PROCEEDINGS OF THE

2024

GREAT PLAINS SOIL FERTILITY CONFERENCE

MARCH 4-5, 2024 • LUBBOCK, TEXAS

GREAT PLAINS SOIL FERTILITY CONFERENCE

RESEARCH INDUSTRY EXTENSION

PROCEEDINGS OF THE

GREAT PLAINS SOIL FERTILITY CONFERENCE

RESEARCH INDUSTRY EXTENSION

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ADVANCEMENTS IN NITROGEN AND POTASSIUM FERTILIZER RECOMMENDATIONS IN NORTH DAKOTA OVER THE PAST 30 YEARS

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ABSTRACT

Beginning my career at NDSU as Extension Soil Specialist June 13, 1994, I inherited the obligation of periodically revisiting crop nutrient recommendations and determining whether adjustments were needed. The state of the state in 1994 was composite soil sampling, a dominantly wheat-based cropping system, and yield-goal-based fertilizer recommendations. First addressing site-specific soil sampling, I was surprised to find that zone soil sampling was an excellent predictor of residual nitrate and other nutrient patterns within fields, making sampling for site-specific nutrient application practical. Zone soil sampling led the realization that nutrient recommendations were poorly related to yield responses within fields, resulting in many N-rate trials in spring wheat/durum, corn, sunflower and most recently 2-row malting barley. The findings indicated that N recommendations should be relative yield-based within regions and cropping systems, not actual yield-based. Soybean is now the dominant ND crop, with wheat #2 and corn #3, canola #4. The change in rotation sapped soil potassium (K) reserves, spurring K rate trials in corn. The results indicated that soil test alone was only half predictive. Considering clay chemistry as well as K soil test resulted in a far better prediction of K need in corn.

My career began at NDSU June 13, 1994. I received my MS in soil fertility under the tutelage of Dr. Fred Welsh at the University of Illinois, then took a job (it wasn't a position) as agronomist for a retail fertilizer chain with headquarters about 20 miles north of Champaign. Being an agronomist at a retail location was unusual for the time. In addition to solving grower problems, keeping up with the latest ag-protection products, and providing support for the soil laboratory within the company I also mixed fertilizer and spray combinations, fixed things, filled ammonia tanks delivered product, tool many, many soil samples, and produced maps (pre-computer coloring pencils) for growers. Within a couple years I was managing the location, then the breadth of the locations. I had the opportunity to make a deal with the owner in 1989 to enter a PhD program under Dr. Ted Peck in a site-specific soil sampling project. I constantly told people that I was still employed, still going to school and still married during those 4 years. Graduating in May, 1993 I continued to work at the firm until the following May, but it was clear that the business would be sold. I interviewed at NDSU for their open Soil Extension Specialist position and was able to get the job. The business sold within 2 months following my move.

North Dakota soil fertility at the time was based on a composite soil test, including 2-foot nitrate-N testing usually in the fall. The major crop was spring wheat, with about 17 other crops following, with corn and soybean as minor crops, grown mostly in the southeast part of the state. My early years were spent continuing the work I conducted for my PhD; determining the grid size for site-specific nutrient application.

However, I found in the second year that nitrate-N patterns, in fact most soil nutrient patterns were stable in area from year to year. The magnitude of nitrate varied, but the patterns remained similar (Figure 1). From that revelation, I continued to develop the zone sampling system for use to direct N application to North Dakota crops, including wheats, corn, sugarbeet, sunflower, barley and others. Various tools were tested for zone delineation usefulness, including satellite imagery, aerial photography, EC sensors, EM sensors, topography and multi-year yield maps. A series of Extension circulars and a sizable number of peer-reviewed publications resulted from these investigations, as well as presentations at this conference.

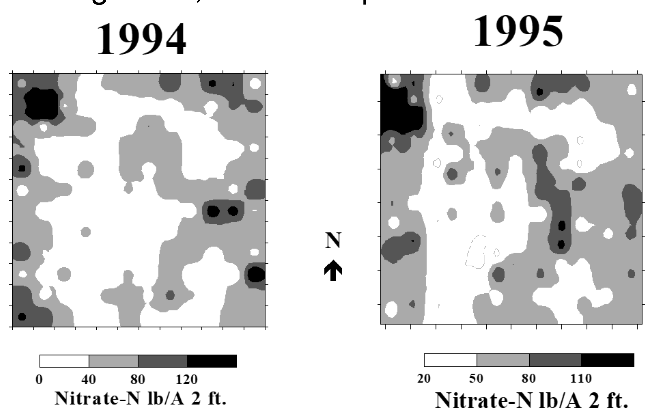

Figure 1. Similar patterns in a 40-acre field near Valley City, ND after spring wheat (left) then after sunflower (right).

In about 2003, I found that although the zone sampling was as useful as a 1 sample per acre grid in determining nutrient patters, and far less expensive, the fertilizer recommendations in place at NDSU did not contribute to advancement in grower profitability. From that date until about 2010, a total of 50+ N rate experiments on spring what and durum were conducted, and 50+ archived studies on spring wheat and durum from the late 1970's until present were combined with the goal of updating N recommendations. Several important principles were stumbled across during this process. The first was the presence of an N credit available against N rate for fields in 6 years or more no-till (including classic no-till, shallow one-pass seeding, and shank strip-till.

In my first winter in North Dakota, January, 1995, I was invited by the then Manitoba-North Dakota Zero-Tillage Conference to speak. I remember it because it was the coldest day I ever spent in my life (45^{o} below zero F), but also because they asked me up to the committee room at the hotel to visit afterwards. After the pleasantries, they stated that they did not follow NDSU N recommendations anymore. They explained that once they were in no-till for a period of years (some had been in no-till for over 20 years by then) that they could shave their N rates without penalty. They had kept on shaving them back enough that their profitable N rates did not resemble NDSU recommendations anymore, so they ignored them. I thanked them, didn't argue (I was from Illinois corn and soybean country, what do I know?) but I remembered.

When it was time to put pen to recommendation in 2010 I remembered the conversation and divided out the long-term no-till sites from conventional sites and they were correct. It took 50 pounds N per acre less N to produce at least the same yield and at least the same wheat protein as it did in conventional till. So it became part of the NDSU recommendations, later part of the N-calculator for spring wheat/durum. When it came time to evaluate N rate in corn, then sunflower, then 2-row malting barley, I deliberately included many sites of long-term no-till with those of conventional tillage and the principle held. The long-term no-till N credit is a part of all of those recommendations.

The second principle was the lack of relationship between yield and N rate. Bill Raun at Oklahoma State University was one of the first to recognize this principle as part of his work with active-optical sensors. It also became apparent to me in my studies that relative yield was far more important than actual yield. Environment is the yield driver. There just needs to be enough N present either in the soil or in supplements to cover basic needs. If environment favors greater yield, it also favors N release from soil and the greater efficiency of uptake by the crop due to favorable moisture conditions.

Support for this principle can be found in Figures 2a of actual spring wheat/durum yield with N rate and Figure 2b of relative spring wheat/durum yield with N rate. Use of relative yield instead of actual yield always resulted in greater regression coefficients, sometimes greater than 3-fold the value of actual yield vs N rate (Table 1).

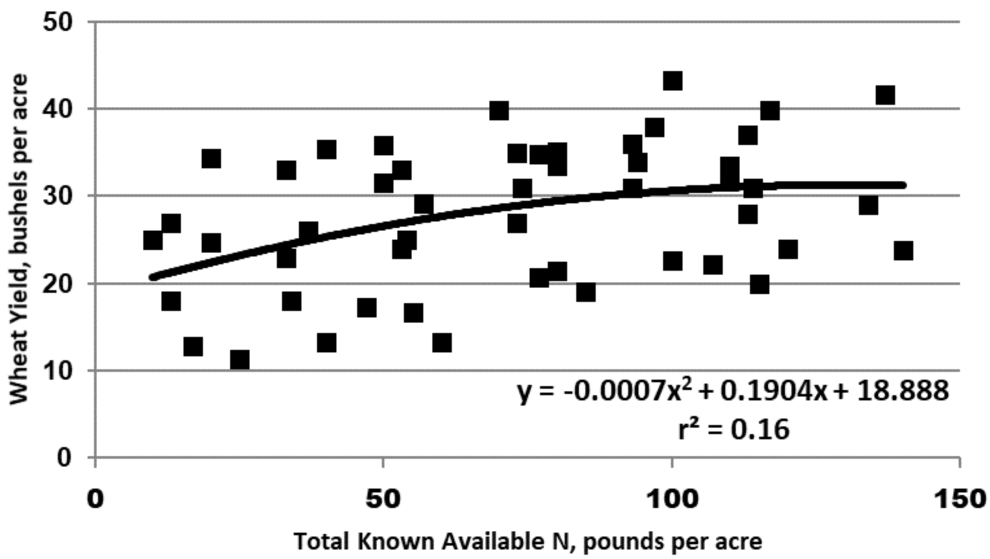

Figure 2a. North Dakota spring wheat/durum yields, west of the Missouri River, compared with total known available N, conventional tillage.

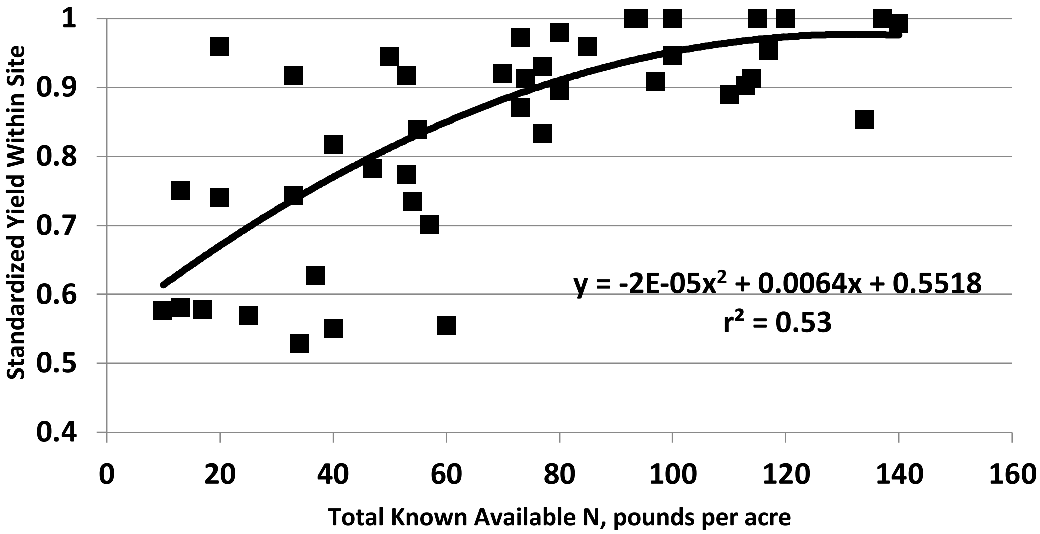

Figure 2b. North Dakota standardized spring wheat/durum yields, west of the Missouri River, compared with total known available N, conventional tillage.

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

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

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

It was important to develop recommendations within regions. The state division between east of the Missouri River and west of the river are intuitive, because of the age of soil sediment west (residual materials about 60+ million years old) compared to recent glacial materials east of the river less than 12,000 years old. However, the area in the north, at the Canadian border was identified first by the lower N rate required to produce yield compared to the rest of the eastern North Dakota region. The reason was determined to be the high amount of small shale pieces in the soil material, which contain significant mineralizable N from ancient non-exchangeable ammonium sources within their original clay constituents.

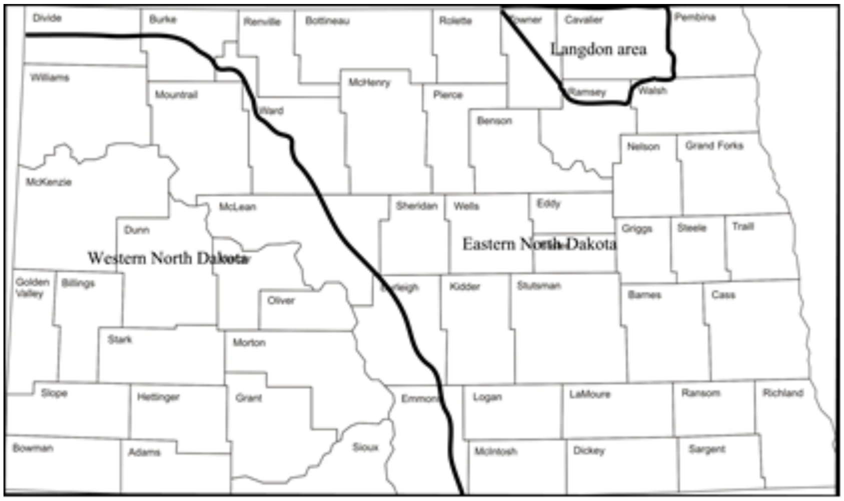

Figure 3. N recommendation regions for spring wheat/durum.

In corn, the high-clay soils of the Red River Valley- the roughly 30-mile-wide area on the very eastern boundary with Minnesota, formerly Glacial Lake Agassiz- is easily saturated by spring rains. Just to the west of these high-clay soils are a series of deep, sandy low organic matter ridges, beach ridges, that are relics of different extents of the glacial lake. Both of those conditions favor loss of preplant/at planting N by leaching in sands, and denitrification in the clays. Corn N rate studies in these soils indicate that loss of over 100 pounds per acre of N during a wet May is not uncommon. Therefore, eastern North Dakota in the corn N-rate recommendation structure is divided into a narrow, Valley encompassing eastern region, while to the west is the Central region, with drier, more forgiving soils.

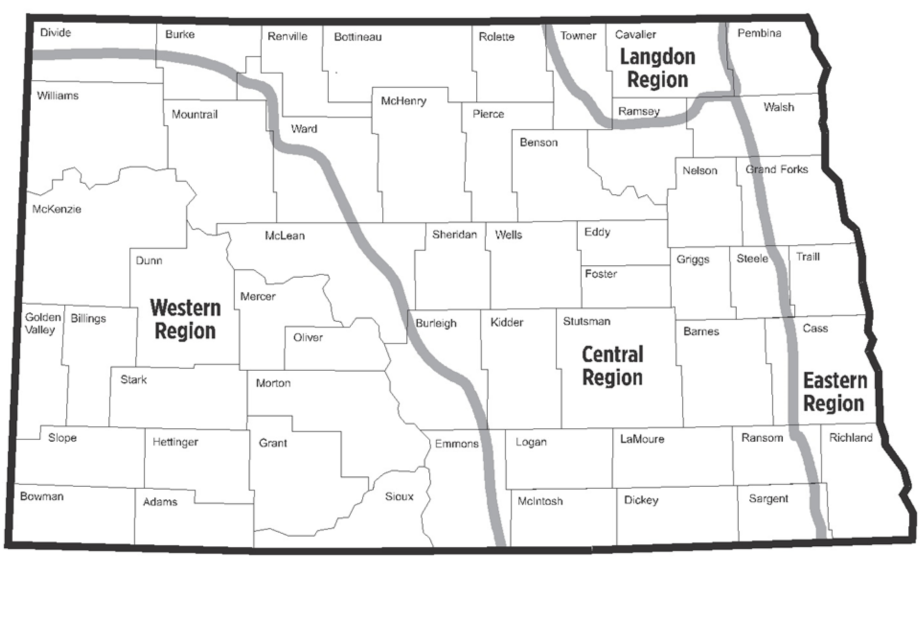

Figure 4. Regions of importance for corn N recommendation in North Dakota.

The N recommendations for corn, spring wheat/durum, sunflower and 2-row malting barley are imbedded within the interaction North Dakota N calculator (Figure 5). The calculator is accessible from my website and contains the sites for all four of these crops.

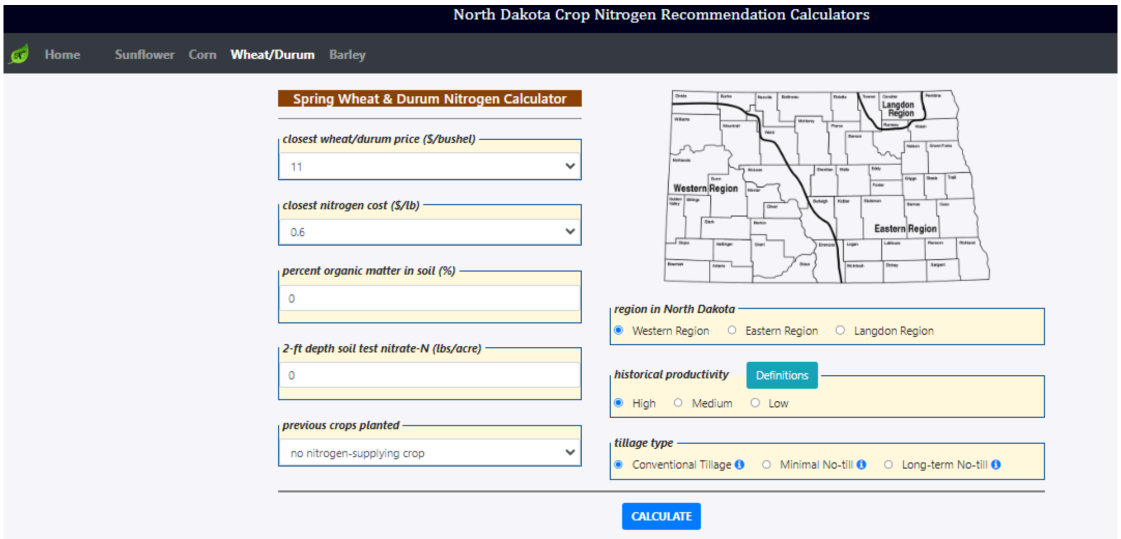

Figure 5. N calculator for spring wheat/durum, sunflower, corn and 2-row malting barley.

Advances in Potassium

I began working in potassium (K) in 2014. By that year, North Dakota was one of the top soybean producers in terms of acreage in the USA and had several million acres of corn as well. In the southeast of North Dakota, corn and soybean had been grown for 30 years in many fields, and the K soil tests were showing drastic declines from their values in the 1970's. I decided it would be a simple matter to have multiple years of multiple K rates in the area, then determine whether 150 ppm was the critical value of not. In the middle of the studies, it was alarming that only half of the sites were diagnosed correctly by the K soil test criteria in place at the time. Some of the studies were responsive with K tests greater than 150 ppm, while other sites with K tests less than 100 ppm showed no yield increase with K fertilizer (Figure 6).

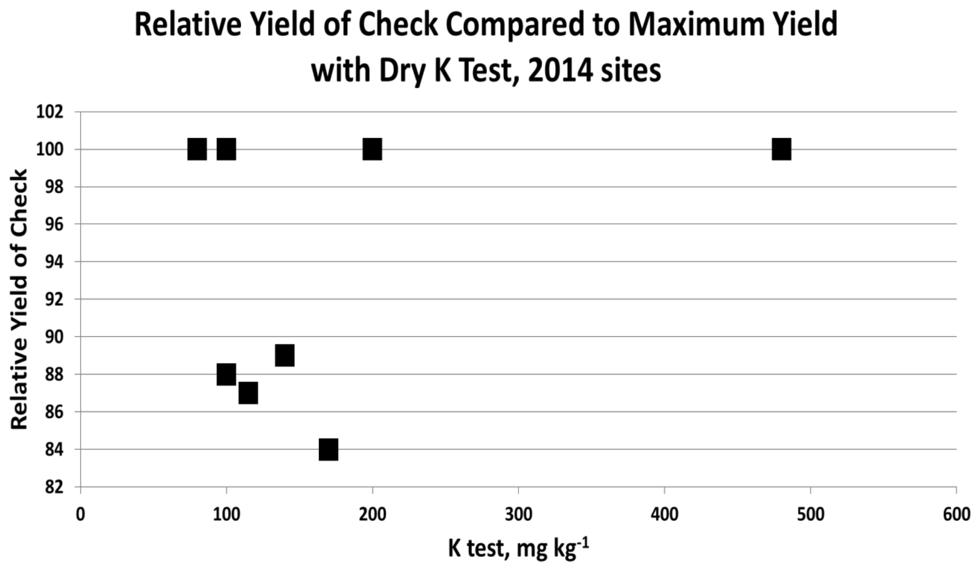

Figure 6. Relationship of soil test K with relative yield of check. Some sites were non-responsive with K tests less than 100 ppm, while some sites were responsive with K tests greater than 150 ppm.

After attending a sobering seminar with Dr. Don Sparks of the University of Delaware, it because apparent that I didn't know anything about K. Because there was a lack of anything but assumptions about North Dakota clay species and potassium feldspar mineralogy, the soil samples from several years of the K rate study were analyzed for clay species. The results indicated that the ratio of smectite to illite clays within a soil helped explain most of the response data (Figure 7; Figure 8).

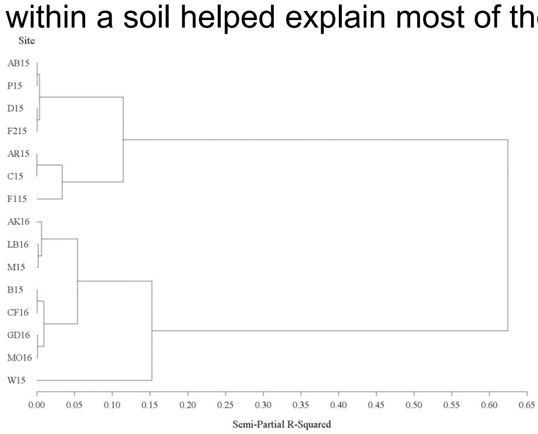

Figure 7. Cluster analysis of K sites by clay species ratio.

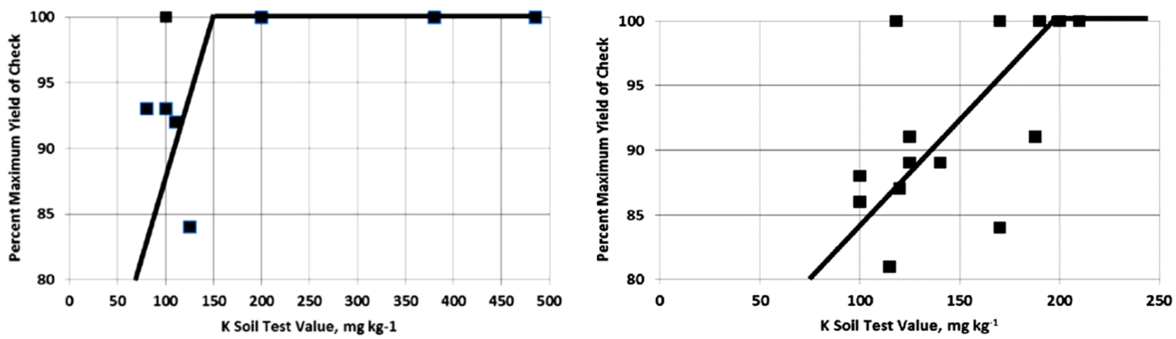

Figure 8. K soil test vs % max yield of check for sites with smectite:illite ration of > 3.5 (left) and <3.5 (right).

Due to the successful relationship of clay species ratio, a survey of North Dakota was conducted, with at least 2, often 3 sites per county sampled and clay species analyzed. The results of this survey was condensed into Figure 9, with areas greater or less than smectite:illite ratio identified.

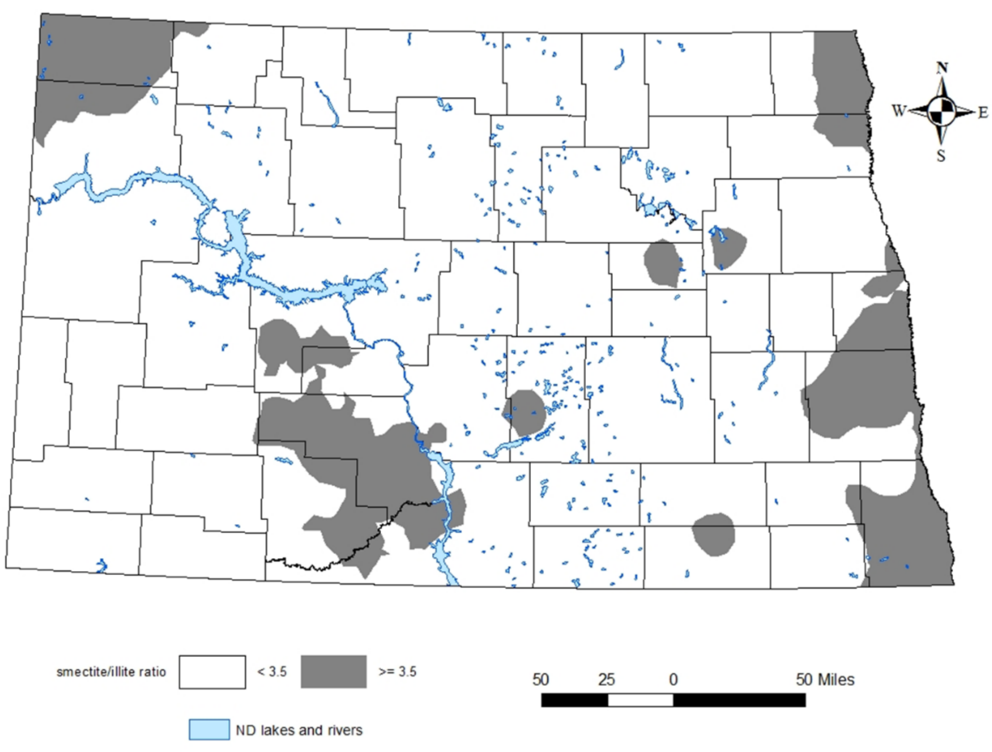

Figure 9. Map of smectite:illite ratio in North Dakota for use in determining K fertilization need.

North Dakota K recommendations are now based on clay chemistry.

For corn, alfalfa:

Smectite/illite > 3.5, critical soil test value is 200 ppm

Smectite/illite < 3.5, critical soil test value is 150 ppm

For sugarbeet

Smectite/illite > 3.5, critical soil test value is 150 ppm

Smectite/illite < 3.5, critical soil test value is 120 ppm

For spring wheat/durum/winter wheat

Smectite/illite > 3.5, critical soil test value is 150 ppm

Smectite/illite < 3.5, critical soil test value is 100 ppm

There are many questions which remain unanswered. Nitrogen and potassium are crop nutrients that are not explained simply. Nitrogen is very biologically and environmentally sensitive, with a little physical chemistry thrown in. Potassium is very physical chemistry-related, with some biology and environmental influence thrown in. My hope is that my contributions and those of my students and colleagues have advanced the science and made farming more profitable and more environmentally sensitive than practices used in the past.

REFERENCES

A host of references may be found at
https://www.ndsu.edu/snrs/people/faculty/dave_franzen/

ASSESSING CORN RESPONSE TO COVER CROPS AND NITROGEN FERTILIZATION IN A NO –TILL, THREE-YEAR ROTATION IN NORTHEAST KANSAS

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Adapted from our 2023 Fertilizer Report (https://doi.org/10.4148/2378-5977.8551)

ABSTRACT

As industry initiatives and government programs begin funding and incentivizing climate-smart agricultural practices, more farmers in the great plains region may be interested in incorporating cover crops into their rotations. Annual yield data can aid in understanding how cover crops impact cash crop productivity in this region. A long-term cover crop experiment in northeast Kansas was established in 2007 based on a wheat – corn – soybean rotation to determinate the effect of cover crops and nitrogen (N) rates on subsequent crop growth and yield. Treatments included different cover crops (cereal rye, crimson clover, a mix of cereal rye and crimson clover, and a diverse seven species mix) and control treatments (chemical fallow, double-crop soybean), planted in late summer after wheat harvest, and five N rates (0, 40, 80, 160, 240 lb/ac). Yield responded differently across cover crops treatments, nitrogen rates and years. In both the 2021 and 2022 growing seasons, corn after chemical fallow and double-crop soybeans had the highest yields with lower N rates (80 and 160 lb/ac), and corn following cereal rye and the cereal rye-crimson clover mix had the lowest yields overall. Nitrogen fertilizer replacement values of each cover crop treatment and double-crop soybeans were determined by solving the quadratic equation model of the chemical fallow treatment yield response to nitrogen fertilizer application rate. These replacement values were negative for most cover crop treatments, with values for the double-crop soybean being the least negative. Overall, nitrogen availability for plant uptake was reduced by the presence of a cover crop, and additional applied nitrogen was necessary for these treatments to reach baseline levels. Decreased precipitation during critical growing periods in 2022 exacerbated the negative yield response following the cereal rye cover crop monoculture and mix compared to 2021. Incorporating cover crops before corn can be done in Kansas, but additional nitrogen may need to be applied to recover what was lost from cover crops. Moisture is also a concern in this region, and cover crops can take up early season moisture leaving little for the germination of the cash crop in a dry year. Alternatively, a double-crop soybean would minimally impact subsequent corn yields and may offer both ground cover and an additional cash crop between wheat harvest and corn planting. In conclusion, cover crops may be implemented in northeast Kansas, but producers will need to consider additional N inputs and current moisture conditions when deciding whether or not to plant covers in a given year.

INTRODUCTION

Cover crops may benefit no-till agricultural systems in a variety of ways including physical protection from erosion and organic matter production. Species with low carbon (C) to nitrogen (N) ratios can release N for the subsequent cash crop (Lu, Y. et al 2000). Because legume cover crops fix their own N, and grass cover crops can scavenge N from deeper in the soil profile, mixtures can be planted to maximize the potential benefits of both species (Fageria, N. K. et al 2005). However, some studies have found that N is immobilized following initial decomposition of legume and grass cover crop species (Jensen, E.S. 1997). Decomposition rates of cover crops significantly depend on weather conditions as well as cover crop quantity and quality (R. Thapa et al 2021). Additionally, sufficient soil moisture in the growing season is critical for corn grain fill. While cover crop mulch can preserve incoming soil moisture, it is possible for covers to take too much moisture from the soil if they are not terminated early enough in a dry spring (Kelley, 2021). Therefore, it is important to continue studying nutrient dynamics and subsequent cash crop yields following cover crops to understand the site-specific relationship between cover crop species, nutrient return to the cash crop, and subsequent yields.

A long-term cover crop study near Manhattan, Kansas has been continuously managed for over 15 years in a sorghum - soybean – wheat/cover crop rotation, with corn replacing sorghum starting in 2020. A 9-year summary of results from this site observed nitrogen immobilization during grain sorghum following cover crop treatments, with the largest reduction following a grass cover crop (G. Preza-Fontes et al 2017). These results were expressed as the N-fertilizer replacement value (NRFV), indicating how much N was added (or lost) to the system following each cover crop. At that time, most cover crop species resulted in negative NRFV values because sorghum grain yields following the cover crops were less than after chemical fallow with no nitrogen fertilizer (G. Preza-Fontes et al 2017). We now have 2 full years of yield and NRFV data for corn following different cover crop species and mixes and can determine if the effects on corn are similar to what was observed in grain sorghum.

MATERIALS AND METHODS

The study was established in 2007 at the Kansas State University Department of Agronomy Research Farm located 8 m south of Manhattan at Ashland Bottoms. The soil at this location was a moderately well drained Wymore silty clay loam, the average annual precipitation is 36 inches, and the annual mean temperature is 54.9 ºF (https://climate.k-state.edu/).

The study consisted of all phases of a wheat (*Triticum aestivum L.*) – corn (*Zea mays*) – soybean [*Glycine max (L.) Merr*] rotation, where each phase of the rotation was present every year. The experimental design was a randomized complete block design with four replications with treatments arranged in a split-plot structure with cover crops as whole plots and N rates applied to corn as subplots. Field measurements were recorded for the corn crop, which was planted immediately after cover crop termination on April 30 and May 11 in 2021 and 2022, respectively. Corn plots were 8 rows wide, and each whole plot was 20 by 225 ft, and each subplot was 20 by 45 ft. Cover crops treatments consisted of two control treatments, chemical fallow (CF) and double crop soybean (DSB), plus four cover crop treatments, crimson clover (CC), cereal rye (CR), crimson clover and cereal rye mix (R/CC), and a diverse seven species cover-crop mix (FTM). The N fertilizer treatment included five rates (0, 40, 80, 160, and 240 lb ac^{-1}) applied as 28% UAN split with 40 lb at planting and the balance at V4-6. UAN was applied with a straight flat-coulter liquid fertilizer applicator to inject N fertilizer below the residue layer. No phosphorous or potassium fertilizer were applied. Plots were sprayed with residual herbicides at and after planting to control weeds both years.

After corn reached physiological maturity, yield was determined by combine harvesting plants from the center two rows of each subplot. Grain moisture and test weight were measured with a moisture meter (Model GAC 2000, DICKEY-John Corp., Springfield, IL), and yields were corrected to 15.5% moisture content. A quadratic regression was used to describe the relationship between corn yield and N fertilizer rate after each cover-crop treatment in each year. Nitrogen fertilizer replacement value for cover crops and double crop soybean were obtained by solving the CF quadratic equation for the amount of N required to produce the grain yield obtained for the 0-N plot of each cover crop (G. Preza-Fontes et al 2017).

Mixed-effects models were fitted with using PROC GLIMMIX of the SAS® software (SAS Institute, 2011). The effects of CCs, N rates, Year, and their interactions were evaluated by ANOVA, and Least Square Means method was used to assess the difference between the means of the treatments.

RESULTS

Weather information from 2021 and 2022 growing seasons was summarized and compared to normal values (30-year average) for this location (Table 1). For both years, precipitation indicated significantly drier conditions than normal, particularly at corn 2022 planting date (April-May). Cover crops biomass following 2022 was higher than the one from 2021 (6 lb/ac vs 11 lb/ac, respectively). The three-way interaction of cover crop × N rate × year was significant for corn yield ($P = <0.0001$); therefore, years were analyzed separately (Table 2).

Table 1. Weather information for 2021 and 2022 corn growing season, and 30-years average.

	Period	30-y avg	2020 - 2021	Departure	2021-2022	Departure
Precipitation (in)	June 1- August 31	18.1	12.1	-6.0	3.2	-14.9
	Sept 1 - Dec 31	11.1	6.0	-5.1	8.2	-2.9
	Jan 1 - April 30	10.1	6.4	-3.7	4.0	-6.1
	May 1 - June 31	12.8	8.8	-3.9	14.7	1.9
	July 1 - Sept 30	15.2	5.7	-9.6	8.1	-7.1
Temperature (°F)	June 1- August 31	76.8	77.8	1.0	78.0	1.2
	Sept 1 - Dec 31	50.1	50.6	-24.4	55.3	-19.7
	Jan 1 - April 30	40.9	40.7	-26.7	40.1	-27.3
	May 1 - June 31	69.5	69.3	13.2	70.9	14.8
	July 1 - Sept 30	75.0	76.7	32.9	76.1	32.3

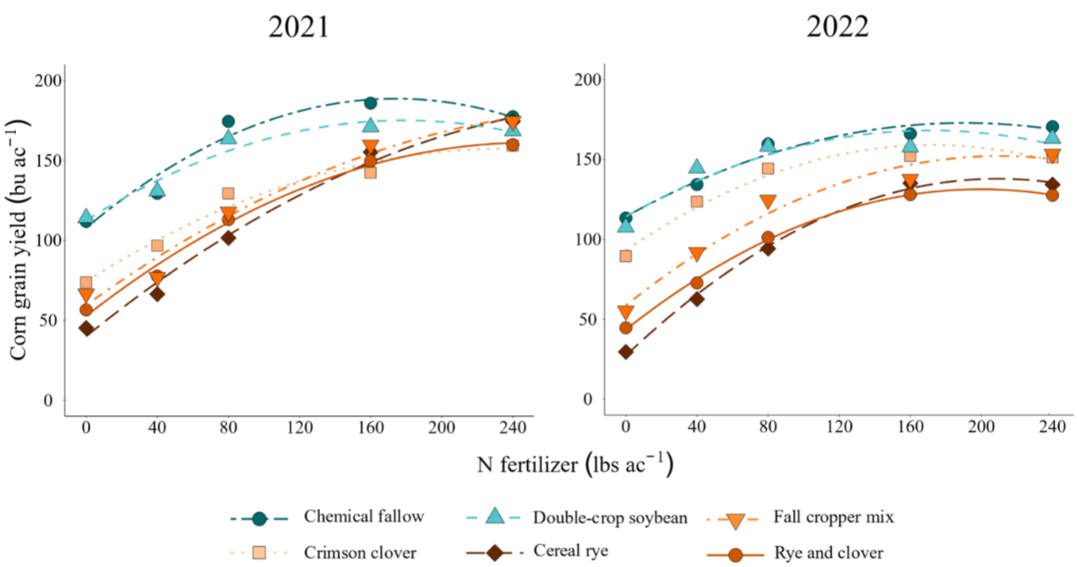
Table 2. Corn yield means for main effects and interaction of cover crops treatments (CCs) and Nitrogen rates (N-rate) in 2021 and 2022. Lower case letters indicate Least Square Means significant differences for interactions, while upper case letter indicate Least Square Means significant differences for main effects.

	CF	DBS	CC	CR	R/C	FTM	N-rate
				bushels per acre			
2021							
0	112 kj	114 ik	74 l	45 n	57 mn	67 lm	78 E
40	129 ghi	131 gh	97 k	66 m	78 l	77 l	96 D
80	174 abc	163 e	129 ghi	174 j	113 jk	118 hij	133 C
160	186 a	171 cde	142 fg	155 d-e	150 ef	160 cde	161 B
240	177 ab	169 bcd	159 cde	175 abc	160 cde	174 abc	169 A
CCs	156 A	150 A	120 B	109 C	111 BC	119 B	
2022							
0	113 ijk	108 jkl	89 mn	30 r	45 r	55 pq	73 D
40	134 fgh	144 c-g	124 hij	63 op	73 no	92 ml	105 C
80	160 abc	158 abc	144 g	94 ml	101 klm	125 hij	130 B
160	166 ab	158 abc	152 e	135 e-h	128 ghi	138 h	146 A
240	170 a	163 ab	151 f	134 fgh	128 ghi	153 bcd	150 A
CCs	149 A	146 A	132 B	91 D	95 D	112 C	

CF: Chemical fallow, DBS: Double crop soybean, CC: Crimson clover, CR: Cereal Rye, R/C: Rye and clover, FTM: Fall cropper mix.

During 2021 growing season, greatest yield was achieved with different N rates depending on cover crops treatment (Fig. 1). Although corn after crimson clover and cereal rye obtained the highest yield at the maximum N rate (240 lb/ac), corn after the fall cropper mix and the rye and clover mix reached maximum yield at 160 lb N per acre. Corn after double-crop soybean and chemical fallow obtained their highest yield at 80 lb/ac. Corn yields after the different cover crop treatments followed a similar pattern in 2022, although corn maximized yield after most cover crops at lower N rates, except for the chemical fallow and rye and clover mix treatments. For both years, when no fertilizer was applied, the highest corn yields were achieved after double crop soybean and chemical fallow treatments, and lowest yields were after cereal rye and cereal rye and crimson clover mix.

Figure 1. Yield response to different N-fertilizer application rates following different cover crops in 2021 and 2022.



The nitrogen fertilizer replacement value differed among cover crop treatments (P = <0.0001). In both years, most cover crop treatments produced a negative NFRV, excepted for double crop soybean, which provided 8 lb/ac of N during 2021 growing season. In general, the lowest values of NFRV were obtained by double crop soybean, while highest values corresponded to cereal rye and cereal rye and crimson clover mix (Table 3).

Table 3: Corn yield at 0 N-rate and Nitrogen fertilizer replacement value (NFRV) for all CC treatments in 2021 and 2022.

Treatment	Yield 0-N	NFRV	Treatment	Yield 0-N	NFRV
	bu/ac	lb/ac		bu/ac	lb/ac
	2021			2022	
CF	112	-	CF	113	-
DSB	114	8 a	DSB	108	-10 a
CC	74	-33 b	CC	89	-36 b
CR	45	-58 c	CR	30	-107 d
R/C	57	-49 bc	R/C	45	-91 cd
FTM	67	-40 b	FTM	55	-79 c

Higher corn yields were achieved following chemical fallow and double crop soybeans, and negative NFRV values along with lower yields were observed for most of the cover crop treatments, except for the double-crop soybean. This suggested that N availability for a subsequent corn crop was reduced after cover crop treatments compared to the chemical fallow. However, weather implications should also be considered, as both years of this study had less precipitation comparing to normal values (Table 1). Indeed, during 2022 growing season, none of the cover crop treatments were able to reach same yield as chemical fallow (Figure 1), even with the highest N rate, indicating another factor (possible available water) may be limiting yield. Thus, the magnitude of N supplied from CC varies because cover crop growth is sensitive to environmental conditions that vary CC biomass production from site to site and from year to year. Total CC biomass production in 2021 and 2022 were approximately 6 lb/ac and 11 lb/ac respectively. More biomass production in 2022 could mean also more water consumption by cover crops and less water available during corn vegetative stages. Finally, looking at differences between cover crops species, cereal rye has a higher C/N ratio, therefore immobilizes more nitrogen than the rest of the cover crops. Legumes and brassicas have a higher capacity to accumulate and provide nitrogen, however, the short growing season that all these cover crops had could limit this potential. According to these results, double crop soybean immobilizes less N than the rest of the cover crops treatments, with a potential for providing N available for plant uptake, which could be lost if it wasn't stored by the cover crop. Further studies should be done in other legumes and mix of species to characterize their growth and N supply capacity in the Northeast plains of Kansas.

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COVER CROPS IN SEMI-ARID DRYLAND WINTER WHEAT (*Triticum aestivum*, L.) FALLOW ROTATION

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ABSTRACT

Winter wheat (*Triticum aestivum*, L.) (WW) is a primary dryland crop in the semi-arid part of the US Great Plains. Local producers have been interested in incorporating cover crops (CC) to a WW-fallow rotation, but information on the CC impacts on soil moisture, plant available nitrogen (N) and competition with weeds in a low precipitation region is limited. In this collaborative study, a producer designed and planted two CC mixes: (1) legume-dominated three species mix (**69-17**-14) (3S legume dominated): forage pea (*Pisum sativum* L.), red clover (*Trifolium pratense* L.), daikon radish (*Raphanus sativus* L.) and (2) grass-dominated four species mix (**55**-35-7-3) (4S grass dominated): oat (*Avena sativa* L.), forage pea (*Pisum sativum* L.), daikon radish (*Raphanus sativus* L.) purple top turnip (*Brassica rapa* L.). Soil and vegetation sampling occurred at eleven weeks and a second soil sampling at twenty-six weeks to determine CC impact on soil moisture, soil inorganic nitrogen (IN) and weed competition. Soil moisture was not compromised by either CC mix treatment. The 4S grass dominated outperformed 3S legume dominated by suppressing weedy species and increasing soil IN. A twelve-week laboratory incubation showed that, under optimum soil moisture levels (23%), ammonium (NH_4) and dissolved organic carbon (DOC) was significantly higher in both CC treatments and was highest in 3S legume-dominated. In areas of low precipitation, legume dominated mixes do not perform as well as grass dominated mixes. At optimum soil moisture however, when plant biomass is incorporated into the soil, legume dominated mixes return more N and C to the soil. Fallow could benefit from incorporation of carefully-designed CC mixes but further testing needs to be conducted to establish the most suitable CC mixes for semi-arid areas of very low precipitation.

INTRODUCTION

In semi-arid regions, WW production typically involves a 24-month wheat-fallow rotation where the fallow period lasts 14 months (Bista et al., 2017). During the fallow period of organically certified production, weed management primarily consists of frequent tillage leading to soil organic matter (SOM) mineralization and loss of soil carbon (C) and nitrogen (N) (Ghimire et al., 2018). A possible solution to overcome these challenges is designing agronomic systems that incorporate cover crops (CC).

Cover crop mixtures with diverse plant families offer more benefits than a CC monoculture (Murrell et al., 2017). Grasses offer fast germination with fibrous roots that aid in weed smothering, N scavenging and C sequestration (Finney et al., 2016). Brassicas can germinate under low water conditions, grow deep taproots, and produce large amounts of biomass and legumes fix atmospheric N (Bowman et al., 2012). Broadleaf plants, like Phacelia (*Phacelia tanacetifolia* Benth L.) offer quick germination, high biomass, and drought tolerance (Smither-Kopperl, 2018). The main objective of this research was to evaluate two producer designed CC mixes from the perspective of soil health benefits and weed competition in SE Wyoming.

MATERIALS AND METHODS

This study took place in Pine Bluffs, Wyoming (41.18°N LAT, 104.07°W LONG, 1539 meters above sea level). Soils are loamy with pH of 7.3. Average precipitation was 44.5 cm with 157.48 cm of snowfall. Average high and low temperatures were 16.3°C and -9.0°C respectively (*U.S. Climate Data*, 2022). The site was under an organic certified dryland WW-fallow with CC inclusion. Two CC mixes were planted on April 7, 2020; (1) three species and legume-dominated (**69-17**-14) (3S legume dominated): forage pea (*Pisum sativum* L.), red clover (*Trifolium pratense* L.), and daikon radish (*Raphanus sativus* L.) and (2) four species and grass-dominated (**55**-35-7-3) (4S grass dominated): oat (*Avena sativa* L.), forage pea (*Pisum sativum* L.), daikon radish (*Raphanus sativus* L.), and purple top turnip (*Brassica rapa* L.) (Table 1). Additional treatments included a weedy fallow (WF) where the ground was tilled once and then allowed to fallow without any weed control and a cultivated fallow (CF) treatment where the ground was tilled five times for weed control throughout the fallow period.

Table 1. Cover crop mix breakdown of common name, scientific name, life form, planting rate and percent of mix.

3 Species Legume Dominated Cover Crop Mix (40 Kg ha^{-1})				
	Scientific Name	Lifeform	Kg ha^{-1}	% Mix
Daikon Radish	*Raphanus sativus*	Broadleaf	6	14
Forage Pea	*Pisum sativum*	Legume	28	69
Red Clover	*Trifolium pratense*	Legume	7	17

4 Species Grass Dominated Cover Crop Mix (81 Kg ha^{-1})				
	Scientific Name	Lifeform	Kg ha^{-1}	% Mix
Oats	*Avena sativa*	Grass	45	55
Daikon Radish	*Raphanus sativus*	Broadleaf	6	7
Purple top Turnip	*Brassica rapa*	Broadleaf	2	3
Forage Peas	*Pisum sativum*	Legume	28	35

Sampling took place during a fallow phase. The timing of samplings provided an examination of soil parameters and plant populations during the growing season while cover crops were actively growing. Vegetation sampling took place during the June (summer) sampling only. Two quadrats (one square foot surface area) were placed randomly in each treatment. Plants were cut at soil level, separated into CC and weeds, and placed into paper bags. The quadrat was then flipped horizontally, and the same collection steps were taken. Plant bags were oven dried at 60°C for 48 hours to establish percent moisture and overall dry biomass.

Soil samples were collected in June and September (fall). Four soil cores (0-15 cm depth) were collected using a step-down auger probe. Samples were homogenized, stored in a plastic zipper bag, placed in a cooler with ice until processing within 48 hours of collection. In the lab, soils were sieved through a 2 mm sieve and analyzed for: (1)

gravimetric soil water content (Gardner, 1986); (2) electrical conductivity (EC) and soil pH on a 1:2 soil-to-water ratio; (3) inorganic N (sum of NH_4-N and NO_3-N) on an extract obtained from placing 10 g of fresh soil to 25 ml of two molar potassium chloride (2 *M* KCl) and analyzed (Doane & Horwáth, 2003) on a spectrophotometer microplate reader (UV-VIS Biotek Instruments, Highland park, USA).

A twelve-week lab incubation was conducted to observe potential C and N mineralization at soil field moisture capacity (23%). Field samples were collected by placing a quadrat (same size as above) at random in each block. Aboveground biomass was clipped at soil level and stored in a plastic zipper bag. The top 15cm of soil was collected (belowground root biomass included) homogenized and placed in a plastic zipper bag. At time of processing, plant biomass was cut into 2.5 cm long segments and homogenized with the soil to imitate tillage practices. Samples were placed in a 50 ml Falcon centrifuge VWR tube. Tubes from each treatment were labeled: month 1, month 2, and month 3 and all were placed in a wide-mouth quart mason jar fitted with a lid containing a septum. To ensure soil 23% moisture level, gravimetric water content was determined and needed amount of DI water was added to each tube. At the end of each month one tube was removed, soil was sieved and processed for gravimetric water content, NH_4, and DOC in the same methods as mentioned above.

All statistical analyses were performed in R version 3.6.2 (Team, 2021). The effects of cover crop treatment and time in growing season, on soil and plant properties were assessed using two-way Analysis of Variance (ANOVA) ($P \leq 0.05$). Data were tested for normality using the Shapiro–Wilk test. Transformations were used to achieve normality. Tukey HSD was used to determine treatment significance at a minimum of $P \leq 0.05$. For non-normal data, a Kruskall-Wallis rank sum test was used, followed by the Dunn test to determine significance. Regression analyses was performed on soil moisture and plant biomass data to assess weed suppression by cover crop treatment (Kutner, M. , Nachtsheim, C., Neter, 2004)**.**

RESULTS AND DISCUSSION

The 4S grass dominated mix produced the highest amount of CC biomass, and weedy species biomass was 27 g m^{-2} less than WF (Figure 1). There was a smothering effect of CC on weedy species at a rate of y = 27.32 – 0.08(4S grass dominated Biomass), $R^2 = 0.60$. Weedy species biomass in WF and 3S legume dominated were comparable however (Figure 1). The 4S grass dominated effectively reduced weedy species and outperformed 3S legume dominated. Planting CC increased total plant biomass by 147% in 3S legume dominated and 165% in 4S grass dominated.

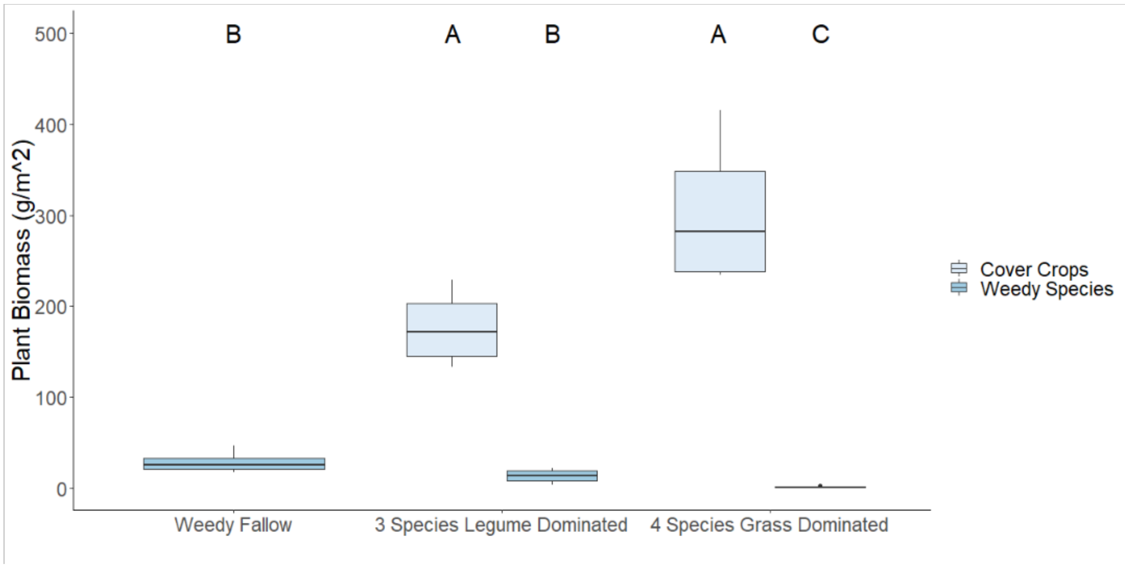


Figure 1. Plant biomass of cover crops and weeds in weedy fallow and cover crop treatments. Different uppercase letters demonstrate treatment differences at $p \leq .05$.

Summer sampling demonstrated that soil moisture beneath the two CC mixes did not significantly differ from that of WF or CF, but WF had the lowest soil moisture overall while CF had the highest (Table 2). At fall sampling, where timing corresponded with WW planting, soil moisture was comparable among all treatments (Table 2). Overall, CF had the highest decline in soil moisture between summer and fall, while changes to soil moisture under CC mixes were negligeable. This is consistent with other findings where good soil coverage from CC biomass helped conserve soil moisture (Wortman et al., 2012, 2013).

Summer sampling showed that WF had the highest IN concentrations of all treatments, while 4S grass dominated had the lowest (Table 2). In contrast, fall sampling showed that IN concentrations beneath 4S grass dominated were the highest of all. Over time, both fallows demonstrated a decrease in IN concentrations with CF having the largest decrease (Table 2), while the most IN concentration gain was observed beneath 4S grass dominated. The beneficial traits of the grass in 4S grass dominated were seen in soil N accrual.

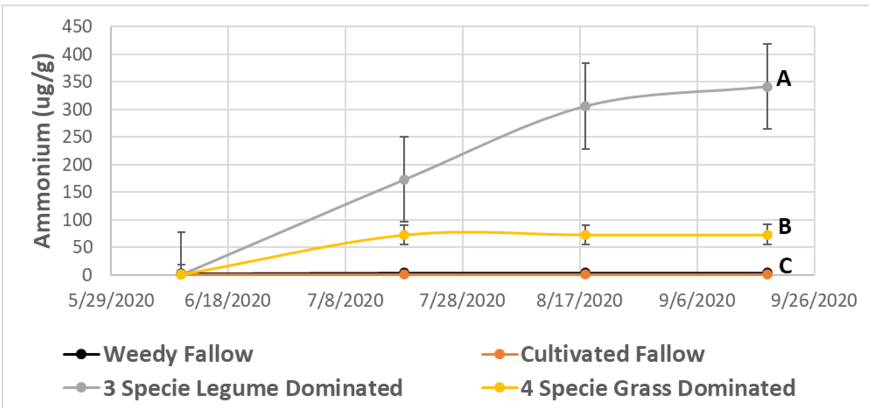
Table 2. Seasonal changes for soil moisture, soil inorganic N and soil labile N in weedy fallow, cultivated fallow and cover crop treatments. Different uppercase letters demonstrate treatment differences at $p \leq .05$.

FARM 2	TRT	Summer	Fall	% Difference
Soil Moisture ($g\ g^{-1}$ OD Soil)	Weedy Fallow	0.01 (.001) B	0.02 (.13) A	100.00
	Cultivated Fallow	0.20 (.07) A	0.09 (.04) A	-55.00
	3 Species Legume Dominated CC	0.10 (0.09) AB	0.12 (0.08) A	20.00
	4 Species Grass Dominated CC	0.11 (0.07) AB	0.09 (0.03) A	-18.18
	Weedy Fallow	40.43 (13.07) A	27.63 (1.99) B	-37.61

Soil Inorganic Nitrogen ($\mu g\ g^{-1}$)	Cultivated Fallow	27.43 (5.17) AB	2.66 (0.99) D	-164.64
	3 Species Legume Dominated CC	11.95 (6.93) BC	12.63 (3.97) C	5.53
	4 Species Grass Dominated CC	5.57 (1.99) C	79.47 (13.67) A	173.80

Laboratory incubation showed that NH_4 and DOC accumulation was the highest in 3S legume dominated, followed by 4S grass dominated and the lowest between CF and WF which were comparable (Figure 2A and 2B).This was likely caused by low C:N ratio of 3S legume dominated leading to quick mineralization of organic residues.

A.



B.

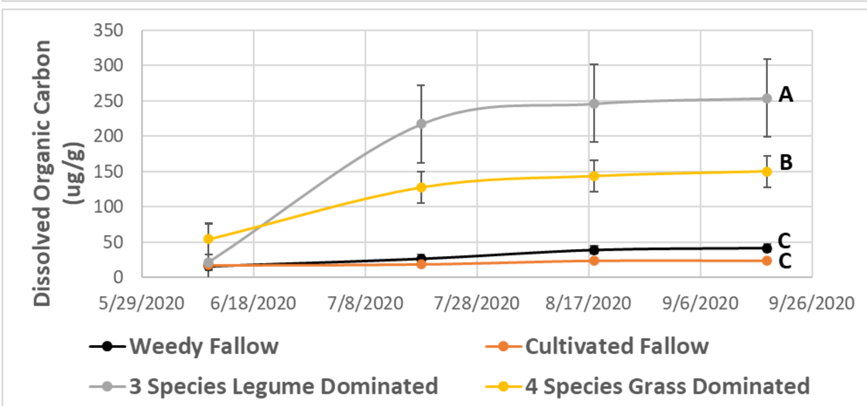


Figure 2. Twelve-week soil incubation for ammonium (A) and dissolved organic carbon (B) in weedy fallow, cultivated fallow, and cover crop treatments. Different uppercase letters demonstrate treatment differences at $p \leq .05$.

CONCLUSIONS

4S grass dominated successfully competed with weeds and significantly increased IN concentrations. The two CC mixes did not compromise soil moisture by the time for WW planting. Cover crop mixtures accumulated more NH_4 and DOC with 3S legume dominated accumulating the most while the two fallows accumulated very low amounts of NH_4 and DOC. In semi-arid, dryland WW production, when producers evaluate the needs of their land and carefully design CC mixes, adequate CC biomass production is possible, resulting in agroecosystem benefits.

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IMPACT OF PHOSPHORUS SOIL TEST LEVEL DIFFERENCES ON CROP RESPONSE IN NO-TILL SOILS IN CENTRAL SOUTH DAKOTA

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ABSTRACT

Water and nutrient dynamics in no-till soils vary significantly from conventionally tilled soils. It is evident that soil structure, chemical parameters, and biological profiles influence the functionality of these different management systems. University soil fertility programs have been developed and calibrated for conventionally tilled management. Dakota Lakes Research Farm (Pierre, SD) conducted three years of research (2019-2021) to investigate the impact of phosphorus soil test levels in long term no-till. Three levels of phosphorus solubility (Low, Medium, High) were established by applying Monoammonium phosphate (MAP) fertilizer over the course of four applications. The long-term crop rotation of this plot is Corn-Corn-Soybean-Wheat-Soybean. No yield response was observed during the experiment's three-year span. Soils were sampled during the growing season to evaluate the effect of soil test phosphorus levels on the presence of arbuscular mycorrhizal fungi (AMF). AMF form relationships with plants and assist in nutrient and water uptake. A method was established to count the most probable number of fungal propagules present in the soil. From 2019 through 2021, the Low level of soil test phosphorus contained 4.5 propagules/g soil compared to 0.7 propagules/g soil in the Medium level and 1.5 propagules/g soil in the High level. It is reasonable to assume that elevated levels of AMF compensated for lower available soil phosphorus. This likely enhances a plant's ability to uptake the nutrient and furthermore maintain crop yield. These data indicate that higher levels of soluble phosphorus may discourage AMF. Increasing fertilizer costs and concerns of fertilizer availability and reserves highlight the importance of responsible phosphorus fertilizer management. In addition, nutrient movement from agricultural land to water bodies has created water quality concerns. These data indicate a low soluble test phosphorus management system in no-till soils is beneficial to an agricultural producer's bottom line and is environmentally responsible.

INTRODUCTION

Phosphorus, the plant nutrient, is vital for growing a healthy crop capable of producing economic grain yield. Phosphorus is also the most limiting factor for blue-green algae in freshwater bodies. Blue-green algae are aquatic organisms responsible for eutrophication of aquatic ecosystems world-wide. Phosphorus enters aquatic ecosystems from both point and non-point sources. In many cases farming operations are the largest producers of non-point source pollution of phosphorus (Withers et. al, 2014). This study evaluates soil test phosphorus rate (specifically soil test level) required under long-term no-till management to maintain crop yields.

The management of phosphorus fertilizers is a serious issue due to its role in the degradation of aquatic ecosystems. There are steps that can be taken to help in the reduction of phosphorus pollution into water bodies. The 4 R's of nutrient management are currently being promoted in an effort to help reduce phosphorus pollution. The 4 R's stand for applying the right amount of a nutrient, in the right form, in the right place, and at the right time. A common tool used in determining the correct amount of a nutrient to use is the soil test. The current recommendations for P fertilization rates from Soil Testing Laboratories are based on the estimation of the P supplying ability of the soil (P solubility) and projected needs of the crop to achieve the stated yield goal. Currently P recommendations assume the application method of the fertilizer is surface broadcast application and that conventional tillage practices are used. There is substantial evidence that banding of P near or with the seed increases the efficiency of P crop uptake, this in turn would allow for rates to be reduced. The P recommendations currently used do not account for the differences in tillage, crop rotations, or mycorrhizal activity. With the promotion of mycorrhizal activity and healthy root systems (i.e. no-tillage, diverse rotations, high crop residue), the soil test P levels (solubility) can be managed at intentionally low levels. These soil test P levels may be lower than the currently recommended levels, without experiencing yield losses. By maintaining lower P soil test levels, the potential for transport of phosphorus to aquatic ecosystems should be reduced. The total P in the soil will not be reduced significantly since lower solubility levels will be maintained with fertilizer applications.

MATERIALS AND METHODS

The project was conducted at the Dakota Lakes Research Farm (29 kilometers southeast of Pierre, SD) under irrigation in a no-till, Corn-Corn-Soybean-Wheat-Soybean rotation. This site has been strictly no-till since 1990. Replicated strips with differing soil test P levels were established in 2014 by applying 0, 112, and 224 kg of MAP (mono-ammonium phosphate) ha^{-1} (equivalent to 0, 58, and 116 kg P205 ha^{-1} or 0, 26, and 52 kg P ha^{-1}) using a JD 750 drill to place the fertilizer on soils where the Olsen P soil levels had been lowered to approximately 5 ppm. The experiment was set up in a randomized complete block design with five replications. Dimensions for each treatment were 6 m by 137 m. A crop of soybeans and two crops of corn were grown in this area during the 2015, 2016, and 2017 years respectively.

In the fall of 2017, the fall of 2019 (after wheat harvest), and the fall of 2021 (after corn harvest) applications of MAP were again made at rates of 0 kg, 112 kg, and 224 kg of MAP ha^{-1} to the same replicated strips that were treated in 2014. A no-till drill was used to place the nutrient at a 3.8 cm depth and 19 cm spacing. Total additions on top of a maintenance side-band application were 0 kg MAP ha^{-1}, 448 kg MAP ha^{-1}, and 896 kg MAP ha^{-1}. This study evaluates crop response under different established levels of soil test phosphorus. The treatments will be referred to as Low P (0 kg MAP ha^{-1} applied), Medium P (448 kg MAP ha^{-1} applied) and High P (896 kg MAP ha^{-1} applied).

Soil tests do indicate that soil test P values have increased in the treatments that have received an additional 448 kg MAP ha^{-1} and 896 kg MAP ha^{-1} since 2014 (112 kg MAP ha^{-1} and 224 kg MAP ha^{-1} respectively applied a total of four times). The soil test difference is small when using the standard 15 cm sampling depth. Taking samples soon after applications or at shallower depths (7.5 cm) accentuates differences.

Winter wheat (WB4462) was grown in 2019. The crop was seeded at a rate of 915,000 pure live seed ha^{-1} on 2018-10-24 using a 6 m JD 750 no-till drill with row spacings of 19 cm. Fertilizer was placed in furrow with the wheat seed at rates of 42 kg MAP ha^{-1} and 5 kg KCL ha^{-1}. Tissue samples were obtained at V6. Yield data was obtained from the combine at harvest.

Soybeans (P28A25L) were grown in 2020. The crop was seeded at a population of 71,000 pure live seed ha^{-1} on 2020-05-14 using a row-crop seeder with 50 cm spacing. Fertilizer was applied at seeding in a sideband 7.5 cm to the side of the seed row and at seed depth. Fertilizer rates applied were 38 kg MAP ha^{-1} and 4 kg KCL ha^{-1}. Tissue samples were obtained at the V3 growth stage. Yield data was obtained from the combine at harvest.

Field corn (P0220AM) was grown in 2021. Corn was seeded at a population of 15,000 seeds ha^{-1} using a row-crop seeder with 50 cm spacing. Fertilizer was applied at seeding in a sideband 7.5 cm to the side of the seed row and at seed depth. Fertilizer rates applied were 63 kg MAP ha^{-1}, 7 kg KCL ha^{-1}, 73 kg UAN (urea ammonium nitrate) ha^{-1}, 9 kg ATS (ammonium thiosulfate) ha^{-1}. Plant samples were collected at V3. The V3 samples were weighed to determine early season total uptake of nutrients. Corn was hand harvested and ears were dried and shelled to determine hand-harvested grain yields. The grain was analyzed for nutrient analysis. The stalks were dried and weighed. A subsample of this material was submitted for nutrient analysis.

Soil samples were obtained during the growing season for each cropping year (2019, 2020, and 2021). Dr. Mike Lehman (USDA-ARS Brookings, SD) conducted an analysis to estimate the colonization of arbuscular mycorrhizal fungi in each treatment. This analysis entails a serial dilution of the soils followed by growing Bahai grass in the diluted soil pots in a greenhouse setting. After four weeks of growth, the plants were harvested and roots were stained and scored for presence of arbuscular mycorrhizal fungi (Lehman et. al, 2012).

Statistical analysis (ANOVA) was performed using R 4.3.2. An ANOVA single factor with replication test was used. For post-hoc analysis, a Fischer’s LSD test at a significance level of 0.1 was performed.

RESULTS AND DISCUSSION

Soil test levels have been elevated in the treatments that have received additional phosphorus fertilizer applications as shown in Table 1.

Table 1 Olsen phosphorus soil test levels in Spring 2020

	Olsen Soil Test Levels (ppm)		
Treatment	0-7.5 cm	7.5-15 cm	15-30 cm
Low P	7.7 b	5.2	3.6
Medium P	11.2 b	5.2	3.7
High P	16.8 a	4.9	3.7
P Value	0.004	NS	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

These data indicate that the soluble phosphorus levels have been elevated in the Medium P (numerically) and High P (statistically significant) treatments. Differences in soil test exist in the 0-7.5 cm soil depth.

In 2019, winter wheat was grown in this study. Plant samples were harvested at V6 and grain samples were obtained at harvest (Table 2).

Table 2 Wheat Plant and Grain P in Summer 2019 under different P soil test levels

	Plant @ V6			Grain		
	Biomass	P Concentration	P Uptake	P Concentration	P Uptake	Yield
Treatment	kg ha^{-1}	P (%)	kg ha^{-1}	P (%)	kg ha^{-1}	kg ha^{-1}
Low P	700 a	0.39	2.7	0.40	15	3,830
Medium P	560 b	0.40	2.2	0.41	16	3,820
High P	590 b	0.45	2.7	0.44	17	3,840
P Value	0.05	NS	NS	NS	NS	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

Biomass yield at V6 was higher in the Low P treatment, however this did not carry through the growing season to increased grain yield. Phosphorus concentration was numerically higher in the plant tissue at V6 and in the grain at harvest for the High P treatment, however these values were not statistically significant. The winter wheat grain yield was not impacted by phosphorus soil test level.

In 2020, soybeans were grown in this study. Plants were sampled at V3 and grain samples were obtained at harvest (Table 3).

Table 3 Soybean Plant and Grain P in Fall 2020 under different P soil test levels

	Plant @ V3		Grain		
	P Concentration	P Uptake	P Concentration	P Uptake	Yield
Treatment	P (%)	kg ha^{-1}	P (%)	kg ha^{-1}	kg ha^{-1}
Low P	0.11	38	0.43 b	18 b	4,110
Medium P	0.11	39	0.46 ab	19 ab	4,080
High P	0.13	40	0.49 a	20 a	4,140
P Value	NS	NS	0.02	0.03	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

No differences were found in the plant sample data. For grain content, phosphorus concentration increased as phosphorus soil test levels increased. This led to higher levels of phosphorus uptake in the Medium P and High P treatments.

In 2021, corn was grown in this study. Plants were sampled at V3 and grain samples were obtained at harvest (Table 4).

Table 4 Corn Plant and Grain P in Fall 2021 under different P soil test levels

	Plant @ V3			Grain		
	Biomass	P Concentration	P Uptake	P Concentration	P Uptake	Yield
	kg ha^{-1}	P (%)	kg ha^{-1}	P (%)	kg ha^{-1}	kg ha^{-1}
Low P	11,100 b	0.07 b	8.2 b	0.29	33	13,060
Medium P	11,800 b	0.07 b	8.3 b	0.32	36	13,120
High P	12,000 a	0.11 a	14.0 a	0.32	36	13,300
P Value	0.04	0.06	0.06	NS	NS	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

At V3, corn plants contained both a higher biomass and phosphorus concentration in the High P treatment. Higher levels of soluble phosphorus likely contributed to this additional biomass and phosphorus concentration. This led to a higher phosphorus uptake value at V3. The early advantage of additional phosphorus did not carry through to statistically higher grain yields.

Table 5 contains grain yield data for all three years of this study. All three years showed no grain yield advantage to higher levels of soil phosphorus.

Table 5 Grain Yields for 2019 (Wheat), 2020 (Soybeans), and 2021 (Corn)

		Low P	Medium P	High P	P-value
Year	Crop		kg ha^{-1}		
2019	Wheat	3,830	3,820	3,840	NS
2020	Soybean	4,110	4,080	4,140	NS
2021	Corn	13,060	13,120	13,300	NS

*P values over the 0.1 significance value are shown as NS (Not Significant).

Table 6 Most probable number of arbuscular mycorrhizal fungi propagules per gram of soil

Year	Crop	Low P	Medium P	High P	
		AMF Propagules per gram of soil			P Value
2019	Wheat	3.8 a	0.5 b	1.4 b	0.01
2020	Soybean	4.4 a	0.6 c	2.0 b	0.002
2021	Corn	5.2 a	1.0 b	1.0 b	0.003
Cumulative Average		4.5	0.7	1.5	

*P values over the 0.1 significance value are shown as NS (Not Significant).

These data indicate that higher soluble soil phosphorus levels discourage the colonization of arbuscular mycorrhizal fungi. The higher levels of AMF in the lower soluble phosphorus treatments might be compensating for the lower levels of the phosphorus nutrient.

The phosphorus concentration was numerically higher at V6 in winter wheat, and statistically higher at V3 in corn and soybeans. Higher levels of soluble phosphorus gave the crop an early advantage and in the case of corn, raised biomass levels at V3. Grain yields, however, showed no significant differences in any of the three years/crops. The increased levels of arbuscular mycorrhizal fungi in the treatments with less soluble phosphorus may have played a role in maintaining yield. Arbuscular mycorrhizal fungi may play a key role in allowing farmers to maintain lower soluble phosphorus test levels while maintaining high yields.

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DUAL-PURPOSE COVER CROP AND OCCASIONAL TILLAGE EFFECTS ON DRYLAND CROP PRODUCTIVITY, PROFITABILITY, AND SOIL PROPERTIES

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ABSTRACT

Grazing or haying dual-purpose cover crops (CCs) could provide an economic benefit to offset potential lost revenue when grain crop yields are decreased after CCs in dry years. However, there is concern that removing CC biomass could limit the beneficial effects of CCs for soil health and that root-limiting soil compaction may occur with grazing on no-till (NT) fields. Occasional tillage (OT) can be used to mitigate soil compaction caused from grazing CCs. The objectives of this study were to determine dual-purpose CC management and occasional tillage (OT) effects on plant available water (PAW), crop yields, net returns, and soil properties in a NT dryland cropping system. This study was initiated in 2015 near Brownell, KS with CCs grown in place of fallow and either hayed, grazed, or left standing. Half of each plot was tilled with a sweep plow once every three years ahead of wheat planting while the other half remained NT. Experimental design was a split-split-plot randomized complete block with four replications with all phases of the rotation present every year. Results showed that CC biomass averaged 2800 lb/ac. Grazing removed 40% of the available forage while haying removed 70%. Profile PAW at wheat planting was greater with fallow than with CCs but unaffected by tillage. Average wheat yield was unaffected by fallow management or tillage. Net returns were in the order of grazed CCs > hayed CCs > fallow = standing CCs but unaffected by tillage on average. Fallow management had no effect on soil bulk density, which was slightly less with OT than NT. Bulk soil and particulate organic carbon were unaffected by fallow management or tillage. However, the mean weight diameter of water stable aggregates was greater with CCs than fallow but unaffected by tillage. Wind-erodible fraction was unaffected by fallow management but increased with OT compared to NT. These results suggest that dual-purpose CCs can provide forage for livestock, increase soil aggregate stability, maintain average crop yields, and increase net returns in NT systems. If OT is necessary to correct root-limiting soil compaction, PAW, crop yields, net returns, and soil properties are generally unaffected compared to long-term NT.

INTRODUCTION

In semi-arid environments like the central Great Plains (CGP), annual grain crop production with growing season precipitation alone is highly erratic but can be stabilized with fallow periods to store plant available water (PAW) between crops. However, fallow is an inefficient practice with only 20–35% of precipitation effectively stored as PAW for future crop use. Despite the challenges with intensified grain production, growing CCs in place of fallow could be superior to alternative short-season grain crops (Obour et al., 2021a). Cover crops could enhance soil health, suppress herbicide-resistant weeds, and increase precipitation use efficiency. However, despite the benefits that CCs could provide, the costs of their establishment and potential reductions in subsequent grain yields because of reduced PAW at planting present major barriers to adoption (Obour et al., 2021a). Most species used as CCs have excellent forage nutritive value attributes and could supply high-quality forage for livestock to compensate for their production costs and potentially increase system profitability. However, one primary concern with grazing CCs in NT systems is the risk of excessive soil compaction that could suppress subsequent crop yields and may require tillage for remediation (Obour et al., 2021b). If root-limiting compaction occurs, one solution could be occasional tillage (OT) to strategically ameliorate compaction, after which the cropping system would return to NT. Additionally, there is concern that biomass removal with dual-purpose CCs could limit the beneficial effects of CCs for soil health (Obour et al., 2021a). Without enough information currently available, the objectives of this study were to determine the effects of dual-purpose CC management and OT on PAW, grain crop yields, net returns, as well as soil chemical and physical properties in a NT dryland winter wheat (*Triticum aestivum* L.)–grain sorghum (*Sorghum bicolor* Moench.)–fallow (WSF) cropping system.

MATERIALS AND METHODS

This study was established in 2015 at the Kansas State University Hearting Beason Ranch near Brownell, KS (38˚38′23″ N, 99˚44′45″ W) to investigate best management strategies for CCs to replace fallow in the dryland cropping systems of the semi-arid CGP. Long-term average (30 yr) annual precipitation at the study site was 22 in. The study design was a split-plot randomized complete block with four replications. Crop phase was the main plot and split-plots were oat (*Avena sativa* L.)−triticale (× *Triticosecale* Wittm.) CCs grown during the fallow phase of the WSF rotation. Cover crops were managed as standing cover, hayed, or grazed and were compared with NT fallow for a total of four treatments. In 2018, the study was modified with each split-plot split again into NT and OT split-split plots to evaluate possible interactions between CC management and tillage for a total of eight treatments. All crop phases (wheat, sorghum, or fallow) of this WSF rotation were present.

Each year, wheat was planted in October using a NT drill at 60 lb/ac and harvested the following year in July. Following an 11-month fallow period, sorghum was planted at 35,000 seeds/ac in June and harvested in November. Cover crops were planted in March at a seeding rate of 32 and 38 lb/ac for oat and triticale, respectively, and were hayed, grazed, and chemically terminated by June. Cover crops were grazed with yearling heifers (*Bos taurus*) at densities from 780–1550 lb/ac on a liveweight (LW) basis for 4–7 days in fenced paddocks across the four replications of this study. This approach required stocking densities be adjusted and grazing be delayed relative to what can be obtained by producers in the region (30 grazing days at 542 lb/ac LW) to balance forage accumulation and removal on the 5.4 ac available for grazing in the study area.

On or within one week following the last day of grazing, hayed CCs were harvested at a 6-in cutting height using a small plot forage harvester (Carter Manufacturing Company). Cover crops were then chemically terminated within one week following hay harvest. Beginning in 2018, split-plots were divided into split-split-plots of NT and OT. Every year, OT was accomplished by tilling once in July or August following CC termination prior to wheat planting to a depth of 3-in with a Premier Tillage Minimizer sweep plow (Premier Tillage, Inc, Quinter, KS, USA).

Each year before grazing was initiated, available CC biomass was determined for the grazing treatment by hand-clipping, to the ground level, two areas of 2 × 3 ft per plot. Samples were dried at 122 ˚F for a minimum of 48 hr in a forced-air oven and weighed to determine dry matter. After grazing, each plot was resampled as previously described. Standing CCs were sampled similarly immediately prior to termination. Hayed CCs were harvested to a height of 6 in. with a small plot forage harvester from a strip of 3 × 100 ft in the middle of each plot. Fresh weights were recorded, subsamples collected and weighed, and then oven-dried to determine hay yield. Profile PAW (0–4 ft) at wheat planting was determined gravimetrically each year in September using a hydraulic probe (Giddings Machine Company). Gravimetric water contents were converted to volumetric water content (VWC) using bulk density (BD). The equivalent depth of PAW was calculated as VWC minus permanent wilting point (−1.5 bars matric potential) water content multiplied by the thickness of the soil layer.

Wheat and sorghum yields were determined each year by harvesting an area 3 × 100 ft from the center of each plot using a Massey Ferguson 8XP small plot combine harvester (Massey Ferguson, Duluth, GA, USA), and yields were adjusted to 13.5% moisture content. Exceptional drought conditions resulted in failed crops in 2022 and 2023. Net returns were calculated for the fallow/CC and wheat phases of the cropping system as total fallow/CC and wheat revenue minus total fallow/CC and wheat costs for each treatment and year. Estimates of current field operations and input costs used 5-yr average custom rate values published by Kansas State University Land Use Survey Program and the Kansas Department of Agriculture (AgManager, 2021). Wheat grain and CC (cool-season grass) hay prices were taken from USDA Economic Research Services market reports (USDA ERS, 2021). Grazing lease rates were valued based on estimated grazing days as a factor of available forage and prices published by Iowa State University Ag Decision Maker (Hofstrand & Edwards, 2015).

Soil samples were collected from the 0-2 and 2-6 in. soil depth in fall 2021 and fall 2022 following the termination of CCs and implementation of tillage. Soil BD was determined as mass of oven dry soil divided by volume of the core following oven-drying at 221°F for 48 hr. The SOC and particulate organic carbon (POC, >53 μm) concentrations were determined by loss-on-ignition, and carbon masses were calculated as concentrations multiplied by BD and the thickness of the soil layer. Lastly, intact soils samples were carefully collected with a flat shovel and were allowed to air-dry and then gently passed through a 0.75-in sieve. Subsamples of <0.31-in diameter aggregates were obtained and used to estimate mean weight diameter (MWD) of water stable aggregates (WSA) by the wet-sieving method. The remaining sample was used to estimate wind-erodible fraction (WEF) (<0.03-in) by the dry-sieving method. Analyses of CC biomass, grain yields, net returns, as well as soil chemical and physical properties were performed using the PROC GLIMMIX procedure in SAS ver. 9.4.

RESULTS AND DISCUSSION

On average, CC biomass remaining after grazing and haying was 61 and 30% of the standing CC, respectively, and CC biomass remaining after haying was 51% of that remaining after grazing (Table 1). Across years, CC biomass remaining after grazing was greater than that after haying in three years and similar in the remaining five years of the study. On average, PAW was not different between standing, hayed, and grazed CCs but all CCs decreased PAW by 19% compared to fallow (Table 1). Profile PAW was unaffected by tillage. Interestingly, despite reduced average PAW, average wheat yields were not different between fallow management (Table 1). Yields following grazed CCs or hayed CCs were less than fallow in four and two years, respectively, but yields were never different than those following standing CCs. Wheat yields were unaffected

Table 1. Cover crop biomass remaining after grazing, haying, and chemical termination as well as fallow management and tillage effects on profile plant available water (PAW) at wheat planting, wheat yields, and net returns from 2015 to 2023 near Brownell, KS. Exceptional drought conditions in 2023 resulted in crop failures.

Treatments	Cover crop biomass	Profile PAW	Wheat yield	Net returns
	lb/ac	in	bu/ac	US$/ac
Fallow management				
Fallow	-	4.3a	49.2a	-15.44c
Standing cover crops	2769a†	3.6b	44.4a	-24.60c
Hayed cover crops	825c	3.5b	46.0a	58.87b
Grazed cover crops	1630b	3.5b	44.2a	88.500a
Tillage				
No-tillage	-	4.0a	47.6a	14.92a
Occasional tillage	-	4.0a	47.9a	4.02a
Year				
2015-2016	2724a	3.9b	57.0a	117.68a
2016-2017	1542cd	4.1b	37.1d	19.22d
2017-2018	2228ab	2.1c	36.5d	30.43cd
2018-2019	2002bc	5.3a	47.7bc	59.73b
2019-2020	1986bc	5.3a	47.1bc	41.44bcd
2020-2021	1304cd	3.5b	52.0ab	49.85bc
2021-2022	10474d	-	44.8c	16.66d
2022-2023	1102d	2.0c	-	-120.33e
Type III test of fixed effects				
Fallow management (M)	<0.0001	0.0179	0.1039	<0.0001
Till (T)	<0.0001	0.7367	0.6829	0.0908
M × Y	<0.0001	0.8850	0.7959	0.8730
Year (Y)	-	<0.0001	<0.0001	<0.0001
M × Y	-	0.0954	0.0051	<0.0001
T × Y	-	0.6354	0.2788	0.0902
M × T × Y	-	0.4912	0.6152	0.1586

†Means followed by the same letter within the same column are not significantly different (α = 0.05) among treatments.

by tillage, which suggests that OT was not required because no yield-limiting compaction occurred with grazing in the present study. Even when subsequent crop yields are reduced after dual-purpose CCs, the diversification of income streams could facilitate increased net profit (Obour et al., 2021a). On average, net returns across fallow management were in the order of grazed CCs > hayed CCs > fallow = standing CCs (Table 1). Net returns with grazed CCs were greater than all other treatments in three years and similar to hayed CCs in five years. Hayed CCs provided net returns greater than fallow or standing CCs in all years. Net returns with standing CCs were similar to fallow in five years, less than fallow in two years, and greater than fallow in one year. Net returns were unaffected by tillage.

Table 2. Fallow management and tillage effects on soil organic carbon (SOC), particulate organic carbon (POC), bulk density (BD), mean weight diameter (MWD) of water stable aggregates, and wind erodible fraction (WEF) in the 0-2 in soil depth at wheat planting in 2021 and 2022 near Brownell, KS.

Treatments	SOC	POC	BD	MWD	WEF
	——— tons/ac ———		lb/ft^3	in	%
Fallow management					
Fallow	4.16a[†]	1.54a	76.2a	0.03b	27.9a
Standing cover crops	4.39a	1.76a	78.0a	0.04a	28.5a
Hayed cover crops	4.30a	1.85a	77.4a	0.04a	30.5a
Grazed cover crops	4.30a	1.68a	76.2a	0.04a	29.1a
Tillage					
No-tillage	4.40a	1.80a	78.7a	0.04a	27.8a
Occasional tillage	4.17a	1.61a	74.9b	0.04a	30.2a
Year					
2021	3.85b	1.43b	72.4b	0.04a	23.8b
2022	4.73a	1.98a	81.8a	0.03a	34.2a
Type III test of fixed effects					
Fallow management (M)	0.7140	0.3135	0.8509	0.0291	0.4063
TILL (T)	0.2258	0.2421	0.0427	0.6555	0.1994
M × Y	0.5611	0.4389	0.1491	0.3692	0.1532
Year (Y)	0.0455	0.0451	0.0246	0.2265	0.0107
M × Y	0.6583	0.3400	0.6080	0.2588	0.6018
T × Y	0.3697	0.9244	0.8522	0.8673	0.0483
M × T × Y	0.3491	0.0611	0.7450	0.6775	0.3533

[†]Means followed by the same letter within the same column are not significantly different (α = 0.05) among treatments.

A primary concern with the adoption of dual-purpose CCs is that removing CC biomass could limit the beneficial effects of CCs for soil health (Obour et al., 2021a). Additionally, grazing CCs in NT systems brings risk of soil compaction from animal hoof action, which could suppress crop yields and require tillage for remediation (Obour et al., 2021b). The SOC and POC were unaffected by fallow management or tillage (Table 2). Similarly, soil BD was unaffected by fallow management, but OT had 5% lower BD than NT. The MWD of WSA was not different between standing, hayed, and grazed CCs and was unaffected by tillage (Table 2). However, all CCs increased MWD by 37% compared to fallow. The WEF was unaffected by fallow management and was not different across tillage in one year but was 17% greater with OT than NT in the other year (Table 2). This suggests that if OT is necessary in long-term NT systems, soil properties are generally not affected compared to NT, but OT could increase WEF.

CONCLUSION

Results from this study showed that CC biomass production averaged about 2800 lb/ac and grazing and haying CCs removed about 40% and 70% of the available forage, respectively. Profile PAW at wheat planting was less following CCs compared to fallow. However, average wheat yields were unaffected by fallow management though effects on wheat yields varied across years. Average net returns were in the order of grazed CCs > hayed CCs > fallow = standing CCs. Fallow management had no effect on BD, SOC, POC, or WEF, but MWD was greater with CCs than fallow. Tillage had no effect on PAW, crop yield, or net returns. Bulk density was slightly lower and WEF was slightly higher with OT than NT, but SOC, POC, and MWD were unaffected by tillage. These results suggest that dual-purpose CCs can provide forage for livestock, increase soil aggregate stability, maintain average crop yields, and increase net returns in NT systems. If OT is necessary to correct root-limiting soil compaction, PAW, crop yields, net returns, and soil properties are generally unaffected compared to long-term NT.

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LONG-TERM TILLAGE WITH WINTER WHEAT GRAIN YIELD IN DRYLAND CROPPING SYSTEM

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ABSTRACT

Long-term studies are important to improve our understanding and evaluate the sustainability of management practices while mitigating climate change. This study evaluated the winter-wheat grain yield stability under long-term tillage practices. Yield stability was assessed using squared deviation from regression (S^2d). This study of winter wheat-fallow rotation was established in 1970 within the High Plains Agricultural Laboratory (HPAL) near Sidney, Nebraska (NE) on Duroc loam soil with slope of ≤ 1%. Wheat grain yield will be presented from 1972 to 2010, with seven years of missing data, under three tillage intensity practices, no-tillage (NT), stubble mulch (SM), and moldboard plow (MP). Throughout the years, average wheat grain yield was about 2.60 Mg ha^{-1} with NT and 2.63 Mg ha^{-1} for MP and SM practices. Tillage did not significantly influence wheat yield ($P = 0.88$) except for six years out of 32 years where tillage had a significant ($P \leq 0.04$) effect on wheat yield. The years and year × tillage interaction significantly influenced wheat grain yield ($P < 0.01$). The influence of years and their interaction with tillage was mostly related to environmental factors (precipitation and temperature) associated with each year within the study period. The stability analysis (yield vs. environment) showed that changes in yield will not be influenced by small changes in environment. The SM practice demonstrates a possibility of yield stability (S^2d = 0.03 that was not significant than zero) under different environments compared with NT and MP practices. In general, SM practice that maintains surface residues could enhance land sustainability and improve yield resiliency under different environmental conditions in dryland cropping systems.

INTRODUCTION

Long-term studies are essential for evaluating the effect of management decisions on sustainable land production (Peterson et al., 2012) while mitigating climate change. In dryland cropping system, water is the most limiting factor for crop production. The wheat-fallow (WF) cropping systems was adapted at the central Great Plain region to improve soil water storage during the fallow period for subsequent wheat crops (Peterson et al., 1998). In this region, the WF system is predominantly associated with specific forms of tillage, either conventional tillage (CT) or moldboard plow (MP). The MP completely inverses and displace the soil surface layer and buries the crop residues in MP furrows, thus depriving the surface soil from its crop residue. In present time, there are multiple tillage practices are being implemented in which can conserve surface residue and reduce soil erosion due to the herbicides availability such as no-tillage (NT), strip, ridge, stubble mulch (SM), and minimum tillage (Reicosky, 2015). With changing climate, it became evident that the agricultural system that can produce stable yield across different environmental conditions could be preferable than the system that is unstable as the environment changes (Kiboi et al., 2017). The stable system is the one that can withstand changes with changing the environment (Raun et al., 1993). Yield stability is defined as the plant's ability to produce yield with less variability under different environmental conditions.

Yield stability analysis was considered useful to interpret the significant year × treatment interaction associated with long-term study where the same treatments were being implemented for several years (Raun et al. (1993). In the last few decades, the concept of yield stability has been used with soil nutrients management (Grover et al., 2009). Recently, Xu et al. (2019) reported that NT and subsoiling exhibit yield stability potential compared with conventional tillage system. In general, the influence of tillage on yield stability is being researched with some uncertainties and more research is yet to be done. Specifically, research regarding yield stability under different tillage practices in dryland cropping system is not extensively studied. Therefore, this research is evaluating the stability of long-term winter wheat grain yield under different tillage practices in dryland cropping system.

MATERIALS AND METHODS

The study was established in 1970 within the High Plains Agricultural Laboratory, Sidney, NE . The soil type is Duroc loam (fine-silty, mixed, superactive, mesic Pachic Haplustolls) with 0–1% slope. The crop rotation consist of winter wheat-fallow (WF), each phase of the rotation was present each year. Tillage practices consist of three levels of tillage intensity and frequencies, no tillage (NT), stubble mulch (SM), and moldboard plow (MP). Stubble mulch tillage accomplished by tilling the soil to a depth of 10–15 cm using 90–150 cm V-Blades with the operation performed two to four times but with a decrease in tilling depth for each subsequent operation. A rotary rod weeder was also used to perform one or two operations. This process maintains soil surface residues. Moldboard plowing was done in the spring at a depth of 15 cm depth followed by two or three operations using a field cultivator and one or two more operations using a rotary rod weeder. The study design was randomized complete block design with three replications with Each experimental unit's area of 8.5 × 45.5 m. Winter wheat was planted in early September. More detailed descriptions of research management were reported by Fenster (1961), Fenster and Peterson (1979), and Peterson et al. (2012). Weather data (precipitation and ambient temperature) from 1970 to 2010 were obtained from the weather station near the experimental site. Throughout the study period, tillage practices and study duration effects on grain yield were tested with F-tests by fitting a linear mixed model appropriate for a randomized complete block design using PROC MIXED procedure (SAS version 9.3). All results were considered significantly different at $P < 0.05$. The yield stability analysis was performed in R. The regression coefficients (βi) and squared deviation from regression (S^2d) were evaluated. The S^2d was used as a measure of dispersion around the regression line to provide an estimate of predictability and repeatability of performance of each tillage practice throughout the study period, represent as an environments. Coefficient of variation (CV) was also used for assessing grain yield variability among the different tillage practices. Detailed description of gain stability analysis is reported in (Aula et al., 2022).

RESULTS AND DISCUSSION

Throughout the study period, wheat grain yield was significantly influenced by study period (years) and by tillage × year interaction ($P < 0.0001$), but not by tillage practices. This indicate that the weather pattern (Precipitation and Temperature) within each year influenced the grain year in combination of tillage. The influence of weather pattern and tillage wheat yield were presented within each tillage practice (Fig. 1). The

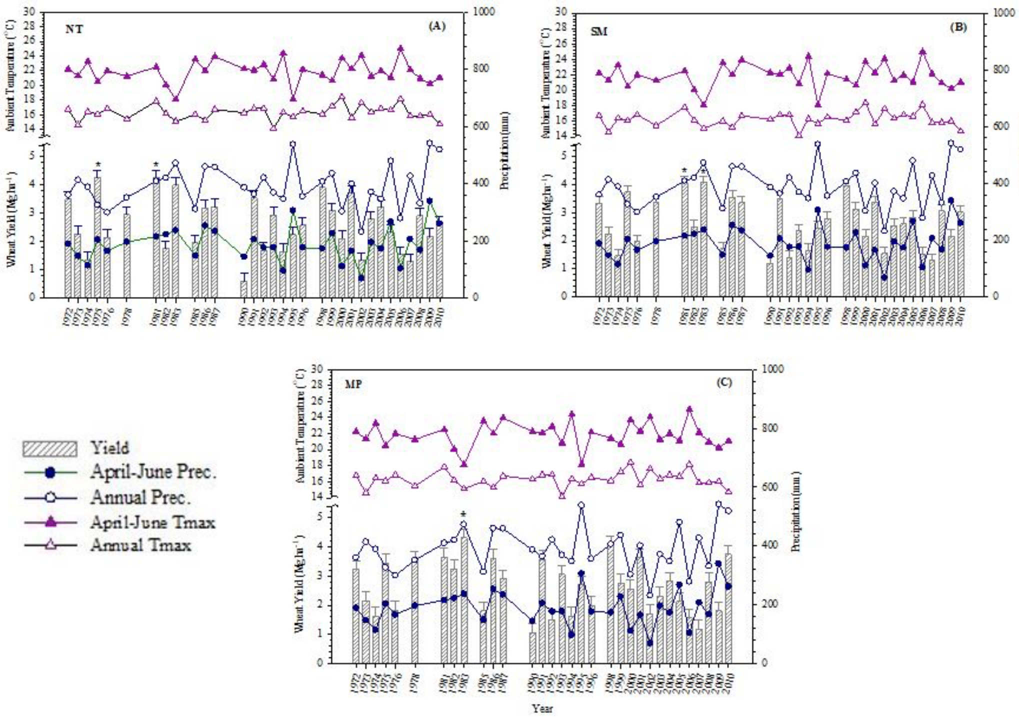

Figure 1. Wheat yield (bars) from 1972 to 2010 influenced by No-tillage, NT; stubble mulch, SM; and moldboard plow, MP tillage practices and by environmental condition, precipitation (blue line with circle symbols) and maximum ambient temperature (purple line with triangle symbols), from April to July. (A) represents wheat yield under NT; (B) represents wheat yield under SM; and C) represents wheat yield under MP. The error bars represent the standard errors of the mean. The filled symbols represent April to June precipitation and maximum temperature while the open symbols represent the annual precipitation and maximum temperature within each year. (*) represents the highest yield observed from 1970 to 2010 within each tillage practice.

highest ($P < 0.001$) wheat yield with NT were recorded in 1975 and 1981 with an average of 4.3 Mg ha^{-1} and the lowest yield was recorded in 1990 with an average of 0.6 Mg ha^{-1} (Fig. 1A). In SM has the highest yield in 1981, 1983, and 1998 with an average of 4.1 Mg ha^{-1} and the lowest yield was in 1990 with an average of 1.2 Mg ha^{-1} (Fig. 1B). Whereas the highest yield for MP management were in 1983 with an average of 4.3 Mg ha^{-1} and lowest yield 1990 with an average of 1.0 Mg ha^{-1} (Fig. 1C). The highest yield varied depending on the individual tillage practices interaction with the weather. Indicating that the weather could influence wheat yield depending on the type of tillage implemented. The lowest yield was reported in 1990 regardless of tillage practices which was probably not related to the precipitation that was not the lowest throughout the study period or to the ambient temperature that was almost like the previous and subsequent years. The low yield was probably related to other factors that we are not accounting for in this study such as rain intensity and temperature fluctuation between day and night during wheat critical growth stage. The quantity of rainfall may not be the restraining factor rather its extreme variability such as high rainfall intensity, uneven spatial or temporal distribution of the few rainy days (Hatibu et al., 2003) and temperatures fluctuations (Zampieri et al., 2020) could affect crop yield in dryland cropping system.

Principal component analysis (PCA) was performed to evaluate the relationship between study parameters (Fig. 2). Our data showed that yield was positively correlated to precipitation while negatively influenced by ambient temperature, indicating that the increase in precipitation will lead to yield increase while increasing in ambient temperature will cause a reduction in wheat yield. The length of the precipitation variables, represented by arrows, (prec. summer and prec. seasonal) has the same length indicating that both variables have equal contribution to the yield increased. However, the length of the temperature variable Tmax. Summer was longer than the variable Tmax. seasonal indicating that the negative influence of Tmax. Summer is more influential on wheat yield than Tmax. Seasonal. In addition, the ambient temperature from April to June, the critical wheat growth stage, is more important than the seasonal temperature.

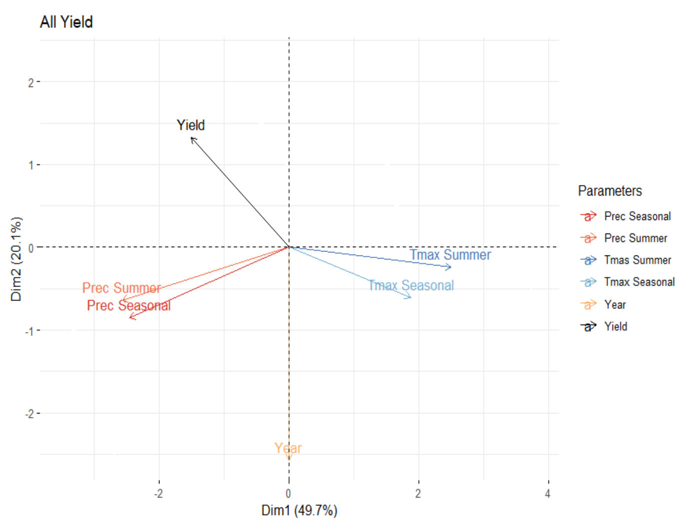

Figure 2. Wheat yield throughout the study period influence by summer (April to June) and seasonal precipitation (mm) and ambient temperature (℃) throughout the wheat growing season from 1972 to 2010. The Prec. Summer and Tmax. summer, represent the period from April to June and prec. seasonal and Tmax. Seasonal represent the wheat growing season within each year of the study. The principal component analysis (PCA): arrows indicate correlation of parameters with the principal component. Percentage refer to variability explained by the principal component.

Wheat yield stability could provide a direct approach in evaluating the influence of the temporal changes on land sustainability (Raun et al., 1993).The regression coefficient, β_i and square deviation from regression, $\delta^2 d_i$ (Table 1), were used to evaluate the performance and the suitability of each tillage, regarding wheat yield, under different environments throughout the 39 years. Our data suggested that different tillage practices (NT, SM, and MP) exhibit average yield stability due to the β_i's that were not significant (P = 0.43) from zero and β_i's values of ~ 1.0 (Table 1). Indicating that all tillage practices were equally adequate to be implemented. The regression line (Fig. 3) of each tillage practice was not different that the regression line of the environmental mean (black line). Indicating that minor changes in the environment have no influence on changing in grain yield among different tillage practices.

Table 1. Wheat yield stability parameters (mean yield, m_i; regression coefficient, β_i; square deviation from regression, $\delta^2 d_i$; and Coefficient of variation CV influenced by No-tillage, NT; stubble mulch, SM; and moldboard plow, MP tillage practices. Table adapted from Aula et al., (2022).

Tillage	$\text{Yield}_{(\text{mean})}$	$\text{Yield}_{(\text{differences})}^{a}$	β_i	$\delta^2 d_i$	CV
	------------ $Mg\ ha^{-1}$	------------			%
NT	2.60	– 0.02	$1.04^{\dagger}$	0.063^{*}	37.6
SM	2.63	0.01	0.97	0.027	33.9
MP	2.63	0.01	0.99	0.075^{**}	36.3

[a] Yield difference was computed as yield associated with a particular tillage practice minus population average yield (2.62 $Mg\ ha^{-1}$).; * Significant at the $P \leq 0.05$.
** Significant at the $P \leq 0.01$; † ns, not significant at $P = 0.43$

The influence of different tillage practices on yield stability could be evaluated using $\delta^2 d_i$, square deviation from regression. For this parameter, $\delta^2 d_i$, the zero value represents high yield stability while the significant deviation from zero represents low yield stability. In our study, the $\delta^2 d_i = 0.03$ was associated with SM practice (Table 1) and was not significant than zero indicating higher yield stability under different environments. While the NT showed the $\delta^2 d_i = 0.063$ and MP had the $\delta^2 d_i = 0.075$ that were significantly different than zero (Table 1), indicating that NT and MP are suitable in specific environments. The NT with $\beta_i = 1.04$ (> 1.0) indicate that NT could perform well in high-yielding environments while MP with $\beta_i = 0.99$ (< 1.0) may perform well in low-yielding environments (Fig. 3). The MP performed well in low-yielding environment could be related to no nutrient addition to this study site since the 1970. We believe that the MP practice of mixing crop residue with soil could provide nutrients for crop through residue decomposition relative to NT practice.

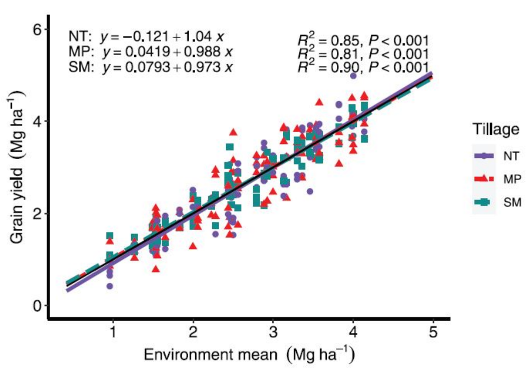

Figure 3. Wheat yield stability analysis throughout the study period 1972-2010 influenced by tillage practices, no-tillage, NT; moldboard plow, MP; and stubble mulch, SM. The solid line represents the population mean. Figure adapted from Aula et al., (2022).

Our observation regarding the $\delta^2 d_i$ relation to yield stability was supported by the Coefficient of variation (CV) valued (Table 1). The CV of 33.9% was associated with SM compared with NT of 37.6% and MP of 36.3% indicate that the variability of the β_i and the intercept of SM practice was low (Fig 3).This study showed that the stability of long-term wheat yield was influenced by different tillage practices in the dryland cropping. Significant grain yield stability was associated with the SM which could be related improvement of soil properties that was not associated with NT or MP practices. Further research regarding soil properties need to be examined to relate soil properties and nutrients dynamics to yield stability under different tillage practices.

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ACCOUNTING FOR NITROGEN FROM OFTEN OVERLOOKED SOURCES

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ABSTRACT

Improving nitrogen use efficiency has long been a goal of both researchers and producers. With increasing interest and adoption of regenerative agricultural practices, fertility strategies can change from traditional methods. However, changes in strategies are often not considered when adopting new practices. The goal of this presentation is to discuss potential sources of nitrogen that are often overlooked when developing nitrogen management strategies. For example, legume cover crops or rotational crops are often a viable component of regenerative practices, but the contribution of N to the system is often not well quantified and accounted for. Our research has shown that soil nitrate levels can be up to three times greater following leguminous cover crops compared to no cover crop systems. In addition, well water nitrate can provide 100% of crop N requirements. Accounting for these sources can result in reduced N inputs, greater N use efficiency, and greater return to the producer.

SOIL N CREDITING FOR TEXAS WHEAT PRODUCTION

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ABSTRACT

The objectives of this research effort were to assess soil N crediting depth and yield-based N fertilizer recommendations across wheat producing regions of Texas. Trials were coordinated among six different regions in 2017, 2018, and/or 2019 for a cumulative 10 site-years (not all sites were represented in all years). Treatments comprised a 6 × 4 factorial with six yield-based N rates (0, 0.5, 1, 1.5, 2, and 2.5 lbs N per target bushel) and four N crediting depths (0, 0-6”, 0-12”, 0-24”). Yield responses to added N fertilizer were observed in 5 of the 10 site-years, and the most accurate yield-based N requirement assumption varied across environments from 1 to 2 lbs per bushel. In no case did crediting soil N result in a yield reduction or negative effect, and in few instances soil N contributed more to test weight and grain protein than applied fertilizer N. Overall, the findings of this work support that wheat uses soil available N at least 24” deep, which may inform fertilizer input reductions and improve fertilizer use efficiency.

INTRODUCTION

Fertilizer is one of the largest variable input costs to wheat producers each year and nitrogen is applied more than any other nutrient. Nitrogen, in the form of nitrate, is a very mobile nutrient in the soil and is readily transported via leaching and runoff. The combination of high application rates and mobility in the environment can lead to low nitrogen use efficiency (NUE) and environmental and economical disadvantages for growers. One way to reclaim some of this “lost” nitrogen is through soil crediting and allowing wheat roots to utilize soil nitrate nitrogen already in the soil profile. Also, environmental conditions vary tremendously across Texas and modern varieties may be more N use efficient, calling into question current recommendations, which are based on data generated over 30 years ago. Therefore, reevaluating region-specific recommendations could help growers better match nitrogen rates with crop requirements. By improving regional recommendation rates and implementing soil nitrogen crediting, wheat growers can increase fertilizer efficiency and net returns. The objectives of this project were to assess soil N crediting depth and yield-based N fertilizer recommendations across wheat producing regions of Texas.

MATERIALS AND METHODS

Plots were planted at each location in a three replicate split-plot design with main plots assigned by N rate (0, 0.5, 1.0, 1.5, 2.0, 2.5 lb N/bu of expected yield) and N crediting depth (0, 0-6", 0-12", 0-24") randomly assigned as subplots within the main plots. Plots were 15' wide × 25' long. N rates were based on estimated yield goals per site. Varieties, planting rate, and planting date were all done using best management practices for each location and thus were not the same across all sites. Initial soil sampling down to 36" (or 24" if soil depth or logistics were limiting) was conducted in the fall at each location prior to study implementation to quantify residual NO_3-N per crediting depth at each site. Other macro and micro nutrients were applied as needed at other locations according to 0-6" soil test results. Some sites received 20 lb ac^{-1} of fertilizer N (with the exception of the untreated check) in the fall. The different N fertilizer treatments were applied (32-0-0) as spring top-dress using streamer nozzles. Application rates were rounded to the nearest 5 lb ac^{-1} rate due to equipment accuracy.

Harvest measurements included grain yield, test weight, protein, stover biomass, stover N content, and grain yield components. All responses were analyzed per site-year using mixed models in SAS with crediting depth, N rate, and their interaction as fixed effects, and block as random. Differences were identified at $\alpha = 0.05$ and means were separated using Fisher's protected LSD.

RESULTS AND DISCUSSION

Yield responses to added N fertilizer were observed in 5 of the 10 site-years. Production environments varied widely, with average yields ranging from ~15 to 55 bu ac^{-1}. Among yield responses to N fertilizer at lower-yielding sites, the most reasonable yield-based N assumption was near 1 lb N ac^{-1} per bushel. However, higher rainfall environments and higher yielding sites supported optimum rates near 1.5 or 2.0 lb N ac^{-1} per bushel. Across all site-years, reducing fertilizer N inputs according to soil N credit did not reduce yield or negatively affect grain protein or test weight. In one case, increasing test weight was observed at greater crediting depths, which may indicate greater utility of soil profile N than added fertilizer N relative to the environmental conditions of that site-year. While the effects (and lack thereof) of crediting soil N support that wheat is accessing soil N at least 24" deep, it is important to note that a yield response to added N fertilizer was not observed at all in 5 of the 10 site-years. This alludes that soil N could likely be credited at even greater depths, particularly in cases where wheat yielded an average 35 to 45 bu ac^{-1} regardless of fertilizer N input. In other cases (very low yielding environments) it is likely that N simply was no more limiting to growth and production than other environmental stresses. This research project establishes a framework to better inform efficient wheat N fertilizer inputs and highlights meaningful relationships between nutrient availability, grain yield, and grain quality.

THE PARADOXICAL PURSUIT OF SUSTAINABLE NITROGEN MANAGEMENT IN IRRIGATED HIGH-ELEVATION HAY MEADOWS

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ABSTRACT

Flood irrigated hay meadows are an integral, but often under-performing component of livestock operations in the Mountain West. Saturated soil and cool temperatures result in buildup an organic (O)-horizon, hindering forage production and nitrogen (N) cycling. For these reasons, many ranchers choose to fertilize with N regardless of large stores of N already in the soil. To improve long-term forage production in meadow systems, it is critical to understand the interaction between N cycling and soil N storage. Experiments were established in four locations in Wyoming and Colorado to monitor nutrient storage between fertilized and unfertilized irrigated meadows and unirrigated native rangelands. Total organic carbon (C) & N, microbial biomass C & N, potentially mineralizable C & N, dissolved organic C & N, nitrate (NO_3^-), and ammonium (NH_4^+) were assessed in each soil horizon to 1.5-m depth. Results confirmed significant accumulation of C and N in the O-horizon and significant differences in other C and N pools between the three systems. Unfertilized meadows stored significantly more stable and labile C and N than fertilized meadows and rangelands. Fertilized meadows stored comparable amounts of C and N to those in rangelands. An additional experiment assessed the impact of different field techniques (targeted grazing and tillage) to stimulate N mineralization from the O-horizon for improved fertility management. Results indicate heavy grazing and tillage stimulates N mineralization but damages the plant community, suggesting the need for other management techniques to manage soil N. A third experiment examined the effect of irrigation by assessing N mineralization with in-field incubation cores. The rate of N mineralization was highest 2-4 weeks after irrigation cessation, as soils warmed and became aerated. Avoiding long-term saturation during the growing season may improve N mineralization and plant utilization.

INTRODUCTION

Flood irrigated high-elevation hay meadows are integral to ranching operations in the Intermountain West as they provide critical winter forage for livestock production. Meadows developed in high mountain basins following the creation of canal and ditch systems to expand the irrigable footprint of land surrounding rivers and creeks (Peck & Lovvorn, 2001). High flow during spring snowmelt provides water to continuously flood meadows for 6-8 weeks from spring to mid-summer, after which one cutting of hay is harvested. Due to the short growing season and inefficient irrigation methods, yields are modest, averaging 1220-2240 kg ha^{-1} yr^{-1} (Ludwick & Rumburg, 1976).

To improve yields, ranchers often apply fertilizer nitrogen (N) at 60-90 kg ha^{-1} which increases forage yield to 3360-5600 kg ha^{-1} yr^{-1} (Ludwick & Rumburg, 1976).

However, the application of fertilizer N to sustain economic yields is paradoxical considering the abundance of organic N in meadow soils. Producers and researchers have noted the development of an organic (O)-horizon or “thatch” layer at the surface of meadow soils resulting from decades of seasonally flooded soil and short growing seasons which constrain microbial decomposition of residue (Lewis, 1957; Sims, 1979). However, few researchers have examined the effect of the O-horizon on nutrient cycling and N management in meadows. Only Siemer, (1979) noted 1220-2460 kg N ha^{-1} were stored in the top 10 cm of meadow soil. Later, Brummer et al., (2000) examined the effect of strip tillage and spike aeration to disturb the O-horizon and stimulate N mineralization but found no positive effect on yield.

With the increasing occurrence of drought, and the volatile nature of hay and fertilizer markets, producers must utilize sustainable management practices to maintain productivity of meadow forage systems. Therefore, the objective of this study is to examine the importance of the O-horizon in meadows as a fertility resource to reduce dependence on synthetic N for improved economic and agronomic sustainability in forage producing meadows.

MATERIALS AND METHODS

Carbon and Nitrogen Pools

To determine how long-term flood irrigation and fertilization have affected meadow soil organic matter (SOM), C and N storage and cycling, we identified four meadow systems in southern Wyoming and northern Colorado in fall 2021. Each meadow was flood irrigated and >2000-m elevation. At each meadow system we identified three management zones: 1) long-term irrigated meadow, 2) long-term fertilized and irrigated meadow, 3) unirrigated, unfertilized rangeland. All management zones were on the same soil series. At each location we excavated a soil pit to 1.5-m depth and took samples in each unique soil horizon from three adjacent pit faces according to Norton et al., (2004). Samples were placed on ice and transported to the lab for determination of total organic carbon (TOC), total nitrogen (TN), dissolved organic carbon (DOC), and nitrogen (DON), potentially mineralizable carbon (PMC), and nitrogen (PMN), nitrate (NO_3^-), and ammonium (NH_4^+). NO_3^-, and NH_4^+ were determined by extraction in 2M KCl followed by colorimetric analysis. PMN was analyzed using a 2-week anaerobic incubation (Waring & Bremner, 1964). PMC was analyzed using a 2-week aerobic incubation analyzed for CO_2 evolution (Zibilski, 1994). DOC and DON were determined by extraction in 0.5M K_2SO_4 and combustion analysis. MBC and MBN were determined using the fumigation method followed by extraction in 0.5M K_2SO_4 and combustion analysis (Horwath & Paul, 1994). TOC and TN were determined using combustion analysis.

Nitrogen Mineralization

To determine how management affects N-mineralization in meadows we established a randomized complete block field study at the Laramie Research and Extension Center (LREC) in fall 2021. Treatments included light, targeted grazing (145,000 kg liveweight ha^{-1} d^{-1}), heavy, targeted grazing (600,000 kg liveweight ha^{-1} d^{-1}), and rototilling to 4-cm depth. All treatments were initiated in fall 2021, and grazing treatments were repeated in fall 2022. Forage yield was determined by cutting a 1 × 15-m swath through the center of each plot in summer of 2022 and 2023. Soil samples were taken to 15-cm depth 7, 10, 13, and 20 months after treatment and analyzed for PMN, NO_3^-, and NH_4^+ using methods described above. PMN, NO_3^-, and NH_4^+ were summed to represent labile N.

To determine how irrigation affects seasonal N-mineralization, we implemented a field incubation on two of the four meadows mentioned above. The incubation was established in April 2023 immediately following soil thaw. Incubation cores were created by sampling a 4.5-cm diameter core encased in PVC plastic tubing to 22-cm depth. Ion exchange resin (IER) bags were placed at the bottom of the core to trap leached inorganic N. Grass was killed at the surface of the core. In this way, we created a field incubation that excludes inorganic N loss from leaching and plant uptake but allows natural exchange of water and gas to quantify season-long plant-available N mineralization. Cores were taken from the field, destructively sampled, and analyzed for NO_3^-, and NH_4^+ in soil and resins at nine pre-determined time points: following soil thaw, before irrigation, halfway through irrigation season, at irrigation termination, then 2 weeks, 4 weeks, 8 weeks, 12 weeks, and 16 weeks following irrigation termination.

Statistical Analysis

To determine differences in total storage of C or N to 1.5-m depth in meadow and rangeland soils, C or N mass (kg ha^{-1}) was determined for each horizon by adjusting for bulk density and horizon depth and summed to 1.5-m depth. Differences among treatments were determined using a linear mixed effects model using the “lme4” package in R version 4.1.1, with management as a fixed effect and site as a random effect. Means separation was performed using Tukey-adjusted pairwise comparisons at $\alpha = 0.05$. Differences in forage yield and labile N among grazing and tillage treatments were determined the same as above, with block being the random effect in the model.

N-mineralization rates were compared using a response feature analysis to determine the rate of change in $NO_3^- + NH_4^+$ concentration in cores between sampling points. The rate of change was then analyzed using a mixed-effects model as above, with sampling period as the main effect and location as a random effect. The estimated marginal mean and corresponding 95% confidence interval were determined using the “emmeans” package in R.

RESULTS AND DISCUSSION

Decades of continuous flood irrigation have resulted in an increase in both stable and labile C and N storage in unfertilized meadow soils compared to unirrigated rangeland soils (Table 1). However, meadows with long-term N fertilization in addition to irrigation had C and N pools that more closely resembled rangeland soils than unfertilized meadows. This may be a result of a priming effect of N fertilization, where increased bioavailable N provides enough microbial stimulation to allow for increased utilization of stable C and N pools which developed following irrigation (Kuzyakov et al., 2000).

Table 1: Total storage of C and N pools for three management systems to 150-cm depth. Values in brackets represent the standard error. Treatment means followed by different letters were significantly different at α = 0.05.

	Treatment					
	Unfertilized meadow		Fertilized meadow		Rangeland	
C or N Pool [a]	---------------- (kg ha^{-1}) ----------------					
TOC	219000 (18800)	a	167000 (14700)	b	134000 (18200)	b
TN	12200 (326)	a	8240 (711)	b	8590 (1060)	b
DOC	1430 (248)	a	610 (37.5)	b	1670 (478)	a
DON	112 (33.8)	a	34.6 (3.62)	b	58.5 (8.79)	a
MBC	3630 (670)	a	1750 (235)	b	1350 (153)	b
MBN	213 (48.5)	a	107 (14.1)	b	87 (11.9)	b
PMC	2300 (186)		1810 (266)		2090 (256)	
PMN	15.5 (4.88)	b	35.5 (8.91)	a	36.5 (8.00)	a
NO_3^- + NH_4^+	70.5 (11.6)	a	63.2 (8.9)	ab	50.6 (10.4)	b

[a] DOC = Dissolved organic carbon, DON = Dissolved organic nitrogen, MBC = Microbial biomass carbon, MBN = Microbial biomass nitrogen, PMC = Potentially mineralizable carbon, PMN = Potentially mineralizable N, TOC = Total organic carbon, TN = Total N

Some of the management tactics at the LREC experiment also resulted in stimulated microbial activity leading to increased N mineralization. Rototilling led to a significant increase in labile N in summer (10 months following treatment) and spring (20 months following treatment) (Figure 1). Heavy grazing also increased labile N, but not significantly more than the control.

Table 2: Forage yield (kg ha^{-1}) in meadows following rototilling, light grazing (145,000 kg liveweight ha^{-1} d^{-1}), and heavy grazing (600,000 kg liveweight ha^{-1} d^{-1}) in 2022 and 2023. All treatments were initiated in fall 2021, and grazing treatments were re-applied in fall 2022 Different letters denote significant differences among treatments at α = 0.05.

	2022		2023	
Treatment	------------Yield (kg ha^{-1})--------------			
Roto-till	1431	b	4143	a
Heavy Grazing	2975	ab	2243	b
Light Grazing	4101	a	3061	ab
Control	4699	a	3828	ab

Forage yields, however, showed the opposite response, where intense disturbance reduced yields (Table 2). Consecutive years of heavy grazing damaged the plant community and led to significantly reduced yields in 2023. Rototilling was similar, where excessive disturbance resulted in significantly decreased yields in 2022, but the plant community and yields recovered in 2023. Although more-intense disturbance increased labile N, it also reduced plant growth and negated potential benefits of increased N mineralization.

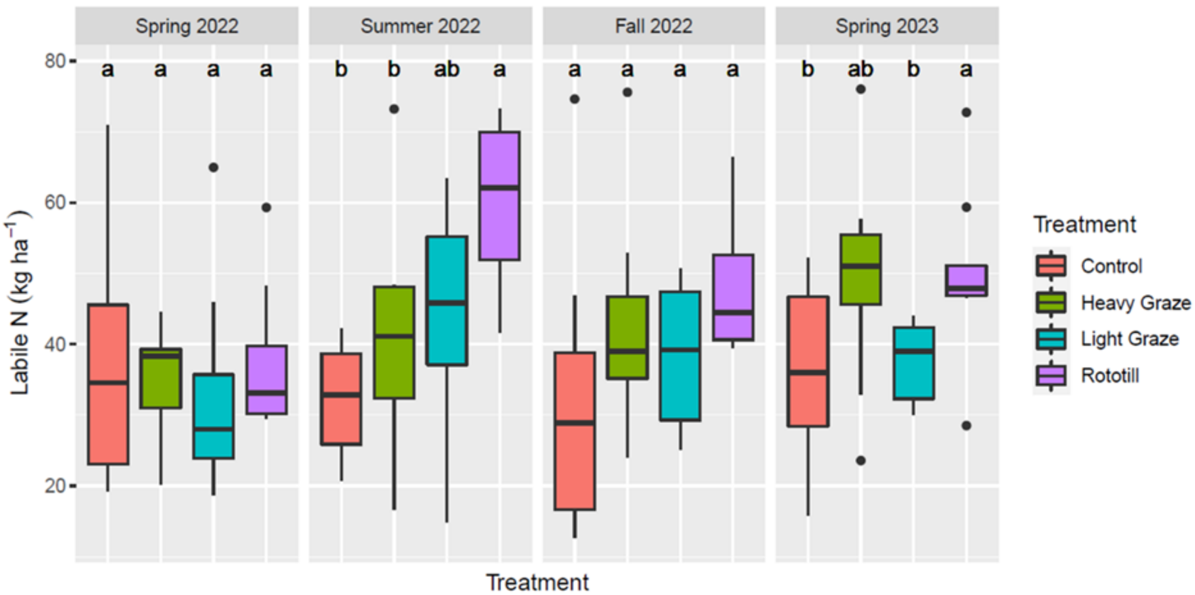

Figure 1: Labile N (kg ha^{-1}) (potentially mineralizable N + NO_3^- + NH_4^+) in meadows at LREC field experiment following rototilling, light grazing (145,000 kg liveweight ha^{-1} d^{-1}), and heavy grazing (600,000 kg liveweight ha^{-1} d^{-1}), for four seasons. All treatments were initiated in fall 2021, and grazing treatments were re-applied in fall 2022, four weeks prior to sampling. Different letters denote significant differences among treatments at each time point at α = 0.05.

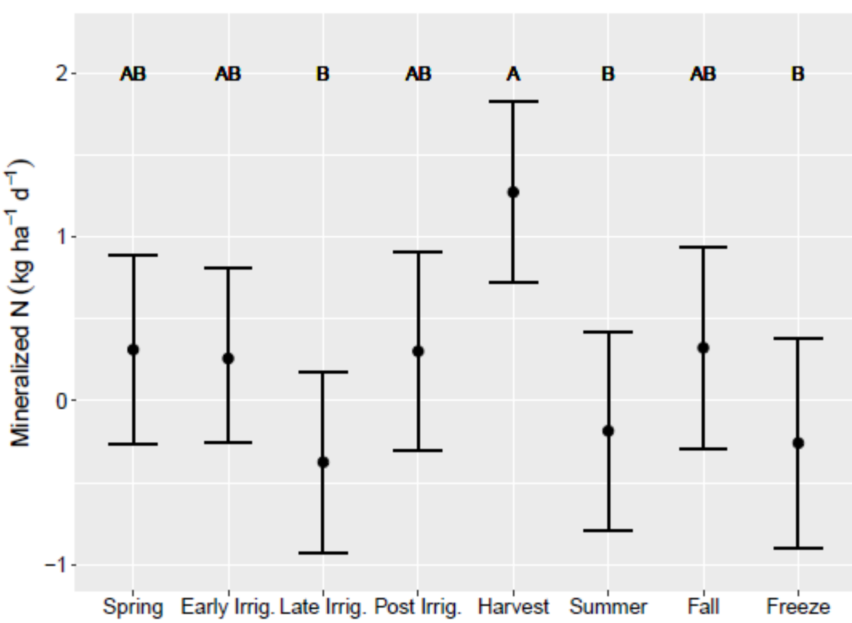

Figure 2: N mineralization rate (kg ha^{-1} d^{-1}) in meadows during eight unique periods of the frost-free season. Error bars denote 95% confidence interval. Different letters denote significant differences among periods at α = 0.05.

The inability of disturbance to increase forage yield through N mineralization means other practical management factors should be considered to leverage N mineralization for increased yield. Early research on meadows suggested that continuous irrigation and soil saturation decreased yield, and that staggered irrigations increased yield (Rumburg & Sawyer, 1965). This is partially due to increased N mineralization from microbial activity following periods of soil aeration between irrigation events. The results of our in-field incubation support this hypothesis, as we observed the highest rate of N mineralization in meadows during harvest, 2-4 weeks following irrigation termination, and the lowest rate of N mineralization 4-8 weeks after irrigation initiation when anaerobic conditions are most prevalent (Figure 2). Mineralization rates were also low in summer and late fall when drought or cold also become limiting factors for microbial activity. Therefore, producers should be cognizant to not over-saturate meadows during the growing season, when opportunities for efficient N mineralization and consequent utilization by the plant community are highest.

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SIDE-DRESS APPLIED ESN REDUCES N_2O COMPARED WITH SINGLE UREA APPLICATION FOR IRRIGATED CORN

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ABSTRACT

Enhanced efficiency fertilizers (e.g., ESN poly coated urea), may reduce soil nitrous oxide (N_2O) emissions while maintaining or increasing crop yields. However, further increases in N fertilizer efficiency may be attainable with a starter fertilizer application followed by side dressed ESN. We monitored soil N_2O using surface chambers from three N treatments (202 kg N ha^{-1} single application of urea, 34 kg N ha^{-1} starter urea combined with 168 kg N ha^{-1} side-dressed ESN, and a 0 N control) to determine their effects on per unit area and yield scaled emissions from a no-tilled clay loam soil under irrigated, continuous corn production for three years. Average annual cumulative emissions were 1.4 kg N ha^{-1} yr^{-1} for the urea treatment, 0.8 kg N ha^{-1} yr^{-1} for starter urea with side-dressed ESN, and 0.3 kg N ha^{-1} yr^{-1} for the control. Interannual variability was large for the urea treatment, ranging from 0.8 to 2.0 kg N ha^{-1} yr^{-1}, and minimal for starter urea with side-dressed ESN (0.7 to 0.9 kg N ha^{-1} yr^{-1}), and the control (0.27 – 0.3 kg N ha^{-1} yr^{-1}). Average annual yield scaled emissions were 0.13 kg N Mg^{-1} yr^{-1} for the urea treatment, 0.08 kg N Mg^{-1} yr^{-1} for starter urea with side-dressed ESN, and 0.05 kg N Mg^{-1} yr^{-1} for the control. Yield scaled emissions showed similar inter-annual variability patterns as observed for unit area. These results provide evidence that side-dressed ESN combined with starter urea application is a reliable way to decrease area and yield scaled N_2O emissions from irrigated no till corn.

INTRODUCTION

Nitrogen (N) fertilizers are typically applied to corn to maintain optimal yields. However, N fertilizers also contribute to adverse environmental impacts including increased atmospheric N_2O concentrations, NO_x and NH_3 emissions which compromise air quality, and nitrate leaching into aquatic systems which enhances eutrophication. In this paper we concentrate on N_2O emissions because N_2O is a powerful greenhouse gas that also contributes to stratospheric ozone depletion. In addition, agricultural soils are the major anthropogenic source of N_2O, and corn is responsible for more N_2O than any other crop grown in the US.

Compared to standard urea (the most common N fertilizer used in the US), enhanced efficiency fertilizers are designed to improve synchrony between N availability in soil and crop N uptake. The polymer-coated urea known as ESN (Nutrien Ltd.) attempts to accomplish this by gradually releasing N as the polymer coating breaks down in response to favorable soil water content and temperature conditions. Meta-analyses suggest that ESN and similar slow release fertilizers reduce N_2O by about 24% on average (Zhang et al. 2019), but results are not consistent, and studies often show no reductions (e.g., An et al. 2021). In theory, ESN should increase crop yields or allow reduced rates without a yield penalty, and recent meta-analysis for maize showed an average increase of about 5% (Zhang et al. 2019).

Previous research in Colorado has shown that broadcast ESN reduced N_2O emissions by about 42% on average from no till and strip till irrigated corn (Halvorson et al., 2014), but did not increase yields compared to urea (Halvorson and Del Grosso 2013). Side-dress applications of a slow-release fertilizer with a starter N application could more closely match plant N demand, increasing yields under no-tillage while at the same time reducing N_2O emissions compared to urea. Combined yield boosts with reduced N_2O emissions could lead to improved yield-scaled N_2O emissions, a critical metric for environmental impact. The objective of this study was to compare N_2O emissions and corn grain yields from a single application of urea with starter urea combined with side-dressed ESN for a no till irrigated system in Colorado over three years.

MATERIALS AND METHODS

The study was located on a Fort Collins clay loam soil (fine-loamy, mixed, mesic Aridic Haplustalfs) at the Agricultural Research Development and Education Center (ARDEC) (lat. 40° 39’6” N, long. 104° 59’57” W; 1535 m above sea level) northeast of Fort Collins, CO. The soil chemical and physical properties of the 0- to 7.6-cm soil depth were: pH, 7.6; SOC, 11.6 g kg^{-1}; TSN, 1.5 g N kg^{-1}; electrical conductivity (1:1 water/soil ratio), 0.34 mS cm^{-1}; bulk density, 1.46 g cm^{-3}; \$0 %sand and 33% clay (Halvorson et al., 2010; Halvorson and Del Grosso, 2012). The experimental design was a split-plot randomized complete block with three replications. Main plot size was10.7 by 21.3 m.

The study was initiated in 2015 in plots that were cropped with no till corn. Corn was directly planted into the previous year’s corn residue followed by application of herbicides for weed control. For the business as usual treatment, urea fertilizer was broadcast applied at 180 kg N ha^{-1} after planting. For improved N management, urea fertilizer was broadcast applied at 30 kg N ha^{-1} after planting followed by a side-dress application of ESN at 150 kg N h^{-1} 30 days after planting. No N fertilizer was applied for the control treatment. A linear-move sprinkler irrigation system was used to apply water as needed during the growing season.

Measurements of the soil–atmosphere exchange of N_2O began in 2015 following procedures reported by Mosier et al. (2006), Halvorson and Del Grosso (2013), and Parkin and Venterea (2010). Measurements were generally made two to three times per week during most of the growing (end of May through August). Sampling frequency was reduced to around twice per week for the end of the growing season (until around the end of the September), and then reduced further to once or twice per month during the non-growing season. This is justified because previous work showed that high N_2O pulses in this system occur only after the application of fertilizer and that emissions return to background levels by the end of September, regardless of the type or amount of fertilizer applied (Halvorson et al. 2016; Liu et al. 2005). The general gas sampling schedule during the time when large pulses occur (June-August) was to collect gas samples on Monday before the scheduled weekly irrigation event (the plots only had opportunity to irrigate on Mondays), Wednesday, and Friday. A vented non-steady-state closed chamber (rectangular aluminum, 78.6 cm x 39.3 cm x 10 cm height, with anchor) was used (Mosier et al., 2006). Anchors were set perpendicular to the corn row so that the corn row and inter-row area were contained within each chamber, and corn plants cut off at about V-6 growth stage to facilitate air tight chamber placement (Halvorson and Del Grosso 2012). Two chambers were placed within each plot for a total of six gas measurements per treatment per sampling date. Air samples from inside the chambers were collected by syringe at 0, 15, and 30 minutes. The samples were transported to the laboratory where the 25-mL air samples were injected into 12-mL evacuated tubes sealed with butyl rubber septa (Exetainer vial from Labco Limited, High Wycombe, Buckinghamshire, UK). The gas chromatograph (Varian model 3800, Varian Inc., Palo Alto, CA) was equipped with an electron capture detector to quantify N_2O concentrations.

Samples were collected mid-morning (time when average daily temperatures typically occur) and were scaled up to calculate daily N_2O fluxes. Daily emissions for non-sampling days were obtained using linear interpolation between adjacent sampling dates and cumulative emissions were derived by summing daily emissions. Emission factors (EF) were calculated by subtracting cumulative annual emissions for the fertilized treatments from the control treatment and dividing by the amount of fertilizer applied (180 kg N ha^{-1}). Nitrous oxide emissions were also calculated on per unit grain yield and per unit grain N bases by dividing cumulative annual emissions by dry matter yields and N in harvested grain, respectively.

Soil water content (0- to 10-cm depth) and soil temperature (5 to 7 cm depth) were monitored at each gas sampling event using 3 soil moisture and temperature probes (EC-TM model, Decagon Devices Inc., Pullman, WA) located ~20 cm from the corn row in each replication. Water-filled pore space (WFPS) was calculated according to the soil bulk density (measured by core method) at 0- to 10-cm depth following crop harvest and an assumed particle density of 2.65 Mg m^{-3} (Linn and Doran, 1984).

RESULTS AND DISCUSSION

Environmental Factors

Soil temperatures (5-7 cm depth) were cooler during May and early June compared with later in the growing season with crop canopy closure when soil temperatures rose to around 22°C, then declined during the latter part of the growing season. Water-filled pore space was generally between 50 and 60% during the growing season each year. Yearly precipitation in 2012 was 159 mm lower than the 126 yr average at Fort Collins, CO, 2013 was 81 mm lower than the long-term average, and 2014 was 59 mm lower than long-term average.

Area Scaled Nitrous Oxide Fluxes and Emission Factors

Annual cumulative N_2O-N fluxes were significantly greater for the fertilized treatments compared to the control during all three years (Figure 1). Cumulative emissions were significantly lower for the starter urea combined with side-dressed ESN compared to single application urea during 2015 and 2017. Averaged across years, cumulative annual N_2O-N fluxes were significantly greater for single application urea (1.37 kg N ha^{-1}) compared to starter urea combined with side-dressed ESN (0.75 kg N ha^{-1}) and both were significantly greater than the control (0.27 g N ha^{-1}). Emission factors for single application urea ranged from 0.28 to 0.83% (mean = 0.55%) and were higher than those for starter urea combined with side-dressed ESN which ranged from 0.2 to 0.3% (mean = 0.24%).

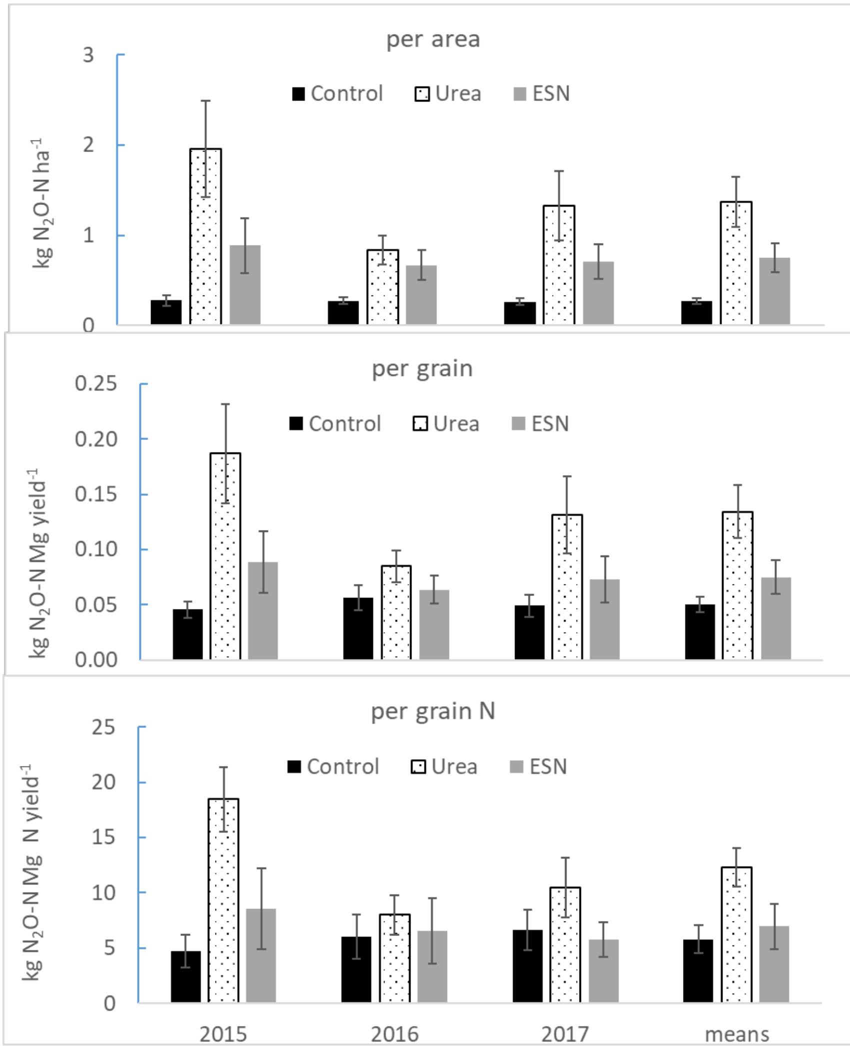

Figure 1. Comparison of nitrous oxide emissions from irrigated corn on area, grain yield, and grain N bases from 0 N addition control plots, business as usual plots amended with180 kg N ha^{-1} after planting, and improved N management plots receiving 30 kg N ha^{-1} urea after planting followed by a side-dress application of ESN at 150 kg N h^{-1} 30 days after planting.

Yield scaled N_2O Emissions

Nitrous oxide emissions per unit of grain yield showed similar patterns of area scaled emissions and when averaged over years were greater for single application urea (0.13 kg N_2O-N per Mg grain) compared to starter urea combined with side-dressed ESN (0.08 kg N_2O-N per Mg grain) and both were significantly greater than the control (0.05 kg N_2O-N per Mg grain). (Figure 1). The individual years showed the same patterns and differences were significant for all years. Patterns were similar for grain N scaled emissions and when averaged over years were greater for single application urea (17 kg

N_2O-N per Mg grain N) compared to starter urea combined with side-dressed ESN (0.08 kg N_2O- N per Mg grain N) and both were significantly greater than the control (0.05 kg N_2O-N per Mg grain N). (Figure 1). The individual years showed the same patterns and differences were significant for all years.

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NUTRIENT CYCLING FOLLOWING COVER CROP TERMINATION IN TEXAS COTTON PRODUCTION

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ABSTRACT

The Southern High Plains (SHP) region of Texas is one of the largest cotton-producing regions in the United States. Climatic conditions and wind erosion hinder cotton production, but attempts have been made to adopt conservation management practices like cover crops and crop rotations to limit these effects. Conservation management practices can reduce a soil's susceptibility to wind erosion, but their adoption has been limited on the SHP due to producers' concerns regarding yield reductions. Previous research in the region has shown that the yield reduction is likely not caused by water usage but by nitrogen (N) availability. This study sought to evaluate the impact of cropping system management and N fertilization on cotton lint yield and gross margins. A field experiment was implemented in 2014 and the observations presented here were from 2018-2020 at the Agricultural Complex for Advanced Research and Extension Systems (Ag-CARES) in Lamesa, TX. Cropping systems consisted of 1) continuous cotton, conventional tillage, winter fallow (CC); 2) continuous cotton, no-tillage, rye cover crop (CCRC); and 3) cotton-wheat-fallow rotation (CWR). Nitrogen fertilization strategies consisted of 1) farmer's practices (FP, 120 lb N acree^{-1}); 2) farmer's practice plus 30 lb N acre^{-1} applied at preplant (PPN, 150 lb N acre^{-1}); 3) farmer's practice plus 30 lb N acre^{-1} applied at post-emergence plus two weeks (PEN, 150 lb N acre^{-1}); and 4) farmer's practice plus 30 lb N acre^{-1} applied at pinhead square plus two weeks (PHSN, 150 lb N acre^{-1}). Results indicated significant increases with the adoption of conservation cropping systems (CCRC and CRW) and N applied at PPN or PEN compared to the CC system with the greatest increases in yield in the CWR system regardless of N fertilization strategy. Gross margins followed a similar trend. Supplemental N fertilization did not benefit cotton lint yield in the CWR rotation. These results indicate that microbes have adequate time to mineralize the organic material following wheat harvest and before cotton planting 11 months later in the fallow period. However, the increase in cotton lint yield with N applications earlier in the growing season with the CCRC system indicates that immobilization of inorganic N by microbes during cover crop decomposition can potentially limit yield in this system. Adopting conservation management practices will rely on adequate nutrient management to maintain yields and minimize the potential yield gap.

INTRODUCTION

Texas annually produces approximately 40% of the annual U.S. cotton crop, making it the largest cotton-producing state (USDA-NASS, 2017). In the Texas High Plains, where most of the state's cotton is produced, limited rainfall and extreme spring winds can severely impact production. Cotton producers can reduce their susceptibility to wind erosion with no-tillage and cover crops. However, producers are concerned that cover crops will compete for limited soil water and reduce cotton yields. Prior research near Lamesa, TX, shows that cover crop water use is likely not the principal factor causing the yield decline in conservation cropping systems (Burke et al., 2021; 2022). Instead, N immobilization by the cover crops is likely causing the cotton yield reductions. Altering N fertilization timing to earlier in the growing season provides an opportunity to minimize the impact of N immobilization. This experiment aimed to determine the impact of N fertilization timing on cotton lint yield following a cover crop.

MATERIALS AND METHODS

Site description and experimental design

The study was arranged as a split-plot design replicated three times with cropping system serving as the main plot and nitrogen fertilization timing serving as the subplot. Cropping systems were demonstrated near Lamesa, TX at the Agricultural Complex for Advanced Research and Extension Systems (Ag-CARES), a cooperative research site between the Texas A&M AgriLife Research and Extension Center in Lubbock, TX and the Lamesa Cotton Growers. The cropping system treatments included: 1) continuous cotton, conventional tillage, winter fallow (CC); 2) continuous cotton, no-tillage, with a rye (*Secale cereal* L.) cover crop (CCRC); and 3) a cotton-wheat (*Triticum aestivum*) -fallow rotation (CWF). The cropping systems were established in 2014 and have been continuous since then. Cotton was planted in May and harvested between October and November of each year. In the CCRC system, the rye cover was planted following cotton harvest and terminated prior to cotton planting in late-March to mid-April. In CWF, wheat was harvested following cotton harvest and then harvested in June. Following wheat harvest, the remaining stubble remained in the field until cotton planting the following year.

The nitrogen fertilizer treatments included: 1) farmer practice (FP) which consisted of 120 lb of N applied at four equal applications during the growing season through fertigation; 2) FP + 30 lb N applied approximately two weeks prior to cotton plant (PPN); 3) FP + 30 lb N applied three weeks after cotton emergence (PEN); and 4) FP + 30 lb N applied at two weeks after cotton reach pinhead square (PHSN). All N fertilizer was applied as 32-0-0.

Calculations and statistical analysis

Analysis of variance for all parameters was calculated using a randomized complete split-plot design with three replications (PROC GLIMMIX, SAS 9.4, 2015). Means of treatment effects were compared among treatments using Fisher's least significant difference (LSD) at alpha level = 0.05 for all analyses.

RESULTS AND DISCUSSION

Cotton Production

There was a significant increase in cotton lint yield with the adoption of cover crops and crop rotations compared to the CC system (Table 1). On average, there was a 23.3 and 50.4% increase in lint yield with the CCRC and CWR systems compared to CC, respectively. In the CCRC system, there was an 18% yield increase with the PPN and PEN fertilization strategies, indicating earlier applications following a cover crop resulted in more cotton lint. The same trend was not observed in the CWF system, indicating that supplemental N did not increase cotton lint yield compared to the FP at any application timing. The increases in the CCRC system were likely caused by the supplemental N fertilization aiding in the decomposition of the cover crop residues and minimizing potential N immobilization by soil microbes. The current Texas A&M AgriLife Extension Service fertilization recommendation following cover crops is an additional 30 lb of N/acre applied at PHSN. This recent study shows that N application timing would be too late to see maximum benefit in our systems.

Table 1. Average cotton production (2018-2020) in different cropping systems and nitrogen fertilization strategies. Continuous cotton, conventional tillage, winter fallow (CC); continuous cotton, no-tillage, rye cover crop (CCRC); cotton-wheat-fallow rotation (CWF); farmer's practice (FP); preplant (PPN); post-emergence (PEN); pinhead square (PHSN); and average (AVG).

Cropping system	**Nitrogen fertilization strategy**				
	FP	**PPN**	**PEN**	**PHSN**	
	Lint yield (lint acre^{-1})				AVG
CC	723	787	715	683	727
CCRC	806	938	965	857	891
CWF	1,134	1,032	1,117	1,064	1,087
AVG	888	919	932	868	

Gross Margins

Gross margins followed a similar pattern as cotton production, where there were 65.5 and 77.1% increases in potential profits with the CCRC and CWF systems compared to CC, respectively. The greatest increases with N fertilization strategies were at PPN and PEN for the CCRC system. The cost of supplemental N did not decrease potential profits in any of the CCRC systems. Conversely, supplemental N decreased profitability in the CWF systems compared to CC.

Table 2. Gross margins (2018-2020) in different cropping systems and nitrogen fertilization strategies. Continuous cotton, conventional tillage, winter fallow (CC); continuous cotton, no-tillage, rye cover crop (CCRC); cotton-wheat-fallow rotation (CWF); farmer's practice (FP); preplant (PPN); post-emergence (PEN); pinhead square (PHSN); and average (AVG).

Cropping system	Nitrogen fertilization strategy				
	FP	PPN	PEN	PHSN	
	Gross margins ($ acre^{-1})				AVG
CC	434	489	441	420	336
CCRC	489	591	608	536	556
CWF	609	575	610	587	595
AVG	511	552	553	514	

CONCLUSIONS

Cover cropping is an important tool in conservation agriculture, but the consequences of their use are poorly understood, especially in semi-arid ecoregions. This has likely impacted the broadscale adoption of cover cropping. We have demonstrated that cover crop biomass remains relatively recalcitrant throughout a cotton growing season and can potentially immobilize inorganic N in cotton following cover crop termination. Further understanding of the N dynamics following cover crop termination in semi-arid cropping systems is essential to reducing producers concerns and maximizing their utility in cotton production. Future studies should examine the timing of N fertilizer applications in conservation management systems for synergistic nutrient availability, productivity, and sustainability.

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COMPARATIVE ANALYSIS OF RESOURCE PARTITIONING AND NUTRIENT UPTAKE EFFICIENCIES IN MODERN COTTON CULTIVARS

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ABSTRACT

Understanding the complex process of resource partitioning within the plant provides prospects to develop new crop improvement strategies for varying environmental factors and agronomic practices. In upland cotton, the partitioning of dry matter is as crucially important as that of macronutrients and micronutrients in improving productivity. This presentation highlights research works pertaining to the changes in macronutrient and micronutrient uptake and partitioning alongside the remarkable improvements in modern cotton cultivars during the past few decades. Results demonstrated that the newer cultivars were more efficient in partitioning and remobilizing nitrogen, phosphorus, potassium, sulfur, zinc, and copper into the developing boll and this increased efficiency translates to greater lint yield production for every unit of nutrient taken up compared to the earlier report in the 1990s. These improvements in nutrient uptake capacity in combination with the availability of high levels of residual soil nitrogen were able to sustain plant growth and maintain yield even under reduced nitrogen application. However, even with improved nutrient uptake efficiencies, growth and development could easily be hindered by slight differences in the availability of possible toxic elements such as sodium in the soil and irrigation sources. The changes in the patterns of assimilation and partitioning of nutrients within the cotton plant influences different aspects of crop adaptation, productivity, and survival. Therefore, it is important to have an utmost understanding of the mechanisms underlying these changes and how these mechanisms contribute to the interactions among genetics, environment, and management in order to maximize the potential of newer and soon-to-be developed cotton cultivars.

INTRODUCTION

Several studies conducted before the 1990s, such as those by Fraps (1919), Armstrong and Albert (1931), Olson and Bledsoe (1942), and Bassett et al. (1970), have documented the nutrient uptake and distribution among different plant tissues of cotton grown under dryland and irrigated conditions. For cotton cultivars grown in the southern USA, the most fundamental and recent report on dry matter and nutrient partitioning was provided by Mullins and Burmester (1990, 1993). This study reported on the patterns of translocation of macronutrients and micronutrients from vegetative to reproductive tissues. The findings of this study have been the basis of the current fertilizer recommendations for the majority of the cotton productions in the Texas High Plains.

After the 1990s, advancements in genetic enhancement and optimal crop management have significantly improved the efficiency of lint production in cotton, consequently boosting its yield potential. There is a likelihood that the nutrient accumulation in plant organs and the required rates for modern cultivars have undergone changes, contributing to these improvements. Since the most recent work was done in the 1990s, a current investigation on patterns of resource partitioning and accumulation is needed. The objective of this study is to compare the resource allocation of modern cultivars with older ones based on the nutrient partitioning to different organs across the growing season and the nutrient uptake per unit of lint produced in irrigated, fertilized cotton.

MATERIALS AND METHODS

Field experiments were conducted in 2018 and 2019 at Texas Tech University Research Farm, New Deal, TX, USA (33° 44' 13.76" N, 101° 43' 58.04" W, 994 m above sea level). The study location is in a semi-arid climate with an average annual precipitation of 19 in for the last seven years. The soil is a Pullman clay loam (fine, mixed, superactive, thermic, Torrertic Paleustolls) (National Cooperative Soil Survey, 2014). The measured soil pH ranged from 7.9 to 8.1 across 0-24 in soil depth.

For each season, three cotton cultivars (Paymaster PM HS26, FiberMax FM 958, Deltapine DP 1646) were planted on the third week of May. Plots were fertilized with an average rate of 100 lb N per acre, 80 lb P per acre, and 27 lb K per acre. The liquid N fertilizer was split-applied as urea-ammonium nitrate (UAN, 32-0-0), using a coulter applicator (40% pre-plant, 60% side-dressed mid-season). Both P and K were applied 100% at pre-plant. The total in-season irrigation applied was 14 in (through subsurface drip irrigation system) and the total seasonal rainfall received was 8 in.

Destructive plant sampling was conducted at 30, 60, 90, and 120 days after planting. Biomass samples were separated into leaves, stems, burs (squares, flowers, immature bolls), and mature bolls. The plant tissues were dried, weighed, and ground prior to analysis. Dry matter samples were submitted to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory (College Station, TX) for nutrient analysis.

RESULTS AND DISCUSSION

The findings of this study showed a notable improvement in the efficiency of newer cultivars when it comes to the partitioning and remobilization of essential nutrients, including nitrogen, phosphorus, potassium, sulfur, zinc, and copper, towards the development of the cotton boll (Figures 1 and 2). This increased efficiency has significant implications, particularly in the context of lint yield production (Pabuayon, Lewis, and Ritchie, 2020). The findings suggest that, in comparison to the earlier report from the 1990s, modern cultivars have an improved ability to convert each unit of absorbed nutrient into a greater yield of lint. The advancements in cultivar characteristics and nutrient uptake contribute to an overall improvement in yield production.

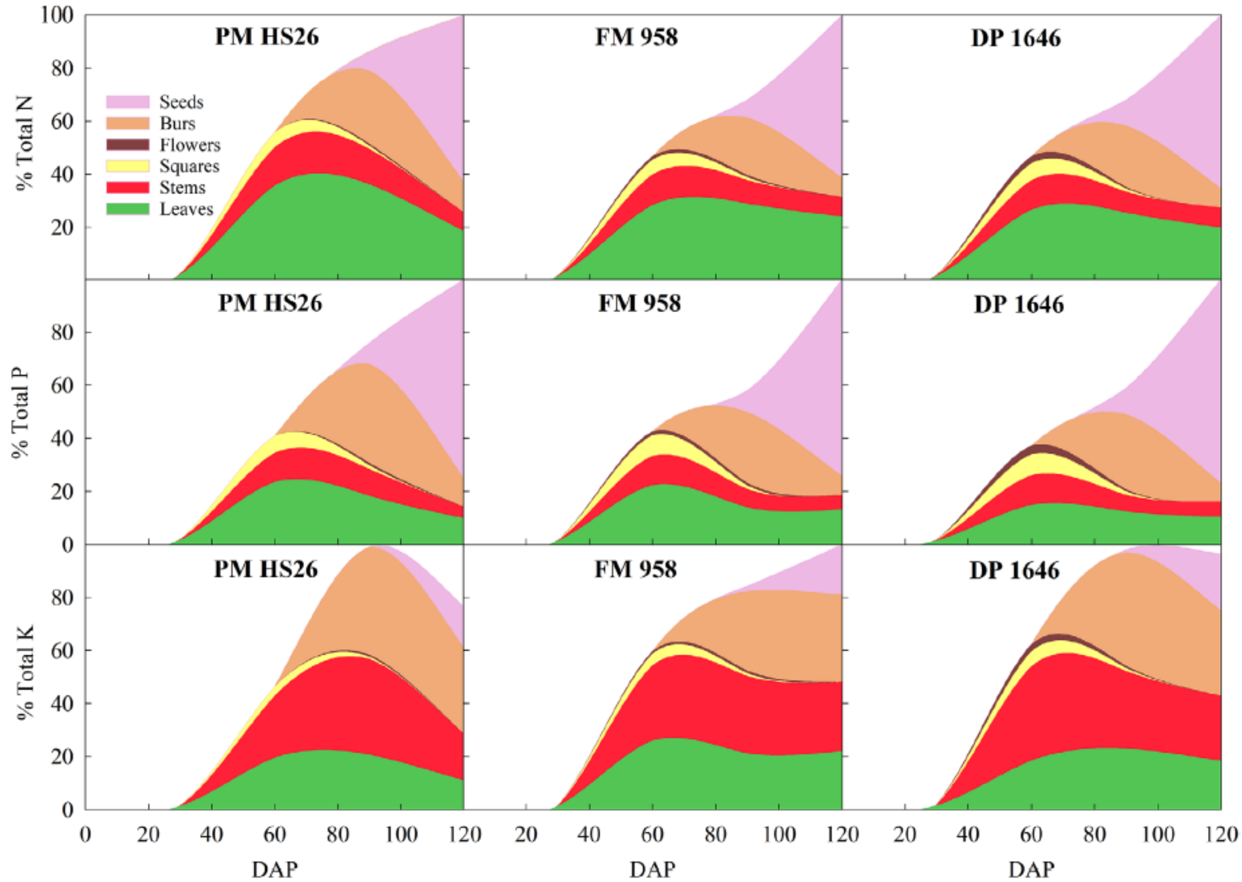

Figure 1. Comparison of the primary macronutrient partitioning between old and new cotton cultivars. DAP means days after planting. This data represents the results from 2018 and has already been published. The results for the 2019 study, including the partitioning patterns for secondary macronutrients can be accessed in the following publication: Pabuayon, I. L. B., Lewis, K. L., & Ritchie, G. L. (2020). Dry matter and nutrient partitioning changes for the past 30 years of cotton production. *Agronomy Journal*, 112(5), 4373-4385.

Aside from the improvements in nutrient uptake efficiencies observed in modern cultivars, our study showed that modern cultivars have the capacity to reallocate potentially toxic elements, such as sodium, to non-photosynthetic tissues. The accumulation of sodium in non-photosynthetic tissues of cotton is thought to be a response to enhance salt tolerance. In situations where there is an excess availability of sodium beyond what is necessary for normal plant growth, a phenomenon occurs where sodium is redistributed and accumulates specifically in the transpiring leaves (Pabuayon, Lewis, and Ritchie, 2021). This suggests an abundance of sodium can lead to its relocation and concentration in the leaves involved in the process of transpiration. This dual response underscores the intricate ways in which plants manage sodium in different tissues as a strategy to cope with varying environmental conditions, particularly in contexts where salt stress is a prevalent concern.

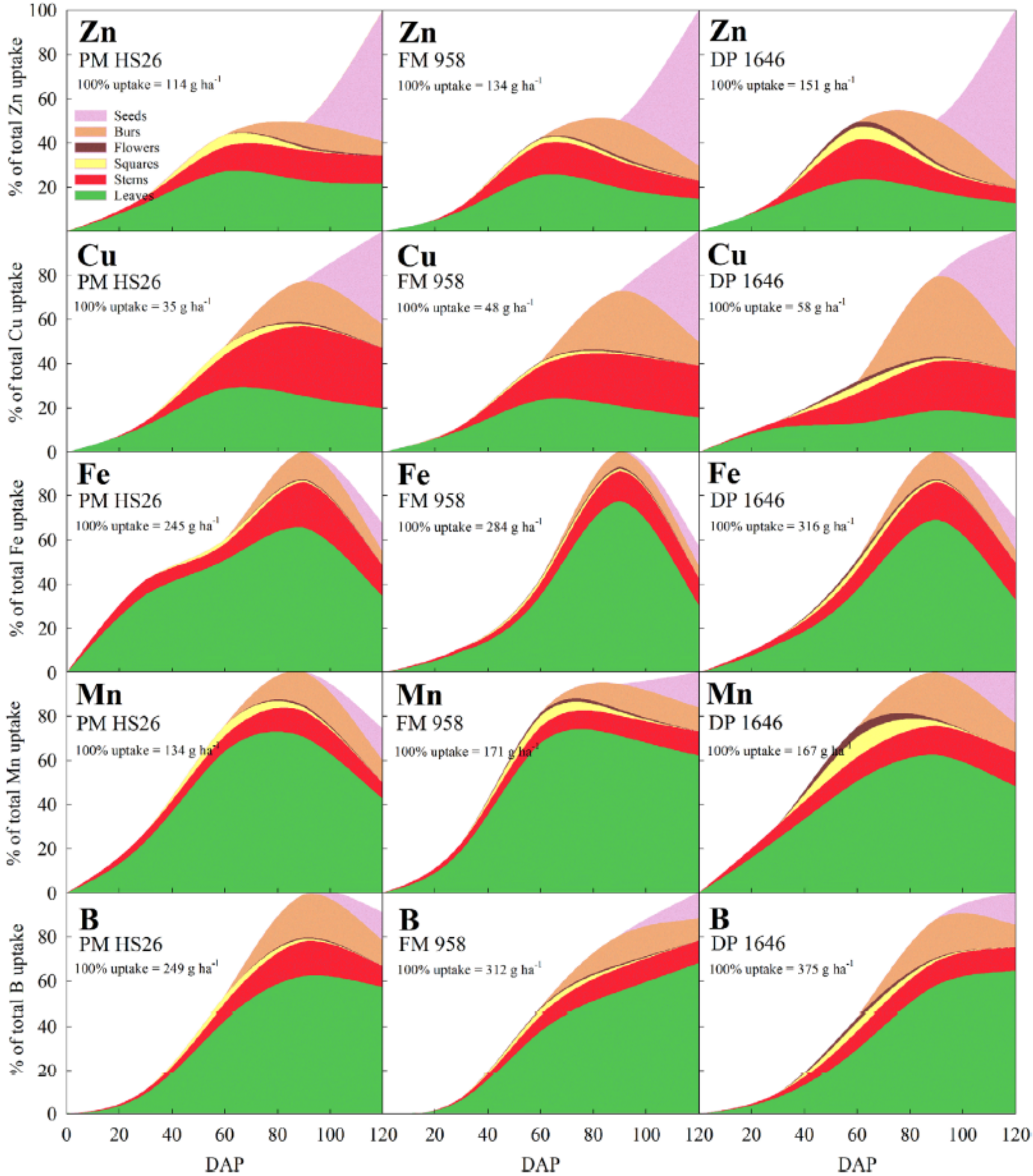

Figure 2. Comparison of the micronutrient partitioning between old and new cotton cultivars. DAP means days after planting. This data represents the results from 2018 and has already been published. The results for the 2019 study can be accessed in the following publication: Pabuayon, I. L. B., Lewis, K. L., & Ritchie, G. L. (2021). Hidden fractions: Another look at micronutrient and sodium partitioning in modern cotton cultivars. *Crop Science*, 61(5), 3623-3636.

CONCLUSIONS

Overall, our research provides insights on the shifts in nutrient uptake and partitioning alongside the remarkable improvements in yields of modern cotton cultivars during the past few decades. Results showed the newer cultivars have an enhanced capacity to accumulate and remobilize nutrients to organs associated with reproductive development. The results from this study can be valuable for researchers and producers, offering guidance in making informed decisions about fertilizer management, especially when precise nutrient requirements at specific growth stages are known.

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EXPERIENCE WITH USING THE SIKORA-2 SOIL/BUFFER pH METHOD IN THE GREAT PLAINS

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ABSTRACT

The extent of acidic soils in the Great Plains continues to increase from long-term cropping and fertilizer nitrogen use. Acidic soils developed initially in dryland fields and/or in areas dominated by sandy soils, but are now relatively common in irrigated systems and finer-textured soils. Soil pH is typically determined a 1:1 soil:water slurry (pH_w) and exchangeable acidity determined by a buffer pH, which then is used to calculate lime requirements. The widely used SMP buffer contains hazardous materials, so soil test laboratories have largely replaced it with the Sikora-1 buffer (Sikora, 2006). The Sikora-1 buffer closely mimicked the SMP buffer, so recalibration was not considered necessary.

Determining soil pH and identifying effective lime in sandy or poorly buffered soils is a challenge for ServiTech and other soil testing laboratories. Clients were frequently frustrated with test results having a low soil pH with a zero lime rate. Alternative methods, like the modified Woodruff or Adams-Evans buffers help to "improve" lime recommendations. These methods were developed and calibrated for the poorly buffered soils of the southeast U.S., but were not calibrated for the Great Plains. These buffer solutions also contain hazardous compounds.

Sikora (2012) developed a method to measure the soil pH in a 1*M* KCl solution followed by measuring pH in the modified Sikora-2 buffer. This method provides a two-point lime response curve to account for the individual buffering capacity of each soil sample. ServiTech adopted the Sikora-2 method in 2012 as an alternative to pH_w and Sikora-1 buffer. The Sikora-2 method has been well accepted by soil testing clients since then. They have more confidence in the results they receive from samples collected from sandy, poorly buffered soils. Drought conditions often resulted in depressed soil pH values which differed from the long-term soil test history. During the current drought cycles, we have found significantly fewer concerns about drought-depressed soil pH results because of the increased use of the Sikora-2 method.

INTRODUCTION

Soil pH is a routine measurement conducted by soil testing laboratories – public and commercial. Soil pH is determined electrometrically in a soil slurry of a specified soil:deionized-water ratio, like 1:1 or 1:2.5 ("water pH", "pH_w") or with 0.01*M* $CaCl_2$ or 1*M* KCl ("salt pH"). Adding the electrolyte increases the ionic strength for pH measurement and avoids variable pH of a soil:water slurry due to varying background salt levels in different soils (Sikora, 2014a).

Soil acidity has increased across the Great Plains following decades of increasing yield potential with subsequent increases in use and rates of ammonium-and urea-based fertilizers. The nitrification process releases hydrogen ions (H^+) that accumulate in the soil solution, and replace basic cations and continue to drive a decline of soil pH. There are substantial areas of the Great Plains that are occupied by sandy soils (Entisols), notably the Nebraska Sandhills, the Arkansas River valley in Colorado and Kansas, and numerous river valleys in other Great Plains states. Some areas of sandy soils have been under production for 100 years or more and have only recently developed obvious acidity symptoms (Green, 2016). Other areas of sandy soils were developed for crop production with the introduction of center pivot irrigation systems. Sandy, poorly buffered soils pose an increased threat to develop acidity problems, but ServiTech clients with sandy soils often became frustrated with the lime rates determined using pH_w and a single buffer. The buffer pH often indicated a “zero” lime rate for soils with a moderately or strongly acidic pH_w value.

The SMP buffer has been used extensively in the North Central and Western Regions, but was formulated with potentially hazardous materials that require special handling. It may not be accurate for soils with low lime requirements, sandy soils, or soils with certain clay fractions (Peters, 2013). Sikora (2006) developed a modification, Sikora-1, using non-hazardous materials that mimicked the SMP.

Other methods have been used to determine the lower lime rates, required by sandy or poorly buffered soils. They include the modified Woodruff (“Woodruff-2”) and the Adams-Evans buffers, but both of solutions contain hazardous materials. Double-buffer methods (SMP, Yuan, etc.) are another approach to improve accuracy. These two-point methods require a second buffer pH measurement to develop an individual titration curve for each soil sample (Sikora, 2012).

Sikora (2012) introduced the Sikora-2 double-buffer method. Soil pH is measured in a 1*M* KCl solution (pH_{KCl}). The Sikora-2 buffer differs from the Sikora-1 buffer only in the potassium chloride concentration. The final concentration of the initial soil slurry plus the buffer solution is 2*M* KCl for both.

Figure 1a illustrates lime rates based on the one-point buffer pH value. The NCR13 calibration is used with the Sikora-1 buffer. No recommendations are made above a Sikora-1 buffer value of 6.8, where lime rates are less than 1 ton/acre. This is a situation where the acid-soil/no-lime anxiety can occur.

Figure 1b illustrates a two-point calibration using the pH_{KCl} and the Sikora-2 buffer pH values. The method uses the measured soil pH_{KCl} to adjust the lime rate that is initially determined by the buffer pH value. This provides a calibration curve for the individual sample. When lime is recommended, the rates are progressively higher as the measured soil pH_{KCl} decreases. The argument can be made to use the pH_w to adjust the lime rate calculated from the single-point Sikora-1 or Woodruff-2 calibration. Sikora (2012) points out that this approach may be misleading. The buffer solution of these two methods have a high ionic strength while the pH_w solution (i.e., soil and deionized water) has a much lower ionic strength. The Sikora-2 method measures both the soil pH and the buffer pH in solutions of the same ionic strength resulting from including potassium chloride in the respective solutions. The advantage is that only two solutions are required for the determination. The other double-buffer methods require a soil pH determination plus two buffer pH determinations.

MATERIALS AND METHODS

A group of 180 diverse soil samples was selected randomly from those submitted to ServiTech Laboratories during September and October 2011 (see Table 1). Summation CEC was used as an indicator of general soil texture. Samples came primarily from Kansas, Nebraska, Oklahoma, Texas, and Colorado.

Soil pH_w, pH_{KCl}, and buffer pH (Sikora-1, Sikora-2, and Woodruff-2) were determined electrometrically. Soluble salts were determined in a 1:1 soil:water slurry. Summation cation exchange capacity (CEC) was calculated from Mehlich-3 extractable cations. Lime rates as "tons of effective calcium carbonate per acre (ton ECC/ac)" for a target soil pH_w of 6.5 at an 8-inch depth were calculated using the respective buffer pH results using equations shown in Table 2.

Table 1. Study population characteristics.	**Mean**	**Standard Deviation**	**Median**	**Minimum**	**Maximum**
1:1 pH_w	5.34	0.70	5.2	3.3	7.4
1:1 pH_{KCl}	4.43	0.72	4.3	2.7	6.6
Meh3 CEC_{sum}, meq/100g	9.5	6.1	8	1	33
1: 1 Soluble salts,	0.26	0.21	0.21	0.05	1.57
Buffer pH					
Sikora-1	6.70	0.37	6.7	5.4	7.4
Sikora-2	6.75	0.37	6.8	5.4	7.4
Woodruff-2	6.52	0.29	6.6	5.4	7.0

RESULTS AND DISCUSSION

Soil pH

Soil pH_w was well correlated with pH_{KCl} (Figure 2, $r^2 = 0.91$). A comparison by Sikora (2014) of 240 Kentucky soils had the relationship in Equation 1. The relationship obtained from the ServiTech study population of 180 samples (Equation 2) was very similar. This suggested to us that there was a robust relationship for pH_{KCl} across a wide range of soils.

[1] $pH_w = (0.91 \times pH_{KCl}) + 1.34$ $r^2 = 0.98$

[2] $pH_w = (0.93 \text{ x } pH_{KCl}) + 1.21$ $r^2 = 0.91$

ServiTech, like the University of Kentucky, does not report the pH_{KCl} to clients. The pH_{KCl} value is converted to a pH_w "equivalent" value listed on the ServiTech soil test report as "1:1 (c) Water-Soil", the "(c)" designating a calculated value. This conversion helps avoid confusion by clients when trying to compare current soil pH results to their historic results, to other laboratory results, or various references. Additionally, we frequently must respond to customers who ask "Why are there two pH values on my soil test?", referring to the soil pH and buffer pH values. Reporting a third pH_{KCl} value would add significantly to their confusion and not lend to understanding the impact of soil acidity.

Lime requirements (LRs)

Relationships between various LRs are shown in Figures 3a, 3b, and 3c. The regression relationship and a 1:1 relationship are shown with dashed lines; the regression line being thicker and more bold than the 1:1 line. SMP lime requirements less than 2 tons/ac may be inaccurate (Peters, 2013), so the Sikora-1 lime rates from 0 to 2 tons/ac are highlighted with a horizontal arrow. Since Sikora buffer pH values mimic the SMP values, we assume the same inaccuracy may apply.

Requirements are well correlated (r^2 = 0.89 and 0.94) and can be described using polynomial equations. Sikora-2 lime rates tended to exceed Sikora-1 rates when Sikora-1 rates were less than 2 tons, but rates were lower above 2 tons. Figure 3b shows the Sikora-1 and Woodruff-2 relationship to be nearly linear. A significant difference occurs when Sikora-1 lime rates are zero, while a number of the Woodruff-2 rates for the same samples ranged from 0 to 1.5 tons/ac. The Sikora-2 and Woodruff-2 lime rates are highly correlated, also defined by a polynomial relationship (Figure 3c). Rates do not differ greatly when less than 2 tons per acre. Woodruff-2 requirements are about 1.5X to 2.0X the Sikora-2 requirements at Sikora-2 rates above 2 tons per acre

Customer perception

For many of our clients, the correlation of the buffer pH methods was of significantly less importance than the practical impact on lime requirements, especially those for sandy soils. Clients could be frustrated when the pH_w indicated an acidic soil and the lime recommendation based on the Sikora-1 buffer pH value and the NCR-13 calculation would yield a “zero” result. They were concerned that the lime requirement result based on the buffer pH was not properly addressing potential soil acidity problems. Using the Sikora-2 method has greatly reduced the acid-soil/no-lime anxiety.

This is illustrated in Figure 4. The charts show the frequency of samples with “zero” lime recommended for each buffer pH method. Fifty (50) of the 180 samples in the Sikora-1 study population had no lime recommended. Six (6) Sikora-1 samples had a pH_w of 7.0 or greater, so no lime would have been recommended. However, 21 of the samples (12% of the study population) had a pH_w of 5.5 or less, so would be considered moderately to strongly acidic. Only three samples analyzed with Woodruff-2 buffer had a zero lime rate; two of them had pH_w of 7.0 or more. Thus, only one of the 180 samples below pH_w 7.0 needed lime. The original Woodruff buffer was thought to underestimate lime requirements compared to the SMP buffer and was modified to better reflect exchangeable aluminum (Brown, 1984). The client perception existed that the Woodruff-2 could be overapplying lime in some cases. Seventeen (17) of the Sikora-2 samples did not have lime recommended, but again, six of them had a soil pH exceeding 7.0.

Severe drought periods frequently cause soluble salt levels to increase by 0.3 to 0.4 mmho/cm. We have observed pH_w of 0.4 to 0.5 units lower due to this additional electrolyte impact during pH measurement, creating a sort of “ephemeral” acidity during drought cycles. Clients in the Texas Panhandle noted pH_w depressions of 0.6 to 0.7 units during the record-setting 2011 drought. Since then, using the 1*M* KCl solution has helped assure clients that they are getting the “right” soil pH value.

Experiences with the Sikora-2 method

From an operations standpoint, an important advantage was eliminating the need to maintain stocks of the Woodruff-2 buffer and to capture and store the spent buffer solution as a hazardous material. Another advantage is that the overall reagent requirements for Sikora-1 and Sikora-2 solutions are virtually identical, so no additional chemical expense had to be incurred. One disadvantage is soluble salt determination. The deionized water extract could allow us to measure conductivity and pH simultaneously. Conductivity has to be determined separately when the 1*M* KCl solution is used for pH_{KCl} determination.

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Table 2. Lime requirement calculations

Source	Method	Calculation
NCR-13*	Sikora-1	LR = 39.4 - (BpH x 5.69)
Woodruff**	Woodruff-2	LR = (7.0 - BpH) x 5
SERA6***	Sikora-2	LR = (target pH_{KCl} – pH_{KCl}) × (BpH – 7.55) ÷ [(BpH – pH_{KCl}) × (-0.364)] × 10 ÷ (g soil)

LR = lime requirement, tons ECC/acre; BpH = buffer pH

* *derived from Table 2, page 4.6, Peters, et.al., 2013.*

** *derived from page 4.5, Peters, et.al., 2013.*

*** *simplified equation; detailed equation in pages 66-68, Sikora, 2014b*

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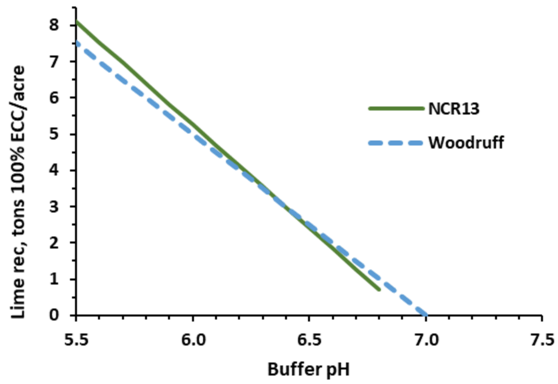

Figure 1a. Lime requirements using one-point buffer calibration methods.

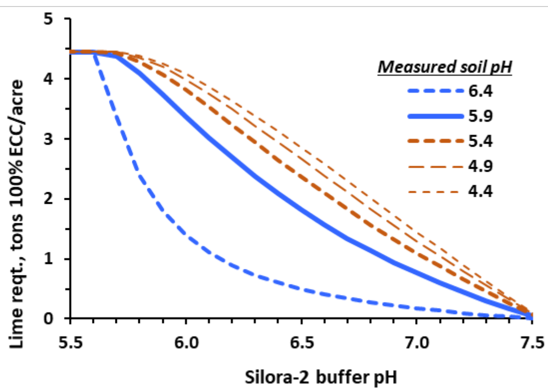

Figure 1b. Lime requirements using two-point buffer calibration method.

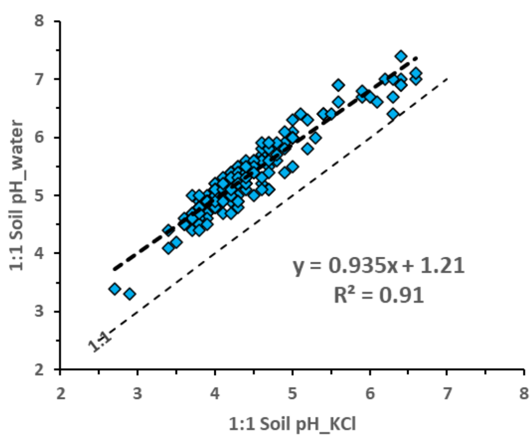

Figure 2. Relationship between soil pH determined with 1*M* KCl or water soil pH.

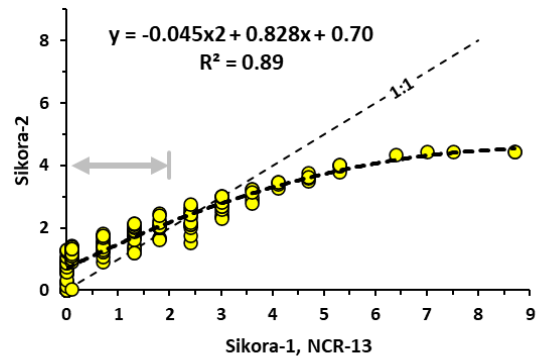

Figure 3a. Lime requirement comparison, Sikora-1 v. Sikora-2, tons ECC lime/acre.

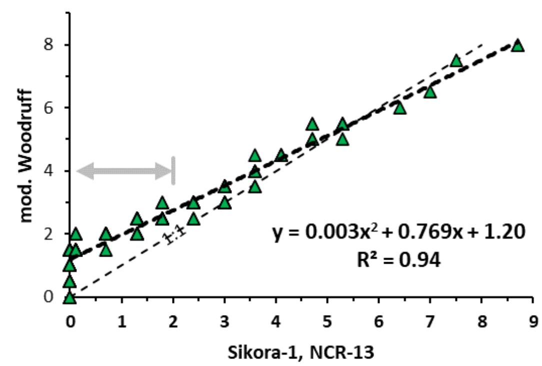

Figure 3b. Lime requirement comparison, Sikora-1 v. Woodruff-2, tons ECC lime/acre.

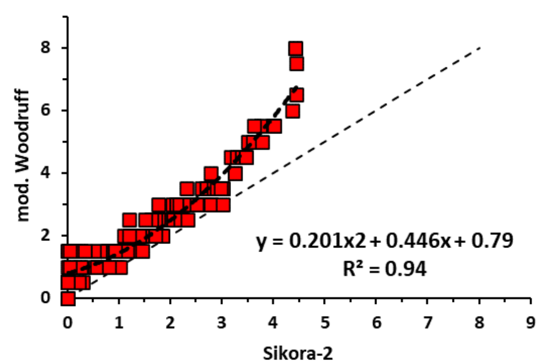

Figure 3c. Lime requirement comparison, Sikkora-2 v. Woodruff-2, tons ECC lime/acre.

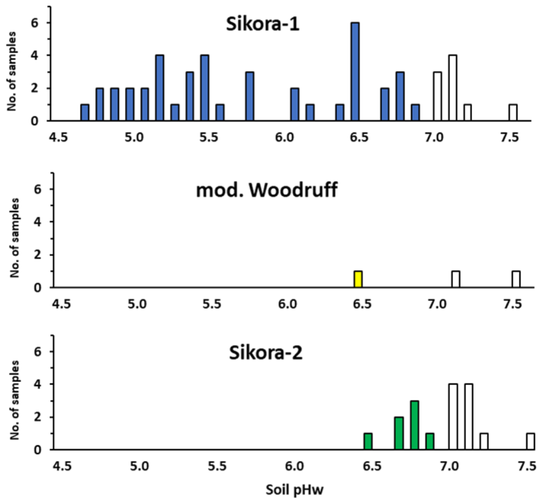

Figure 4. Frequency of "zero" lime requirements by soil pH_w for three buffer methods.

DEVELOPING NITROGEN AND PHOSPHORUS FERTIGATION STRATEGIES IN COTTON

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ABSTRACT

The objective of this research was to develop nitrogen (N) and phosphorus (P) fertigation strategies using subsurface drip irrigation (SDI) that increase nutrient use efficiency, cotton lint yield, and fertilizer return on investment. More specifically, we determined the number of fertilizer applications that result in optimized uptake and yield when using SDI. The research was conducted on a recently installed 67-zone SDI field at the Texas A&M AgriLife Research and Extension Center, Lubbock, TX, in 2021 - 2023. Results indicated less concern to greater application frequency with N; however, a greater return on investment was determined with fewer applications of P throughout the growing cotton (*Gossypium hirsutum*).

INTRODUCTION

Subsurface drip irrigation (SDI) is becoming a popular option for maximizing the water use efficiency of cotton (*Gossypium hirsutum*), especially in semi-arid environments of the Midsouth and Western United States. In the Texas High Plains where underground water resources from the Ogallala Aquifer are rapidly declining, there is increased adoption of water conservation technologies like center pivot and drip irrigation. In addition to increased water efficiency, drip irrigation allows for more precise fertilization through fertigation with application directly in the plant root zone. Applying fertilizers through SDI provides an opportunity to prescriptively apply nutrients at peak nutrient demand, which could minimize loss and increase uptake. Still, the application frequency and timing are poorly understood. This research aimed to develop nitrogen (N) and phosphorous (P) fertigation strategies using SDI that increase cotton lint yield.

MATERIALS AND METHODS

Cotton was planted at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX. The Center includes a recently installed SDI system with 67 zones that allows the flexibility and control to apply nutrients through fertigation to each zone precisely. Plots were 4 rows wide (40” spacing) by 68 ft long. Treatments were arranged as a split-plot design with four replications. Main plots were designated for variety and fertility treatments were assigned to split plots. Ginned lint samples were sent to the Fiber and Biopolymer Research Institute (Texas Tech University, Lubbock, TX) for high-volume instrument analysis.

2021

Cotton (DP 2143 and DP 2020) was planted on 13 May 2021 then replanted on 7 June 2021. Fertilizer was applied via fertigation on 10, 28 May, 18 June, 20 July, and 2, 11, 20, 30 August 2021. Cotton lint yield was determined from mechanical harvesting on 18 November 2021. Harvested samples were ginned on a scaled gin at Texas A&M AgriLife Research and Extension in Lubbock, TX.

2022

Cotton (DP 2143 and DP 2020) was planted on 27 May 2022. Fertilizer was applied via fertigation on 7, 16, 24 June, 8, 15, 18, 29 July, and 12, 26 August 2022. Cotton lint yield was determined from mechanical harvesting on 12 December 2022. Harvested samples were ginned on a scaled gin at Texas A&M AgriLife Research and Extension in Lubbock, TX.

2023

Cotton (DP 2143 and DP 2020) was planted on 10 May 2023. Fertilizer was applied via fertigation on 17, 25 May, 2, 12, 21, 30 June, 10, 20 July, 8 August 2023. Cotton lint yield was determined from mechanical harvesting on 3 November 2023. Harvested samples were ginned on a scaled gin at Texas A&M AgriLife Research and Extension in Lubbock, TX.

RESULTS

2021

With DP 2020 and three nitrogen fertilizer applications, cotton lint yield was greater with one phosphorous application than with zero and nine (Figure 1). Differences were not determined for DP 2143 in 2021; however, similar trends to DP 2020 were observed.

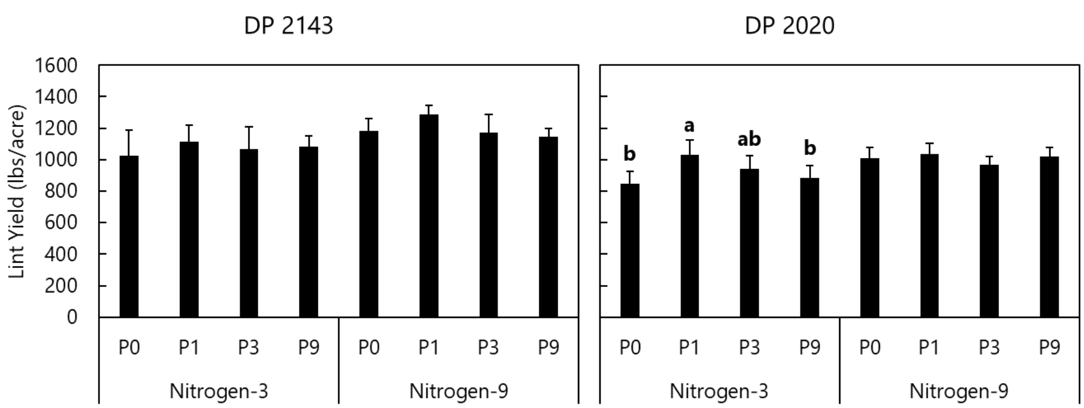

Figure 1. Cotton lint yields for two varieties, two nitrogen fertilization timings, and four phosphorous (P) fertilization timings at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX. Letters represent significant differences between phosphorous fertilization frequency within cotton variety and nitrogen application frequency. Error bars represent standard deviation of the mean. Differences were only determined for DP 2020 B3XF.

2022

With DP 2020 and three N fertilizer applications, cotton lint yield was greater with zero, one, and three P applications than with nine applications. When N was applied in nine equal applications, lint yields were greater with one P application compared to the no P control and three applications. Regardless of variety, fewer P applications generally generated more cotton lint than three or nine applications.

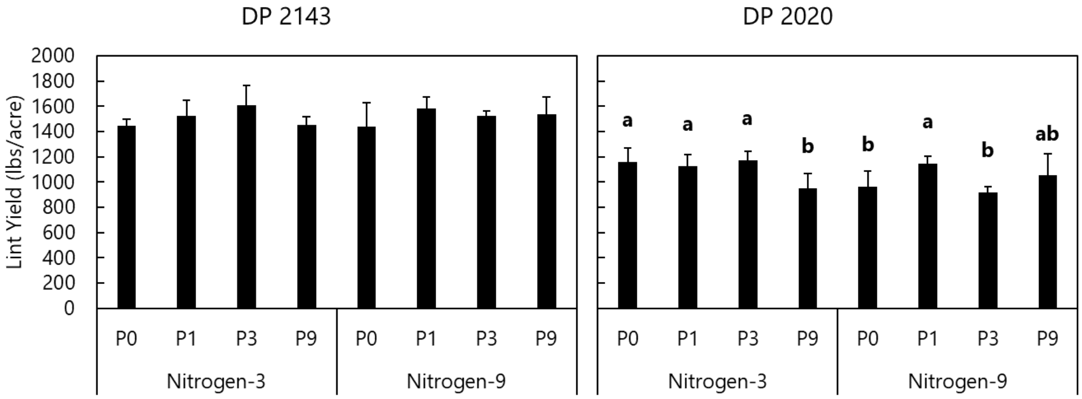

Figure 2. Cotton lint yields for two varieties, two nitrogen fertilization timings, and four phosphorous (P) fertilization timings at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX. Letters represent significant differences between phosphorous fertilization frequency within cotton variety and nitrogen application frequency. Error bars represent standard deviation of the mean. Differences were only determined for DP 2020 B3XF.

2023

With DP 2143 and three nitrogen fertilizer applications, cotton lint yield was greater with three phosphorus applications than with zero, one, and nine applications (Figure 3).

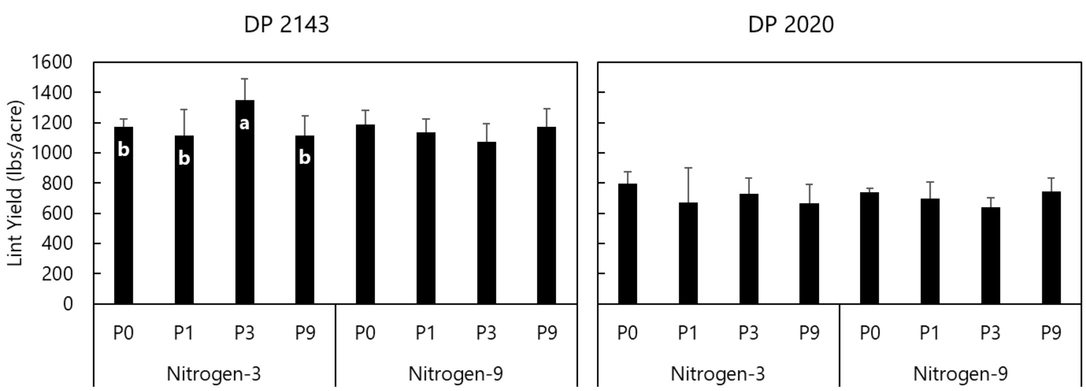

Figure 3. Cotton lint yields for two varieties, two nitrogen fertilization timings, and four phosphorous (P) fertilization timings at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX. Letters represent significant differences between phosphorous fertilization frequency within cotton variety and nitrogen application frequency. Error bars represent standard deviation of the mean. Differences were only determined for

DP 2143 B3XF.

Preliminary data suggest different management approaches needed for N and P when fertigating using SDI. Nitrogen resulted in generally greater yield response with greater frequency of applications. Greater applications of N likely minimized losses from denitrification and immobilization. Results demonstrate that prescriptive N fertilizer applications produce greater lint yield and reduce nutrient losses compared to greater quantities applied at fewer frequencies. Phosphorous did not result in a greater yield response when applied at a greater frequency. We believe that nine P applications may be causing antagonistic effects with zinc and possibly other micronutrients. Past work has demonstrated greater P uptake with nine applications even though lint yield was reduced. This leads us to hypothesize an antagonistic effect of increased P uptake reducing the uptake of other essential elements. Future work should explore the potential antagonistic effects that could potentially be taking place.

CROP PRODUCTION AND SOIL PROPERTIES IMPACTS OF INTEGRATING ANNUAL FORAGES AND RUMINANT LIVESTOCK INTO WHEAT-BASED CROPPING SYSTEMS

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ABSTRACT

Integrating annual forages and ruminant livestock to intensify dryland cropping systems have the potential to increase profitability, increase water use efficiency, and improve soil health. The objective of this study was to determine the crop yield and soil property impacts of intensifying traditional no-till winter wheat *(Triticum aestivum L.)*-grain sorghum *(Sorghum bicolor Moench)*-fallow (WW-GS-F) with annual forages as well as integrating livestock to graze forages and crop residues. This study was initiated in 2021 at the Kansas State University Agricultural Research Center-Hays in Hays, KS. Treatments were WW-GS-F (control), WW-GS-F with grain sorghum residues grazed, winter wheat/forage sorghum-forage sorghum-fallow (WW/FS-FS-F) with forage sorghum grazed, and WW/FS-FS-F with forage sorghum hayed. The treatments were replicated four times with all phases of the rotation present each year. Grain and forage yields were determined every year with sampling to characterize soil properties in fall 2023. Results showed that full-season forage sorghum harvested for hay produced 5,994 lb/ac on average, while post-wheat forage sorghum harvested for hay produced 1,682 lb/ac. Before grazing, full-season forage sorghum produced 9,735 lb/ac with about 51% biomass remaining as residue after livestock were removed. On average, post-wheat forage sorghum produced 2,988 lb/ac before grazing. Because of smaller yields, post-wheat forage sorghum plots were grazed only in one year when 82% biomass remained as residue on the plots after livestock were removed. In 2023, WW yields were low due to dry weather, but there was no difference among treatments and average was 15 bu/ac. The WW/FS-FS-F (grazed) treatment had greater crop residue cover (77%) at winter wheat planting than all other treatments (53%) in fall 2023. No differences in bulk density or penetration resistance in the 0-2-in and 2-6-in soil depths were observed across treatments. Despite no differences in bulk soil organic carbon (SOC) in the 0-2-in and 2-6-in soil depths, dry aggregate associated SOC was greater with WW-GS-F (grazed) and WW/FS-FS-F (grazed) treatments than WW-GS-F and WW/FS-FS-F (hayed). No differences in mean weight diameter of (MWD) water stable aggregates or the wind-erodible fraction were observed across treatments. These preliminary results suggest that intensifying the WW-GS-F rotation with annual forages and integrating livestock increased available forage, soil residue cover, and dry aggregate associated organic carbon with no effect on winter wheat yields.

INTRODUCTION

Intensifying dryland cropping systems with annual forages and integrating ruminant livestock have the potential to increase profitability, enhance fallow water use efficiency, and improve soil health by increasing residue cover and reducing wind and water erodibility. Currently, the most common crop rotation in this region is winter wheat (WW)-summer crop-F. The most common crops utilized within that rotation are grain sorghum (GS) *(Sorghum bicolor (L.) Moench)* and corn *(Zea mays L.)* (Schlegel et al., 2002). Typically, after the summer crop is harvested, a 12-14-month fallow period ensues to build soil water content for the next WW crop. Due to high evaporation in this climate only 17-30% of precipitation is retained as stored soil moisture during the fallow period (Peterson & Westfall et al., 2004). Even with no-till (NT), less than half of precipitation is retained, and soil cover is lost. Intensifying the rotation with annual forages may reduce soil water and have a negative impact on subsequent grain yield, but the forage that is produced for grazing and haying may offset negative impacts to profitability. Adding annual forages in wheat-based systems may even boost profitability (Holman et al., 2018, 2021, 2023a, 2023b; Carr et al., 2020). Concerns also may arise with the negative impacts haying and grazing could potentially have on soil organic carbon (SOC) reserves, water stable aggregates, and wind erodible fraction due to grazing or haying crop residue. Grazing is often seen negatively as it may increase soil compaction as indicated by greater bulk density (BD) and penetration resistance (PR). The objective of this study was to analyze crop yield and soil health impacts of intensifying traditional NT WW-GS-F system with annual forages, as well as integrating ruminant livestock to graze forages and crop residues.

MATERIALS AND METHODS

This study was initiated at the Kansas State University Agricultural Research Center-Hays in Hays, KS with all phases of the experiment in place by 2021. The study design was a randomized complete block with four replications in a WW-GS-F rotation system. The study compared WW-GS-F rotation with grazing of the GS stalks and with grazing or haying of annual forages grown in place of GS. Each crop phase and hayed or grazed treatments were present each year. Plots were 60-ft wide x 127-ft long for the grazed treatments, and 30-ft wide x 127-ft long for the hayed treatments. Each treatment was grown under NT conditions.

Treatments:

1. Year 1: winter wheat; Year 2: grain sorghum; Year 3: fallow: (WW-GS-F)
2. Year 1: winter wheat; Year 2: grain sorghum (grazed stalks); Year 3: fallow: (WW-GSG-F)
3. Year 1: winter wheat/double-crop forage sorghum (grazed); Year 2: forage sorghum (grazed); Year 3: fallow: (WW/FSG-FSG-F)
4. Year 1: winter wheat/double-crop forage sorghum (hayed); Year 2: forage sorghum (hayed); Year 3: fallow: (WW/FSH-FSH-F)

Winter wheat was planted the end of September, GS and FS were planted at the beginning of June, and post-wheat FS was planted as soon as WW was harvested.

Winter wheat was harvested mid-late June, and GS was harvested mid-October. All grain crops were harvested using a Massey Fergusson 8XP plot combine with a 5-ft wide header attached. Grain yields were determined by a single 5-ft x 127-ft pass with the combine. Hayed FS was harvested at the end of August. Forage sorghum yields were determined by a single harvest of a 3-ft x 127-ft pass with a Carter forage harvester at heading. Grazing of GS stocks occurred post GS harvest and at heading in FS. To determine FS amount before grazing, a 2-ft x 3-ft quadrant was used to sample two different locations within the plot. After grazing, the methods were repeated to determine amount of residue remaining.

In August 2023, soil samples were taken from each plot pre-wheat planting. The soil properties examined were residue cover (RC), wet and dry aggregate stability, BD, PR, SOC, and particulate organic matter (POM). Residue cover was analyzed using the line transect method. Two samples were collected per plot for aggregate stability and BD, while ten samples per plot were collected for all other soil property analyses. Wet aggregate stability MWD was conducted by the wet sieving method using intact soil samples collected at the 0-2-in depth (Nimmo and Perkins, 2002). Dry aggregate stability was determined using a set of rotary sieves and wind erodible fraction was estimated as proportion of aggregates <0.84 at the 0-2-in depth (Chepil, 1962). Wet and dry aggregates were then analyzed for SOC for the >2mm, 2-0.25mm, and <0.25mm size distributions using the dry combustion method (Helmke et al., 2013). The same method was repeated for bulk SOC at 0-2-in and 2-6-in depths. The POM was conducted using the procedure outlined by Cambardella and Elliot (1992) at 0-2-in and 2-6-in depths. Bulk density was determined by the core method with samples taken from 0-2-in and 2-6-in depths (Grossman and Reinsch, 2002). Penetration resistance was determined using an Eijkelkamp Hand Penetrometer (Eijkelkamp Soil & Water, Morrisville, NC). Statistical analyses were completed in the SAS version 9.4 (SAS Institute, 2012, Cary, NC) using PROC GLIMMIX with year and treatment considered fixed and replication considered random. Treatment differences were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Forage Sorghum

Average hayed full season FS produced 5,994 lb/ac, while post-wheat hayed FS produced 1,682 lb/ac. The maximum full season FS production was in 2021 (8812 lb/ac), while the maximum post-wheat FS production was in 2023 (1899 lb/ac) for hayed treatments. Full season grazed FS produced 9,735 lb/ac on average before grazing and left approximately 51% of the forage as residue. Post-wheat FS was grazed only one year during the study due to extreme droughts in 2022 and 2023. In 2021, post-wheat FS produced 5,348 lb/ac and approximately 82% of total biomass was left after grazing.

Winter Wheat Yield

Due to a hail event in 2021 and an extreme drought in 2022, the only WW yields recorded were in 2023. In 2023 yields were low due to dry weather, but there were no significant differences in yield across treatments and the average was 15 bu/ac.

Residue Cover

In August 2023, treatments, WW/FSG-FSG-F had the greatest RC (78%) (Figure 1). The next highest treatments were WW-GS-F (61%) and WW/FSH-FSH-F (56%). With WW-GSG-F (41%) leaving the least soil cover.

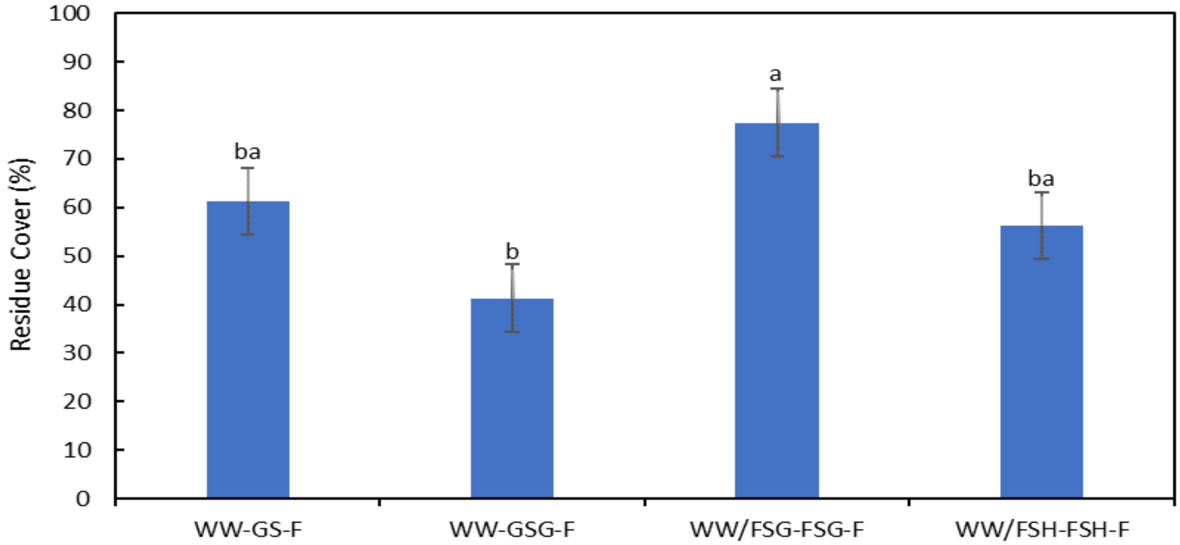

Figure 1. Intensification of WW-GS-F with grazing and forage sorghum effects on residue cover. Means with the same letter are not significantly different ($P<0.05$).

Soil Organic Carbon and Aggregate Associated Carbon

Despite the differences in RC, bulk SOC was not significantly different among treatments. Likewise, water stable aggregate-associated carbon at the 0-2-in depth showed no significant differences among treatments. However, treatments differed significantly in dry aggregate-associated carbon in all three size classes (Figure 2). Grazed treatments (WW-GSG-F and WW/FSG-FSG) ranked first or second in SOC in all aggregate size classes compared to WW-GS-F and WW/FSH-FSH-F.

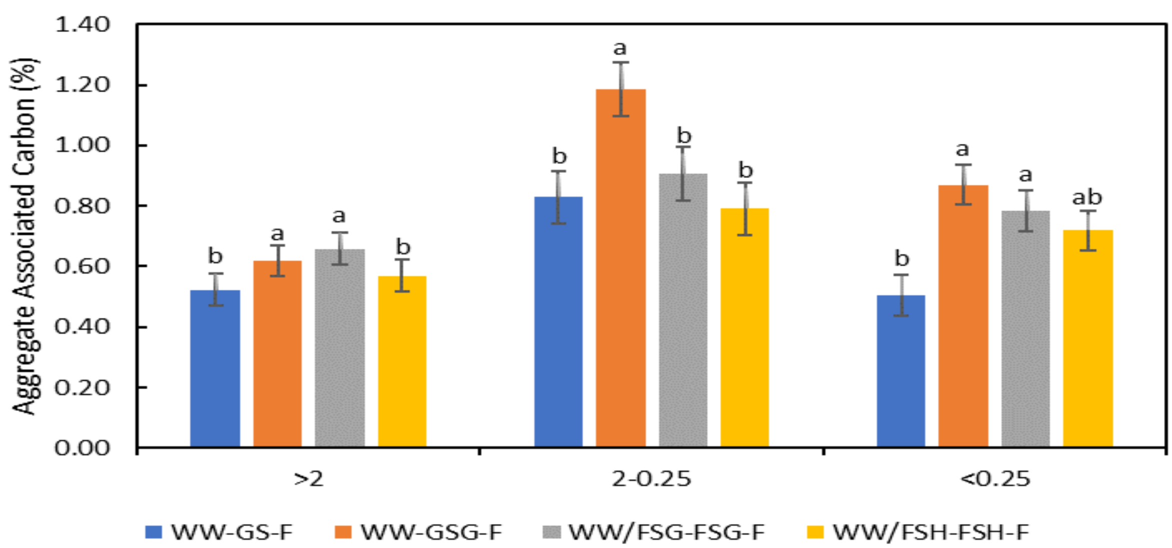

Figure 2. Intensification of WW-GS-F with grazing and forage sorghum effects on dry aggregate-associated carbon. Means with the same letter are not significantly different (*P*<0.05).

Particulate Organic Matter

Treatment differences in POM differed with depth (Figure 3). At the 0-2-in depth POM was greater for WW-GS-F and WW/FSG-FSG-F than for WW-GSG-F and WW/FSH-FSH-F. At the 2-6-in depth, there were no differences in POM among treatments.

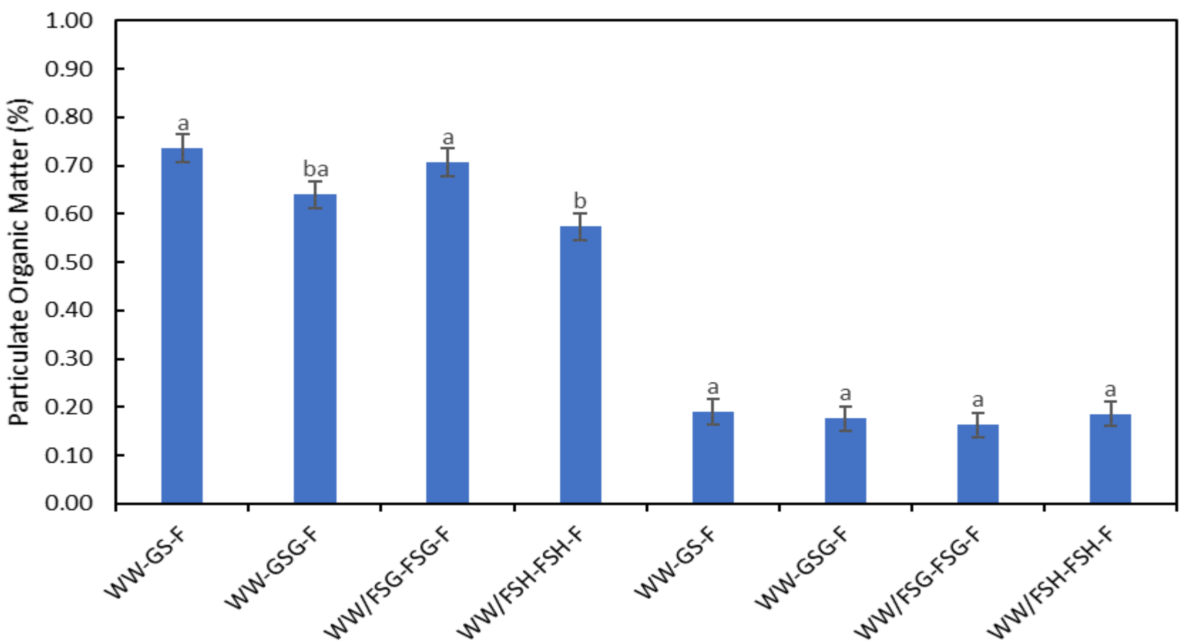

Figure 3. Intensification of WW-GS-F with grazing and forage sorghum effects on particulate organic matter. Means within a depth with the same letter are not significantly different (*P*<0.05).

Aggregate Analysis

Wet aggregate stability and dry aggregate stability (MWD) and wind erodible fraction were not different across treatments at the 0-2-in depth.

Measures of Soil Compaction

Penetration resistance and BD at 0-2-in and 2-6-in depths were not different across treatments.

Conclusion

Intensifying the WW-GS-F rotation with annual forages and integrating ruminant livestock increased aggregate associated organic carbon and residue cover. The addition of annual forages and livestock had no effect on MWD, WEF, PR, BD, bulk SOC, and WW yields. These results occurred while an additional forage available for haying and grazing, potentially increasing profits.

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RELATIONSHIP BETWEEN SOIL HEALTH AND NUTRIENT AVAILABILITY IN SEMI-ARID COTTON PRODUCTION

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ABSTRACT

The use of conservation management practices, like cover crops and no-tillage, is common in semi-arid cropping systems to reduce wind erosion. However, the use of these practices can also reduce cotton lint yield. The purpose of this study was to determine the impact of nitrogen (N) management in conservation cropping systems to increase cotton lint yield. An experiment was conducted at the Agricultural Complex for Advanced Research and Extension Systems in Lamesa, TX, USA. Treatments included: 1) conventional tillage, winter fallow; 2) no-tillage, rye (*Secale cereal* L.) cover crop; and 3) no-tillage, mixed species cover crop. Mixed cover crop species included hairy vetch (*Vicia villosa* Roth, 10%), radish (*Raphanus sativus* L. 7%), winter pea (*Pisum sativum* L., 33%), and rye (50%, by weight). Conventional tillage and no-tillage with rye cover crop treatments were established in 1998 and the mixed species cover was seed in 2014 by splitting the 32 row plots into 16 rows within the rye cover crop plots. The experiment utilized litterbags in 2020 and 2021 to determine cover crop decomposition rates following termination. In 2020, approximately 75% of the cover crop biomass remained 128-d following termination, while approximately 25% of the biomass remained 128-d after termination in 2021. These results indicate that only 31-32 kg N ha^{-1} would be available for cotton growth during the entire 2020 growing season. This limited biomass mineralization could have resulted in N limitations as soil microorganisms immobilized the N to complete their cellular functions. The differences in decomposition rate between 2020 and 2021 are likely the result of significant differences in biomass production between the two years. Following cover crop termination, soil inorganic N levels remained constant 0-8 DAT before increasing at 16 DAT. This increase in inorganic N at 16 DAT follows increases in soil proteins 8 DAT. Following termination, proteins are one of the first products to be released from the biomass, as soil microbes mineralize those proteins, they release soil inorganic N resulting in the increase in soil N observed at 16 DAT. After the peak at 8 DAT, soil protein levels decreased throughout the rest of the cotton growing season. Soil inorganic N levels were similar between 16 and 32 DAT, but significantly increased at 64 DAT. The increase in NO_3-N and inorganic N observed at 64 DAT is likely due to N fertilization shortly after cotton planting. These results indicate that there is likely N immobilization early in the growing season following cover crop termination. These results demonstrate that N management practices that account for potential N

immobilization following cover crops can significantly increase cotton lint yield and decrease the potential yield loss associated with conservation management practices in semi-arid regions.

COMBINED NITROGEN WITH MAGNESIUM OR ZINC EFFECTS ON SUGARBEET YIELD SUCROSE CONCENTRATION UNDER CONVENTIONAL AND NO-TILL SYSTEMS

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ABSTRACT

Sugar beet (*Beta vulgaris* L.) is an important cash crop in the Lower Yellowstone River valley. Fertility, especially nitrogen (N) fertilizer management, is critical for sugar beet yield and sucrose concentration. While farmers are switching from a conventional tillage method to a no-till system for sugar beet cultivation, nitrogen (N) fertilizer application timing might need to be adjusted. Furthermore, micronutrients may enhance sugar beet yield and sucrose concentration. A two-year study was conducted in Sydney, Montana, to investigate the effects of nitrogen rate, application timing, and combination of nitrogen with magnesium (Mg) or Zinc (Zn). The objective of this study was to 1) determine the nitrogen rate and application timing for maximal sugar beet yield and sucrose concentration under conventional tillage (CT) and no-till (NT) systems, 2) examine if foliar application of Mg and Zn in combination with N can enhance sugar beet yield and sucrose concentration, and 3) assess if fertilizer management should be adjusted while shifting from CT to NT. The field experiment was conducted on clay loam soil in a rotation with spring wheat (*Triticum aestivum* L.). The results revealed that sugar beet root yield and sucrose concentration showed no consistent differences between no-till and conventional farming practices or between spring and fall application of N. The lack of tillage management suggests farmers can achieve comparable yields and sucrose concentrations by adopting no-till practices, thereby reducing energy and labor inputs while safeguarding soil and water resources. Foliar application of Mg in combination with soil application of N tended to improve sugar beet root yield.

INTRODUCTION

Sugar beet (*Beta vulgaris* L.) growers throughout the USA commonly employ conventional tillage (CT). While the exact techniques may differ from region to region, conventional tillage for sugar beet typically involves deep plowing using a moldboard plow ripper or chisel plowing. This is followed by multiple passes of disking, mulching, and leveling to create a finely prepared seedbed. The goal is to ensure optimal seedling establishment, a robust plant stand, and a high yield (Khan & McVay, 2014). Including bedding or ridging in the operational procedures may vary depending on the irrigation systems employed. However, these intensive tillage practices have numerous adverse effects on soils and the environment. The consequences associated with CT include the depletion of soil organic matter and beneficial soil organisms, heightened soil erosion and pesticide runoff, diminished soil fertility, disruption of soil structure and porosity, surface crusting, the development of plow pans, and the release of greenhouse gases. Furthermore, implementing these practices incurs significant expenses, considering fixed and variable costs associated with tractors and implements, labor, fuel, lubricants, and other related factors. Researchers are exploring the viability of incorporating conservation tillage in sugar beet production to address these challenges. Conservation tillage, characterized by maintaining a minimum of 30% soil surface residue cover throughout the year, holds promise for carbon sequestration, improvement of soil organic matter, and erosion reduction. Moreover, these practices can substantially decrease fuel consumption and the time needed for field preparation, resulting in a lower overall production cost when compared to CT systems (Crane, 2014). Limited research has been conducted on no-till (NT) sugar beet production.

Achieving an optimal root yield and sucrose concentration in sugar beet necessitates a substantial amount of nitrogen (N) (Chatterjee et al., 2018). Inadequate fertilization hampers root yield, while excessive fertilization can diminish sucrose concentration and elevate impurities in sugar beets, thereby influencing sucrose recovery. Overapplying nitrogen (N) fertilizer can lead to contamination of surface and groundwater, as well as an escalation in production expenses. However, the optimal N application rate information is scarce, particularly under different tillage systems, especially no-till (NT).

The study aimed to achieve three objectives: 1) identify the optimal nitrogen rate and application timing for maximizing sugar beet yield and sucrose concentration in both no-till (NT) systems and conventional tillage (CT), 2) examine the potential enhancement of sugar beet yield and sucrose concentration through the combined foliar application of Mg or Zn with N, and 3) evaluate the necessity of adjusting fertilizer management when transitioning from CT to NT.

MATERIALS AND METHODS

Two field experiments were conducted in 2019 and 2020 in Sidney, MT, using a sprinkler irrigation system. The soil at the experimental site is characterized as deep, well-drained, and nearly level savage clay loam (fine, smectitic, frigid Vertic Argiustolls) with a composition of 210 g kg^{-1} sand, 460 g kg^{-1} silt, and 330 g kg^{-1} clay (Afshar et al., 2019). Initial composite soil samples were collected to assess the soil fertility status, and the results are presented in Table 1. Over the period from April to September, the site received 10.4 inches of precipitation, supplemented with 9.81 inches of irrigation water from planting to harvesting in 2019, while from April to September, the site received 5.81 inches of rainfall, supplemented with 13.2 inches of irrigation water in 2020. Notably, sugar beet trials were conducted in rotation with spring wheat at this site.

Table 1. Initial soil test results. Composite soil samples were collected from conventional tillage (CT) and no-till (NT) managements from 12 inches deep in the spring before planting sugar beet.

Tillage	pH	OM	NO_3-N	P-Olsen	K	Ca	Mg	Na	Zn	Fe	Mn	Cu	B	CEC
		(%)	(mg/kg)											(meq/100g)
								2019						
NT	8.3	3.3	32	15	351	6209	614	156	0.54	8.5	5.74	1.33	1.8	37.7
CT	8.2	3.7	38	17	431	6050	615	148	0.57	8.1	6.08	1.18	1.8	37.1
								2020						
NT	7.9	1.9	42	21	162	--	--	--	--	--	--	--	--	--
CT	7.9	1.8	42	21	162	--	--	--	--	--	--	--	--	--

Sugar beet (*Beta vulgaris*), Crystal S696 GEM 100 variety, was used in 2019 and 2020. The planting date was performed on April 24, 2019, and harvested on September 24, 2019. In 2020, sugar beet was sown on April 22, 2020, and replanted on May 11, 2020, due to frost damage, and harvesting was done on September 21, 2020. Sugar beet planting was done using a no-till drill. Sugar beet trials have been in rotation with spring wheat.

The experiments are laid out in a split-split plot in a randomized complete block design with four replications. The main plots were dedicated to no-till and conventional tillage management. At the same time, the sub-plots were used for two fertilizer-N application times: spring application in April 2019 and April 2020 and fall application in October 2018 and October 2019. Three N rates (120, 160, and 200 lb N/ac) and applications of Mg and Zn were implemented within the sub-sub plots. Each fertility plot had dimensions of 24 ft in width and 30 ft in length, with 5 ft alleyways between plots. The row spacing was set at 24 inches, resulting in 12 rows of sugar beets per plot. All 12 rows received fertilizer-N treatments. Three distinct rows within each N rate were dedicated to applying a single rate of Mg (1.0 lb Mg/ac) and Zn (0.8 lb Zn/ac). Chelated EDTA-Mg and EDTA-Zn liquid fertilizers served as the sources of Mg and Zn, respectively, and were applied using a CO_2 backpack sprayer when the plants reached a minimum of 8-10 leaf stage to prevent excessive fertilizer-N application. The N rates were adjusted based on the residual soil NO_3-N measured at a depth of 60 cm in the fall of the previous year. The fertilizer-P application followed Montana State University's recommended guidelines due to initial results indicating low P in the soil. Soil test K fell within the sufficiency range, eliminating the need for fertilizer-K application. While soil test Mg exceeded sufficiency levels for many agronomic crops, Zinc was not deficient but approached the borderline for deficiency in other crops. All soil-applied fertilizers were broadcast. Standard laboratory procedures were employed for the analysis of sugar content and impurities.

All data were subjected to analysis of variance using split-split-plot in a randomized complete block design after checking for homogeneity of error variances using the Levene test (Levene, 1960) and testing for normality distribution using the Shapiro and Wilk approach. The collected data were tested for the validation of assumptions underlying the combined analysis of variance by a separate analysis of each season, and a combined analysis across the two seasons was then performed if the homogeneity of individual error variances examined by the Levene test (Levene, 1960) was insignificant. The statistical analysis used GenStat 19th Edition (VSN International Ltd, Hemel Hempstead, UK).

RESULTS AND DISCUSSION

A summary of the significance of the main effects of tillage managements, N application timings, N fertilizer treatments, and their interactions for the ANOVA for the measured parameters are shown in Table 2. The coefficient of variation (CV%) was reported to be statistically acceptable for all studied traits and ranged from 0.6 for sucrose % in 2019 to 15.4% in root yield in 2019 (data not shown).

Tillage systems which included no-till (NT) and conventional tillage (CT) across different fertilizer-N application timing and rates were insignificant for root yield, sucrose % extraction, impurity value (IV), and sucrose loss to molasses (SLM) in both years except for sugar beet root yield only in 2019 ($P \leq 0.01$) (Table 2). There was no significant difference ($P \leq 0.05$) between NT and CT in sucrose %, IV, and SLM in both years (Figure 1). However, root yield varied as there was no significant difference ($P \leq 0.05$) between NT and CT in 2020, but NT and CT differed significantly in 2019, where NT increased root yield 5.98 t/ac compared to CT (Figure 1).

Fertilizer-N application timing included N application in spring and fall across tillage systems, and N rates were insignificant in root yield, sucrose %, IV, and SLM in both years

2019 and 2020 ($P≤0.05$), excepting root yield in 2020 (Table 2). The spring application had 2.66 tons/acre higher than fall in 2020 (Figure 2).

Fertilizer-N application rate effects were significant in root yield, sucrose %, IV, and SLM in both years except root yield in 2019 (Table 2). There was a trend of fertilizer-N application increasing sugar beet root yield both in 2019 and in 2020, even though the increase was not statistically significant in 2019, and the root yield plateaued at 160 lb N/ac. In contrast, increasing the N rate significantly reduced sucrose % in both years. Moreover, this reduction coincided with the gradual increase of the N rate to 200 kg N/ac. For example, the N rate at 160 and 200 lb/ac significantly reduced sucrose% by 2.7 and 4.5 rel.%, respectively, compared to 120 lb N/ac in 2019 (Figure 3). Impurity value (IV) and sucrose loss to molasses (SLM) behaved typically regarding the N fertilizer application rate response. Fertilizer-N application significantly increased ($P≤0.05$) IV and SLM in both years, coinciding with increasing N fertilizer application rate. For example, in 2019, the N rate at 160 and 200 lb/ac significantly increased IV by 13.8 and 24.6%, respectively, compared to 120 lb N/ac. However, no significant difference existed between the 160 and 200 lb/ac N rate (Figure 3).

Table 2. Analysis of variance (mean square error) of sugar beet yield and its quality influenced by tillage systems, fertilizer-N application timing, and rates and their interactions in 2019 and 2020.

Source of variation	d.f.	Root yield (t/ac)	Sucrose (%)	Impurity value	SLM
			2019		
Rep	3	36.27	0.3651	0.00051	0.00115
Tillage	1	429.4**	0.143	0.000523	0.00118
Residual	3	12.49	0.0507	0.002267	0.0051
Timing	1	5.68	0.1657	0.01223	0.02752
Tillage*Timing	1	29.69	0.118	0.000113	0.00025
Residual	6	24.06	0.0876	0.006422	0.01445
N	2	25.98	2.3653**	0.078285**	0.17614**
Tillage*N	2	15.67	0.125	0.001535	0.00345
Timing*N	2	50.63	0.1477	0.002347	0.00528
Tillage*Timing*N	2	16.03	0.154	0.003108	0.00699
Residual	24	37.06	0.1081	0.009013	0.02028
			2020		
Rep	3	83.924	0.1524	0.001679	0.003778
Tillage	1	506.901	0.9633	0.034922	0.078574
Residual	3	72.78	0.1484	0.005853	0.013169
Timing	1	84.62**	0.0147	0.000007	0.000017
Tillage*Timing	1	6.202	0.0056	0.00415	0.009338
Residual	6	1.439	0.0617	0.001188	0.002672
N	2	41.854*	0.9362*	0.0201**	0.045224**
Tillage*N	2	1.312	0.0275	0.001664	0.003745
Timing*N	2	6.581	0.1173	0.005864	0.013193
Tillage*Timing*N	2	20.126	0.0147	0.00227	0.005108
Residual	24	8.828	0.2315	0.003481	0.007831

SLM, sucrose loss to molasses. *and** indicate significant and highly significant at $P≤0.05$ and $P≤0.01$; respectively.

Applying Mg tended to improve the usage of N fertilizer at 160 and 200 lb/ac. Combined with Mg, it increased root yield by 11.2% and 10.6%, respectively, compared to the application of N alone. Moreover, even when using N at 120 lb/ac, Mag improved root yield by 1.5%. Zn effects were inconsistent; there were no differences at 120 and 160 N levels but a slight increase in the 200 N level (Table 4).

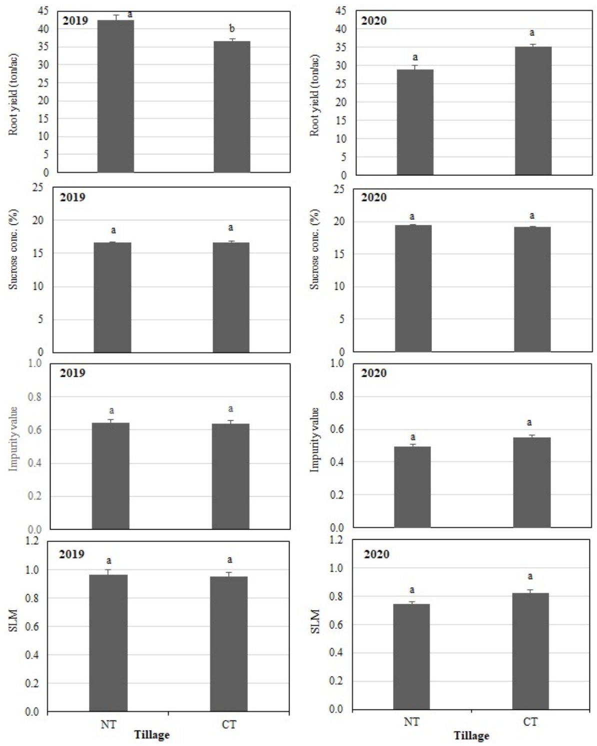

Figure 1. Sugar beet root yield, percent of sucrose extraction, impurity value (IV), and sucrose loss to molasses (SLM), influenced by no-till (NT) and conventional tillage (CT) systems under different fertilizer-N application timing and rates. Error bars are standard errors of the mean. Means with the same letters are not significantly different at *P*≤0.05 according to the least significant difference (LSD) test.

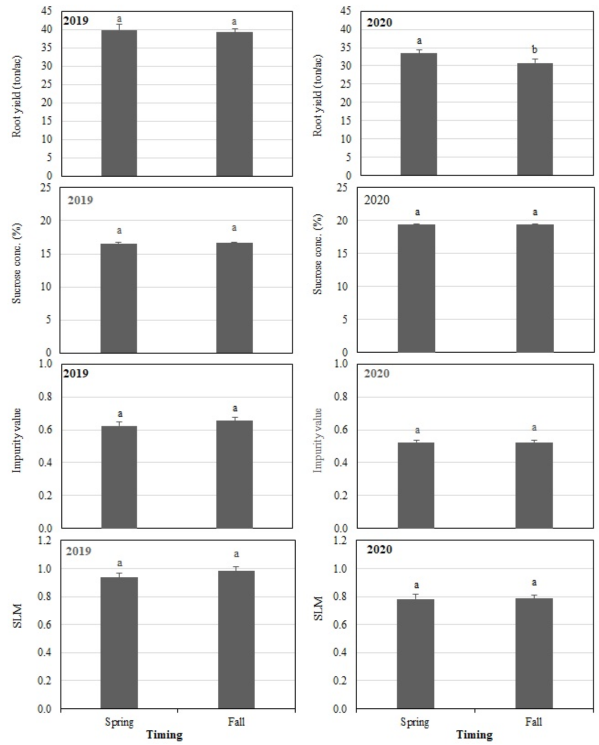

Figure 2. Sugar beet root yield, percent of sucrose extraction, impurity value (IV), and sucrose loss to molasses (SLM), influenced by fertilizer-N application spring and fall timing under different no-till (NT) and conventional tillage (CT), systems and N rates. Error bars are standard errors of the mean. Means with the same letters are not significantly different at *P*≤0.05 according to the least significant difference (LSD) test.

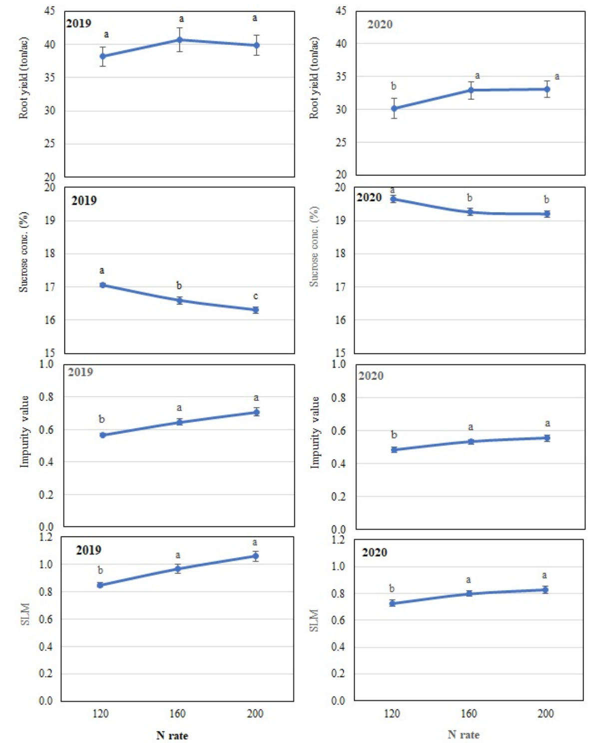

Figure 3. Sugar beet root yield, percent of sucrose extraction, impurity value (IV), and sucrose loss to molasses (SLM), influenced by fertilizer-N application rates (120, 160, and 200 lb N/ac) under different no-till (NT) and conventional tillage (CT), systems and spring and fall timing. Error bars are standard errors of the mean. Means with the same letters are not significantly different at *P*≤0.05 according to the least significant difference (LSD) test.

In contrast, N application decreased the sucrose%, coinciding with increasing N levels. However, the combined effect of Mg or Zn with N scored significantly lower sucrose % than N solely under all N levels. Impurity value (IV) and sucrose loss to molasses (SLM) behaved typically regarding the response to the combined effect of Mg or Zn with N. Fertilizer-N application increased the IV and SLM, and this increase was in parallel with increasing N levels. For example, applying N at 160 and 200 lb/ac increased by 12.0 and 19.8%, respectively. The combined effect of Mg or Zn with N aggravated the IV and SLM concentration compared to the N application alone (Table 4).

Table 3. Combined analysis of variance (mean square error) of sugar beet yield and its quality influenced by combined effects of N fertilizer rate with foliar nutrition (FN) with Mg or Zn under different tillage systems and fertilizer-N application timing across two years (Y) 2019 and 2020.

Source of variation	d.f.	Root yield (t/ac)	Sucrose (%)	Impurity value	SLM
Y	1	3865.16**	666.49**	1.08173**	2.43389**
Residual	6	65.37	0.8002	0.01664	0.03744
FN	8	68.81*	2.2295**	0.033477**	0.07532**
Y*FN	8	58.26	0.8088	0.006327	0.01424
Residual	48	31.07	0.5513	0.0083	0.01867

SLM, sucrose loss to molasses. *and** indicate significant and highly significant at $P \leq 0.05$ and $P \leq 0.01$; respectively.

Table 4. Sugar beet yield and its quality as influenced by combined effects of N fertilizer rate with foliar nutrition (FN) with Mg or Zn under different tillage systems and fertilizer-N application timing across two years (Y) 2019 and 2020.

Treatment	Root yield (t/ac)	Sucrose (%)	Impurity value	SLM
N120	34.2† c	18.4 a	0.526 d	0.788 d
N120+Mg	34.7 bc	17.9 bc	0.552 cd	0.828 cd
N120+Zn	34.3 c	18.0 ab	0.557 cd	0.835 cd
N160	36.8 abc	17.9 b	0.589 abc	0.883 abc
N160+Mg	38.0 a	17.5 cd	0.589 abc	0.884 abc
N160+Zn	35.9 abc	17.8 bcd	0.597 abc	0.896 abc
N200	36.5 abc	17.8 bcd	0.630 a	0.945 a
N200+Mg	37.8 a	17.5 d	0.614 ab	0.920 ab
N200+Zn	37.2 ab	17.7 bcd	0.576 bc	0.864 bc

†Mean values within the same column for each trait with the same lower-case letter are not significantly different according to the least significant difference (LSD) test at $P \leq 0.05$. SLM, sucrose loss to molasses.

The results revealed that sugar beet root yield and sucrose concentration showed no consistent differences between no-till and conventional farming practices or between spring and fall application of N. The lack of tillage management suggests farmers can achieve comparable yields and sucrose concentrations by adopting no-till practices, thereby reducing energy and labor inputs while safeguarding soil and water resources. Foliar application of Mg in combination with soil application of N tended to improve sugar beet root yield.

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COMPOSTED MANURE IMPACTS ON ORGANIC WHEAT PRODUCTION IN THE NORTHERN GREAT PLAINS

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ABSTRACT

Montana leads the nation in organic production of small-grain crops including wheat (*Triticum* spp.). A major challenge faced by dryland farmers when growing wheat organically is supplying adequate N for optimum wheat yield and quality. A onetime application of composted manure at four rates (0, 5.6, 11, and 22 tons/acre) vs. annual applications of urea based on soil test results when growing wheat in wheat/fallow and wheat + biennial sweetclover [(*Melilotus officinalis* (L.) Lam.]/green fallow systems were compared for impacts on grain yield and protein concentration in central Montana, beginning in 2021. Wheat yield differences were not detected in plots where urea was applied vs. check (0 applied N) plots in any year ($P > 0.05$). In contrast, wheat yields were greater in plots receiving a onetime application of composted manure at 22 tons/acre vs. urea-fertilized plots in both 2021 (10 vs. 5 bu/acre) and 2023 (49 vs. 29 bu/acre). Grain yield was lower when wheat was grown with and following a green manure (green fallow) vs fallow. Protein concentration was elevated in wheat grain harvested from plots receiving an application of composted manure at all three rates (average = 19.5%) compared to urea-fertilized or check plots (18.7%) in 2021, but lower in manure-amended (average = 11.8%) and check (11.4%) plots than in urea-fertilized plots (13.4%) in 2023. The threshold for grain protein concentration indicating N sufficiency when growing winter wheat (12.1%) suggests that N limited grain yield in manure amended plots in 2023. Results from this ongoing study suggests that grain yield benefits can result when wheat is grown organically three years after a single application of composted manure in the northern Great Plains, although lack of plant-available N may prevent maximum amounts from being produced.

INTRODUCTION

Montana was the leading domestic producer of organic wheat in 2021, producing just under 704,000 bushels on over 66,000 acres that year, or nearly 18% of the U.S. total (USDA NASS, 2022). Low organic wheat yields (11 bu/acre average) reflect a severe drought that persisted across much of the state in 2021 (Ragar & Monares, 2021), but also the other abiotic as well as biotic stresses that dryland organic farmers encounter when growing wheat. For example, low soil fertility was identified as the second greatest obstacle after weeds to growing wheat profitably when organic farmers were surveyed across Montana (OAEC, 2017).

Soils in fields on organic farms generally are low in one or more plant nutrients in the northern Great Plains (Knight et al., 2010). In a Montana survey, nearly 80% of organic farmers reported that soil nutrient deficiencies were a problem on their farms, with a majority (67%) basing their conclusion on soil test results (OAEC, 2017). Growing green manures, notably pea (*Pisum* spp.) and biennial sweetclover (clover), was the most common practice for remediating low soil fertility on organic farms reported in that survey. Other practices used to improve soil nutrient status included crop rotation, incorporating grazing into the cropping system landscape, and applying livestock manure, but only on a minority of organic farms.

The facts that most organic farmers reported soil nutrient deficiencies occurring in fields on their farms, and that green manuring was a common practice used to maintain soil fertility, suggest that other practices must be used to improve soil fertility for optimum grain yield and quality in Montana. Previous research demonstrated that wheat grain yield was elevated for several years after applications of manure were discontinued in Alberta, CA (Larney and Olson, 2018). Our objective is to determine if a similar legacy impact occurs following a onetime application of composted cattle (*Bos taurus*) manure in Montana, and how the presence or absence of a green manure crop grown during the fallow-phase impacts subsequent wheat yield in a fallow-wheat system.

MATERIALS AND METHODS

The study was established in a field at the Montana State University, Central Agricultural Research Center (47°03´ N, 109°57´ W; 4200 ft elevation), in April 2021. Treatments were arranged in a randomized complete block in a split-plot pattern. Composted manure applied at four rates (0, 5.6, 11, and 22 tons/acre) along with a urea fertilized treatment comprising main plots and cropping system phases comprising subplots: 1. wheat/fallow system, wheat phase; 2. wheat/fallow system, fallow phase; 3. wheat + clover/green fallow system, wheat phase; and 4. wheat + clover/green fallow system, green fallow phase. Fertility and cropping systems phases were established in each of four blocks; subplot dimensions were 20 x 35 ft.

Composted manure was applied once and incorporated using a tandem disk when the study began. Urea (46-0-0) was broadcasted and incorporated in fertilizer main plots annually based on soil test results from samples collected within a few weeks of planting wheat. The original intent was to plant winter wheat during wheat phases in both systems but a delay in project startup forced the substitution of spring wheat (planted in May) for winter wheat (planned for planting the previous September) during the 2020-21 growing season. During the 2021-22 growing season, spring wheat was planted into poorly established winter wheat (<50%) because of persistent drought, resulting in mixed spring and winter wheat subplots. Good growing conditions throughout 2022-23 resulted in excellent establishment and survival of winter wheat so spring wheat was not planted.

Austrian winter pea [*Pisum sativum* L. subsp. *sativum* var. *arvense* (L.) Poir] was planted in May 2021 as a substitute for “second-year” clover in green fallow plots in the 2020-21 growing season. Clover was planted with spring wheat in wheat + clover plots in 2021 with the clover becoming the green manure in the green fallow plots in 2022 (i.e., 2021-22 growing season). Clover planted in May 2022 into winter wheat planted the previous September became the green manure crop in green fallow plots in 2023. Fallow (i.e., not green fallow) plots were tilled from spring through summer to control weed growth, as needed.

Above-ground plant biomass (crops and weeds) was determined within a 5.4-ft^2 area in each subplot when wheat was at the watery ripe to early milk stages of kernel development (Zadoks growth stage 71-73, Zadoks et al., 1974). Plants were clipped at the soil surface, separated by type (weeds, wheat, and green manure), dried at 125-130^o F and then weighed once a constant weight was reached (roughly 7 to 10 d after clipping). Leaf area index (LAI) was calculated from photosynthetic active radiation measurements made at three locations within each subplot using an Accupar LP 80 ceptometer just prior to harvesting plant biomass samples. Wheat grain was harvested from the center of each subplot using a small-plot combine after wheat reached physiological maturity and kernel moisture content was <16%. Grain yield is reported as bu/acre adjusted to a 12% moisture concentration. Grain protein concentration was determined by NIRS for a subsample from each subplot using a CropScan 3000B Whole Grain Analyzer in 2001 and a Foss Infratec Analyzer in 2023. Grain was mixed (spring and winter wheat) in 2022 so grain protein concentration was not determined that year. Grain test weight was determined from a subsample in each year.

Treatment effects were analyzed separately across years because of differences in wheat (spring wheat in 2021, mixed wheat in 2022, and winter wheat in 2023). A split plot analysis was conducted using the ‘splitplot’ function in the ‘doebioresearch’ package for R statistical software, with rep as block, composted manure and urea treatments as main plots, and wheat production method (± sweetclover) as subplots. Treatment means were separated using a protected LSD at *P* < 0.05. The ‘agricolae’ package for R statistical sofware’s ‘aov’ and ‘LSD.test’ functions were used to compare sweetclover biomass across wheat whole plots in the +sweetclover plots.

RESULTS AND DISCUSSION

The LAI of plant canopies receiving 11 or 22 tons/acre of composted manure was larger than canopies receiving ≤6.5 ton/ac in 2021, including the urea-fertilized plots (Table 1). In 2022, differences in plant canopy LAI were only detected between plots which had received the heaviest composted manure rate previously (larger) and the urea- fertilized plots (smaller; Table 2). In 2023, plant canopy LAI was greater in plots that received composted manure at 22 tons/acre previously than urea-fertilized plots and in 0 check (i.e., non-manure-amended or urea-fertilized) plots (Table 3). Plant canopy LAI was lower when wheat was planted following and with green manures than in wheat monoculture in each of the three years (Tables 1-3).

Above-ground biomass produced by weeds, wheat, and green manures generally was nonresponsive to composted manure and urea applications, with two exceptions. In 2023, biomass production by weeds was greater in plots where composted manure was applied at 11 and 22 tons/acre back in 2021, or urea was applied annually, then in 0 check plots (Table 3). In 2021, wheat produced more above-ground biomass in plots that

Table 1. Leaf area index (LAI), aboveground weed and crop biomass, and wheat grain yield and quality across four composted manure rates, a urea fertility application, and a 0 (check) treatment in wheat ± Austrian winter pea (AWP) plots in central Montana during 2021.

		Above-ground biomass			Wheat grain		
Treatment	LAI	Weeds	Wheat	AWP	Yield	Protein	Test weight
		-----------lbs/acre------------			-bu/acre-	--%--	-lbs/bu-
Main plot							
0	0.51b†	233	917b	22	6.3ab	18.7b	57.9
5.6	0.61b	338	1104ab	2	7.0ab	19.4a	57.7
11	0.84a	308	1210a	1	9.6a	19.6a	57.7
22	0.93a	187	1214a	7	9.5a	19.5a	58.2
Urea	0.45b	128	849b	10	5.1b	18.7b	57.5
Subplot							
+AWP	0.68b	204	1032	--	7.1	19.1	57.4b
-AWP	0.74a	273	1089	--	7.9	19.2	58.2a
	P-values						
Main plot (MP)	<0.01	0.760	0.0367	0.4	0.04	0.011	0.515
Subplot (SP)	0.04	0.076	0.4516	--	0.31	0.494	0.006
MP x SP	0.07	0.311	0.0460	--	0.22	0.568	0.445

†Differences in a letter within a column and heading (e.g,, Main plot) indicate differences in treatments at $P < 0.05$.

Table 2. Leaf area index (LAI), aboveground weed and crop biomass, and wheat grain yield and quality across four composted manure rates, a urea fertility application, and a 0 (check) treatment in wheat ± sweetclover (clover) plots in central Montana during 2022.

		Above-ground biomass			Wheat grain		
Treatment	LAI	Weeds	Wheat	Clover	Yield	Protein	Test weight
		---------- lbs/acre ------------			bu/acre	-- % --	- lbs/bu -
Main plot							
0	1.37	402	1517	8	25.9	--	51.7
5.6	1.48	885	882	75	21.2	--	58.1
11	1.54	545	2391	173	28.2	--	51.8
22	1.62	651	1199	76	30.4	--	59.2
Urea	1.19	283	2047	84	25.4	--	59.1
Subplot							
+clover	1.15b†	628	1042b	--	15.1b	--	52.8
-clover	1.73a	478	2172a	--	37.3a	--	59.1
	P-values						
Main plot (MP)	0.18	0.278	0.0620	0.177	0.725	--	0.621
Subplot (SP)	<0.01	0.415	0.0003		<0.001	--	0.159
MP x SP	0.83	0.959	0.1049		0.269	--	0.549

†Differences in a letter within a column and heading (e.g,, Main plot) indicate differences in treatments at $P < 0.05$.

received 11 and 22 tons/acre of composted manure than in urea-fertilized or 0 check plots (Table 1). In contrast, wheat grain yield was equal or greater in plots that received a

Table 3. Leaf area index (LAI), aboveground weed and crop biomass, and wheat grain yield and quality across four composted manure rates, a urea fertility application, and a 0 (check) treatment in wheat ± sweetclover (clover) plots in central Montana during 2023.

		Above-ground biomass			Wheat grain		
Treatment	LAI	Weeds	Wheat	Clover	Yield	Protein	Test weight
		----------- lbs/acre -----------			- bu/acre -	-- % --	- lbs/bu -
Main plot (MP)							
0	0.72c†	668b	2751	8.9	33.4b	11.4bc	60.9a
5.6	1.07abc	1552ab	2154	59.9	30.4b	11.2c	60.5ab
11	1.23ab	2464a	2806	55.5	37.6ab	12.2b	59.7c
22	1.43a	2422a	3716	10.0	48.6a	11.9bc	59.8c
Urea	0.94bc	2007a	1950	8.9	29.3b	13.4a	60.0bc
Subplot							
+clover	0.78b	1574	1584b	--	17.4b	12.2a	59.6b
-clover	1.37a	2076	3766a	--	54.2a	11.9b	60.7a
	P-values						
Main plot	0.024	0.0369	0.1571	0.61	0.022	<0.001	0.007
Subplot (SP)	<0.001	0.3103	0.0001	--	<0.001	<0.001	<0.001
MP x SP	0.717	0.5675	0.2152	--	0.069	0.054	0.171

†Differences in a letter within a column and heading (e.g., Main plot) indicate differences in treatments at $P < 0.05$.

onetime application of composted manure at 22 tons/acre than at other rates, in urea fertilized plots, and in 0 check plots in both 2021 and 2023 (Tables 1 and 3). No differences in wheat grain yield were detected across plots receiving composted manure, urea fertilizer, and 0 check plots in 2022 ($P = 0.062$; Table 2). Grain yield was greater in wheat monoculture than wheat + clover subplots in both 2022 (37 vs 15 bu/ac; Table 2) and 2023 (54 vs. 17 bu/ac; Table 3).

Protein concentration of wheat grain was greater when composted manure was applied at any rate than following an application of urea or in 0 check plots in 2021 (Table 1). In contrast, grain protein concentration of wheat was higher in urea-fertilized plots in 2023 than in 0 check plots or plots that received the onetime composted manure applications back in 2021 (Table 3). Protein was more concentrated in grain when wheat was intercropped with the green manure crop than grown in monoculture in 2023 (Table 3), but not in 2021 (Table 1). Protein concentration was not determined for wheat grain harvested in 2022, as noted previously. In 2023, wheat grain test weight was responsive to a urea fertilizer application or previous composted manure applications (Table 3), but not in 2021 or 2022 (Tables 1 and 2). Wheat grain test weight was nonresponsive to manure or urea-fertilizer amended soil in 2021 and 2022 (Table 1-2). In 2023, grain with heavier test weight was harvested in 0 check plots than plots that received 11 or 22 tons/ac of composted manure previously or in urea-fertilized plots (Table 3).

Results indicate that plant canopy LAI, above-ground biomass, and wheat grain yield are comparable or elevated when composted manure is applied once at 22 tons/acre compared with annual urea applications during the first three years in this ongoing study. Interestingly, grain yield differences were not detected between 0 check plots and plots where urea was applied annually each year, suggesting that an early spring application of urea is not an efficient N-delivery system in shallow soils such as those that occur at this location, since these soils are prone to nitrate leaching (Sigler et al.2020). Grain protein was more concentrated in wheat when urea was applied than a previous heavy application of composted manure in 2023, which was less than the 12.1% threshold indicating N sufficiency when growing winter wheat (Engel et al.., 2006) under dryland management, suggesting that the legacy impact of a one-time heavy application of composted manure may be insufficient to maintain adequate N for optimum wheat grain yield and quality. This study will be continued through 2024.

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

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ABSTRACT

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

INTRODUCTION

Peppermint is used in the food, pharmaceutical, and perfume industries for various purposes. Peppermint oil is the end product and primarily consists of menthol (Zheljazkov et al., 2009). The US is the world's largest producer of peppermint oil. Most peppermint is grown in the Northwest Pacific region (Idaho, Oregon, Washington), which accounts for 91% of US peppermint production (Brown et al., 2003). The Peppermint oil market shows steady growth, and Western NE has peppermint growing conditions, such as long days (>15 hours) and cool nights during the summer, like in the Northwest Pacific region (Okwany, 2012). A few local farmers have started growing peppermint in Western NE and found it profitable. Those farmers have been using the fertilizer nitrogen (N) recommendation from other peppermint growing states, especially from Idaho. Based on Idaho N recommendation, peppermint requires more N (280-325 kg ha^{-1}) (Brown et al., 2003) than irrigated corn (224-280 kg ha^{-1}) for optimal yield (Gumz, 2007). Therefore, in such a high N-input system, a considerable amount of applied N can be lost to the environment, including emission of nitrous oxide (N_2O) if managed improperly. N_2O is a significant greenhouse gas (GHG) and the most important ozone-depleting emission. Increasing N_2O emissions from agriculture are linked to soil management and the application of N fertilizers (Maharjan et al., 2014). Therefore, proper N management practice is required for commercial peppermint production in Western NE. However there hasn't been any published report on N_2O emission in peppermint, which is essential for inventorying GHG emissions from agriculture and informing our mitigation efforts.

The objective of this study is to assess the effects of different N fertilizer sources and rates on peppermint yield, oil and N_2O emission in the Western NE.

MATERIALS AND METHODS

Field experiment was conducted at the Panhandle Research Extension and Education Center (PREEC) in Scottsbluff, NE (41°03'39" N, 103°40'54" W; elevation 1198 m), in 2022 and 2023. The experiment was in a randomized complete block design with four replicates. The N sources used were conventional Urea (46-0-0) and controlled-release fertilizer, Duration (43-0-0), with application rates of 0,140, 210, 280, and 350 kg N ha^{-1}), which corresponded to 0, 50, 75, 100, and 125% of the recommended N rate for commercially grown mint in the pacific northwest region. Peppermint biomass was collected at fully flowering stage and reported as dry matter. Oil concentration in leaves was measured using a Gas Chromatography-Mass Spectrometer (GCMS). N_2O Gas fluxes were measured twice a week using LI-COR 7820 N_2O/H_2O trace gas analyzer (LI-COR Biosciences, Lincoln, NE, U.S.). Cumulative N_2O emission from fluxes were calculated using trapezoidal integration of flux over time. The treatment effects on measured variables were determined by the ANOVA test in SAS.

Table 1. Treatments used in the field experiment.

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

*Treatment included N applied as urea or Duration at different rates.
* Soil available N is the summation of applied N and residual N (spring soil test N).

RESULTS AND DISCUSSION

Peppermint Dry Matter Biomass

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

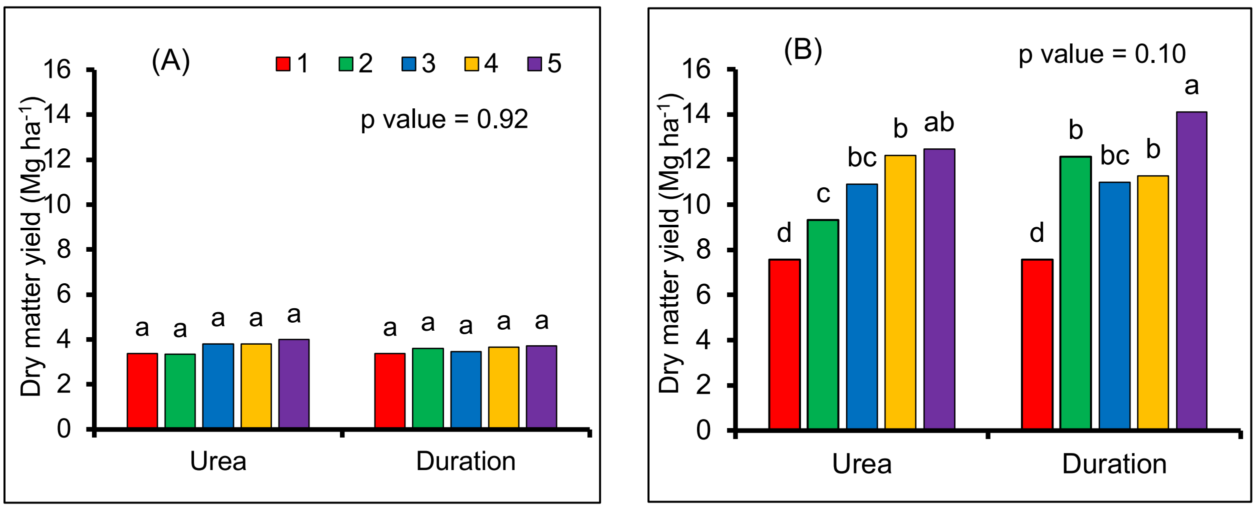

Figure 1. Interaction effect of N source and N rates on peppermint dry matter yield 2022 (A) and 2023 (B).
Different small case letters above bars indicate significant treatment differences at given p value.

Nitrous Oxide (N_2O) Emission

In year 1, among urea treatments, emissions were in the order of treatments 4=3=2>1=control. In year 2, they were in the order 4=3>2>1>control. All Duration treatments had similar emissions as the control in both years. N_2O emissions were greater in urea than in Duration in both years, except for the lowest applied N rate in year 1 (2022).

It's well-established in previous studies that applying N fertilizers leads to increased N_2O emissions from agricultural cropping systems, and this increase is directly proportional to the higher N application rates (Dusenbury et al., 2008; Hoben et al., 2011).

Nitrous oxide emissions in Duration did not increase with different N rates. Several studies have shown that the N source can affect soil N_2O emission (Drury et al., 2012). Polymer-coated urea (Duration®) reduces the N_2O emission since durable polymer coated technology to gradually and efficiently releases nutrients (the nutrients releasing process is diffusion) by improving N use efficiency and reducing environmental N losses. Halvorson et al. (2010), and Sistani et al. (2011) have reported that PCU (Duration®) reduces N_2O emissions compared to urea in different cropping systems (corn and potato), by confirming the results of this study for peppermint.

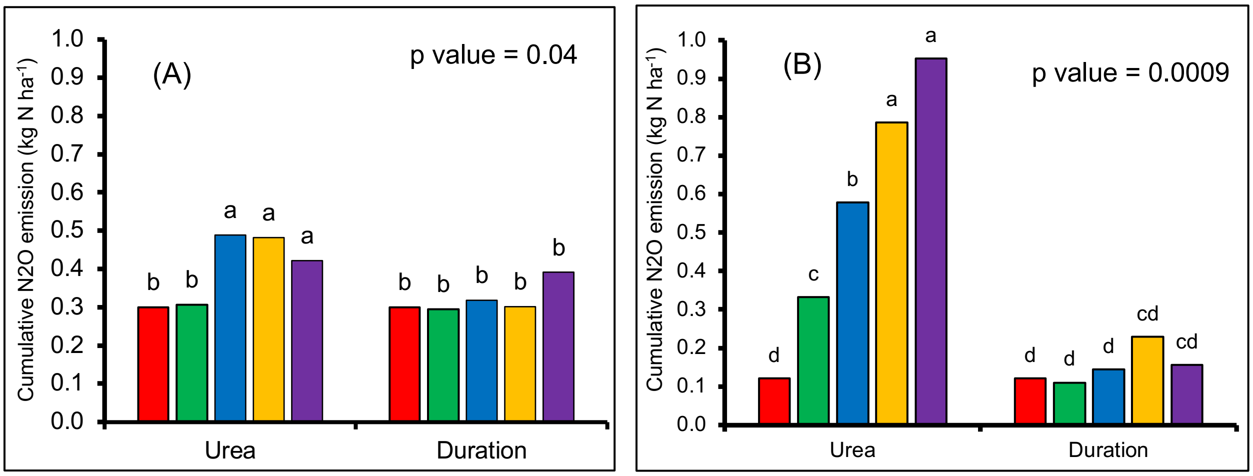

Figure 2. Interaction effect of N source and N rates on cumulative N_2O emission in 2022 (A) and 2023 (B).
Different small case letters above bars indicate significant treatment differences at given p value.

Peppermint oil

The menthol and carvone concentrations in peppermint leaves were significantly affected by the different N rates irrespective of the different N sources in both years. However, fertilizer application increases the menthol and carvone concentration in leaves. Those results contrast with Kothari et al. (1987) and Poshtdar et al. (2016) who found that when increasing N levels oil concentration get reduce due to dilution or increase the concentration of other oil types. But Marotti et al. (1994) have found that when increasing N mineral fertilizer rates increase the menthol concentration when compared to control, this finding has been proved in this study.

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

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

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

CONCLUSIONS

There was no significant yield response across N rates and sources due to the establishment issue in 2022. Across N rates, Duration increased peppermint dry matter yield and reduced emissions compared to urea in 2023. Fertilizer application increased menthol and carvone concentrations. Fertilizer N can be optimized for sustainable peppermint production in NE using advanced fertilizer technology such as PCN (here, Duration). More site-year data would be necessary to determine the optimum N rates for greater dry matter yield and oil concentration (menthol and carvone).

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IMPACT OF FERTILIZER PHOSPHORUS (P) SOURCE, RATE, AND PLACEMENT STRATEGY ON YIELD, NUTRIENT UPTAKE, AND P LOSSES IN SNOWMELT RUNOFF WATER ACROSS VARIABLE TOPOGRAPHIES IN SASKATCHEWAN, CANADA

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ABSTRACT

The plant availability and mobility in soil of a fertilizer phosphorus (P) source is influenced by the solubility of the fertilizer product and the reaction products formed in soil over time. In 2021, 2022 and 2023, responses of wheat, pea and canola yield, P uptake and recovery were determined using eight fertilizer P sources applied in a broadcast and incorporate or side-band placement strategy at a low and high (20 vs 40 kg P_2O_5 ha^{-1}) rates in upper (knoll) and lower (depression) landscape positions in a farm field in southern Saskatchewan, Canada. The P sources containing sulfur generally produced higher yields, P uptake and recovery in both landscape positions, while those of low solubility such as rock phosphate resulted in lowest uptake and lowest residual soil available P. The controlling influence of slope in driving nutrient transport in runoff water was investigated in a simulated snowmelt experiment using intact slabs of surface soil removed from the field. Differences in mobility of the fertilizer P sources were reflected in measured concentrations of Soluble Reactive inorganic Phosphorus (SRP_i) in snowmelt water. Less soluble P forms like rock phosphate and struvite resulted in lower P export in water.

INTRODUCTION

The application of 4R Nutrient Stewardship to fertilizer P management practices seeks to optimize crop nutrient uptake and yield while limiting nutrient losses from their place of application. While a variety of fertilizer P sources are commercially available, few studies have compared their agronomic and environmental performance under Canadian Prairie conditions. As the mobility of fertilizer P and its reaction products in soil is a function of its solubility (Chien et al., 2011), the optimal combination of fertilizer P source, rate, and placement strategy to limit losses in runoff water is important to discern. Furthermore, P fertilizer performance may be influenced by varying soil moisture dynamics across the landscape. Given the controlling influence of topography and soil properties on soil water dynamics (Biswas et al., 2012; Crossman et al., 2014), consideration of the influence of landscape and soil properties on fate of added P can benefit development of site-specific prescriptions intended to maximize crop P recovery and limit losses in snowmelt runoff water. Spring snowmelt represents the primary runoff event across the Prairie Pothole Region (PPR) (Pomeroy et al., 2005).

MATERIALS AND METHODS

Field experiments were established at two sites in the Brown soil climatic zone located in SW Saskatchewan. Recognizing the collective impact that slope and soil characteristics have on water redistribution and associated nutrient transport across the landscape and to capture the range of soil-water dynamics across the hummocky landscape of the PPR, each of the two sites are situated on a unique topographic position within the landscape. The sites are intended to represent typical upper (knoll) and lower (depression) slope positions in cultivated landscapes dominated by chernozemic soils. The sites are situated in a farm field near Central Butte, SK (herein referred to as CB Upslope and CB Lowslope). This three-year crop rotation study was established in the spring of 2021 with wheat, followed by pea in 2022, and canola in 2023. For each site, 36 treatments including combinations of eight fertilizer P forms (Table 1) two P application rates (20 and 40 kg P_2O_5 ha^{-1}), and two placement methods of P fertilizer (side-band and broadcast immediately prior to seeding) along with an unfertilized control were established in the spring of 2021.

Table 1. Phosphorus fertilizer sources used in study, listed by name and chemical analysis.

	Fertilizer P Name	Chemical Analysis (%N - %P_2O_5 - %K_2O - %S)
1	Monoammonium Phosphate (MAP)	11-52-0-0
2	Polymer Coated MAP (CMAP)	11-52-0-0
3	Liquid Ammonium Polyphosphate (LAP)	10-34-0-0
4	Triple Superphosphate (TSP)	0-45-0-0
5	MAP + Elemental Sulfur (MAP + ES)	9-43-0-16
6	Ammonium Phosphate Sulfate (APS)	17-20-0-15
7	Struvite (S)	5-28-0-0
8	Rock Phosphate (RP)	0-3-0-0

A plot seeder having a 1m-wide tool bar with four openers on 25.4 cm spacing was used for each 4 m x 1 m plot. The seeder is equipped with a double-shoot opener configuration to allow independent placement of seed and fertilizer, where fertilizer was placed in a band approximately 1.9 cm below and 1.9 cm to the side of the seed row for the side-band treatments. For the broadcast treatments, fertilizer was broadcast by a hand spreader to ensure that all the fertilizer was contained within the individual plot immediately prior to seeding. Total nitrogen and sulfur application rates were held constant among all treatments through addition of urea or potassium sulfate to balance nutrients as needed. At harvest, two 1 m length rows were harvested by hand from each plot and then air dried until threshing. Grain yield was weighed and recorded on a kg per ha basis. Straw yield was determined by subtracting grain yield from total biomass.

A simulated snowmelt runoff experiment using an intact slab of surface soil removed from the field plots after harvest was conducted following the method of Wiens et al. (2019) with slight modification as described below to meet the unique objectives of this study. As topographic factors are well known to influence nutrient transport mechanisms in runoff water an added factor of slope manipulation was added to the experiment, as described below. The simulation was conducted in a controlled environment room, where the temperature was kept at 10℃ to approximate the daytime high temperature during peak spring snowmelt. To account for the impact of topography and to allow for the lateral movement of snowmelt water, each slab was set at a predetermined angle. As each of the field sites represent a unique topographic position, a common slope was assigned to each site including 5% and 7% for the CB Lowslope and CB Upslope locations respectively to approximate the slopes as they exist in the field at the sites. Once the slope was set, an amount of snow representing 7.5 cm depth of snow on a per area basis (~ 600 g) was added to each slab and the snow was allowed to melt. Due to the low soil moisture content upon slab removal from the field, a second 600 g addition of snow was applied approximately 24 hrs after the first addition. Once the second addition had melted, the volume of run-off water was measured and a sub-sample of the runoff water collected for analysis.

RESULTS AND DISCUSSION

Yields

The yield results of the 2023 season canola (*Brassica napus*, var. PV681) are presented by site and experimental factor in Table 2. The 2023 growing season was drought affected, with lower-than-normal rainfall in June and July. In 2023, grain and straw yield were significantly influenced by site, with higher yields in the wetter Lowslope site. Fertilizer P source had a significant influence ($P < 0.10$) at the CB Lowslope site but not in the drier CB Upslope site. At the CB Lowslope site, grain yields were highest from application of MAP, followed closely by MAP+ES. These were the only treatments where a significant yield increase was observed relative to the control treatment. Overall, the limited yield response to P fertilization may be explained by dry conditions. Higher canola yield obtained using P sources containing S is consistent with similar responses observed in 2021 with spring wheat (data not shown), where yield and crop P uptake was greatest with APS and lower when less soluble P sources like rock P and struvite were used. Mobility and plant availability of fertilizer P is influenced by its solubility (Chien et al., 2011) and is reduced under dry conditions.

At both sites in 2023, neither fertilizer P rate nor placement method was shown to significantly influence canola grain or straw yield ($P > 0.10$) (Table 2). In 2021, a small but significant benefit of side-banding versus broadcasting was observed in spring wheat yield and P uptake. The lack of significant yield response in 2023 to placement or rate in P fertilized treatments also reflects three successive years of fertilizer P application in which there was reduced P uptake and crop removal due to dry conditions. Soil samples collected in fall of 2022 revealed each site to be more than sufficient in plant-available phosphate (data not shown). This observation agrees with Karamanos (2007), where out of 22 experiments conducted across Western Canada with canola, only 13% demonstrated a positive yield response to fertilizer P application where residual soil test Olsen P levels were greater than 30 lbs per acre. Differences in fertilizer P response observed in the two contrasting slope position sites in the current study supports the creation of site-specific Beneficial Management Practices that consider soil and landscape factors.

Table 2. Mean canola grain and straw yield by experimental factor and treatment for each field site.

		Site			
		CB Upslope		CB Lowslope	
		Grain Yield ($kg\ ha^{-1}$)	Straw Yield ($kg\ ha^{-1}$)	Grain Yield ($kg\ ha^{-1}$)	Straw Yield ($kg\ ha^{-1}$)
Factor	Treatment				
Source	C	1027^{a}	2199^{a}	2357^{b}	4964^{b}
	APS	1069^{a}	2666^{a}	2759^{ab}	5849^{ab}
	LAP	990^{a}	2454^{a}	2582^{ab}	5547^{ab}
	MAP	1081^{a}	2392^{a}	2978^{a}	6405^{a}
	MAPC	1051^{a}	2678^{a}	2882^{ab}	5967^{ab}
	MAP+ES	1090^{a}	2637^{a}	2974^{a}	6278^{a}
	RP	1034^{a}	2506^{a}	2593^{ab}	5406^{ab}
	S	1099^{a}	2542^{a}	2606^{ab}	5573^{ab}
	TSP	1174^{a}	2702^{a}	2629^{ab}	5614^{ab}
	P Value	0.88	0.84	0.09	0.09
	SEM	116	178	600	955
Rate	Low (20 kg P_2O_5 ha^{-1})	1074^{a}	2488^{a}	2682^{a}	5638^{a}
	High (40 kg P_2O_5 ha^{-1})	1063^{a}	2574^{a}	2731^{a}	5829^{a}
	P Value	0.86	0.34	0.61	0.27
	SEM	62	90	96	174
Placement	Side-band	1025^{a}	2566^{a}	2717^{a}	5705^{a}
	Broadcast	1112^{a}	2495^{a}	2696^{a}	5762^{a}
	P Value	0.17	0.43	0.83	0.75
	SEM	87	90	96	174

P Concentration in Run-Off

Soluble Reactive inorganic P (SRP_i) concentrations in simulated snowmelt runoff from intact soil slabs collected after harvest of spring wheat in fall of 2021 are shown in Figure 1. In general, addition of fertilizer P resulted in higher SRP_i concentrations in snowmelt runoff water relative to the control treatment where no fertilizer P was applied. In the case of rock phosphate (RP) however, SRP_i losses were not significantly different than the control treatment. This is consistent with the lower solubility of P forms (apatite) in rock phosphate fertilizer sources and the low measured extractable and exchangeable P in the soil following application of this source (Table 3). Trends in SRP_i losses from fertilizer P sources were not consistent between the two different landscape position sites. This may reflect differences in P fertilizer reaction products formed in the different soils from the P forms and agrees with soil and landscape properties as driving factors in nutrient transport (Crossman et al., 2014).

Overall, SRP_i losses in the simulated snowmelt run-off were not found to be significantly influenced by fertilizer P placement method (P >0.10) (Data not shown). Side-band at seeding had slightly higher post-harvest extractable and exchangeable P in the surface soil than the pre-seeding broadcast (Table 3), which may reflect reduced fixation from banding of the P. This could offset the benefit of deeper placement with banding compared to broadcasting on reducing run-off P. In this study, the timing of the surface broadcast application immediately prior to seeding, with incorporation accomplished during seeding with the seeding tool, could also be an important factor to limit P losses in runoff water, and agrees with previously conducted work (Weiseth, 2015; Wiens et al., 2019).

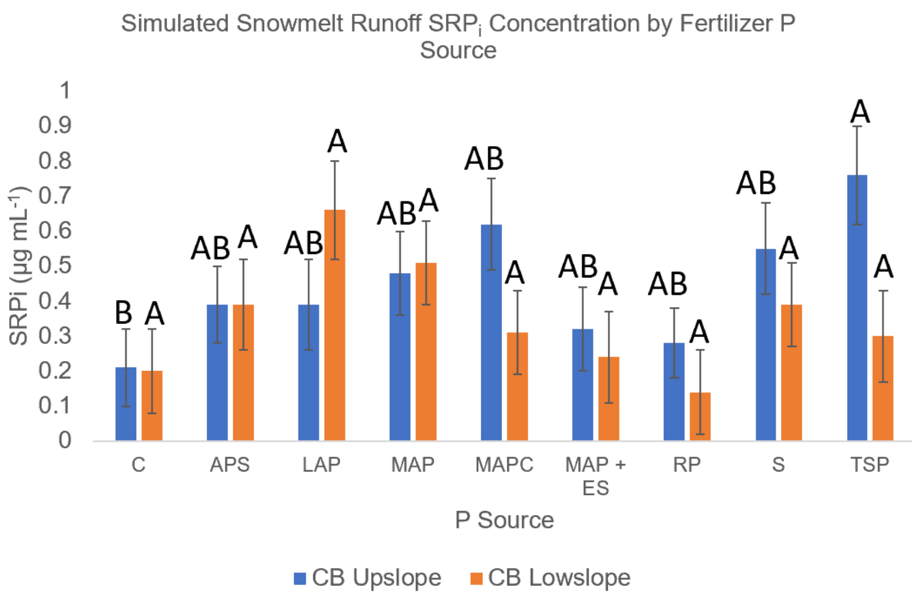

Figure 1. Mean SRP_i concentration in simulated snowmelt runoff water by fertilizer source conducted on intact surface soil slabs removed in fall of 2021 from the two field sites. Error bars represent the standard error of the mean of each treatment. For a site, bars followed by different letters indicate a significant (p<0.10) difference.

Table 3. Post-harvest 2021 soil (0-15cm) extractable (modified Kelowna) and exchangeable (anion exchange resin membrane) P by field site and treatment.

Factor	Treatment	Site: CB Upslope	Site: CB Lowslope	Site: CB Upslope	Site: CB Lowslope
		MK-P (mg kg^{-1})		Anion Exchange Membrane P ($\mu g\ 10cm^{-2}$)	
	C	8.2^{ab}	10.1^{b}	2.4^{c}	2.9^{a}
	APS	14.2^{a}	13.1^{ab}	5.3^{ab}	2.7^{a}
	LAP	12.0^{ab}	11.2^{ab}	4.1^{abc}	3.0^{a}
	MAP	13.0^{ab}	13.1^{ab}	4.9^{a}	3.5^{a}
	MAPC	12.2^{ab}	16.2^{a}	4.4^{ab}	5.0^{a}
Source	MAP+ES	11.4^{ab}	15.1^{ab}	3.6^{abc}	3.9^{a}
	RP	8.3^{b}	11.6^{ab}	2.6^{bc}	3.0^{a}
	S	12.1^{ab}	13.3^{ab}	4.5^{ab}	4.8^{a}
	TSP	11.3^{ab}	11.71^{ab}	3.3^{abc}	3.6^{a}

	P Value	<0.05	0.01	0.001	0.24
	SEM	3.5	2.4	1.7	1.1
Rate	Low (20 kg P_2O_5 ha^{-1})	10.3^{b}	12.4^{a}	3.4^{b}	3.5^{a}
	High (40 kg P_2O_5 ha^{-1})	12.5^{a}	13.3^{a}	4.4^{a}	3.6^{a}
	P Value	<0.01	0.46	0.03	0.19
	SEM	0.8	2.4	1.7	1.1
Placement	Side-band	12.1^{a}	13.7^{a}	4.4^{a}	3.9^{a}
	Broadcast	10.6^{a}	12.0^{a}	3.4^{b}	3.2^{a}
	P Value	<0.01	0.10	0.04	0.98
	SEM	0.8	2.4	1.7	1.1

CONCLUSION

Lower solubility P fertilizer forms demonstrated lower plant availability and yield response but also lower losses in snowmelt run-off from prairie soils. Drought conditions were a factor limiting the overall crop response to rate and placement of added P fertilizer in this study. Differences in performance and fate of P forms observed in the up versus low slope sites point towards a need for site-specific P management in prairie pothole landscapes.

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IMPLICATIONS OF NUTRIENT AND pH STRATIFICATION IN NO-TILL

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ABSTRACT

Stratification of non-mobile nutrients in no-till is not a surprising result. However, this presentation will share the findings of soil sampling a series of long-term NPK fertility studies which have been in no-till production for more than ten years. This data set includes a non-treated check. Beyond stratification of nutrients we found significant stratification of OM, soil acidity, and Al3+. The impacts of stratification in a production system will be discussed along with potential problems and solutions.

SHINING LIGHT ON NOVEL PATHWAYS FOR POTASSIUM FIXATION IN SOIL

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ABSTRACT

Cotton has a high demand for potassium, and potassium significantly affects both cotton yield and fiber quality. Thus, bioavailability of potassium from the soil is paramount. Bioavailability and leaching of potassium to crops and from soils has been studied since the 1940s. However, problems that confronted agronomists in the 1980s continue to impact growers and crop production, including unpredictable potassium bioavailability and inconsistent plant response to fertilizer application under a variety of soil physical and chemical conditions. Part of the challenge of understanding potassium fixation pathways is the lack of fundamental information on potassium adsorption mechanisms. Our goal is to understand and illustrate at a clay mineralogical (and molecular) level how novel pathways of potassium fixation may be contributing to this persistent potassium problem. Our hypothesis is that the formation of new mineral surface precipitates, which develop on fast time scales, provides access to new adsorption sites for potassium surface complexation, effectively increasing the adsorption capacity of mineral solids and the potential to remove potassium from the soil solution. We present recent results relating to novel surface complexation mechanisms of potassium with layered mineral surface precipitates through a series of wet-chemical and spectroscopic experiments. X-ray absorption spectroscopy (XAS) is applied in these experiments to “shine light” on newly identified adsorption pathways for potassium in oxide mineral systems. Batch adsorption experiments were conducted with potassium, aluminum oxides, and silicon oxide in the presence and absence of co-ions. Overall, our results showed increased amounts of potassium sorption for samples reacted for longer time periods, suggesting that potassium sorption is time dependent. Importantly, we identified novel binding mechanisms of potassium to surface precipitates in the presence of different co-ions and dissolved silicate. Inner-sphere surface complexation to different types of surface precipitates was identified, and an increase of on average 30% in potassium adsorption was observed when silicon oxide was present along with aluminum oxides. Collectively, these results imply that considering only the traditional view of potassium fixation, which heavily relies on potassium incorporation into the interlayer spaces of soil clay minerals already present, could perhaps underestimate the potential of soils to sequester potassium.

INTRODUCTION

The United States has a vital role in the global cotton market and is a critical producer and exporter of cotton fiber. Between August 2019 and July 2020, the US produced about $7 billion of cotton (USDA, 2022). Cotton has a high demand for potassium, and potassium significantly affects both yield and fiber quality (Oosterhuis et al., 2014). Bioavailable potassium requirements for cotton plants have become even greater with the use of modern, genetically improved cultivars of cotton that partition more nutrients, such as potassium, into the fruit than cultivars from the 1990s (Pabuayon et al., 2020). Thus, bioavailability of potassium from the soil is critical (Suelter, 1985). Potash is a major potassium fertilizer for many crops, including cotton, and the US imports large quantities of potash. Fertilizer prices, including potash, have been near record levels and can fluctuate markedly (Nti & Jones, 2022). The US is heavily dependent on imported potash, and almost all countries rely on just a few countries, mainly Canada, Russia, and Belarus for potassium fertilizer. Disruptions from any of these countries causes serious potassium fertilizer shortages, further increase in prices, and import-export restrictions (Nti & Jones, 2022).

Potassium chemistry in soil has been studied since the early 20th century (Volk, 1934); however, part of the challenge of understanding novel fixation pathways is a lack of fundamental information on potassium adsorption mechanisms (Coyle et al., 2023; Pham et al., 2022). The traditional four "pools" model used to describe potassium in soil (i.e., solution potassium, exchangeable potassium, non-exchangeable potassium, and structural potassium in feldspars) does not capture the dynamics of potassium supply to plants or potassium turnover in soils amended with fertilizers, plant residues, or waste products (Bell et al., 2021; Coyle et al., 2023; Pham et al., 2022; Schmidt et al., 2022).

Specifically, the interlayer space between phyllosilicate clays is often labeled as the culprit for excessive potassium fixation. Illite, for example, is often heavily enriched in potassium, and that potassium is non-bioavailable (Schmidt et al., 2022). Other major sources of non-bioavailable potassium in soil include primary minerals, such as micas or feldspars (Bell et al., 2021). These long-standing concepts, however, may only be partially guilty for potassium fixation. Specifically, they do not account for the rapid fixation of potassium from applied potash fertilizer.

This work aims to address potentially overlooked fundamental mechanisms by which potassium can become bound to newly formed surface precipitates in soil. These precipitates include metal hydroxides and silicated metal hydroxides, whereby potassium can become sequestered or "fixed". This additional mechanism adds to our understanding of excessive potassium fixation in soil systems. The experimental objective of this research is to examine potassium surface chemistry to identify how it can potentially be incorporated into newly formed surface precipitates (Coyle et al., 2023; Pham et al., 2022).

MATERIALS AND METHODS

Initial studies were conducted using whole soil fractions to determine alterations in potassium chemistry due to traditional soil extraction techniques (Schmidt et al., 2022). Additional studies investigated the extent of potassium adsorption on aluminum and silicon oxides, where multiple sets of batch adsorption experiments were carried out. Three types of (hydr)oxide minerals used, including two aluminum oxides (boehmite and gamma alumina) and amorphous silicon oxide (Coyle et al., 2023; Pham et al., 2022). The purpose of selecting these minerals was to provide different yet common types of surface adsorption sites (aluminum and silicon surface sites) found in soils. Potassium adsorption experiments were conducted at pH 8.5 at ambient temperature using 0.1 g or 1.0 g of mineral. Minerals were reacted in solutions of 3 mM magnesium, iron, zinc, or nickel nitrate, along with 50 mM HEPBS buffer, 10 mM $NaNO_3$ background electrolyte, and 1 mM KNO_3 solution. Dissolved elemental concentrations of potassium, aluminum, iron, silicon, nickel, and zinc were measured using inductively coupled plasma optical emission spectrometry (ICP-OES). Thermodynamic modeling was carried out using Visual MINTEQ. Points of zero charge of the mineral surface were determined using a Particle Metrix STABINO Particle Charge Mapping System. Potassium K-edge X-ray absorption near edge structure (XANES) spectra were collected from the reacted, freeze-dried samples at beamline 9-BM-B,C at the Advanced Photon Source (APS). 40 mg freeze-dried sample was pressed into round 7 mm pellets and mounted at 90 degrees incident to the detector an incident beam (Coyle et al., 2023; Pham et al., 2022).

RESULTS AND DISCUSSION

Effects of wet chemical extractants on soil potassium chemistry

We examined how traditional wet chemical extractants (e.g., Mehlich III) affected residual potassium speciation in agricultural soils. Figure 1 is a summary diagram of the molecular-scale processes. The changes in potassium coordination described in Figure 1 were evident in the X-ray absorption spectroscopic data, where the Mehlich III

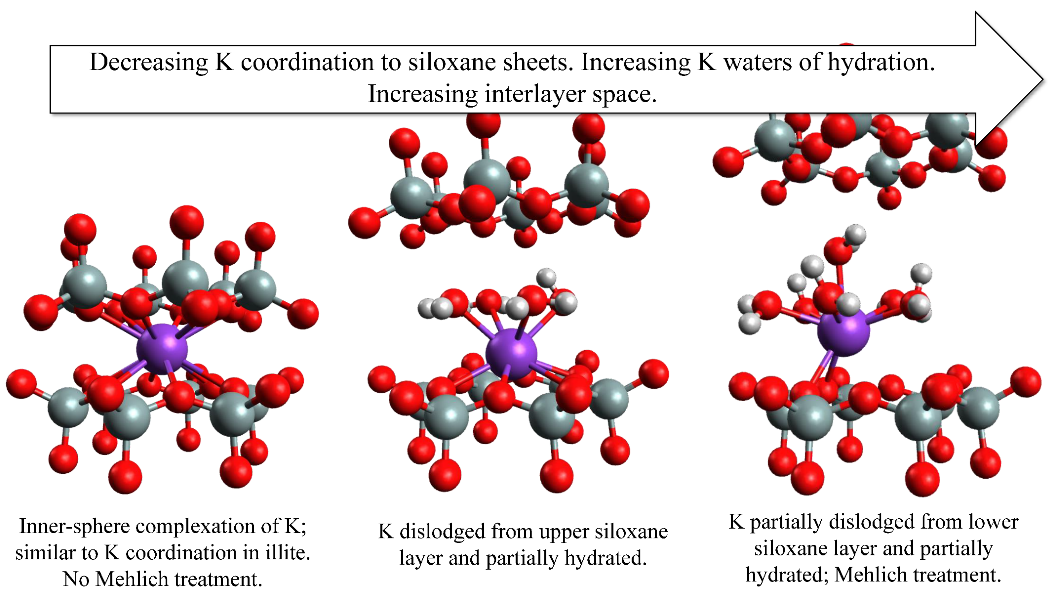

Figure 1. *A structural model illustrating the coordination chemistry of potassium bound in the interlayer space of 2:1 clay minerals. During Mehlich extractions, the spectroscopic data indicated that potassium appears to become dislodged from the silica layers and increases in hydration. From (Schmidt et al., 2022), with permission.*

extractant caused a dampening in spectra oscillation intensities. This indicated that Mehlich III can dislodge potassium from its inner-sphere siloxane bonds (i.e., the bonds it forms with the silicate molecules that compose clay mineral tetrahedral sheets) (Schmidt et al., 2022). Based on a Linear Combination Fitting (LCF) approach, the amount of potassium associated with montmorillonite increased by 25%. The interlayer space of layered clay minerals, such as smectite (i.e., montmorillonite), served as a sink for potassium. This work made it clear that we cannot directly measure potassium bound to the surfaces of clay minerals due to the high concentration of recalcitrant potassium remaining in the mineral solids. Therefore, to determine the coordination chemistry of surface-bound potassium, we examined the role of silicon and aluminum oxides as well as surface precipitates in potassium sorption (Schmidt et al., 2022).

Potassium sorption to silicon and aluminum surface precipitates

During the adsorption studies and subsequent analyses through X-ray absorption spectroscopy (XAS), and specifically the near-edge X-ray spectra (XANES), a distinct feature in the potassium spectra, i.e., a peak at 3625 eV and a valley at 3632 eV (Figure 2A) was observed (Coyle et al., 2023). The presence of the peak at 3625 eV indicates the possibility that potassium is forming an inner-sphere surface complex with newly formed precipitates, which in this case were layered double hydroxides (LDH) for the nickel and zinc systems. The spectral differences between the systems with and without surface precipitates were evident (i.e., the magnesium-system system did not have any surface precipitates, Figure 2A).

Figure 2B provides a direct comparison between silicon, aluminum, and mixed AlSi systems. Sample notation is as follows: Al, aluminum; Si, silicon; Mg, magnesium; 1M, 1-month. When the single oxide systems (i.e., the AlMg1M and SiMg1M) are compared with the mixed oxide system (AlSiMg1M), the shapes of the white lines are distinct. The doublet is pronounced in the mixed AlSi system compared to single silicon system

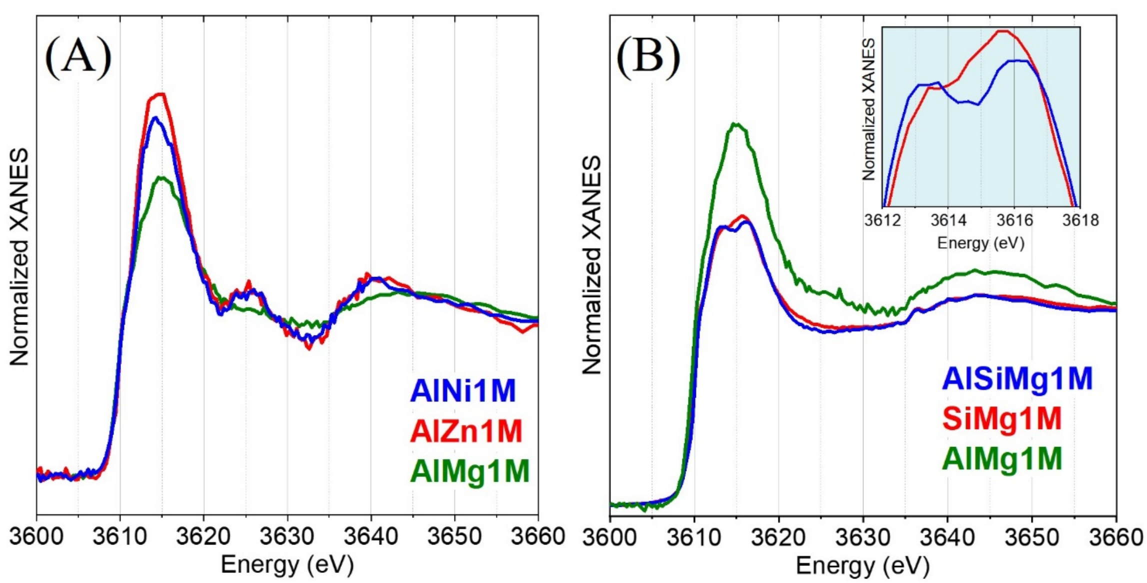

***Figure 2A**. Potassium XANES spectra for aluminum oxide reacted with different co-ions, and (**2B**) a comparison of XANES for mixed oxide systems. The clear doublet feature is present only in the samples with both silicon and aluminum. From (Coyle et al., 2023), with permission.*

(Figure 2B, inset). The pronounced doublet in the AlSiMg1M indicates that the combined presence of aluminum and silicon is affecting the local coordination environment of potassium (i.e., its chemical form, or speciation). These spectra indicate a significant difference in X-ray scattering of aluminum versus silicon as a second nearest neighbor of potassium, and that a distinct bonding mechanism is present in the mixed oxide system which requires the presence of both silicon and aluminum. The sharper features indicate that potassium is more highly coordinated and potentially more tightly bound (Coyle et al., 2023).

CONCLUSION

The experiments indicated that an increase in time also increased the amount of potassium bound to the mineral solids, and that silicon oxide was more reactive than aluminum oxide (Coyle et al., 2023; Pham et al., 2022). This was likely due to the much lower point of zero charge of the silicon oxide. Incorporation of dissolved silicate onto hydroxides may provide new interlayer spaces that can potentially incorporate potassium (Coyle et al., 2023). Surface area by itself did not account for the changes in potassium sorption, and the presence of silicon appeared to promote incorporation into newly formed surface precipitates; overall, a 29% increase in potassium sorption above the predicted amount was observed, and this indicates that dissolved silicate may play a critical role in increasing potassium sorption (Coyle et al., 2023; Pham et al., 2022). The role of dissolved silicate will be pursued in future studies.

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LIME MANAGEMENT IN THE SEMI-ARID REGIONS OF THE US

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ABSTRACT

Soil acidity is increasing in the semi-arid regions of the US; however, questions exist about the efficacy of different liming products to raise soil pH and how long the lime benefits last. Therefore, we monitored the efficacy of three liming products: sugarbeet lime (tilled and non-tilled), prilled lime (seed-placed), and aglime (tilled) to improve soil pH and crop yields at two sites in Montana. Soil samples were collected from 0-3 in. and 3-6 in. for soil pH, nitrate-N, Olsen-P, and extractable Al analysis. Crop yield and plant tissue aluminum concentration were also determined to evaluate the crop response to different lime products. We also evaluated how different sugarbeet lime rates perform to mitigate soil acidity over a 5-year period at three on-farm sites. Soil samples were collected to determine pH at 0-2 in. and 2-4 in. soil depths. Crop yield data were obtained through yield combine monitors. Data indicated that tilling sugarbeet lime is the most effective strategy to increase soil pH and improve crop yields. We observed that if precipitation is high, not-tilling lime can also improve soil pH and yield within a year. Under a low annual precipitation zone, no pH improvement occurred at the 2-4 in. soil depth after 5 years. Soil pH data collected after the 5-year of lime application indicated that lime may need to be re-applied after 5 years under semi-arid environments to mitigate soil acidity. These findings are useful to growers to prepare a lime management plan in semi-arid regions.

INTRODUCTION

Soils in the semi-arid regions of the US are undergoing soil acidification due to current agronomic management practices (Tarkalson et al., 2006). Since 1985, nitrogen fertilizer application has increased threefold in Montana to obtain high-yielding high protein wheat (Jones et al., 2019). Specifically, nitrification of ammonium-based fertilizers releases hydrogen ions in soil, ultimately causing soil acidification. Furthermore, prevalence of continuous wheat cropping system is likely to worsen the acidification issue in the region due to high N needs of hard red wheat. According to a survey, 24 of 56 counties in MT have at least one field with pH less than 5.5 (Jones et al., 2019). Growers in the region are experiencing huge economic losses due to soil acidity but limited information is available to manage soil acidity in semi-arid regions of the U.S.

Liming is an effective means of raising soil pH. Factors such as particle size and purity of liming products, cost associated with application, and potential of a liming product to increase crop yield within a given time interval can affect a grower's decision to use one product over the other. Some liming products such as sugarbeet lime are available for free at sugarbeet plants, whereas products like prilled lime cost around \$250-\$300/ton in Montana, which could be cost prohibitive if more than about ½ ton/ac is applied. Despite the cost, some growers may favor the use of prilled lime due to the ease of application with a seed-drill and to avoid tillage and the purchase of an expensive lime spreader. Studies from other states show that products like prilled lime may or may not provide yield benefits and soil pH improvement may not be uniform across the field (Brown et al., 2008; Lollato et al., 2013, Huggins et al. unpub). No Montana data are available to compare prilled lime and other lime products to help producers and their advisers make informed decisions. Therefore, it is important to test the ability of different liming products and mode of application to raise soil pH and increase crop yield to make soil management decisions in a sustainable and economical manner. Another question pertains to the frequency of lime application to maintain the soil pH in neutral zone. A study from Saskatchewan indicated that single application of lime improved soil pH and crop yields for 16 to 27 years (Malhi et al., 1995). However, the duration of lime impacts in somewhat warmer and drier environments is relatively unknown. Therefore, we conducted two lime-based studies in Montana to evaluate the performance of different lime products to increase soil pH. Our objective for the first study was to evaluate the efficacy of different liming products to raise soil pH and improve crop yield. The second study was designed to determine how long lime benefits last in the semi-arid regions.

MATERIALS AND METHODS

Efficacy of different liming products

A study was conducted at the Springhill Experimental Farm near Bozeman and at an on-farm site near Billings in MT in 2022-2023. Soil at the Bozeman site is a Blackdog silt loam with pH 5.1. The Billings site had Shaaky silt clay loam with pH 5.2. The study had six liming treatments: no lime or control (tilled and no-tilled), sugarbeet lime (tilled and not-tilled), prilled or pelletized lime (seed-placed), and aglime (tilled), replicated four times. In Fall 2022, sugarbeet lime and aglime were applied based on calcium carbonate equivalent and pH buffer test, targeting a pH of 6.2 (1–4-ton lime /acre). The prilled lime was seed-placed in Spring 2023 at the rate of 250 lb/ac. Lime was incorporated with a chisel plow (about 4 in. depth) at Bozeman and with a rotary tillage at Billings during Fall 2022. One of the controls was also tilled to account for any tillage impact on crop yields and soil properties. Durum wheat, which has no aluminum tolerance, was planted in Spring 2023 at both sites.

In Summer 2023, plant samples were collected from a 3.3 ft strip of two adjacent rows. Dried and ground plant samples were sent to a commercial laboratory for nitrogen, phosphorous and aluminum analysis. In Fall 2023, soil samples were collected from 0-3 in. and 3-6 in. All the soil samples were air-dried and ground to pass through a 2-mm sieve and sent to a commercial laboratory for soil pH, nitrate-N, Olsen-P, and 0.12M KCl extractable-Al using standard lab protocols. Crop yield data were collected using a plot-scale combine in Aug 2023.

How long do the lime benefits last?

The second experiment was conducted as a strip trial at three Montana on-farm sites near Ft. Benton, Big Sandy, and Geraldine. Ft. Benton and Geraldine soils are Bearpaw-Vida clay loams and Big Sandy is a Telstad loam. Each site had a control and a 4-ton lime/ac treatment, replicated three times. All three sites also had a 2-ton/ac lime strip. Big Sandy and Geraldine had a non-replicated 1-ton/ac strip, whereas Ft Benton had a 6-ton/ac lime strip. Lime was applied at these sites in Fall 2017. At Ft Benton and Geraldine, lime was tilled whereas at Big Sandy, lime was not tilled.

Over the 5-year period, soil samples were collected in the fall from 0-2 in. and 2-4 in. to monitor soil pH changes. Crops varied from year to year at each site and included winter wheat, spring wheat, lentils, and corn. Crop yield data was obtained from combine's yield monitors.

RESULTS AND DISCUSSION

Efficacy of different liming products

Liming products significantly affected the soil pH (Fig.1). At Billings, soil pH at 0-3 in. was highest in the tilled beet lime treatment. The tilled aglime and not-tilled beet lime also had higher soil pH than the control and prilled lime treatments. A similar pattern of soil pH change was observed at Bozeman with the lowest soil pH in the controls and prilled lime treatments. At Bozeman, tilled and not-tilled beet lime had the highest soil pH. Soil pH did not differ at 3-6 in. among treatments at any site.

The results indicated that incorporating sugarbeet lime is the most effective way of raising soil pH, but no-till beet lime also increased the pH levels above 6 in this study conducted in 2023. The results suggest that freely available lime products (e.g., sugarbeet lime) are as, or more, effective as costly lime products (e.g., aglime) to raise soil pH. Prilled lime, which was seed-drilled (250 lb/ac) to investigate as an option for no-till farmers, was not an effective strategy to raise pH. Liming did not affect nitrate-N or Olsen-P in soil. The concentration of aluminum in plant tissue was also similar among the treatments.

Liming treatment also affected the durum wheat yield at both sites. At Billings, the not-tilled control (64.3 bu/ac) produced 14 bu/ac less yield than tilled control (78.1 bu/ac) and aglime (78.5 bu/ac). The durum wheat yield was greater in the tilled beet lime (56.6 bu/ac) treatment than tilled aglime (41.0 bu/ac) and not-tilled control (39.2 bu/ac) treatments at Bozeman. It appears that yield was affected by a combination of improvement in soil pH and some artifact of tillage at both sites.

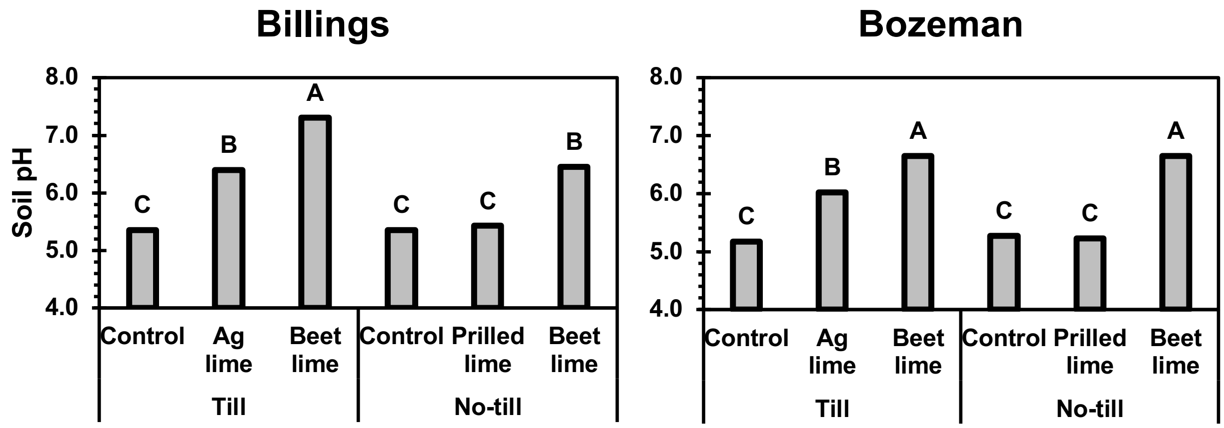

Fig. 1. Soil pH at 0-3 in. under different liming products and modes of application at two sites in MT in Fall 2023. Application of products and tillage occurred in fall 2022 except seed-drilling of prilled lime which was done in spring 2023.

How long do the lime benefits last?

The application of lime increased the soil pH at all sites at the 0-2 in. soil depth; however, by 2022, pH decreased from the 2019 peak at all sites except at not-tilled Big Sandy (Fig. 2). The drop in pH below 5.5 at Geraldine indicates that re-application of lime could be needed after 5 years to raise pH to the optimum pH zone at least in some soils. At the other two sites, even though surface pH was above 6, pH at 2-4 in. was below 5.5 which could negatively affect the crop growth. It is important to consider that 2-4 in. is in, or directly below, the seeding zone, therefore an optimum pH could be critical in that soil zone. The highest rate at each site (4-ton or 6-ton/ac) increased soil pH the most, whereas 1- and 2-ton/ac rates were not able to keep the soil pH in the optimum zone by 2022 at two of the sites, even in the upper 2 inches. At the Big Sandy site where lime was not tilled, no pH increase occurred at 2-4” over the 5-year period, demonstrating that there is not enough moisture to dissolve and move lime below 2 in. in a low annual precipitation zone (14”). This is a disappointing finding given the importance of no-till at reducing wind erosion losses and conserving moisture. This stresses the importance of catching low soil pH before it becomes a problem as liming is expensive and requires tillage to be effective in dry environments prone to wind erosion.

At the Ft Benton site, spring wheat yield was 4.5 bu/ac higher in the 4-ton/ac lime treatment than the 0-ton/ac treatment in 2022 (data not shown). The results indicate that applying 4-ton/ac lime produced yield benefits over no lime 5 years after lime application (lime was applied in 2017). In contrast, at the Big Sandy site, winter wheat showed no yield improvement with the 4-ton/ac lime application. As mentioned previously, lime was not incorporated into the soil at this site. We suspect that low pH at 2-4 in. negatively affected crops. Another reason for the lack of a lime benefit at Big Sandy in 2022 could be extreme drought which may have limited yield more than pH.

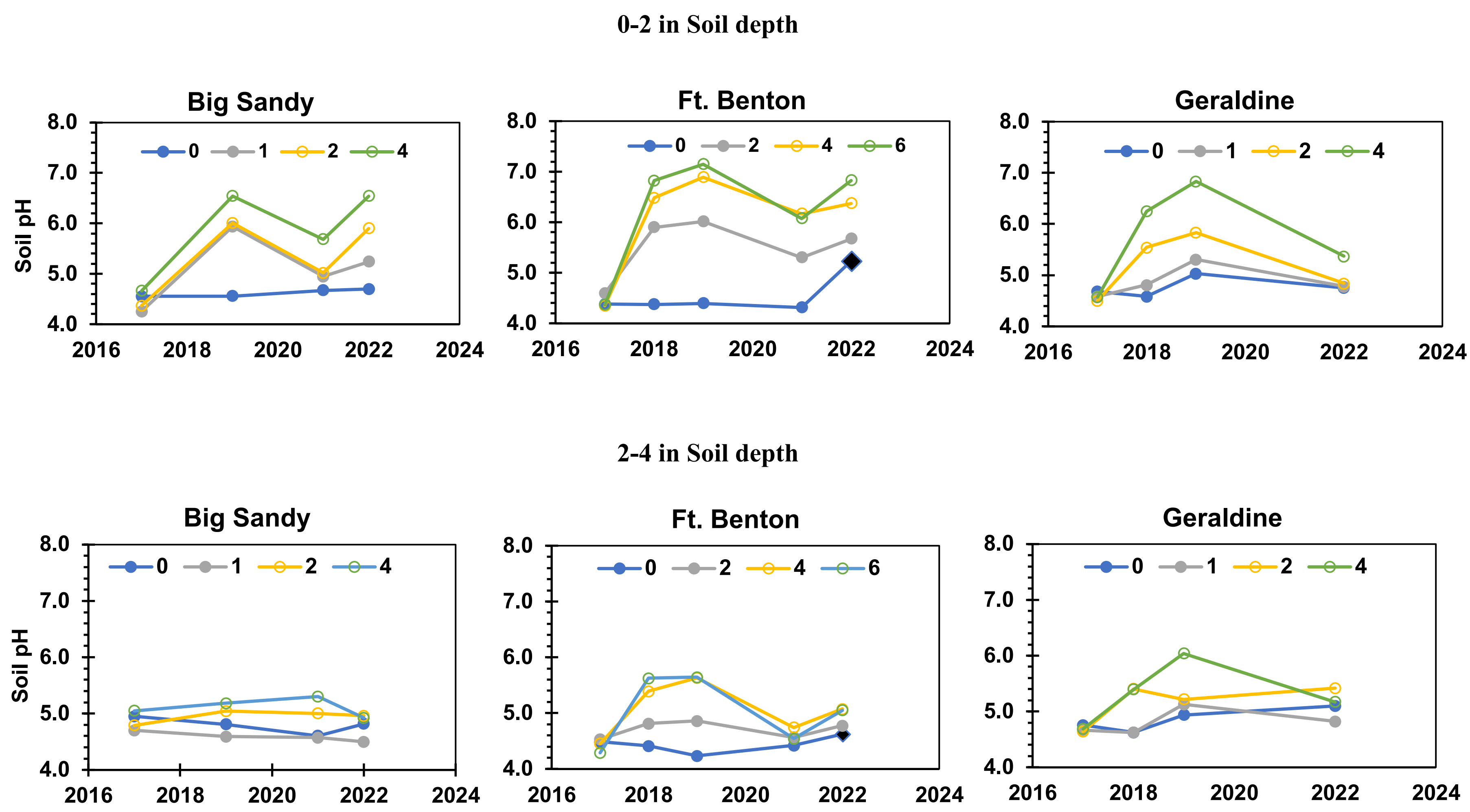

Fig. 2. Soil pH at 0-2 in. and 2-4 in. soil depth under four different lime rates over 5 years at three sites in MT. Lime was applied in fall 2017 without tilling at Big Sandy, with vertical tillage at Ft. Benton and with intensive tillage at Geraldine site. At Ft Benton, the 0 ton/acre treatment received 2-ton/acre lime after 2021 sampling which increased soil pH in 2022. Numbers in legend are beet lime rates in wet tons/ac

In conclusion, liming is an effective way of mitigating soil acidity. The efficacy of liming products and longevity of lime varies with management. The research findings indicated that beet lime can improve soil pH and crop yields better than tilling aglime and seed-placed prilled lime under MT conditions. Not-tilling beet lime can also improve soil pH under good soil moisture conditions. However, in low rainfall zones of Montana, not-tilling beet lime didn't show improvement in the 2-4 in. soil depth over 5-yr period. Based on strip-trial results, it appears that re-application of lime could be needed after 5-yrs of lime application to keep the soils in optimum pH range.

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IMPACT OF TILLAGE, COVER CROPPING AND NITROGEN TIMING ON SOIL CARBON AND NITROGEN DYNAMICS IN TEXAS SOUTHERN HIGH PLAINS COTTON

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ABSTRACT

Cover cropping and no tillage are the most common conversation practices in the Texas Southern High Plains (TSHP) region. However, less than a quarter of cultivated acres in the region utilize these practices. Concerns over cover crop nutrient and water use, yield decline and increased cost are common barriers to adoption for TSHP producers, despite potential benefits such as reduced wind erosion and increased soil organic matter. For these conservation practices to be successful, adjustments in other management practices may be necessary to account for factors such as increased nitrogen (N) demand of cover crops. Adjustment of N application timing could compensate for this by supplying more N earlier in the season to offset N immobilization during cover crop decomposition. Here, we investigate the impact of N rate and timing on soil carbon (C) and N dynamics in conventionally tilled-winter fallow, no-till-winter fallow and no-till with wheat cover cotton (*Gossypium hirsutum*) cropping systems. Our results indicate that splitting N between pre-plant and in-season side dress application positively impact cotton yield, while no-till with wheat cover did not negatively impact cotton yield and significantly increased soil organic carbon seven years after implementation. Our data adds to the varying results for cover cropping in the region, having increased cotton lint yield in this case, but resulting in no difference or reduced yield in other cases. When attempting to implement cover crops or no-till in their operations, producers should consider benefits and drawbacks to conservation practices for their specific circumstance. However, adjustments in other practices, such as N management could be necessary for successful implementation on their farm.

INTRODUCTION

Conservation practices in semi-arid environments can have varied effects on cotton production. Low rainfall and relatively low inherent soil fertility in the semi-arid TSHP has led to low adoption rates of conservation practices due to concerns over cover crop water use and nutrient availability. Previous research has indicated conservation practices generally have a negative or neutral impact on cotton lint yields but contribute positively to other parameters such as soil organic C (SOC) (Lewis et al., 2018). Although reduced yields are a potential drawback to conservation practices, increasing SOC can provide benefits such as increased water storage, soil stability and a slow-release nutrient source (Gregorich et al., 1994; Lehmann et al., 2020; Weil & Magdoff, 2004), which may provide system benefits after medium to long term implementation. Nitrogen management may mitigate some negative effects associated with the implementation of conservation practices, such as nutrient immobilization from cover crop decomposition, by compensating for immobilization during decomposition through additional N application up front or apply N after immobilization has slowed.

MATERIALS AND METHODS

To investigate the impact of N timing in conservation and conventional cotton systems in the TSHP, a study was conducted at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX during the 2021 and 2022 growing seasons. Systems included no-till cotton with wheat cover crop, no-till cotton with winter fallow and conventionally tilled cotton with winter fallow, with no-till and conventionally tilled systems representing conservation and conventional practices, respectively. Nitrogen was applied at 168 kg per hectare (0 kg per hectare for control) at the following application timings: 100% preplant (PP), 100% side-dressed in-season (SD), 40% preplant and 60% side-dressed in-season (SPLIT) and 100% preplant with N stabilizer (PPS). System and N treatments had been in place for 4 years prior to 2021. Study design was a randomized complete block arranged as a split-plot. Plots were 4 rows (1 m spacing) by 15 m in length. The main-plot was the tillage regimes with N timing as the split plot. Cotton variety DP 2143 was planted at 133K seeds per ha. Soil samples were collected prior to cotton planting each year and analyzed for nitrate-N, total N and SOC to a depth of 30 cm.
Data were analyzed using proc glimmix in SAS ver 9.4 and significance level α=0.05.

RESULTS AND DISCUSSION

Soil Nitrogen

Total profile soil NO_3-N was not significant between systems in 2021, however at the 20-30 cm depth CT was significantly greater than NT and NTW (Figure 1a.) Total profile N was also not significant in 2021, however NTW was significantly greater than CT and NT (Figure 1b.). In 2022 both total profile N and NO_3-N were significant, with CT having significantly greater NO_3-N than NT and NTW (Figure 1c.), and NTW having significantly greater TN than CT and NT (Figure 1d.). In 2022, data was also analyzed by N treatment. There were few differences among TN, with SD NTW having significantly greater profile TN than all other system/N combinations (Figure 2b.). There were several differences among N treatments in terms of total profile NO_3-N. Side-dress was significantly greater than all other N treatments for CT and NT systems, however was only different from control in the NTW system (Figure 2a.).

Inorganic N was likely greatest in the CT system because there were no cover crops to scavenge residual N over winter. However, it was likely that organic N from wheat cover in the NTW system contributed to greater total profile N in 2022, as well as TN at 20-30 cm in 2021.

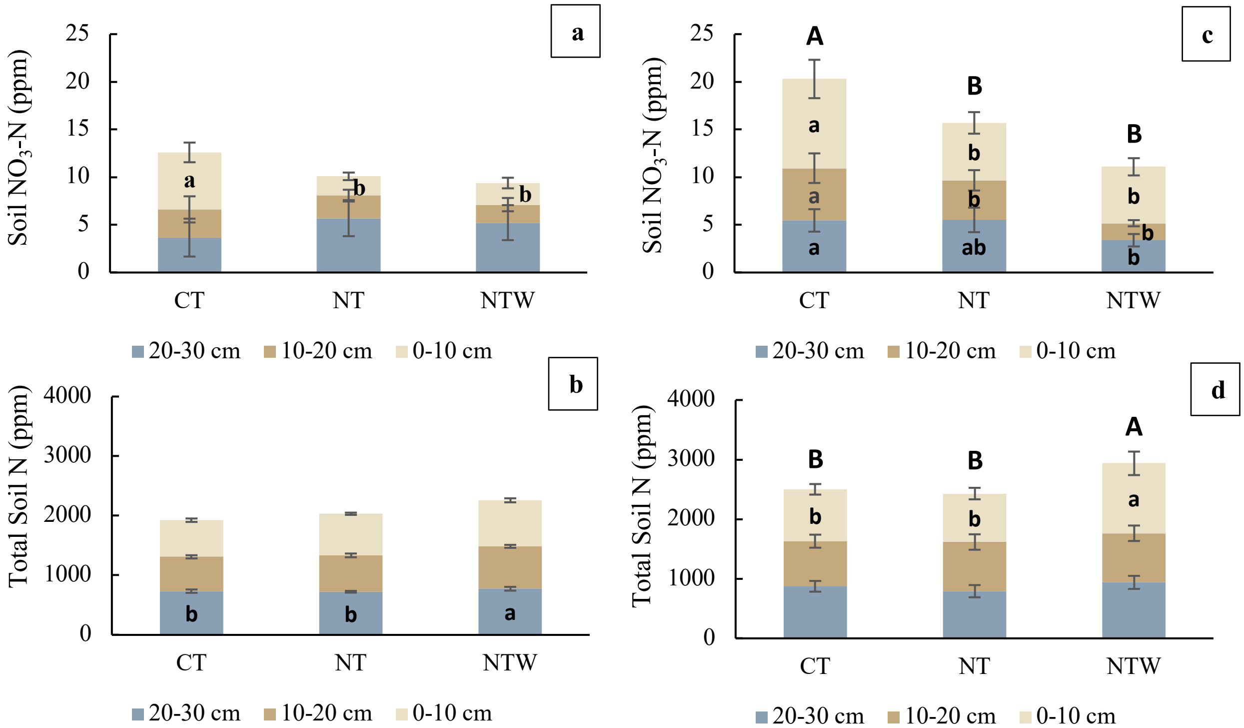

Figure 1. Soil NO_3-N and TN at 0-10, 10-20 and 20-30 cm depths in 2021 (a & b, respectively) and 2022 (c & d, respectively) averaged by system. Bars with different capital letters are different for the total profile within year ($p<0.05$), while bar segments with lower case letters are different within depth and year. Error bars are standard errors.

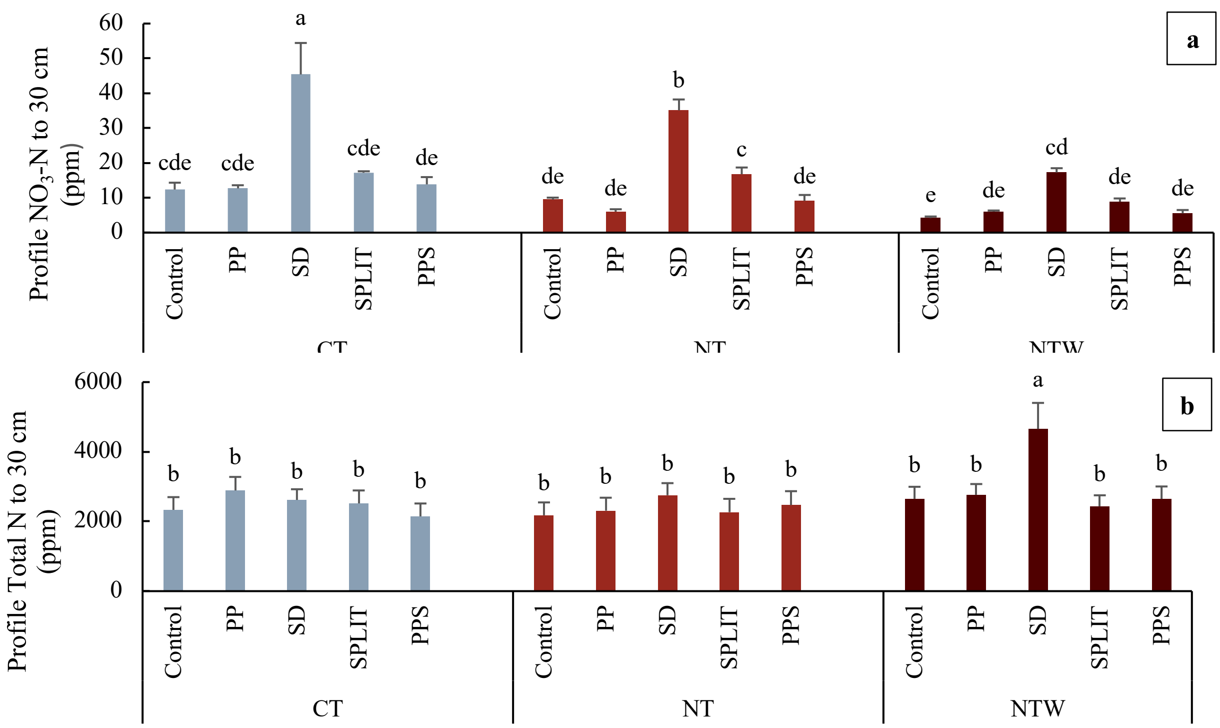

Figure 2. Profile NO_3-N (a) and total N (b) in 2022 averaged by N fertilization within system. Bars with different letters are significantly different ($p<0.05$). Error bars are standard errors.

Soil Carbon

Soil organic was significantly different between systems at 0-10 and 10-20 cm depths in 2021 (Figure 3.), representing 4 years after system implementation. At the upper depth NTW was significantly greater than CT and NT, however at the lower depth NTW was only different from CT. NTW was likely greater due to input from wheat cover crop biomass. Carbon dioxide emissions were slightly greater in the CT system compared to NT (data not show) which likely contributed to differences in SOC decomposition at the upper depth.

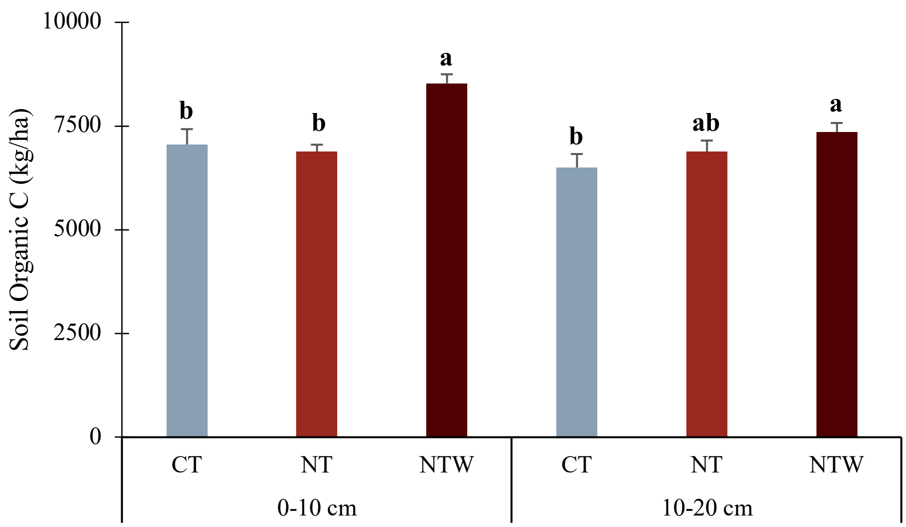

Figure 3. Soil organic carbon by system at 0-10 and 10-20 cm in 2022. Bars with different letters are significantly different ($p<0.05$) within depth. Error bars are standard errors.

Yield

System effects were only significant in 2021 with NT and NTW having significantly higher yields than CT (Figure 1a). Although this study was irrigated, drought in 2022 likely negated any differences between yields (Figure 1b). In 2021, residual soil organic N may have been mineralized late in the season, allowing for additional in season N and helping to increase cotton yield.

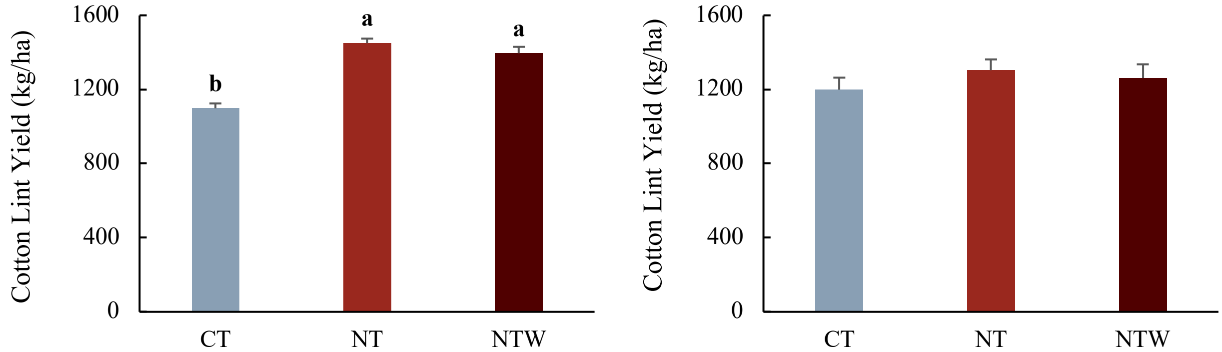

Figure 4. Cotton lint yield by system in 2021 (a) and 2022 (b). Bars with different letters are significantly different within year ($p<0.05$). Error bars are standard errors.

CONCLUSIONS

Here, we investigated the effect of cropping system and N timing on cotton yield and soil N and C parameters. Although NTW and NT reduced NO_3-N, they either increased or had no effect on cotton lint yield and SOC. In 2021, these conservation practices increased yield compared to CT, while in 2022 NTW increased TN compared to CT. This demonstrates that conservation practices can have positive impacts on cotton production in the TSHP, however other studies have demonstrated the potential for negative effects. Producers should make decisions based on their operation and production goals when considering the implementation of conservation practices in semi-arid regions such as the TSHP.

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RESEARCH INDUSTRY EXTENSION

ANALYSIS OF 13 YEARS OF NITROGEN RATE AND TIMING WORK IN OKLAHOMA WINTER WHEAT

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ABSTRACT

In 1999, Raun and Johnson estimated that the worlds nitrogen use efficiency (NUE) in cereal grains was 33%. After two decades of improvement (Omara et al, 2019) revised the prior world NUE for cereal grains to 35%. This improvement can be partially attributed to the change in producer practices of timing of nitrogen applications from an all pre-plant application to a split application of both pre-pant and in-season. The experiment that is analyzed within this study was established in 2009 with the intent to evaluate the effect of nitrogen application rate and timing of nitrogen application on Oklahoma winter wheat (*Triticum aestivum L.)* grain production as a random complete block design (RCBD). Over the course of thirteen year this experiment was conducted over seven experimental locations (Lahoma, Lake Carl Blackwell, Hennessy, EFAW, Perkins, Chickasha, and NOE) where sixteen treatments tested two application timings (pre-plant and In-season) and seven nitrogen rates (28, 56 , 84, 112, 140, 168, 224 kgs N ha^{-1}), resulting in 51 site years if grain yield data. Nitrogen source used in this study was UAN-28. Data collected from this experiment was captured using a Kincaid 8X-P small plot combine equipped with a five foot header and a harvest master unit. Statistical analysis of the grain yield data collected in this study was analyzed using SAS 9.4 and the general linear model procedure (GLM) procedure at an alpha level of .1. Results from the initial analysis of variance indicated that grain yield responded positively to the application of nitrogen in thirty-one sites years. Of the thirty-one site years in which had a response to nitrogen fourteen of which the main effect of timing significantly increased grain yield. In nine site years split applications of both pre-plant and in-season top-dress resulted in grain yields statistically greater than applications made that were solely as a pre-plant.

CARBON AND NUTRIENT DYNAMICS IN REGENERATIVE COTTON PRODUTION SYSTEMS OF THE TEXAS SOUTHERN HIGH PLAINS

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ABSTRACT

Carbon (C) sequestration in soil provides environmental and agronomic benefits. However, building soil C in semi-arid cotton systems is difficult due to low rainfall, low biomass production and high temperatures. Regenerative systems, which utilize practices such as cover cropping and crop rotation, can increase the amount of C input in cotton (Gossypium hirsutum) production systems, but they may increase C losses via carbon dioxide (CO_2) due to increased respiration from soil microorganisms and plants. Thus, the C losses from increased CO_2 production must be discounted from added C when considering C sequestration potential. Nitrogen (N) dynamics can also be affected by regenerative practices. Increased heterotrophic activity in the soil can increase the occurrence of gaseous N losses as N_2O, via nitrification. Heterotrophic respiration may also lead to denitrification, as over stimulation of respiration can quickly deplete soil oxygen, causing anoxic conditions and the production of gaseous forms of nitrogen. This study evaluates the effects of the inclusion of a rye cover crop (Secale cereale), or rotation with wheat (Triticum aestivum), on cotton production in the Texas Southern High Plains. The inclusion of the rye cover crop did increase CO_2 loss compared to conventional practices, while emission from the cotton-wheat rotation were not different from conventional. Terminated rye biomass contains more labile c and has a lower C:N ratio, causing a stimulation of microbial activity and faster decomposition. Wheat stubble has a high C:N ratio and more recalcitrant C, so it is less likely to stimulate microbial activity. Our preliminary results indicate that cover crops can increase CO_2 production compared to conventional cotton production, while crop rotation with wheat does not, but further analysis of C inputs and soil C in both systems is required to gain a clear understanding of their sequestration potential.

INTRODUCTION

Carbon sequestration in semi-arid agroecosystems can be difficult given low net primary production. Adding to this challenge in the semi-arid Texas Southern High Plains is that cotton, a low biomass crop, is the most commonly produced crop, and conservation practices are utilized on less than half of all production acres. Regenerative agriculture is thought to benefit C sequestration by increasing the presence of living plants, thereby increasing C inputs. However, it is not clear how regenerative practices affect soil CO_2 emissions in semi-arid cotton cropping systems. Monitoring the effects of new production practices on CO_2 emissions is important because adding C to soil can increase C loss due to priming, negating some C sequestration benefits Agnew et al.,2010). Here, we assess the impact of two regenerative practices, cover crops and crop rotation, on soil CO_2 emissions from cotton cropping systems. These systems were compared to the regional standard practice of continuous cotton with conventional tillage. The overall goal of this study was to determine the impact of regenerative practices on C sequestration; however this paper specifically addresses soil C losses.

MATERIALS AND METHODS

This study took place at the Texas A&M AgriLife Agricultural Complex for Advanced Research and Extension Systems, located in Lamesa, TX. Management systems included continuous cotton with conventional tillage and winter fallow (CC), no-till cotton with cereal rye cover crop (CR), and a cotton-wheat-fallow rotation (CWF). The rotation was replicated twice so that at least one replication was in the cotton phase each year (CFW-C) and the other was wheat/fallow (CFW-F). Each system was irrigated at two different levels; base (60% ET replacement) and low (<30% ET replacement). Cotton varieties DP 2143 and FM 2498 were planted on May 15, 2023 at 53,000 seeds/acre. Soil CO_2 flux rates were determined via the chamber method using a Gasmet FTIR gas analyzer and an eight minute measurement time for each collar. Each system contained eight PVC collars installed in the soil (four in each irrigation level) from which measurements occurred approximately monthly from June to December 2023.

RESULTS AND DISCUSSION

Carbon Dioxide Emissions

Emissions in all systems at both irrigation levels peaked in July, corresponding to increased cotton growth and microbial activity (Figure 1). Wheat harvest in the CWF-F rotation occurred in late June, so peak emissions in July were likely due to peak wheat residue decomposition. After wheat harvest, the CWF-F system consistently had the lowest CO_2 emission rate under both irrigation levels (Figure 1). CR was the system that consistently had the greatest CO_2 flux rate, with rates significantly greater than at least one other system at every sampling event under base irrigation (Figure 1a). When comparing regenerative systems in the cotton phase, CR had significantly greater CO_2 flux rates than CWF-C at three of six sampling events (6/7, 8/23 and 12/20) at base (Figure 1a) and one of six (6/7) events at the low irrigation rate (Figure 1b). CWF-C flux rate was never significantly greater than CR during any event. Cumulative emissions in the CC, CR, CWF-C and CWF-F systems were 2,837, 3,659, 2,880 and 2,298 lbs CO_2-C per acre, respectively under base irrigation while at the low irrigation level they were 2,649, 2,938, 2,545 and 2,217 lbs CO_2-C per acre. At both irrigation levels the CR system was significantly different from CC while CWF-C was not due to the nature of the additional C input in those systems. Terminated rye biomass in CR was from immature plants, had a low relative C:N, and greater labile C compared to wheat stubble from the CWF system. As a result, rye biomass was decomposed quicker and converted to CO_2 while the wheat stubble was slower to decompose, preventing CO_2 emissions from the CWF-C system from exceeding those of CC. Similar results were observed by McDonald et al. (2019), where wheat cover and no tillage increased soil

CO_2 emissions relative to conventionally tilled cotton with winter fallow, while no-till cotton without cover did not. It is likely that the labile C source of wheat cover, similar to rye cover in this study, stimulated microbial activity causing increases in CO_2 flux compared to the other systems. Further data is needed to determine the full nature of C dynamics of regenerative systems investigated in our study, but we can conclude that the inclusion of rye cover in cotton systems increases C losses compared to rotation with wheat and conventional cotton production.

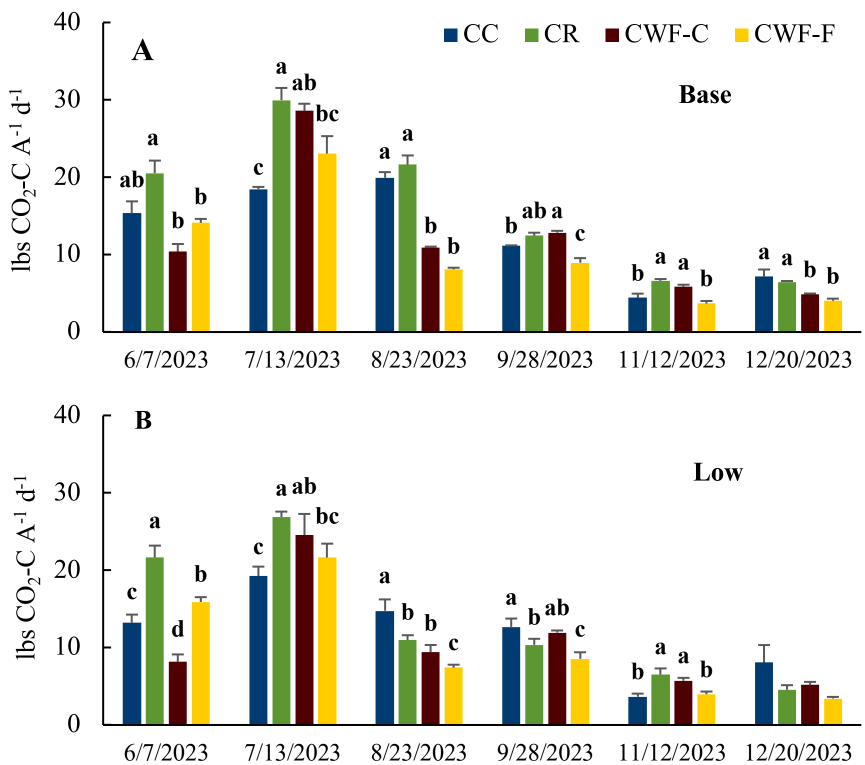

Figure 1. CO_2-C flux rates from June 7 to December 20, 2023 at base (a) and low (b) irrigation levels. Bars with the same letters within irrigation level and sampling event are not significantly different ($p<0.1$). Error bars are standard errors.

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COMPARATIVE ANALYSIS OF DIFFERENT ON-THE-GO SOIL SENSOR SYSTEMS

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ABSTRACT

Soil is an essential natural resource that requires crucial attention due to its significant role in crop yield. Understanding the spatial variability of soil chemical and physical attributes optimizes the profitability of nutrient management for crop development. Soil mapping systems with various types of proximal soil sensors provide crop growers with an excellent opportunity to access soil heterogeneity at a higher spatial resolution and in an efficient and less invasive manner.

Research indicates that it is possible to acquire data related to soil pH, electrical conductivity, organic matter content, soil moisture, and other factors in a cost-effective manner (Adamchuk 2007; Lund 2011; Heege 2013; Huang 2018). Different types of ongoing soil sensors can indirectly assess the range of soil characteristics that are typically measured by traditional soil testing methods currently available in the market.

The utilization of traditional soil sampling methods and subsequent laboratory analysis is both a time-consuming and costly process. Soil conductivity sensors, ion-selective sensors, and soil reflectance based on Passive gamma-ray spectroscopy sensors are commonly used in precision farming applications. These sensors are capable of scanning soils with high spatial resolution and can provide insights into variations in soil parameters. (Srinivasan, 2006).

- ***Non-contact conductivity sensors*** typically utilize electromagnetic induction to detect the electrical conductivity of soil. A main field is generated by a transmitter coil, which in turn generates a secondary field in the soil. The heterogeneity of the soil can be quantified by means of the receiver coil and subsequently translated into various soil parameters through the application of mathematical models. This sensor comprises an array of transmitter and receiver coil configurations (R1 – R4) that are specifically designed to detect changes in the upper layers of soil. By analyzing these changes, we can gain insights into various parameters such as soil compaction, water content variation, and soil type. (Grisso, Alley, Holshouser, and Thomason 2009).

- ***Proximal gamma-ray spectrometer sensors*** possess the ability to examine soils with a high spatial resolution and explain inconsistencies in soil characteristics. It has long been recognized that information on the composition of minerals or soil can be obtained from gamma radiation. As early as the 1930s, gamma detectors were developed and employed for the purpose of mineral (uranium) exploration. With the use of advanced technologies, it has been possible to separate the observed radiation into several components, including naturally occurring radioactive elements such as potassium (40K), thorium (232Th), and uranium (238U). A number of studies have investigated the associations between radionuclide concentrations and soil mineral characteristics (de Meijer, 1998).

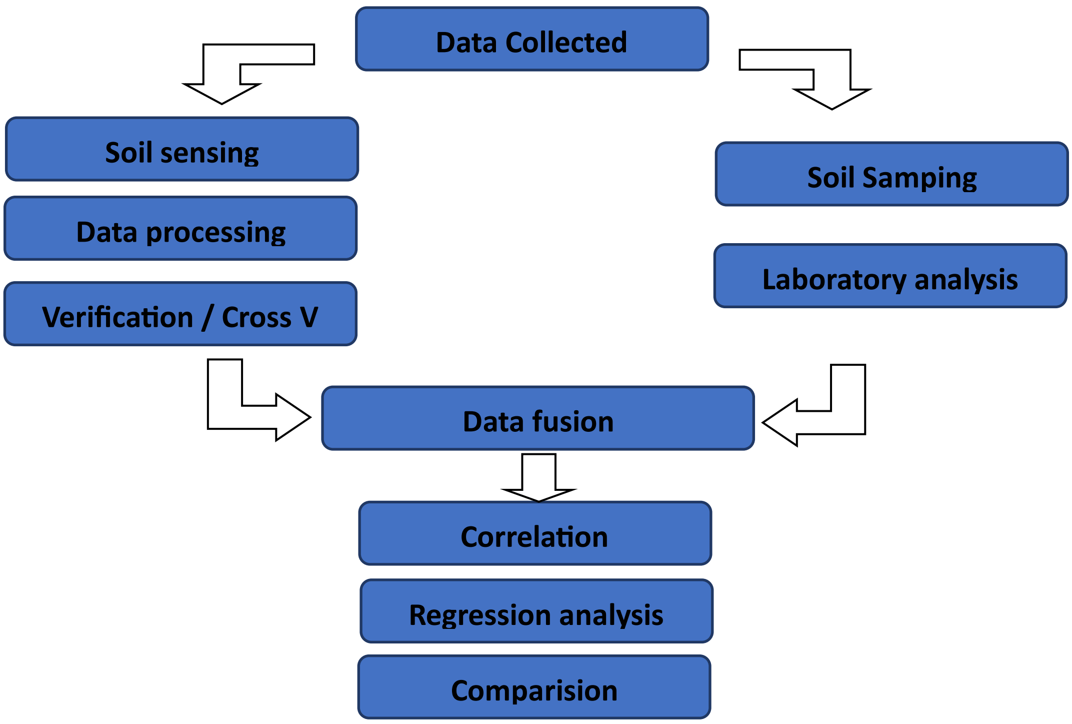
- ***Direct contact conductivity sensors*** are one of the methods used to estimate Soil EC, Organic Matter, pH, and other parameters. This technique involves creating a small amount of electricity and transferring it into the soil using a pair of rolling electrodes colter disks. Another set of disks is used to quantify the decrease in voltage, which is directly related to the electrical conductivity of the soil at a specific position (Sudduth et al. 2005).

Although many sophisticated soil mapping systems that can be used to detect specific soil properties, one single system capable of responding to all soil properties does not yet exist (Adamchuk et al. 2011; Mahmood et al. 2012)
Multiple sensor systems are currently accessible in the market, and there is a continuous endeavor to create new prototypes. In this study, our main objective is to assess the effectiveness of three commercially available soil sensing systems, specifically the Veris system MSP3, SoilOptix Technologies system, and Geoprospectors system TSM. We aimed to determine their accuracy in estimating different soil parameters such as organic matter content, pH level, cation exchange capacity (CEC), soil texture, and nutrient elements.

In addition, the study utilizes machine learning to investigate the relationship between laboratory analysis and various soil sensors, focusing more on Organic matter content because this parameter can be measured by the three soil sensors.

Workflow

The steps illustrated in Figure below were followed to evaluate the predictability of the soil parameter using the three soil sensors compared to the laboratory



Study Area

The study data was conducted across seven fields namely N40_NE, N40_SW, N40_NW, LCB_HFE, LCB_HFS, LCB_North, and LCB_Canola , in three distinct geographical locations within Stillwater, Oklahoma, each of these fields has an area ranging from 1 to 5 acres, and each field also has distinct environmental conditions and soil characteristics.

The selection of these different locations was intentionally made to represent the wide range of agricultural landscapes that are common in the region.

The study recognized the importance of geographic differences in soil characteristics by conducting experiments in several places.

Soil Sample Collection and Treatment

To collect the data, we adopted a deliberate sampling strategy to evaluate the accuracy of the sensors used. Following the Three soil mapping systems Topsoilmapper (TSM), Veris MSP3, and SoilOptix were used to collect dense geo-referenced sensor measurements. Grid sampling was performed using selected 40-foot sections to ensure a representative composite soil sample. With each section, one composing sample was collected by mixing a minimum of 15 cores at a fixed depth of 15 cm with a total of 456 Samples across all the locations. These soil samples were submitted to the SWAFL lab at Oklahoma State University, Stillwater, for chemical and textural analysis to obtain soil property content that will be used to evaluate and calibrate the soil sensors.

This sampling density aimed to capture the spatial variability of soil properties accurately.

To spatially consolidate the collected data, ArcGIS Pro software was employed, facilitating the creation of a fishnet grid. This grid served as a framework for spatially averaging the dense geo-referenced points while accounting for variations in sensor speed during data collection. This step ensured a comprehensive and standardized spatial representation for subsequent analyses.

Prediction Method and Mapping

Python was employed during this study to create heat maps that visually represented the relationships between the laboratory results and the parameters obtained from the sensors. By utilizing Python's tools, such as Matplotlib and Seaborn, these heatmaps provided an easy-to-understand and detailed representation of the observed correlations.

The process of identifying robust correlations involved the utilization of statistical analytic techniques, which facilitated the identification of significant patterns from the large dataset. The study utilized statistical techniques such as Pearson's correlation coefficient and Spearman's rank correlation to determine the magnitude and direction of correlations between laboratory results and parameters collected by sensors.

The predictive modeling step involved the application of complex algorithms, including the Random Forest model. This model, developed using tools like scikit-learn in Python, aimed to utilize the identified correlations for predictive purposes. Techniques for improving and validating the model have been used to assure the accuracy and precision of the predictive results. The regression coefficient (R2) is used as a quality indicator.

The initial phase of my analysis began by creating correlation heatmaps to explore the relationships between the raw data collected from the three soil sensors and the laboratory results. These heat maps provided a comprehensive overview of the variables' interdependencies. My primary focus in the first step was on understanding the correlation between the sensor readings and the percentage of organic carbon in the soil. Following this exploratory phase, I delved into the application of machine learning techniques.

As the second step, I employed the RandomForestRegressor model to predict the percentage of organic carbon based on the sensor data. This involved training the model on the existing dataset and subsequently extracting the feature importance list to identify the most influential variables. with this information, I proceeded to the final step by re-running the model, this time incorporating only the key features identified in the feature importance list.

By optimizing the model with the best parameters derived from the feature importance analysis, my aim was to enhance the predictive performance and increase the coefficient of determination (R-squared) for a more accurate representation of the relationship between soil sensor data and organic carbon content.

COVER CROP TERMINATION TIMING EFFECTS ON SOIL AND COTTON NUTRIENT AVAILABILITY

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ABSTRACT

Depletion of groundwater resources in the Southern High Plains (SHP) of Texas drives a need for more regenerative agricultural practices in semi-arid regions. Here we define regenerative agriculture in the context of the SHP as the *continued capacity of agricultural systems to function in a changing climate that supports soil health, communities, economic output, environmental sustainability, and resiliency to the outside threats of those outcomes*. Within the capacity of this definition, our core values for regenerative agriculture are to 1) *maintain economic viability of the system*, 2) *optimize soil water conservation*, 3) *minimize soil disturbance*, 4) *maintain soil surface coverage*, 5) *incorporate a living root in the soil for as long as possible*, and to 6) *minimize the global climate change effects derived from agricultural practices*. Regenerative practices relevant to the region and associated core values include the implementation of ***cover crops***, crop rotations, conservation tillage, and livestock integration. Cover crop termination timings can have large impacts on the amount of soil coverage, nutrient availability, and stored soil moisture in a system. Producers in semi-arid regions must gamble the possibility of increased soil infiltration and reduced soil water evaporation against the potential of decreased soil moisture; in the SHP, success is dependent on irrigation capacity and precipitation. *Optimizing termination timings for semi-arid regions and in deficit-irrigation/dryland systems is critical for the success of regenerative practices across this large agricultural region.* Small unmanned aerial systems (sUAS) can be used to observe plant physiological parameters across large areas. This data in tandem with ground-truthed soil parameters and plant characteristics can be integrated into crop simulation models to create high-throughput diagnostic tools to determine the sustainability of regenerative agricultural practices in semi-arid regions. sUAS was used to collect field images via multispectral lenses, capturing 6 separate bands of light per photo (RGB, red [630-690 nm], green [510-580 nm], blue [450-510 nm], red edge [670-760 nm], and NIR [700-1,200 nm]). Flights were conducted at or as close to solar noon as permissible with a minimum vertical and horizontal image overlap of 80% to ensure total mapping area coverage. Flights were taken at 8, 6, 4, and 2 weeks from cotton planting and at key cotton growth stages (pinhead square, full bloom, and first cracked boll). Volumetric water content (θ) was determined at soil depth (0-10 cm, 10-30 cm, 30-60 cm, and 60-90 cm) at each 2-week timing interval from cotton planting (8 weeks from cotton planting, 6 weeks, 4 weeks, and 2 weeks) and at cotton planting (0 weeks; 5/16/23). Year one of the study showed no significant differences in cotton lint yield between treatments within irrigation level.

CROP PRODUCTION AND SOIL PROPERTIES IMPACTS OF INTEGRATING ANNUAL FORAGES AND RUMINANT LIVESTOCK INTO WHEAT-BASED CROPPING SYSTEMS

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ABSTRACT

Integrating annual forages and ruminant livestock to intensify dryland cropping systems have the potential to increase profitability, increase water use efficiency, and improve soil health. The objective of this study was to determine the crop yield and soil property impacts of intensifying traditional no-till winter wheat *(Triticum aestivum L.)*-grain sorghum *(Sorghum bicolor Moench)*-fallow (WW-GS-F) with annual forages as well as integrating livestock to graze forages and crop residues. This study was initiated in 2021 at the Kansas State University Agricultural Research Center-Hays in Hays, KS. Treatments were WW-GS-F (control), WW-GS-F with grain sorghum residues grazed, winter wheat/forage sorghum-forage sorghum-fallow (WW/FS-FS-F) with forage sorghum grazed, and WW/FS-FS-F with forage sorghum hayed. The treatments were replicated four times with all phases of the rotation present each year. Grain and forage yields were determined every year with sampling to characterize soil properties in fall 2023. Results showed that full-season forage sorghum harvested for hay produced 5,994 lb/ac on average, while post-wheat forage sorghum harvested for hay produced 1,682 lb/ac. Before grazing, full-season forage sorghum produced 9,735 lb/ac with about 51% biomass remaining as residue after livestock were removed. On average, post-wheat forage sorghum produced 2,988 lb/ac before grazing. Because of smaller yields, post-wheat forage sorghum plots were grazed only in one year when 82% biomass remained as residue on the plots after livestock were removed. In 2023, WW yields were low due to dry weather, but there was no difference among treatments and average was 15 bu/ac. The WW/FS-FS-F (grazed) treatment had greater crop residue cover (77%) at winter wheat planting than all other treatments (53%) in fall 2023. No differences in bulk density or penetration resistance in the 0-2-in and 2-6-in soil depths were observed across treatments. Despite no differences in bulk soil organic carbon (SOC) in the 0-2-in and 2-6-in soil depths, dry aggregate associated SOC was greater with WW-GS-F (grazed) and WW/FS-FS-F (grazed) treatments than WW-GS-F and WW/FS-FS-F (hayed). No differences in mean weight diameter of (MWD) water stable aggregates or the wind-erodible fraction were observed across treatments. These preliminary results suggest that intensifying the WW-GS-F rotation with annual forages and integrating livestock increased available forage, soil residue cover, and dry aggregate associated organic carbon with no effect on winter wheat yields.

INTRODUCTION

Intensifying dryland cropping systems with annual forages and integrating ruminant livestock have the potential to increase profitability, enhance fallow water use efficiency, and improve soil health by increasing residue cover and reducing wind and water erodibility. Currently, the most common crop rotation in this region is winter wheat (WW)-summer crop-F. The most common crops utilized within that rotation are grain sorghum (GS) *(Sorghum bicolor (L.) Moench)* and corn *(Zea mays L.)* (Schlegel et al., 2002). Typically, after the summer crop is harvested, a 12-14-month fallow period ensues to build soil water content for the next WW crop. Due to high evaporation in this climate only 17-30% of precipitation is retained as stored soil moisture during the fallow period (Peterson & Westfall et al., 2004). Even with no-till (NT), less than half of precipitation is retained, and soil cover is lost. Intensifying the rotation with annual forages may reduce soil water and have a negative impact on subsequent grain yield, but the forage that is produced for grazing and haying may offset negative impacts to profitability. Adding annual forages in wheat-based systems may even boost profitability (Holman et al., 2018, 2021, 2023a, 2023b; Carr et al., 2020). Concerns also may arise with the negative impacts haying and grazing could potentially have on soil organic carbon (SOC) reserves, water stable aggregates, and wind erodible fraction due to grazing or haying crop residue. Grazing is often seen negatively as it may increase soil compaction as indicated by greater bulk density (BD) and penetration resistance (PR). The objective of this study was to analyze crop yield and soil health impacts of intensifying traditional NT WW-GS-F system with annual forages, as well as integrating ruminant livestock to graze forages and crop residues.

MATERIALS AND METHODS

This study was initiated at the Kansas State University Agricultural Research Center-Hays in Hays, KS with all phases of the experiment in place by 2021. The study design was a randomized complete block with four replications in a WW-GS-F rotation system. The study compared WW-GS-F rotation with grazing of the GS stalks and with grazing or haying of annual forages grown in place of GS. Each crop phase and hayed or grazed treatments were present each year. Plots were 60-ft wide x 127-ft long for the grazed treatments, and 30-ft wide x 127-ft long for the hayed treatments. Each treatment was grown under NT conditions.

Treatments:

1. Year 1: winter wheat; Year 2: grain sorghum; Year 3: fallow: (WW-GS-F)
2. Year 1: winter wheat; Year 2: grain sorghum (grazed stalks); Year 3: fallow: (WW-GSG-F)
3. Year 1: winter wheat/double-crop forage sorghum (grazed); Year 2: forage sorghum (grazed); Year 3: fallow: (WW/FSG-FSG-F)
4. Year 1: winter wheat/double-crop forage sorghum (hayed); Year 2: forage sorghum (hayed); Year 3: fallow: (WW/FSH-FSH-F)

Winter wheat was planted the end of September, GS and FS were planted at the beginning of June, and post-wheat FS was planted as soon as WW was harvested.

Winter wheat was harvested mid-late June, and GS was harvested mid-October. All grain crops were harvested using a Massey Fergusson 8XP plot combine with a 5-ft wide header attached. Grain yields were determined by a single 5-ft x 127-ft pass with the combine. Hayed FS was harvested at the end of August. Forage sorghum yields were determined by a single harvest of a 3-ft x 127-ft pass with a Carter forage harvester at heading. Grazing of GS stocks occurred post GS harvest and at heading in FS. To determine FS amount before grazing, a 2-ft x 3-ft quadrant was used to sample two different locations within the plot. After grazing, the methods were repeated to determine amount of residue remaining.

In August 2023, soil samples were taken from each plot pre-wheat planting. The soil properties examined were residue cover (RC), wet and dry aggregate stability, BD, PR, SOC, and particulate organic matter (POM). Residue cover was analyzed using the line transect method. Two samples were collected per plot for aggregate stability and BD, while ten samples per plot were collected for all other soil property analyses. Wet aggregate stability MWD was conducted by the wet sieving method using intact soil samples collected at the 0-2-in depth (Nimmo and Perkins, 2002). Dry aggregate stability was determined using a set of rotary sieves and wind erodible fraction was estimated as proportion of aggregates <0.84 at the 0-2-in depth (Chepil, 1962). Wet and dry aggregates were then analyzed for SOC for the >2mm, 2-0.25mm, and <0.25mm size distributions using the dry combustion method (Helmke et al., 2013). The same method was repeated for bulk SOC at 0-2-in and 2-6-in depths. The POM was conducted using the procedure outlined by Cambardella and Elliot (1992) at 0-2-in and 2-6-in depths. Bulk density was determined by the core method with samples taken from 0-2-in and 2-6-in depths (Grossman and Reinsch, 2002). Penetration resistance was determined using an Eijkelkamp Hand Penetrometer (Eijkelkamp Soil & Water, Morrisville, NC). Statistical analyses were completed in the SAS version 9.4 (SAS Institute, 2012, Cary, NC) using PROC GLIMMIX with year and treatment considered fixed and replication considered random. Treatment differences were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Forage Sorghum

Average hayed full season FS produced 5,994 lb/ac, while post-wheat hayed FS produced 1,682 lb/ac. The maximum full season FS production was in 2021 (8812 lb/ac), while the maximum post-wheat FS production was in 2023 (1899 lb/ac) for hayed treatments. Full season grazed FS produced 9,735 lb/ac on average before grazing and left approximately 51% of the forage as residue. Post-wheat FS was grazed only one year during the study due to extreme droughts in 2022 and 2023. In 2021, post-wheat FS produced 5,348 lb/ac and approximately 82% of total biomass was left after grazing.

Winter Wheat Yield

Due to a hail event in 2021 and an extreme drought in 2022, the only WW yields recorded were in 2023. In 2023 yields were low due to dry weather, but there were no significant differences in yield across treatments and the average was 15 bu/ac.

Residue Cover

In August 2023, treatments, WW/FSG-FSG-F had the greatest RC (78%) (Figure 1). The next highest treatments were WW-GS-F (61%) and WW/FSH-FSH-F (56%). With WW-GSG-F (41%) leaving the least soil cover.

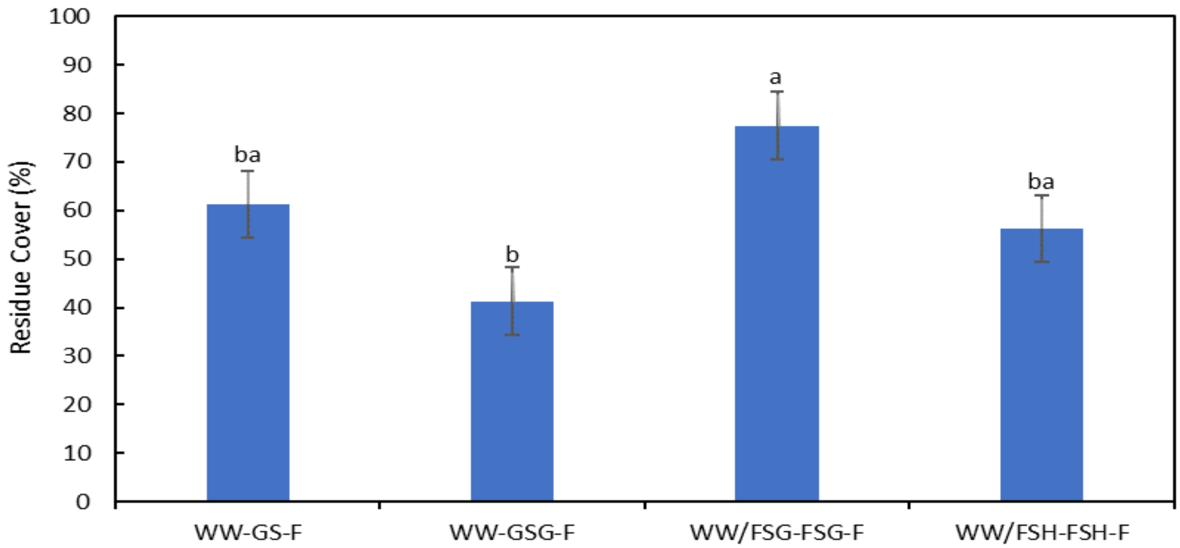

Figure 1. Intensification of WW-GS-F with grazing and forage sorghum effects on residue cover. Means with the same letter are not significantly different (*P*<0.05).

Soil Organic Carbon and Aggregate Associated Carbon

Despite the differences in RC, bulk SOC was not significantly different among treatments. Likewise, water stable aggregate-associated carbon at the 0-2-in depth showed no significant differences among treatments. However, treatments differed significantly in dry aggregate-associated carbon in all three size classes (Figure 2). Grazed treatments (WW-GSG-F and WW/FSG-FSG) ranked first or second in SOC in all aggregate size classes compared to WW-GS-F and WW/FSH-FSH-F.

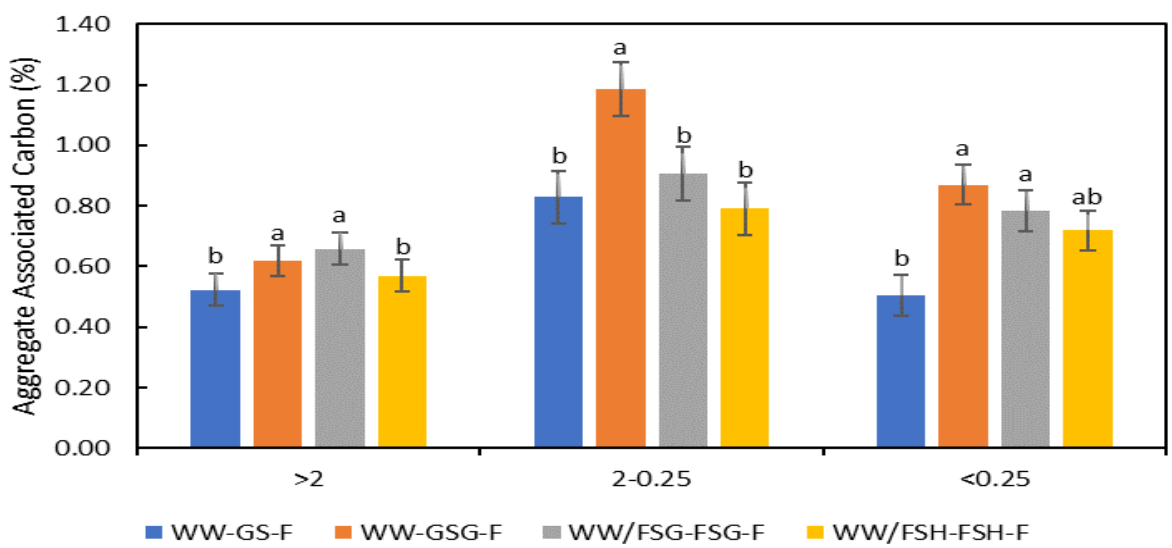

Figure 2. Intensification of WW-GS-F with grazing and forage sorghum effects on dry aggregate-associated carbon. Means with the same letter are not significantly different (*P*<0.05).

Particulate Organic Matter

Treatment differences in POM differed with depth (Figure 3). At the 0-2-in depth POM was greater for WW-GS-F and WW/FSG-FSG-F than for WW-GSG-F and WW/FSH-FSH-F. At the 2-6-in depth, there were no differences in POM among treatments.

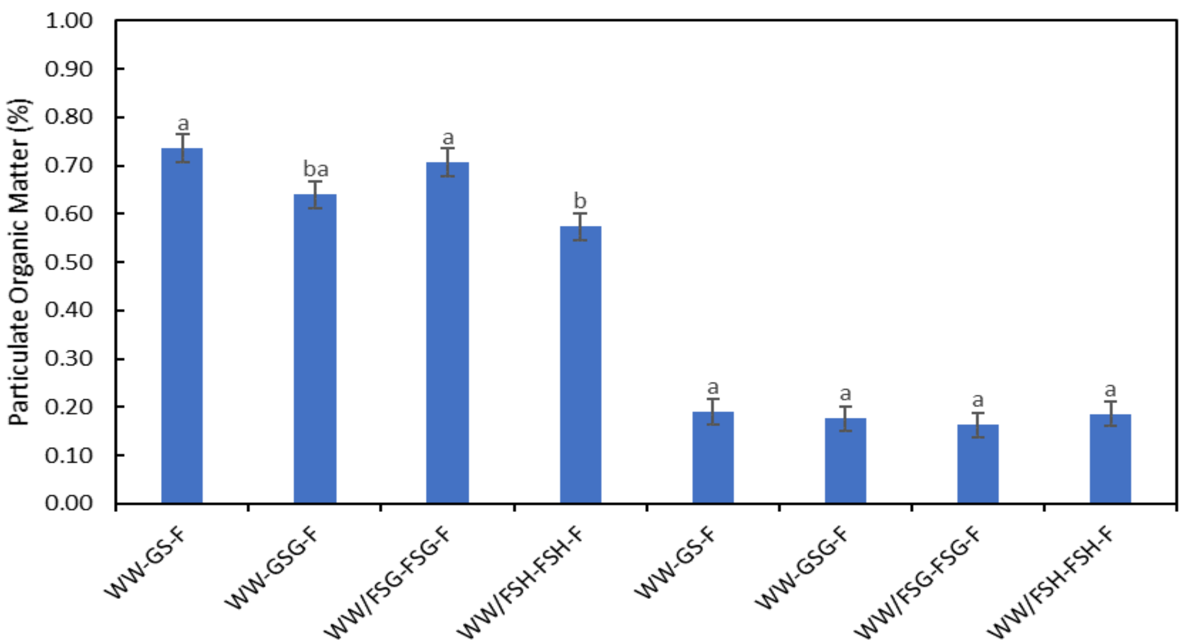

Figure 3. Intensification of WW-GS-F with grazing and forage sorghum effects on particulate organic matter. Means within a depth with the same letter are not significantly different (*P*<0.05).

Aggregate Analysis

Wet aggregate stability and dry aggregate stability (MWD) and wind erodible fraction were not different across treatments at the 0-2-in depth.

Measures of Soil Compaction

Penetration resistance and BD at 0-2-in and 2-6-in depths were not different across treatments.

CONCLUSION

Intensifying the WW-GS-F rotation with annual forages and integrating ruminant livestock increased aggregate associated organic carbon and residue cover. The addition of annual forages and livestock had no effect on MWD, WEF, PR, BD, bulk SOC, and WW yields. These results occurred while an additional forage available for haying and grazing, potentially increasing profits.

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EFFECT OF NITROGEN RATE AND TIMING ON FORAGE SORGHUM BIOMASS YIELD AND QUALITY

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ABSTRACT

Forage Sorghum *(Sorghum drummondii)* is a summer annual sorghum-Sudan grass hybrid that is a high yielding and high-quality source of feed for livestock. Forage sorghum can produce multiple biomass harvests in a single growing season, and is harvested in a silage or dry hay form. Because of the high yield of forage sorghum, this crop is a valuable choice for producers in Oklahoma and surrounding regions with heavily dominated livestock production. For such a high yielding crop nitrogen fertilizer application is extremely important. However, due to the increasing price of nitrogen, the need to understand how nitrogen timing can affect production is essential. Applications of nitrogen fertilizer can benefit forage sorghum yield, however the need to understand how N application rate and timing affect forage quality is a key attribute to observe when taking protein and digestible feed values into consideration. Along with beneficial qualities, knowledge of nitrogen's potential effect on nitrate levels in forage sorghum commonly experienced during periods of drought and excess heat conditions would be beneficial to producers. Therefore, this project evaluated N application in forage sorghum production and quality. The effect of nitrogen rate and timing on forage sorghum biomass yield and quality study was conducted in north central Oklahoma. This study consists of five sites years of data conducted during the 2021, 2022, and 2023 growing seasons. Both dryland and irrigated field conditions are observed, and two harvests per site each year. The treatment structure of this study is designed with seven total nitrogen rates, with a zero-nitrogen check. Three treatments are a split application with four pre-plant only applications. Pre-plant nitrogen rates are 56 kg/ha^{-1} 112 kg/ha^{-1} 168 kg/ha^{-1} and 224 kg/ha^{-1}. A split application of 56 kg/ha^{-1} 84 kg/ha^{-1} and 112 kg/ha^{-1} was applied after the first biomass collection to equal the highest 3 pre-plant treatments. The nitrogen source is urea ammonium nitrate (UAN) applied use SJ3 streamer nozzles. This research study showed value in application methods of nitrogen on forage sorghum production and quality. Results suggest nitrogen positively correlated with biomass production. However, nitrogen applications did not have a significant effect on forage quality. Overall this study has provided a beneficial source of information to those involved.

DOUBLE CROPPING WHEAT SYSTEM EFFECTS ON SOIL EXTRACELLULAR ENZYME ACTIVITY RELATED TO NITROGEN AND PHOSPHOROUS CYCLING ACROSS TEXAS

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ABSTRACT

Conventional management of agricultural systems can threaten soil health by contributing to soil erosion, soil carbon loss, and inefficient water use in crop production. Cover crops and conservation tillage have been reported to improve soil health, but the additional planting and maintenance comes at an additional cost. Double-cropping systems have the potential to mitigate that cost by providing producers with a secondary crop and an additional income source while supporting soil health benefits. One key metric for evaluating the effects of management on soil health is through extracellular enzyme activity, which plays a vital role in nutrient cycling of a system. This project evaluated double-cropping wheat systems and tillage practices across three study locations in Texas: Texas A&M AgriLife Research Lubbock, Stiles Farm Foundation in Thrall, and Texas A&M AgriLife Research Beeville. Tillage treatments included: 1) conventional tillage (disk plow), 2) strip-till, and 3) no-till. Cropping treatments included: 1) wheat-sorghum, 2) wheat-sesame, 3) wheat-cowpea, 4) wheat-cover crop mix, and 5) wheat-summer fallow. Activities of β-glucosaminidase, phosphatase (acid and alkaline), related to nitrogen and phosphorus cycling, respectively, will be measured on samples collected from 0-5 and 5-15 cm depths in the summer of 2021. Expect to see greater β-glucosaminidase and phosphatase activity in study plots that incorporated year-long cover with a grain crop or a cover crop and no-till compared to a wheat-fallow and conventional tillage system. Results will help to identify conservation management practices, specifically double cropping, that can help provide additional economic value to producers while providing data on maintaining or improving the health of soil systems.

INTRODUCTION

Evaluating soil enzyme activities can provide information about the nutrient cycling potential of a system and soil organic matter dynamics (Udawatta et al., 2008). Although many enzymes exist within the soil environment, two of the more common enzymes evaluated in agricultural systems include β-glucosaminidase and phosphatase (acid/alkaline) due to the release of associated nutrients, as they are involved in the final hydrolysis step, required by soil microorganisms and plants (Tabatabai, 1994). These enzyme assays are common indicators of nitrogen and phosphorus cycling, respectively.

Management practices that can affect enzyme activity levels found in soil include cropping system management such as diversity, rotations, and residue management

(Deng and Tabatabai, 1997; Zak et al., 2003; Karlen et al., 2006), tillage practices (Sharma et al., 2013; Chu et al., 2016; Veum at al., 2015), and soil amendments including fertilizers, manure, and compost (Miller and Dick, 1995; Klose et al., 1999, Deng et al., 2000). These variations in management practices affect the microbial communities by increasing the diversity and amount of organic material inputs, disturbing soil aggregates, exposing and relocating sequestered and bound organic residues, and adding variable nutrient loads into the system.

Improving the health of soil can be done by introducing conservation management practices that include cover cropping, reduction in tillage, or a combination of both (Veum et al., 2015; Dairon et al., 2017; Nunes et al., 2018). Although cover cropping can provide soil health benefits, the planting and maintenance that comes along with this practice can be a deterrent for adoption by many producers. Double cropping, defined as a secondary crop grown within the same growing season, can replace a cover crop. This type of cropping system has the potential to provide soil health benefits and can be used as a secondary income source, offsetting planting and maintenance costs. Conservation tillage, including no-till and strip-till, can improve soil health by reducing the amount of physical disturbance to the soil environment. This reduction in disturbance can positively increase soil aggregation, water infiltration and holding capacity, nutrient retention, and soil carbon sequestration (Tebrugge and During, 1999). Currently, in the Southern Great Plains, only 2.1% of agricultural lands are double-cropped (Boechers et al., 2014) and Texas alone has one of the lowest implementation rates of no-till (15%) in the United States (Myers and LaRose, 2019). With reductions in croplands in the South-Central United States (USDA-NASS, 2017) and long fallow periods following the harvest of winter wheat (*Triticum aestivum* L.), the identification and implementation of double cropping systems suited to the area needs to be researched.

This study examined the effects of conservation management practices on β-glucosaminidase and phosphatase activity in short-term (~5 years) plots located at three sites across Texas. The objective of this study was to quantify the impact of conservation management practices (double cropping and reduced tillage) on nutrient cycling potential related to nitrogen and phosphorous cycling compared to conventional management practices (summer fallow and conventional tillage) in a wheat production system.

MATERIALS AND METHODS

Three study sites across Texas were used for the purpose of this research: Texas A&M AgriLife Research and Extension Center at Lubbock, TX, USA (33°4’27” N 101°49’31” W, elevation 1,003 m), Texas A&M AgriLife Research - Beeville Station, TX, USA (28°27’16” N 97°42’22” W, elevation 77 m), and the Stiles Farm Foundation located in Thrall, TX, USA (30°35’53” N 97°17’58” W, elevation 172 m). This study began in the winter of 2016 with the planting of winter wheat to be used as the primary crop in the double cropping system. Field layout is presented by Bekewe et al. (2022) and consisted of a randomized complete block split-plot design with tillage as main-plot and cropping system as split-plot, with three replications. Tillage treatments included: (1) conventional tillage (disk plow; 15 cm depth), (2) strip-tillage, or (3) no-tillage.

Secondary summer cropping treatments included: (1) cowpea (*Vigna unguiculata* L. Walp.), (2) sesame (*Sesamum indicum* L.), (3) grain sorghum (*Sorghum bicolor* L. Moench.), (4) a cover crop mix [Sunn hemp (*Crotalaria juncea* L.), Lablab (*Lablab purpureus* L. Sweet), Buckwheat (*Fagopyrum esculentum* Moench.), Cowpea, Pearl millet (*Pennisetum glaucum* [L.] R. Br.), Foxtail millet (*Setaria italica* [L.] P. Beauv.), Sunflower (*Helianthus annus* L.), Guar (*Cyamopsis tetragonoloba* [L.] Taubert), and Peanut (*Archis hypogaea* L.)], with a (5) fallow treatment as a control. Composite soil samples, using three cores, were collected at depths of 0-5 and 5-15 cm during the summer of 2021 (Beeville: June 23rd; Thrall: June 24th; Lubbock: July 15th) using a Giddings hydraulic soil probe following winter wheat harvest.

Potential soil enzyme activity of β-glucosidase, β-glucosaminidase, acid phosphatase, and arylsulfatase were assayed following protocols described in Tabatabai (1994), Parham and Deng (2000), and Dick (2011). The amount of soil and volume of solutions was reduced by half maintaining the soil:solution ratio used in the original assays (Acosta-Martinez and Cotton, 2017) without the addition of toluene to reduce environmental concerns associated with generated waste (Acosta-Martinez and Tabatabai, 2011). In brief, 0.5 g of air-dried soil was weighed out in duplicate and one control into 50 mL conical centrifuge tubes. For each assay 2 mL of appropriate buffer and 0.5 mL of substrate at optimal pH was added to samples and incubated at 37 °C for 1 h. After incubation 0.5 mL of 0.5 M $CaCl_2$ and 2 mL of appropriate stop solution was added to develop color of solution and stop reaction. Controls received 0.5 mL of substrate after reaction was stopped. Table 2.1 outlines buffers, substrates and stop solution for each individual enzyme. Samples were centrifuged at 1750 rpm for 5 minutes and a 250 µL aliquot of solution was pipetted into a 96-well assay plate. Enzyme activity was determined colorimetrically using a microplate spectrophotometer (BioTek Epoch) to measure amount of p-nitrophenol (PNP), expressed as mg PNP kg^{-1} soil h^{-1}, released at 400 nm. Measured control values were subtracted from the average of the two duplicates.

RESULTS AND DISCUSSION

β-glucosaminidase

Significant differences in β-glucosaminidase activity were present in Beeville and varied between cropping systems, tillage, and depth treatments (Figure 1). No significant differences were found in Lubbock and Thrall amongst cropping systems or tillage treatments. This enzyme activity had significant differences in cropping system at 0-5 and 5-15 cm, and in tillage treatments at 5-15 cm in the Beeville location. The greatest β-glucosaminidase activity measured at 0-5 cm in cropping systems was in sorghum (19 mg PNP kg^{-1} soil h^{-1}) compared to cowpea, fallow, and sesame (15, 13, and 15 mg PNP kg^{-1} soil h^{-1}, respectively). At 5-15 cm the greatest activity was measured in sorghum (9 mg PNP kg^{-1} soil h^{-1}) compared to cowpea and fallow (7 and 6 mg PNP kg^{-1} soil h^{-1}, respectively).

Generally, systems that implemented a secondary crop compared to fallow had greater activity at 0-5 cm and 5-15 cm depths. This increase in nutrient cycling potential is likely due to the benefits associated with double cropping systems. These benefits included maximizing soil cover, extending the amount of living plants in terms of biomass production and below ground root systems, increased soil organic matter through increased plant production and root exudates, and an increase in microbial population growth and associated byproducts.

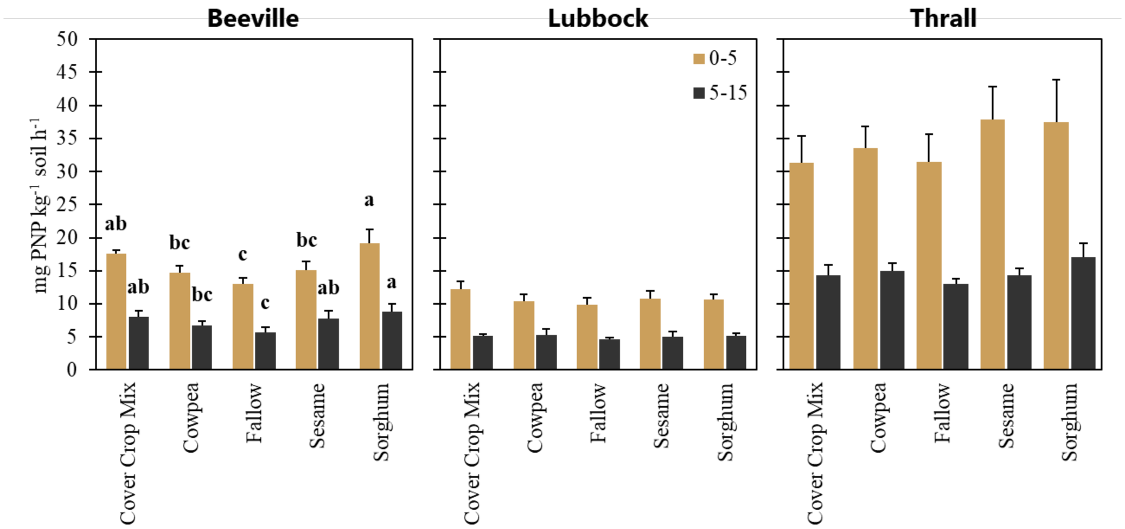

Figure 1. Enzyme activity potential as affected by cropping systems at 0-5 and 5-15 cm β-glucosaminidase in Beeville, Lubbock, and Thrall, TX. Means within location, cropping treatment, and depth with differing LSD letters represent significant differences at $p < 0.05$. If letters are not included, differences were not determined. Error bars represent standard error of the sample mean.

Acid Phosphatase

Significant differences in acid phosphatase activity were not determined at any location amongst cropping system treatments (Figure 2). Generally, systems that implemented a secondary crop compared to fallow had greater activity at 0-5 cm and 5-15 cm depths.

Acid phosphatase has been reported to be associated with soil pH and recommended to assay on soils with a pH below 7 (Acosta-Martinez and Tabatabai, 2000). Therefore, this assay is limited, and not recommended, in discerning management effects in soils with a soil pH greater than 7 at which the recommendation of enzyme assay to evaluate becomes alkaline phosphatase. Soil pH values determined at the 0-5 and 5-15 cm depths in Beeville, Lubbock, and Thrall ranged from 6.98 to 8.47, 7.77 to 8.49, and 5.44 to 7.83, respectively, and was likely affecting the difference in activity between locations. Thrall acid phosphatase activity ranged from 105 to 575 mg PNP kg^{-1} soil h^{-1}, with Beeville and Lubbock ranging from 33 to 209 mg PNP kg^{-1} soil h^{-1}, and 9 to 79 mg PNP kg^{-1} soil h^{-1}, respectively.

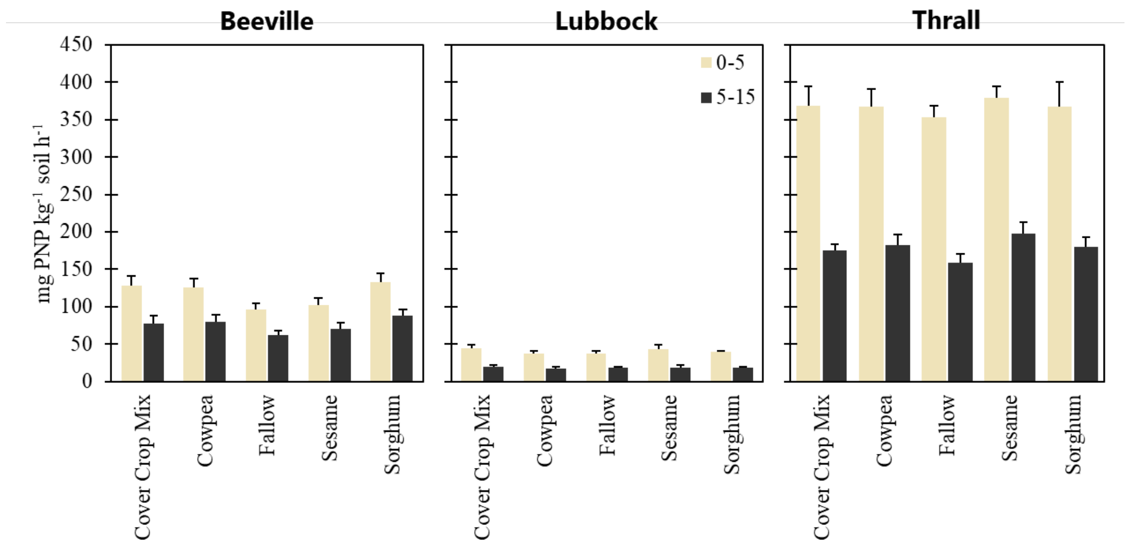

Figure 2. Enzyme activity potential as affected by cropping systems at 0-5 and 5-15 cm for acid phosphatase in Beeville, Lubbock, and Thrall, TX. Significant differences were not determined at a $p < 0.05$. Error bars represent standard error of the sample mean.

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EVALUATION OF FERTILITY TIMING FOR DOUBLE CROP SOYBEANS

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ABSTRACT

Double crop soybeans (Glycine max), or soybeans following a winter wheat (Triticum aestivum) crop are a popular choice for producers who are looking for a way to maintain field coverage through the summer and an opportunity to capture additional profit from their field. In Oklahoma, double crop soybeans have a lower success rate in a rain fed system due to the unpredictability of rainfall and the later planting date of the double crop soybeans. Because of this, producers traditionally treat the double crop as a low input system to minimize cost risk and minimal fertilizer is applied. In some cases, fertilizer for the double crop will be applied prior to the planting of the winter wheat.

The motivation for this trial was the observation of double crop soybean yields comparable to full season soybean yields when sufficient moisture and nutrients were available. The purpose of this study was to test the impact of Phosphorous (P) and Potassium (K) fertilizer timing on double crop soybean yield. To test timing there are three different application times for the double crop fertility: pre-plant wheat, top-dress wheat, and pre-double crop soybean. These timings were chosen to complement when a producer would already be making a pass over the field and the double crop fertility could be included. Winter wheat P and K fertility is considered as well and is applied to all double crop fertility treatments at pre-plant wheat. Nitrogen (N) fertilizer is applied to the wheat in a split application evenly across all treatments.

The resulting treatment structure consist of thirteen treatments, replicated four times across multiple locations throughout Oklahoma, including Ottawa County and Grant County. The amount of P and K fertility applied was based upon site specific soil test values. Winter wheat and double crop fertility were applied to meet the required sufficiency level set by Oklahoma State University's Soil, Water, and Forage Analytical Laboratory (SWAFL), 33 ppm P 100% sufficiency for P for wheat and soybeans, 125 ppm K 100% sufficiency for winter wheat and 138 ppm K 100% sufficiency for soybeans. The first year of double crop beans were just harvested and data will be presented at the conference.

EVALUATION OF N SOURCE IN NO-TILL WINTER WHEAT

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ABSTRACT

Nitrogen (N) source efficacy is dependent upon product used, application timing, and the condition of the environment in which it is placed. This study serves to look at how different N sources can be affected across different regions of Oklahoma, specifically in a heavy residue, no-till environment. N sources that were included in the study were Urea, Urea-Ammonium Nitrate (UAN), UAN + Anvol, and SuperU. The N sources were evaluated across nine site-years (SY) where each product had four different application timings at a base rate of 66 kg ha-1. The relative grain yields and protein measurements were used as the determining factors for establishing which N source produced the most favorable results across all SYs. An ANOVA analysis concluded that additives to N fertilizer sources had no statistical impact on grain yield or protein, therefore, we excluded the two N sources that contained additives out of the study. Our analysis also concluded that application timing and product had little interaction, so each were looked at independently. The analysis of product performance determined that urea had an overall higher bump in protein and yield levels over its UAN counterpart. The analysis also indicates that out of all application timings, a late February/early March application period had the highest results for protein and yield. The results indicate that a late February/early March application of Urea could potentially serve as the best option for production under similar environmental conditions. Additional research will be conducted to further examine product efficacy across application timings, however, reaction to different tillage settings will also be included in the project.

FRUITING PATTERNS AND PRODUCTIVITY OF MODERN COTTON CUYLTIVARS IN THE TEXAS HIGH PLAINS

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ABSTRACT

This study aims to re-evaluate the partitioning patterns and nutrient uptake index of new and soon-to-be released cotton cultivars to optimize the nutrient inputs for farmers and producers. The study will be divided into two phases: Phase I will be the determination of different nutrient uptake indices of 10 modern cotton cultivars and Phase II will be the development and establishment of new fertilizer management strategies for modern cotton cultivars using the results of plant nutrient uptake from Phase I. The location of the study trial will be at the Texas Tech University Research Farm in New Deal, TX which is equipped with subsurface drip irrigation system. The new cotton cultivars will be grown in a non-limiting environment in terms of irrigation and fertilizer management, with 4 replications. The expected results from this study are determined values of total nutrient uptake and nutrient uptake index specific for each cultivar, partitioning patterns of nutrients throughout the growth cycle of each cultivar and new fertilizer management strategies for each cotton cultivar based on the nutrient uptake indices developed in the study.

EXPLORING LONG-TERM PHOSPHORUS MANAGEMENT STRATEGIES FOR OPTIMIZING CROPS YIELDS IN KANSAS

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ABSTRACT

Phosphorus (P) is a crucial nutrient for sustaining crop productivity, yet its scarcity often challenges agricultural endeavors. Recognizing the essential role of P fertilization in maintaining agricultural productivity, this study takes a multi-year approach to P management. It specifically delves into the intricate dynamics of long-term P placement, evaluating its impact on crop yield under varying rates and combinations. The primary objective is to discern the most effective phosphorus fertilization approach in the context of long-term agricultural studies in Kansas, aiming to maximize crop yield. The study began in Manhattan, KS, in 2006 and has 12 distinct treatments, each representing a different combination of diverse rates and placement methods in a 3-year rotation of wheat, corn, and soybean. By using a cyclical rotation, the study ensures that each phase is present annually, providing a comprehensive understanding of crop responses over time. Different variance analyses are employed to determine statistically significant differences in crop yields among the treatments. The optimal fertilizer treatment varies depending on the crop. Among all crops, wheat is the most responsive to P fertilizer. One of the most effective treatment combinations for all crops is to use 20 lb./ac as a starter fertilizer and then add an extra 60 lb./ac as deep band in wheat and corn and an extra 40 lb./ac in soybean, which was applied by broadcast. This study can contribute to the scientific understanding of phosphorus management and offer practical insights for optimizing fertilization strategies in Kansas's dynamic agricultural system. As we navigate the complexities of phosphorus fertilization, this research serves as a valuable resource for enhancing sustainable crop productivity.

INFLUENCE OF IRRIGATION TIMING AND AMOUNT ON BIOMASS PARTITIONING AND YIELD OF COTTON

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ABSTRACT

This study explores the impact of varying water levels on nutrient uptake in cotton plants, known for its sensitivity to environmental conditions. Recognizing the pivotal role of water availability in agricultural productivity, the experiment employed different irrigation scenarios and assessed the efficiency of nutrient absorption in cotton under these varied circumstances. The research also focused on analyzing nutrient content in different plant tissues, including leaves, stem, squares, flowers and bolls with a specific emphasis on crucial elements like nitrogen, phosphorus, and potassium.

The study aimed to unravel the complex relationship between water availability and nutrient absorption in cotton, thus providing valuable insights for optimizing agricultural practices. The study also aims to provide contemporary scientific evidence and propose avenues for future research through innovative and high-quality contributions. These contributions intend to enhance the understanding of the mechanisms governing interactions among soil, water, and nutrients, which in turn regulate yield, quality, and productivity. The study's implications extend to the broader context of global agriculture, where water resources are increasingly constrained. Efficient water management is crucial for maximizing crop yield while minimizing environmental impact. By understanding the nuanced and complex interplay between water levels and nutrient absorption in cotton, researchers and farmers can develop targeted interventions to optimize crop productivity and resource use.

PRESERVING THE PAST, NUTURING THE FUTURE: INORGANIC FERTILIZERS AND THE VITAL ROLE OF PHOSPHORUS AND POTASSIUM IN NATIVE PRAIRIE RESTORATION

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ABSTRACT

Phosphorus (P) and potassium (K) are macronutrients required to sustain plant growth and reproduction. They are commonly applied as inorganic fertilizer by farmers across the world for their crops but these nutrients are also important for the development and sustainment of native grassland systems. Much of the Great Plains region has either been used as farmland or grazing land. These practices can disturb natural nutrient cycling by removing nutrients without adequate replacement. Current literature regarding nitrogen (N) application in rangelands has largely focused on production of biomass and its relation to carbon (C) cycling, but little research exists regarding the application of P and K in rangeland systems. This study evaluates effects of inorganic fertility application on soil and plant communities in the southern great plains region. This experiment was placed on disturbed prairie soils in central Oklahoma. N, P, and K were added as urea, 0-46-0, and 0-0-60 at 67 lbs/ac, 57 lbs/ac, and 57 lbs/ac respectively. Soil sample analysis included macronutrients, micronutrients, texture, pH, and EC. Forage sample analysis looked at nutrient uptake and total N and total C. Currently, ample literature is available for nitrogen application on native grasslands but response to P and K is unclear. This study looks to better understand native prairie responses to immobile nutrients and assist in native prairie restoration in the future.

INVESTIGATING ADSORPTIONCAPACITIES AND INTERACTIONS OF ELECTROCHEMICALLY TREATED WASTE ACTIVATED SLUDGE FOR ITS POTENTIAL USE AS FERTILITZER

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ABSTRACT

As the global population rapidly grows, food producers are faced with the task of feeding as many as ten billion people by 2050. The current state of fertilizer use cannot sustainably support this growth, and the overuse and mismanagement of fertilizers has led to degraded soil, water, and air quality over time. On average, the recovery efficiency of nitrogen by crops is only about 50% due to rapid dispersion/loss of applied fertilizers to the environment. Due to leaching and runoff of fertilizer, eutrophication and hypoxia of surrounding water bodies often occurs, creating significant environmental issues. In addition, about four billion tons of solid waste from municipal wastewater treatment plants are produced annually on a global basis, with much of it being disposed of in landfills or via incineration at a high cost. A potential solution to both of these issues is the development of novel fertilizers that recycle nutrients from wastewater treatment plants. This study investigates the chemistry of a novel set of fertilizers derived from waste activated sludge (WAS), a byproduct of municipal wastewater treatment, that has been electrochemically treated (EWAS) to remove pathogens and release ammonium (NH_4^+) and nitrate (NO_3^-). WAS and EWAS were applied to agricultural soil and a potting mix to conduct laboratory batch adsorption experiments. The resulting aqueous samples were analyzed to determine the concentrations of nitrogen (N), phosphorous (P), carbon (C), and other macro and micronutrients adsorbed to the soil and released into solution. Commercially available inorganic and natural fertilizers were used to compare their soil chemistry dynamics to EWAS and WAS. Results indicate that EWAS releases a higher percentage of organic and total carbon into solution than any other treatment due to the structure of the organic matter becoming deformed by the alkaline electrolysis process. EWAS and WAS also released less total nitrogen into solution than any other treatment, which, if extrapolated to a field setting, could have positive implications for reduced runoff. This is likely due to biomolecules present in the organic matter in EWAS/WAS being bound to clay minerals (i.e., organoclay complexation of N-containing organic molecules), as well as differences in solubility of the forms of nitrogen released by the various fertilizers. Amongst all treatments, the amount of ammonium released into solution decreases over time while the amount of nitrate released increases. This is likely partially due to the nitrification process which transforms ammonium/ammonia into nitrate via nitrifying bacteria. Additionally, this decrease in the amount of ammonium released corresponds

to an increase in ammonium adsorption over time. EWAS, however, adsorbed the least amount of ammonium, again likely due to the disruption of the organic matter structure via alkaline electrolysis, effectively limiting ammonium from being chelated to organic ligands. Overall, this project is ongoing, but EWAS preliminarily demonstrates promise as an effective and sustainable fertilizer.

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

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ABSTRACT

The soybean crop provides one of the best opportunities to include a cool season cover crop (CC) ahead of planting. This study aims to maximize phosphorus (P) use efficiency by the soybean crop by using CC planting as a window of opportunity for better P fertilizer placement and timing. Specifically, combining P fertilizer with cereal CC seeds will place the fertilizer below the soil surface and combine two operations (CC planting and fertilizer application) in one pass. Other benefits include eliminating the environmental risk of P fertilizer runoff and potentially creating a synergistic benefit of the CC and fertilizer combination on P availability to the soybean crop. The overall objective of this study was to improve phosphorus management for soybean production in Kansas, increasing yields using improved diagnostic tools and fertilization strategies, and leveraging opportunities for application placement with a CC in the rotation. Nine sites were established, with five locations under supplemental irrigation and four rainfed locations. Phosphorus treatments included a control with no P application and three P rates of 45, 90, and 135 Kg P2O5/ha, using mono-ammonium phosphate (MAP). CC treatments included oat and triticale with no P application and with P application of 45 Kg P2O5/ha. CC samples were collected before soybean planting to measure biomass and P uptake. Soybean whole plant samples were collected at the V3-4 stage to analyze for P Uptake. At harvest, grain yield was recorded for each plot. The results obtained with this research showed that in locations non-responsive to P fertilization, there was no significant response to CC treatments. In responsive locations to P fertilization, there was a penalty in soybean growth and yields when adding CC to the system. Excessive CC biomass seems to negatively affect soybean growth and yield, suggesting the need for timely termination of the CC.

INTRODUCTION

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

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

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

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

MATERIALS AND METHODS

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

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

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

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

* Yield was not included for this analysis.

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

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

RESULTS AND DISCUSSION

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

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

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

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

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

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

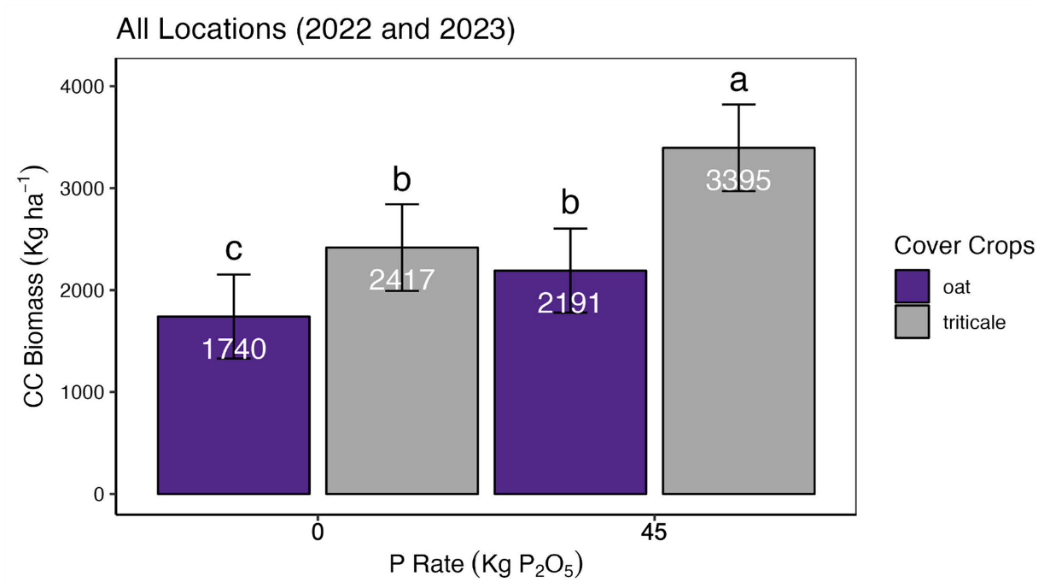

Figure 1: Cover crop biomass (Kg ha-1) as affected by different P rates and cover crop species across 9 locations.

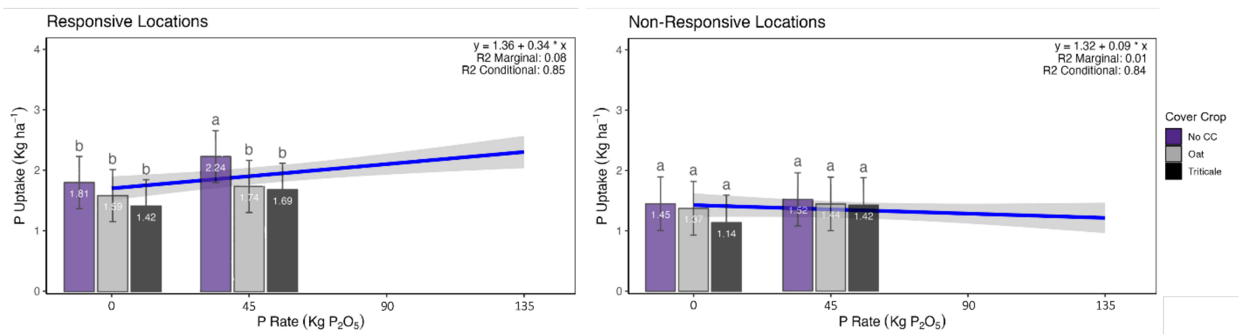

Figure 2: Phosphorus uptake (Kg ha-1) as affected by different P rates (regression line) and Phosphorus uptake (Kg ha-1) as affected by different P rates and cover crop species (bars) in <u>responsive</u> and <u>non-responsive</u> locations to P fertilizer.

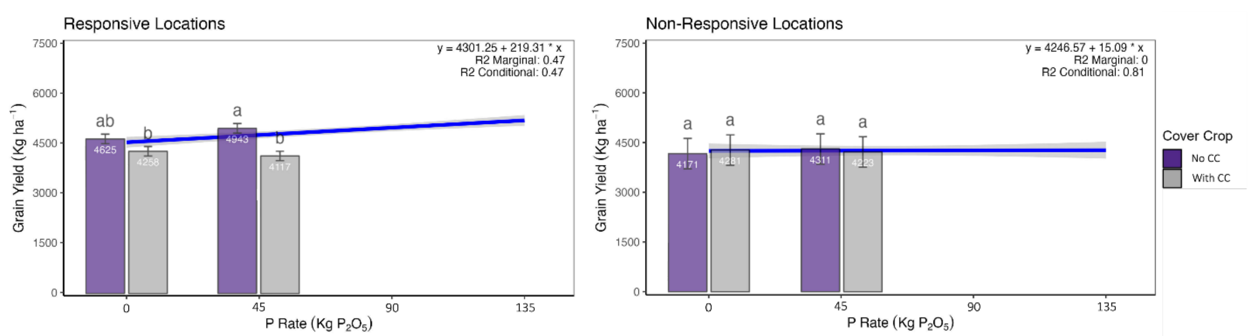

Figure 3: Grain yield (Kg ha-1) as affected by different P rates (regression line) and grain yield (Kg ha-1) as affected by different P rates and cover crop species (bars) in <u>responsive</u> and <u>non-responsive</u> locations to P fertilizer.

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NITROGEN MANAGEMENT OF COTTON FOLLOWING CORN IN THE HIGH PLAINS

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ABSTRACT

Nitrogen (N) management in cotton (Gossypium hirsutum) is challenging given physiological dynamics in an indeterminate crop. Cotton performance may be harmed due not only to under fertilization of N, but also excessive fertilization. This is especially pertinent when managing cotton for earliness. Often these challenges occur in the form of delaying the onset of reproductive structures due to the crops indeterminate nature, leading to problems associated with "finishing" the cotton crop in a short-season environment. These factors can be compounded when considering N dynamics following a corn crop where often excessive N application rates are applied as a safety net or in expectation of high yields. This can lead to excessive amounts of residual N for the following cotton crop lending itself to managment concerns, especially in a semi-arid environment such as the high plains in which residual N is likely well within the available soil volume for N uptake. This experiment looks to evaluate cotton lint yield response to N applied in the previous growing season in combination with an in-season application of N at the pinhead square stage of cotton development or an omission of in-season N managment in the cotton crop. This experiment was placed at the Oklahoma Panhandle Research and Extension Center in Goodwell, OK - located in the central Oklahoma Panhandle. The experiment utilizes a split plot design consisting of eight row corn plots recieving anywhere from 0 to 336 kg N ha-1. These eight row plots were then split into four row cotton plots each recieving 0 or 56 kg N ha-1. Corn yield was not influenced by N rate with an average corn yield of approximately 20 Mg ha-1. Cotton lint yield was influenced by corn N rate when combined with an in-season application in the cotton crop with yields decreasing linearly upon reaching 224 kg N ha-1 total. Cotton lint yield was maximized with 56 kg N ha-1 in-season with 0 N applied in the corn crop. This project indicates that excessive residual N in the previous crop may have a profound impact on cotton lint yield the following season.

SUSTAINABLE AND RESILIENT CROPPING SYSTEMS TO MITIGATE WIND EROSION FOR THE ENHANCEMENT OF HUMAN HEALTH

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ABSTRACT

In the Texas High Plains, regenerative cropping practices in a predominantly conventional farming area can be used to prevent further depletion of topsoil by wind erosion. This loss of topsoil can cause a decrease in agricultural productivity and form dust storms that can be detrimental to human health causing a rise in hospitalizations of chronic lung damage, cardiovascular disorders, and diseases contracted by inhalation. Using regenerative farming practices, both the number and size of dust storms may be mitigated to sustain agricultural productivity and improve human health in this semi-arid environment. We seek to provide a full range assessment of dust properties to enhance human health and agricultural productivity. To achieve this, paired sites of conventional and conservation are implemented in seven counties (Randall, Cochran, Hale, Lubbock, Terry, Dawson, and Martin) to create a transect of this region. Each of these sites contained dust collectors, providing a full assessment of microbial communities, nutrient composition, and provide an estimate of topsoil lost per month within the site. In combination with dust collection, soil cores are taken for soil health fluctuations and analysis throughout the year. Soil moisture will be monitored using a lab calibrated CPN 503 neutron probe, highlighting the differences between cropping systems and stored soil moisture. This project will allow us to identify losses in the system and contribute to calculating a dollar amount eroded each year, and enhance human health by reducing particulate matter inhalation.

SUSTAINABLE SUFFICIENCY: AN ALTERNATIVE PARADIGM FOR PHOSPHORUS FERTILIZER MANAGEMENT

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ABSTRACT

Sustainable, widespread adoption of conservation practices on-farm demands alignment of agronomic productivity and environmental protection goals. Phosphorus (P) fertilizer management is a critical control point for conservation P management, to reduce agricultural P loss to the environment. Phosphorus fertilizer recommendations follow either a low-P sufficiency (SF), or a higher-P build and maintain (BM) approach. Reduced P fertilizer inputs are recognized as an effective control measure to reduce P loss, but current low-P SF management is not the favored P rate decision making system for producers. Compared to BM, SF is viewed as unsustainable by producers as consecutive years of SF management will lead to a drawdown in soil test P (STP). To promote the adoption of conservation-minded P fertilizer management, and reduce P loss, a new paradigm for low input P management that aligns production and conservation goals is required.

To develop a sustainable sufficiency (SSF) P fertilizer management paradigm, we will establish an SSF maintenance threshold (SSF-MT). Soils with STP<SSF-MT are expected to respond to P fertilizer rates in excess of maintenance rates, with maintenance rates are determined based on expected P_2O_5 removal. Historical P response data is being analyzed to determine the MT and preliminary results will be presented. Additionally, novel field studies will validate the MT and investigate corn and soybean yield response to maintenance rates of P fertilizer across a range of STP. So far, preliminary 2023 results indicate a maintenance rate of P fertilizer is sufficient to meet crop P demand at STP as low as 10 ppm Mehlich-3. Eighteen additional field studies will be conducted in 2024.

INTRODUCTION

Phosphorus (P) fertilization is frequently required to maintain agronomic productivity; however, agricultural P is subject to runoff loss with substantial environmental consequences for surface water quality and safety. Aligning agricultural P demands with environmental protection from P loss is a critical step to improve sustainability of our production systems.

Current P fertilizer management decisions are made following a build and maintain (BM) or sufficiency (SF) program. A BM program aims to increase soil test P (STP) above the critical threshold for yield response, with P fertilizer inputs in excess of expected crop P removal. The increased STP is then maintained above the critical threshold with routine maintenance applications of P fertilizer, even to soils where we would not expect crop response to P fertilizer. Under SF management P fertilizer decisions are made based on current STP and expected yield, with rates based on capturing 95% of maximum yield. Under SF management, P fertilizer is only recommended when STP is less than the critical threshold for yield response. The current critical threshold for yield response in Kansas is 20 ppm Mehlich-3 P. From a producer perspective, SF is often viewed as unsustainable as SF management year over year will draw STP down into the low or very low fertility range. Environmentally, SF management is superior to BM as it is a lower P system with less P susceptible to environmental loss. Optimizing P fertility management to ensure producer needs are met with environmental protection goals is critical, and neither SF nor BM management offers this combined outcome.

Agronomic and economic evidence in support of a BM program is limited; long-term data from Nebraska indicated BM did not benefit corn yield compared to SF management over a 12-year period (Olson et al., 1987). The cost of BM management was almost double the cost of SF, and BM increased STP almost threefold. A more recent study from Minnesota showed similar results, with no corn yield increase in response to BM management compared to SF (Fabrizzi et al., 2017). Similarly, a comparison of corn yield in response to build rates of P fertilizer and crop removal rates found no difference in corn production between the 'high P' and 'low P' intensity systems (Wortmann et al., 2018). Evidently, increased STP from BM systems does not consistently equate to increased crop production. Increased STP comes at a greater environmental risk, with higher concentrations of STP subject to increased P loss in runoff water (Osmond et al., 2019; Sharpley, 1995).

The substantial economic investment and environmental risk associated with a BM program may not be necessary to maximize agronomic productivity. At the same time, traditional SF is interpreted by producers as posing a higher risk to production due to the uncontrolled drawdown of STP overtime and variability of crop response to P across STP concentrations. An alternative strategy that better accommodates producer preferences and the environmental need to reduce STP is thereby necessary to advance sustainability of P fertility management. We will define a sustainable sufficiency (SSF) paradigm that combines reduced inputs and lower STP of a traditional SF system with benefits of risk management from a BM system. Our specific objectives are to: i) investigate corn and soybean yield response to a maintenance rate of P fertilizer across a range of STP concentrations, using novel field studies and ii) determine the SSF maintenance threshold (SSF-MT) STP using historical data.

MATERIALS AND METHODS

Field Study

Maintenance rate studies will be conducted directly overtop of traditional P rate response studies from the previous growing season to capture crop response to maintenance rates across a range of background STP concentrations. In 2023, four maintenance sites were established in Riley, Reno, Republic, and Franklin counties. The Republic location was established on a soybean P rate response study from 2022 that included rates of 0, 40, 80, and 120 lbs P_2O_5 ac^{-1} as MAP. The other three locations were conducted on top of 2022 corn sites that had received P rate treatments of 0, 30, 60, 90, and 120 lbs P_2O_5 ac^{-1}. These sites were planted to soybean in 2023. Maintenance rates and target yields for each site are in Table 1.

Table 1. Maintenance rates, associated target yields, and STP (Mehlich-3) range for each 2023 maintenance site.

Location	Target Yield (Crop)	Maintenance Rate Applied	STP Range
Riley	60 bu ac^{-1} (soybean)	48 lbs P_2O_5 ac^{-1}	6-43 ppm
Reno	65 bu ac^{-1} (soybean)	52 lbs P_2O_5 ac^{-1}	17-40 ppm
Republic	250 bu ac^{-1} (corn)	82 lbs P_2O_5 ac^{-1}	5-21 ppm
Franklin	50 bu ac^{-1} (soybean)	40 lbs P_2O_5 ac^{-1}	4-31 ppm

Maintenance rates were determined based on target yield and expected removal, using standard average removal values of 0.33 lbs P_2O_5 bu^{-1} for corn and 0.8 lbs P_2O_5 bu^{-1} for soybean. Maintenance treatments were broadcast by hand, as MAP, to each plot immediately following planting in the spring. Yield data was collected by harvesting the center two rows of each plot and correcting grain moisture to 13%. Harvest data was analyzed by ANOVA using PROC GLIMMIX in SAS. There will be an additional 18 maintenance sites in 2024.

Historical Data Analysis

Data from P rate response studies conducted in KS from 1980 to present were compiled, including STP and yield data. Our preliminary dataset includes 20 corn and 9 soybean P response trials. Yield response to P fertilizer rate was determined from published results or using ANOVA for studies with raw data available. A linear-plateau model was fit to data from each responsive site, using PROC NLMIXED in SAS, to determine optimum P fertilizer rate (P_O). For sites with no yield response to P fertilizer, P_O was set to zero. Phosphorus removal (P_R) at P_O was calculated based on standard estimates of 0.33 lbs P_2O_5 bu^{-1} for corn and 0.8 lbs P_2O_5 bu^{-1} for soybean. Using P_O and P_R, delta P_2O_5 (ΔP_2O_5) was calculated for each site-year, using the following equation:

$$\Delta P_2O_5 = P_O - P_R$$

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

RESULTS AND DISCUSSION

Field Study

Preliminary results from 2023 indicate a maintenance rate of P fertilizer was enough to meet crop demand, even with STP <5 ppm. None of the sites had a significant yield response to increased STP with a maintenance rate of P fertilizer applied (Figure 1).

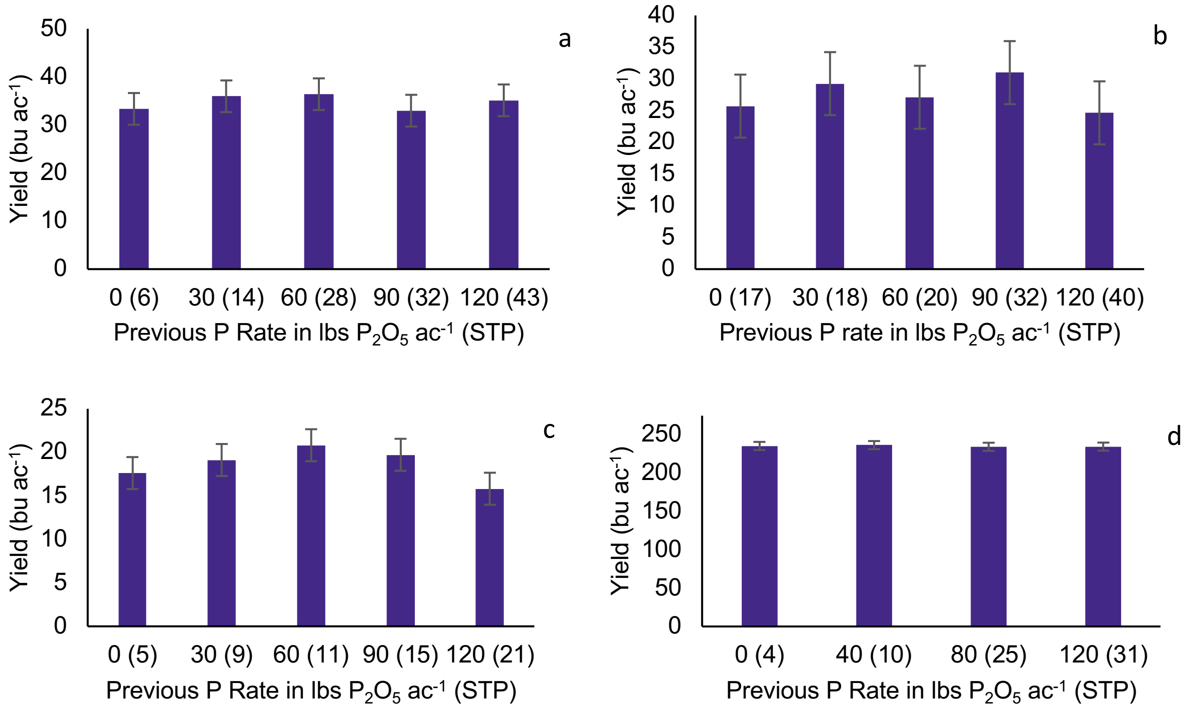

Figure 1. Soybean yield from Reno Co. (a), Riley Co. (b), Franklin Co. (c) and corn yield from Republic Co. (d) with a maintenance rate of P fertilizer applied as a spring broadcast application of MAP (n.s.)

The three soybean site-years underperformed achieving only 36 to 54% of target yield, likely due to dry growing season conditions. As maintenance rates applied were based on expected yield and removal, our applied P rates were greater than actual crop removal. In a year where actual and target yields are closer, STP could play a larger role in yield response to maintenance rates of P fertilizer. That being said, the corn site-year achieved an average of 94% of target yield and there was no difference in yield between a background STP of 4 ppm and 31 ppm with a maintenance rate of P fertilizer applied.

Historical Data Analysis

Out of 20 corn site-years, only five required P fertilizer to optimize yield and only one of these site-years required more than a maintenance rate of P fertilizer to reach optimum yield (Figure 2). The dataset includes a number of sites with $P_O < P_R$, more than we anticipated, particularly for sites with background STP less than 20 ppm, the current critical threshold for yield response to P fertilizer. Given this, and the large spread in the data, we have not yet attempted to fit a linear model to determine the optimum SSF-MT. Model fitting will occur as more data points are added, particularly as we add additional site-years in the low to very low STP range.

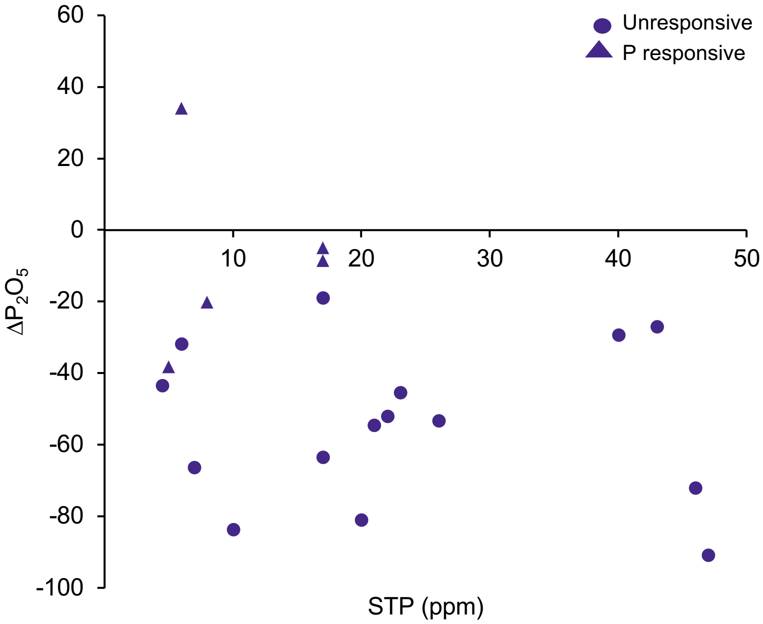

Figure 2. Preliminary ΔP_2O_5 results for corn (n = 20), where ΔP_2O_5 is the difference between optimum P fertilizer rate, P_O, and P removal at optimum yield, P_R.

None of the nine soybean site-years included in our initial analysis required P fertilizer to optimize yield (Figure 3). As such, a maintenance rate of P fertilizer was enough to optimize yield for all of these sites. Similar to the preliminary corn dataset, there were also more soybean site-years with $P_O < P_R$ than anticipated. Model fitting to determine the theoretical optimum STP for maintenance will be carried out once the dataset is complete.

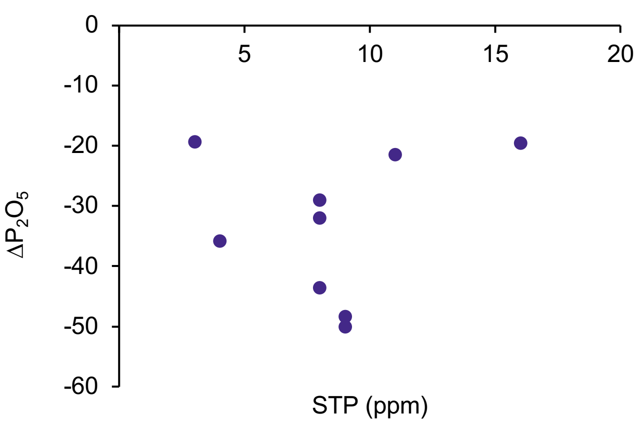

Figure 3. Preliminary ΔP_2O_5 results for soybean (n = 9), where ΔP_2O_5 is the difference between optimum P fertilizer rate, P_O, and P removal at optimum yield, P_R.

Initial results from the historical data analysis indicate a maintenance rate of P fertilizer may be more than enough to optimize yield >95% of the time. Therefore, we may be able to set a MT for SSF management that is below 20 ppm Mehlich-3, without consequences to crop yield. Model fitting from historical data analysis and results from the 2024 field studies will be used to suggest a MT to determine STP where maintenance rates are sufficient to achieve yield potential.

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TEMPORAL AND SPATIAL VARIABILITY OF NITROGEN USE EFFICIENCY ACROSS LANDSCAPE POSITIONS IN SOUTHERN HIGH PLAINS

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ABSTRACT

Optimizing nitrogen use efficiency (NUE) is crucial for enhancing crop productivity, managing resources effectively, and promoting environmental sustainability. In response to the growing significance of sustainable agriculture, this research rigorously explores the temporal and spatial dynamics of NUE in the unique agroecosystem of the Southern High Plains. With a focus on precision nitrogen management tailored to the region's distinctive conditions, the study aims to provide valuable insights crucial for advancing sustainable agricultural practices. The first objective involves a meticulous analysis of nitrogen data collected during 2023 in a dryland field and an irrigated field in Lynn County, Texas. Employing a randomized complete block design with three nitrogen rates (0, 30, and 60 lb/ac in dryland and 30, 60, and 90 lb/ac in irrigated), this analysis seeks to discern temporal patterns in NUE. By shedding light on seasonal variations and identifying factors contributing to efficiency fluctuations, this objective lays the groundwork for a nuanced understanding of the temporal dynamics of nitrogen utilization. The second objective focuses on the spatial evaluation of NUE across various landscape positions within dryland and irrigated fields. Implementing a detailed assessment, the study aims to pinpoint areas characterized by high or low NUE, unraveling landscape-specific factors influencing nitrogen utilization. Through this spatial perspective, the research seeks to enhance precision nitrogen management strategies, enabling more targeted and effective applications. This research not only advances comprehension of nitrogen dynamics in both dryland and irrigated environments but also holds significant implications for sustainable agriculture practices. Anticipated outcomes are poised to guide precision nitrogen management strategies, promoting resource-efficient and environmentally conscious approaches. By contributing to the development of sustainable agricultural practices tailored to the unique conditions of the Southern High Plains, the study strives to bridge the gap between heightened productivity and ecological responsibility in this vital agricultural region.

THE EFFECTS OF MANURE APPLICATIONS ON COTTON YIELD AND SOIL GREENHOUSE GAS EMISSIONS IN THE TEXAS HIGH PLAINS

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ABSTRACT

The cost of inorganic fertilizer is continually rising, which has caused an increased interest in alternative solutions. Along with fertilizer prices increasing, carbon emissions are following the same trend. There is an upcoming demand for carbon mitigation/sequestration research. The purpose of this study was to assess the effects of various manure applications on crop growth and greenhouse gas emissions in three different cropping systems in the Texas High Plains. The no-tillage cropping systems consist of wheat cover/continuous cotton, fallow/cotton/wheat, and fallow/wheat/cotton. The treatments utilized in this study included: 1) no fertilizer applied, 2) inorganic fertilizer, 3) composted manure, 4) separated dairy feedlot manure, 5) whole digestate, and 6) commercial raw feedlot manure. Results included the 2023 growing season. Greenhouse gases (CO_2, CH_4, N_2O, NH_3) were measured from the soil surface throughout the season using a multi-gas FTIR analyzer. Results included cotton lint yield and greenhouse gas emissions for CO_2, CH_4, and N_2O that were presented as CO_2 equivalents.

INTRODUCTION

There is a need for alternative fertilizer sources that are both economically and environmentally viable, specifically in a semi-arid climate. The Texas High Plains is a top producing region for cotton (*Gossypium hirsutum*), producing 30 to 35% of the nation's cotton (Bishop, 2023). Fertilizer is an essential economic component for successful yields in cotton production. Manure is more easily accessible and renewable compared to inorganic nitrogen sources. Approximately 16 million acres (8%) of US cropland were fertilized with manure (Havlin, 2016). Along with the use of more renewable fertilizer sources, the environmental effects of that source need to be assessed. The objective of this study was to assess the effect of anaerobic digestate and manure applications on crop growth and soil greenhouse gas emissions. Agricultural practices, such as fertilizer application, release greenhouse gas emissions (GHG) into the atmosphere. The most important greenhouse gases associated with agriculture practices include carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). CO_2 is the most abundant gas in the atmosphere. Agricultural practices are known to cause the increase of carbon dioxide (CO_2) in the atmosphere, contributing to global warming. Because of the semi-arid climate, minimal precipitation and soil erosion are factors that must be considered throughout the growing and nongrowing season. The minimal precipitation and high temperatures can greatly affect the amount of GHGs emitted from the cotton crop. Each GHG is given a global warming potential to compare the amount of energy the emissions of 1 ton of gas will absorb over a given amount of time, compared with the emissions of 1 ton of CO_2. N_2O has a GWP of 265 times that of CO_2. CH_4 has a GWP of 28 times that of CO_2 (EPA, 2023). Increased absorption of energy by greenhouse gases can cause harmful effects for the environment. Utilizing manure as fertilizer sources is a common practice around the world, but the environmental effects of replacing inorganic sources with organic requires more research.

MATERIALS AND METHODS

This study was located at Texas A&M AgriLife Research and Extension Center in Lubbock, TX. The soil series for this study was an Acuff loam. The no-tillage cropping systems consisted of wheat/cotton/cotton, fallow/cotton/wheat, and fallow/wheat/cotton rotations. Wheat was planted on October 27th, 2022. Cotton was planted on May 9th, 2023; Replanted June 7th, 2023. A RCBD arranged as a split-plot was utilized for this study. Each plot was eight rows wide and 40 ft long with four replications. The treatments utilized in this study included: 1) no fertilizer applied, 2) inorganic fertilizer, 3) composted manure, 4) separated dairy feedlot manure, 5) whole digestate, and 6) commercial raw feedlot manure. Both inorganic and organic fertilizer sources were calculated based on a 150lb/A rate for the 1st application and 50lb/A for the 2nd application. For statistical analysis, SAS 9.4 was utilized. Greenhouse gas emissions were measured throughout the season. Sampling times included 1, 3, 7, 10, 14, 21, 28, 35, 49, 56, 63, 70, 77, and 98 days after treatment. Temporal soil samples at 0-6in and 6-12in depths were collected from every plot in the continuous cotton rotation each GHG sampling time.

RESULTS

Results indicated that the inorganic fertilizer treatment presented numerically greater cotton lint yield compared to the other treatments. The increased cotton lint yield presented by the no fertilizer treatment could be a result of residual nutrients found in the preseason soil. From the organic treatments, compost and whole digestate presented greater cotton lint yield compared to separated dairy manure and raw manure treatments. CO_2 equivalent results indicated separated dairy manure had significantly greater CO_2e compared to all other treatments at 35 DAT. At 42 and 98 DAT, no fertilizer and compost had significantly greater CO_2e compared to all other treatments. At 70 and 77 DAT, no fertilizer had significantly greater CO_2e than all other treatments. Overall, results indicated the no fertilizer treatment presented greater CO_2 equivalents compared to all other treatments. Separated dairy manure, raw manure and digestate presented the least CO_2 equivalents compared to all treatments.

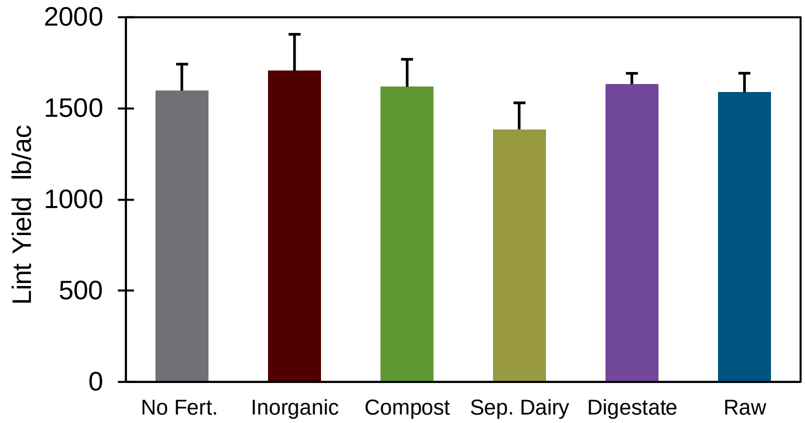

Figure 1. Cotton lint yield (lb/ac) at Lubbock by treatment. Data presented from November 17,2023. No significant differences were found at $p<0.05$.

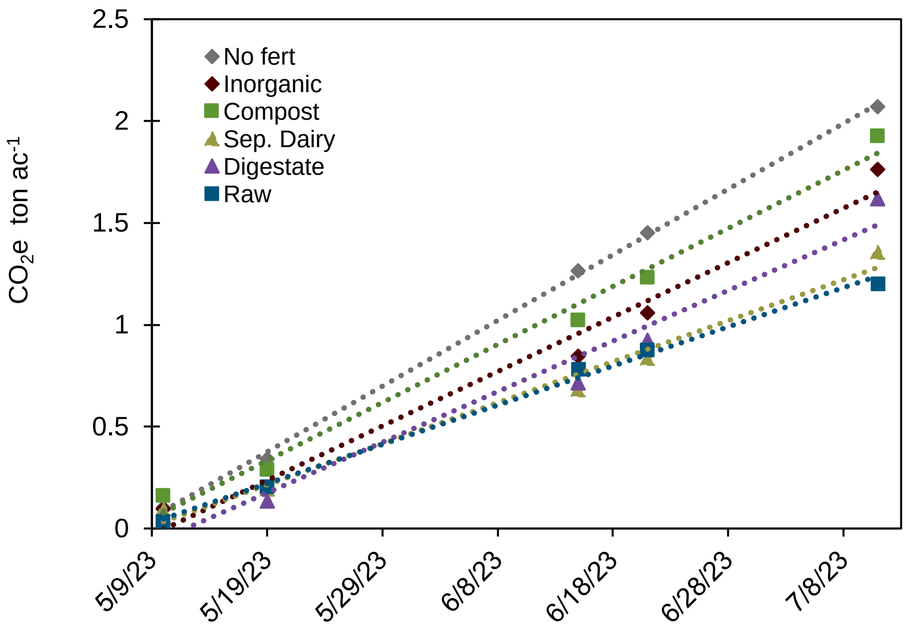

Figure 2. CO_2 equivalents (ton ac^{-1}) at Lubbock by treatment. Data presented from May 10th, May 19th, June 15th, June 21st, and July 11th (35,42,70, 77, and 98 days after 1st application). Wet conditions prevented measurements on 56 and 63 DAT. CO_2 equivalents calculated using CO_2e = [CO2 * 1] + [CH4 * 28] + [N2O * 265]

SUMMARY

With the increase in demand for fertilizer, more renewable and efficient sources need to be supplied. Manure as a fertilizer source has the capability to provide environmental and economic benefits for crop production. The concern for implementing manure as a fertilizer source pertains to its' effect on the environment. Separated dairy manure, digestate, and raw manure as a fertilizer source has potential to reduce carbon dioxide emissions compared to no fertilizer, inorganic fertilizer, and composted manure. Further research is being conducted to assess the environmental impacts of manure sources as fertilizer for multiple growing seasons.

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

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ABSTRACT

Long-term crop rotation intensity and diversity can affect key soil properties. In semi-arid regions, the combined factors of rotation and soil properties may also affect the overall water use efficiency from either limited irrigation or rainfall. The objective of this study was to evaluate changes in soil properties, and water use efficiency of corn grown under different rotation intensities and diversity, and limited/supplemental irrigation. A field experiment was conducted over seven years in Gothenburg, Nebraska, to compare different irrigated crop rotations including five rotation intensities/diversity. All plots were irrigated with an annual average of 150 mm/year, and 100 mm in 2021. The annual accumulated precipitation for 2021 at the study site was 589 mm. After seven years, soil samples were collected in 2021 to include at least two full rotations for the 3-year rotation treatment. Soil samples were collected using a Giddings probe at six depths (0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm). Soil samples were analyzed for soil C using dry combustion. Grain yield was measured for every crop every year, however, data for corn yield is presented for the 2021 harvest season only. Corn grain yield in 2021 was numerically higher when following wheat in the rotation, likely due to the summer fallow after the wheat harvest allowing for additional water storage and availability to the corn crop. Water use efficiency for corn in 2021 was higher when following winter wheat in the rotation (treatments with Corn-Wheat and Corn-Corn-Wheat). After seven years (two full cycles for the 3-year rotation), soil organic matter was higher for rotations with more frequent corn in the rotation (Corn and Corn-Corn-Wheat). After seven years, continuous corn and the Corn-Corn-Wheat rotation showed significantly lower soil pH. This was likely due to the higher total nitrogen fertilizer applied over this period, which will require additional/more frequent investment in lime application. Soil carbon in the soil profile was also generally higher for rotations with high biomass and carbon input.

RECENT 2-ROW MALTING BARLEY REVISION FOR NORTH DAKOTA

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ABSTRACT

As the demand of two-row malting barley (*Hordeum vulgare* L.) increases, having sound nitrogen (N) recommendations is increasingly necessary. Not only does N play a role in grain yield, but it may also significantly impact grain malting characteristics including protein, plump, and test weight. To determine the impacts N rate and N availability have on two-row malting barley, two experimental sites were established in both spring 2020 and 2021. The experiments were organized as a randomized complete block design with a split-plot arrangement; each site consisted of 100 experimental units in 2020 and 50 experimental units in 2021. Treatments consisted of five fertilizer rates (0, 40, 80, 120, and 160 pounds N per acre) and two barley cultivars (ND Genesis and AAC Synergy), with cultivar as the main plot treatment and N rate as sub-plot treatment. Soil nitrate-N samples were taken prior to planting and N credits from the previous crop were considered to determine the total known available soil N (TKAN). It was determined there was a strong relationship between N rate and relative grain yield. There was also a strong positive correlation between N rate and grain protein. When the relationship between relative grain yield and TKAN was modeled using a best-fit regression, it was determined maximum yield can be reached at 187 TKAN per acre. Additionally, grain protein content at 187 pounds TKAN per acre was 12.8 %, which meets malting quality requirements. No significant interactions between N rate and kernel plump or test weight were noted at the N rates applied in these experiments. When factoring in economic information, the TKAN range needed to produce the barley crop at the highest profitability is lower than TKAN of maximum yield; ranging from 106 up to 189 pounds TKAN per acre.

INTRODUCTION

The Northern Great Plains region states and provinces are large producers of barley. Historically, the barley cultivars in this region destined for the malting industry were six-row types; however, very recently, malting companies began to contract only two-row barley cultivars, leading to a shift in production. One of the reasons behind this change in preference from six-row to two-row barley for malting is the generally lower grain protein content (McKenzie et al., 2005; Franzen and Goos, 2019). Barley with lower protein content results in more rapid water uptake during malting, which allows the grain to progress through the process more quickly (Hertsgaard et al., 2008), decreasing malting costs. Additionally, high protein in the malt produces problems during beer fermentation, generating cloudiness in the final product. McKenzie et al. (2005) asserted N fertilization is the most important factor in malting barley production since N in excess of what is required for yield increases grain protein (Lauer and Partridge, 1990).

There is an established correlation between N fertilization and percentage of plump kernels, protein content, and test weight, malting quality factors established by maltsters (Lauer and Partridge, 1990; McKenzie et al., 2005; O'Donovan et al., 2015). The American Malting Barley Association sets the ideal criteria for two-row barley as follows: protein content ≤130 g kg^{-1} and >90% plump kernels retained on a 2.38 mm sieve (American Malting Barley Association, 2023b). Two of the most common reasons for malting barley rejection are high protein content and a low percentage of plump kernels. The consequence of grain rejection by maltsters is very severe; feed-barley price is about half that of malting grade.

Baethgen et al. (1995) stated a balance must be found between obtaining profitable yield for malting barley and meeting quality requirements. This balance between yield and quality should also consider N use efficiency. As a result, grain could be produced at a yield which will maximize economic returns for the farmer, meet malting quality requirements, and minimize residual soil nitrate-N following harvest. The purpose of this study was to determine the rate of available N which will maximize profitable yield and optimize grain quality characteristics for two-row malting barley in the Northern Great Plains.

METHODS

These on-farm experiments took place during the 2020 and 2021 growing seasons, with two experimental sites each year. In total, four site-years of data were generated on non-irrigated, no-till locations in Grand Forks and Barnes Counties in North Dakota, near Logan Center (LC) and Valley City (VC), respectively.

Both VC sites had been under no-till management for over 40 years, producing several rotational crops including corn (*Zea mays* L.), soybean (*Glycine max* L.), oil-seed sunflower (*Helianthus annuus* L.), six-row malting barley, and hard red spring wheat (*Triticum aestivum* L.). The previous crop at the 2020 VC site (46.88403N, 97.915529W) was oil-seed sunflowers, with corn being previously grown in another VC site in 2021 (46.880486N, 97.913760W).

The LC sites in 2020 (47.795544N, 97.773766W) and 2021 (47.791001N, 74 97.775661W) were transitioned to no-till management less than 5 years before the establishment of the experiment. Crops in rotation consisted of pinto bean (*Phaseolus vulgaris* L.), soybean, six-row malting barley, and hard red spring wheat. The previous crop on the LC sites was pinto bean in 2020 and 2021.

Table 1. Soil properties and chemical analyses for each experimental location, measured prior to barley seeding. Nitrate-N was sampled to a depth of 2-feet while P, K, pH, and organic matter were sampled to a depth of 6 inches.

Environment	Series	Texture	NO_3-N	P, Olsen	K	pH	OM
			ppm	ppm	ppm		%
VC2020	Swenoda†	sandy loam	43	27	201	5.2	2.6
LC2020	Barnes‡	loam	47	15	282	6.7	3.9
VC2021	Barnes	loam	49	23	67	5.1	2.2
LC2021	Barnes	loam	60	25	207	5.6	5.2

†Coarse-loamy, mixed, superactive, frigid Pachic Hapludolls (Soil Survey Staff, 2023)
‡Fine-loamy, mixed, superactive, frigid Calcic Hapludolls (Soil Survey Staff, 2023)

The independent variables consisted of 5 N fertilizer treatments within two cultivars of two-row barley. The N treatments ranged from 0 to 160 pounds N per acre in 40 pound per acre increments (0, 40, 80, 120, 160 pounds N per acre) spanning the range above and below current N recommendations for two-row barley. The two cultivars used in this experiment were ND Genesis and AAC Synergy, which are two-row malting barley cultivars recommended by the American Malting Barley Association (American Malting Barley Association, 2023a). ND Genesis was released in 2015 by North Dakota State University and AAC Synergy in 2015 by Syngenta Seeds (Basil, Switzerland). Each experimental unit was 8 feet wide by 40 feet long and they were organized in a randomized complete block design with a split-plot arrangement, with cultivar as the main plot and N-rate as sub-plots. In 2020, the treatments were replicated 10 times producing 100 experimental units at each site. The number of experimental units were reduced by 50% in 2021, consisting of five replications for a total of 50 experimental units at each site.

To determine the optimum N rate for a crop, fertilizer N is only one factor considered in North Dakota State University Extension recommendations; the total known plant available N

(TKAN) from all known sources should be considered for profitable and environmentally responsible N management. To determine TKAN, preplant soil nitrate-N (N_S) was added to crop N credits (N_{PC}), no-tillage N credits (N_{TC}), and amount of fertilizer N applied (N_{Fert}) (Equation 1) (Clark et al. 2020; Franzen, 2018; Hergert, 1987; Schultz et al., 2018).

$$TKAN = N_{PC} + N_{TC} + N_S + N_{Fert} \quad [1]$$

Previous crop N credits, reported in Franzen (2018), include a 40 pound N per acre credit after soybean, edible bean, and other annual legumes. A 40 pound N per acre credit is assessed in systems under continuous no-till for >6 years, systems in transitional or intermittent no-till are penalized 20 pounds N per acre, conventional systems receive no N credit or reduction (Franzen, 2023).

In 2020, the sum of soil nitrate-N (N_S), N credits from previous crops (N_{PC}), and tillage (N_{TC}) ranged from 52 pounds N per acre to 84 pounds N per acre across research sites and transects, in 2021 the range was from 64 pounds N per acre to 83 pounds N per acre (Table 3). In 2020 and 2021, the LC site received a 44.8 kg N ha^{-1} credit from the previous crop of pinto beans, but was penalized 20 pounds N per acre for being in the transitional no-till stage (Franzen, 2023). No previous crop credits were assessed at the VC site, but a 40 pound per acre long term no-till N credit was added each year (Franzen, 2023).

At planting, N fertilizer was hand-broadcast applied to the specific treatments, using pre-weighed SUPERU (46% N) as the fertilizer N source. SUPERU is a urea-based fertilizer treated with *dicyandiamide* (DCD) and *N-(n-butyl) thiophosphoric triamide* (NBPTP), which are a nitrification inhibitor and urease inhibitor, respectively (Koch Agronomic Services LLC, 2019). Additionally, 100 pounds per acre of pelletized gypsum (calcium sulfate, 20% S) was broadcast applied at the time of N application to ensure S deficiency did not confound N response.

Barley was no-till drilled on 6 May 2020 at both the LC and VC site, 5 April 2021 at VC, and 6 April 2021 at LC. At all sites, the barley was sown in 7.5 inch rows at the seeding rate of 1.2 million seeds per acre using a John Deere 1890 No-Till Air Drill (Deere and Co., Moline, IL). In-furrow fertilizer (12% N, 40% P_2O_5, 4% Zn) was applied at both of the 2021 sites at the rate of 75 pounds per acre at VC and 100 pounds per acre at LC (Franzen and Goos, 2019). In-season crop and pest management was uniformly completed by the cooperating farmers.

Grain was direct harvested on 10 August 2020 at the VC site and on 18 August 2020 at LC, 5 August 2021 at VC, and 11 August 2021 at LC using a plot combine (ALMACO, Nevada, IA). To limit edge interaction from N movement among the treatments, only the center 5 feet of each experimental unit was harvested. Grain was collected in breathable cloth bags and transported to the laboratory for all post-harvest measurements and quality analyses.

2.5 Data collection and lab analysis

The harvested, field moist, grain samples were placed into convection driers at 60℃ for 12 h prior to processing. Samples were weighed and then cleaned using a Clipper Model-2B cleaner (A.T. Ferrell Co., Bluffton, IN) to separate chaff and debris not eliminated by the combine.

Grain moisture was measured using a Dickey-John model GAC500 XT grain analyzer (Dickey-John, Auburn, Illinois). Grain harvest weights were adjusted to the standard moisture content of 13.5% for yield calculations. Quality measurements were conducted by the NDSU Barley Quality Laboratory. Quality relating to kernel size was determined by sieving. Percent plump kernels were considered as the percent of kernels, by weight, which do not pass through a 2.38 mm sieve (American Malting Barley Association, 2023b). Grain protein content was determined using FOSS Infratec 1241 Grain Analyzer (FOSS, Hilleroed, Denmark).

Data analysis was performed using SAS 9.4 and JMP (SAS Institute, Cary, NC). Analysis of variance (ANOVA) was conducted as randomized complete block design with a split plot arrangement using SAS PROC MIXED. Year and location were combined into one source of variation, environment, and considered a random effect. Replication was analyzed as a random effect and barley cultivar and N-rate as fixed effects. Data was tested for homogeneity of variance using Bartlett's chi-square test. Regression analysis was performed using JMP Nonlinear Modeling. Data in this study was considered statistically significant at $p \leq 0.05$.

Recognizing the independence of actual crop yield and N rate (Vanotti and Bundy, 1994; Raun et al., 2011), this approach used in this study relies on the strong relationship between relative (also referred to as standardized or normalized) yield and TKAN (Franzen et al., 2021). Relative yield was calculated by dividing the maximum yielding experimental unit at each site by yield of each experimental unit. For the development of the N recommendation, mean TKAN and yield within each N-rate treatment for each environment was calculated. Relative yield was then determined within each environment and regressed against TKAN. For economic analysis, the relative yield was then multiplied by the average yield to convert the proportion back to bushels per acre The economic optimum N rate (EONR) for two-row malting barley was calculated based on the relationship between barley price (P_b) and cost of N fertilizer (P_n) (Nafziger et al., 2004; Sawyer et al., 2006). The relative grain yield regression coefficients (a, b, and c) from the yield to TKAN comparison were used in Equation 2 to calculate EONR at various barley and N fertilizer costs (Fausti et al., 2018).

$$EONR = \frac{P_n}{P_b} \times \frac{1}{2a} - \frac{b}{2a} \quad [2]$$

$$TC = (N)P_n \quad [3]$$

$$TR = [aN^2 + bN + c]P_b \quad [4]$$

Total cost (TC) related to N input (N) and P_n was calculated using Equation 3. Total return (TR) was calculated as yield as a function of N multiplied by P_b (Equation 4). Net return (NR) was then calculated as the difference between TR and TC.

RESULTS AND DISCUSSION

The yields between the two barley cultivars was similar, and yield and protein increased with N rate (Table 3). When relative grain yield was plotted against TKAN and fitted with polynomial trendline (r^2=0.66), maximum potential yield is realized at 182 pounds TKAN per acre (Figure 1). As a comparison, when actual (non-normalized) yield was plotted against TKAN, the relationship was very poor (r^2=0.04), further supporting the independence of yield and N rate (Franzen et al., 2021). The relationship between grain protein content and TKAN was modeled using a linear regression (r^2=0.29) (Figure 2); using the linear equation, grain protein content at 182 pounds TKAN per acre is 12.8%. Since the data shows the grain protein content is, on average, below the maximum malting content of 13 % at the TKAN of maximum yield, EONR was calculated without any limitations put in place based on grain protein content.

Table 3. Mean barley yield, grain protein and, kernel plump, over four North Dakota environments.

Effects	Variables	Yield	Relative Yield‡	Protein	Plump
		bu/acre		ppm	%
Cultivar	Synergy	64.8	.66	11.6	94
	Genesis	59.2	.61	12.0	94
	P-value	NS	NS	NS	NS
N Rate lb/a	0	43.5 a	.46 a	10.7 a	93
	40	58.5 ab	.61 ab	11.3 b	94
	80	68.6 b	.70 b	11.9 c	94
	120	69.8 b	.71 b	12.4 d	94
	160	70 b	.71 b	12.7 d	93
	P-value	*	*	***	NS

†Means with the same letter within column are not significantly different at the 0.05 probability level.
‡Relative yield is calculated as the maximum yield divided by each experimental unit within individual environments.
*, *** Significant at the 0.05, and 0.001 probability levels
NS Nonsignificant.

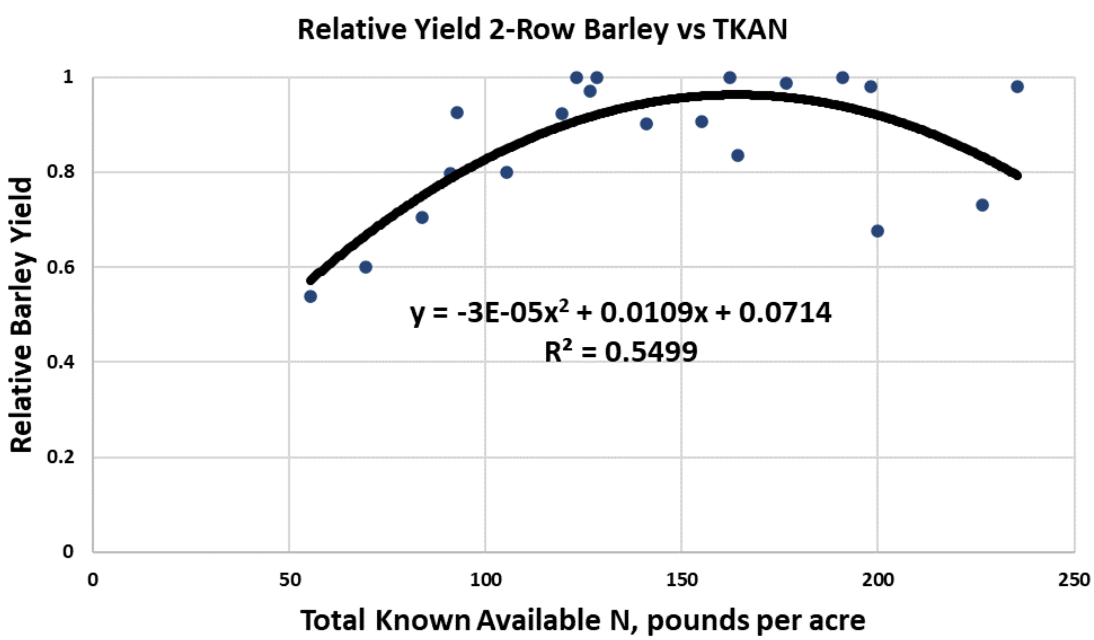

Figure 1. Relative two-row barley yield data averaged across replications and cultivars at four eastern North Dakota sites compared to total known available N, fitted with a quadratic trendline.

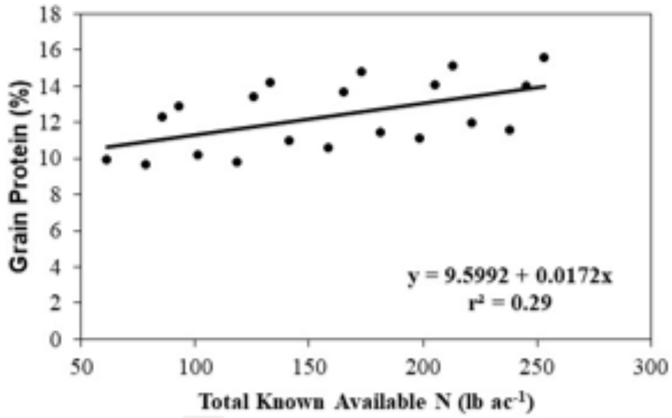

Figure 2. Two-row barley grain protein content averaged across replications and varieties at four eastern North Dakota sites compared to total known available N, fitted with a linear trendline.

Barley prices to the farmer range from $3.50 per bushel to $6.50 per bushel, with N costs the past decade ranging from 40 cents per pound N to $2 per pound N. The maximum Economic N rate from these experiments is 174 pounds N per acre (at $6.50 per bushel barley and $1.30 per pound N). As barley price decreases, N cost increases, or both, the ratio between N cost and barley price (N:barley) becomes larger, indicating tighter potential margins and thus promoting lower N rates. The benefit of calculating N rate based on the EONR method is to attain maximum economic return at higher N:barley price ratios, without the necessity of fertilizing to maximum yield (Figure 3).

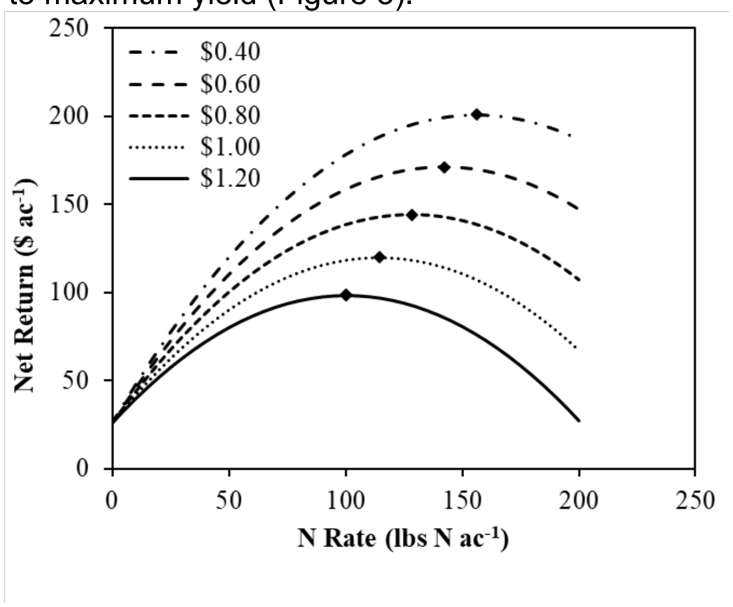

Figure 3. Comparison of economic optimum N rates for two-row malting barley in eastern North Dakota and net return with barley price at $4.40 per bushel and N costs at $0.40, $0.60, $0.80, $1.00, and $1.20 per pound of N.

CONCLUSIONS

The results from four site-years of data support previous findings that N rate is a driver of grain yield and protein concentration in 2-row malting barley. There was no relationship between N rate and kernel plump. Regression analysis of grain yield and TKAN determined maximum grain yield was attainable at 235 pounds N per acre. Additionally, when fertilized at the rate of maximum yield, grain protein content averaged 12.8 %, which is below the 13.0 % standard maximum protein for malting (American Malting Barley Association, 2023b). When factoring in economics, the TKAN range needed to produce the barley crop at the highest profitability is less than the TKAN for maximum yield.

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COMBINATION OF NITROGEN FERTILIZER AND RHIZOBIUM TO IMPROVE YIELD AND QUALITY OF MUNG BEAN AND ADZUKI BEAN IN MONTANA

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ABSTRACT

Mung bean and adzuki bean are alternative grain legumes that may provide benefits to Montana's cropping systems by improving long-term diversification and productivity. The objective of this study was to investigate mung bean and adzuki bean responses to nitrogen fertilizer and rhizobium inoculation combinations. Two adzuki bean (Organic and O.R) and two mung bean (Organic and L.N) cultivars were grown under five nitrogen and rhizobium combinations, including (A) 22N-22P-22K, (B) 74N-22P-22K, (C) 74N-22P-22K + Rhizobia, (D) 22N-22P-22K + Rhizobia, and (E) Rhizobia only during 2019 and 2020 in Sidney, Montana. Results showed that seed yield was greatly affected by species/cultivar and fertilizer treatments. Generally, mung beans had greater yields than adzuki beans. One mung bean cultivar (Organic) produced a greater yield than the other one (L.N.) in 2019 with no difference in 2020. Treatment C (74N-22P-22K + Rhizobia) produced the highest yields in both years. Treatments A (22N-22P-22K) and E (Rhizobia only) were the lowest yielding in both years. Fertilizer affected bean protein concentrations in 2020 but not in 2019 with treatment C (74N-22P-22K + Rhizobia) producing the highest protein concentrations in 2020. Grain yield was greater in 2019 compared to 2020, however, grain protein showed the opposite trend with higher concentrations in 2020.

INTRODUCTION

Mung bean and adzuki bean have been cultivated as traditional grain legumes in Asiatic countries for food consumption and medical benefits for decades (Alemu, 2016; Torabian et al., 2021). Due to the unique seed quality and nutritional value, mung beans and adzuki beans have become commercially attractive in some regional markets, including as sprouts (predominantly mung bean) in the United States (Alemu, 2016; Torabian et al., 2021; Nair et al., 2012; Rubatzky and Yamaguchi, 2012; Pandian et al., 2021, Kondo et al., 2004). Adzuki bean grains and sprouts contain balanced amounts of digestible protein, essential minerals, fatty acids, bioactive photo-chemicals, polyphenols and phytates, making them a great source of food with pharmaceutical functions (Campos-Vega et al., 2010, Agarwal and Chauhan., 2019).

Although mung beans and adzuki beans offer nutritional benefits in human diets and potential improvements in farm sustainability, adoption by growers is lacking due in part to the absence of production and management information and associated production risks. Evaluation of yield and agronomic traits of mung bean and adzuki bean cultivars and fertility management linked to yield improvement may prompt farmers and researchers to pursue these new alternative crops thereby providing benefits to farm sustainability and the Montana economy. The objectives of this study were: 1) to investigate the combination of N, P, K fertilizer with rhizobia inoculant effects on biomass, yield, and protein concentration of mung and adzuki beans; and 2) to provide production recommendations to farmers in Montana and surrounding regions.

MATERIALS AND METHODS

A field experiment was carried out at the Montana State University Eastern Agricultural Research Center (EARC) irrigated farm located in Sidney, MT (47°43′32″ N, 104°9′5″ W) in 2019 and 2020. Soil at this site is a deep, well-drained, nearly level (field slope of ~0.15%) Savage Clay Loam (fine, smectitic, frigid Vertic Argiustolls). The average monthly air temperatures and precipitation from March–October for 2019 and 2020 are shown in Figure 1.

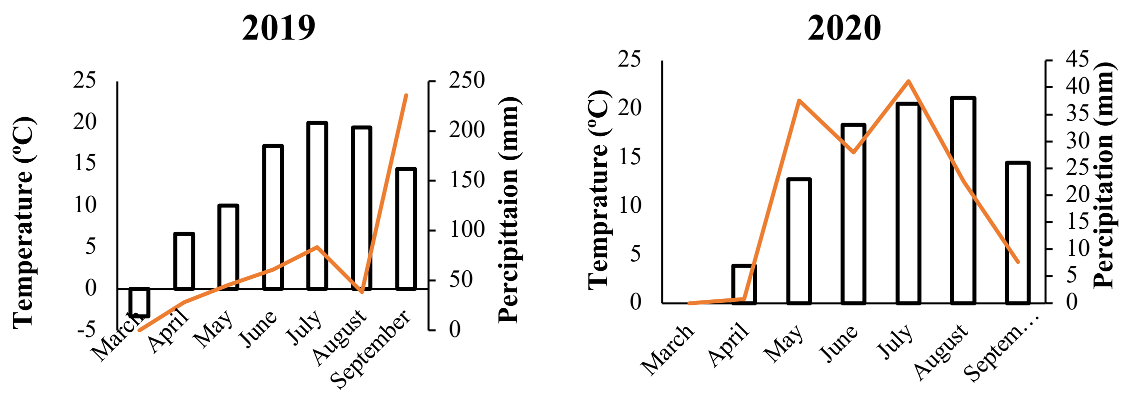

Figure 1. Growing season monthly average temperature and precipitation.

The experiment was conducted as a randomized complete block design with 3 replicates, where mung and adzuki bean cultivars and fertilizer treatments were randomly assigned to plots within each block. There were two mung bean (cv. Organic and L.N) and two adzuki bean (cv. Organic and O.R) cultivars and five nitrogen and rhizobium combinations, including (A) 22N-22P-22K, (B) 74N-22P-22K, (C) 74N-22P-22K + Rhizobia, (D) 22N-22P-22K + Rhizobia, and (E) Rhizobia only. In treatments A through D, a starter fertilizer was applied in the same furrow with seeds at planting at a rate of 22 kg ha^{-1} N, 22 kg ha^{-1} P_2O_5, and 22 kg ha^{-1} K_2O. In addition, treatments B and C received a top-dress of urea at the 8-leaf stage at a rate of 52 kg ha^{-1} N. A commercial rhizobia inoculant was mixed with seed at planting in those treatments containing rhizobia.

Planting dates were May 14, 2019 and May 8, 2020, and trials followed sugar beets in both years. Seeding rates were 129 pure live seed per m^{-2}. The plot size was 1.5 m wide x 4.6 m long. Prior to planting seeds were treated with Cruiser Maxx insecticide and Apron Maxx fungicide. Outlook herbicide (720 g l^{-1} Dimethenamid-P) was applied pre-emergence at the rate of 1.0 l ha^{-1}. Hand weeding was performed as needed during the growing season. Plots were harvested in late September when seeds were completely matured using a plot combine harvester. The grain yield was calculated and adjusted to 6% moisture content. A sub-sample of grain was ground to test nitrogen concentration by Dumas combustion using a Perkin Elmer Series Ⅱ Nitrogen Analyzer and then converted to protein content by multiplying a factor of 6.25.

RESULTS AND DISCUSSION

Biomass and Grain Yields

The analysis of variance for biomass is presented in Table 1. Cultivar effects (*P*<0.001) and cultivar x year interactions (*P*<0.01) were significant for biomass. Mung beans produced more biomass than adzuki beans in both years (Figure 2). There were no differences in biomass between the two mung bean cultivars nor between the two adzuki bean cultivars. The biomass yields were higher in 2020 than in 2019 for adzuki beans but not mung beans. The magnitude of difference between mung beans and adzuki beans was less in 2020 relative to 2019 giving rise to the cultivar x year interaction.

Fertility treatments have moderate (*P*=0.059) effects on mung and adzuki bean biomass yields. Treatment C (74N-22P-22K) produced the highest biomass yields in both years (Figure 3).

Table1. Analysis of variance table for cultivar, year and treatment effects on biomass yield, grain yield and grain protein.

Source of Variation	df	Biomass Yield *P>F*	Grain Yield *P>F*	Grain Protein *P>F*
Cultivar	3	<0.001	<0.001	<0.001
Treatment	4	0.059	<0.001	0.023
Year	1	0.262	<0.001	<0.001
Cultivar*Treatment	12	0.813	0.009	0.880
Cultivar*Year	3	0.008	0.049	0.305
Treatment*Year	4	0.275	<0.001	0.016
Cultivar*Treatment*Year	12	0.216	0.318	0.960

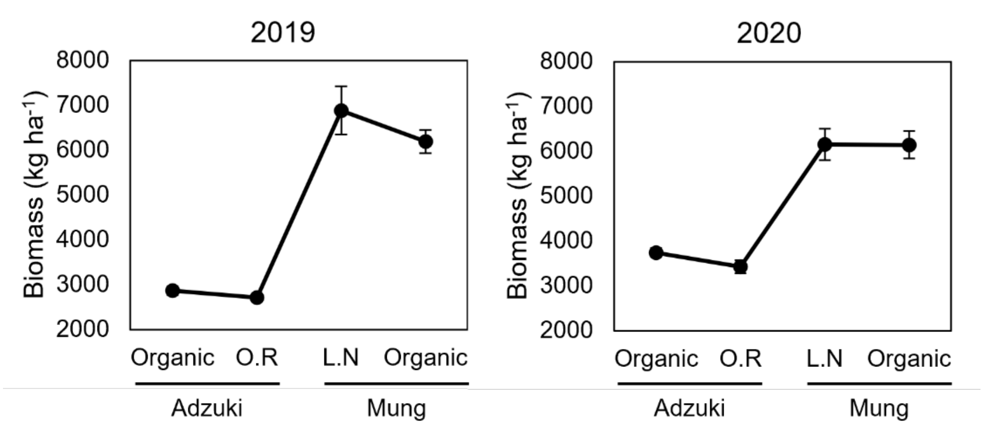

Figure 2. Biomass yield of mung and adzuki bean cultivars in 2019 and 2020. Error bars represent standard error.

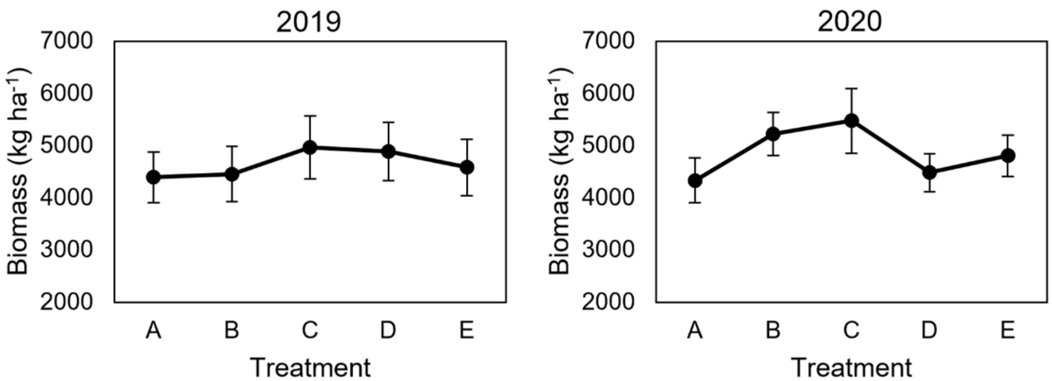

Figure 3. Biomass yield affected by treatments in 2019 and 2020. Treatments: (A) 22N-22P-22K, (B) 74N-22P-22K, (C) 74N-22P-22K + Rhizobia, (D) 22N-22P-22K + Rhizobia, and (E) Rhizobia only. Error bars represent standard error.

The analysis of variance for grain yield is presented in Table 1. Cultivar, treatment, and year effects were significant for grain yield (P<0.001). Significant interactions were observed for cultivar x treatment (P<0.01), cultivar x year (P<0.05) and treatment x year (P<0.001). Mung beans produced higher grain yields than adzuki beans, and the grain yields were higher in 2019 than 2020 (Figure 4) for both for mung bean and adzuki beans. The reduction in yield from 2019 to 2020 was greater for the two adzuki bean cultivars resulting in a cultivar x year interaction. The fertility treatment had significant effects on grain yield. Treatment C produced the highest yield and treatment E produced the lowest yield (Figure 5). The patterns of the fertility effects looked similar, but the magnitude of the effects was greater in 2019 than in 2020 (Figure 5) resulting in a significant treatment x year interaction.

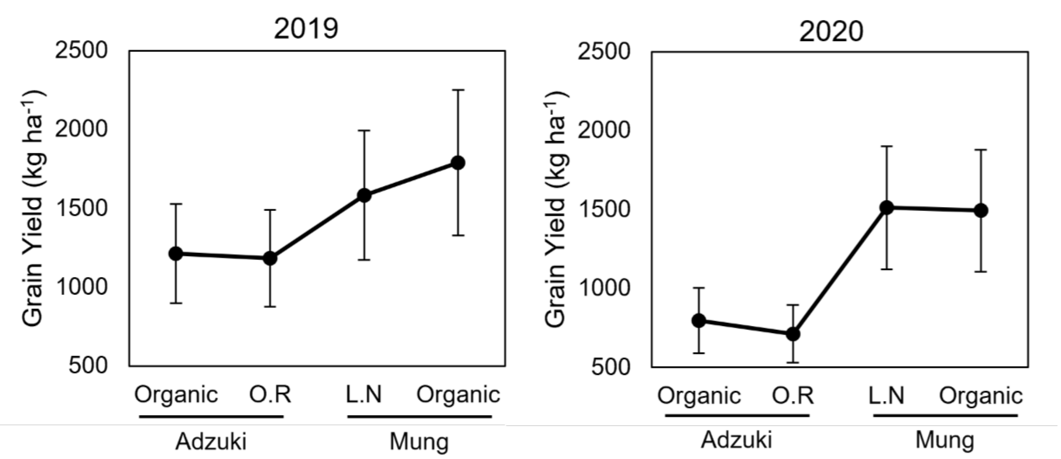

Figure 4. Grain yield of mung and adzuki bean cultivars in 2019 and 2020. Error bars represent standard error.

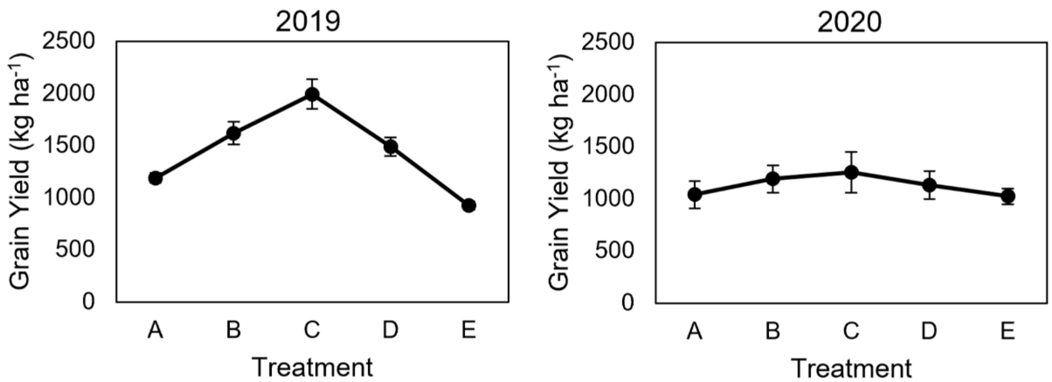

Figure 5. Grain yield affected by treatments in 2019 and 2020. Treatments: (A) 22N-22P-22K, (B) 74N-22P-22K, (C) 74N-22P-22K + Rhizobia, (D) 22N-22P-22K + Rhizobia, and (E) Rhizobia only. Error bars represent standard error.

Grain Protein

Table 1 includes analysis of variance for grain protein. Cultivar (P<0.001), treatment (P<0.05), and year (P<0.001) effects are all significant for grain protein. Grain protein concentrations were higher in 2020 than in 2019. Mung beans had higher grain protein concentrations than adzuki beans, but the protein concentration did not differ between the mung bean cultivars nor between the adzuki bean cultivars (Figure 6).

Grain Treatment effects on grain protein concentration differed between 2019 and 2020 (Figure 6) producing a significant treatment x year interaction (P<0.05). In 2020, treatment B and C had the highest protein concentrations and treatment A and E had the lowest protein concentrations, while there was little difference among the treatments in 2019.

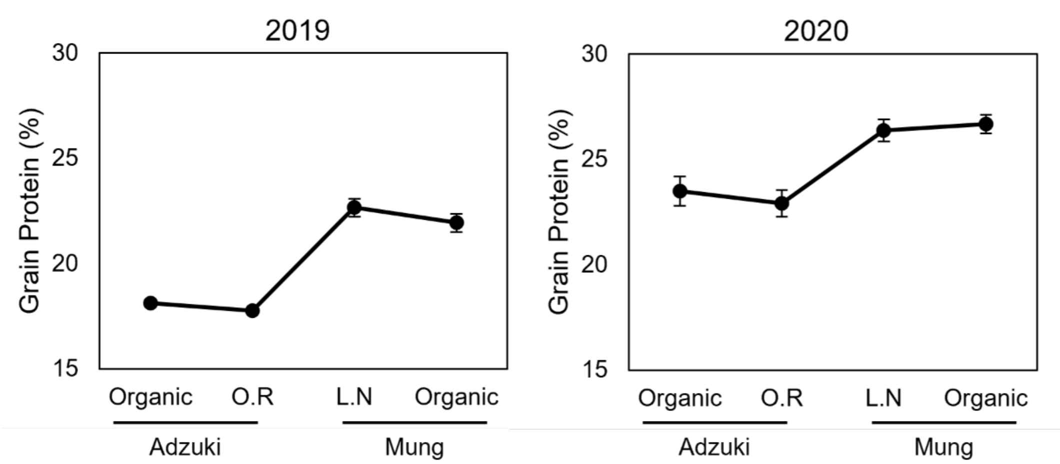

Figure 6. Grain protein of mung and adzuki beans in 2019 and 2020. Error bars represent standard error.

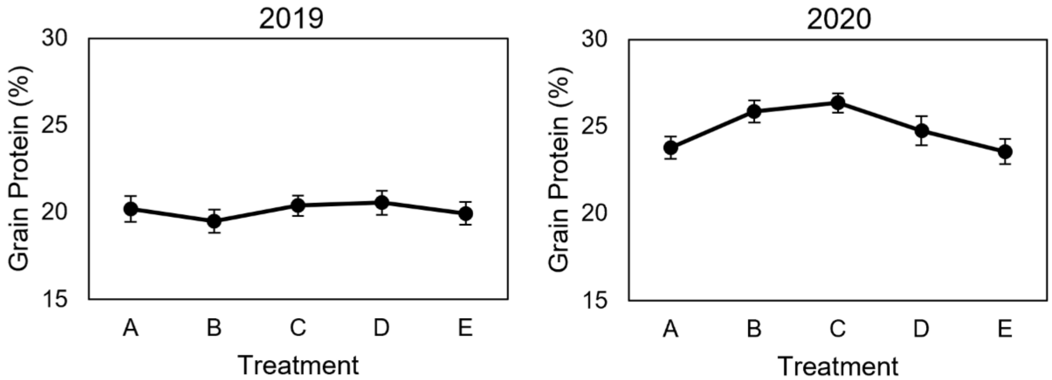

Figure 7. Grain protein affected by treatments in 2019 and 2020. Treatments: (A) 22N-22P-22K, (B) 74N-22P-22K, (C) 74N-22P-22K + Rhizobia, (D) 22N-22P-22K + Rhizobia, and (E) Rhizobia only. Error bars represent standard error.

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AGRONOMIC EVALUATION OF CAMELINA GENOTYPES SELECTED FOR YIELD, OIL CONCENTRATION, AND NITROGEN USE EFFICIENCY

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ABSTRACT

In recent years, camelina (*Camelina sativa* L.) has received global recognition for its role as a biofuel crop and multipurpose addition to cereal-based farming systems in the Northern Great Plains (NGP). The present study objected to investigative the differential responses of selected camelina varieties to nitrogen (N) and sulfur (S) inputs. Biomass, seed yield, seed oil concentration, and nitrogen use efficiency (NUE) of five varieties, variety 229, variety 35, variety 53, Suneson, and Check1, were investigated under five nitrogen (N) rates ranging from 33 to 168 kg ha^{-1} and two sulfur rates of 0 and 22 kg ha^{-1} in Sidney, Montana. Cultivars differed in stand count, plant height, biomass, yield, oil content, oil yield, and nitrogen uptake, and fertility treatment affected biomass, seed yield, oil concentration, and N uptake. Averaged over all N and S input levels, variety 229 had the highest and variety 35 had the lowest biomass yield, while Check1 had the highest and variety 35 had the lowest seed yield. Variety 229 also had the highest and variety 35 had the lowest oil concentration. Averaged over the cultivars, increasing the N rate resulted in increased camelina biomass and seed yield but decreased oil concentration. Contrast analysis showed inconsistent S effects at varying N rates. Based on the N response regression curves, the optimum N rate for the maximal seed yield was determined as 125 kg N ha^{-1} for variety 229 with 1894 kg ha^{-1} yield, 286 kg N ha^{-1} for variety 35 with 1470 kg ha^{-1} yield, 141 kg N ha^{-1} for variety 53 with 1957 kg ha^{-1} yield, 158 kg N ha^{-1} for Suneson with 1977 kg ha^{-1} yield, and 132 kg N ha^{-1} for Check1 with 2137 kg ha^{-1} yield. The NUE at the optimum N rate was 15.2, 5.1, 13.9, 12.5, and 16.2 kg seed per kg N for varieties 229, 35, 53, Suneson, and Check1, respectively. Results demonstrated that variety 229 and Check1 are the two superior cultivars with high yield, low optimal N input rate, and high NUE.

INTRODUCTION

Camelina has been successfully integrated into the cropping system in the northern Great Plains (NGP) of the United States bringing advantages of yield stability, further diversification, economic profitability, and correspondingly proceeding energy initiatives (Milliken et al., 2007). While it is regarded as a low-input crop, camelina responds significantly to nitrogen fertilizers, with a comparatively lesser impact from phosphorus and sulfur, as indicated by Solis et al. (2013). Application of 60 kg ha^{-1} N (Mohammad et al, 2016), 90–100 kg N ha^{-1} applied plus soil N (McVay and Lamb, 2008), and 90 kg ha^{-1} (Afshar et al., 2016) were reported for camelina grown in Montana to perceive the maximum grain yield and oil composition. Subsequently, sulfur fertilization is justified when nitrogen is supplied optimally (Mohammad et al, 2016). Kumari et al

(2015) recommended the application of 40 N kg ha^{-1} and 20 S kg ha^{-1} resulting in the highest grain yield and oil content. Apparently, the performance of camelina is shaped by a combination of genetic characteristics, ecological conditions, and agronomic practices, including fertilization (Jiang et al., 2014). The objective of the current study was to evaluate the differential responses of camelina genotypes to nitrogen and sulfur inputs and determine the optimum N input level and N use efficiency (NUE) of selected camelina varieties in Montana.

MATERIALS AND METHODS

Five camelina cultivars including Check 1, Suneson, variety 229, variety 53, and variety 35, were evaluated at the Eastern Agricultural Research Center Sidney, MT (47◦43′32″ N, 104◦9′5″ W) in 2023 under five incremental N rates of 33, 68, 100, 132, and 168 kg N ha^{-1} from urea (46% N) and two S levels at 0 and 22 kg S ha^{-1} from garden Gypsum (16% S) in a factorial randomized complete block design with four replicates. Stand count, plant height, and biomass weight were recorded at physiological maturity. Plants were harvested when seeds were completely matured (late July to early August) using a plot combine. After harvesting, sub-samples of seed were taken to measure the oil concentration using an MQC + benchtop NMR analyzer (Nuclear Magnetic Resonance, Oxford Instruments). The following oil yield was obtained by multiplying seed oil concentration in seed yield. To determine nitrogen uptake and nitrogen use efficiency, the grain nitrogen content was assessed using a Perkin Elmer CHNS/O Analyzer Model 2400. Seed N uptake and Nitrogen use efficiency (NUE) were computed by the following formulas:

N uptake = Seed N Content × Grain Yield

$$\text{NUE} = \frac{\text{Seed Yield}}{\text{N Supply}}$$ (Rathke et al., 2006)

Data was analyzed using SAS 9.4 software while the LSD test at 0.05 was employed to compare the means when significant differences were identified. The graphs were drawn using Excel 2010.

RESULTS AND DISCUSSION

The stand count varied among varieties, ranging from 70.1 plants m^{-2} in variety 35 to 149.7 plants m^{-2} in Check1. Plant height also differed significantly from 60.1 cm in variety 35 to 74.6 cm in variety 229. Stand count and plant height were not significantly affected by applying N and S combinations. Biomass was significantly affected by varieties ranging from 4351 kg ha^{-1} in variety 35 to 6463 kg ha^{-1} in variety 229. Additionally, 120N+20S and 150N+0S were identified as more effective in promoting biomass production, yielding 6463 kg ha^{-1} and 6322 kg ha^{-1}, respectively indicating a significant increase in biomass as N increased. Harvest index (HI) showed no significant variation in response to different varieties or fertilizer treatments, averaged at 26.9% (Table 1, Table 2).

Seed yield varied among varieties extending from 1153 kg ha^{-1} in varieties 35 to 2015 kg ha^{-1} in Check1. Moreover, yield varied with varying N and S rates. Averaged over all varieties, the maximum yield was obtained in 150N+20S (Table 2).

Nevertheless, variety 35 responded to N differently from other varieties demonstrating lower yield at all N levels (Figure 1 b). In addition, sulfur tended to further increase seed yield at higher N input level (Figure 1 a). The contrast analysis showed that sulfur did not increase the yield of camelina varieties at low N levels, which is in agreement with the insignificant effect of S on camelina yield documented by Solis et al. (2013); Wysocki et al. (2013); Sintim et al. (2015), by applying different sources of S including gypsum, ammonium sulfate, ammonium thiosulfate, and elemental S. From the N response regression curves, the optimum N rate was determined for each variety (Figure 2). The optimum N rate for the maximal seed yield was determined as 125 kg N ha^{-1} for variety 229 with 1894 kg ha^{-1} yield, 286 kg N ha^{-1} for variety 35 with 1470 kg ha^{-1} yield, 141 kg N ha^{-1} for variety 53 with 1957 kg ha^{-1} yield, 158 kg N ha^{-1} for Suneson with 1977 kg ha^{-1} yield, and 132 kg N ha^{-1} for Check1 with 2137 kg ha^{-1} yield.

Seed oil concentration was reduced with increasing N rate (Figure 3 a). However, camelina genotypes trended to respond differently to the increasing N rate (Figures 3b and d). Averaged over N and S levels, the minimum oil concentration was observed in variety 35 (35.53%) and the maximum was found in variety 229 (41.48%) Variety 53, Suneson, and Check1 exhibited comparable levels of oil concentrations (Table 2). Similarly, camelina oil content was reported at 300 g kg^{-1} (Obour et al., 2018), ranging from 28% to 41% in different sites and years according to Palvlista et al., (2016). The variations in yield and oil concentration led to differences in oil yield, yet the findings indicated that oil yield was more influenced by yield than by oil concentration. The lowest oil yield was observed in variety 35 while the maximum oil yield was found in Check1 (Table 2). Nitrogen uptake in the seed increased with higher nitrogen rates, reaching the maximum in 150N+20S. Among the varieties, Check1 and variety35 were identified as the most and least promising, respectively, for nitrogen uptake. Nitrogen Use Efficiency (NUE) was influenced by the interactions between variety and fertilizer, ranging from 15.1 kg seed per kg N in variety 35 to 26.5 kg seed per kg N in Check1. Additionally, NUE decreased with higher nitrogen rates. Contrast analysis showed an insignificant S effect on N uptake and NUE (Table 1, Table 2). From regression curves, the NUE at the optimum N rate was 15.2, 5.1, 13.9, 12.5, and 16.2 kg seed per kg N for varieties 229, 35, 53, Suneson, and Check1, respectively (Figure 2). Cultivars with higher NUE can contribute to reduced amount of nitrogen without decreasing grain yield. These findings align with a study by Mohammed et al. (2017) on camelina grown in Montana, revealing NUE ranging from 12.4 to 6.7 kg seed per kg N at nitrogen rates of 45 and 90 kg N ha^{-1}, respectively. Obeng et al (2021) showed that the maximum yield of camellia was obtained by applying 54 kg N ha^{-1} while sulfur fertilizer did not have any significant effect on grain yield and oil concentration.

In summary, different varieties exhibited significant variations in response to nitrogen availability, indicating that the optimal nitrogen level varies for each genotype to achieve maximum yield, oil content, and NUE. Results demonstrated that varieties 229 and Check1 are superior cultivars with high yield, low optimal N input rate, and high NUE.

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Table 1. ANOVA analysis of camelina varieties at different N and S rates.

Source	Stand Count	Plant Height	Biomass	HI*	Seed Yield	Oil Content	Oil Yield	Seed N Uptake	NUE
V	***	***	***	ns	***	***	***	***	***
F	ns	ns	***	ns	***	***	***	***	***
V× F	ns	ns	ns	ns	ns	ns	ns	ns	***
LSD	16.74	1.86	355.57	1.65	103.6	0.36	40.37	5.19	1.68
CV	31.46	6.26	14.11	13.91	13.54	2.08	13.29	14.59	16.88
Mean	120.4	67.45	5702.27	26.92	1731.18	39.44	687.47	80.59	22.52

*Harvest Index

Table 2. Mean comparison of camelina affected by N and S.

Variety	Stand Count (Plants m^{-2})	Height (Cm)	Biomass (Kg ha^{-1})	HI (%)	Seed Yield (Kg ha^{-1})	Oil Content (%)	Oil Yield (Kg ha^{-1})	Seed N Uptake (Kg ha^{-1})
Check1	149.7^{a}	69.4^{b}	6043^{b}	27.8	2014.6^{a}	39.8^{c}	801^{a}	93.1^{a}
Suneson	139.2^{ab}	66.1^{c}	5492^{c}	27.8	1845.3^{b}	40.2^{b}	755^{b}	85.3^{b}
Variety	124.2^{bc}	67.1^{c}	6162^{ab}	26.3	1864.3^{b}	40.0^{bc}	742^{b}	86.1^{b}
Variety	110.2^{c}	74.6^{a}	6463^{a}	26.3	1811.5^{b}	41.8^{a}	727^{b}	79.6^{c}
Variety	79.1^{d}	60.1^{d}	4351^{d}	26.4	1152.8^{c}	35.5^{d}	413^{c}	58.8^{d}
F (N+S)								
30+0	113.6	66.6	4868^{f}	26.6	1526.3^{d}	40.6^{a}	625^{c}	68.2^{d}
30+20	120.7	66.6	5024^{ef}	27.1	1579.6^{d}	40.2^{ab}	639^{c}	71.3^{d}
60+0	124.1	66.8	5491de	27.6	1642.3^{cd}	40.0^{bc}	665^{bc}	74.7^{cd}
60+20	124.9	66.9	4884^{f}	27.1	1575.5^{d}	40.1^{ab}	638^{c}	70.6^{d}
90+0	132.7	69.0	5798^{bcd}	26.3	1773.5^{ab}	39.3^{d}	703^{ab}	82.2^{b}
90+20	129.5	67.2	5726^{cd}	26.2	1750.8^{bc}	39.5^{cd}	697^{ab}	81.9^{bc}
120+0	110.9	69.1	6301^{ab}	27.8	1845.6^{ab}	38.7^{e}	720^{ab}	88.1^{ab}
120+20	113.5	68.9	6463^{a}	26.7	1863.2^{ab}	38.7^{e}	725^{a}	88.2^{ab}
150+0	121.7	68.2	6322^{a}	26.7	1839.6^{ab}	38.6^{e}	714^{ab}	88.1^{ab}
150+20	112.8	66.3	6145^{abc}	27.1	1915.5^{a}	38.7^{e}	750^{a}	92.5^{a}

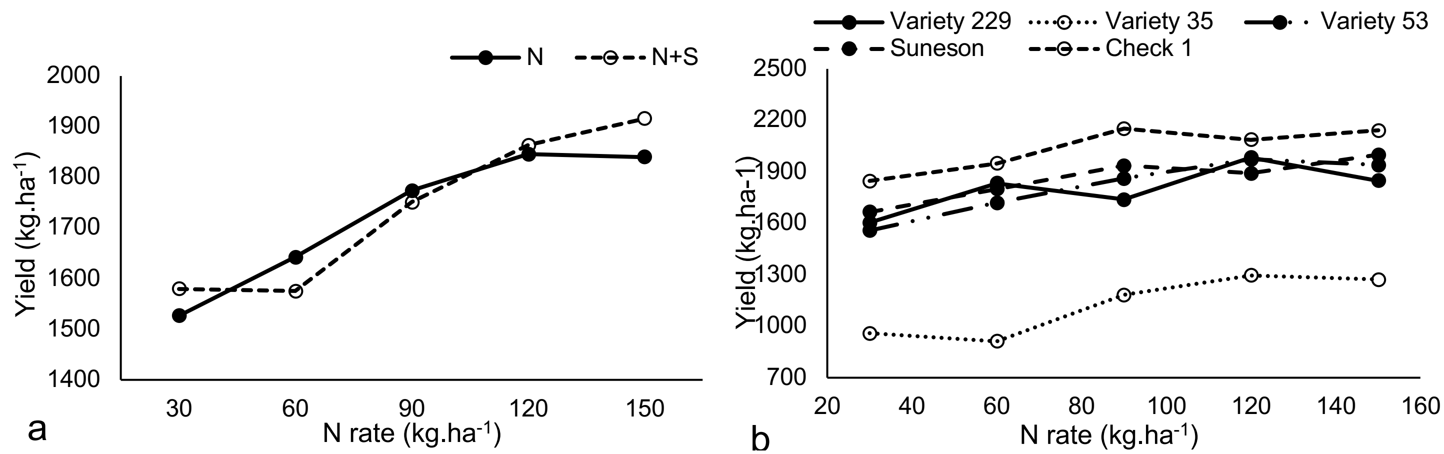


Figure1. Yield trends of different varieties of camelina affected by N and N+S.

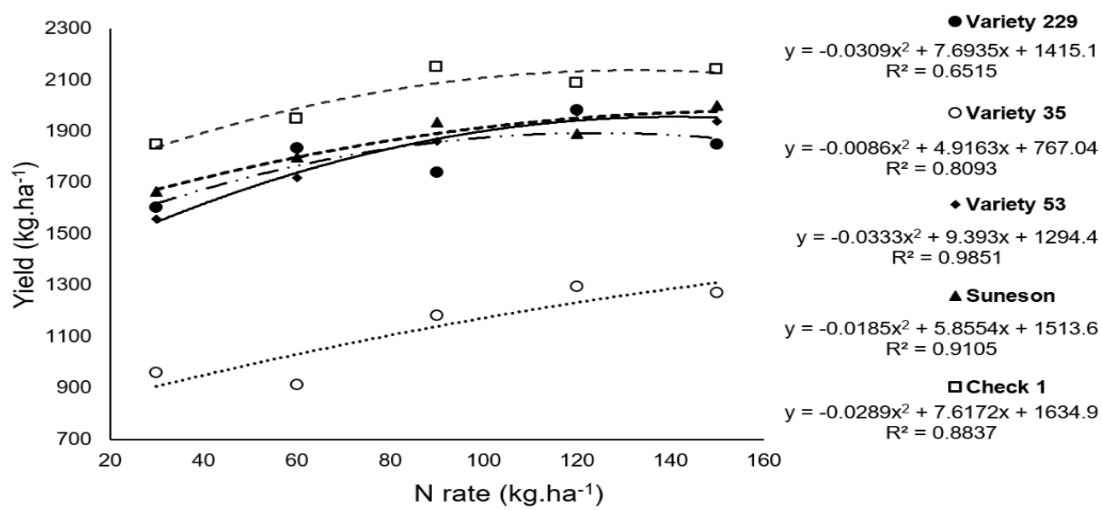
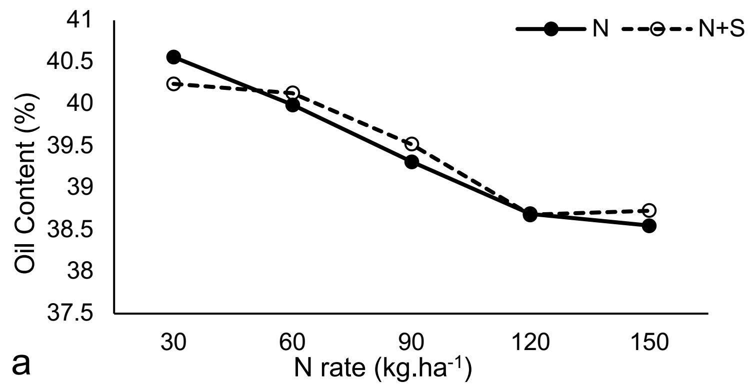


Figure 2. Regression response of camelina varieties to N rate.



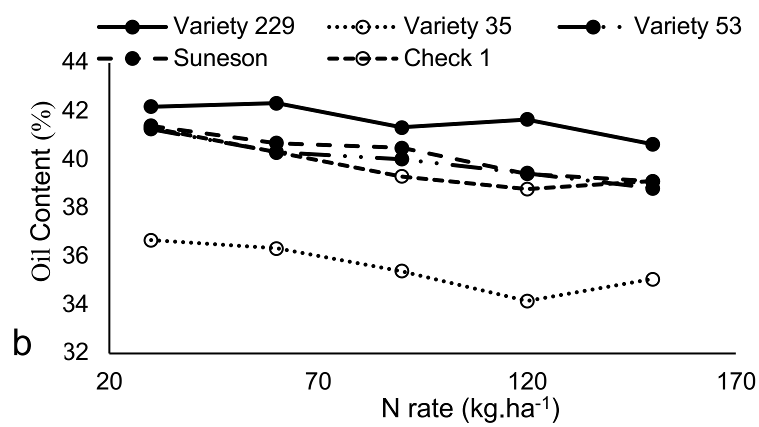


Figure 3. Oil concentration trends of different varieties of camelina affected by N and N+S.

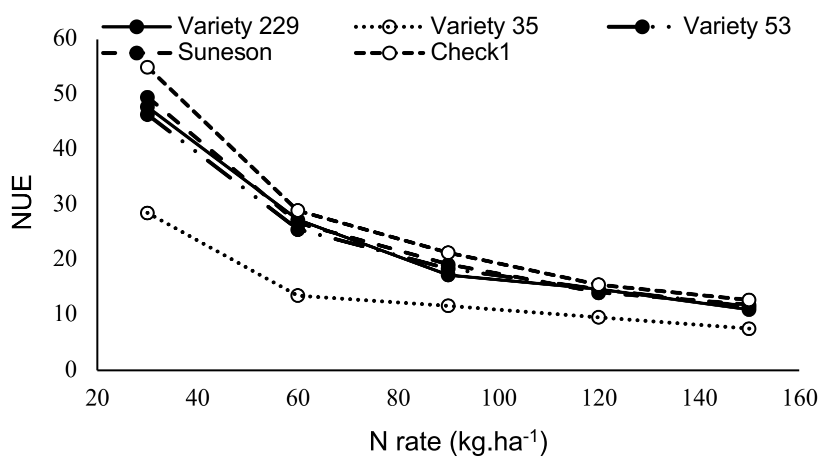


Figure 4. The interactive effects of Variety × Fertilizer on NUE.

EFFECT OF SEEDING RATE ON ANNUAL WARM SEASON FORAGE YIELD AND PLANT STRUCTURE

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ABSTRACT

Due to the decline of the Ogallala Aquifer and reduced irrigation capacity, there is growing interest in more water-efficient cropping systems in the semi-arid central Great Plains. To support the region's livestock industry, there is increased interest in forages because they use water more efficiently than grain crops. However, there is insufficient information on summer annual forage seeding rates in the range of environments encountered in the region. The objective of this study was to evaluate the effect of seeding rate on forage yield, nutrient value, plant height, stalk diameter, tillers and leaf- to- stem ratio for four types of summer annual forages: forage sorghum [*Sorghum bicolor (L.) Moench*], sudan grass [*Sorghum x drummondii*], pearl millet [*Pennisetum glaucum*], and sorghum [*Sorghum bicolor (L.) Moench*]-sudan [*Sorghum x drummondii*] hybrids. The study was conducted in 2022 at Garden City, KS, under irrigated and rainfed conditions, and in 2023 at Garden City (irrigated and rainfed conditions) and Hays, KS (rainfed conditions). The 2022 rainfed study was lost due to drought conditions. Six seeding rates were tested for each species (370,000, 740,000, 1,110,000, 1,480,000, 1,850,000, and 2,220,000 seeds/ha). Initial results showed significant differences between seeding rates for forage yield, plant height, stalk diameter, and tillers but not for leaf-to-stem ratio. Forage yield had a positive linear relationship with seeding rate but plateaued at different seeding rates depending on the species. These initial results indicate that a unique seeding rate recommendation for each species will be necessary to maximize yield-to-cost ratio under irrigation.

SUMMER ANNUAL LEGUMES: YIELD POTENTIAL AND WATER USE

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ABSTRACT

Due to the decline of the Ogalla Aquifer and reduced irrigation capacity, there is a growing interest in more water-efficient cropping systems in the semi-arid central Great Plains. One of the most water-intense crops grown on the semi-arid central Great Plains is alfalfa (*Medicago sativa L.).* Alfalfa is grown for its nutritive value and protein, which is highly desired by cow/calf, feed yards, and dairies of the central and southern Great Plains. The purpose of this study was to evaluate the potential of summer annual legume species to serve as a more water-efficient alternative to alfalfa while retaining high-forage nutritive value and protein levels. This study sought to accomplish this by analyzing the viability, yield potential, nutritive value and water use efficiency (mass of forage/water used) of four summer annual legume species (cowpea [*Vigna unguiculata*], forage soybean [*Glycine max (L.)*], lablab [*Lablab purpureus*], and sunn hemp [*Crotalaria juncea*]) as well as two summer annual grass species (BMR forage sorghum [*Sorghum bicolor (L.) Moench*] and pearl millet [*Pennisetum glaucum*]). This study was conducted in 2022 and 2023 at three locations: Garden City, KS (irrigated), Colby, KS (dryland), and Hays, KS (dryland). In Garden City and Colby, forage sorghum and pearl millet were significantly higher yielding than any of the legume species, but in Hays, while forage sorghum was the highest yielding, there was not a significant difference in yield between cowpea and pearl millet. In Garden City, water use efficiency was as follows forage sorghum > millet > sunn hemp > forage soybean = cowpea. Based on initial results, the potential to incorporate alternative summer annual legumes into Semi-arid Great Plains cropping systems seems limited because the more commonly grown forage grass species both yielded better and used water more efficiently than any of the legume species.

SOIL MICROBES ARE CRITICAL TO MAINTAINING SOIL FERTILITY IN THE GREAT PLAINS

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ABSTRACT

Soil in the Great Plains is known to be susceptible to wind and water erosion due to moisture deficits throughout the region that limit soil organic matter (SOM) accumulation that helps form stable soil structure. Conservation management practices like reduced tillage are emphasized to maintain SOM that provides habitat for soil microbes to perform ecosystem services related to nutrient cycling and soil aggregation to increase resistance to erosion and maintain fertile topsoil. Soils under long-term no-till management in Great Plains states of North Dakota, South Dakota, Nebraska, Colorado, and Texas were used to evaluate how parameters of biological soil fertility influence soil aggregation under reduced tillage. Soil properties (pH, clay content) were related to the following critical assessment measures for SOM dynamics and microbial characteristics: soil organic carbon (SOC), permanganate oxidizable carbon (POXC), β-glucosidase enzyme activity (Bglu), ester-linked fatty acid methyl esters (ELFAME), and water-stable aggregation (WSA). Results showed that SOC and POXC were higher in Northern and Central great plains sites, which was likely because of lower temperatures that reduce SOM degradation and higher clay content that increases surface area for holding SOM. Soil microbial communities had more biomass and enzyme activity in temperate and cool climates based on total ELFAME and Bglu activity. Soil stability as measured by WSA was highest in SD, the location with the highest total ELFAME and Bglu activity. Although some soils had more SOC and POXC than others, these metrics were not the sole determining factor for soil stability. Principal components analysis revealed that ELFAME and Bglu activity were more correlated to WSA than other biological soil fertility metrics, which suggests that soil microbial activity is a critical component to maintaining soil fertility against erosion in the Great Plains.

EFFECT OF EXTRACTANT pH ON EXCHANGEABLE CATION DETERMINATION USING AMMONIUM ACETATE AND MEHLICH-3

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ABSTRACT

Neutral pH ammonium acetate is a standard soil test extractant for concentrations of exchangeable bases: calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), which are used to estimate cation exchange capacity by summation of cations (CEC_sum) and exchangeable sodium percentage (ESP). However, the concentrations of Ca and Mg may be artificially inflated due to dissolution of free carbonates and gypsum. The study objectives were to determine the impacts on CEC_sum and ESP of four exchangeable cation extraction methods [1*N* NH_4OAc at pH 7.0, 7.5, or 8.5 ("AA_7.0", "AA_7.5", "AA_8.5", respectively) or Mehlich-3 at pH 2.5 ("Meh-3")]. The K, Mg, and Na were generally well correlated across extractants ($r^2 \geq$ 0.98). However, the Ca concentrations decreased as extractant pH increased. This was most apparent with high levels of reactive carbonates and most noticeable with Meh-3. Correlations with Meh-3 CEC values were most affected when Meh-3 Ca concentrations exceeded 5000 ppm. The CEC_sum and ESP calculated from AA_7.0 and Meh-3 were not significantly different if Ca concentration values were limited to 5000 ppm).

INTRODUCTION

Exchangeable Ca, Mg, K, and Na can be determined simultaneously from soil samples using a single extractant, typically 1*N* ammonium acetate (NH_4OAc) at pH 7.0 or Mehlich-3 at pH 2.5. Concentrations of Ca, Mg and, especially, K are used in nutrient management decisions, although Ca concentrations are almost always sufficient for crop production. Additionally, the exchangeable base concentrations are used to estimate the soil's cation exchange capacity (CEC) by the method of summation(CEC_sum). Soil testing laboratories often use the CEC_sum to estimate soil texture used to make nutrient recommendations, as well as in estimating soil sodicity. However, Ca and Mg concentrations may be artificially inflated due to dissolution of free carbonates and/or gypsum, which will inflate the CEC_sum. This overestimates the clay content. This inflation could also reduce the exchangeable sodium percentage (ESP), potentially underestimating the percent of Na and, thus, the potential for sodicity hazard.

MATERIALS AND METHODS

Soil samples from the High Plains region were randomly selected from those submitted to the ServiTech Laboratories in 2011. Samples were not pretreated to remove soluble salts. These were extracted with 1*N* NH4OAc buffered to pH 7.0, 7.5, and 8.5 ("AA_7.0", "AA_7.5", "AA_8.5"), and Mehlich 3 ("Meh-3") buffered to pH 2.5. The Ca, Mg, K, and Na concentrations were measured using Inductively Coupled Plasma-

Optical Emission Spectroscopy (ICP-OES) and used to estimate the CEC_sum and ESP for each extractant. Samples were also analyzed for soil pH, "excess lime" (estimated visually by effervescence), and total carbonate percentage. The AA_7.0 values were compared to the other extractants by linear regression and ANOVA.

RESULTS AND DISCUSSION

The K and Na concentrations were statistically similar for all extractants (Table 1), and the methods were highly correlated with each other ($r^2 > 0.99$; data not shown). The Mg concentrations were statistically similar for the NH_4OAc regardless of pH, but the Meh-3 was significantly higher (Table 1). The NH_4OAc methods were highly correlated with each other ($r^2 > 0.98$; data not shown), but Meh-3 was significantly different than NH_4OAc. The Ca concentrations were inversely proportional as a function of extractant pH (Table 1). The AA_7.5 and AA_8.5 were well correlated with AA_7.0 ($r^2 > 0.96$), but progressively extracted less Ca as concentrations increased (Figs. 1b, 1c, 2b, 2c and Table 1). The Meh-3 increasingly extracted more Ca than AA_7.0 as concentrations increased (Fig. 1a), and was highly correlated at concentrations <4000 ppm Ca ($r^2 > 0.98$, data not shown), but poorly correlated at higher concentrations. The Meh-3 extracted 2 to 8 times as much Ca than AA_7.0 at higher concentrations.

The inflated Ca concentrations from Meh-3 extraction are partially related to soil pH and total carbonate content, but are heavily affected by carbonate reactivity (Fig. 2a). Reactive carbonates tend to have finer particle sizes and more surface area. The acidic Meh-3 reacts with the increased surface area to extract non-exchangeable Ca. This effect with reactive carbonates did not impact Mg concentrations in this population, likely due to a predominance of Ca, rather than Mg, associated carbonates.

Cation concentrations are used to calculate CEC_sum. The calculated Na percentage (ESP) of the CEC_sum is used to identify sodic soils. The CEC_sum values are used to estimate the approximate soil texture for certain nutrient and pesticide applications. The inflated Ca concentrations also inflate the CEC_sum, possibly distorting the texture estimates and ESP values. "Capping" the Meh-3 Ca values at 5000 ppm resulted in CEC_sum values that were well correlated with AA_7.0 values (Fig. 3 and Table 2). The corresponding ESP values using "capped" Meh-3 Ca were also well correlated with AA_7.0 ($r^2 > 0.99$, slope = 0.93).

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Table 1. Mean cation concentrations in ppm. Values within a column sharing the same letter are not significantly different from one another. (α = 0.10)								
Extractant	**Potassium (K)**		**Sodium (Na)**		**Magnesium, (Mg)**		**Calcium, (Ca)**	
AA_7.0	321	a	100	a	329	a	3127	b
Meh-3	339	a	103	a	395	b	4501	c
AA_7.5	345	a	108	a	347	a	2986	b
AA_8.5	334	a	108	a	329	a	2467	a
LSD	*41*		*27*		*31*		*417*	

Table 2. Mean cation exchanged capacity by summation (CEC_sum) and exchangeable sodium percentage (ESP). Values within a column sharing the same letter are not significantly different from one another. (α = 0.20)				
Extractant	**CEC_sum, meq/100g**		**ESP, Na %**	
Meh-3	27.1	a	2.0	a
Meh-3_{capped}*	21.1	b	2.1	a
AA_7.0	19.6	bc	2.3	ab
AA_7.5	19.1	c	2.6	bc
AA_8.5	16.5	d	2.8	c
LSD	*1.6*		*0.4*	

* *Meh-3_{capped} = If Ca ppm > 5000, then Ca ppm = 5000*

Figure 1. Relationships for extracted calcium contents where x = AA_7.0

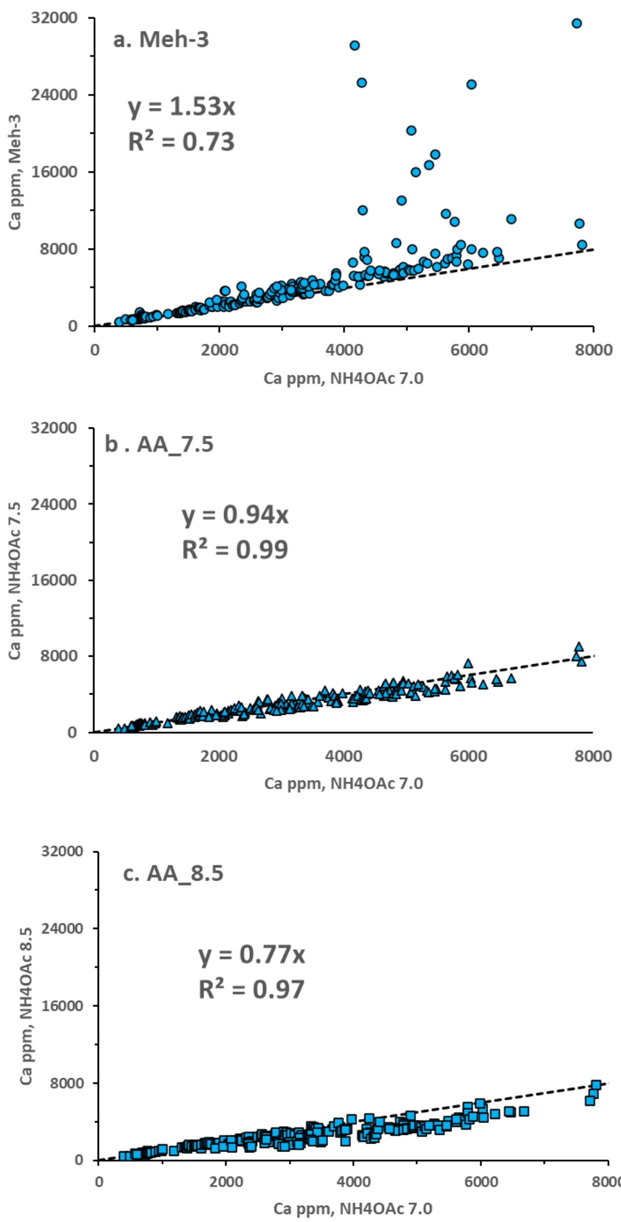

Figure 2. Difference in calcium extracted by soil pH, where: Difference = extractant Ca minus AA-7.0 Ca

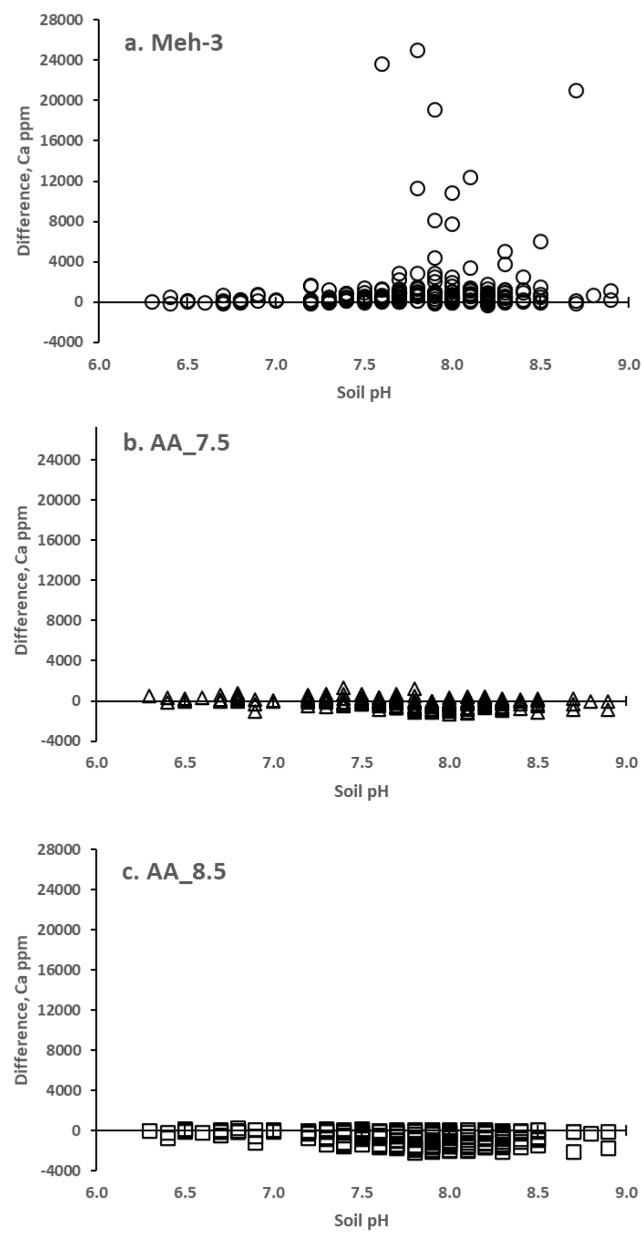

Figure 1. CEC using Mehlich-3 cations, unadjusted Ca vs. "capped" Ca