SSC) and full-stature hybrids (DKC61-41RIB and DKC62-70RIB). Three corn seeding rates at 32,000, 38,000, and 44,000 seeds per acre. Four nitrogen fertilizer rates (160, 200, 240, and 280 lbs N/acre) were applied using UAN (28-0-0) at the V5 growth stage, with all plots receiving an initial 2x2 starter nitrogen application totaling 40 lbs N/acre.

The trial was established on Drummer Fine-Silty soil with a 0-2% slope. Corn was planted on May 11, 2023, and harvested on October 22, 2023. Soybean served as the previous crop, and conventional tillage practices were employed. The trial data collection included soil samples at a depth of 0-8 inches before trial initiation, followed by plant stand counts at the V4 growth stage. Leaf area index (LAI) was measured at the R2 growth stage, while ear height and plant height were recorded at the R3 growth stage. Grain yield was measured (adjusted to 15.5% moisture), kernel number and kernel weight also analyzed. Data analysis was subject to ANOVA using lme4 package in R. Treatment means were estimated and separated using the emmeans package in R and considered statistically different at P<0.1.

RESULTS

Table 1. Analysis of variance (ANOVA) for corn grain yield in response to the main effects of nitrogen (N) fertilizer rate, corn seeding rate, hybrid type, and their interactions. West Lafayette, IN 2023.

Source of Variation	*Pr>F*
Corn Hybrid	**<0.001**
Nitrogen Fertilizer Rate	**0.09**
Corn Seeding Rate	**<0.001**
Hybrid * N Rate	0.112
Hybrid * Seed Rate	**0.013**
N Rate * Seed Rate	0.298
Hybrid* N Rate* Seed Rate	0.784

Figure 1. Mean corn grain yield (bu/ac) interaction differences between corn hybrid type and corn seeding rate. Black diamonds indicate mean values. *Individual box plots that contain letters different from each other indicate a significant difference at P<0.1. West Lafayette, IN 2023.

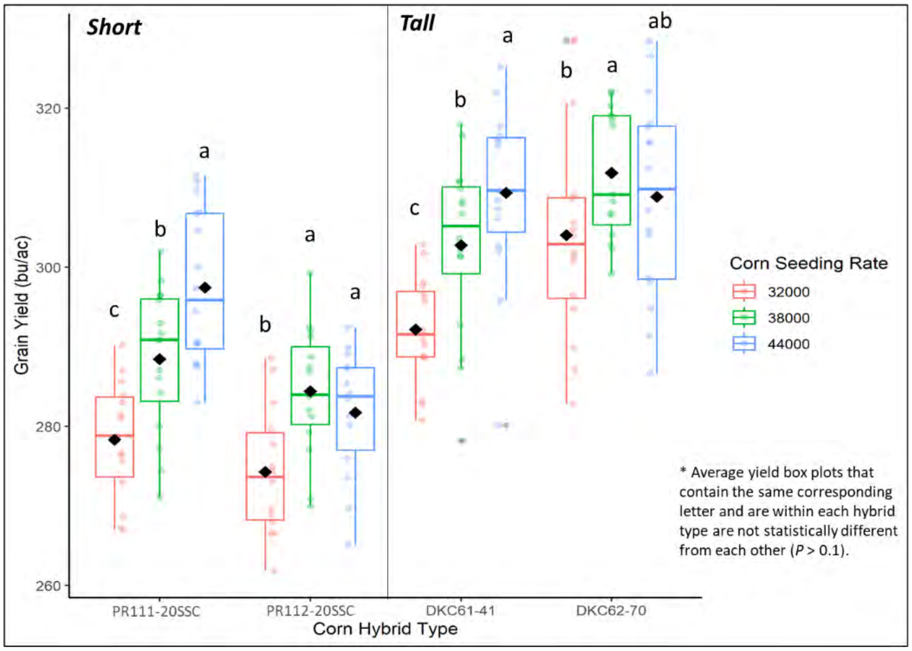

Figure 2. Mean corn grain yield (bu/ac) interaction differences between corn hybrid type and corn nitrogen rate (lbs/ac). Black diamonds indicate mean values. *Individual box plots that contain letters different from each other indicate a significant difference at P<0.1. West Lafayette, IN 2023.

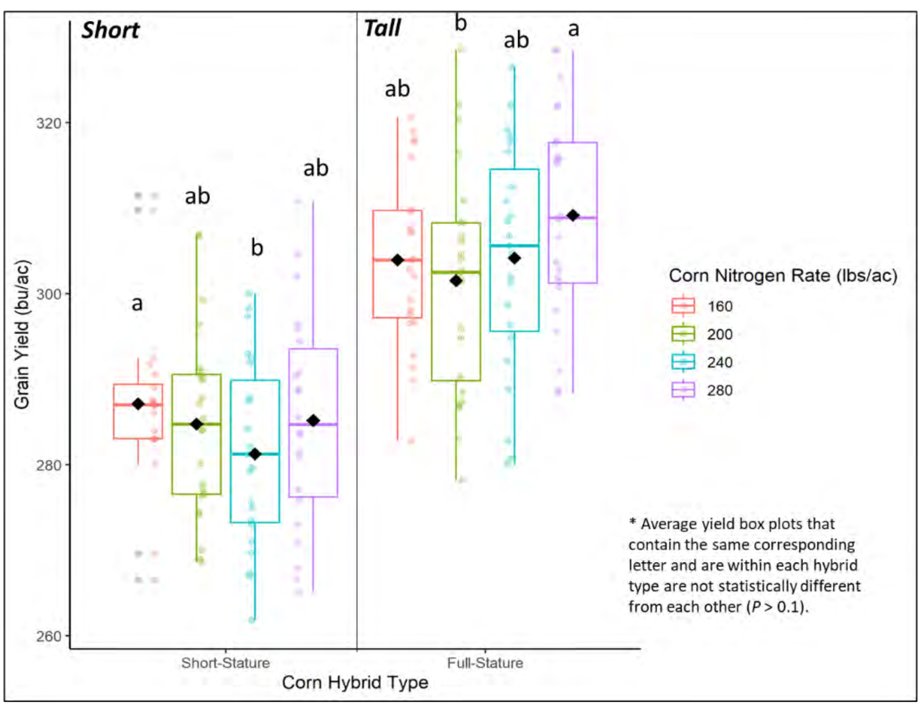

Table 2. Short and tall-stature corn yield, stalk nitrate, harvest index, kernel number, kernel weight, stover biomass, and total N uptake. Mean values which contain different letters and are within the same column are significantly different at P<0.1. West Lafayette, IN 2023.

Hybrid (Type)	Grain Yield	Stalk Nitrate	Harvest Index	Kernel #	Kernel Wt	Stover Biomass (R6)	Total N Uptake (R6)
	-- bu/ac --	--- ppm ---		kernels/ear	1000 kernels	-- lbs/ac --	-- lbs/ac --
PR111-20SSC (Short) †	299 ab	0.11 ab	0.67 b	471 b	349 a	7953 a	60 a
PR112-20SSC (Short)	288 b	0.05 b	0.71 a	590 a	284 c	6751 b	45 b
DKC61-41RIB (Tall)	311 a	0.14 a	0.71 a	566 a	299 bc	7039 b	48 b
DKC62-70RIB (Tall)	304 a	0.12 ab	0.68 b	570 a	312 b	7404 ab	45 b

CONCLUSIONS

- A significant hybrid x seeding rate interaction was observed in this research trial (Table 1) which suggests that the different hybrids examined required different optimum seeding rates within this year and environment (Figure 2).
- Across all hybrids examined, the hybrids did not differ in their response to applied total N fertilizer rates (Table 1 and Figure 2). Results suggest optimum N fertilizer rates do not differ between short and full-stature corn hybrids. Lower N application rates added in 2024.
- Significant differences between grain yield, stalk nitrate, harvest index, kernel numbers, kernel weights, stover biomass, and total plant uptake were observed between the four hybrids examined (Table 2).
- Preliminary results suggest optimum seeding rates, yield levels, and various physiological characteristics differ between different short and tall-stature hybrids. However, optimum N rate does not.

LONG-TERM (16-YEAR) COMPARISON OF PHOSPHORUS FERTILIZATION STRATEGIES: TARGETED SOIL TEST VALUES VS. CROP REMOVAL IN CORN PRODUCTION

S. Patel, C. Shapiro, and J. Iqbal
University of Nebraska-Lincoln

ABSTRACT

Developing effective phosphorus (P) fertilization strategies to optimize corn (Zea mays L.) yields across varying environmental conditions is essential. This 16-year study, conducted on Nora silt loam soil in Concord, NE (initial Bray-1 P of 16±3 mg kg^{-1}), evaluated different P fertilization strategies under dry, normal, and wet years. The treatments included: no P or N (NPNN), no P (NP), phosphorus applied at crop removal (CRP), and maintaining soil P at 15 (B15), 30 (B30), and 45 (B45) mg kg^{-1} Bray-1 P, with equivalent nitrogen rates across all treatments except NPNN. Results indicated a 25% and 33% reduction in soil test phosphorus (STP) for the NPNN and NP treatments, respectively. Maintaining soil P at B30 and B45 required 1.8 times more P than CRP and B15. Although the B30 and B45 treatments increased corn grain P concentration by 6-12% compared to B15 and CRP, they did not lead to yield improvements during normal and dry years. The NP treatment reduced yields by 9% in normal years and 12% in wet years. In contrast, CRP outperformed B15 during wet years, yielding 8% more. Economic analysis revealed that B45 generated a 56% higher net return in normal years, while CRP delivered the highest return on investment (ROI) at 4.8. This study emphasizes the challenges of managing soil P under varying environmental conditions, showing that while higher STP levels (B30 and B45) may enhance grain P concentration, they do not consistently boost yields or ROI compared to CRP and B15.

INTRODUCTION

Phosphorus (P) is a critical nutrient in corn (Zea mays L.) production, second only to nitrogen (N) in both agronomic importance and cost (Olson et al., 1987; Beegle, 2005). Effective P management is essential, though recommendations vary widely due to differing soil properties and environmental conditions. Corn production typically relies on two main P management strategies: maintaining soil test P (STP) at a critical level (CL) or applying P based on crop removal (CRP). The CL approach keeps STP above a deficiency threshold, while CRP replaces only the P removed during harvest, allowing gradual STP increases over time (Fulford & Culman, 2018). Climate variability further complicates P management, as crop yields and STP levels may respond differently under dry, normal, or wet conditions.

The debate continues about whether maintaining STP above the CL could enhance yield resilience under stress or if CRP and CL applications can yield similar or better returns on investment (ROI) with lower input costs (Penn et al., 2023; Fixen & Grove, 1990). This 16-year study in eastern Nebraska assessed the long-term impacts of maintaining STP levels at 15, 30, and 45 ppm Bray-1 P, compared with CRP, on corn yield, STP dynamics, and economic returns. The study's objectives included evaluating whether higher STP levels boost yields and economic outcomes and whether CRP would be more cost-effective than CL.

MATERIALS AND METHODS

A long-term (2000–2015) study was conducted on Nora silt loam soil at the Haskell Agricultural Laboratory in Concord, NE, where continuous corn had been grown since 1974. The soil, depleted of P due to nitrogen-only applications since 1986, had a baseline STP of 16 ppm Bray-1 P, pH of 5.4, and 280 lb/ac K. Six treatments in a randomized block design with four replications were applied: no P or N (NPNN), no P (NP), CRP, and targeted STP levels of 15 (B15), 30 (B30), and 45 (B45) ppm Bray-1 P. Except for NPNN, equivalent amount of nitrogen was applied to all treatments annually. Phosphorus was applied preplant, initially as monoammonium phosphate (MAP) or diammonium phosphate (DAP) and later as triple superphosphate from 2002 onward.

The targeted STP levels were achieved using initial P applications calculated from baseline STP values, with an estimated requirement of 8.6 lb P/ac to raise STP by 1 ppm (Fernández & Hoeft, 2009). CRP applications were adjusted annually based on the previous year's crop removal. Soil samples were taken post-harvest from an 8-inch depth and analyzed for STP to inform P applications, adjusted if STP deviated more than 5 ppm from target levels. Standard crop management practices were used, and yields were measured with a plot combine. Precipitation and evapotranspiration data helped categorize growing conditions as dry, normal, or wet years (Shekhar & Shapiro, 2019). Economic analysis included net profit and ROI, calculated from yield increases, corn prices, and P fertilizer costs.

RESULTS AND DISCUSSION

Phosphorus Application Mass and Changes in STP Levels

This study required varying amounts of P application across treatments to maintain target STP levels. To reach their respective target STP level, the B30 and B45 treatments received substantial P in the early years, based on the estimate of 8.6 lb P ac^{-1} to raise STP by 1 ppm Bray-1 P (Fernández & Hoeft, 2009). During the first two years, B15, B30, and B45 received 23%, 44%, and 63% of their total P, respectively. By 2004, B30 achieved its target, while B45 maintained STP above the target until 2009. This suggests a multi-year build program could be more practical for producers, as it spreads costs and prevents excessive initial applications. Over the 16-year study, total P applied was highest for B45 (569 lb P ac^{-1}), followed by B30 (390 lb P ac^{-1}), B15 (234 lb P ac^{-1}), and CRP (290 lb P ac^{-1}). Statistically, B45 received more P than B30, with both surpassing B15 and CRP, which were similar.

Without P application (NP and NPNN), STP levels declined from 16 ppm to 7 ppm (NP) and 11 ppm (NPNN) over 16 years, consistent with soil P depletion due to crop uptake. This gradual decrease aligns with findings that soil P levels decline more slowly than they increase, due to P's limited availability from less labile pools (Randall et al., 1997; Rehm & Schmitt, 1993). Conversely, the targeted P treatments initially exceeded their respective targets: two years after the first application, STP levels

Table 1. Effect of phosphorus application strategies on phosphorus application rates and quantity by year and across years (2000-2015) at Concord, NE.

Treatments†	CRP	B15	B30	B45	SE‡
Year applied	-------------------- lb P ac^{-1} --------------------				
2000	8c§	11c	124b	259a	9.8
2001	21b	43ab	46ab	100a	20.9
2002	20a	6a	12a	0a	6.5
2003	17a	0b	0b	0b	0.2
2004	13a	10a	10a	8a	4.7
2005	16a	8a	25a	11a	9.2
2006	22a	0b	0b	0b	0.4
2007	32a	29a	29a	4a	8.9
2008	20a	21a	14a	22a	9.9
2009	19a	21a	19a	14a	4.4
2010	20a	22a	66a	52a	14.6
2011	26a	21a	12a	12a	5.4
2012	15ab	13ab	7b	3a	6.2
2013	8a	6a	7a	12a	4.5
2014	7a	8a	8a	18a	4.1
2015	25a	15ab	9b	28a	4.9
Total (2000 – 2015)	290c	234c	390b	569a	26.9

†CRP indicates P applied at crop removal, and B15, B30, B45 indicate treatments to maintain STP levels at 15, 30, and 45 ppm (Bray-1P), respectively.

‡Indicates weighted standard error (SE) for all variables.

§Different letters in the same row indicate means are significantly different at $P < 0.05$

Table 2 Effect of phosphorus application strategies on soil phosphorus levels by year (2000-2015) at Concord, NE.

	Soil test P levels						
Treatments†	NPNN	NP	CRP	B15	B30	B45	SE‡
Year	----------------------------- Bray-1P ppm -----------------------------						
2000	14b§	16b	18b	16b	35a	37a	4.4
2001	14c	11c	25bc	21bc	47b	102a	9.7
2002	16c	15c	36c	34c	72b	133a	12.8
2003	13b	13b	23b	22b	36b	90a	10.4
2004	13c	13c	23bc	22bc	31b	68a	5.2
2005	17c	15c	37c	36c	73b	133a	12.3
2006	9c	8c	23bc	18c	35b	77a	5.3
2007	9d	10d	24c	18cd	36b	55a	3.4
2008	11de	8e	25c	16d	33b	51a	2.4
2009	9c	7c	19b	12c	25b	42a	2.5
2010	20cd	7d	22c	21c	43b	60a	4.8
2011	10cd	7d	21b	17bc	38a	44a	2.3
2012	11d	8d	25bc	18cd	34b	52a	3.8
2013	10d	8d	24c	19c	34b	44a	2.2
2014	13c	9c	26b	21b	40a	46a	2.8
2015	12cd	8d	32b	21c	37b	55a	3.7

†NP and NPNN indicate treatments with no added P and neither P nor N applied, respectively, CRP indicates P applied at crop removal, and B15, B30, B45 indicate treatments to maintain STP levels at 15, 30, and 45 ppm (Bray-1P equivalents), respectively.

‡Indicates weighted standard error (SE) for all variables.

§Different letters in the same row indicate significant mean differences at $P < 0.05$

reached 19, 42, and 91 ppm for B15, B30, and B45, respectively, reflecting an initial overshoot. These levels peaked in 2002, then gradually declined to near target levels, suggesting that high initial applications have prolonged residual effects. Splitting initial applications over time may better align with target attainment and prevent overshoot (McCallister et al., 1987; Richards et al., 1995).

In later years, P applications for B30 and B45 decreased to maintenance levels, similar to or even lower than CRP, indicating a stabilizing effect after target STP was achieved. The CRP and B15 treatments maintained similar STP levels across most years, with CRP gradually increasing STP from 16 ppm in 1998 to 28 ppm by 2015, without falling below the initial level. These results support that CRP applications can gradually raise STP over time (Sims et al., 2023; Wortmann et al., 2018).

Grain Yield and Grain P Concentration

In the early years, yield differences from phosphorus (P) application were minimal due to soil test P (STP) levels near the critical threshold of 16 ppm. Over the 16-year study, however, P application significantly increased average corn grain yield compared to no P, while nitrogen absence reduced yield by 38%. Average yields across P treatments (CRP, B15, B30, and B45) were similar, at 123, 120, 121, and 126 bu ac^{-1}, respectively, with B45 showing a 5% higher trend than B15 but without statistical significance. This aligns with findings that yield gains diminish when STP exceeds critical levels (Penn et al., 2023; Iqbal et al., 2019). In dry years, yields across treatments were 28-44% lower than in normal or wet years, indicating moisture limitations on yield. Yields in the absence of P (NP) were reduced by 9% and 12% in normal and wet years, respectively, while CRP showed an 8% higher yield than B15 in

Table 3 Effect of P fertilizer application strategies on corn grain yield during dry (SPEI > -1.13 < -2.17), normal (SPEI > -0.69 < 0.51), wet (SPEI > 1.16 < 1.59), and across all study years (2000-2015) at Concord, NE.

	Corn yield			
	Dry years (3 years)	Normal years (10 years)	Wet Years (3 years)	All years (2000-2015 years)
Treatments‡	----------------bu ac^{-1}----------------			
NPNN	72	73	83	75
NP	78	112	142	112
CRP	84	123	166	123
B15	84	121	153	120
B30	84	121	161	121
B45	80	127	167	126
SE§	17.5	8.0	6.4	8.0
Contrasts †		*P* > F		
NPNN vs (NP + CRP + B15 + B30 + B45)	**	***	***	***
NP vs (CRP + B15 + B30 + B45)	NS	***	***	***
CRP vs B15	NS	NS	*	NS
B30 vs B45	NS	NS	NS	NS
(CRP + B15) vs (B30 +B45)	NS	NS	NS	NS

*, **, ***: Significant at $P < 0.05$, 0.01, and 0.001, respectively.
†Orthogonal treatment comparisons.
‡NP and NPNN indicate treatments with no added P and neither P nor N applied, respectively; CRP indicates P applied at crop removal, and B15, B30, B45 indicate treatments to maintain STP levels at 15, 30, and 45 ppm (Bray-1P equivalents), respectively.
§Indicates weighted standard error (SE) for all variables.
Corn grain yields expressed at 15.5 % moisture.

wet conditions, suggesting potential yield losses when STP is only maintained near the critical level under high-yield potential.

Absence of P fertilization (NP treatment) showed a 16% decrease in grain P concentration compared to P-applied treatments, with CRP and B15 averaging 0.32% grain P concentration. Higher STP levels in B30 and B45 increased grain P concentration by 9% compared to B15 and CRP, demonstrating "luxury consumption" where excess P uptake does not enhance yield (Cadot et al., 2018; Penn et al., 2023). In dry years, grain P concentration increased by 6-10% due to limited carbohydrate production from moisture stress, causing less P dilution. Overall, maintaining soil at higher STP levels (B30 and B45) raised grain P concentration by 11% and 6% in dry and normal years, respectively, compared to CRP and B15, reflecting increased P uptake without a significant yield benefit.

Table 4 Effect of phosphorus application strategies on grain P concentration during dry (SPEI > -1.13 < -2.17), normal (SPEI > -0.69 < 0.51), wet (SPEI > 1.16 < 1.59), and across all study years (2000-2015) at Concord, NE.

	Grain P concentration			
	Dry years (3 years)	Normal years (10 years)	Wet Years (3 years)	All years (2000-2015)
Treatments[‡]		------------------------------------ %	------------------------------------	
NPNN	0.34	0.32	0.33	0.32
NP	0.29	0.28	0.27	0.28
CRP	0.33	0.32	0.3	0.32
B15	0.34	0.32	0.31	0.32
B30	0.37	0.34	0.32	0.34
B45	0.38	0.34	0.34	0.35
SE[§]	0.02	0.02	0.05	0.02
Contrasts [†]		*P* > F		
NPNN vs (NP + CRP + B15 + B30 + B45)	NS	NS	NS	NS
NP vs (CRP + B15 + B30 + B45)	***	***	**	***
CRP vs B15	NS	NS	NS	NS
B30 vs B45	NS	NS	NS	NS
(CRP + B15) vs (B30 + B45)	*	***	NS	***

*, **, ***: Significant at $P < 0.05$, 0.01, and 0.001, respectively.

[†]Orthogonal treatment comparisons.

[‡]NP and NPNN indicate treatments with no added P and neither P nor N applied, respectively, CRP indicates P applied at crop removal, and B15, B30, B45 indicate treatments to maintain STP levels at 15, 30, and 45 ppm (Bray-1P equivalents), respectively.

[§]Indicates weighted standard error (SE) for all variables.

Economic Analysis of Fertilization Strategies

The economic analysis of P fertilization strategies revealed that the highest yield increase and net income were observed with the B45 treatment, though not significantly different from crop removal-based P application (CRP). The B45 and CRP treatments generated additional revenue of $14 and $24 per acre, respectively, over the B15 treatment. However, B45 incurred the highest annual P costs at $18 per acre, while CRP costs were similar to B15 and lower than B30 and B45. Despite higher marginal income, the B45 and B30 treatments had the lowest return on investment (ROI) at 3.0, whereas CRP yielded the highest ROI at 4.9, making it the most economical approach for maximizing net profit. Under dry conditions, applying P should be minimized when soil test P is near or above the critical level (CL), as higher application rates increase financial risk without yield benefits. In contrast, normal growing conditions supported B45's profitability due to yield gains, emphasizing that high STP levels could be beneficial if soil P loss risk and budget constraints are manageable.

Table 5. Annual net profit and return on investment (ROI) of P fertilization strategies during dry (SPEI > -1.13 < -2.17), normal (SPEI > -0.69 < 0.51), wet (SPEI > 1.16 < 1.59), and across all study years (2000-2015) at Concord, NE.

	Average across year (2000 – 2015)						Dry year		Normal year		Wet year	
	Δ Yield[a]	Net income[b]	P applied	Cost[c]	Net return	ROI[e]	Δ Yield	Net return	Δ Yield	Net return	Δ Yield	Net return
Treatment[†]	bu ac^{-1}	\$ ac^{-1}	lb P ac^{-1} yr^{-1}	\$ ac^{-1}	\$ ac^{-1}		bu ac^{-1}	\$ ac^{-1}	bu ac^{-1}	\$ ac^{-1}	bu ac^{-1}	\$ ac^{-1}
CRP	12ab	43ab	18c	9c	34	4.9	-27	-104	11b	31b	54	185
B15	8c	30c	14c	7c	22	3.6	-27	-106	9b	25b	41	140
B30	11bc	38bc	24b	12b	25	3.1	-27	-108	10b	24b	49	163
B45	15a	53a	36a	18a	36	3	-32	-132	17a	42a	56	182
SE[‡]	4.1	15	1.7	1	15	1.3	4.6	17	1.4	6	4.5	16
						P > F						
	*	*	***	***	NS	NS	NS	NS	***	*	NS	NS

ΔYield [a] = Increase in yield over average no P (NP) yield across all years (112 bu ac^{-1}).
[b]Net income = Income calculated from increase in yield (Δ Yield) and corn price.
[c]Cost = Cost of P application calculated using price of P fertilizer and average P applied each year.
[e]ROI = Return on investment from P application calculated as ratio of income and cost.
[†]Treatments are P applied at crop removal (CRP), and B15, B30, B45 are treatments to maintain STP levels at 15, 30, and 45 ppm (Bray-1P equivalents), respectively.
SE[‡] = Indicates weighted standard error.

SUMMARY

This study compared crop removal (CRP) and critical level (CL) approaches to phosphorus (P) fertilization, investigating whether raising the CL from 15 ppm Bray-1 P would improve yield and economic returns. Results showed that maintaining soil test P (STP) above the CL, especially at very high levels (B45), tended to enhance yield by 5%, particularly in normal and wet years, though benefits were less evident in dry conditions due to moisture constraints. While B45 generated additional revenue, it required twice the P application of CRP, leading to lower return on investment (ROI). CRP emerged as the most cost-effective strategy, achieving the highest ROI (4.9) by increasing yield moderately (1–8%) without the high costs associated with maintaining elevated STP levels. This approach also reduces soil testing frequency, supporting sustained productivity without excessive P inputs. These findings highlight the importance of adjusting P management based on weather and crop demands and suggest a potential need to revisit Nebraska's P recommendations for dryland corn. Further regional research is recommended to validate these outcomes for broader applicability.

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CORN GRAIN YIELD AND QUALITY RESPONSE TO COMMERCIAL BIOSTIMULANT PRODUCTS AND NITRIFICATION INHIBITORS

R. Paul[a], G. Singh[a], K. Nelson[a], and G. Kaur[b]
[a]Division of Plant Science and Technology, College of Agriculture, Food and Natural Resources, University of Missouri
[b]Northern Missouri Research, Extension, and Education Center, University of Missouri

ABSTRACT

Biological nitrogen (N) fixation by microorganisms plays a crucial role in the N cycle, transforming atmospheric nitrogen (N_2) into ammonia (NH_3) and enhancing plant growth. The objective of this study was to evaluate three biological N fixing products or biostimulants (BS), including *Gluconacetobacter diazotrophicus* (BS-1), *Klebsiella variicola* + *Kosakonia sacchari* (BS-2), and *Methylobacterium symbioticum* (BS-3) for their in-field performance in enhancing corn (*Zea mays* L.) grain yield and quality parameters. A three-year study was established at the University of Missouri Lee Greenley Jr. Memorial Research Farm in Novelty, MO from 2020 to 2022 with different levels of N fertilization to corn (0, 50, 100, 150, 200 lb N ac^{-1}) along with an application of three BS and a nitrification inhibitor (NI) nitrapyrin at 100 lb N ac^{-1}. Over three years, grain moisture, test weight (TW), and grain quality parameters were measured. Significant differences were observed among N treatments for TW in 2021 and 2022. Averaged over 3 years, TW was non-significant. Furthermore, the results indicated that when averaged over three years Biostimulants did not improve corn yield over the N treatments when data was averaged over three years. There were yearly differences in corn grain yield among N rate treatments and 200 lb N ac^{-1} had 98 to 118% yield increase over the control. In 2021, the 100 lb N ac^{-1} + NI treatment had 14 to 23 bu ac^{-1} higher corn grain yield compared to other treatments except for 100 lb N ac^{-1} + BS-3. The treatments with BS and NI showed higher grain oil content in all the years when compared to the treatments with higher N rates (150 and 200 lb N ac^{-1}). The highest grain protein was found in the treatment 200 lb N ac^{-1}. All treatments were non-significant for corn grain starch content. The findings suggest that integrating biological N fixers and NI's into N management strategies does not always improve grain yield and might not help reduce reliance on synthetic fertilizers in corn production.

ENHANCING NITROGEN FERTILIZER EFFICIENCY IN GRAIN SORGHUM TO BOOST YIELDS AND REDUCE NITROGEN LOSS

M. Platero, P. Morinigo, D. Ruiz Diaz and P. Tomlinson
Kansas State University, Manhattan, KS

ABSTRACT

Effective nitrogen (N) management is essential for optimizing plant growth, increasing yield, and reducing environmental impacts, such as nitrogen runoff. Grain sorghum, a staple crop in Kansas, can greatly benefit from precise nitrogen application strategies. This study aimed to identify the optimal nitrogen application rate and best management practices to prevent over-application, minimize nitrogen losses, and avoid deficiencies.

Research was conducted on rain-fed fields across six sites in North-East and West Kansas from 2021 to 2024. The objectives were to (1) determine nitrogen response in grain sorghum using broadcast-applied urea at rates of 0, 30, 60, 90, 120, 150, and 180 lb/ac, and (2) evaluate yield response to a fixed nitrogen rate of 60 lb/ac under various nitrogen management strategies. These strategies included different nitrogen sources (urea, UAN), timings (at planting, growth stage 6), placements (broadcast, coulter, streamed, subsurface), and additives (ESN, NBPT, Super U).

Nitrogen fertilization significantly increased yield at Site 1, where a rate of 98 lb/ac produced a yield of 128.62 bu/ac. Similarly, at Site 5, a rate of 110 lb/ac resulted in a yield of 80.27 bu/ac. In contrast, other sites showed no yield response to nitrogen fertilization. Specific nitrogen management practices demonstrated trends toward increased efficiency over the standard of broadcast urea applied at planting; however, these differences were not statistically significant at Sites 1 or 5.

CROP AND SOIL RESPONSE TO DIFFERENT PHOSPHORUS MANAGEMENT APPROACHES

M. Rakkar, L. Fleuridor, S. Culman, G. LaBarge
The Ohio State University

ABSTRACT

Phosphorus (P) management has implications for crop production and water quality in Ohio. Recent data from 457 field P trials conducted in Ohio reported less than 25% positive yield response to P fertilization. It warrants further evaluation of crop P uptake, soil P levels and other relevant factors to improve the predictability of crop yield response. Therefore, we collected soil and plant data from three P fertilizer trials (Northwest, Western and Wooster) established in 2006. These sites have three P-fertilization approaches: no P (0x), maintenance approach (1x), and build up approach (3x), replicated four times with a corn-soybean rotation. Data show that soil P levels were different across the treatments with 0x treatment with the lowest soil P levels. Despite different soil P levels, yield differences during the study period were sporadic. We observed a significant correlation of soil P content and grain P uptake. The soil P budget over six years was negative for no P plots, near zero for maintenance and positive for build up approach. Overall, the findings of the study provided insights into how soil P levels and yield could change with different P management strategies. The study will have implications on P management in Ohio.

INTRODUCTION

Phosphorus (P) management is crucial for Ohio growers, not only for optimizing crop yield and productivity but also to mitigate its impact on water quality (Hanrahan et al., 2019; Brooker et al., 2017). Phosphorus management practices have long been guided by the Tri-State Fertilizer Recommendations, which provide nutrient management guidelines for Ohio, Michigan, and Indiana (Culman et al.,2020; Vitosh et al., 1995). These recommendations follow a build-up and maintenance strategy, specifying application rates and conditions under which a yield response may be expected. When soil test phosphorus (STP) falls within the maintenance range of 20-40 ppm (Mehlich-3), P additions are recommended at crop removal rates. Below this maintenance range, P applications include a build-up component to replenish STP to these maintenance levels over 4 years (Vitosh et al., 1995). The 20-ppm threshold is considered the critical STP level for corn and soybean, above which the likelihood of a significant positive yield response to additional P decreases (Culman et al., 2023; Culman et al.,2020; Vitosh et al., 1995).

Growers and researchers implementing the recommended strategies frequently report inconsistent yield responses or failure to build STP even when exceeding Tri-State Recommendations (Culman et al., 2023; Wade et al., 2019; Fulford & Culman 2018). Out of 457 trials evaluating crop yield response to P fertilization, only 23% showed a positive yield response (Culman et al., 2023). The occurrence of responsive sites was sporadic, with no clear trends or identifiable factors driving these responses.

While the intuitive response may be to further increase P application rates, the economic viability and efficacy of such practices remain questionable. To ensure sustainable P management, a better understanding of best management strategies is essential to balance crop nutrient requirements with continuous efforts to minimize agricultural P losses. Here, our study evaluated soil and crop response to three P management approaches, 1):no P (0x), 2): maintenance (1x: crop removal rate) and 3) build up approach (3x crop removal rate). The objective is to determine crop response to these management strategies and their implication on P- budgets.

MATERIAL AND METHODS

An experiment was established in 2006 at three sites at the Northwestern, Western and Wooster Research and Development centers in Ohio. Soil characteristics varied between sites. Northwest site has a Hoytville clay loam, Western has a Kokomo silt loam and Wooster has a canfield silt loam. The soil pH varies from 5.8 to 6.7 and organic matter range from 1.6 to 2.5 percent across sites. Baseline nutrient analysis showed initial available P at 22 ppm, 27 and 29 ppm at Northwest, Western and Wooster, respectively.

The study consisted of three fertilizer treatments: no P (0x), maintenance approach (1x), and build up approach (2x), x represents the P removal rates. Treatments were replicated four times on a corn-soybean and corn-corn-soybean rotation until 2014. Phosphorus fertilizer was applied following soybean harvest only. In 2015, the fertilizer application rate was increased in 2x treatment to three times of crop removal P rate (3x) and the corn-corn-soybean was changed to corn-soybean. In this paper, we summarized crop and soil response to different P approaches from 2015-2020.

Soil samples were collected each fall after crop harvest from 0 to 8 inches. The samples were air-dried, ground, and analyzed for available P using Mehlich-3 extraction procedure (NCERA-13, 2015). Leaf tissue samples were collected at reproductive stage (R1) to determine plant P concentration. At harvest, grain yield data was collected by harvesting the two center rows of corn plots and center six rows of soybean plots. Grain yield is reported at 15.5% moisture content for corn and 13% for soybeans. A sub-sample of harvested grain was used to determine P concentration for both crops.

Analysis of variance was conducted by site, crop, and year using proc mixed in SASv9.3 (SAS Institute, Cary, NC) to determine the effect of P management on soil P and crop yield. The significance level was set at $P \leq 0.05$ for all statistical analysis. All subsets regression models were constructed to identify the most parsimonious sets of predictors of corn and soybean yields based on the AIC values using the olsrr package in R.v4.3.3 (Hebbali, 2024). To determine P budget, the following equation was used for the plots with corn-soybean rotation.

P budget (2015-2020) = P input (fertilizer amount)- P removal (crop yield x grain P concentration) for each site and P-management combination.

RESULTS AND DISCUSSION

Management strategies significantly affected available soil P (Fig 1). The soil P levels were the highest for buildup approach (3x) whereas no P approach (0x) had the lowest soil P across sites. The magnitude of soil P level difference varied among P treatments and varied by year and site. For example, at Northwest, the 3x treatment had 41 ppm more soil P compared to the 0x treatment in 2015. At the same site, the difference of soil P between 0x and 3x treatments increased to 117 ppm by 2020. At Wooster, the soil P difference among 0x and 3x treatments changed from 30 to 49 ppm over the six-year time-period. The observed difference can be explained by two factors: First, soil P decreased in no P treatment over six years, but the magnitude of decrease differed across sites. The highest drawdown was observed at the Northwest with 14 ppm, Wooster location showed only 1 ppm drop in soil P level over six years. Second, soil P build up showed substantial difference across sites. The soil P level increased from 76 to 138 ppm at Northwest whereas it changed from 49 to 67 ppm at the Wooster location. Our data suggest that different P approaches can significantly affect the soil P levels, however the magnitude of change is site-specific. Our findings have important implications for future research that should evaluate the fixation and distribution of P into different P pools with fertilizer input.

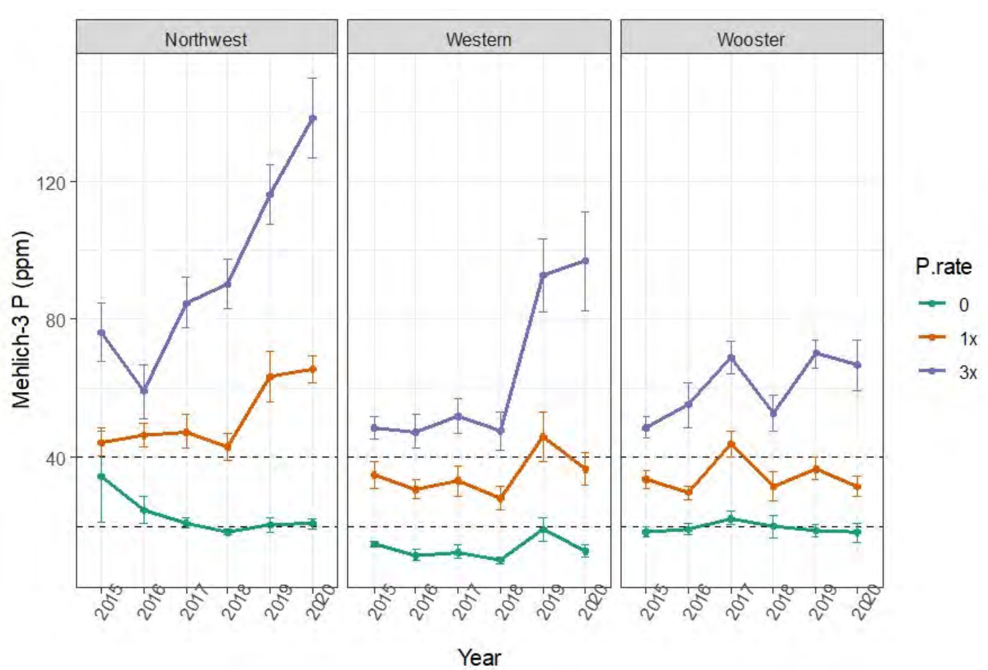

Fig. 1. Available soil P (Mehlich 3-P) under three different P management approaches (0x: no P, 1x: maintenance approach, 3x: build up) from 2015 to 2020 at three sites in Ohio.

Contrary to soil available P results, yield response was infrequent to P management. From 2015-2020 only 5 trials significantly responded to P application (4 corn and 1 soybean). The yield was higher in the buildup P management strategy than other P approaches. Significant corn yield differences were observed at the Northwest location in 2018 and 2019 and at the Wooster location in 2015 and 2016. Soybean yield differed among treatments in 2020 at the Western location (Table 1.). The difference in yield response ranged between 10-23% between the no P approach and the buildup approach at both Northwest and Wooster site.

Table 1. Average grain yield for corn and soybean from different P management approaches: no P application (0x), maintenance approach (1x) and build up approach (3x) from 2015 to 2020.

Sites	P.Rate	2015	2016	2017	2018	2019	2020
		Corn grain yield (bu/ac)					
Northwest	0X	117.23 (10.11)	145.71 (4.49)	149.77 (6.3)	186.26 (2.43)[b]	150.95 (3.84)[b]	104.32 (4.76)
	1X	106.65 (4.5)	154.61 (6.16)	151.42 (7.45)	199.64 (4.09)[a]	161.27 (4.18)[ab]	106.84 (8.3)
	3X	120.25 (2.3)	152.34 (5.32)	159.79 (1.39)	206.23 (5.61)[a]	180.04 (2.68)[a]	91.33 (9.75)
Western	0X	199.35 (6.83)	119.22 (32.38)	194.63 (6.58)	.	121.62 (17.19)	195.19 (45.78)
	1X	191.6 (6.69)	107.58 (24.69)	204.79 (7.54)	215.09 (13.17)	109.13 (15.92)	187.84 (6.86)
	3X	209.68 (7.33)	175.95 (13.23)	216.94 (4.54)	234.38 (1.35)	139.74 (6.37)	224.19 (7.1)
Wooster	0X	151.63 (6.54)[b]	95.08 (1.82)[b]	169.01 (16.05)	138.9 (8.86)	99.77 (2.85)	169.66 (1.9)
	1X	166.98 (10.53)[ab]	103.88 (3.5)[ab]	149.9 (30.69)	182.79 (12.41)	104.1 (2.81)	200.63 (9.77)
	3X	174.48 (5.64)[a]	117.6 (9.3)[b]	173.51 (11.32)	169.48 (4.75)	102.09 (3.01)	174.94 (9.39)
		Soybean grain yield (bu/ac)					
Northwest	0X	43.31 (2.31)	65.06 (1.51)	42.8 (2.76)	75.32 (1.31)	47.15 (2.21)	50.78 (1.51)
	1X	46.94 (2.62)	65.19 (3.12)	41.07 (1.09)	72.15 (1.36)	48.32 (2.72)	53.02 (1.13)
	3X	47.65 (2.16)	67.82 (0.99)	43.39 (4.64)	76.86 (0.52)	49.24 (2.35)	50.85 (1.5)
Western	0X	48.7 (3.26)	56.32 (5.18)	69.56 (3.17)	66.82 (4.64)	40.77 (0.28)	18.55 (1.74)[b]
	1X	47.33 (4.02)	48.58 (3)	80.48 (5.59)	61.29 (1.73)	44.13 (7.14)	23.35 (1.47)[ab]
	3X	53.1 (4.62)	58.29 (1.48)	85.03 (4.05)	65.78 (4.05)	53.17 (5.67)	28.39 (3.23)[a]
Wooster	0X	44.33 (1.59)	37.6 (2.21)	49.54 (1.29)	47.72 (1.07)	28.39 (2.99)	47.32 (3.2)
	1X	46.95 (0.63)	38.93 (1.53)	58.48 (6.87)	43.73 (1.35)	25.17 (1.27)	49.79 (2.98)
	3X	47.48 (2.18)	39.89 (0.59)	60.35 (3.93)	46.89 (2)	26.44 (2.52)	48.35 (3.6)

Crop P tissue data for both corn and soybean showed a positive, but weak relationship with soil P (R^2 of 0.077 for corn and $R^2 = 0.023$ for beans), whereas P concentration in the grain showed stronger relation to soil P ($R^2 = 0.26$ for corn and $R^2 = 0.43$ for beans). To further evaluate the most relevant factor that explains the crop yield, we tested the significance of organic matter, leaf tissue P and grain P concentration, soil P levels, P fertilizer rate, soil pH, and cation exchange capacity (CEC). Corn yield prediction was best explained by soil pH, CEC, organic matter, P fertilizer rate, soil P and leaf P concentration at R1. Soybean yield prediction was best explained by soil pH, organic matter, and leaf P concentration at R1.

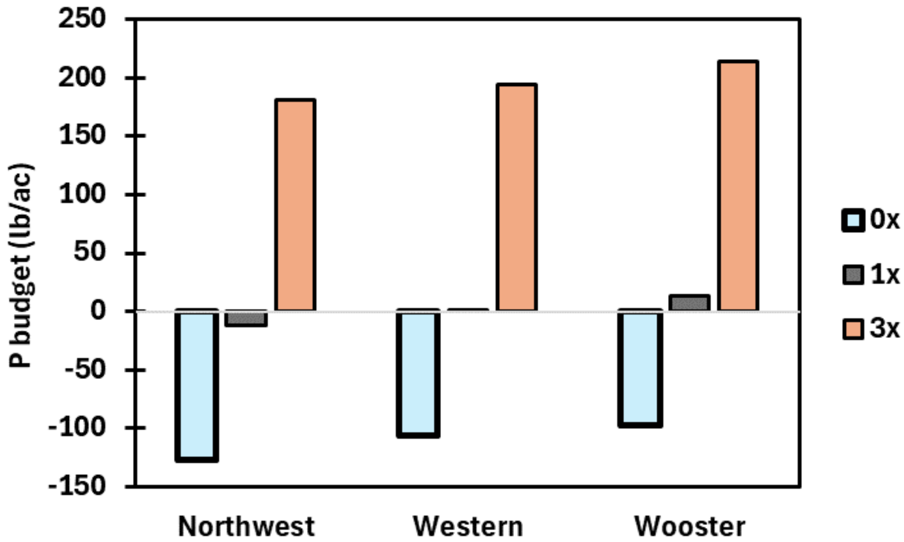

Fig. 2. Net P gain or loss from cropping system over six years due to different P management approaches at three locations in Ohio.

The P budget was affected by different P management approaches (Fig. 2). The 0x treatment showed negative P budgets at all three locations with a range of 97 to 127 lb P removed per ac over six years. It is interesting to note that even though crops removed P (106 lb/ac at Wooster and 97 lb/ac at Western) out of the system, the soil P levels of 0x treatment remained relatively similar at Western and Wooster over six-year period (Fig. 1). The P budget was slightly negative at Wooster, near zero at Western, and slightly positive at Wooster for maintenance approach. As expected, the buildup approach added 181 to 214 lb of P/ac to P net budget across sites.

Overall, our results indicate that different P management approaches can significantly affect the soil P levels and net P budget of a cropping system. To predict yield response, our study indicated that parameters such as soil pH and organic matter should be considered along with P fertilizer rate and soil P levels. The P budget findings revealed an interesting pattern of negative P budget under no P addition scenarios, yet no corresponding decline in available soil P levels were observed. Future studies should evaluate the contribution of other P pools and available soil P beyond routine soil sampling zone to explain the crop P uptake and yields.

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TILLAGE, CEREAL RYE COVER CROP, AND N PLACEMENT EFFECTS ON CORN AND SOYBEAN

F. Rolle[1], D. Schaefer[2], E. D. Nafziger[1], G. Preza Fontes[1]

[1]Department of Crop Sciences, University of Illinois, [2]Illinois Fertilizer & Chemical Association

ABSTRACT

Although conservation tillage and cover crops can improve soil health, producers are hesitant to adopt these practices due to concerns about potential yield reductions. We conducted field experiments for four years (2020-2023) near Urbana, Illinois, to explore how these practices affected corn and soybean yields. The experiment was conducted on a Flanagan silt loam soil, with corn and soybean following one another on two sides of the same field. Treatments were arranged in a RCBD with four replications. There were four tillage treatments: conventional tillage (CT, fall chisel plow + spring field cultivator), spring field cultivator (SpFC, one-pass before planting), no-till (NT), and fall strip-till (ST). Except for CT, each tillage strip was split with and without cereal rye (CR) cover crop. In corn only, tillage × CR plots were split, and nitrogen as UAN solution was applied after planting at 200 kg N ha^{-1} either all injected between rows, or with half surface-dribbled near the rows and half injected between rows. Tillage and CR treatments remained on the same plots throughout the experiment. Over 4-years, corn without CR was significantly higher with SpFC than NT (10.9 vs. 10.4 Mg ha^{-1}), but equivalent to ST (10.8 Mg ha^{-1}) and CT (10.7 Mg ha^{-1}). The inclusion of CR significantly lowered yields from 0.5 Mg ha^{-1} (NT) to 1.2 Mg ha^{-1} (SpFC). Neither N placement nor tillage × CR × N placement effect was significant, but across 4 years the tillage × Npl interaction was significant and splitting N application significantly increased yield under ST (+ 0.3 Mg ha^{-1}), but not in NT and SpFC. Over the 3-years (no soybean trial in 2020), there was no tillage or tillage × CR interaction effect on soybean yield. However, using CR before soybean significantly decreased yield by 0.2 Mg ha^{-1} across tillage treatments. We conclude that, for both crops, yields can be maintained with reduced tillage, and even at modest levels of biomass, CR cover crop lowered yield of both corn and soybean in this study. While such effects may be amplified by removal of water by cover crops when soils are dry after planting, continued testing in production fields may be helpful in weighing possible yield effects against benefits of cover crops.

A NOVEL CALCIMETER FOR SOIL CARBONATE ASSESSMENT WITH IMPLICATIONS FOR ACCURATE SOIL TEST METHODS

E. Bryan Rutter[1] and D. Ruiz Diaz[1]
[1]Department of Agronomy, Kansas State University

ABSTRACT

Calcium carbonate equivalent content is an important soil characteristic, with rammifications for decisions made in agricultural production and soil testing labs alike. However, soil carbonate measurements are rarely included with soil fertility analyses in Kansas due to their tedius nature and the cost of analysis. The objectives of this study were to develop a reliable calcimeter using open-source electronics and readily available labware, and to evaluate it's performance against procedures currently in use at the KSRE Soil Testing Lab. Measurements collected by the novel calcimeter were strongly correlated to the mass of reagent-grade calcium carbonate (R^2=0.9998). Likewise, regression analysis indicates strong relationships between calcium carbonate equivalent content determined using the novel calcimeter and median values reported by the NAPT program (slope = 0.998; R^2 = 0.984). Sample throughput was improved by approximately 10-fold using the new calcimeter when compared to the manometer apparatus currently employed by the KSRE Soil Testing Lab. Other quality-of-life factors were also improved, such as elimination of eye-strain from reading burettes and transcription errors, were an added benefit but are difficult to quantify.

SHORT TERM EFFECT OF DOUBLE CROPPING AND COVER CROPPING ON SOIL PHYSICAL PROPERTIES

F. Sheikhi Shahrivar[1], O, Ola[1], O, Guzel[1], K. L. Gage[1], K, W. J. Williard[2], J. E. Schoonover[2], S. Mueller[3], A. Sadeghpour[1,4]
[1]School of Agricultural Sciences, Crop, Soil, and Environmental Program, Southern Illinois University
[2]School of Agricultural Sciences, Forestry and Horticulture Program, Southern Illinois University
[3]Energy Resources Center, University of Illinois Chicago
[4]Adaptive Cropping System Laboratory, USDA-ARS Beltsville Area Research Center-West

ABSTRACT

Integrating cover crops into corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation has been promoted as a sustainable practice to reduce soil erosion, enhance soil health, and improve agricultural sustainability. However, growers are less inclined to include cover crops into their cash crop rotations especially winter cereals such as winter rye (*Secale cereale* L.) behind corn. One strategy to minimize the fallow period in corn-soybean rotation is by intensifying the corn-soybean rotation using winter wheat (*Triticum aestivum* L.) as a double crop. This study investigates the short-term impact of double cropping and cover cropping on key soil physical properties including bulk density, aggregate size distribution and stability, soil compaction, saturated hydraulic conductivity, and soil porosity at two different soil depths (0-5 and 5-20 cm). A three-year field trial was conducted at the Agronomy Research Farm in Carbondale, Illinois, with four treatments: (1) corn-soybean rotation with no cover crop (CNSN), (2) corn-rye-soybean-rye rotation (CRSR), (3) corn-wheat-soybean cash crop rotation without cover crops (CWSN), and (4) corn-wheat-soybean cash crop rotation with a rye cover crop (CWSR). Results indicated that the influence of cover crops and double cropping systems on soil physical properties was more pronounced at the 0-5 cm depth compared to the 5-20 cm depth. No significant treatment effects were observed at the 5-20 cm depth, suggesting that the impact of these practices is limited to the surface soil layer in the short term. The findings suggest that the observable benefits of these practices on soil physical properties may require a longer duration of implementation to manifest. This study provides insights into the early-stage effects of cover cropping and double cropping systems, contributing to the understanding of soil health dynamics in sustainable agricultural systems.

INTRODUCTION

Cover cropping and double cropping systems are increasingly recognized for their potential to improve soil health by mitigating the negative impacts of intensive agriculture. Cover crops, like Winter rye, improve soil physical properties by reducing erosion, enhancing porosity, and increasing soil carbon (Kaspar & Singer, 2011; Blanco-Canqui & Ruis, 2020). While the benefits of cover crops, over time, are well-known, the short-term effects of double cropping on soil, especially in rotations with corn and soybean, remain less explored (Sadeghpour et al., 2021; Wang et al., 2022). This study aims to evaluate the impacts of cover and double cropping systems on key soil physical properties, including aggregate stability, bulk density, compaction, and organic matter.

MATERIAL AND METHODS

Field trials were conducted at Southern Illinois University's Agronomy Research Farm in a randomized complete block design with four replications. Treatments included: (1) corn-soybean rotation without cover crops (CNSN), (2) corn-rye-soybean-rye rotation (CRSR), (3) corn-wheat-soybean cash crop rotation without cover crops, and (4) corn-wheat-soybean cash crop rotation with a rye cover crop. Wheat received 150 lbs DAP in fall and 70 lbs/acre UAN at each tillering and jointing, following discussions with growers in the region. Soil samples per plot were collected at 0-5 cm depth. Dried samples were analyzed for aggregate size distribution per Weidhuner et al. (2021). Compaction was also measured by a digital penetrometer in pounds per square inch (psi) (Herrick and Jones, 2002). Compaction depths were 0-10, 10-20, 20-30, and 30-40 cm depths. ANOVA (PROC MIXED) assessed treatment, depth, and their interactions as main effects, and block as random effect. For the compaction readings, PROC MIXED in SAS was used with treatment, depth, and their interactions as main effects. Sampling depth was considered as a repeated measure with AR1 as covariate structure.

RESULT AND DISCUSSION

Aggregate size distribution

Figure 1 shows the soil aggregate distribution at the 0-5 cm depth under four cropping treatments: CNSN, CRSR, CWSN, and CWSR. Treatments significantly impacted the 1-2 mm and 0.5-1 mm aggregates, with CRSR, CWSN, and CWSR showing increases in these sizes compared to CNSN by over 25% and 33%, respectively.

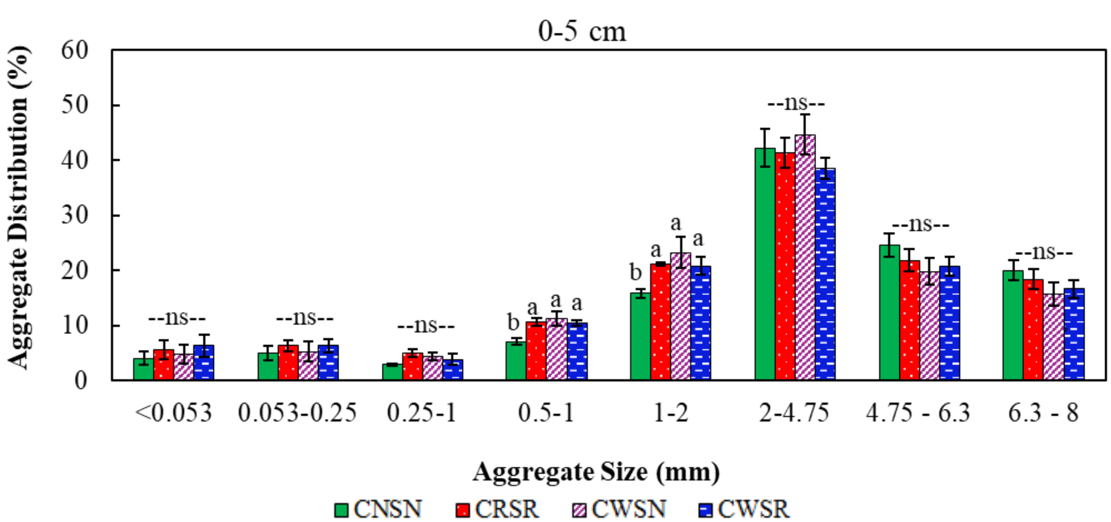

Fig 1. Effect of cropping system on dry aggregate size distribution (%) at a) 0-5 cm. Treatments include CNSN (Corn-Soybean Rotation with No Cover Crop), CRSR (Corn-Rye-Soybean-Rye Rotation), CWSN (Corn-Wheat-Soybean Rotation with No Cover Crop), and CWSR (Corn-Wheat-Soybean Rotation with Rye Cover Crop). Same letters within each aggregate size class indicate no significant differences (P < 0.05), while 'ns' denotes non-significant differences among treatments.

Compaction

Figure 2 indicates the effect of the cropping system on soil compaction (PSI) across different depths. The analysis indicates that soil compaction was only influenced by depth and there were no significant differences in compaction between treatments (denoted as 'ns'). The same letters within each aggregate size class suggest no significant differences (P < 0.05).

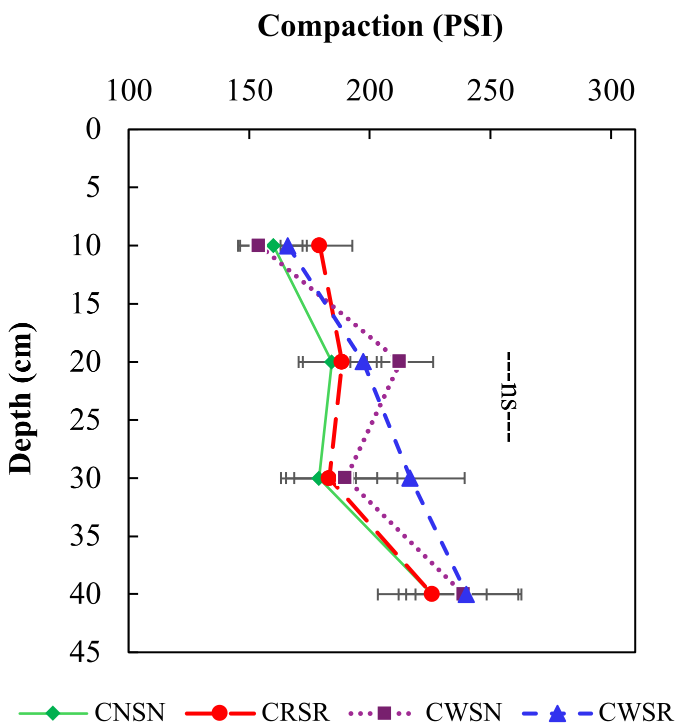

Fig 2. Effect of cropping system on soil compaction (PSI) at different sampling depths. Treatments include CNSN (Corn-Soybean Rotation with No Cover Crop), CRSR (Corn-Rye-Soybean-Rye Rotation), CWSN (Corn-Wheat-Soybean Rotation with No Cover Crop), and CWSR (Corn-Wheat-Soybean Rotation with Rye Cover Crop). Same letters within each aggregate size class indicate no significant differences (P < 0.05), while 'ns' denotes non-significant differences among treatments.

CONCLUSION

Cover cropping (rye-cash crop) and double cropping (wheat-soybean), enhanced medium-sized aggregate formation in surface soil, improving short-term soil structure with no effect on soil compaction. This suggests that soil aggregation can be improved over time by cover crop and double cropping but long-term research is needed to see greater benefits.

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IMPACT OF DIFFERENT INORGANIC PHOSPHORUS (P) FERTILIZER RATES ON SOIL P POOLS

J. Singh, J. Ippolito, G. Labarge, and M. Rakkar
The Ohio State University

ABSTRACT

Phosphorus runoff from agricultural fields is one of the contributors to the contamination and degradation of various aquatic ecosystems. Data from Ohio fertilizer trials show applying phosphorus (P) leads to an accumulation of P in the available pool, but the crop yield response remains unaffected. A better understanding of other P pools would be beneficial for comprehending the yield responses. This study aims to determine the impact of different inorganic P fertilizer rates on soil P pools. This study includes three different sites in Ohio: northwest, western, and north-central Ohio. Each location has three fertilizer treatments: control (0x), maintenance approach (1x), and buildup approach (2-3x) within corn-soybean crop rotation. These sites have received fertilizer applications since 2006 and have been in the drawdown phase (no fertilizer application) since 2021. The soil samples were collected from 0-8 inches in the summer of 2024 from the soybean phase. Samples were analyzed for the P saturation index and different P pools. The preliminary data shows that P saturation levels were highest in buildup rate (9.12%) followed by maintenance approach (7.09%) and control (5.67%) treatments across sites. The relationships between P saturation and water-extractable P (P-solubility) will be examined to illustrate how soil P solubility changes as soil P saturation increases. The results of this study will highlight the impact of fertilizer rates on soil P pools and their effect on crop production and water quality.

EVALUATING THE EFFECTS OF NITROGEN SOURCE, PLACEMENT, AND TIING ON CORN YIELD AND NITROGEN LOSSES IN THE SANDY SOILS OF NORTHEAST NEBRASKA

A. Singh, C. Misar and J. Iqbal
University of Nebraska-Lincoln

ABSTRACT

The impact of nitrogen sources, placement, enhanced efficiency fertilizers (EEFs), and application timing on improving groundwater quality in groundwater management areas remains unclear. This study assessed the effects of various N fertilizer sources, EEFs, application timing, and placement on corn yield and nitrogen losses via nitrate (NO_3^-) leaching and ammonia (NH_3) volatilization. The experiment was conducted in 2023, a notably dry year, at a farmer's site in Concord, Nebraska. The experimental design included 11 treatments with four nitrogen fertilizer sources: anhydrous ammonia (AA), urea ammonium nitrate (UAN), ESN (environmentally smart N), and urea. Each source was applied using both preplant and split application. Anhydrous ammonia was injected into the soil, while urea and ESN were broadcast. UAN was applied both by broadcast and injection.

The results showed that nitrogen fertilizer sources significantly affected corn grain yield, while placement and application timing did not influence yield. In contrast, nitrogen sources, timing and placement significantly affected both NO_3^- leaching and NH_3 volatilization. Split application increased NH_3 volatilization compared to pre-plant application but it reduced NO_3^- leaching losses ($p<0.001$). Furthermore, injected UAN reduced NH_3 volatilization and NO_3^- leaching by 75% and 18%, respectively, compared to broadcast urea. ESN applied pre-plant significantly reduced NO_3^- -N leaching compared to pre-plant anhydrous ammonia, UAN broadcast, and urea broadcast, with leaching levels like those from the split application of other nitrogen sources. Additionally, ESN pre-plant substantially reduced NH_3 volatilization compared to all other nitrogen sources, regardless of application timing, except injected UAN. Overall, the findings suggest that nitrogen sources, EEFs, placement, and timing of application significantly influence both crop yield and nitrogen losses, even in dry years.

INTRODUCTION

Over time, fertilizer consumption in Nebraska has grown significantly, rising from 47,000 tons of nitrogen (N) in 1955 to a peak of over 960,000 tons in 2019. Much of this nitrogen comes from Urea Ammonium Nitrate (UAN) solutions (57%), followed by anhydrous ammonia (23%) and urea (14%). However, despite increased fertilizer use, Nitrogen Use Efficiency (NUE) has stagnated since 2000, with farmers applying 0.8 to 0.9 pounds of nitrogen per bushel of grain (Ferguson et al., 2024). This plateau suggests that traditional fertilization practices have reached their efficiency limits, highlighting the need for innovative strategies to sustain productivity while reducing nitrogen losses.

A promising approach to address these challenges is the 4Rs nutrient stewardship, which emphasizes the right source, right rate, right time, and right place for nutrient application. This framework seeks to enhance NUE while minimizing environmental impacts such as nitrate leaching and ammonia volatilization. However, despite its potential benefits, few studies have explored the simultaneous impact of all 4R practices on both grain yield and nitrogen losses, particularly in the Midwest. Currently, N-recommendation tool from the University of Nebraska-Lincoln (UNL) focus primarily on right rate of fertilizer, with limited guidance on right fertilizer sources and placement. Given the dominance of UAN, anhydrous ammonia, and urea in Nebraska's fertilizer practices, the integration of Enhanced Efficiency Fertilizers (EEFs)—such as Environmentally Smart Nitrogen (ESN)—offers a promising scientific alternative.

The source, placement, and timing of nitrogen fertilizer significantly influence both crop yield and nitrogen losses. It is hypothesized that selecting the appropriate fertilizer source, combined with strategic placement and application timing, will (1) improve grain yield, and (2) reduce environmental nitrogen losses by minimizing nitrate leaching and ammonia volatilization. So, the objectives of the study were to: 1) Quantify the effect of nitrogen fertilizer source, placement, and timing on crop yield, and 2) measure the reduction in nitrate leaching and ammonia volatilization under different nitrogen management practices. This study aims to fill critical knowledge gaps by evaluating the environmental and agronomic impacts of 4Rs practices, providing actionable insights for sustainable nitrogen management in corn production systems.

MATERIAL AND METHODS

In 2023, a field experiment was established near the Haskell Agricultural Laboratory (HAL) on a farm site in Concord, NE (42° 23.613' N, 96° 56.673' W). The study employed a randomized complete block design (RCBD) with 11 treatments, each replicated four times, during the corn phase of a corn-soybean rotation. Treatments included four fertilizer sources: anhydrous ammonia (82% N), urea ammonium nitrate (UAN, 32% N), environmentally smart nitrogen (ESN, 44% N), and urea (46% N), applied either pre-plant or as a split application. Anhydrous ammonia was injected, ESN and urea were broadcast, while UAN was applied using both broadcast and injection methods (see Table 1 for details).

To assess total dry matter production, six corn plants were harvested at the R6 stage, with ears shelled and stover processed to measure moisture and calculate dry weight. Nitrogen content in the stover and grain was analyzed and multiplied by yield to determine total nitrogen uptake. Grain yield was calculated by harvesting from a specified area, shelling the ears, adjusting for moisture, and combining it with stover yield for total biomass. Ammonia volatilization losses were measured using acid traps placed on the soil surface in spring 2023, covered with plastic buckets to prevent air mixing, with samples collected and analyzed periodically over 30 days. Nitrate leaching losses were quantified using two suction cup lysimeters installed at a 1.2 m depth in each plot, following protocols by Singh et al. (2024) and Maharjan et al. (2014).

Table 1. Fertilizer-N treatments at farmer's site located at Concord, NE in 2023

Treatments			&Stage of fertilizer application	N rate (% of #RRF)	4Rs Treatments
§ N-source	Placement	Time			
AA	Injected	Preplant	PP	100% at PP	S/T
	Injected	Split±	PP + SD at V6	40% at PP + 60% at SD	S/T
UAN	Broadcast	Preplant	PP	100% at PP	S/T/P
	Broadcast	Split±	PP + SD at V6	40% at PP + 60% at SD	S/T/P
	Injected	Preplant	PP	100% at PP	S/T/P
	Injected	Split┴	PP + SD at V6	40% at PP + 60% at SD	S/T/P
ESN	Broadcast	Preplant	PP	100% at PP	S/T
	Broadcast	Split┴	PP + SD at V6	40% at PP + 60% at SD	S/T
Urea	Broadcast	Preplant	PP	100% at PP	S/T
	Broadcast	Split┴	PP + SD at V6	40% at PP + 60% at SD	S/T
Control	-	-	-	-	-

§ AA = Anhydrous Ammonia, UAN-B = Urea Ammonia Nitrate, &PP = pre-plant; SD = side dress; # RRF= recommended rate of fertilizer (140 lbs N/ha^{-1}) was calculated using UNL-N Algorithm.

RESULTS AND DISCUSSION

Crop Yield

This study examined the impact of various nitrogen fertilizer sources, application timing, and placement on corn grain yield. Corn yield response to N-fertilizer treatments was significantly higher than the control (Figure 1). Among fertilizer treatments, there were no statistically significant differences in yield except for the split-applied UAN broadcast treatment. Timing of application (pre-plant vs. split) did not significantly affect yield, as pre-plant applications across all fertilizer types produced similar yields to split treatments. When averaged across both pre-plant and split applications, anhydrous ammonia resulted in a significantly lower yield compared to other fertilizer sources (p = 0.057).

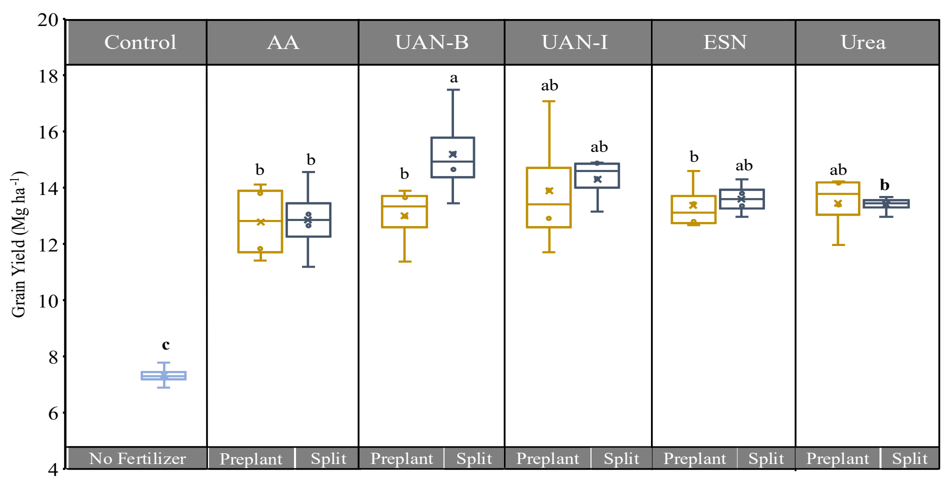

Figure 1. Effect of different nitrogen fertilizer sources and their application timing on corn grain yield at Farmer's site, Concord, NE. Treatments followed by the same letter are not significantly different at p = 0.05

Ammonia Volatilization

The temporal variation in NH_3 emissions following pre-plant and split applications of N-fertilizer is illustrated in Figure 2a and Figure 2b, respectively. N-fertilizer treatments significantly affected cumulative NH_3 losses ($p < 0.001$), with the highest losses observed in split-applied urea, comparable to split-applied UAN broadcast. UAN, whether applied as a pre-plant or split treatment, resulted in significantly lower NH_3 losses, comparable to the no-fertilizer control, with reductions of 84.7% and 83.8%, respectively, compared to split-applied urea. Overall, contrast analysis indicated that pre-plant treatments generally led to lower NH_3 losses than split treatments. ESN application reduced NH_3 losses by 30.1% compared to urea, regardless of application timing ($p = 0.028$). Additionally, UAN placement had a significant impact, with injected UAN reducing NH_3 loss by 76.1% compared to broadcast applications ($p < 0.0001$).

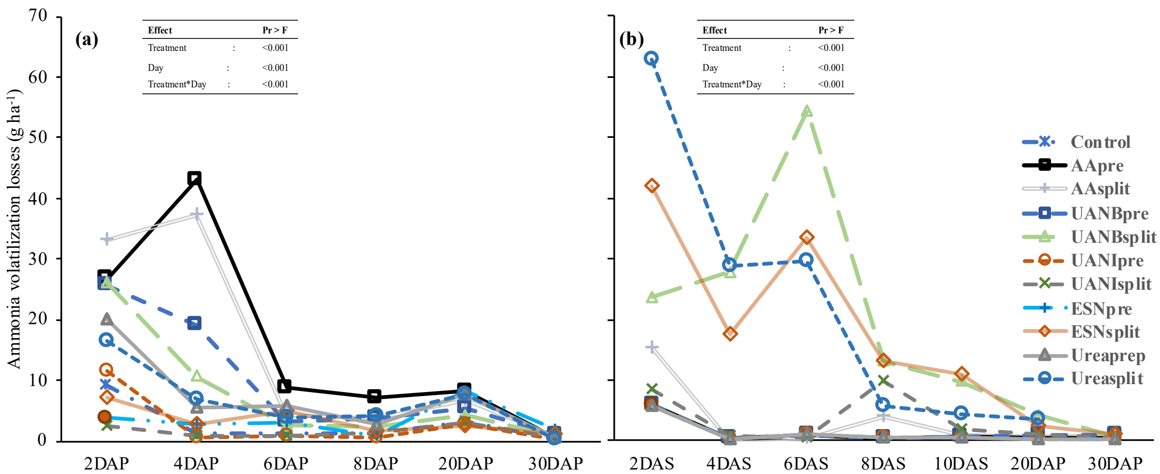

Figure 2. Ammonia volatilization losses (a) after preplant application of N-fertilizer (b) after split application of N-fertilizer at the farmer's site, Concord, NE. Note: DAP=Days after Preplant application, DAS=Days after Split application.

Nitrate Leaching

Figure 3 shows pore water NO_3^--N concentrations from samples collected throughout the season at a 4-foot depth using a lysimeter, with 19 samples taken after precipitation or irrigation events. Sampling date significantly influenced NO_3^--N concentrations ($p < 0.001$), which ranged from <1 to 82.9 mg kg^{-1} over the corn growing season. Following the pre-plant nitrogen application, NO_3^--N levels were between 12.7 and 66.4 mg kg^{-1}, then increased to 24.3–82.9 mg kg^{-1} after a split application in mid-June. Most treatments showed a gradual decline in NO_3^--N levels as the season progressed, except for the anhydrous ammonia (AA) pre-plant treatment, where delayed nitrification kept NH_4^+ stable longer, sustaining higher NO_3^--N levels later. The urea pre-plant treatment showed higher pore water NO_3^--N concentrations from early on through mid-July, resulting in the highest average NO_3^--N levels throughout the season, comparable to those in the anhydrous ammonia pre-plant treatment.

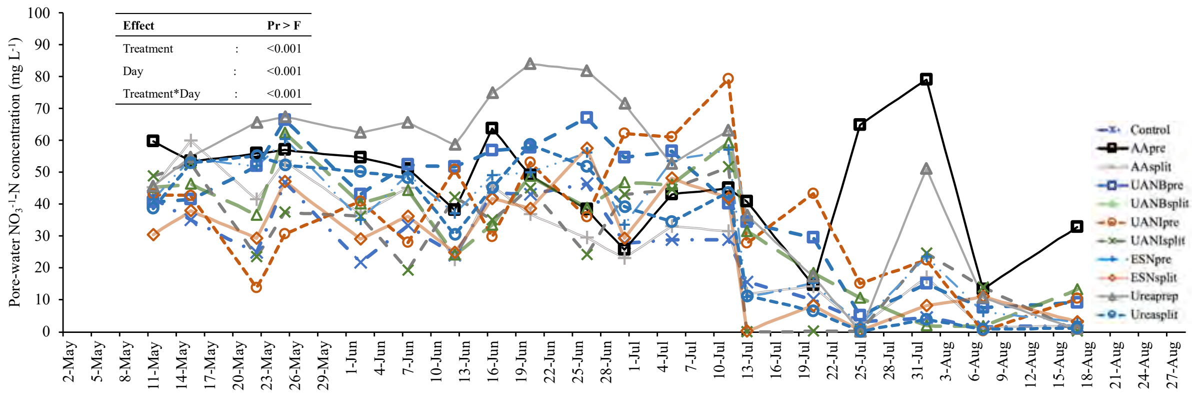

Figure 3. The pore-water NO_3^--N concentration (mg L^{-1}) of water samples collected from 4 feet depth throughout the corn growing season at the farmer's site, Concord, NE.

The contrast estimate for fertilizer-N treatments (Figure 4) shows that split applications significantly reduced porewater NO_3^--N concentrations compared to pre-plant applications ($p < 0.0001$). UAN injection also resulted in lower NO_3^--N levels than UAN broadcast applications, regardless of application timing ($p < 0.018$). Among the sources, split-applied ESN was the most effective in minimizing porewater NO_3^--N, followed by split-applied UAN injection, with ESN maintaining NO_3^--N concentrations comparable to the control (no fertilizer) due to its controlled-release properties. ESN's gradual nitrogen release aligns with crop demand, reducing nitrogen losses and limiting nitrate accumulation in the soil. Enhanced efficiency fertilizers like ESN are valuable for mitigating nitrate leaching into groundwater while providing adequate nitrogen for crop growth.

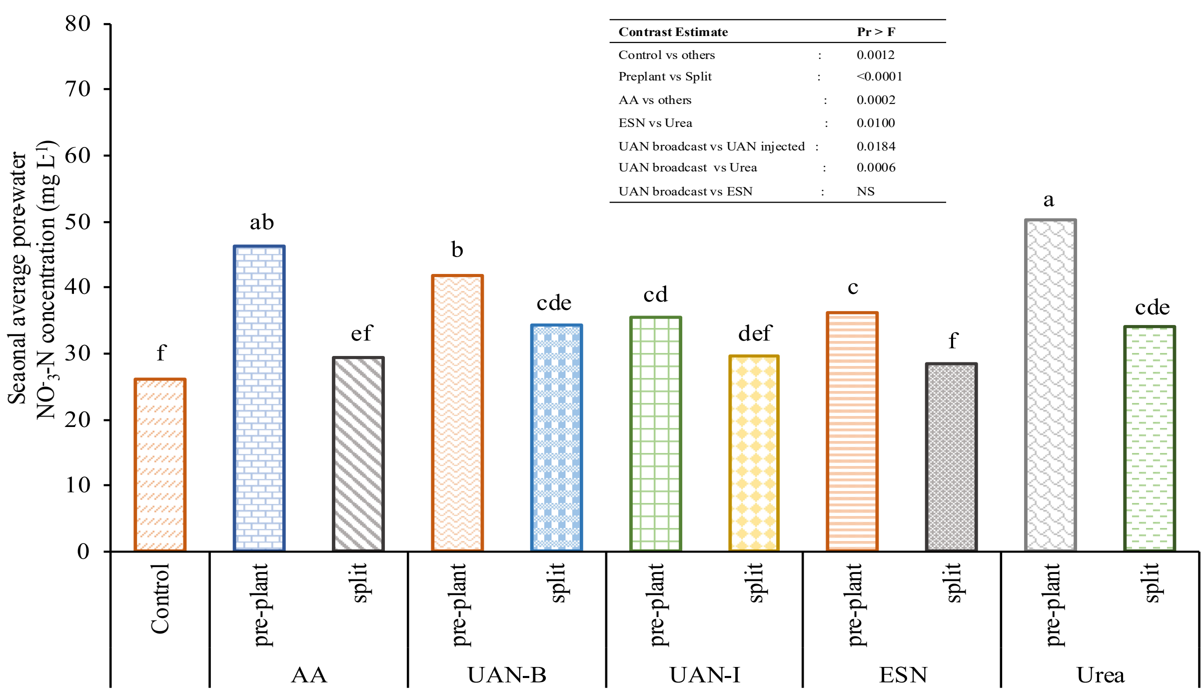

Figure 4. Seasonal average pore-water NO_3^--N concentration (mg L^{-1}) at the farmer's site, Concord, NE. Treatments followed by the same letter are not significantly different at $p = 0.05$

CONCLUSIONS

Ammonia losses were generally higher with split-applied treatments, with the lowest levels observed in UAN-I. Split applications proved effective in reducing NO_3^--N leaching, with split-applied ESN and UAN-I treatments showing the least leaching losses. In terms of nitrogen efficiency and corn yield, split-applied UAN injection performed best, resulting in minimal nitrogen losses and high yields, second only to split-applied UAN-B. While different nitrogen sources did not significantly influence corn grain yield, they did notably affect nitrogen losses, even in dry conditions. Collecting additional data from various locations and under different weather conditions would help refine statewide recommendations.

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INVESTIGATING THE EFFECTS OF TILLAGE PRACTICES AND FERTILIZER PLACEMENT STRATEGIES ON CORN YIELD AND NUTRIENT UPTAKE IN EASTERN SOUTH DAKOTA

C. Tesch, P. Kovacs
Department of Agronomy, Horticulture and Plant Science, South Dakota State University

ABSTRACT

In South Dakota, phosphorus (P) and potassium (K) fertilizers are often used to optimize corn (*Zea may* L.) grain yields and maintain soil fertility. The placement of these fertilizers often has an impact on the nutrient accessibility to the plant and the fertilizer's impact on the environment. The management of these fertilizers is largely influenced by the tillage system utilized. In the western corn belt, producers have historically used a combination of conventional and conservation tillage systems to address their regional growing conditions. Strip-tillage has emerged as an alternative conservation tillage practice combining benefits of no-tillage and chisel plow systems, while also allowing for subsurface fertilizer banding. The objective of this study is to compare the effect of tillage practices and P and K fertilizer placement strategies on corn grain yield and nutrient uptake in eastern South Dakota. The study includes five different tillage and nutrient placement combinations, three different fertilizer rates, and treatments with and without starter fertilizer. Temperature sensors were installed to monitor soil temperature at a 2-inch depth throughout the growing season and during the off season. For nutrient accumulation analysis, V6 biomass, VT ear leaf, and R6 biomass were collected and processed. Grain yield and yield components were determined using combine harvest and individual ear harvest data.

AN EVALUATION OF SUMMER COVER CROPS FOR AGROECOSYSTEM SERVICES IN SMALL GRAIN SYSTEMS

S. Watkins, H. Poffenbarger, and D. Van Sanford
University of Kentucky

ABSTRACT

Cover cropping has been gaining popularity in recent years, specifically for its ability to improve soil properties and suppress weeds. However, cover crop species differ in the agroecosystem services they provide. Our objective was to evaluate a variety of summer cover crop treatments and their ability to provide soil physical protection, increased yield and quality of subsequent small grains, nitrogen input reduction, and weed suppression. Six summer cover treatments were evaluated for these services in summer 2022 between wheat and barley crops on a silt loam soil in Loretto, Kentucky. The treatments included four cover crops (forage soybean (*Glycine max*), daikon radish (*Raphanus sativus* var. Longipinnatus), pearl millet (*Pennisetum glaucum*), and a mixture of forage soybean, daikon radish, and pearl millet) and two controls (weedy fallow and cash crop soybean (*Glycine max*)). Ground cover was measured in August 2022 while cover crop and weed aboveground biomass were collected just before termination in September. Pearl millet provided the greatest ground cover, aboveground biomass production, and weed suppression, with the mixture following directly behind. The cash soybean treatment provided the greatest soil inorganic N, while the pearl millet provided the lowest, and these differences corresponded with differences in small grain yield. Cover crop treatment did not have an effect on protein content of subsequent small grains. Our results suggest that pearl millet is a highly productive summer cover crop in Kentucky that is effective at soil protection and weed suppression but may have detrimental effects on small grain yields after short-term adoption.

INTRODUCTION

Cover crops are a key component of sustainable agriculture and have been gaining popularity in recent years for their ability to improve soil properties and suppress weeds (Wallander et al. 2021). In Kentucky, after wheat or barley harvest in late spring, land may be planted to double crop soybeans (*Glycine max*), planted to summer cover crops, or left fallow. Summer cover crops fit well between small grains crops in Kentucky, but the performance and benefits of different species are not well understood. They have the potential to lessen soil erosion, restore soil health and fertility, and may provide a high-quality forage for livestock. Previous research shows that summer cover crops have high biomass potential and therefore can be effective at building soil organic matter and can provide reduced fertilizer requirements, when leguminous cover crops are utilized (Mclelland et al. 2020 and Mahama et al. 2020). Different functional groups (e.g., grasses, legumes, and brassicas) can provide specific benefits, but mixtures may merge these benefits from individual species. Mixtures also may be more productive than monocultures due to complementary resource uptake patterns (Snapp et al. 2004).

The objective of this study was to provide new information about how cover crops grown in the summer may benefit a small grains system. We evaluated the agroecosystem services of summer cover crop monocultures and a mixture using several indicators (Table 1).

Table 1. Measurements used as indicators of the agroecosystem services assessed

Agroecosystem Service	Indicator
Soil Physical Protection	Canopy Cover
Weed Suppression	Proportional Biomass of Weeds
N Scavenging	Soil Inorganic N
Residue Persistence and N Release Potential	Cover Crop N% and Lignin%
Performance of Small Grains	Yield and Grain Protein

MATERIALS AND METHODS

The study site, established in summer 2022, is located in Loretto, KY on a floodplain soil with a silt loam surface texture. The study was conducted as a split-split plot randomized complete block design with summer cover crop as the main plot, small grain variety as the split plot, and nitrogen rate as the split-split plot. There are 4 replicates followed by wheat and 4 replicates followed by barley. The main plot treatments included four cover crops (forage soybean (*Glycine max*), daikon radish (*Raphanus sativus* var. Longipinnatus), pearl millet (*Pennisetum glaucum*), and a mixture of forage soybean, daikon radish, and pearl millet) and two controls (weedy fallow and cash crop soybean (*Glycine max*)). Soybean treatments were planted at seeding rates of 50lb/acre, daikon radish at 12lb/acre, pearl millet at 10lb/acre, and the mix planted at 1/3 of the seeding rate of the monocultures. Cover crops were planted mid-July 2022 and terminated mid-September. All treatments were mowed with the residue left in place, aside from the cash soybean treatment, which was mowed and bagged to imitate harvest as a forage. The three wheat varieties were Pembroke 2021, Pembroke 2014, and Truman, while the three barley varieties were Avalon, Calypso, and Flavia. Small grains were planted in late October 2022 with herbicide (2-4D, sharpen, and roundup) sprayed mid-September to control for weeds. The two N fertilizer levels were 35 and 70 lb N $acre^{-1}$, which were hand-broadcast mid-March 2023.

Summer canopy cover was measured in August, 22 days after emergence. Two photos of each plot were taken, uploaded into Canopeo, analyzed, and then averaged together (Patrignani and Ochsner 2015). Cover crop biomass was sampled mid-September with two $0.25m^2$ samples collected from each plot. The samples were separated by species (weeds all together) before drying. Each sample was dried at 65°C until a constant weight was achieved. Cover crop weighted averages of % nitrogen and lignin were calculated for each treatment based on the biomass proportion and nitrogen or lignin concentration of each species. Lignin and protein concentrations were determined using Near Infrared Spectroscopy, and protein was converted to nitrogen concentration assuming a conversion factor of 6.25 x N = protein. Soil sampling occurred in early November with main plots being sampled with 8-10 cores at 0-15cm. The samples were then analyzed for inorganic nitrogen using the 1M KCl extraction method for mineral soils and a colorimetric microplate analysis method (Crutchfield and Grove 2011).

The small grains were harvested with a research plot combine mid-June. The average protein and starch content was then calculated for each treatment from Near Infrared Spectroscopy results.

Statistical analyses were made using R version 4.4.1.(R Core Team 2021). Analysis of variance was used to determine statistically significant differences ($p<0.05$ significance level) and mixed effect models were performed using lmer package (Kuznetsova et al. 2017). Figures shown below were made with the ggplot2 package (Wickhan 2016).

RESULTS AND DISCUSSION

Cover Crops

Three weeks after planting, all treatments provided 80-90% canopy cover indicating that all treatments provided similar soil physical protection (data not shown). The cover crops produced between 1889 and 7260 lbs dry matter per acre. Cover crop biomass production and weed suppression was greater in pearl millet and the mix compared with the other treatments (Figure 1). Even in the mix treatment, pearl millet was the most competitive. In a Kentucky field with high summer weed pressure, pearl millet, in a monoculture or as the primary constituent of a mix, was the only cover crop species to provide a distinct advantage over weedy fallow in terms of biomass production.

The cash soybean treatment provided the greatest inorganic N following cover crop growth, which was 14.98 mg/kg in the top 30 cm, while pearl millet provided the least (8.19 mg/kg) (Figure 2). The mix and pearl millet had relatively low lignin and N concentrations compared to the other summer covers (Figure 3). The low N concentration may indicate slower decomposition during early stages, but the low lignin concentration may favor faster decomposition in later stages. Although the mix was not superior to all the monocultures based on measured parameters, it was more productive than the cash soybean, forage soybean, and daikon radish treatments, and as productive as pearl millet, the most productive monoculture.

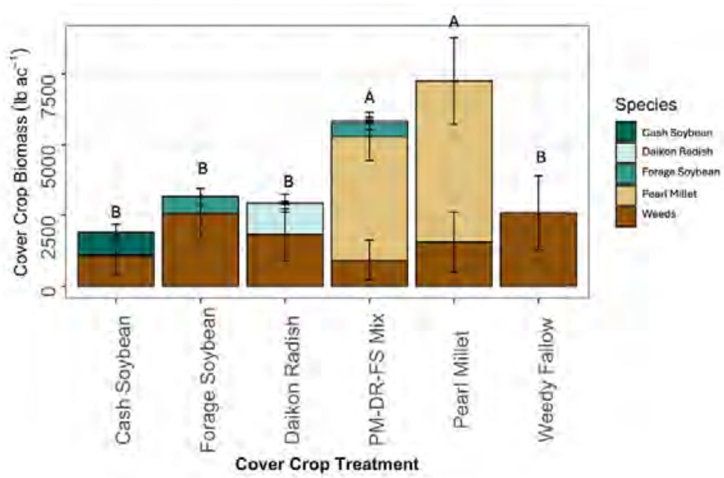

Figure 1. Aboveground biomass production and composition of cover crop treatments. Error bars are ± one standard deviation.

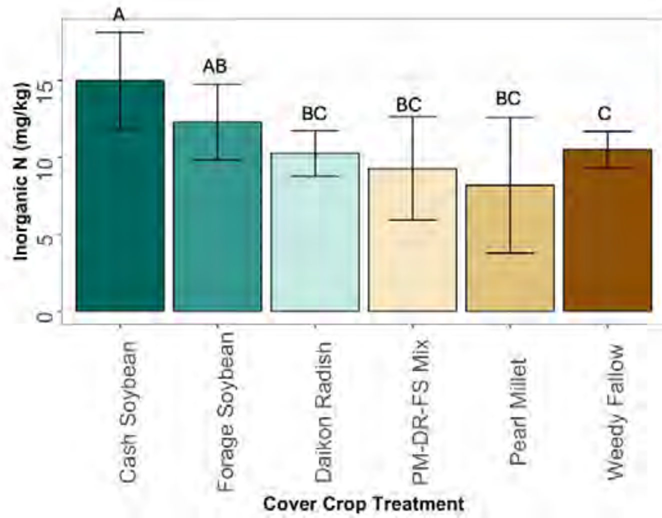

Figure 2. Inorganic N of soil (0-30cm) after cover crop termination. Error bars are ± one standard deviation.

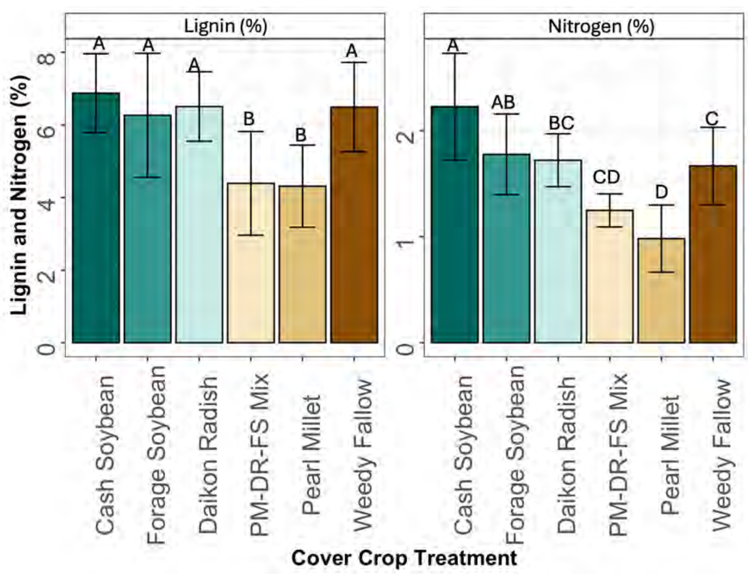

Figure 3. Lignin (left) and nitrogen (right) concentrations of cover crop treatments from NIRS results. Error bars are ± one standard deviation.

Small Grain Quality and Quantity

Wheat yield averaged 65.7 bu/acre across treatments and was higher in the cash soybean treatment than in the mixture and pearl millet treatments (Figure 4, left). Barley yield averaged 78.5 bu/acre across treatments and was higher in the cash soybean treatment than the pearl millet and weedy fallow treatments (Figure 4, right). There was a nitrogen rate effect across all cover crop species with the 70 lb/acre rate having higher yields in both wheat and barley. Protein content averaged 8.51 and 10.33% for wheat and barley, respectively, and did not differ among cover crop treatments (data not shown).

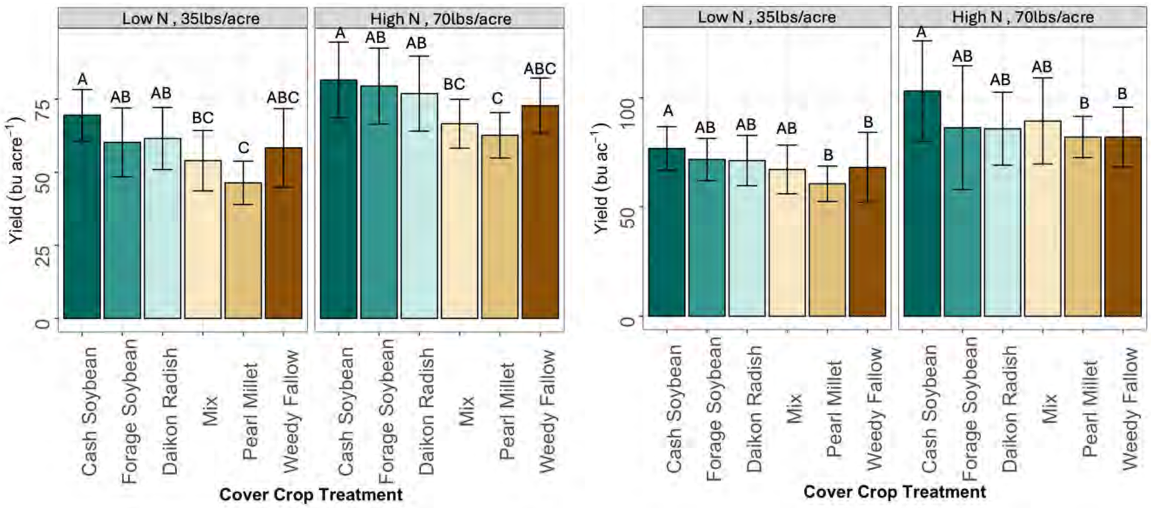

Figure 4. Wheat yield (left) in bu/acre by each cover crop treatment with a low N rate of 35 lb/acre (left) and high N rate of 70 lb/acre (right) applied to the small grains. Barley yield (right) in bu/acre by each cover crop treatment with a low N rate of 35 lb/acre (left) and high N rate of 70 lb/acre (right) applied to the small grains. All values were adjusted to a standard 13.5% moisture. Error bars are ± one standard deviation. Different uppercase letters indicate significant differences among cover crops within each cash crop and N rate level.

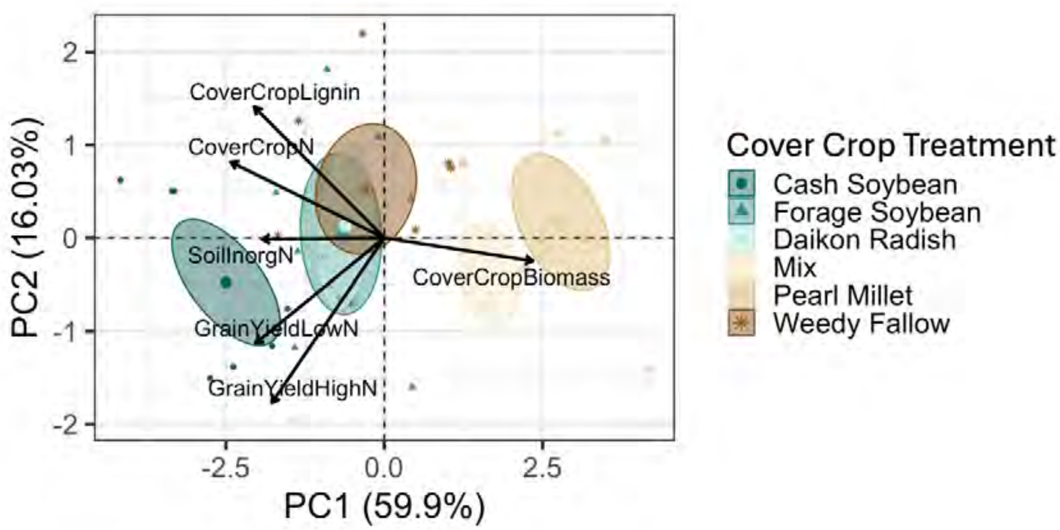

Figure 5. PCA Biplot showing measured cover crop parameters and yield of small grains.

The first two components of the PCA explained 60% and 16% of variation, respectively. PC1 primarily reflected a tradeoff between cover crop biomass production and soil inorganic N measured in the fall. The soil inorganic N concentration was also positively correlated with the N concentration and lignin concentration of cover crops as well as small grain yields. The cover crop treatments were oriented primarily along PC1, with the mix and pearl millet associated with higher cover crop biomass and the soybean treatments associated with lower cover crop biomass but higher available N and small grain yields (Figure 5). In summary, the trade-off between cover crop biomass production and nitrogen availability to small grains suggests that optimizing buildup of soil organic matter via high biomass cover crops may involve a yield depression or additional N fertilizer inputs for the cash crops.

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S.S. Snapp, R. Leep, J. Nyiraneza, and K. O’Neil, Dep. of Crop and Soil Sciences, Michigan State Univ., East Lansing, MI 48824; S.M. Swinton, R. Labarta, and J.R. Black, Dep. of Agric. Economics, Michi- gan State Univ., East Lansing, MI 48824; and D. Mutch, W.K. Kellogg Biological Stn., Michigan State Univ. Ext., Land and Water Program, Hickory Corners, MI 49060. Received 26 Mar. 2004. *Corresponding author (snapp@msu.edu).