2020
GREAT PLAINS SOIL FERTILITY CONFERENCE

MARCH 10-11, 2020 • DOUBLE TREE HOTEL, DENVER, CO

PROCEEDINGS OF THE

Volume 18

DENVER, COLORADO MARCH 10-11, 2020

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GREAT PLAINS SOIL FERTILITY CONFERENCE

Speaker Presentations

NITROGEN FERTILIZATION AND LONG-TERM NO TILLAGE IMPACTS ON SOIL PROPERTIES AND DEEP SOIL C STORAGE UNDER IRRIGATION

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ABSTRACT

The net soil greenhouse gas mitigation potential of conservation agricultural management practices is strongly influenced by the direction and magnitude of soil organic C (SOC) change in deep soil layers (>6"). Deep SOC is typically old, highly processed, and consists of microbial products and root exudates associated with clay and other minerals. However, it can be susceptible to decomposition and priming from the addition of new, labile organic C. We examined long-term soil C dynamics (organic and inorganic) 13 years after conversion to no-tillage (NT) under varying nitrogen fertilizer rates (0 or 220 lbs a^{-1}). We present preliminary data from throughout the soil profile (0-4') of δ^{13}C of SOC and SIC, ^{14}C, and organic and inorganic chemical composition by FTIR. Although there was surface (0-3") accumulation of new, corn-derived-C, it was lost from the deeper soils (>3"). Nitrogen fertilizer had little effect on SOC and SIC except in the 0-3" layer. After NT adoption, deep soil C became older, from both □^{13} SOC and ^{14}C data. Soil inorganic C increased at the two deepest depths, which was confirmed by FTIR. The □^{13}SIC suggested disequilibrium of C sources with carbonate minerals after only 13 years. These results indicate that deep soil C (both organic and inorganic) is surprisingly dynamic and susceptible to loss, despite conservation management practices.

INTRODUCTION

The net soil greenhouse gas mitigation potential of conservation agricultural management practices in non-flooded systems is driven by changes in nitrous oxide emissions and soil carbon stocks. In many cases, net fluxes are strongly influenced by the direction and magnitude of soil organic C (SOC) changes in subsurface soil (>6"). Deep SOC is typically old, highly processed, and consists of microbial products and root exudates associated with clay minerals. However, it can be susceptible to decomposition and priming from the addition of new, labile organic C (such as dissolved organic C). After conversion to no-tillage (NT) for 11 years, we previously documented a net loss of 14-19 Mg C ha^{-1}, primarily from soils deeper than 1' (Stewart et al. 2017). However, questions remain regarding the source and turnover of these soil C pools.

Nitrogen fertilizer could either promote SOC stabilization through greater plant productivity or C loss through stimulated microbial mineralization. In irrigated soils with carbonitic lithology, the addition of fertilizer could promote surface carbonate dissolution and reprecipitation in the soil profile. These effects have been observed over 50-100 years in some systems, but have typically involved comparing cultivated to non-disturbed soil profiles (Cihacek & Ulmer 2002).

Here, we examine the impact of long-term no-tillage on soil C dynamics (organic and inorganic) in more detail using $\delta^{13}C$, ^{14}C, and FTIR throughout the soil profile (0-4') 13 years after conversion to conservation NT.

MATERIALS AND METHODS

The study was located on a Fort Collins clay loam soil (fine-loamy, mixed, mesic Aridic Haplustalfs) with a 1 to 2% slope at the Agricultural Research Development and Education Center (ARDEC) (lat. 40° 39'6" N, long. 104° 59'57" W; 1535 m above sea level) near Fort Collins, CO. The study was initiated in 1999 and described in detail in Stewart et al. (2017) on a field that had previously been cropped under conventional tillage (CT) continuous corn for 6 yr. (moldboard plow, 6" depth). The study was a randomized complete block design under no-tillage (NT) continuous corn with five N rates and three field replicates with 10.7 by 15.2 m plots.

We report data for two N rate treatments 0, 220 lb a^{-1} from 2001 to 2014. N source was urea ammonium nitrate (UAN, 32–0–0) from 2001 through 2005 applied preplant in subsurface bands (2") with a liquid fertilizer applicator. In 2006, surface band (split applications) of a polymer-coated urea (ESN) was applied at corn emergence in May and dry granular urea N fertilizer was applied in mid-June. From 2007 to 2014, surface band applications of a polymer-coated urea near the corn row at emergence in May were used. Triple superphosphate (0–46–0) was applied in 1999 (56 kg P ha^{-1}), 2004 (28 kg P ha^{-1}), 2005 (53 kg P ha^{-1}), 2009 (20 kg P ha^{-1}), and 2010 (56 kg P ha^{-1}) to avoid P deficiency in corn.

Soil samples were collected in 2001, and 2014 using a GPS to relocate the sampling sites. One soil core (2" diameter) within each plot was collected in the fall after harvest, and separated into increments of 0-3", 3-6", 6"-1', 1'-2', 2'-3', 3'-4'. After 2mm sieving and large root removal, soils were air dried and finely ground for analysis. Soil total C, SOC and N concentration and $\delta^{13}C$ were analyzed with dry combustion mass spectrometry using methods described in Stewart et al (2019). Carbonates were removed before mass spec analysis using an 8 hr. acid fumigation in concentrated HCl vacuum atmosphere (Stewart et al., 2019). All analyses are expressed as oven dry weight (55°C).

The ^{14}C analyses were completed after carbonate removal. Samples were graphitized in the Carbon, Water and Soils Lab, USDA-Forest Service Northern Research Station Radiocarbon measurements were conducted at the Keck Carbon Cycle AMS Facility, Earth System Science Dept., UC Irvine.

The soil FTIR spectra of the dried and ground samples were obtained in diffuse reflectance mode with a Digilab FTS 7000 Fourier Transform spectrometer (Varian, Inc., Palo Alto, CA,) with a Pike AutoDIFF auto-sampler (Pike Technologies, Madison, WI). Resolution was 4 cm^{-1}, Spectral range was 10,000 - 4000 cm^{-1} for the NIR and 4000 - 400 cm^{-1} for the MidIR with 64 co-added scans per spectrum.

RESULTS AND DISCUSSION

Deep soil C is surprisingly dynamic in these semi-arid irrigated NT corn soils and susceptible to both redistribution and loss, despite conservation practices (Figure 1). Soil OC accrual was observed only in the surface horizon under the two N treatments, with the majority profile SOC loss below 6” (Figure 1a). Surface C accrual with deep soil C losses has recently been observed under conservation practices such as NT (Watts et al., 2020) and irrigated cover crops treatments (Tautges et al., 2019), suggesting that soil processes deep in the profile are more important than previously thought.

After only 13 years, there is also evidence of carbonate dissolution and redistribution through the soil profile, although this comprised a relatively small proportion of total SIC stocks (~kg C ha^{-1}). Carbonate was lost from the 1’-2’ depth and redistributed to the 2’-3’ and 3’-4’ depths (Figure 1b) with no effect of N fertilizer. Carbonate redistribution under agricultural management had been observed elsewhere and can comprise and significant proportion of total soil C stocks in irrigated semi-arid systems (Denef et al., 2008).

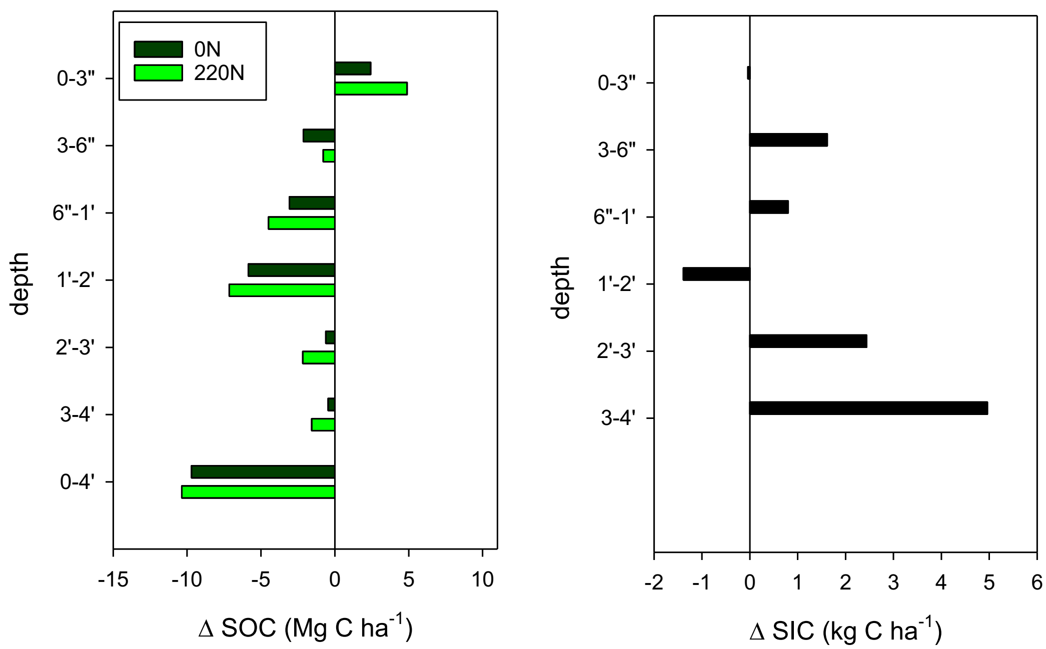

Figure 1. Change in (a) soil organic C (SOC) stock (Mg C ha^{-1}) by N rate (0 and 220 lbs a^{-1}) and (b) soil inorganic C (SIC) (kg C ha^{-1}) stocks (averaged over N rate) from 2001 to 2014 for the two N rates under irrigated no-tilled continuous corn.

depth	2001	2014	2001	2014
	^{14}C age (years BP)		$\delta^{13}C$	
0-3"	310	300	-18.18	-16.43
3-6"	385	825	-19.62	-18.33
6-12"	650	895	-19.74	-19.43
1-2'	3575	3930	-17.90	-18.86
2-3'	5930	4990	-18.24	-20.68
3-4'	9275	11600	-17.00	-23.72

Table 1. The ^{14}C age (years BP) and SOC $\delta^{13}C$ for the 220 lbs a^{-1} rate through the soil profile in 2001 and 2014.

After the adoption of NT, surface accumulation of new, corn-derived-C was evident by the less negative $\delta^{13}C$ and the loss of corn-derived C in the remaining 1-4’ depths (Table 1). The ^{14}C data indicate a substantial shift from the 2001 baseline to older C and confirm the $\delta^{13}SOC$ results.

SOC age and $\delta^{13}C$ are known to increase with depth, but these relatively rapid changes are somewhat perplexing. Further research will be required to tease apart possible mechanisms but could include SOC decomposition at deeper depths (priming) from increased dissolved C or N flow. The addition of fresh C to deep soil horizons can result in a substantial loss of previously stable SOC (Fontaine et al., 2007). Increased surface SOC and a decreased SOC content at depth was also observed under irrigation with high-C waste-water (Jueschke et al., 2008). Another mechanism could be decreased C input from the upper soil layers (from lack of tillage). Residue C is placed deeper in the soil with conventional tillage (Angers and Eriksen-Hamel, 2008) and increases C inputs below the surface (Gregorich et al., 2009) where decomposition rates are slower compared to the surface (Leichty et al., 2018). A third possibility could be decreased root growth at depth under NT may also decrease corn-derived C inputs (Qin et al., 2005). Further studies will be required to look at these mechanisms of potential C loss.

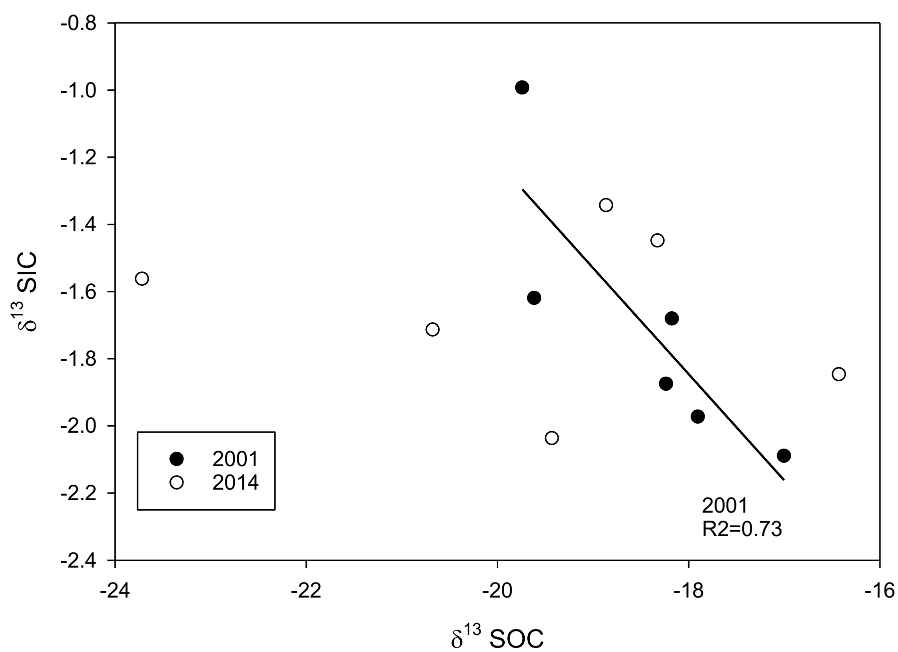

Figure 2. SIC $\delta^{13}C$ as a function of SOC $\delta^{13}C$ for the 232N rate through the soil profile in 2001 and 2014.

Inorganic C is a function of soil CO_2, which could have plant, soil, or lithological C sources. In 2001, the SIC $\delta^{13}C$ is closely related to SOC $\delta^{13}C$, suggesting carbonate formation was in equilibrium with soil organic matter at each depth (Figure 2). However, in 2014, the lack of correlation suggests that the system is at disequilibrium and that other sources of CO_2 are the primary source for reprecipitated carbonate.

Agricultural management induced changes in water and pH levels have been found to increase inorganic C storage in cultivated versus native systems. This effect may depend on management and plant-mediated changes in water storage. Crop fallow treatments commonly practiced in this region store water and potentially move SIC down the profile along the wetting front (Cihacek & Ulmer 2002).

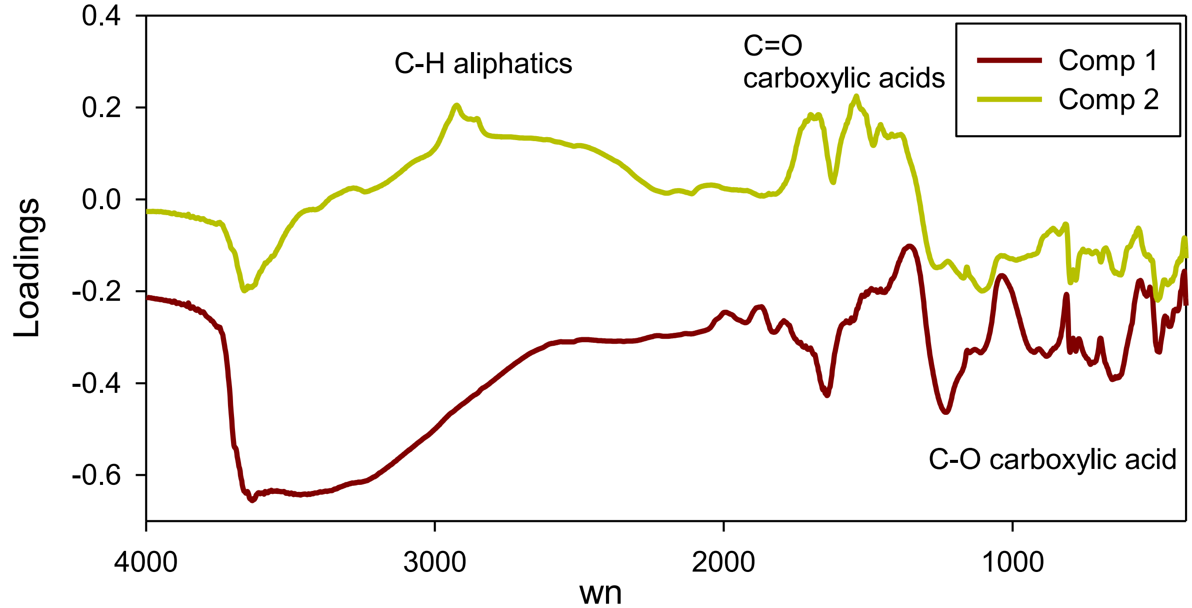

Figure 3. FTIR showed accumulation of new, corn-derived-C (aliphatics & double bonded carboxylic acids) in 2014 compared to 2001 (component 2), with the loss of single-bond carboxylic acids. Sampling times are resolved along component 2, with the 2014 samples having higher scores than the 2001.

FTIR spectra confirm surface accretion of plant-derived waxes (aliphatics) and lignin phenols (carboxylic acids) with the conversion from CT to NT (Figure 3). However, fewer effects in chemical composition were observed deeper in the soil profile. This suggests that the change in soil C stocks at depth was not a function of a change in SOC chemistry. Deep soil C is highly microbially processed with a low C:N ratio. Changes in hydrology with NT may have changed the amount of C delivered and C cycling, not chemistry. Soil inorganic C increased slightly at the two deepest depths between 2001 and 2014, which was confirmed by the FTIR (data not shown).

Together these preliminary data suggest that NT management can affect both organic and inorganic C in a relatively short period of time and that the effects of N fertilizer were modest when the entire soil profile was considered. No tillage maintains surface residue cover, which can directly and indirectly alter soil hydrology. In addition, SOC increases soil aggregation, maintains root channels and promotes soil faunal activity. Wet/dry cycles promote the turnover of aggregates and the release of dissolved organic C and N. This change in hydrology and C source could change both organic and inorganic C stocks and signatures. Irrigation could deliver water high in dissolved organic C and N deeper in the soil profile, stimulating microbial decomposition and loss of previously stabilized SOC stocks.

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TILLAGE AND NITROGEN MANAGEMENT FOR IRRIGATED SUGAR BEET PRODUCTION IN EASTERN MONTANA

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ABSTRACT

Sugar beet (*Beta vulgaris* L.) is an important cash crop in the Lower Yellowstone River region. Nitrogen management is very critical while farmers are transitioning sugar beet production from conventional tillage to no-till system. The objectives of this study were to: (i) evaluate the effects of fertilizer-N rate and application timing on sugar beet root yield, sugar content, and quality under conventional and no-till managements, (ii) determine N uptake and N use efficiency (NUE) as influenced by fertilizer-N and tillage management, and (iii) evaluate if foliar application of Mg and Zn improves root yield, sugar content, and sugar quality. A field study was initiated in the fall of 2018 on a clay loam soil at the Eastern Agricultural Research center, near Sidney, Montana in a rotation with spring wheat (*Triticum aestivum* L.). Nitrogen management included fertilizer-N applied in the fall of 2018 and in the spring of 2019 at the rate of 120, 160, and 200 lb N ac^{-1} prior to sugar beet planting. A single rate of Mg and Zn was foliar-sprayed with each tillage and N management to evaluate if these two nutrients improve root yield and sugar content. Soil NO_3-N increased with the increase of fertilizer-N rates in the 12 inch deep profile. Although not statistically significant, there was evidence of NO_3-N loss during winter when fertilizer-N was applied in the fall. Sugar beet root yield was greater under no-till management and was not affected by fertilizer N rates. Higher sugar content and quality was achieved at lower fertilizer-N rates. Foliar application of Mg, when applied with a higher rate of fertilizer-N, increased root yield without affecting sugar content and quality. Plant N uptake and NUE were not affected by tillage managements but N uptake increased with the increase of fertilizer-N rates. Higher NUE was achieved with lower rate of fertilizer-N application. After one year of observation, data indicated that no-till management can be a promising cultural management in the eastern Montana and the western North Dakota area. The study will be continued in the 2020 growing season to support the data we have collected in 2019 to make robust conclusions in decision making.

INTRODUCTION

In modern agriculture, the most important challenge is to maximize the crop production with minimum farm inputs. Sugar beet is an important cash crop for eastern Montana and western North Dakota. In Montana, sugar beet harvested from 42,700 acres with a production value of more than $57.7M in 2017 (NASS, 2019). Sugar beet growers get paid by tonnage and sucrose concentration in the root. Therefore, it is important to increase sugar concentration in addition to root yield.

Nitrogen management is very critical for sustainable sugar beet production. Adequate N is needed for optimum growth and root development. Farmers tend to apply fertilizer-N based on yield goal and greater economic return which often lead to over application of fertilizer-N. Excessive uptake of NO_3-N from soil can stimulate excessive canopy growth but reduce sugar content in the roots (Afshar et al., 2019). Higher rate of N is also associated with higher concentration of ammonium-N including Na and K in the brei, which in turns reduce the overall extractable sugar.

All N sources are very mobile in the soil, and N in excess of crop need may lose to ground and surface water through leaching. The amount of N lost is an increasing concern for the environment and human health. Therefore, it is needed to minimize N loss and improve NUE for a sustainable agricultural production system. The most efficient way to improve nitrogen use efficiency and minimize N leaching is to determine the best N application timing with appropriate rates.

Fall fertilizer-N application can benefit farmers in many ways including extended time of fertilizer application, lower input cost, and better soil conditions for farm equipment operations. Soil temperatures are usually below 50 degrees F in late October and early November. The cool soil temperature in fall helps delay nitrification to applied ammonium-based N fertilizer (Havlin et al., 1999). Under low cool temperature, applied N fertilizer is still in the NH_4^+ form which is not subject to leaching or denitrification. In contrast, Time is usually limited in the spring for field work especially in cooler temperature in the eastern Montana.

Most sugar beet fields in Montana are in conventional tillage management. No-till farming offers a range of benefits including improving soil health, help soil nutrient balance, and suppress weed and disease pressure. With less farm operations and off-farm input net profits can be maximized. Some sugar beet producers in eastern Montana has switched to no-till system, however, facing a number of challenges. One of the challenges is the adoption of efficient N management strategies. Not enough work has been done and there are limited data available on how no-till and N managements interact with each other and affect sugar beet production.

This research is intended to address the challenges in N and tillage managements for sugar beet production and will identify the best management practices to maximize farm profit and promote environmental sustainability. The objectives of this study were to: (i) evaluate the effects of N rate and application timing on sugar beet root yield, sugar content, and sugar quality under conventional and no-till managements, (ii) determine N uptake, and N use efficiency as influenced by N and tillage managements, and (iii) evaluate if foliar application of Mg and Zn improves root yield, sugar content, and sugar quality. The soils in eastern Montana are predominantly high in Mg, however, conditions such as cooler temperature, application of ammonia-based N fertilizers, and higher concentration of competing cations (K^+ and Ca^{+2}) may lead to a response to supplemental Mg application in sugar beet (Hermans et al., 2005).

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

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

MATERIALS AND METHODS

The experiment was performed in 2019 under sprinkler irrigation system near Sidney, MT. The soil at this site is a deep, well drained, nearly level savage clay loam (fine, smectitic, frigid Vertic Argiustolls) containing 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 determine the soil fertility status and are given in Table 1. The site had 10.4 inch of precipitation from April to August and was irrigated with 9.81 inch of water from planting to harvesting. Mean monthly air temperature ranged from 44 degrees F in April to 67 degrees F in August. Sugar beet trials has been in a rotation with spring wheat.

Table 2: Significance of the main effects of tillage management (Till), N application timing (Time), fertilizer treatments (Tmt) and their interactions of the ANOVA for soil NO_3-N, root yield, sugar content and quality, nutrient uptake, and nitrogen use efficiency in 2019 at the Eastern Agricultural Research Center near Sidney, MT.

Parameter	Till	Time	Tmt	Till×Time	Till×Tmt	Tmt×Time	Till×Time×Tmt
	----------	----------	----------	---------- *P* > F ----------	----------	----------	----------
Soil NO_3-N†	<0.01	0.22	<0.01	0.19	0.01	0.09	0.32
Stand count	<0.01	0.68	0.32	0.55	<0.01	0.46	0.25
Root yield	<0.01	0.84	0.02	0.09	0.83	0.49	0.93
Sugar content	0.47	0.79	<0.01	0.01	0.80	0.97	0.33
Sugar yield	<0.01	0.85	0.16	0.47	0.83	0.60	0.84
Sodium conc.	0.20	0.68	0.03	0.33	0.33	0.23	0.85
Potassium conc.	0.34	0.15	<0.01	0.22	0.68	0.67	0.94
Amino-N conc.	0.14	0.06	<0.01	0.44	0.36	0.70	0.29
Impurity value	0.49	0.18	<0.01	0.39	0.84	0.48	0.98
Sucrose loss	0.49	0.18	<0.01	0.39	0.84	0.48	0.98
Ext. sugar	<0.01	0.90	0.21	0.53	0.84	0.59	0.84
Ext. sugar yield	<0.01	0.89	0.21	0.53	0.84	0.59	0.84
N uptake	0.38	0.09	<0.01	0.65	0.57	0.64	0.95
Mg uptake	0.14	0.06	<0.01	0.77	0.58	0.74	0.67
Zn uptake	0.56	0.07	0.35	0.92	0.60	0.99	0.69
NUE	0.08	0.08	<0.01	0.14	0.90	0.02	0.70

† Composite soil samples were collected from 12″ depth.

The experiment was set up in a split-split-plot randomized complete block design with four replications. Conventional tillage and no-till managements were the main plots. Sub-plots were two fertilizer-N application timings. Fertilizer-N was applied in October 2018 for fall application and applied in April 2019 for spring application. Sub-sub plots consisted of three N rates (120, 160, and 200 lb N/ac) and foliar application of Mg and Zn. Each plot was 24 ft wide and 30 ft in length with 5 ft alley ways between plots. The row spacing was 24 inch which means each plot had 12 rows of sugar beets. All 12 rows received fertilizer-N treatments. To avoid excessive application of fertilizer-N, the rates of N were adjusted with the residual soil NO_3-N to a depth of 60 cm measured in the fall of the previous year. Fertilizer-P was applied based on the Montana State University recommended guidelines as initial results indicated low P in the soil. Soil test K was within the sufficiency range and therefore, fertilizer-K was not applied. Soil test Mg was considered to be above the sufficiency range for many agronomic crops. Zinc was not deficient but close to the borderline to be considered deficient for other crops. All soil applied fertilizers were broadcast.

Three separate rows were used for single rate of Mg (1.0 lb Mg/ac) and Zn (0.8 lb Zn/ac) application. Chelated EDTA-Mg and EDTA-Zn liquid fertilizers were used as sources of Mg and Zn and were sprayed with a CO_2 backpack sprayer when the plants were at least 8-10 leaf stage.

Glyphosate was applied at the rate of 24 oz/ac three times for weed control including a preplant application. Inspire XT was aerial sprayed at the rate of 8.5 oz/ac in August to control *cercospora* leaf spot disease.

Sugar beet variety Crystal S696 GEM 100 was planted on April 24th with a no-till drill. Measurements were taken throughout the growing season and at the final harvest to determine soil NO_3-N, crop stand, root yield, sugar content and quality, nutrient uptake, and nutrient use efficiency. A composite soil sample of at least three cores were collected from each plot from 12 inch depth to measure available NO_3-N before planting sugar beet. Sub-samples of roots and shoots were dried in the oven, ground, and analyzed for nutrient concentrations. Sugar content and analysis of impurities were conducted using standard laboratory procedures. Nitrogen removed by the roots was used to calculate NUE. Final sugar beet was harvested on September 24th.

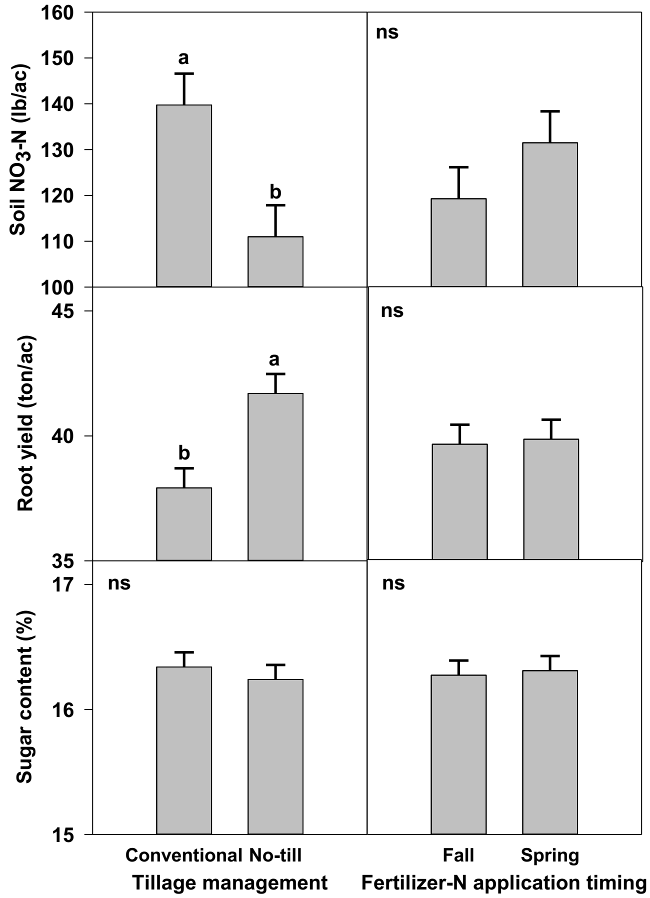

Fig. 1: Soil NO_3-N concentration at 12 inch depth and sugar beet root yield and sugar content as influenced by tillage and fertilizer-N application timing. Error bars are standard errors of the mean. Means with the same letters are not significantly different at $P \leq 0.05$.

All data were analyzed using GLIMMIX procedure of SAS 9.4 software.

RESULTS AND DISCUSSION

A summary of the significance of the main effects of tillage managements, N application timings, fertilizer treatments, and their interactions for the ANOVA for the measured parameters are presented in Table 2.

Soil NO_3-N concentration was affected by both tillage managements and fertilizer-N rates but was not affected by whether N was applied in the fall or in the spring (Fig. 1). Conventional tillage had higher soil NO_3-N on the top 12 inch compared to no-till but in both tillage managements, application of higher rates of fertilizer-N increased soil NO_3-N. The exception was that under conventional tillage management, soil NO_3-N was similar when fertilized with 200 and 160 lb N/ac and greater compared when fertilized with 120 lb N/ac. In contrast, under no-tillage management, soil NO_3-N was greater when fertilized with 200 lb N/ac compared to when fertilized with 160 and 120 lb N/ac. Although not statistically significant, across tillage and fertilizer-N rates, at least 12 lb N/ac was lost when N was applied in the fall compared to N applied in spring.

Both conventional tillage and no-till sites had good sugar beet stand. Compared to no-till, conventional tillage had higher plant density (40888 plants/ac) indicating higher seed germination rate, but the plant density in the no-till (34082 plants/ac) was considered to be normal.

Sugar beet had about 4.0 ton/ac higher root yield under no-till management compared to conventional tillage (Fig. 1). Fertilizer-N application timing and rate had no effect on root yield, however, when Mg was applied with higher rates of N, root yield increased, indicating Mg may have effects on root yield only when N was applied at higher rates (Fig 2a). Magnesium deficiency induced by other cations has been reported in the literature for many crops. This induced Mg deficiency is caused due to reduced Mg uptake by plants in the presence of high rate of K^+, NH_4^+, Ca^{+2}, and Mn^{+2} ions in the soil (Marschner, 2002). Ammonia-based fertilizer urea for N was applied in this study. Fertilizer-N might still be in the NH_4^+ form in the cool spring when sugar beet was planted which is conducive to the weather condition in eastern Montana. There was no evidence of root yield increase by the application of Zn.

Sugar concentration was slightly higher when fertilizer-N was applied in the spring under conventional tillage management (data not shown). Across tillage managements, concentration of sugar decreased with the increase of N rates (Fig. 2b). Application of Mg and Zn did not improve sugar concentration in the root. Because root yield was higher under no-till system and the concentration of sugar did not differ between the two tillage managements, sucrose yield was higher under no-till than conventional tillage management.

Sugar impurities such as concentration of Na, K, and amino-N in the root extract generally increased as nitrogen rate increased. The difference between N application timings on the root amino-N was very close to the significant level (P = 0.06) where concentration of

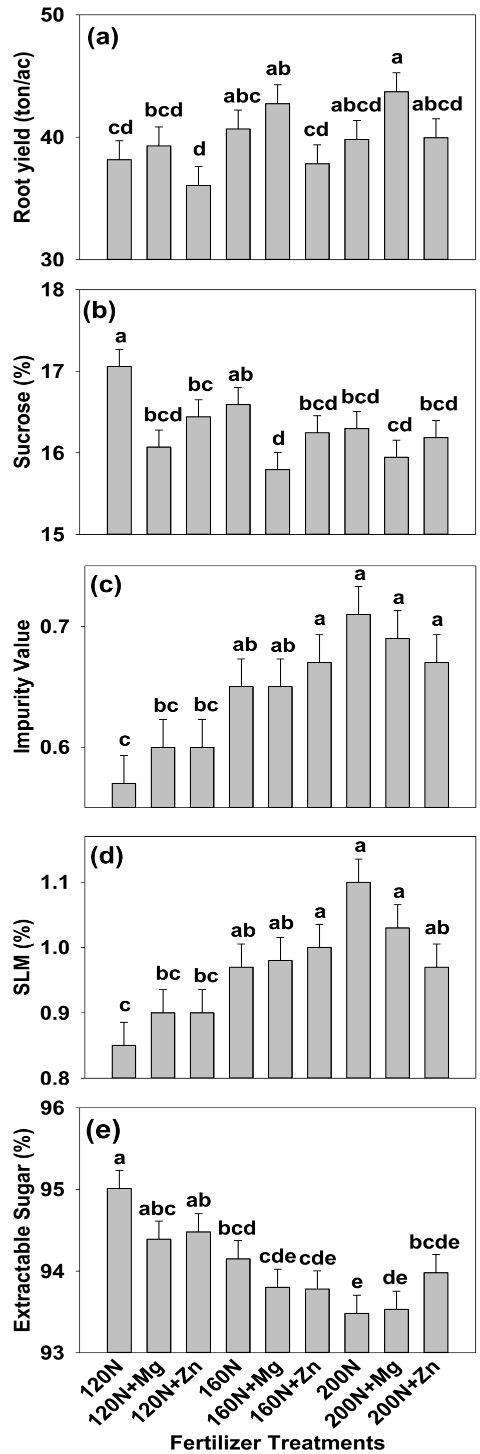

Fig. 2: Sugar beet root yield (a), sugar content (b), impurity value (c), sucrose loss to molasses (d), and percent extractable sugar as influenced by fertilizer application. Error bars are standard errors of the mean. Means with the same letters are not significantly different at $P < 0.05$.

amino-N increased when fertilizer-N was applied in the spring (data not shown). This was because soil NO_3-N was higher when fertilizer-N was applied in the spring. Likewise, impurity value and sucrose loss to molasses (SLM) were also increased with the increase of N rates (Fig. 2c and 2d). These results indicated that higher concentration of soil NO^3-N will likely to reduce sugar extractability. Extractable sugar in the brei was 95.0% with the lowest N rate and decreased to 93.5% when N was applied at the rate of 200 lb N/ac (Fig. 2e). The decrease in percent extractable sugar fertilizer-N rates was too small that fertilizer-N rates did not affect extractable sugar yield (data not shown). Greater extractable sugar yield was obtained under no-till management due to higher root yield compared to conventional tillage management. There was no evidence that sugar impurities was affected by the application of Mg and Zn.

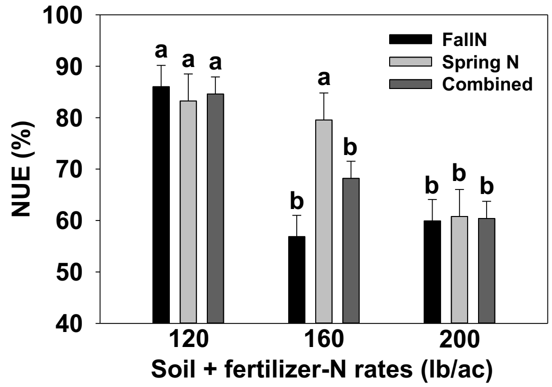

Fig. 3: Nitrogen use efficiency as affected by the interaction of fertilizer-N application timing and rates. Error bars are standard errors of the mean. Means with the same letters are not significantly different at $P \leq 0.05$.

Nitrogen uptake was similar between all N rates but increased with the application of Mg and Zn when N was applied at the rate of 200 lb N/ac. Uptake of Mg increased due to increase in root yield and root and shoot Mg concentration when Mg was applied with high rates of N. Although tissue Zn was increased by the application of foliar Zn, however, uptake of Zn was not affected by any of the main effects and their interactions likely due to increase of tissue Zn concentration was too small to make statistically significant difference.

Nitrogen use efficiency (NUE) was similar under both tillage managements. Greater NUE was obtained with the lowest rate of N (120 lb N/ac) when applied in the fall (Fig. 3). In contrast, when fertilizer-N was applied in the spring, NUE was similar between 120 and 160 lb N/ac which was greater compared to when 200 lb N/ac was applied. This means higher NUE can be achieved with higher rate of fertilizer-N when applied in the spring.

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FALL AND SPRING SOIL RESIDUAL NITRATE-N AS AFFECTED BY IRRIGATION AND NITROGEN MANAGEMENT

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ABSTRACT

Nitrogen credit from residual nitrate-N from soil samples collected in spring is widely considered and accounted for in managing N in crop production. That is important from both economic and environmental perspectives. However, there is no incentives for farmers to determine post-harvest soil residual nitrate-N in fall. It is important to note that any difference in fall and spring soil residual nitrate-N would suggest environmental N losses via denitrification or leaching in that fallow period. Therefore, as much as it is important to measure and account for spring soil residual nitrate-N to optimize N management, it is equally important to measure fall soil residual nitrate-N to assess how effective N management was that crop year and if needed, other management practices such as cover crop can be identified to address N losses. The field trial was conducted in 2018 to determine soil residual nitrate-N in fall following maize harvest under varying N and irrigation management and in spring of 2019 in the same plots. The experimental design was split-plot randomized complete block with three replications. The main plot factor was irrigation at four levels (0, 50, 100, and 133% of full irrigation). Sub-plot factor was N treatment that included N1- N5 (0, 50, 75, 100, and 125 % of recommended N rate based on spring soil test) applied around emergence, N6 (30% of recommended N rate at emergence, and 70% at V8), N7 (all of recommended N at V8), N8 (30% of recommended N rate at emergence, and supplemental N based on crop sensing at V8), and N9 (30% of recommended N rate at emergence, and supplemental N based on crop sensing at V12). Soil samples at depths 0-8, 8-24, and 24-48 inches were collected after harvest and also in the following spring to determine residual nitrate-N in all treatment plots. This paper will discuss effects of N and irrigation management on soil residual nitrate-N and an important role weather plays in that soil N dynamics.

ASSESSMENT OF LONG-TERM EFFECTS OF TILLAGE AND NITROGEN MANAGEMENT PRACTICES ON IRRIGATED CORN YIELDS AND NITROGEN USE EFFICIENCIES

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ABSTRACT

Corn grain yields and crop nitrogen uptake are affected by management factors such as tillage intensity and nitrogen rates. Additional data about the long-term effects of tillage and nitrogen rates on yields and nitrogen use efficiencies of irrigated corn are needed. We are presenting preliminary results from a 17-year study about the effects of these management practices on irrigated corn yields and nitrogen uptake in a Fort Collins clay loam soil at Colorado State University's Agricultural Research, Development and Education Center (ARDEC) near Fort Collins, Colorado. We monitored the effects of different nitrogen rates on irrigated corn under no-till (NT), conventional tillage (CT) and strip-tillage (ST). Corn grain, cob, stalk and total aboveground biomass were measured at about 146 days after planting (DAP), harvest grain yields were measured at about 173 DAP, and nitrogen content was measured for all crop components. The effects of nitrogen rates on NT, ST and CT systems were fit with a linear-plus-plateau model, which is defined by a classic switching regression type of function. This long-term research suggests that ST and NT are recovering about 75% of the nitrogen fertilizer that is being applied to the system and that any nitrogen that is applied over a rate of 165 kg N/ha will be lost. However, the nitrogen losses could potentially be higher as the recovery of the nitrogen with the harvested grain component is much lower (close to 50%). Details of preliminary results on how tillage intensity has affected yields, nitrogen dynamics, and recovery use efficiencies will be presented.

INTRODUCTION

Corn is one of the most fertilized crops in the USA and there remains a need to continue improving nitrogen management practices to increase nitrogen use efficiencies (Ribaudo et al., 2011). The Northern Plains region ranks second-highest out of ten U.S. regions in total farmland area receiving nitrogen fertilizer applications, and third-highest in tonnage applying excess nitrogen fertilizer application (Ribaudo et al., 2011). Nehring and Mosheim (2019) reported that in farms in the United States, the nitrogen recovery efficiency for corn increased from 73% in 1996 to 81% in 2010. They assessed the corn nitrogen recovery efficiency as the ratio of the amount of nitrogen in the harvested crop to the amount of nitrogen applied. Several publications have reported on how nutrient losses from farm areas are impacting air and water quality and having potential negative impacts on human health (International Joint Commission, 2013; Monchamp et al., 2014; Smith et al., 2018; Temkin et al., 2019). Although crop nitrogen use efficiencies have been reported to be increasing, there remains a need to assess how management factors such as tillage and nitrogen rates impact nitrogen use efficiencies, and in particular there is a need to conduct long-term studies that can be used to conduct nitrogen budgets. Managing tillage and nitrogen application rates is a key strategy that can impact nitrogen use efficiencies and yield responses from corn. Long-term studies in drier areas of the Northern Plains have been conducted to assess nitrogen use efficiencies and budgets (Sindelar et al., 2016). Additional long-term studies that monitor the effects of tillage systems on irrigated corn yields, nitrogen uptake and nitrogen use efficiencies are needed. Our goal is to present preliminary results from our analysis of this long-term tillage study (2001 to 2017) that we have been conducting.

MATERIALS AND METHODS

Site and Experimental Design

The field study was conducted at Colorado State University's Agricultural Research, Development and Education Center (ARDEC) near Fort Collins, Colorado. A field that was cultivated in corn for seven years prior to 2000 was used. In 2000, part of the field was converted to no-till and monitoring of the no-till and cultivated area began. In 2006, the no-till plots were split into east and west plots, and strip till was added and monitored until 2012, when it was converted back to no-till. The no-till yields and nitrogen uptake were monitored in the area that has continuously been no-till since the establishment of the study. The cultivated plots were monitored until 2008, and in 2009 the cultivated field was converted to strip till. Data from 2001 to 2017 were used from all tillage systems. The 2008 data were not used because the field had received heavy hail damage and the data were dropped from the study.

Tillage and Cultivation Operations

For the cultivated site (2001-2008): A flail chopper was used to chop up corn stalks to make them easier to incorporate pre-planting, then a disc plow was used to incorporate surface residue prior to moldboard plowing and sometimes again after moldboard plowing to break up soil aggregates. A moldboard plow was used to invert the top 30 cm of soil. A roller harrow was then used to help break up the furrows and large soil aggregates, typically twice. Finally, a land plane was used in multiple passes to level the finely tilled soil surface (2001-2008). In 2003 only, a spring-tooth harrow was used pre-planting to loosen up soil from hard rains prior to leveling. Also in 2003 only, a 3 m rotary hoe was used pre-emergence to break up a hard crusted soil surface and aid crop emergence. In 2004 only, we ripped after plowing to fracture the compaction layer to a depth of 61 cm using a 6-shank parabolic plow. This operation was then followed by the typical rolling and leveling operations. In 2005 only, pre-planting, we used a drag to level the field after fertilizer application had left deep ruts in the tilled seedbed.

For the no-till (2001-2017): The flail chopper was used on corn stalks pre-planting in 2001 only. From 2002-2012, the stalks were left standing and from 2013 to 2017 the corn stalks were roll-chopped post-harvest to increase their contact with the soil to aid in residue decomposition. After a decade of NT in an arid climate the buildup of desiccated residue was beginning to cause planting issues, resulting in less-than-ideal germination and inconsistent crop emergence.

For the strip tillage (2006-2017): From 2012-2017, a stalk roller/chopper was used on corn stalks post-harvest for consistency. From 2006-2017, the plots were strip tilled pre-planting at a tillage depth of 23 cm.

Biomass Harvesting Operations, Nitrogen Analysis and Statistical Analysis

Fifteen corn plants were collected at about 146 days after planting (DAP) to determine corn grain, cob, stalk and total aboveground biomass. Harvested grain yields were determined by harvesting 15 m of row at about 173 DAP. Nitrogen analyses were conducted using a dry combustion method with an Elementar Vario Macro C-N analyzer (Elementar Americas Inc.). Initially in 2000 the nitrogen rates ranged from 0 to 202 kg N/ha, but due to minimal grain yields in 2000 (Halvorson et al., 2006), the rates were reduced to a range from 0 to 168 kg N/ha in 2001, and increased again to a range from 0 to 202 kg N/ha in 2002 (Halvorson et al., 2006). The nitrogen fertilizer rates were increased to a range from 0 to 224 kg N/ha in 2003. The rates were increased again in 2005 to a range from 0 to 246 kg N/ha and maintained at that range.

Additional information about the experimental study can be found in Halvorson et al. (2006) and Stewart et al. (2017). The effects of nitrogen rates on NT, ST and CT systems were studied with a linear-plus-plateau model, which is defined by a classic switching regression type of function. We used R nls to solve the nonlinear fixed-effects regression model and checked results with MATLAB fitnlm for robustness. Additionally, we used the likelihood ratio (LR) test (Greene, 2008) to determine if the estimated parameters were statistically different for the no-tillage, conventional tillage, and strip tillage treatments.

RESULTS AND DISCUSSION

Yields

A detailed discussion of these results will be presented at the conference. In agreement with Halvorson et al. (2006) we found that by converting a cultivated and irrigated continuous corn system into a no-till system, the yields will be reduced. The average yields for no-till from 2001 to 2007 (9.45 Mg/ha) were lower than the yields observed with the cultivated system (9.85 Mg/ha; $P<0.01$). However, the average yields for no-till from 2006 to 2007 (9.41 Mg/ha) were significantly higher than the conventional tillage grain yields (9.27 Mg/ha; $P<0.01$). The higher average corn yields in the cultivated system for 2001 to 2007 were achieved with a significantly lower amount of nitrogen (88.4 kg N/ha) than it took for no-till (160.5 kg N/ha) to achieve its highest yields ($P<.01$). Even when the no-till had higher yields during the 2006 to 2007 years, it also required a higher amount of fertilizer nitrogen (112.4 kg N/ha) to achieve those yields than the fertilizer nitrogen (75.0 kg N/ha; $P<0.01$) for the cultivated yields.

The strip tillage yields during 2006 to 2007 (9.90 Mg/ha) were the highest ($P<0.05$) of all tillage treatments in each of those years. Although strip tillage needed more nitrogen (113.3 kg N/ha) than the conventional tillage (75.0 kg N/ha), the strip tillage and no-till nitrogen fertilizer requirements to achieve their maximum yields were not significantly different. No-till (10.2 Mg/ha) and strip tillage (10.3 Mg/ha) yields from 2006 to 2017 were not significantly different.

Nitrogen

No-till had significantly lower grain N uptake (114.8 kg N/ha) than conventional tillage (130.1 kg N/ha) during the 2001 to 2007 period ($P<0.01$). The lower grain N uptake with the no-till was achieved at a higher nitrogen rate (168.5 kg N/ha; $P<0.05$) than the nitrogen rate required to achieve the maximum grain N uptake with the conventional tillage (149.5 kg N/ha). Although during the 2006 to 2007 period no-till still had significantly lower grain nitrogen uptake (97.9 kg N/ha) than the nitrogen uptake with the conventional tillage (125.1 kg N/ha; $P<0.01$), there were no significant differences between the nitrogen fertilizer rate of the no-till (100.8 kg N/ha) and the nitrogen fertilizer rate of the conventional tillage (114.2 kg N/ha) needed to achieve the maximum nitrogen uptake in the corn grain, suggesting that more nitrogen is cycling through the system after a few years of the no-till system. No-till also had significantly lower grain N uptake (120.8 kg N/ha) than strip tillage (129.9 kg N/ha; P<0.10) during 2006 to 2017, but the rates of N fertilizer where the maximum grain N uptake was obtained for no-till (155.2 kg N/ha) and strip till (158.7 kg N/ha) were not significantly different.

Preliminary Summary

These long-term research results suggest that even with NT there are significant losses of N to the environment. The data suggest tilled systems lose a greater fraction of applied N than do no-till systems for continuous corn. We are currently working on several N balance assessments and papers to verify this current hypothesis. The results from 2006 to 2017 suggest that NT and ST both recover over 100% (195.0 kg N/ha) of the total N fertilizer applied if we just consider the total aboveground N uptake versus the N fertilizer applied. However, since the non-fertilized control plots assess the background N sources and they averaged a total uptake of 77.6 kg N/ha, then the fertilizer N uptake for NT and ST is estimated to be about 117.4 kg N/ha (195.0 – 77.6 kg N/ha). This suggests that we are losing at least about 47.3 kg N/ha of the applied N fertilizer (NUE of 71.3%). It also supports the conclusion that any N fertilizer applied over 165.0 kg N/ha will be lost. The losses from the system could be much higher since a significant amount of the N uptake is also returned to the soil with the crop residue. The percentage of recovery of the N fertilizer with the grain component is lower (125.3 kg N/ha – 47.8 kg N/ha = 77.5 kg N/ha removed/157.0 kg N/ha = NUE of 49.4%). A detailed analysis will be presented.

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SOIL QUALITY AND NITROGEN AVAILABILITY AFTER EIGHT YEARS OF A MIXED COVER CROP - WHEAT ROTATION

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ABSTRACT

Despite a large interest in cover crops in the northern Great Plains, little is known about their effect on both the following wheat crop and soil quality. In 2012, a cover crop study was started in Montana to compare wheat production and soil quality after growing cover crop mixes containing 2-, 6-, or 8-species, with both summer fallow and a sole pea cover crop control, in a 2-yr rotation with wheat. The 2-species mixes represented functional groups (legumes, brassicas, tap rooted, or fibrous rooted species), the 8-species mix consisted of all four functional groups, and the 6-species mixes had all but one functional group ("minus" treatments). In odd years, the wheat crop was fertilized with either 0, 60 or 120 lb N/acre. In April 2019, after growing cover crops for four seasons as a partial fallow replacement, and wheat for three years, the upper four inches of soil at two locations (Amsterdam and Conrad) were sampled for potentially mineralizable nitrogen (PMN), microbial biomass (MB), soil organic carbon (SOC), and soil total nitrogen (STN), and the upper 3 ft for soil nitrate. In general, soil quality parameters were higher in cover crop treatments than after fallow ($P<0.10$), yet relatively few differences were detected among the cover crop treatments, and surprisingly, no soil quality differences were detected among N rates. Notably, MB, PMN, SOC, and STN were not different between sole pea and the full mix, yet soil in both treatments had higher SOC and STN than summer fallow. In 2019, in the 60 lb N/ac treatment at Amsterdam, wheat yield after the full 8-species mix was higher ($P<0.10$) than after the minus brassica, minus fibrous, and legume treatments, and lower than after the minus tap treatment. At Conrad, wheat yield after the full mix in the 60 lb N/ac treatment was not different than any other treatment, likely due to water limitation. Grain protein was generally higher at both sites in legume treatments. This study demonstrates the power of long term studies to determine whether there are soil quality, wheat yield, and wheat protein differences among cover crop treatments.

INTRODUCTION

Cover crops have become increasingly popular in the U.S. and Canada over the past twenty years, with soil quality often cited as a reason for growing them. In humid climates, high cover crop biomass production coupled with somewhat rare soil water limitations, often lead to improved soil quality and similar subsequent grain yields as controls (McDaniel et al. 2014; Olson et al. 2014; Yost et al. 2016). In the semi-arid northern Great Plains, lower residue returns, and frequent severe water limitation, have often produced relatively modest or no soil quality benefits from pea cover crops (O'Dea et al. 2013) with generally lower profit than recropping or wheat-fallow (Miller et al. 2015a; Miller et al. 2015b). Much of this work has been done with single species pulse cover crops, namely pea or lentil. To determine if multi-species cover crop mixes (CCM) can increase soil quality compared to a sole pea cover crop, and whether certain "functional groups" improve specific soil quality properties more than others, we started a mixed species cover crop study in Montana in 2012.

METHODS

This study was begun near Amsterdam and Conrad, MT in 2012 in farm fields with no-till management histories (Table 1). Study sites have four randomized complete blocks with 11 randomly assigned cover crop treatments that included a fallow and sole pea control (Table 2). Cover crop plots were 24 x 50 ft. During the wheat year, blocks were sown at a right angle to the cover crop seeding and nitrogen (N) fertilizer trisected into three rates; 1) none added, 2) 60 lb N/ac, and 3) 120 lb N/ac.

Table 1.

Site	Amsterdam	Conrad
Elevation (ft)	4740	3410
Texture	Silt loam	Clay loam
pH	8.2	6.5
SOM (%)	2.4	2.4
NO_3-N (mg kg^{-1})	6.0	8.5
Olsen P (mg kg^{-1})	13	28
Exch. K (mg kg^{-1})	359	498

The CCM treatments were designed to include four plant functional groups: **legumes**, included for their N fertility inputs; **fibrous rooted** plants, for their potential to add carbon (C) to the soils; **tap rooted** species, for their effects on soil structure and infiltration; and **brassicas**, due to their unique biochemistry and contribution to ground cover. We selected two species for each functional group. The CCM treatments include four single functional-group treatments, one full treatment mix of all eight species, and four treatments which include all but one functional group (minus fibrous root, minus legume, minus tap root, and minus brassica; Table 2). This addition-subtraction approach allows us to potentially identify the positive, negative, or neutral effects of each functional group. Functional groups have remained the same but some species were replaced because a) they were non-competitive under our management scheme - proso millet (*Panicum miliaceum* L.) and camelina (*Camelina sativa* L.); b) posed an unanticipated weed threat - Italian ryegrass (*Lolium multiflorum* Lam.); or c) could not be terminated with glyphosate - common vetch (*Vicia sativa* L.).

Soil Analyses - A final comprehensive suite of biological, chemical, and physical soil assays were based on samples taken prior to wheat seeding in spring 2019 to measure soil changes after four cycles of cover crops. This sample timing affords a 'read' of potential cover crop effects coincident with wheat at the start of its growing season. Soils were collected from the medium N rate of all 11 cover crop treatments, and in all three N rates for fallow, pea, and the full mix.

Soils were analyzed for nitrate-N (colorimetrically) and soil water to 3 ft. The surface four inches were analyzed for potentially mineralizable nitrogen (PMN; 2-week anaerobic incubation); microbial biomass by substrate-induced respiration over a 4-hour period, analyzed with gas chromatography; total carbon and soil total nitrogen (STN) by combustion. Soil organic C was assumed to equal total C in soils with pH < 7.5 and inorganic C was measured on all others (Sherrod method) and subtracted from total C to obtain SOC.

Table 2. Plant species included in 10 cover crop treatments and a chem fallow control.

Treatment	Abbrv	Plant Species
Fallow	SF	Incidental weeds
Pea	Pea	Forage pea
Full Mix	Full	Forage pea (*Pisum sativum* L. cv. Arvika) Black lentil (*Lens culinaris* Medik. cv. Indianhead) Oat (*Avena sativa* L.) Canaryseed (*Phalaris canariensis* L.) Turnip (*Brassica rapa* L.) Safflower (*Carthamus tinctorius* L.) Forage radish (*Raphanus sativus* L. var. *longipinnatus)* Winter canola (*Brassica napus* L.)
Brassicas	Brass	Forage radish, Winter canola
Minus Brassicas	Mbrass	All but canola, radish and turnip
Fibrous Roots	Fibrous	Oat, canaryseed
Minus Fibr Roots	Mfibr	All but oat and canaryseed
Legumes	Leg	Forage pea, black lentil
Minus Legumes	MLeg	All but pea and lentil
Taproot	Tap	Turnip, safflower
Minus Taproots	MTap	All but turnip and safflower

RESULTS AND DISCUSSION

Soil –Microbial biomass was greater for Full and Pea than Fallow at Conrad, and Pea MB was greater than Fallow at Amsterdam, where N for plant growth was more limiting (Fig. 1). Similar to microbial biomass, PMN of Pea and Full was greater than Fallow at Amsterdam, and PMN of Pea was greater than Fallow at Conrad. These biological parameters are generally in agreement with SOC and STN differences (Table 3). These differences indicate that cover crops increased soil organic matter. While the difference in values do not appear great, they represent an approximate average 2,000 lb/ac difference in soil C, and 200 lb/ac difference in soil N, slightly less at Amsterdam, and slightly more at Conrad, in only the top 4 inches. Soil nitrate-N pool to 3 ft. at Amsterdam was higher after Pea, Legume and Fallow treatments than after the Full mix (data not shown), yet did not differ between the Full mix and any other treatment. Surprisingly, N fertility rates used in this study did not affect any soil parameter when analyzed across Fallow, Pea, and Full mix.

Wheat Yield and Protein

Cover crop effects on wheat yield and protein depended strongly on N rate at both sites, averaging 34, 49, and 52 bu/ac across all cover treatments at Amsterdam, and 29, 37, and 33 bu/ac across all cover treatments at Conrad, for the 0, 60, and 120 lb/ac N rates, respectively. Thus, cover crop treatments were compared within each N rate. Legumes increased yield and protein at the 0 N rate at both locations (Table 4) but our interest was in understanding cover crop treatment effects at the N rate where yield was not N-limited based on protein values ~13.2% (Engel et al. 1999). Thus, we focused on the 60 lb/ac N rate. Sole Pea cover increased wheat grain protein by an average of 1.6 and 3.1 %-units at Amsterdam and Conrad, compared with Fallow and Full (Table 5). At Amsterdam, the presence of legume in the cover crop generally increased wheat grain protein. A similar pattern was observed at Conrad. Thus, we may conclude that legumes were the only cover that exerted an effect on wheat grain protein.

Table 3. Soil organic carbon (SOC) and soil total nitrogen (STN) measured Apr 2019 in top 4 inches of soil at Amsterdam and Conrad, MT, after eight years and four cycles of cover cropping.

	Amsterdam		Conrad	
Cover	SOC	STN	SOC	STN
	---------- % ----------		---------- % ----------	
Full Mix	1.39 a	0.132 a	1.19 a	0.121 a
Pea	1.35 a	0.133 a	1.22 a	0.127 a
Fallow	1.25 b	0.119 b	1.05 b	0.108 b

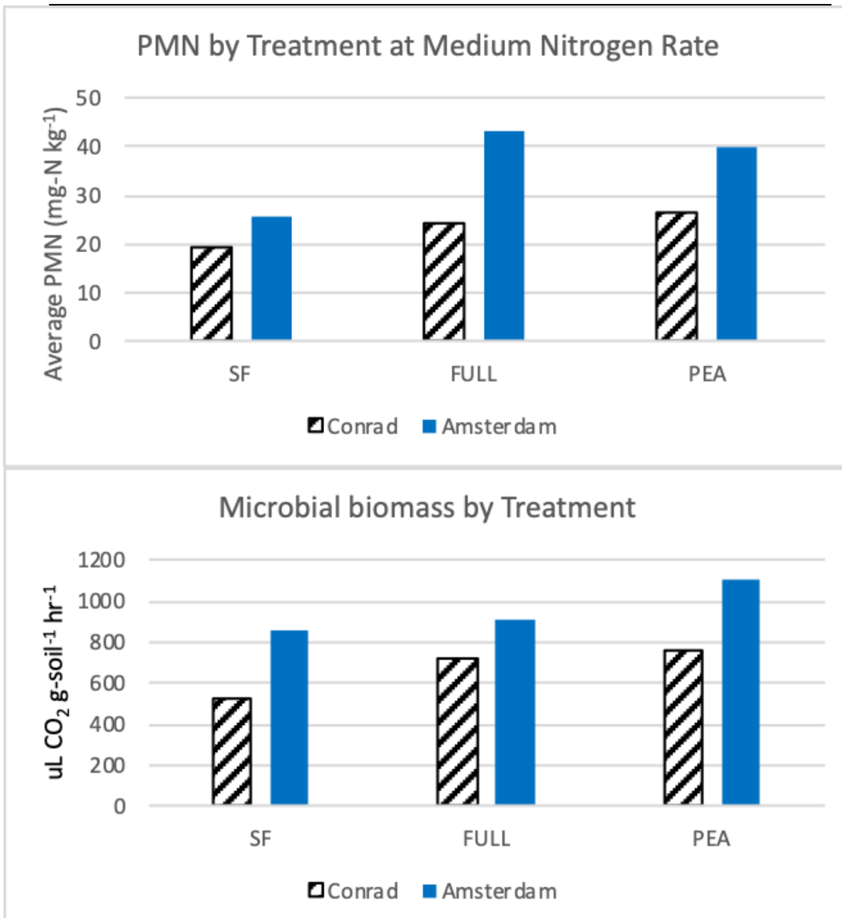

Fig 1. PMN (upper panel) and MB as inferred by CO_2 respiration rate (lower panel) at Conrad and Amsterdam, MT, measured from 4-inch soil samples collected in the medium N rate treatments in April 2019. At Conrad, both covers had greater MB than SF (Summer Fallow) and Pea had higher PMN than SF, but Pea did not differ from Full for MB or PMN. At Amsterdam, only Pea and SF differed statistically for MB and both covers had greater PMN than SF ($P<0.10$).

The Amsterdam weather year was unusually cool and wet, delaying crop development, although no effective rainfall was received after July 30. Possibly wheat growth occurred too quickly on legume-enriched plots, using soil water too quickly, and causing a yield depression. Grain test weight was slightly lower

(62.5 vs 62.9; *P*=0.06) following legumes, adding some credence to this “haying off” argument. It is noteworthy that the Brassica functional group increased wheat yield at Amsterdam (Table 4), and at both locations in 2017 (data not shown). Brassica residues are more likely to inhibit wheat disease in cool, wet springs, and this benefit from brassica cover crop merits further investigation. At Conrad, wheat following legume covers yielded 24% greater than the ‘minus legume’ cover crop mix, indicating that N release from legumes was important to building yield, even in this drier environment.

Table 4. Spring wheat yield (bu/ac @ 12% moisture) for 11 cover crop treatments x 3 N application rates (0, 60, and 120 lb N/ac) at Amsterdam and Conrad, MT, 2019.

	Amsterdam			Conrad		
Treatment	0	60	120	0	60	120
Fallow	32.2 B	53.3 A	53.6 A	24.2 C	38.6	33.9
Full mix	36.7 AB	49.7 B	50.3 AB	28.3 B	38.4	35.3
Pea	41.5 A	47.2 B	48.1 B	36.0 A	35.6	34.1
Brassica	32.5	**52.0**	**56.7**	25.7	34.6	**30.8**
M Brass	36.2	**44.8**	**51.7**	28.1	38.5	**37.1**
Fibrous	**26.9**	46.6	49.2	**23.4**	40.1	32.6
M Fibr	**37.3**	45.4	52.2	**31.9**	36.3	32.7
Legume	**37.7**	44.3	**46.0**	**40.0**	**39.4**	**35.7**
M Legu	**28.8**	47.0	**55.7**	**22.2**	**31.7**	**27.5**
Tap	29.0	51.2	56.5	27.4	**40.9**	33.2
M Tap	33.9	54.3	51.6	29.1	**33.6**	31.5
$LSD_{0.10}$	*5.8*	*3.1*	*5.0*	*3.1*	*7.1*	*5.7*

When means in the top tier of table are followed by the same or no letter, they do not differ (P > 0.10). For each paired comparison of presence and absence of each functional group, bolded values differ (P < 0.10).

The differential response for Tap vs Minus Tap at Conrad is likely because very little biomass was present in the Tap treatment in 2018 due to drought and N stress on turnip and preferential grazing of safflower by antelope, likely leaving more soil water for the following wheat crop.

In conclusion, by growing cover crops more frequently than most producers grow them, we were able to detect soil quality and wheat production differences among cover crop treatments after four cycles. The largest soil quality differences were generally between fallow and cover crops, rather than among cover crops. Perhaps the amount of residue returned is more important at affecting soil quality properties, rather than the specific functional group.

Table 5. Spring wheat grain protein (@ 12% moisture) for 11 cover crop treatments x 3 N rates (0, 60, 120 lb N/ac) at Amsterdam and Conrad, MT, 2019.

	Amsterdam			Conrad		
Treatment	0	60	120	0	60	120
Fallow	10.6 B	12.8 B	14.5 B	11.0 A	13.2 B	15.8 B
Full mix	10.7 B	12.4 C	14.4 B	9.5 B	13.1 B	16.1 B
Pea	11.8 A	14.2 A	14.9 A	11.1 A	16.2 A	16.8 A
Brassica	10.6	**12.3**	**14.1**	9.5	13.5	16.3
M Brass	10.6	**13.2**	**14.6**	9.5	14.4	16.3
Fibrous	10.3	**12.1**	14.4	11.4	**13.5**	**16.3**
M Fibr	10.5	**12.9**	14.4	11.1	**14.9**	**16.7**
Legume	**11.9**	**14.3**	**14.9**	11.0	**15.3**	16.7
M Legu	**10.1**	**12.0**	**14.1**	9.8	**12.9**	16.7
Tap	**10.0**	**11.8**	**14.2**	**11.1**	13.2	**15.9**
M Tap	**10.9**	**12.9**	**14.5**	**9.5**	13.4	**16.5**
$LSD_{0.10}$	*0.47*	*0.34*	*0.20*	*1.35*	*1.08*	*0.38*

Means in top tier followed by the same letter do not differ (P > 0.10). For each paired presence/absence of each functional group, bolded values differ (P < 0.10).

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NITROGEN AVAILABILITY FOLLOWING COVER CROPS IN TX CROPPING SYSTEMS

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ABSTRACT

Cover crops have been heavily promoted to improve soil health and function in US agricultural productions systems. Within semi-arid environments, interest in cover crops continues to grow although several concerns hinder adoption. As soil water use by cover crops is often a chief concern, nutrient availability to subsequent crops is also a concern. The objective of this study was to measure soil chemical and biological properties following various cover crops in a continuous cotton system under rainfed conditions. The study was conducted at the Texas A&M AgriLife Chillicothe Research Station with the following treatments: 1) conventional till; 2) no-till; and no-till with the following cover crops, 3) Austrian winter pea; 4) hairy vetch; 5) crimson clover; 6) wheat; and 7) multi-species mixture. Pea and vetch cover crops resulted in greater N accumulation and lower C:N ratios in the herbage mass. Soil nitrate was greater for Austrian winter pea and hairy vetch 6 weeks after termination compared to other treatments. Soil nitrate was not different between grass cover crop treatments and non-cover crop treatments. Trends for soil respiration were similar as observed with soil nitrate. Soil respiration in the upper 10 cm was greater for pea compared to non-cover crop treatments for each date Initial results found that N availability following cover crops was greater for legume cover crops and grass cover crops did not immobilize N in continuous cotton systems that received no inorganic fertilizer applications.

INTRODUCTION

Cover crops and crop rotation have been shown to enhance soil fertility, soil organic matter, and soil structure. Identification of cover crops that can be successfully established and terminated in time for nutrients to be available at key time points in crop growth cycles is critical for maximizing yields and reducing input costs. A global meta-analysis indicated that non-leguminous cover crops substantially reduced nitrate leaching into freshwater systems by 56% (Thapa et al., 2018). Furthermore, nonlegume-legume cover crop mixtures reduced nitrate leaching as effectively as nonlegumes and significantly more than legume cover crops. Seman-Varner et al. (2017) suggested that a legume cover crop may effectively scavenge poultry litter nitrogen in low nitrogen systems and result in increased residual nitrogen availability over time. As cover crops may affect the availability of nitrogen, research has shown that cover crops can have detrimental effects on subsequent cash crop yields in semi-arid environments (Nielsen et al., 2016; Holman et al., 2018). In the Texas Rolling Plains, research has shown that cover crops have not negatively affected cotton lint yields (DeLaune et al., 2012; DeLaune et al., 2020). Hence, research is warranted to better understand nutrient cycling in adverse climatic conditions that are common across the US Great Plains. The objective of this study was to measure soil chemical and biological properties following cover crops in a continuous cotton system in the Texas Rolling Plains.

MATERIALS AND METHODS

A study was initiated in Fall 2011 at the Texas A&M AgriLife Chillicothe Research Station near Chillicothe, TX. Historically, the study area had been under conventional tillage with various field crops. Results for this paper are based upon sampling in Spring 2017. Evaluated treatments included: 1) conventional tillage (CT); 2) no-till (NT); and NT with the following cover crops, 3) Austrian winter field pea (pea); 4) hairy vetch (vetch); 5) crimson clover (clover); 6) wheat; and 7) multi-species mixture (mix). Plots were 8 rows wide (1 m row spacing) and 12 m long and arranged in a randomized complete block design with four replicates. Conventional tillage consisted of an offset disc used in the fall and winter followed by bedding of rows. One in-season cultivation was conducted using a sweep plow. After cotton harvest in 2016, cover crops were planted using a NT drill 22 November 2016. Seeding rates for cover crops were 39.2 kg ha^{-1} for pea, 33.6 kg ha^{-1} for wheat and mix, and 22.4 kg ha^{-1} for clover and vetch. The mix consisted of 13.4 kg ha^{-1} cereal rye, 10.1 kg ha^{-1} wheat, 6.7 kg ha^{-1} pea, and 3.4 kg ha^{-1} vetch. Cover crops were chemically terminated on 20 April 2017. Cotton was planted on 30 May 2017 using a four-row vacuum planter.

Soil samples were collected 0 (20 April), 3 (9 May), and 6 (30 May) weeks after cover crop termination. Soil samples were collected using a 2.54 cm diameter soil core sampler at depths of 0-10 and 10-20 cm. Air dried soil was passed through a 2 mm sieve for analysis. A total of 2 g soil was extracted with 20 mL of 1N KCL. After 1 hr of shaking at 160 oscillations per minute, the extract was filtered through Whatman No. 42 filter paper into 20 mL plastic scintillation vials. The filtrate was analyzed using a Skalar flow analyzer for ammonium and nitrate (Keeney and Nelson, 1982; Dorich and Nelson, 1983). Mineralizable carbon (evolved CO_2, soil respiration) was determined as outlined by Franzluebbers (2016). A subset of soil samples was passed through a 4.75 mm sieve and 100 g of soil was weighed into a graduated glass bottle. Water was added to achieve 50% water-filled pore space. A 0.5 M NaOH alkali trap (10 mL) and a vial containing 10 mL of DI water to sustain humidity was added to the bottle, which was then placed in a 1 L glass jar and sealed for 72 hrs. After the incubation period, 0.5 N HCl was used to titrate the alkali solution to determine the amount of carbon dioxide evolved.

RESULTS AND DISCUSSION

Cover Crop Biomass

Clover produced less biomass than all other treatments (Table 1). Pea produced greater biomass than clover and wheat. There were no differences among wheat, mix, and vetch. Nitrogen accumulated in the above ground biomass was significantly greater for pea and vetch (Table 1). There were no differences in N accumulation among clover, wheat, and mix. The ratio of C:N is a good indicator of nitrogen mineralization potential (Wagger et al., 1998). A high quality residue may be defined as having a C:N value below 25 to 30, whereas greater values indicate a low quality residue. Adding legumes to the mix did not change the C:N ratio compared to wheat, as the mix was dominated by rye.

Table 1. Cover crop biomass production and above ground nitrogen accumulation at Chillicothe Research Station in 2017. Different letters represent significant difference at $P<0.05$.

	Biomass (kg ha^{-1})	C:N	N Accumulation (kg ha^{-1})
Clover	342c	16.4b	7.6b
Wheat	1766b	38.9a	17.4b
Mix	2491ab	38.9a	27.8b
Vetch	2950ab	11.1b	111.8a
Pea	3148a	14.1b	93.7a

Nutrient Cycling

Adding legume cover crops can provide nitrogen to the subsequent cash crop as well as stimulate the microbial biomass, which improves crop nutrition and soil structure (Crews and Peoples, 2004). Therefore, the use of cover crops with high quality biomass is required to increase soil nitrogen supply. At cover crop termination and 3 weeks after termination, nitrate concentrations in the upper 10 cm of the soil did not differ among treatments (Figure 1A and 1B). However, pea had greater soil nitrate concentrations than all other treatments in the upper 10 cm 6 weeks after termination (Figure 1C). Vetch had greater soil nitrate concentrations in the upper 10 cm than CT at 6 weeks after termination. Trends were similar for the 10-20 cm depth, where soil nitrate concentrations were numerically greater for pea and vetch than other treatments. Soil nitrate concentrations at the 0-10 cm depth were significantly greater than all other treatments except the mix (Figure 1F). These results correspond with the nitrogen accumulation and C:N ratios observed in the cover crop biomass. As nitrogen accumulation was greater for pea and vetch, higher soil nitrate concentrations were also observed just prior to cotton planting. Although C:N ratios for wheat and mix were greater than the level expected for nitrogen immobilization to occur, soil nitrate concentrations did not differ between these treatments and the non-cover crop treatments CT and NT.

Inorganic nutrient availability alone does not offer a complete assessment of soil fertility or of soil biological influences on important soil properties and processes that affect crop yield and environmental quality (Franzluebbers, 2016). Franzluebbers (2016) proposed that soil testing could be elevated to a more complete evaluation of soil fertility and health with the adoption of a test for biological activity by using the flush of CO_2 during 1 to 3 day following rewetting of dried soil and incubation period to measure soil respiration. Trends were similar for soil respiration as observed with soil nitrate (Figure 2). The concentration of CO_2 evolved was numerically higher for pea than all treatments for each date and depth (Figure 2). These levels were significantly greater for pea than CT and NT for all dates and depths except for six weeks after cover crop termination in the 10-20 cm depth (Figure 2F). Vetch produced more evolved CO_2 after pea. In general, the amount of CO_2 evolved decreased with time after cover crop termination, which could be a result of much drier conditions over time since the cover crops were terminated leading to reduced microbial activity. Water extractable organic nitrogen, thought to be an essential substrate for microorganisms, had a strong positive correlation with evolved CO_2 ($R=0.62$, $P<0.0001$; data no shown).

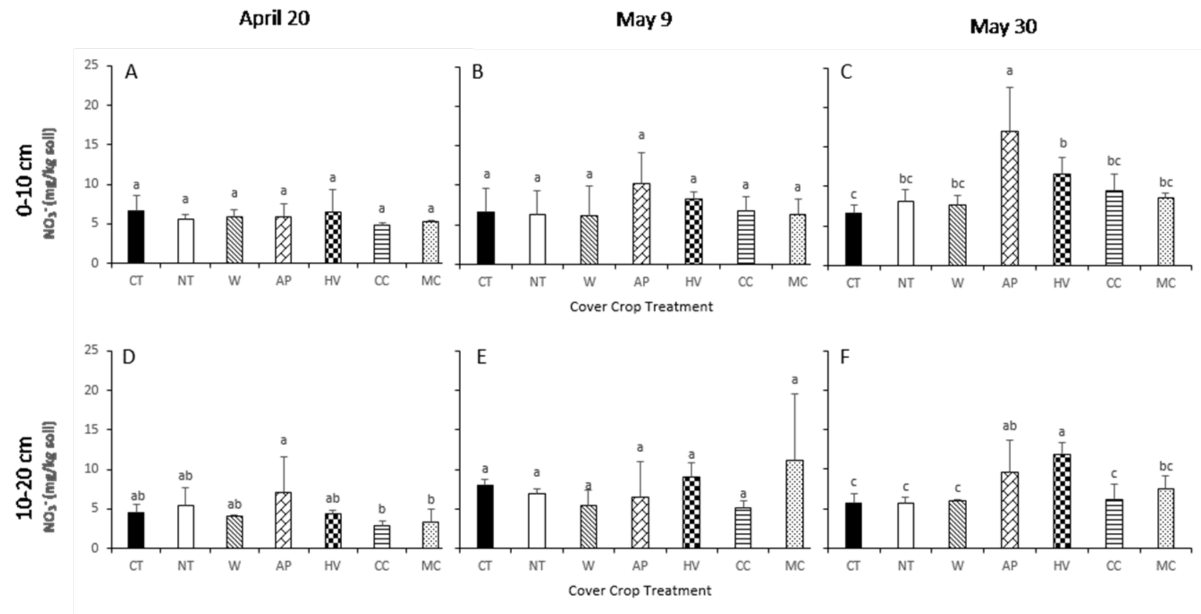

Figure 1. Soil nitrate as affected by tillage and cover crop treatments. Samples represent 0-10 cm from A) April 20, B) May 9, and C) May 30 and 10-20 cm from D) April 20, E) May 9, and F) May 30. Statistical significance within each date and depth denoted by different letters ($P < 0.05$). CT = conventional till; NT = no-till; W = winter wheat; AP = Austrian winter pea; HV = hairy vetch; CC = crimson clover; MC = mixed species cover.

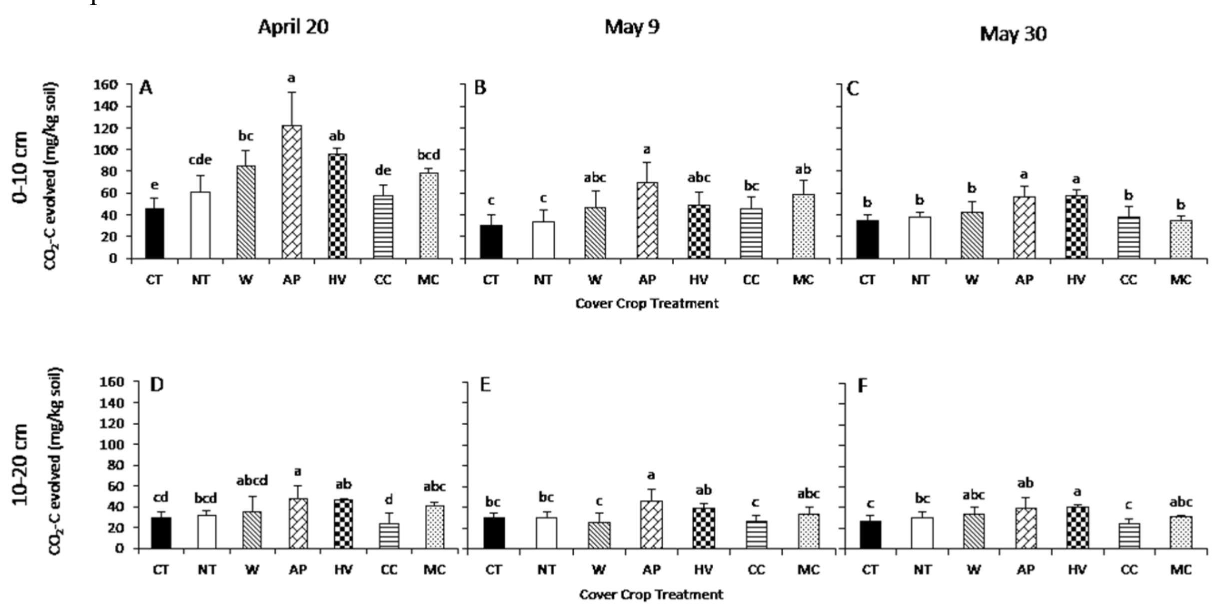

Figure 2. Soil respiration as affected by tillage and cover crop treatments. Samples represent 0-10 cm from A) April 20, B) May 9, and C) May 30 and 10-20 cm from D) April 20, E) May 9, and F) May 30. Statistical significance within each date and depth denoted by different letters ($P < 0.05$). CT = conventional till; NT = no-till; W = winter wheat; AP = Austrian winter pea; HV = hairy vetch; CC = crimson clover; MC = mixed species cover.

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PHOSPHORUS FERTILIZER MANAGEMENT AND COVER CROP EFFECTS ON PHOSPHORUS LOSS FROM NO-TILL CORN AND SOYBEAN

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ABSTRACT

Loss of phosphorus from non-point source agricultural sources is a known contributor to the degradation and contamination of surface waters. Therefore, it is imperative to adapt agricultural best management practices which promote and preserve surface water quality. The goal of this study was to quantify the impacts of phosphorus fertilizer management practice (placement and timing) and winter cover crop on concentrations of total suspended solids, total phosphorus, and dissolved reactive phosphorus in surface runoff from natural precipitation events for a no-till, corn (*Zea mays*)-soybean (*Glycine max*) rotation. The study was conducted between October 1, 2015 and September 30, 2019, in the Central Great Plains (Manhattan, KS) and featured a 3x2 complete factorial treatment structure arranged in a randomized complete block design replicated in triplicate. Treatments used included three phosphorus fertilizer management practices (no P, fall broadcast P, and spring injected P), each implemented with and without a winter cover crop. Flow-weighted composite surface runoff samples from natural precipitation events generating more than 0.08 inches of surface runoff were collected throughout the year and analyzed for total suspended solids, total phosphorus, and dissolved reactive phosphorus concentrations. Analysis of runoff from the 2018 water year revealed a clear runoff event by fertilizer management practice by cover crop interaction for both total phosphorus and dissolved reactive phosphorus. Additionally, a main effect of cover crop on total suspended solids concentration was found where the absence of a cover crop resulted in sediment concentrations at least 65% greater than those from the cover crop treatment.

INTRODUCTION

Minimizing phosphorus loss from agricultural production systems is a fundamental factor in protecting surface water quality. As excess phosphorus moves into surface waters, mineral enrichment of surface water may occur, leading to eutrophication, promotion of harmful algal growth, and potential increased water treatment costs (Correll, 1998; Carpenter et al., 1998). While excessive phosphorus input into surface water can lead to a decrease in surface water quality, farmers throughout the world apply phosphorus-based fertilizers to help increase crop yields.

Studies have shown when phosphorus-based fertilizers are applied below the soil surface, phosphorus losses may decrease compared to surface application. Kimmel et al. (2001) found that, under no-till management, subsurface placement of phosphorus-based fertilizers decreased total and dissolved reactive phosphorus loss by 30 and 75%, respectively. Similarly, Zeimen et al. (2009) showed that subsurface placement of phosphorus-based fertilizers resulted in similar or less phosphorus loss compared to surface application of phosphorus-based fertilizer.

Additionally, rainfall simulation studies have found that surface application of phosphorus-based fertilizer, when applied at the same time as subsurface placed fertilizer, results in greater losses of phosphorus (Baker & Laflin, 1982; Mostaghimi et al., 1988).

A common proposed best management practice (BMP) to reduce nutrient loss is the addition of a cover crop during a normally fallow period (DeBaets et al., 2011). Cover crops have been shown to benefit the soil through reduced erosion, enhanced water infiltration, and improved soil properties (Dabney et al., 2001). Although cover crops are often proposed as a BMP to curb phosphorus loss, there is inconclusive evidence as to their effectiveness to do so (Sharpley & Smith, 1991; Dabney et al., 2001; Christianson et al., 2017).

The objectives of this study were to quantify the impacts of phosphorus fertilizer management and the addition of a winter cover crop on total suspended solids, total phosphorus, and dissolved reactive phosphorus concentrations of surface runoff from natural precipitation events throughout the year.

MATERIALS AND METHODS

This large-scale field study ran from October 1, 2015 through September 30, 2019 and was conducted at the Kansas Agricultural Watershed (KAW) field laboratory located near Manhattan, KS. The KAW field lab is comprised of eighteen small-scale watersheds with an average size of approximately 1.2 acres. Each watershed was fitted with a 1.5 ft H-flume and automated water sampling equipment. This study examined total suspended solids and phosphorus concentrations of edge-of-field runoff from natural precipitation events from a no-till, corn (*Zea mays*)-soybean (*Glycine max*) rotation.

A total of six management practices (treatments) were used and treatments were structured in a randomized complete block design with three replicates. Three levels of phosphorus fertilizer management were used: control (0 lb P_2O_5/ac), fall broadcast (55 lb P_2O_5/ac), and spring subsurface injected (55 lb P_2O_5/ac). Each level of phosphorus fertilizer management practice was expressed with and without a winter cover crop.

Flowweighted composite samples of surface runoff were collected when natural precipitation events generated greater than 0.08 inches of surface runoff. Events with less than 0.08 inches of surface runoff were omitted due to a large number of missing data points.

Data are presented from the 2018 water year (October 1, 2017-September 30, 2018). Data from the 2016, 2017 and 2019 water years will be presented if available.

2018 Water Year

In Fall 2017, a winter cover crop mixture of triticale (*x Triticosecale* var. *TriCal 780*) and rapeseed (*Brassica napus* var. *Dwarf Essex*) was sown at a seeing rate of 50 lb/ac and 5 lb/ac, respectively, immediately following corn harvest. The fall broadcast treatment received 55 lb P_2O_5/ac applied as diammonium phosphate (DAP, 18-46-0) after harvest and prior to soil freezing. The spring injected plots received 55 lb P_2O_5/ac injected as ammonium polyphosphate (APP, 10-34-0), approximately 2 inches below and 2 inches to the side of the seed at the time of soybean planting. Phosphorus fertilizer rates were based on the Kansas State University build-and-maintain fertilizer recommendation system and were calculated using initial soil test phosphorus levels (Leikam et al., 2003).

Prior to soybean planting, all cover crop plots where chemically terminated.

Statistical Analysis

All data were analyzed using SAS ver. 9.4 (SAS Institute, Cary, NC). A PROC GLIMMIX procedure with repeated measures analysis of variance was used to test for treatment effects. All data required transformation to satisfy the assumption of normal variance.

RESULTS AND DISCUSSION

In the 2018 water year, a main effect of cover crop was observed with the cover crop treatment resulting in a lower concentration of total suspended solids in 80% of all observed runoff events. The presence of a cover crop reduced erosion losses by over 65% in the 2018 water year.

While the cover crop dramatically reduced sediment concentration in surface runoff during the 2018 water year, it also increased both total and dissolved reactive phosphorus concentrations across the majority of runoff events in the 2018 water year. Three out of five observed runoff events in 2018 showed that cover crop, regardless of fertilizer practice, increased total phosphorus concentration of surface runoff, and four out of five events showed that cover crop, again regardless of fertilizer placement, increased dissolved reactive phosphorus concentrations in surface runoff. This finding runs counter to the often touted benefit that cover crops help to curb phosphorus loss from agricultural fields. In 1994, Miller et al. stated nutrient leaching from crop tissue during rainfall events may increase the potential for nutrient loss from fields. Additionally, Liu et al. (2019) found that cover crops grown in areas which may exhibit sub-freezing temperature could result in increased phosphorus loss from fields.

In the 2018 water year, no differences in total phosphorus and dissolved reactive phosphorus concentrations of surface runoff between the fall broadcast and spring injected phosphorus fertilizer treatments were observed. This runs contrary to the findings of Kimmell et al. (2001) and Zeimen et al. (2009) who both found that subsurface placement of phosphorus fertilizer resulted in less phosphorus loss compared to surface applied phosphorus fertilizer. However, it is important to note the timing of collected runoff events observed in the 2018 water year. The first two collected runoff events occurred in October 2017. The next such event occurred ten months later. This extreme lag between runoff events precluded the possibility of capturing potential differences in phosphorus loss based on phosphorus fertilizer application method.

ACKNOWLEDGEMENTS

This research is supported by the 4R Research Fund, Kansas Soybean Commission, Kansas Corn Commission, USDA-NRCS Grant #69-3A-75-17-32, the Kansas Agricultural Experiment Station, and the Kansas State University Department of Agronomy.

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LONG-TERM CROP ROTATION DIVERSITY EFFECTS ON SOIL C AND N

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ABSTRACT

The objective of this study was to evaluate the effects of nitrogen (N) fertilizer level and crop rotation diversity on soil organic carbon (SOC) and N stocks from a 34-yr study located in eastern Nebraska. Seven crop rotations (three continuous cropping systems; two 2-yr crop rotations, and two 4-yr crop rotations) and three N levels were compared. Soil samples were taken to a depth of 60-inches. Differences in SOC stocks were largely confined to the 0 to 3-inch depth with greater SOC ($P = 0.0002$) in rotations than continuous cropping systems and greater SOC ($P = 0.0004$) in 4-yr vs. 2-yr rotations. Total soil N was greater with increased crop rotation diversity for the 0 to 12-inch soil profile. At the full sampled soil profile (0-60 inches), SOC stocks were similar between N levels and greater for the 4-yr vs. 2-yr crop rotations ($P = 0.0492$). Trends in total N stocks were similar to those of SOC stocks. Overall, crop rotation had a larger effect on SOC and N stocks than N fertilizer.

INTRODUCTION

Sustainable crop production requires management strategies aimed at enhancing the potential to sequester or increase soil organic carbon (SOC). Maintaining or increasing SOC is one method for greater resiliency for agricultural systems under extreme weather events. Agricultural management strategies to increase SOC within annual cropping systems include cover crops, residue retention, manure-application, diverse crop rotations, crops with greater root mass, and N fertilizer (Jarecki and Lal, 2003; McDaniel et al., 2014; Paustian et al., 2016; Poffenbarger et al., 2017; Tiemann et al., 2015). Diverse cropping systems that includes cover crops tend to increase SOC by increasing C input (King and Blesh, 2018; McDaniel et al., 2014). Nitrogen fertilizer has been reported to increase, decrease, or have no effect on SOC (Brown et al., 2014; Khan et al., 2007; Lu et al., 2011; Mahal et al., 2019; Poffenbarger et al., 2017; Russell et al., 2005). Significant SOC responses to management changes (i.e. crop rotation, N fertilizer management) however, may take years to detect, so the ability to quantify management effects improves with experiment duration.

Crop rotation and N fertilizer level influences grain yield and aboveground biomass impacting SOC, soil N, and other agroecosystem functions (Liebig and Varvel, 2003; Sindelar et al., 2016; Varvel, 2006). Long-term cropping studies under no-till have resulted in increased SOC and total N with increased crop rotation diversity (Alhameid et al., 2017; Maiga et al., 2019). Cropping systems that incorporate legumes under no-till have also resulted in increased SOC (Conceição et al., 2013; Hobley et al., 2018) while other results suggest incorporating legumes causes a rhizosphere priming effect on SOC, which reduces the benefit of residue retention on SOC (Chen et al., 2018).

Long-term effects from crop rotation and soil management practices on SOC and soil N stocks provides important information on sustainable cropland management under a changing climate. Quantifying SOC storage both by soil layer and cumulatively is important in detecting the influence of management on SOC changes. The objective of this study was to evaluate N fertilizer rates and crop rotation diversity on SOC and N stocks from a 34-yr study.

MATERIALS AND METHODS

The experiment was conducted at the Eastern Nebraska Research and Extension Center near Mead, NE. Soil series is a Yutan-Tomek silty clay loam-silt loam complex (fine-silty, mixed, superactive, mesic Mollic Hapludalfs and fine, smectitic, mesic Pachic Argiudolls, respectively). Mean annual temperature and precipitation is 50.9°F and 30 inches, respectively. The experiment is a randomized complete block design in a split plot arrangement with five replications. Crop rotation is the main plot, and fertilizer N rate is the split plot. The experiment comprises of seven crop rotations and three nitrogen fertilizer levels. Crop rotations include continuous crops [continuous corn (*Zea mays* L.); continuous grain sorghum (*Sorghum bicolor* (L.) Moench); continuous soybean (*Glycine max* L.)], 2-yr (corn-soybean; grain sorghum-soybean) and 4-yr crop rotations (corn–soybean–grain sorghum–oat [*Avena sativa* L.]+clover [80% *Melilotus officinalis* Lam. + 20% *Trifolium praetense* L.]; corn–oat+clover– grain sorghum–soybean). Each phase of every crop rotation is present each year for a total of 15 rotations per replication or block. Fertilizer N treatments were initiated in 1982 and included 0, 80, and 160 lbs. N acre^{-1} (0, 90, and 180 kg N ha^{-1}) for corn and grain sorghum and 0, 30, and 60 lbs. N acre^{-1} (0, 34, and 69 kg N ha^{-1}) for soybean and oat/clover. In 1983, the experiment was expanded to five replications. Split-plots are 30-ft wide (30-inch rows; n = 12) and 33-ft long. The study was annually disked twice in the spring from 1983 until 2006. In 2007, the study was converted to no-till. Crop management practices used in the study best represent those commonly used in the region and are performed with commercial-scale field equipment. Oat and rhizobium-inoculated clover is seeded in mid- March to early April at 89 and 16 lbs. acre^{-1} (100 and 18 kg ha$^{-1)}$, respectively, using a no-till grain drill with 7.5-inch row spacing. In-season crop management practices include weed control and fertilizer N application. No in-season herbicide applications occur in the oat/clover plots. Fertilizer N is manually broadcasted without incorporation.

Dry matter samples were collected for oat, corn, soybean, and grain sorghum at physiological maturity. Soybean and oat samples were weighed and dried for dry matter yield determination before being threshed using a stationary plot thresher. For corn and grain sorghum, heads or ears were removed, and the remaining plant was chopped, dried to a constant mass, and weighed. Corn ears and grain sorghum heads were dried at 140°F to a constant dry mass and threshed, and corn cobs, grain sorghum panicles, and grain were additionally weighed for total aboveground biomass determination. For all crops, 15-ft of row (3.8-m^2) was sampled. Non-grain biomass of oat, corn, soybean, and grain sorghum were analyzed for C and N. Data on non-grain biomass C and N values are from 1990 to 2016. Detailed site, management, yield, and weather information can be accessed at the USDA-ARS Agricultural Collaborative Research Outcomes System (AgCROS) website (https://agcros-usdaars.opendata.arcgis.com/).

Soil samples (n=1125) have been taken to a depth of 5-feet at sampling increments of 0 to 3, 3 to 6, and 6 to 12, 12 to 24, 24 to 36, 36 to 48, 48 to 60 inch in all five replicates in November 2016. Four cores (1.3-inch diameter) are taken from each N subplot and composited by depth. All samples are weighed for bulk density determination. All samples are air-dried, ground to pass a 2-mm screen, and analyzed for total C and N.

Statistical Analysis

The effects of crop rotation and N fertilizer rate on SOC and total N stocks were analyzed using a generalized linear mixed model approach (PROC GLIMMIX in SAS). Rotation (main plot) and N fertilizer treatments (split-plot) were fixed effects while block was analyzed as a random effect. Analysis of variance (ANOVA) were run by soil layer depth and by cumulative soil depth. Preplanned comparisons were run using the contrast statement. Statistical probability was set at 0.05.

RESULTS AND DISCUSSION

Surface SOC and N stock differences by rotation and N fertilizer level

Crop rotation impacted SOC stocks at the near surface soil depth (Table 1). Differences by rotation and N level were largely confined to the 0 to 3-inch soil level. For SOC stocks at the 0 to 3-inch soil depth, differences were found between continuous crops and rotational cropping systems (Table 1).

Table 1. Surface soil organic carbon and soil nitrogen stock for each rotation (CC = continuous corn; CSB = continuous soybean; CSG = continuous sorghum; C/SB = corn-soybean; SG/SB = sorghum-soybean; C/O/SG/SB = corn-oat+clover-sorghum-soybean); C/SB/SG/O = corn–soybean–grain sorghum–oat+clover) and N fertilizer level.

	Soil depth (inches)					
	SOC stock			Total N		
Parameters	0-3	3-6	6-12	0-3	3-6	6-12
Rotation	ton acre^{-1}					
CC	7.45	6.69	9.90	0.69	0.63	0.97
CSB	7.67	6.56	10.9	0.70	0.62	1.05
CSG	8.34	6.82	10.6	0.78	0.64	1.04
C/SB	8.03	6.65	10.9	0.74	0.62	1.05
SG/SB	8.12	6.47	9.50	0.76	0.61	0.97
C/O/SG/SB	9.01	7.14	11.8	0.84	0.67	1.12
C/SB/SG/O	8.83	6.78	11.0	0.83	0.64	1.07
N level						
Zero	7.94	6.65	10.8	0.75	0.62	1.05
Low	8.30	6.69	10.5	0.76	0.63	1.03
High	8.34	6.82	10.6	0.78	0.64	1.04
Source of variation	*P*-value					
Rotation	**0.0001**	0.3814	0.3480	**<.0001**	**0.0067**	0.3013
Continuous v rotation	**0.0002**	0.7175	0.6035	**<.0001**	0.4762	0.4171
2-yr vs. 4-yr	**0.0004**	0.0696	0.0945	**<.0001**	**0.0013**	0.0744
Among 2-yr	0.6909	0.5248	0.1713	0.2192	0.5965	0.2689
Among 4-yr	0.4524	0.2042	0.3901	0.4943	**0.0290**	0.3667
Nitrogen level	**0.0103**	0.5050	0.8362	**0.0214**	0.1193	0.8306
0 N vs N	**0.0025**	0.3500	0.5856	**0.0134**	0.0537	0.6489
Rotation x Nitrogen	0.1604	0.9818	0.9997	0.0653	0.8031	0.9981

Four-yr rotations had greater SOC stocks than 2-yr rotations. Nitrogen fertilizer level affected SOC stocks for the 0 to 3-inch soil depth with greater SOC levels under N fertilized treatments (Table 1). Crop rotation affected total N at the 0 to 3 and 3 to 6-inch soil depth (Table 1). Total soil N was lower for the continuous cropping systems compared with the rotational cropping systems at the 0 to 3-inch soil depth. Soil N was greater under the four-year rotations compared to the two-year rotations at the 0 to 3-inch and the 3 to 6-inch soil depth. Nitrogen fertilizer increased total soil N at the 0 to 3-inch soil depth (Table 1). Total soil N was greater (P = 0.0290) for the corn–oat/clover– grain sorghum–soybean 4-year rotation compared to the corn–soybean–grain sorghum–oat/clover rotation. Increased N fertilizer effects on soil organic C concentration at the 0 to 3-inch soil depth was first documented eight years after crop rotation and N fertilizer treatments were initiated (Varvel, 1994).

Cumulative SOC and N stock

The main effects of rotation and N level were similar for the 0-12, 0-24, 0-36, and 0-48 inch soil depths (data not shown). At the 24 to 36-inch soil depth, a rotation effect (P = 0.0514) occurred mainly through differences between two-year rotations (Table 2).

Table 2. Soil organic carbon stocks for each rotation (CC = continuous corn; CSB = continuous soybean; CSG = continuous sorghum; C/SB = corn-soybean; SG/SB = sorghum-soybean; C/O/SG/SB = corn-oat+clover-sorghum-soybean); C/SB/SG/O = corn–soybean–grain sorghum–oat+clover) and N fertilizer level by soil depth.

	Soil Depth (inches)					
Parameters	0-12”	12-24”	24-36”	36-48”	48-60”	0-60”
Rotation			Mg C ha^{-1}			
CC	24.0	11.3	5.76	4.24	2.85	48.1
CSB	25.2	14.3	8.47	6.11	4.01	57.9
CSG	25.7	12.4	6.16	4.46	3.17	51.9
C/SB	25.6	15.4	9.63	7.09	4.91	62.5
SG/SB	24.1	11.1	5.89	4.06	2.77	47.8
C/O/SG/SB	27.9	15.8	9.63	7.05	4.82	65.1
C/SB/SG/O	26.5	14.7	8.61	6.33	4.33	60.5
N level						
Zero	25.4	14.1	8.12	5.89	4.06	57.5
Low	25.5	13.3	7.67	5.49	3.70	55.7
High	25.8	13.3	7.45	5.44	3.70	55.7
Source of variation			*P*-value			
Rotation	0.1411	0.0976	**0.0514**	0.0610	0.0948	**0.0204**
Continuous v rotation	0.2291	0.1826	0.0823	0.1091	0.1232	0.0947
2-yr vs. 4-yr	0.0260	0.1118	0.1650	0.1429	0.1942	**0.0492**
Among 2-yr	0.3213	0.0309	**0.0177**	0.0164	0.0200	**0.0164**
Among 4-yr	0.3303	0.4833	0.4134	0.4641	0.4739	0.3355
Nitrogen level	0.8583	0.7772	0.7777	0.8060	0.7917	0.8682
0 N vs N	0.6701	0.4801	0.5056	0.5137	0.4952	0.5956
Rotation x Nitrogen	0.9994	1.0000	0.9997	0.9961	0.9982	0.9999

A rotation effect (P = 0.0204) was found for the surface to 60-inch soil depth with differences between the two-year and four-year rotations as well as among the two-year rotations. Cumulative SOC stocks ranged from a low of 47.8 tons C acre^{-1} (107.1 Mg C ha^{-1}) for sorghum-soybean to a high of 65.1 tons C acres^{-1} (146 Mg C ha^{-1}) for corn-oat+clover-sorghum-soybean (Table 2). Four-yr rotations resulted in greater SOC stocks (62.8 tons C acre^{-1}; 140.9 Mg C ha^{-1}) than 2-yr rotations (55.2 tons C acre^{-1}; 123.7 Mg C ha^{-1}). Differences between 4-yr and 2-yr rotations was largely an effect of lower SOC stocks from sorghum-soybean (47.8 tons C acre^{-1}; 107.1 Mg C ha^{-1}) compared with corn-soybean (62.5 tons C acre^{-1}; 140.2 Mg C ha^{-1}). Differences between 2-yr rotations were not the result of crop residue C mass as sorghum-soybean had similar residue C mass by N fertilizer level than corn-soybean (data not shown). This was the first time SOC stocks were statistically different by crop rotation for the cumulative soil profile at this site. Previous results from this study showed similar SOC stocks between crop rotation in the 0 to 60-inch soil profile after 14-yr, indicating the duration required to determine SOC changes from crop rotation practices (Varvel et al., 2002).

The main effect of crop rotation was significant for total soil N at the 0 to 12, 36 to 48, and 0 to 60-inch soil depths (data not shown). For the 0 to 12-inch soil depth, greater soil N was present in the crop rotational systems versus the continuous cropping systems. Four-year rotations were greater than 2-year rotations. At the 36 to 48-inch soil depth, soil N was greater for corn-soybean than sorghum soybean. Similar to SOC stocks at the 0 to 60-inch soil profile, differences in soil N were present ($P = 0.0465$) between corn-soybean and sorghum-soybean with greater total N stocks in the corn-soybean rotation (data not shown). There was no N fertilizer response on cumulative soil N stocks.

Overall, N fertilizer effects on SOC and N stocks were largely confined to surface soil depths. Long-term N fertilization levels did not impact SOC stocks for cumulative soil depths. Cumulative SOC stocks (0 to 60-inch) ranged from 47.8 tons C acre^{-1} (107.1 Mg C ha^{-1}) for sorghum-soybean to 65.1 tons C acres^{-1} (146 Mg C ha^{-1}) for corn-oat+clover-sorghum-soybean rotation. In general, 4-yr rotations resulted in greater cumulative SOC stocks for the surface to 60-inch soil depth than less complex rotations but the dominant rotation for this region (corn-soybean) had similar SOC stocks as the 4-yr rotations. Increased crop rotation diversity on SOC and N stocks was not immediate for this region, suggesting prolonged use would be required.

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SOIL ACIDIFICATION OF CULTIVATED FIELDS IN SEMIARID MONTANA: ADAPTATION AND CHALLENGES TO REMEDIATION

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ABSTRACT

Historically, soil acidification was not a problem in Montana because the parent material of most cultivated soils exhibited a neutral to an alkaline reaction. However, fertilizer ammonium-N use (including urea) by farmers has grown tremendously in recent decades contributing to leading to a downward trend in soil pH and with incidences of soil acidity/Al toxicity now beginning to appear. Here we summarize the results from on-farm sugar beet lime trials to remediate soil acidity; seed-placed P fertilizer applications to mitigate crop Al toxicity aluminum toxicity; growth; and define the relationship between soil pH and cumulative fertilizer-N inputs, in order, to better understand the legacy effects of fertilizer-N on soil pH. On-farm sugar beet lime strip-trials (15 to 25 ac) have demonstrated this product is effective at raising soil pH within one year if incorporated with tillage after application. Pulse crops, particularly lentil (*Lens culinaris*) and yellow pea (*Lathyrus aphaca*) were observed to exhibit greater early-season biomass or seed yield in response to sugar beet lime applications. Small-plot replicated fertilizer trials have shown that seed-placed P can significantly increase the yield of durum wheat (*Triticum durum*) under acidic soil conditions (pH 4.4), and even when soil P levels test very high (50 ppm Olsen-P). Long-term cropping systems studies have revealed that soil pH falls about 0.044 units for every 100 lb/ac of N input. Hence, once pH is corrected with lime the impacts will likely last for a prolonged time (>20 yr).

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INTRODUCTION

Historically, soil acidity related production problems have been virtually unknown in Montana because the parent material of most cultivated soils exhibited a neutral to an alkaline reaction. Over the past 40 years, Montana has experienced tremendous growth in fertilizer-N use (**Fig. 1**) such that N consumption is now 300% of the levels used in 1985. Fertilizer-N inputs are most frequently applied as urea, 46-0-0 (86% of all N) and often as a broadcast application to the soil surface. Coupled with this has been a no-till revolution among dryland farmers that began in the early 1990s due to the popularity of direct-seeding equipment, and then later with the introduction of low-cost glyphosate following the expiration of Monsanto's patent (2000). Because of these factors, plus nitrification of ammonium-based N fertilizer (including urea) results in acidification, it is not surprising that soil pH of surface layers has fallen. In 2011, dryland growers in central Montana approached County Extension and the Montana Agricultural Experiment Station faculty members with concerns about declining crop performance and stand-establishment in fields under long-term cultivation. Insect, disease, and plant nutrient deficiencies were all considered and eliminated as causal factors. Ultimately, soil test results revealed pH levels < 5 (some as low as pH 4.0), KCl-extractable aluminum concentrations >25 ppm, and crop roots with classic aluminum toxicity symptoms. Since this initial discovery, Montana farmers have become more aware of soil acidification and concerned/interested in its impact on crop production as well as remediation In 2016, at the bequest of farmers we initiated a study to investigate the efficacy of liming practices, fertilizer management, and cultivar selection on soil acidity management and remediation. Our presentation (and this manuscript) will highlight the results obtained from research and demonstration trials. Our objectives were i) to evaluate the efficacy of sugar beet lime applications to remediate soil acidity problems in on-farm trials; ii) determine if seed-placed P fertilizer applications would mitigate aluminum toxicity and improved crop growth; and iii) define the relationship between soil pH and cumulative fertilizer-N inputs at a long-term cropping system study field site, so as to better understand the legacy effects of fertilizer-N on soil pH.

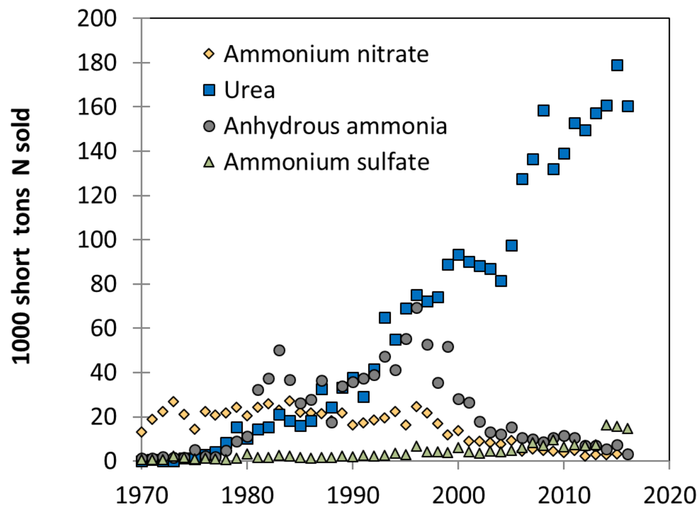

Figure 1. Historical fertilizer-N use in Montana for the most common N sources (1970 –2017).

MATERIALS AND METHODS

Sugar beet lime strip-trials

We conducted on-farm sugar beet lime strip-trials at three locations in Chouteau County, northwest of Big Sandy, south of Fort Benton and north of Geraldine. The Fort Benton and Geraldine trials were under a continuous crop management program and the Big Sandy trial was under a fallow-crop system. Each trial consisted of eight strips with three sugar beet lime rates, i.e., 0, 1, 2- and 4-ton material/ac at Big Sandy and Geraldine, and 0, 2, 4, and 6-ton material/ac at Fort Benton. The 0 and 4 ton/ac rates were replicated three times in a randomized complete block design. The sugar beet lime was transported from the Western Sugar Cooperative in Billings to the field locations. Beet lime was applied to each field site in the fall of 2017 using a Stolzfus wet lime applicator and incorporated with tillage at Fort Benton and Geraldine, but not Big Sandy (left on surface). Chemical analysis of the beet lime indicated it contained 30% moisture and 55% $CaCO_{3e}$ (wet-weight basis). Individual strips had a long and narrow configuration to incorporate natural variances in terrain and/or background soil pH that occurred across the field sites (**Fig. 2**). In 2018, the Big Sandy, Fort Benton and Geraldine locations were seeded by cooperating farmers to safflower, lentils and durum, respectively. In 2019, the Fort Benton and Geraldine the field sites were seeded to spring wheat and yellow pea, respectively, and the Big Sandy site was in fallow. The dominant soil series at Big Sandy was a Telstad loam and Bearpaw-Vida clay at Fort Benton and Geraldine. Soil pH (0-4”) at Big Sandy, Fort Benton and Geraldine prior to lime application averaged 4.87, 4.6, and 4.8, respectively, but exhibited considerable variance across the field locations. Five soil cores (0-8") were collected at georeferenced locations in the fall 2017 (prior to beet lime application), 2018 (1-yr post, and 2019 (2-yr post), and composited by depth increments of 0-2", 2-4", 4-6" and 6-8".

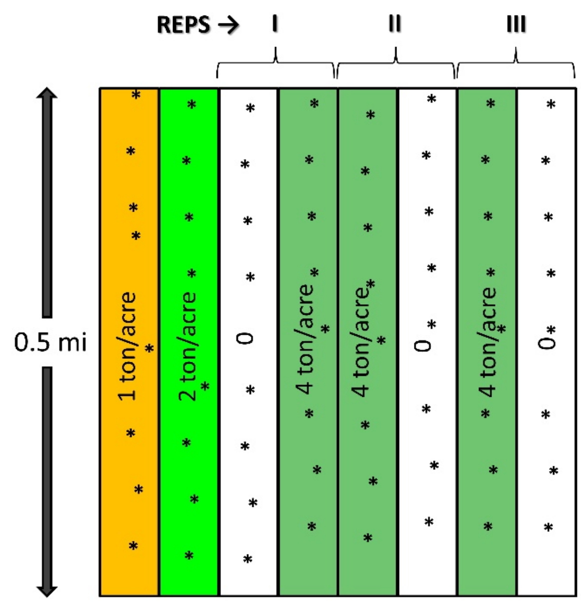

Figure 2. On-farm sugar beet lime strip-trial plot design at Big Sandy and Geraldine farm sites. Plot plan at Fort Benton was similar except strips were 0.28-mile-long and a 6-ton/ac rate replaced the 1-ton/ac rate. Individual plots were 60' feet wide. Soil cores were collected at geo-referenced locations (*) along a transect that ran parallel to the length of each plot (precise locations not identified in the figure).

Seed-placed P fertilizer trials

We conducted a replicated small-plot P fertilizer trial with durum wheat in 2018 and 2019 at a farm on the Highwood Bench, south of Fort Benton Montana. The soil was a Gerber silty clay with pH 4.4. The study was a factorial of five P fertilizer rates of 0, 15, 30, 60 and 90 lb P_2O_5/ac and two Ag-lime treatments (0, 5 ton/ac). The Aglime was purchased from Montana Limestone Company, broadcast applied in the fall of 2017 with a Stolzfus wet-lime applicator, and incorporated with tillage (6" depth). Treatments were replicated three times in a split-block design with lime main-plot and P rate sub-plots. Plots were five rows or 5' wide and 20'in length.

Soil pH at the MSU-GGRS long-term cropping system trial

The MSU-Greenhouse Gas Research Study consists of eight-crop management systems (including fallow-wheat, continuous wheat, and diversified wheat-based systems with pulse and oilseed crops) managed under two fertilizer-N input levels. The field study was initiated west of Bozeman at the MSU Post Farm in Fall 2002. The soil is an Amsterdam silt loam. This study was initiated principally to determine the impact of cropping systems on soil organic C in

Montana. However, it also provided a controlled study where cumulative fertilizer-N inputs varied greatly among the 16 treatments (20 to 2050 lb N/ac) over a 14-yr time-window (2002-2016). In 2016, soil cores (0-4" depth) were collected from all plots and analyzed for pH to quantify the long-term impact of cumulative fertilizer N inputs on surface soil pH.

RESULTS AND DISCUSSION

Sugar beet lime strip-trials

We found sugar beet lime applications (applied Fall 2017) at Fort Benton and Geraldine raised soil pH (0-4") over a 1-year and 2-year time window according to the curvilinear relationship of **Fig. 3.** The dominant soil series at both field sites was Bearpaw-Vida clay loam, and so it was not surprising then the pH change with lime was similar at the two locations. Overall, the relationships demonstrated beet lime was effective at ameliorating soil acidity, and that most of the pH changes occurred during the 1st year if the lime material was incorporated with tillage. Sugar beet lime requirements necessary to raise soil pH by 1.3 units to a target pH of 6 was approximately 2.5 tons/ac, or 2750 lb $CaCO_3$/ac. This application rate equates to a $100/ac investment for transport and field application with tillage incorporation**†.** While this is a considerable cost input, we believe the costs are modest when viewed over a long-term time horizon (e.g., 20 years - discussed below).

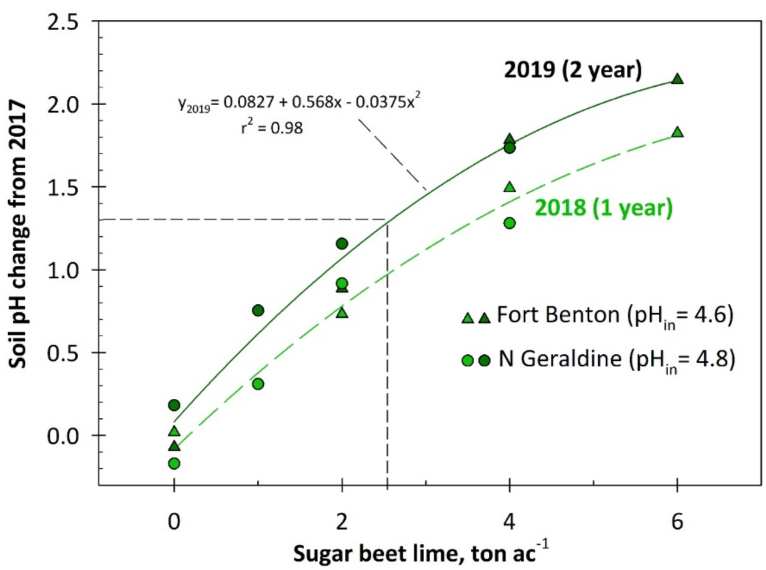

Figure 3. Soil pH change from 2017 at 1-year (2018) and 2-year (2019) post-application of sugar beet lime.

Soil pH depth-profile relationships at the 4 ton/ac beet lime application rate revealed that pH was affected in the 0-2" and 2-4" depth layers at Geraldine and Fort Benton trial, and only the 0-2" layer at Big Sandy (**Fig. 4**). This response was not surprising as sugar beet lime was incorporated with tillage at Geraldine and Fort Benton, while at Big Sandy it was left on the soil surface without incorporation. These results demonstrated for the benefit of area farmers that beet lime does not wash into the soil if left on the surface, and that incorporation will be necessary to correct soil acidity to eliminate pH stratification in Montana's semiarid climate.

† Sugar beet lime transport cost to the farm was estimated at $35/ ton, and field application plus tillage was estimated at $12/ac.

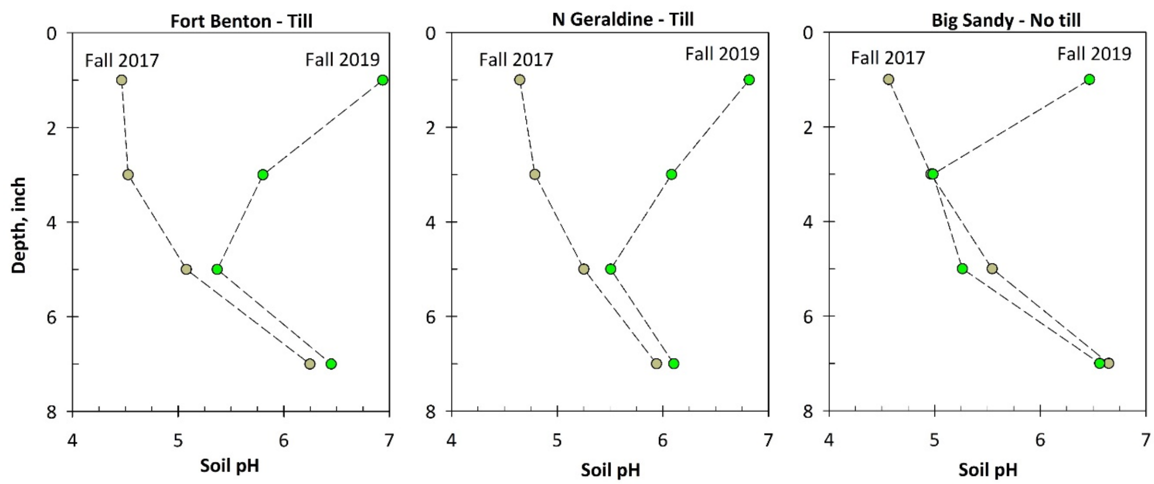

Figure 4. Soil pH depth-profile in fall 2017 and 2019, or before and after sugar beet lime application (4 tons/ac) at Fort Benton (till), N Geraldine (till), and Big Sandy (no-till).

Significant grain yield responses to sugar beet lime at our strip-trial locations were not been observed for durum, spring wheat and safflower in 2018 and 2019. However, we have found visually obvious differences in lentil and yellow pea growth to beet lime applications. In 2018, lentil top growth was greener, and biomass was 50% greater in areas receiving lime compared to the non-limed area at Fort Benton (**Fig. 5A**). Similarly, in 2019 we observed yellow pea growth at Geraldine was more robust where lime was applied (**Fig. 5B),** seed yields were significantly impoved relative to areas/strip without lime (-lime = 23.3 bu/ac vs. +lime =30.0 bu/ac). The benefit of liming was believed to result from improved rhizobia activity, nodulation, and N-nutrition of these pulse crops.

A. Lentil – May 29, 2018 **B. Yellow pea – June 19, 2019**

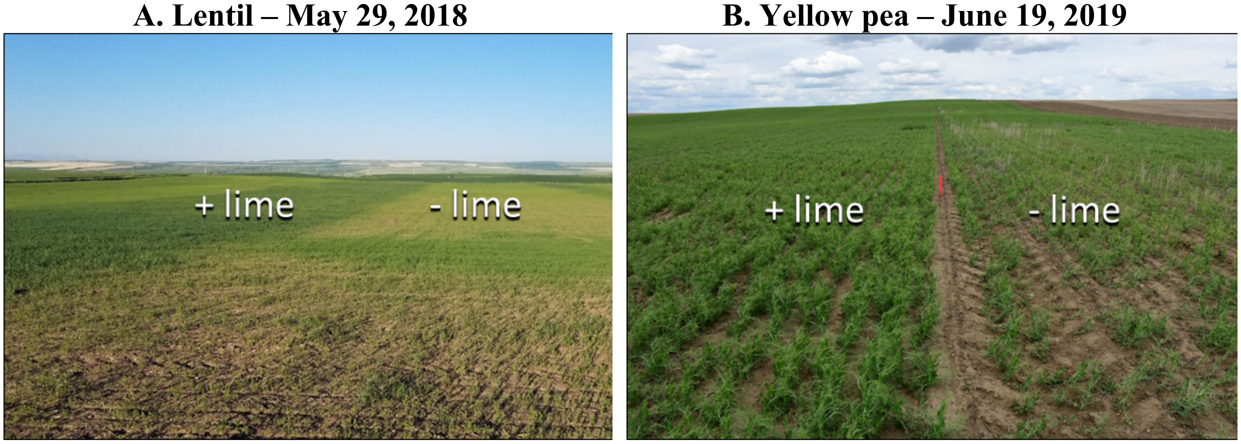

Figure 5. Visual differences in lentil and yellow pea growth were apparent from the sugar beet lime applications at Fort Benton (left) and Geraldine (right) sites.

Seed-placed P fertilizer trials

In 2018, we observed a large growth response to P fertilization in durum where the soil pH was not amended with Aglime application (**Fig. 5)**. Grain yield was affected by the interaction of lime and P fertilizer (**Fig. 6**). Briefly, seed-placed P fertilizer mitigated Al toxicity symptoms and improved grain yield 20 bu/ac over unfertilized controls where lime was not applied. Conversely, durum was unresponsive to P fertilizer where lime was applied to correct soil acidity. In 2019, a similar response by durum to P fertilizer was evident early in the growing season at the Highwood Bench field site. However, two hailstorm events during the growing season reduced yield by approximately 50% and the mitigated the response to P fertilizer. Our results indicate that seed-placed P fertilizer provides a method for mitigating Al toxicity at field sites with acidic soils, and occurs even at sites with very high soil P levels. Reports from Kansas winter wheat trials, some dating back to the 1990s, have shown a similar response. Utilization of high rates of seed-placed P to mitigate Al toxicity should be viewed as a short-term approach to manage acidic soils. In Montana, this strategy might best be applicable where a farmer is renting land under a short-term lease agreement (e.g., 5-years).

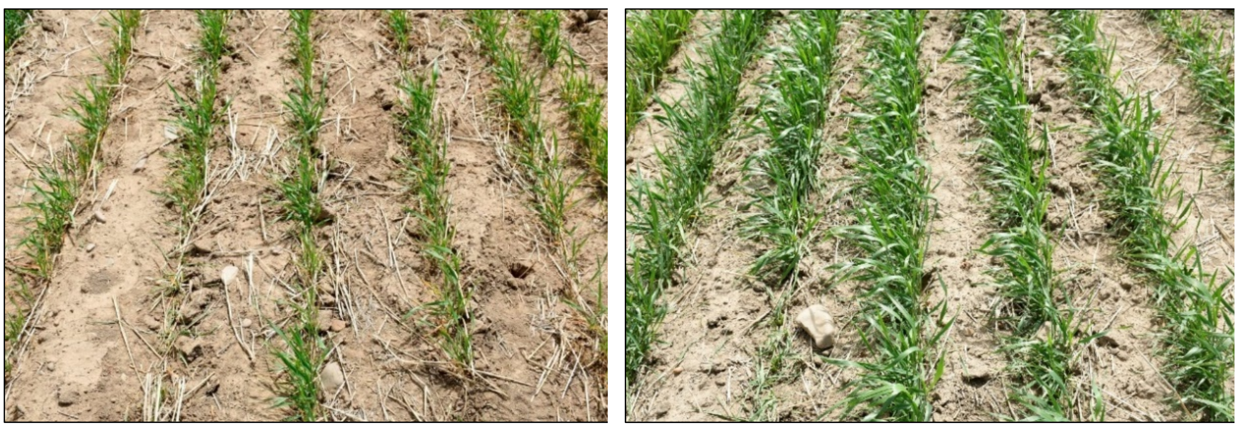

Figure 6. Seed-placed P (right) resulted in more vegetative growth and higher durum yields than 0 P, control areas (left) at our field site on the Highwood Bench and where soil pH was not remediated with lime.

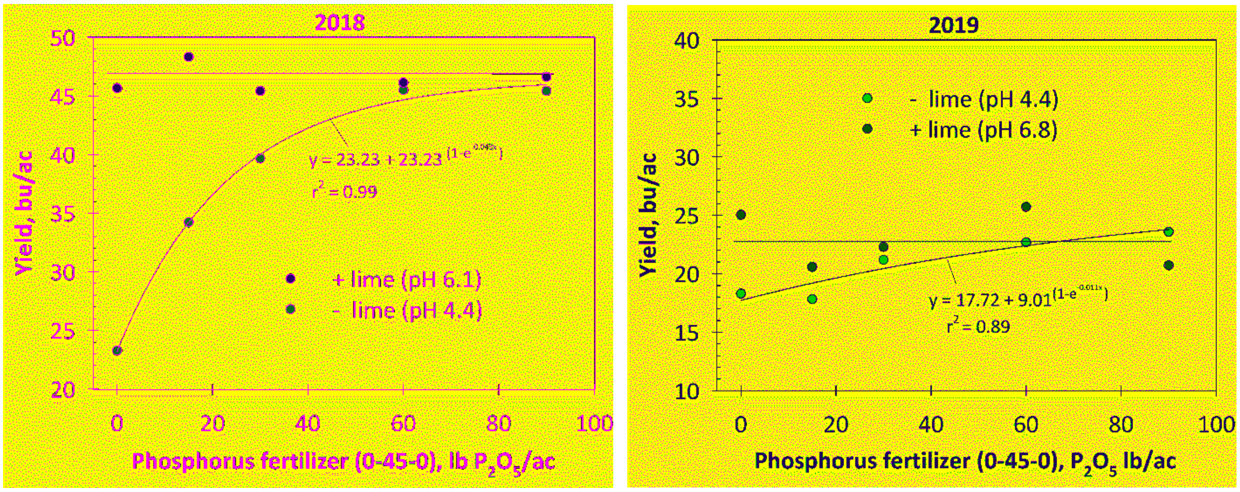

Figure 7. Durum grain yield on the Highwood Bench was improved with P fertilizer under acid soil conditions (-lime) but was not affected where soil acidity was mitigated with lime applications. Olsen soil P level = 50 ppm in 2018 and 83 ppm in 2019 (very high).

Soil pH at the MSU-GGRS long-term cropping system trial

Soil pH vs. cumulative fertilizer-N input relations (**Fig. 8)** demonstrated that soil pH was directly related to fertilizer-N for eight cropping system x two fertilizer-N level treatments. The slope of the lines indicates that soil pH fell 0.044 for every 100 lb N/ac input, which equates to a drop of 1 pH unit over 23-year at this level of fertilizer-N. These results are significant as they provide an index of the buffering capacity of Montana soils. Our on-farm investigations with sugar beet lime revealed that 2.5 tons of sugar beet lime material were required to remediate soil pH 4.6 to 4.8 to a target pH of 6. The estimated cost of this remediation is approximately \$100/ac. If we assume soil acidity-Al toxicity problems do not develop until pH < 5, then a similar soil would require 2300 lb/ac of cumulative fertilizer-N inputs before a production problem might be expected. Although, fertilizer-N inputs and soil buffering capacity vary among farms these results add credibility to our belief that lime remediation of acidic soils in Montana's climate will have a prolonged impact on land productivity (>20 years).

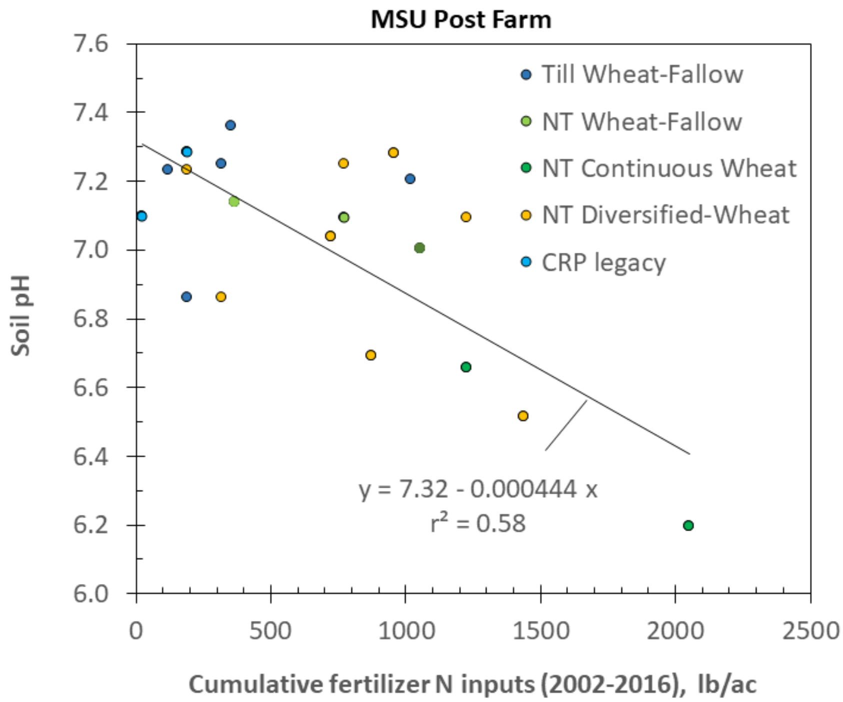

Figure 8. Soil pH vs. cumulative fertilizer N inputs over 14 years at the MSU-Greenhouse Gas Research Study location near Bozeman, Montana.

EFFECT OF FOLIAR ZINC APPLICATION ON SPRING WHEAT GRAIN YIELD AND QUALITY

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ABSTRACT

Zinc (Zn) deficiency represents a common micronutrient deficiency in human populations, especially in regions of the world where staple food crops are the main source of daily calorie intake. Micronutrients like Zn also plays an important role in growth and development of plant thereby affecting crop yield and quality. A two-year field trial was conducted at Sidney, Montana, to investigate the effect of foliar application of Zn on yield and grain quality of spring wheat. Zinc treatment included foliar application of Zinc Sulfate at a rate of 1.12 kg ha^{-1} 1) at heading (Feekes 10.1) and 2) at both heading and flowering (Feekes 10.5) stages compared to control (nill Zn application). Cultivars responded differently to Zn fertilization but grain Zn concentration as well as grain yield increased in overall with Zn treatments. First application of Zn only increased grain Zn concentration marginally and, for most of the tested cultivars, the second application at flowering was required to bring grain Zn concentration above the health limit. Zinc fertilization also increased chlorophyll and carotenoid contents in wheat crops. Our results showed that Zn foliar application can be used as an efficient biofortification tool to increase nutritional quality of Montana wheat.

INTRODUCTION

Considering the area cultivated (232 million ha) and amount of grain produced (595 million t) (Sultana, et. al., 2016), wheat (*Triticum spp*.) is the third most-produced cereal after corn and rice (Kandoliya, et. al., 2018). The amount of Zn in wheat grain must meet a standard for human health in many countries, and nutritionists suggested that 40 mg Zn kg^{-1} is required in grain wheat (Ram, et. al., 2016). Management strategies targeting grain Zn densities are urgently needed to fight Zn deficiency in human populations. Approximately two billion of world population is affected by Zn deficiency (Zn D) due to low dietary intake of Zn (Chen, et. al., 2017). Zinc is a crucial element in regard to plant growth, as a functional, structural, or regulatory cofactor of many enzymes (Ma, et. al., 2017). However, information is lacking if there is Zn D in Montana produced wheat and if late-season foliar application of Zn will improve spring wheat yield and Zn concentration. It is, however, important to notice that genotypes may respond differently to foliar Zn application in terms of absorption and translocation at the reproductive stage (Mabesa, et. al., 2013). The timing of Zn fertilization is also critical when looking to improve Zn concentration in wheat grains (Zou, et. al., 2012). More information is needed on behavior of wheat genotypes in respect to Zn absorption and distribution in plants, which will contribute to improvement of the agronomic and genetic biofortification strategies.

The objective of this study was to assess the effects of foliar Zn application on the uptake, translocation and accumulation of Zn in five cultivars of spring wheat with different timing and rates of foliar application of Zn.

MATERIALS AND METHODS

A 2-yr field trial (2017 and 2018) was carried out at the Eastern Agricultural Research Center at Sidney, MT. Five cultivars of spring wheat (Velva, Faller, Prosper, Glenn, Eagan) were used in this study. Zinc treatment included 1) foliar application of Zn sulfate (ZnSO4 containing 35.5% Zn), at a rate of 1.12 kg ha^{-1} at heading stage (Feekes 10.1), 2) foliar application of 1.12 kg ha^{-1} at both heading and flowering stages (Feekes 10.5), and 3) control (nill Zn application).

The experiment was set up in a factorial arrangement within randomized complete block design with four replications. Wheat was planted on April 21st. The measurements in season included: photosynthesis pigments (chlorophyll and carotene) at four times (June 23, July 03, July 11, and July 14). After harvesting plants on August 15th, plant parts were separated into straw and grain. The measurements included total biomass, grain yield, grain protein, grain and straw Zn concentration.

Zinc use efficiency (ZUE) (Fageria and Baligar, 2001) and Zn translocate ratio (ZTR) (Impa et. al., 2013) was calculated to reflect varietal difference among tested cultivars in term of efficient use of applied Zn as follows:

$$ZUE = \frac{\text{Zn concentration in grain}}{\text{Total Zn applied}}$$

$$ZTR = \frac{\text{Zn content in grain}}{\text{Zn content in whole plant}}$$

Data Analysis:

Data were analyzed using analysis of variance (ANOVA) in SAS. Mean were separated using the Tukey test at 95% confidence level ($P < 0.05$).

RESULTS AND DISCUSSION

Grain yield and protein

Zinc foliar application affected wheat grain yield significantly (Table 1). Zinc application at heading stage (Zn1) increased grain yield by 10.7 % and the second application at flowering stage (Zn2) further increased yield by 19.7 % compared to untreated control (average over all cultivars). Similar results have been reported by others indicating that foliar application Zn can improve cereal yield (Cakmak and Kutman, 2018). Foliar application Zn also enhanced grain protein concentration from 156 g kg^{-1} (in control) to 158 and 161 g kg^{-1} in Zn1 and Zn2 treatments, respectively (Table 1). This enhancement in grain protein can be attributed to the role of microelements in maintaining balanced plant physiological growth and activation of plant enzymes. In fact, micronutrients have been reported to affect the physiological processes of plants, which has a significant impact on grain yield and quality (Niyigaba, et. al., 2019).

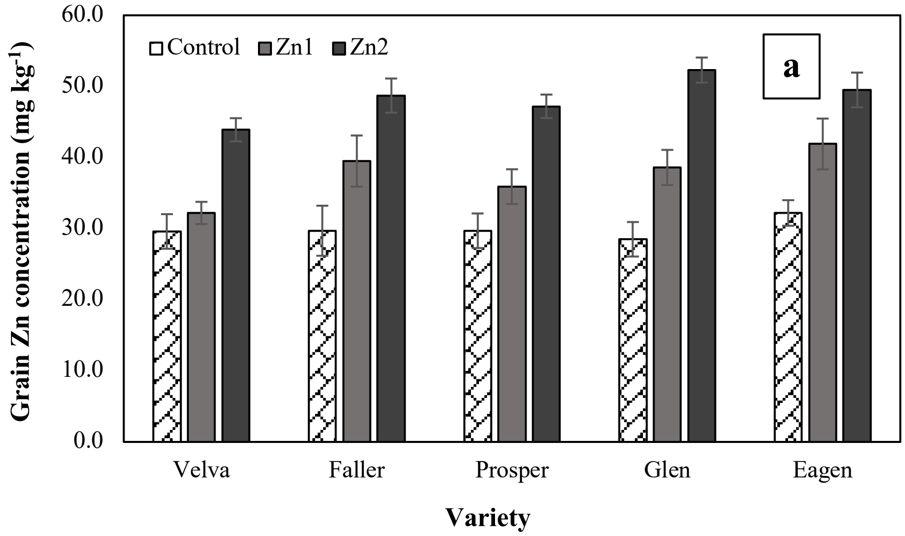
Table 1. Effect of Zn foliar application on grain yield, protein content, grain and straw Zn concentration of five spring wheat varieties in field trial.

Spring wheat	**Grain yield ($kg\ ha^{-1}$)**	**Protein ($g\ kg^{-1}$)**	**Grain Zn ($mg\ kg^{-1}$)**	**Straw Zn ($mg\ kg^{-1}$)**
Ctrl	2057c	156b	29.9c	5.0c
Zn1	2277b	158ab	37.6b	13.9b
Zn2	2462a	161a	48.3a	38.2a
Level of significance	**	*	**	**
Velva	2687a	155c	35.4c	19.4b
Faller	2353b	153c	39.6ab	21.0ab
Prosper	2295c	153c	38.1b	19.3b
Glenn	2203c	159b	40.3a	13.9c
Egan	1928d	172a	41.6a	23.9a
Level of significance	**	**	**	*
Zn*V	ns	ns	*	*

*Significant at $P \leq 0.05$; **Significant at $P \leq 0.01$; ns: non-significant

Zn concentration in grain and straw

Grain and straw Zn concentrations were influenced by foliar Zn application (Fig. 1 a, b). Cultivars, however, responded differently to Zn application in terms of grain Zn concentration. Velva was the least responsive cultivar to Zn application at heading. The second application of Zn significantly boosted grain Zn concentration in all cultivars. Average over all cultivars, grain Zn concentration raised from 29.9 mg kg^{-1} (in control) to 37.6 mg kg^{-1} in response to one time foliar application at heading, and to 48.3 mg kg^{-1} in response to the second application of Zn at flowering (Fig. 1 a, b). A successful biofortification treatment should bring up grain Zn concentration to about 40–45 mg kg^{-1} (Cakmak, 2008). In our study, this level was achieved by the second application of Zn at flowering stage. While enhancement of grain Zn concentration was slight in response to the foliar application of N, a notable increase in straw Zn concentration was observed in response to Zn application specifically in Zn2 treatment. As shown in Fig. 2, some cultivars have a greater capacity to translocate absorbed Zn into the grain (with greater ZTR values) so have greater potential for biofortification of Zn.



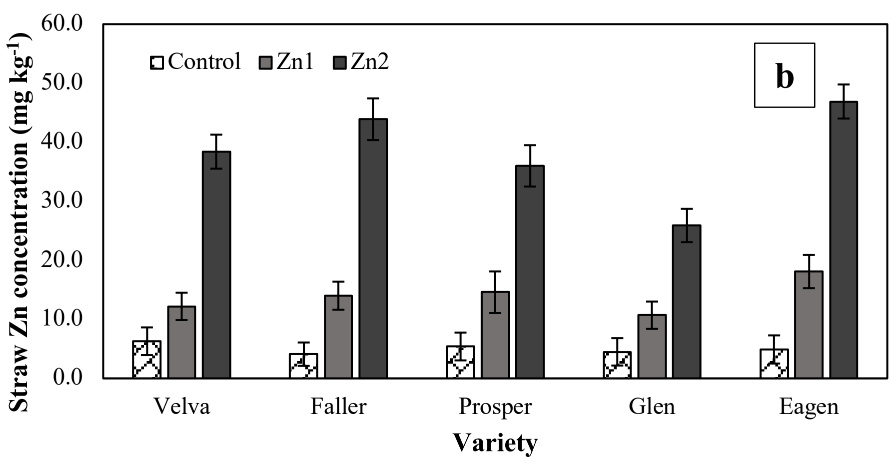


Figure 1. Effect of Zn application on spring wheat grain (a) and straw (b) in field trial

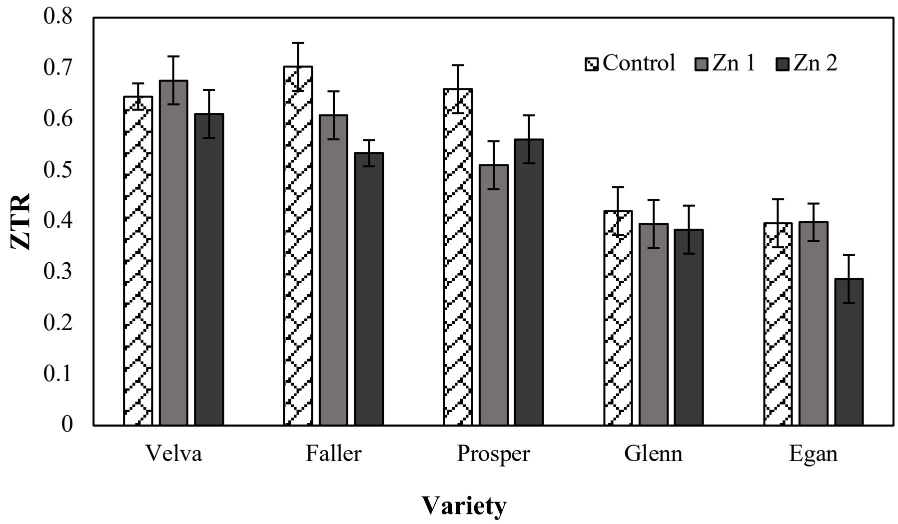


Figure 2. Zinc translocation ratio on spring wheat grain in field trial

Leaf pigments

In this experiment, Zn foliar application affected the chlorophyll content in wheat leaves (Table 2). At all growth stages, leaves of plant treated with Zn showed greater concentrations of total chlorophyll content compared to untreated control. Carotenoid content also showed a similar response to Zn application (Table 3). It has been hypothesized that chlorophyll synthesis is improved by Zn application, because Zn acts as a structural and catalytic component of proteins, enzymes, and as co-factor for normal development of pigment biosynthesis (Ma, et. al., 2017). This indicates that sufficient Zn can prolong the period of flag leaf active photosynthesis, which is the most important for grain filling. This could explain, in part, the grain yield increased in response to Zn application.

Table 2. Effect of Zn foliar application on chlorophyll content (mg/g) on June 23, July 03, 11, and 14 in two spring wheat varieties (Velva, Glenn).

	June 23		**July 03**		**July 11**		**July 14**
	Flag	**Second**	**Flag**	**Second**	**Flag**	**Second**	**Flag**
Ctrl	11.8b	7.0a	3.9b	1.6a	2.6a	0.7a	0.5b
Zn1	14.9a	7.6a	4.5b	1.8a	3.0a	1.2a	1.2a
Zn2	-	-	5.6a	2.1a	3.1a	1.3a	1.3a
Level of significance	**	ns	*	ns	ns	ns	*
Velva	13.7ab	5.8b	4.9a	1.8a	2.6ab	1.5a	1.1a
Glenn	11.6c	6.4b	4.4a	1.9a	2.0b	0.6b	1.2a
Level of significance	*	ns	ns	ns	*	*	ns
Zn*Variety	*	ns	ns	ns	ns	ns	*

*Significant at $P \leq 0.05$; **Significant at $P \leq 0.01$; ns: non-significant

Table 3. Effect of Zn foliar application on Carotene (µg/g) on June 23, July 03, 11, and 14, in two spring wheat varieties (Velva, Glenn).

	June 23		July 03		July 11		July 14
	Flag	**Second**	**Flag**	**Second**	**Flag**	**Second**	**Flag**
Ctrl	2.1b	1.3b	0.8a	0.2a	0.5b	0.2a	0.2a
Zn1	2.8a	1.4a	0.8a	0.3a	0.5b	0.2a	0.3a
Zn2			0.9a	0.3a	0.7a	0.3a	0.4a
Level of significance	**	*	ns	ns	*	ns	*
Velva	2.3ab	1.0b	1.0a	0.4a	0.5a	0.2a	0.2ab
Glenn	2.1b	1.2b	0.7a	0.2a	0.6a	0.2a	0.1b
Level of significance	*	ns	ns	ns	ns	ns	*
Zn*Variety	*	ns	ns	ns	ns	ns	*

*Significant at $P \leq 0.05$; **Significant at $P \leq 0.01$; ns: non-significant

CONCLUSION

Foliar application of Zn increased grain yield, grain protein, and grain Zn concentration. In four out of five tested cultivars, one single application of Zn at heading was not sufficient to boost grain Zn concentration and a second application at flowering stage was required to significantly enhance grain Zn concentration. Majority of Zn applied remained in wheat leaves and stems, and was not translocated to the grain at grain filling stage. Cultivars represented various abilities and efficiencies for Zn translocation. Our results showed that ZTR could be used as an effective measure to select those with greater potential for biofortification Zn. Therefore, this index can be integrated into a breeding program for improving cultivars more suitable for biofortification and production healthier grain with a higher Zn concentration.

ACKNOWLEDGEMENT

Funding Summary: The project was supported by Montana Wheat and Barley Committee.

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RATE AND DEPTH OF LIQUID P FERTILIZER PLACEMENT AFFECTS ROOT ARCHITECTURE AND ARBUSCULAR MYCORRHIZAL FUNGAL ASSOCIATIONS IN GRAIN CORN

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ABSTRACT

A two-site, two-year study was conducted on corn root response to liquid phosphorus (P) fertilizer applications as a function of rate and depth of placement. Corn planted into no-till at two locations (Thrall & Snook, TX) was fertilized with banded liquid P applied 15 cm off seed row at different rates and depths. The upper portion of the root systems were excavated along with all top plant matter at the V10 - V12 growth stage. Digital images of washed roots were analyzed for spatial density of roots relative to the zone of concentrated P fertilizer. Images were processed using the free-ware application ‘ImageJ’. Results for two years at both sites indicated decreased root densities associated with the volume of soil nearest the banded zone. Yield differences, when present did not show a relationship to rate of P application. However, there was a positive relationship between both rate of phosphorus and depth of application to concentration of P in corn leaf tissue collected at the same time. In the second year, the association between arbuscular mycorrhizal fungi (AMF) and roots was examined. Root-AMF colonization was negatively affected by both rate and depth of P fertilizer application.

INTRODUCTION

Phosphorus (P) is an essential primary macronutrient for crops. Grain crops such as corn (*Z. mays*) have a high relative P requirement, and exhibit characteristic yield responses to application of fertilizer P when soil supply is less than sufficient (Grant et al., 2001; Dodd and Mallorino, 2005; Veneklaas et al., 2012). However, Plant uptake of P fertilizer is constrained by poor solubility of phosphate (PO_4^{3-}), low mobility, and high favorability of chemical reactions that precipitate or fix PO_4^{3-}, in soil. Furthermore, the mineral source supply of P is finite and is becoming more costly each year. Therefore, improvements to P fertilizer use efficiency are key to ensuring food security and to the sustainable production of crops worldwide (Schröder et al., 2011).

A number of strategies for improving efficiency and sustainability in the use of P resources in agricultural production have been identified, i) including intensification of recycling of nutrients from manures, ii) reducing inputs via adoption of better fertilizer source, timing, placement and rate of application practices, iii) erosion prevention, iv) improvement of crop genotypes, v) modification of root systems, and vi) enhancement of mycorrhizal symbioses (Shenoy, and Kalagudi, 2005; Ramaekers et al., 2010; Schröder et al., 2011). Plant root architecture is a major determinant of soil P acquisition, and P availability in and of itself is known to affect root architecture. When experiencing stress from low P availability, plants respond by shifting photosynthetic product to the root system to improve access to soil P supplies (Péret et al., 2011). Lopez-Bucio et al. (2002) reported a negative relationship between phosphorus availability and both lateral root and root hair formation in *Arabidopsis.*

Plant root architecture and P acquisition can be enhanced through mutualistic association with arbuscular mycorrhizal fungi (AMF). Kabir et al., (1998) showed that AMF density in corn roots was positively associated with phosphorus uptake, and that AMF activity was greater in no till, as compared to moldboard plowed, soils. The level of mutualism between corn and AMF is negatively related to the plant availability of phosphorus in soils (Ryan et al., 2000). The paradigm in this system appears to favor greater activity in soil P acquisition by root / AMF combined activity under P stress conditions. Yet there is no evidence to suggest that this system can, in the absence of P fertilization, produce yields competitive with conventional fertilizer practice.

Work in Texas has shown that the use of banded liquid P fertilizer as *source* (e.g. ammonium polyphosphate) can increase use-efficiency and yield in grain production (Miller, 1998; Coker et al., 2007). The primary goal of this study was to further investigate the effect of depth of placement of ammonium polyphosphate (APP) on P fertilizer use efficiency in corn production. The second goal of this study was to examine the effect of fertilizer rate and placement on corn root architecture in the field. In the second year of the study, additional supporting data was collected to examine the effect of the treatments on root / AMF associations.

MATERIALS AND METHODS

Study Location

Field experiments were conducted at the Bottom Farm (Snook, TX; 30.524669, -96.439846) and at the Stiles Farm (Thrall, TX; 30.595260, -97.283772) during the spring and summer of 2016 and 2017. The soil at the Bottom farm is a Weswood series (fine-silty, mixed, superactive, thermic Udifluventic Haplustept). The soil at the Stiles farm study site is a Burleson series (fine, smectitic, thermic Udic Haplustert).

Experimental Design

Treatments for rate and depth of P fertilizer placement are shown in Table 1. All other nutrients were supplied at the Texas A&M AgriLife Extension Soil Water and Forage Testing Laboratory recommended rate according to soil test results (SWFT Laboratory, College Station TX). Nitrogen contained in the APP applied at different rates was accounted for. The field experimental design was randomized complete block with a minimum of four replicates for each site-year. In the second year, 2017, the only change was to move the plots to an immediately adjacent area to avoid carryover from different P fertilizer applications in 2016.

Table 1. Corn P fertilizer rate and depth treatments at 4 site-years

#	Treatment Abbr. rate-depth	Treatment Description
1	0-0	Control - No P fertilization
2	1-0	Surface applied APP at the recommended rate
3	0.5-10	APP at half soil test recommended rate at 10 cm below soil
4	1-10	APP at 0.5x soil test recommended rate at 10 cm below soil
5	1.5-10	APP at 1.5x soil test recommended rate at 10 cm below soil
6	0.5-20	APP at 0.5x soil test recommended rate at 20 cm below soil
7	1-20	APP at 1x soil test recommended rate at 20 cm below soil
8	1.5-20	APP at 1.5x soil test recommended rate at 20 cm below soil

Soil and Tissue Sampling and Analysis

Soil samples were collected as 0-20 cm samples for routine nutrient recommendations, and as 20-61 cm depth samples for residual NO_3-N. Routine nutrients were analyzed at the SWFT Laboratory in College station for pH, EC, P, K, Ca, Mg, and S (Mehlich III/ICP-AES), and NO_3-N (1M KCl/ cd reduction colorimetry). Tissue samples were collected at V6-V10 growth stage range as time and conditions allowed, and again after tasseling but before the onset of dry down. Ten uppermost unfolded leaves were collected for the early sampling, and ten ear leafs were collected at the later sampling events. Total nitrogen was measured by combustion. Nutrient concentrations (e.g. P, K, Ca, Mg, S) were measured by first digesting (microwave assisted aacid digestion) and measurement on ICP-AES.

Root Sampling and Analysis

Three replicates from each treatment were excavated by hand shovel at V8-V10 growth stage as a ‘column’ of soil and roots centered at the base of the stalk, at least 30 cm in diameter and 40 cm deep. The columns were allowed to soak in water in 20 liter plastic buckets for 24 to 48 hours before washing with gentle pressure. The band side of the plant was tracked using a wooden skewer with a blue marking on the band side inserted through the stalk. The entire root mass was imaged with a digital camera on a black background. The image was separated into 4 quadrants situated relative to the axis of the stalk. Each quadrant was 10 cm x 10 cm (Figure 1.)

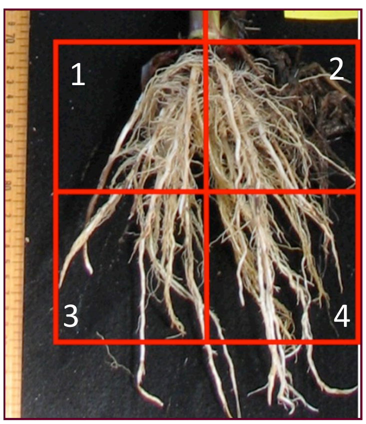
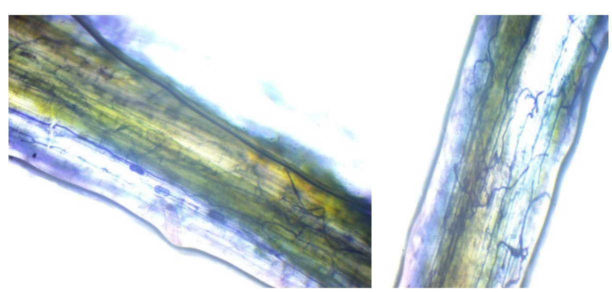


Figure 1. (to left) 10 x 10 cm quadrants were imposed on the corn root crown. A ruler placed in the frame was used to establish scale. Percent coverage within each quadrant was measured using ImageJ freeware. (https://imagej.nih.gov/ij/).

AMF Measurement

Ten 1 cm segments of from each quadrant from each of the excavated plants were cut for AMF staining and imaging. The segments were boiled in 10% KOH for 13 minutes and stained with an ink-vinegar method (Vierheilig et al., 1998). The roots were digitally imaged on the microscope, and the density of AMF quantified as percentage of 10 root subsections for each segment with evidence of colonization (Figure 2.) The mean of each of the 10 sections was used for statistical comparison.

Figure 2. (to right) root images with evidence of AMF hyphae as blue-dyed ‘tendril’ like structures and arbuscules as blue ‘kidney’ shaped structures.



Statistical Analysis

Yield, leaf tissue P content, root density by quadrant, and AMF colonization percentage were all tested as response variables for effect of treatments imposed in Table 1. The GLM procedure in SAS software (SAS Institute Inc., Cary, NC, USA) was used to calculate analysis of variance at $\alpha = 0.1$. The model used was response variable = rate depth rate*depth. Post-hoc analysis was performed as comparison of means (Dunnett's in PROC GLM) at $\alpha = 0.1$ and multiple linear regression analysis (PROC REG) whenever ANOVA results were significant for rate or depth.

RESULTS AND DISCUSSION

Corn Grain Yield

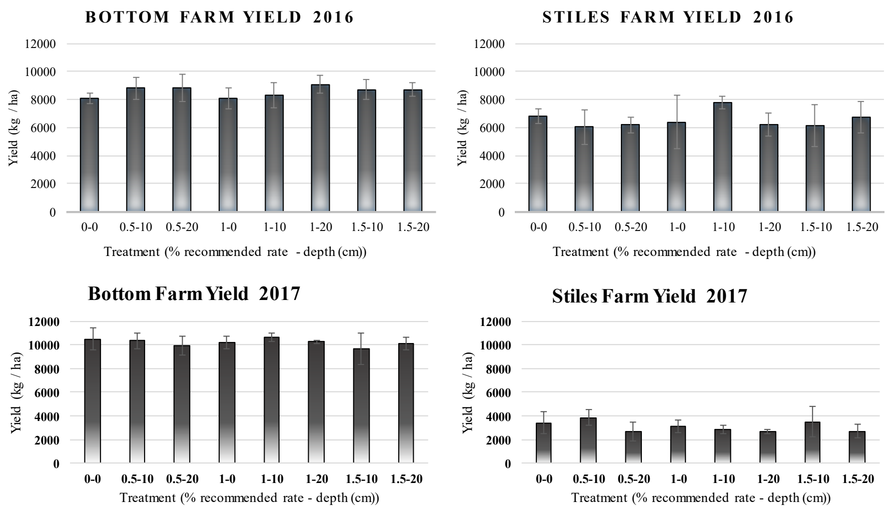


Figure 3. Corn grain yields were not responsive to rate or depth of P fertilizer applications in any of the 4 site years of the study. Recommended rates of P application varied from 56 to 67 kg / ha (50 to 60 lbs / acre) P_2O_5. Yields were near or above goals in 3 site years. Stiles 2017 harvest was below yield goal.

Root Architecture

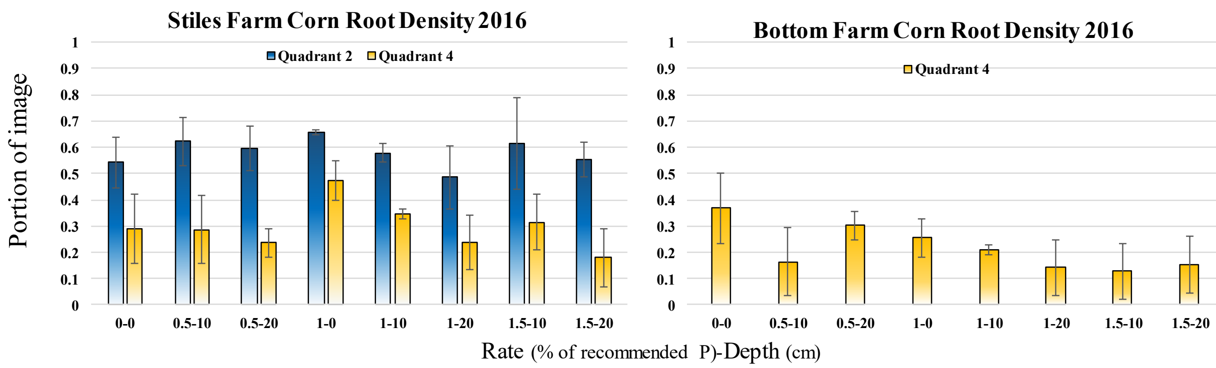
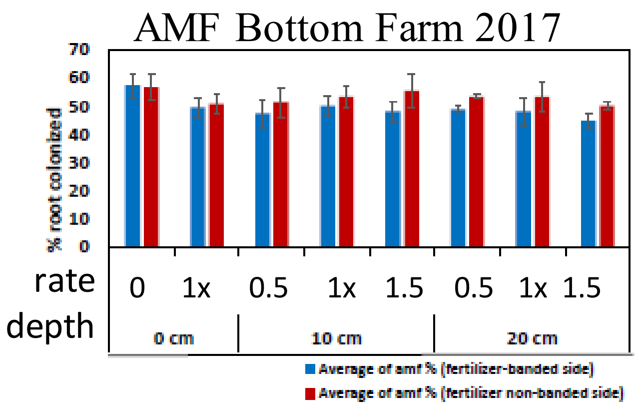


Figure 4. Root density in quadrants from image analysis indicate a significant effect of depth on density in the 2nd and 4th quadrants at the Stiles Farm in 2016 and in the 4th quadrant at the Bottom farm in 2016. The 2nd and 4th quadrants were adjacent to the band. The 1st and 3rd quadrants were unaffected by rate or depth of P fertilizer placement in all site years. In both 2016 and 2017 at the Bottom Farm, the control treatment exhibited the greatest root mass in quadrant 4.

Corn Root / AMF Association



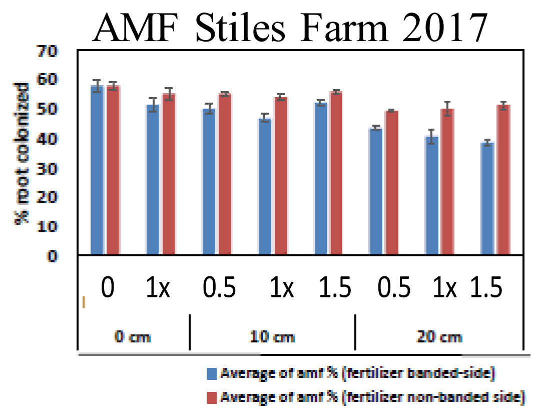


Figure 5. AMF association with corn roots was in every case greater on the side of the seed row away from the band placement. This indicates an inhibitory effect of P fertilizer on AMF association in the field. In the control treatment, no difference was seen in AMF density between sides of the seed row. The control treatment also either significantly the greatest or grouped with the greatest treatments in terms of amf density in any single quadrant. This indicates that *any* application of P fertilizer can inhibit amf / root association.

The need to increase P fertilizer use efficiency has stimulated suggestions for strategies towards achieving that goal. However, as this study indicates, there are potential negative interactions between some of these strategies. In this case, the use of an improved P fertilizer source inhibited the effect of other strategies, such as the encouragement of rooting architecture that is more prolific and capable of accessing immobile P from a greater soil volume. Mutualism between corn and AMF was also depressed by both rate and depth of placement of APP. This research raises questions about the accuracy of soil test recommendations for no-till crops. Correlation and calibration work in the U.S. has historically and almost exclusively been performed on conventionally tilled soils. The established relationships between soil disturbance (and now P fertilizer application) and rooting proliferation and AMF association suggest that a new examination of P fertilizer recommendations in conservation tillage is an appropriate and timely area for research updates.

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MANAGING NUTRIENTS IN BEEF FEEDLOT MANURE – LESSONS FROM A 45-YEAR FIELD STUDY

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ABSTRACT

The original objective of a long-term field experiment established in 1973 was to determine the safe loading capacity of soil with beef cattle feedlot manure. Manure was applied annually at 0, 30, 60, and 90 Mg ha^{-1} (wet weight) under rainfed and 0, 60, 120, and 180 Mg ha^{-1} under irrigated conditions. The long-term manure applications increased organic matter, nitrogen (N), phosphorus (P) and potassium (K) content and salinity in the soil, and barley forage yield at all manure rates but reduced barley grain yields at higher application rates. The N and P content in barley forage and grain also increased with the rate of manure application. Manure improved soil biological quality by increasing soil microbial biomass and enzyme activities. Active carbon (C) (permanganate-oxidizable C) was sensitive to both water and manure management, while appearing to be the soil health indicator most closely related to the enzymes involved in C, N, P and S cycling, representing meaningful, high throughput, and thus emerged as a cost-effective soil health indicator for manured soils of the Great Plains. When 30 years of manure application at 60 Mg ha^{-1} was followed by a decade or so without manure, there were limited legacy effects on GHG fluxes and most soil health indicators. The high nutrient levels in manured soil increases the potential for nutrient losses and surface and groundwater contamination. The soil nutrient enrichments were long-lasting and could pose environmental threats long after application has stopped.

INTRODUCTION

Manure is a valuable resource when used judiciously as a soil amendment, but can become an environmental polluter when mismanaged. While traditional farm crop and livestock production complemented each other locally with minimal nutrient export, this local linkage has now been broken in the specialized modern farm. Various subsidies and cheap inorganic fertilizers have also contributed to livestock/crop production decoupling. Nutrient export/import has increased, and nutrients now flow over great distances compared to the prior practice of nutrient recycling within a farm. For example, the beef cattle industry in southern Alberta imports corn feed from the U.S. mid-west and exports timothy grass to Japan and Korea as a source of fiber for dairy cows and horses. The decoupling of animal and crop production has led to manure over-supply near the source (large confined feeding operations), which often have insufficient surrounding land base to accommodate the volume of manure produced. Since the N/P ratio in animal manure is generally lower than crops need, repeated applications of manure based on crop N needs leads to excess P accumulation in soil.

The research objectives were to determine: (1) the optimum loading rates of feedlot manure; and (2) the legacy effects of repeated annual applications of beef feedlot manure on soil properties, barley production, and groundwater quality; and (3) legacy effects on greenhouse gas emission, soil carbon storage and soil health.

MATERIALS AND METHODS

The long-term manure (LTM) experiment was established in Lethbridge, Alberta in autumn 1973 on a Dark Brown Chernozemic (Typic Haploborolls) clay loam soil. Two adjacent fields were used, one was rainfed and the other irrigated with about 15-cm water/year. The beef feedlot manure application rates were 0, 30, 60, and 90 Mg ha^{-1}, wet mass, for the rainfed field (Treatments Mr0, Mr30, Mr60, and Mr90) and 0, 60, 120, and 180 Mg ha^{-1} for the irrigated field (Treatments Mi0, Mi60, Mi120, and Mi180). The application rates corresponded to one, two and three times the 1973 recommended rates for rainfed and irrigated crop production for the soil type. To compare methods of incorporating manure into the soil, three tillage treatments (plow, rototill, and cultivator plus disc) were used. All treatments were replicated three times. Since tillage system had no effect on most soil properties investigated, since 1987 manure was incorporated with a cultivator for all plots. Manure applications for the previously rototilled strip were ceased after 14 annual applications. Then in 2003, manure application ceased for the previously plowed strip after 30 annual applications (Table 1).

Table 1. The LTM treatment description

Field	Treatment	Description
Rainfed	Mr0	No fertilizer or manure input since 1973
	Mrf	Fertilizer at 50 kg N ha^{-1} yr^{-1} since 1990
	Mr30	Manure at 30 Mg ha^{-1} yr^{-1} since 1973
	Mr60	Manure at 60 Mg ha^{-1} yr^{-1} since 1973
	Mr90	Manure at 90 Mg ha^{-1} yr^{-1} since 1973
	Dr30	Manure at 30 Mg ha^{-1} yr^{-1} from 1973 to 1986 (14 annual applications); application ceased in 1987
	Dr60	Manure at 60 Mg ha^{-1} yr^{-1} from 1973 to 1986 (14 annual applications); application ceased in 1987
	Dr90	Manure at 90 Mg ha^{-1} yr^{-1} from 1973 to 1986 (14 annual applications); application ceased in 1987
	DDr30	Manure at 30 Mg ha^{-1} yr^{-1} from 1973 to 2002 (30 annual applications); application ceased in 2003
	DDr60	Manure at 60 Mg ha^{-1} yr^{-1} from 1973 to 2002 (30 annual applications); application ceased in 2003
	DDr90	Manure at 90 Mg ha^{-1} yr^{-1} from 1973 to 2002 (30 annual applications); application ceased in 2003
Irrigated	Mi0	No fertilizer or manure input since 1973
	Mif	Fertilizer at 100 kg N ha^{-1} yr^{-1} since 1990
	Mi60	Manure at 60 Mg ha^{-1} yr^{-1} since 1973
	Mi120	Manure at 120 Mg ha^{-1} yr^{-1} since 1973
	Mi180	Manure at 180 Mg ha^{-1} yr^{-1} since 1973
	Di60	Manure at 60 Mg ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications); application ceased in 1987
	Di120	Manure at 120 Mg ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications); application ceased in 1987
	Di180	Manure at 180 Mg ha^{-1} yr^{-1} from 1973 to 1986 (after 14 annual applications); application ceased in 1987
	DDi60	Manure at 60 Mg ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications); application ceased in 2003
	DDi120	Manure at 120 Mg ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications); application ceased in 2003
	DDi180	Manure at 180 Mg ha^{-1} yr^{-1} from 1973 to 2002 (after 30 annual applications); application ceased in 2003

RESULTS AND DISCUSSION

Soil Chemistry and Salinity

Soil organic C, N, P, K, Zn and Cu contents in soil increased with the manure rates. The increase was mainly due to applying nutrients via manure at greater rates than crop removal.

After 25 annual applications, soil electrical conductivity, soluble sodium (Na), K, magnesium (Mg), bi-carbonate, sulfate and chloride concentrations increased with the manure rates, reflecting the soluble ions composition of the manure applied. The increases in K were greatest, changing the soil solution from initially calcium (Ca)-dominant to K-dominant in the manured soil. The increases were greater under rainfed than irrigated conditions. The greater increases in soil salinity under rainfed conditions largely reflect the semi-arid climate whereby the annual evaporation potential far exceeded precipitation. Under irrigation, soluble ions may be leached beyond the 1.5 m sampling depth used in our study.

The potential salinity problems due to long-term manure applications on arable land in southern Alberta are probably greater from potassium than from sodium because of the high potassium content in cattle manure and the low mobility of K in Chernozemic soil. Although soil salinization due to cattle manure was lower with irrigation, leaching of salt to groundwater may compromise groundwater quality over time. In either case, repeated applications of high manure rates are not sustainable under dry semi-arid conditions.

Soil Microbiology

Soil phospholipid fatty acid analysis showed that after 37 years of annual manure applications at 60 Mg ha^{-1}, soil microbial biomass was 3.2 times that of the control, but 20 years of fertilizer N applied at 100 kg N ha^{-1} had no effect. β-glucosidase activities with manure were 1.9 to 2.4 times the control, but fertilizer N had no effect. Increasing the manure rate to 180 Mg ha^{-1} increased soil microbial biomass linearly, but quadratic increases were observed for β-glucosidase activity. The soil microbial biomass and enzyme activities were positively correlated with soil organic C, total N, and available P. MiSeq sequencing revealed that 43 years of annual manure applications increased the relative abundances of soil *Firmicutes*, γ-*Proteobacteria*, and *Gemmatimonadetes*, but decreased the relative abundance of *Acidobacteria*. Discontinuation of manure application for up to 29 years showed that manure legacy effects on the activities of the soil enzymes involved in C, N, P and S cycling decreased with the number of years without manure, following quadratic patterns, and the legacy effects on enzymes lasted longer than the microbial biomass.

Crop Yield and Quality

After 16 consecutive annual applications, rainfed grain barley yield decreased by 10 and 16% for the 60 and 90 Mg ha^{-1} manure rates, respectively, when moisture conditions were below normal. However, barley grain yield increased when manure was applied under irrigation, with the 60 Mg ha^{-1} rate producing a 20% higher average yield than the control. After 18 annual applications, barley yield decreased for both rainfed and irrigated conditions. Regardless of irrigation, N, P, K, Mg, Na, Cu and Zn contents in barley forage (harvested at the growth stage for making silage) were higher, but Ca content was lower in manure plots than the control. All elemental contents, except Ca, increased with increasing manure application rates. The Ca content was negatively related to manure rate. The reduction in Ca content and uptake observed in barley may be due to increased salinity caused by repeated manure applications. In some years the Ca/P and K/(Ca+Mg) ratios fell outside the optimum range for barley forage used as cattle feed, while high nitrate levels (> 2 g kg^{-1}) were also observed during the drought years.

Rate of Soil Recovery after Manure Application Ceased

Using an exponential decay function and data from 14 annual manure applications (1973-1986) followed by no application (1987-1998), the estimated recovery time for soil to return to the pre-manure N, P and salinity levels increased with the previous manure application rate and was shorter under irrigation than rainfed conditions. For soil total N and P, and soil test P, estimated recovery time ranged from 17 to 99 years for surface soil and 0 to 157 years for the 15-30 cm depth, while soil nitrate-N and salinity in the soil profile (0-150 cm) could require 182 to 297 years under rainfed and 24 to 52 years under irrigation. Thus, long lasting nutrient enrichment from excessive long-term cattle manure applications poses important challenges with respect to sustainable manure management, not to mention the environmental consequences, long after manure applications have ceased.

Greenhouse Gas Emission

Greenhouse gas (GHG) fluxes were measured for two years following manure application in November 2015 until late October 2017. Continuous manure application at 60 Mg ha^{-1} yr^{-1} led to greater cumulative CO_2 and N_2O emissions than non-amended, synthetically fertilized, and discontinued manured soils under rainfed and irrigated conditions ($p < 0.05$). With continuous manure, irrigated soils emitted more CO_2 and N_2O than rainfed soils. However, irrigation did not alter soil CO_2 and N_2O fluxes from unamended soil. Legacy effects of manure application on soil GHG fluxes were negligible in the long-term; residual, bioavailable C/N fractions were likely depleted 17 (2003) and 33 (1987) years after manure application stopped as the GHG fluxes returned to baseline rates for the manure application rate monitored.

Soil Health Assessment

The suitability of the Comprehensive Assessment of Soil Health was assessed for manured fields using soil samplings collected in spring and fall 2016. Our results showed that three indicators (soil pH, wet aggregate stability and active C) were sensitive to both the effects of water and manure management over more than four decades. Soil pH decreased with irrigation and continuous manure application, suggesting that both irrigation water and manure had neutralizing effects on this calcareous soil. Both wet aggregate stability and active C were significantly greater with irrigation and continuous manure. This provides further evidence that wet aggregate stability and active C are sensitive to a variety of management practices in different climates. Active C was positively correlated to the potential enzyme activity of NAGase, Acid phosphomonoesterase, and Arylsulfatase ($r = 0.49$ to 0.71; $p < 0.05$). When 30 years of manure application was followed by a decade or so without manure, there were limited legacy effects on most soil health indicators, but soil organic C, active C and cation exchange capacity remained higher than the non-amended control soil. Overall, the soil health indicator mean values were near or within the range recently reported for fine-textured soils from the Mid-Atlantic, Midwest, and Northeast regions of the USA. Published values of soil health indicators that include the complete suite of physical, chemical and biological properties from the Midwest US, north through the Northern Great Plains are limited, and thus there is a need to get data published or conduct further studies in this vast region.

Current Ongoing Research

The focus of the current 3-year project (April 2018 – March 2021) is to investigate the stability of manure C after application to soil. This was achieved by employing a density and particle-size fractionation approach. By comparing the amount and forms of soil C associated with light, sand, silt or clay fractions in soil for treatment with various time periods of manure applications and legacies (the time since manure application stopped), we hope to be able to gain some insight into the effectiveness of livestock manure application on soil C sequestration, storage and stability.

Summary

The 45-year LTM field experiment demonstrated that annual manure applications increased soil organic matter, N, P, soluble salts and trace element contents and crop straw yield at all manure rates, but reduced grain yields and negatively affected crop quality at higher manure rates. Increased soil nutrient levels also increase the potential for nutrient losses and surface and groundwater contamination. Manure improved the biological quality of the soil by increasing soil microbial biomass and the activities of enzymes involved in C, N, P and S cycling. Active C was sensitive to both water and manure management, while appearing to be the soil health indicator most closely related to the enzymes involved in C, N, P and S cycling, representing a meaningful, high throughput, and cost-effective soil health indicator for manured soils of the Great Plains. When 30 years of manure application was followed by a decade or so without manure, there were limited legacy effects on GHG fluxes and most soil health indicators.

ACKNOWLEDGEMENTS

Special thanks to Dr. Theron Sommerfeldt, who started this long-term manure plot research in 1973, Dr. Chi Chang, who managed it from 1980s until his retirement in 2011, and Toby Entz for statistical analyses over the years. The efforts of the dedicated present and past technical staff, including Hongjie Zhang, Jessica Stoeckli, Douglas Marchbank, Brett Hill, Pam Caffyn, Greg Travis, Greg Nickel, Brian Lamond, past and present field crews, post-doctoral fellows, and numerous undergraduate and graduate students, are much appreciated. Our appreciation is also extended to all funding agencies who supported our research over the past 45 years.

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NITROGEN MANAGEMEMT IN DRYLAND WINTER WHEAT TO IMPROVE GRAIN YIELD AND PROTEIN

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ABSTRACT

Maximizing the yield along with adequate protein content in winter wheat is an emerging challenge for dryland wheat producers. Proper nitrogen (N) management with optimization of fertilizer application rate and timing might be a potential strategy to improve grain yield and protein. The objective of the study was to evaluate the effects of different N rates and application timing on grain yield and protein content of hard red winter wheat in Nebraska. Field study was carried out at four locations across the state in a split-plot design with six N rates and three application timings. The results showed that N rates had significant effect on grain yield and protein content at all locations except for grain yield at one of the locations. Regression analysis showed that the grain yield response and grain protein response to fertilizer N was closely described by significant linear regression equations at two out of three locations. Further, the results revealed that application timing of fertilizer N had no significant effect on grain yield or protein at two out of three locations. The presented results from the first year of the study suggest a potential gain in grain yield and protein with a relatively higher N fertilizer rates.

INTRODUCTION

Hard red winter (HRW) wheat (*Triticum aestivum* L.) is an important class of wheat in terms of production and market. HRW wheat accounts for almost 40% of the total wheat production in United States (Tilley et al. 2012). Moderately high protein content (11-12%) in HRW wheat makes it well suited for preparation of wide range of flour based products (Gibson and Newsham, 2018). Moreover, the grain protein is used as a criteria to determine the price of wheat grains in market. Wheat producers lose income as a discount kicks at protein levels below 10%-11% depending on the elevator.

Despite high yields in the 2016 Nebraska wheat crop, low protein levels caused an estimated $2.3 million to $9.6 million loss in income (personal communication, grain elevator personnel). Similar low protein issues persisted in 2017. Improving the yield along with adequate protein content is an emerging challenge for dryland wheat producers. Among many potential factors, soil nitrogen (N) is probably the most central factor that affected protein (Zorb et al. 2018). Previous studies have reported that optimizing fertilizer N application rate and time may potentially contribute to an increased yield along with desirable protein level (Ma et al., 2019; Abedi et al., 2011; Bole and Dubetz, 1986). Therefore, further investigation about the effect of soil N on wheat grain yield and protein content is imperative. A two-year study was started in fall of 2018 at four different locations in Nebraska with an objective to evaluate effects of the combination of different rates and application timing of N on grain yield and quality of HRW wheat.

MATERIALS AND METHODS

Field study was carried out at four different research stations located across Nebraska (Mead, Grant, Sidney and Scottsbluff) in 2018/19. The wheat plots at Scottsbluff were damaged by hail and therefore no data presented. At all locations, the experimental layout was split plot randomized complete block design with four replications. The main plot factor was wheat variety (Ruth and Freeman). The sub plot factor was combination of: Three fertilizer N application timing - 100% in fall, 100% in spring and Split (30% in fall and 70% in spring) and six N rate (0, 25%, 50%, 75%, 100% and 125% of recommended N rate). The recommended N rate was 80 lbs acre^{-1} at Mead and 60 lbs acre^{-1} at other three locations.

Ammonium nitrate (34-0-0) was used as fertilizer and was surface broadcasted by hand in the plots. The fall application of N was done at around two weeks after planting and the spring application was done at around Feeks-5 stage of wheat. The average yield per plot was recorded by the harvest-master during harvest and was adjusted to 12% moisture. The protein analysis of whole grains was carried out using DA 7250^{TM} NIR analyzer (Perten Instruments) and reported on dry basis. Pre-plant and post-harvest soil sampling was done at three different soil depths (0-8, 8-24 and 24-48 inches) to account for residual soil N.

Effects of variety, N rate and application timing on yield and protein was determined using Proc Mixed in SAS (SAS Institute, Cary, NC) with N rate and N timing as the fixed effects and block and all interactions of block with other terms as random effects (Little et al. 2006). Comparisons of the means was conducted by comparing differences in least-square means in SAS. Differences were considered as significantly different at $P < 0.05$. Regression relationship between N rate and yield and N rate and protein was analyzed in MS Excel.

RESULTS AND DISCUSSION

The mean values of grain yield and protein for different treatment factors are presented in Table 1. No significant interactions between the treatments was observed.

Table 1: Effect of variety, N rates and application timing on grain yield and protein

Treatments		***Yield (bu acre^{-1})***			***Grain Protein (%, dry basis)***		
		Grant	Mead	Sidney	Grant	Mead	Sidney
Variety	Ruth	94.22^{a}	61.5^{b}	38.17^{b}	10.98^{a}	12.58^{a}	11.28^{a}
	Freeman	95.03^{a}	71.3^{a}	44.14^{a}	10.64^{a}	12.29^{a}	10.93^{b}
N Rate	0%	87.35^{d}	67.7^{a}	30.94^{d}	10.36^{cd}	11.60^{c}	11.05^{b}
	25%	91.85^{c}	67.3^{a}	33.84^{d}	10.17^{d}	12.18^{b}	11.05^{b}
	50%	92.47^{c}	66.9^{a}	39.49^{c}	10.72^{bc}	12.25^{b}	10.95^{b}
	75%	96.79^{b}	67.6^{a}	42.21^{c}	10.82^{b}	12.41^{b}	10.98^{b}
	100%	96.76^{b}	64.1^{a}	47.91^{b}	11.26^{a}	12.95^{a}	11.19^{ab}
	125%	102.54^{a}	65.0^{a}	52.51^{a}	11.51^{a}	13.21^{a}	11.43^{a}
Application timing	Fall	92.34^{b}	66.5^{a}	41.56^{a}	10.75^{a}	12.29^{a}	11.08^{a}
	Split	95.81^{a}	67.2^{a}	42.08^{a}	10.80^{a}	12.41^{a}	11.21^{a}
	Spring	95.73^{a}	65.5^{a}	39.81^{a}	10.87^{a}	12.60^{a}	11.04^{a}

Values in the same treatment fraction followed by different letter denotes significant differences at $P<0.05$ for the given location in column

Grain yield response to N fertilizer rate and application timing

The results showed that N rates had significant effect on grain yield at Grant and Sidney but a non-significant effect at Mead (Table 1). At Grant and Sidney, all the N applied plots had significantly higher yields compared to the control plots. Regression analysis results showed that the grain yield response to fertilizer N was closely described by significant linear regression equations ($r^2 = 0.9399$, $p < 0.01$ and $r^2 = 0.9915$, $p < 0.0001$ at Grant and Sidney, respectively) (Figure 1 & 2) where yield increased with the increasing N rates. The wet spring this year could have resulted in good grain yield across N treatments. The availability of water during critical growth stages has shown to enhance the N use efficiency in wheat (Ma et al., 2019). Similar results of yield improvement with N fertilization have been reported in previous studies (Bhatta et al., 2017; De Silva et al., 2018).

The indifferent yield among N treatments at Mead might be because of Fusarium Head Blight (FHB), among other factors. Severe infestation of FHB was reported around the study location. Lemmens et al (2003) have reported that the severity of FHB could be higher in wheat fertilized with higher N rates and thereby potentially reducing the yield.

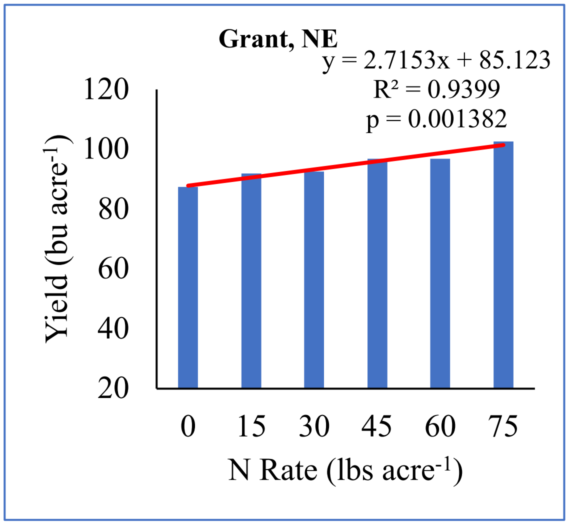

Fig. 1: Grain yield as affected by N rates

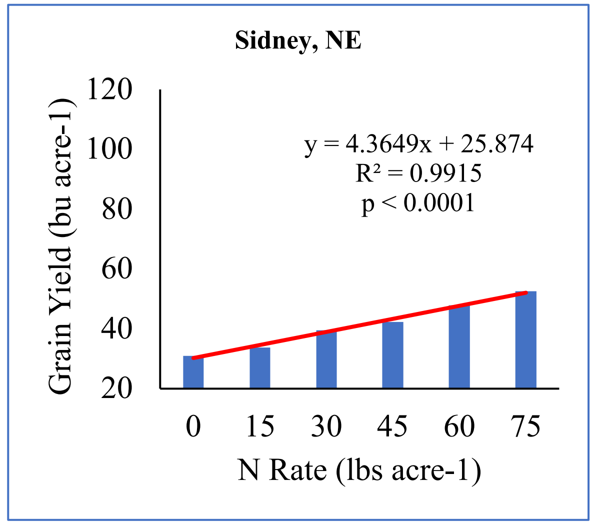

Fig. 2: Grain yield as affected by N rates

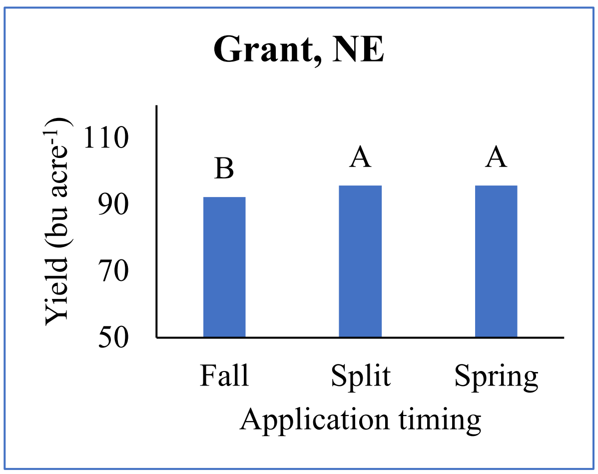

Fig. 3: Grain yield as affected by application time

Further, the results showed that N fertilizer application timing had no significant effect on the grain yield except for Grant (Table 1). At Grant, the split and spring N applied plots were found to have significantly higher yield compared to the plots with N applied in fall (Figure 3). Most of the N uptake by wheat occurs during stem elongation and N application prior to this stage has higher loss potential (Zebarth et al., 2007). This might have resulted in lower yield for fall N applied plots at Grant.

Grain protein response to N fertilizer rate and application timing

The results revealed that N rates had significant effect on grain protein at all locations (Table 1). Results of linear regression analysis showed that the grain protein response to fertilizer N was closely described by significant linear regression equations at Mead ($r^2 = 0.9492$, $p < 0.001$) and Grant ($r^2 = 0.9051$, $p < 0.01$) (Figure 4 & 5). The plots applied with higher N had greater protein compared to low or no N applied plots. However, the highest protein level was always below 12% at Grant and Sidney. In contrast, higher grain protein levels (>12 %) were achieved at all N applied plots at Mead with the highest (13.21%) in plot applied with 100 lbs N acre^{-1}.

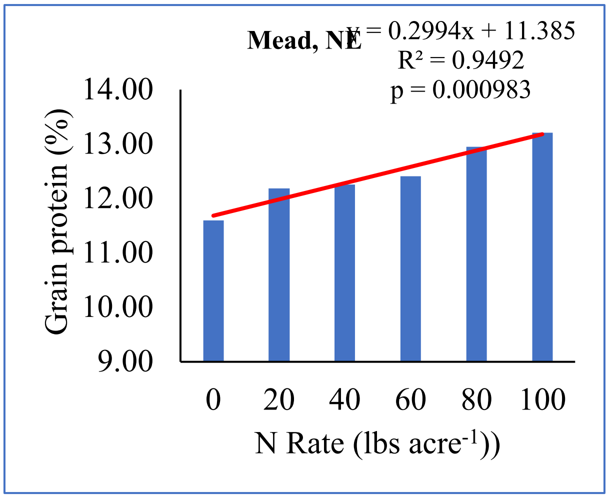

Fig. 4: Grain protein as affected by N rates

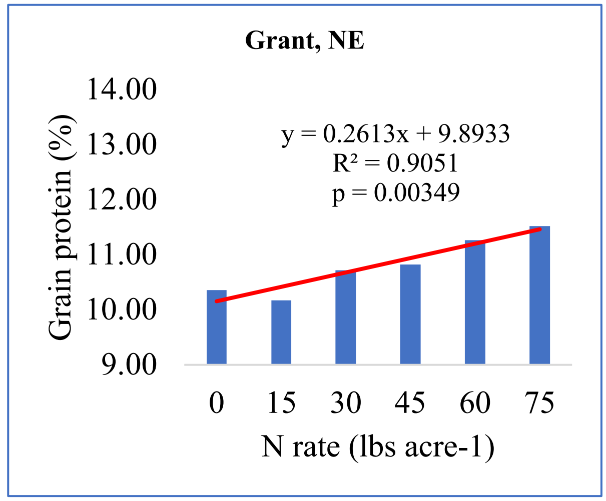

Fig. 5: Grain protein as affected by N rates

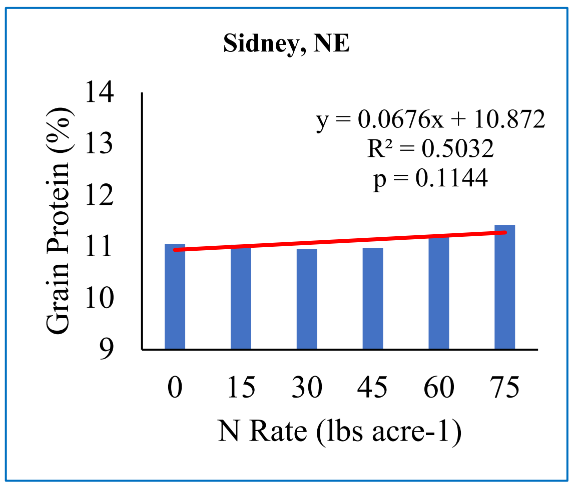

Fig. 5: Grain protein as affected by N rates

No significant difference was observed in grain protein among the N fertilizer application timing at all locations. In contrast, studies (Zebarth et al., 2007; Weber et al., 2008)) have reported an increase in grain protein with delayed fertilizer N application. The currently study considered Feeks-5 as the late N application time while the fore-mentioned researches have considered N application at more later stages which might be the reason for the contrasting results.

SUMMARY

As indicated by the results, the grain yield and protein content of hard red winter wheat is likely to be improved by the application of optimum nitrogen rates. However, the application timing showed limited response on grain yield and protein. These results justify for further investigation in coming years to get a clear picture of the N treatment effects on wheat yield and protein.

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N DYNAMICS IN NO-TILL CROP RESIDUES IN THE NORTHERN PLAINS

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ABSTRACT

Although many studies have been conducted on no-till cropping systems, little is yet known about the dynamics of N mineralization from accumulated crop residues as it relates to providing N to subsequent crops. We conducted incubation studies using individual crop residues placed on the surface of soil columns in leaching tubes and incubating the tubes for approximately 12 weeks (simulated growing season) with periodic leaching. This was repeated 5 times with a freezing period (winter simulation) and residue addition at thawing in order to evaluate N contribution of accumulating residues to the available N pool in the soil during the incubation period. All crop residues (corn, soybean, spring wheat, and winter wheat – high C:N ratios) demonstrated N immobilization across the incubation periods. Only winter pea and radish (narrow C:N ratios) showed actual net N mineralization that would be available to following crops. This may be an important consideration when adjusting N fertilization rates for high N requiring crops.

INTRODUCTION

Recent research by Aher et al. (2016) and Chatterjee et al. (2015) have shown that significant levels of crop residues can accumulate in no-till crop rotations in which corn is a frequent component crop. This residue accumulation is partly due to the relatively cool climate in the northern Great Plains of the U. S. Corn is also a crop that has a high nitrogen (N) requirement and N fertilizer is a major input in the cost of corn production.

Little information is available in the literature about the rate of N mineralization and the N contribution of residue decomposition to the N requirements of subsequent crops. Generally, crops with a high C:N ratio (corn, wheat) have a lower N mineralization rate than crops with lower C:N ratios (soybean, alfalfa, cover crops). Although crop residues contain potentially available pools of N, N by itself, can be a limiting factor in N mineralizing from the residues. NDSU soil test recommendations provide a 40 lbs. N/A credit in fertilizer recommendations when the preceding crop is a legume. However, the interaction between the residue of a legume crop mixed with corn or wheat residue is unknown especially when making recommendations for a high N requirement crop like corn.

In Wisconsin, Bundy (1998) recommended that an additional 30 lb. N/A should be applied to corn where at least 50 % of the soil surface was covered by previous corn residue. Ketterings et al. (2003) and Jokela et al. (2004) have also recommended an additional application of 30 lbs. N/A for no-till corn in New York and Vermont, respectively, in order to compensate for reduced mineralization in the cooler northern-tier U. S. states. Montana recommends an additional 20 lb. N/A for every 2000 lb. straw remaining for spring wheat for a subsequent crop (Dinkins et al., 2014).

Franzen et al. (2011) examined fertilizer N responses in North Dakota conventional tillage and no-till systems in spring wheat and reported that similar yields could be achieved with up to 50 lbs. N less in no till systems. However, this research did not account for soil moisture conservation differences or wheat protein quality between tillage systems. In recent revisions of N fertilizer recommendations, Franzen (2018) recommended a 20 lbs. N/A credit for no-till systems of 5 or less years of age and a 50 lbs. N/A credit for N-till systems of 6 years or age or greater. However, these recommendations have not been verified by more detailed research and there is scant information from research into crop N requirements in conservation or no-till systems with high residue accumulation in the literature especially in cool climate environments.

Work by Aher, et al. (2016) indicated that, based on residue C:N ratios and mass of residue on the soil surface, potential residue N deficit to the succeeding crop could range from 50 to 94 lb. N/A after over-winter weathering of the crop residue. Chatterjee, et al. (2016) reported that increasing rotation length and diversity may increase mineralizable substrate diversity that reduces residue decomposition rate. Our preliminary research (2017-2108) exhibited that that only crops with low C:N ratios (C:N<20) (winter pea, forage radish) showed net N mineralization from soil incorporated crop residue. High C:N ratio (C:N>20) crop residues (corn, soybean, flax, spring wheat, winter wheat) showed net N immobilization across a 140 day incubation period approximating a frost free cropping period in North Dakota. But this does not address the N mineralization dynamics of unincorporated residue on the soil surface as found under no-till conditions.

The objective of this research is to establish N mineralization rates for residues of individual crops that can be found in no-till crop rotations commonly utilized in North Dakota and their potential contribution to N nutrition of subsequent crops.

MATERIALS AND METHODS

Ground post-harvest residues from crops including corn, soybean, spring wheat, winter wheat, and two cover crops (field pea and radish) were used in this study. These crops were included in different crop rotation systems of the original study after 12 years of no-till management in the Conservation Cropping Systems Project (CCSP) managed by the Wild Rice Soil and Water Conservation District near Forman, ND (Aher, et al., 2016). The residues were collected after harvest in 2012. The individual carbon to nitrogen (C:N) ratios are shown in Table 1.

Table 1. Crop residues and their carbon:nitrogen (C:N) ratios used in this study.

Crop Residue	C:N Ratio
Corn	73
Winter Pea	18
Forage Radish	8
Soybean	53
Spring Wheat	76
Winter Wheat	101

The mineralization study used a Forman clay loam (fine-loamy, mixed, superactive, frigid Calcic Argiudolls) (5.1 % SOM) soil utilizing the incubation method described by Stanford and Smith (1972). This soil is similar to many of the soils found on the glacial till plain across North

Dakota. The study was conducted using 15 g soil + 15 g washed sand + 0.5 g crop residue placed on the soil surface in glass leaching tubes to simulate residue under no-till conditions. Leaching was done with 40 ml of 0.01 M $CaCl_2$ for the first leaching (dry soil) and 30 ml for subsequent leachings (moist soil). Each leaching was followed by addition of 10 ml nutrient solution as described by Stanford and Smith (1972) to replace nutrients other than N required by soil microorganisms that may have been leached out along with the N. The six residues along with an untreated soil sample were evaluated with three replications. A 12-week incubation period (approximate growing season in North Dakota) at 22°C was conducted with leaching and analysis for NO_3^--N every 14 days.

In order to simulate repeating cropping seasons, soil leaching tubes were frozen at -5ºC for three weeks at the end of the incubation period. Then the samples were thawed and an additional 0.5g of like residue was added to the surface of the appropriate tubes and the incubation was conducted for another 12 weeks. A total of 5 "growing seasons" were thus simulated. The iterative process of incubations was designed to evaluate the response of the soil microbial communities to repeated additions of residues on the soil surface similar to that which might be found under no-till cropping system management.

RESULTS AND DISCUSSION

The results of the N mineralized/immobilized during each of the 5 incubation iterations are shown in Figures 1a through 1e. The horizontal lines in Figures 1a-e represents the N mineralized by the untreated soil and the N mineralization of each residue is plotted against the soil mineralization. Residues with mineralization lines above the horizontal line indicate that they are contributing mineralized N to the soil while those below the line are immobilizing N. N immobilization means that native N mineralized by the soil alone is being drawn upon to provide N nutrition to soil microbes in order to break down the residue materials.

Figure 1a shows the results of the first incubation series (or simulated growing season). Only the radish residue mineralizing N to contributing to the soil N pool. The winter pea N mineralization curve is close to the soil alone mineralization line but contributes slightly the soil N pool. All of the other residues parallel the soil only line but are below the line indicating that they are immobilizing N during the entire growing period.

Figure 1b shows the N mineralization characteristics after the second addition of residue and the second incubation period. The radish residue N mineralization peaks at about 4 weeks of incubation and then tails off toward the end of the incubation cycle. At the end of the cycle, it is still mineralizing N. This kind of mineralization would be expected from a residue with a narrow C:N ratio where the bulk of the mineralization occurs shortly after the residue comes in contact with the soil. The pea residue has a small but constant quantity of N mineralization throughout the incubation period. The remaining residues show slight immobilization throughout the incubation period.

Figure 1c shows the N mineralization characteristics after the third addition of residue and third incubation period. The relationships appear similar to the second incubation period but the quantity of the N mineralized is lower than that of the second incubation. However, the mineralization of the radish residue appears to "tail-out" over a longer portion of the incubation period. This appears to be characteristic where the soil microbial populations have adapted to decomposing specific types of residue. In other words, the soil microbial populations have adapted to decomposing the specific residues they have been exposed to which generally also occurs in nature.

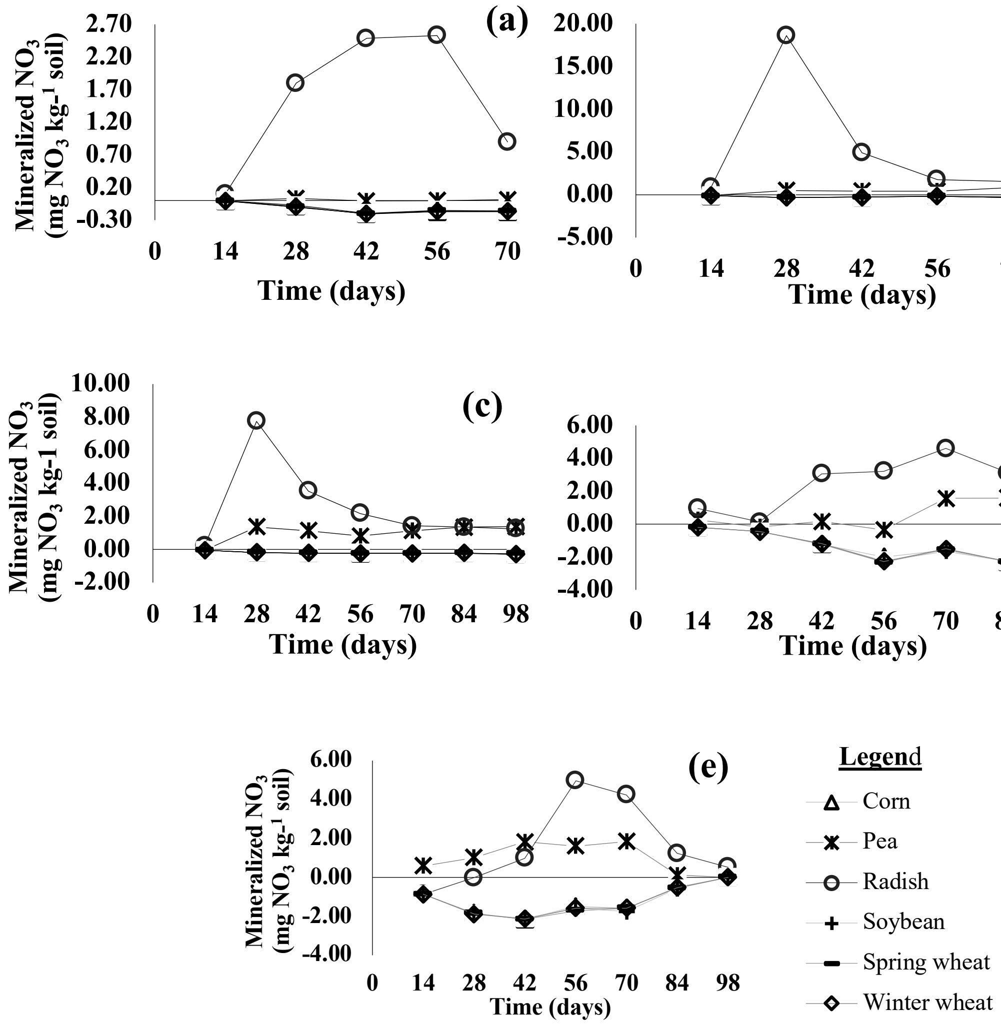

Figure 1. Relative N mineralization from six surface applied crop residues over 10-12 week incubation period. Individual graphs show the data for: (a0 the first incubation period ("growing season"); (b) the second incubation period; (c) the third incubation period; (d) the fourth incubation period; and (e) the fifth incubation period. The N mineralization of each residue material is compared to untreated soil for that incubation interval (horizontal line).

Figure 1d shows the N mineralization characteristics after the third freezing period and the fourth residue addition. Something has changed here. The baseline N mineralization of the untreated soil greatly increases (See Figure 2) therefore affecting the horizontal baseline in Figure 1d. However, the low C:N residues still show net N mineralization while the other residues still show N immobilization. An explanation for this is that the microbial population that normally is responsible for mineralizing N from easily decomposable soil organic matter have expanded their food sources resulting in a shift in the composition of soil microbes to those that functionally break down more resistant soil organic matter in the absence of new C sources.

Figure 1e shows the N mineralization characteristics of the residues after the fourth freezing period and the fifth addition of crop residue (or simulated growing season). The high baseline of N mineralization from native organic matter in the untreated soil was observed here, too. The N mineralization characteristics of the residues were similar to those observed for the fourth incubation period.

Figure 2 illustrates the change in N mineralization of the untreated soil control during the fourth incubation period. Again, this was likely due to a shift in microbial species from those that function best breaking down the easily degradable soil organic matter in the absence of added residue C. Other microbes better adapted to breaking down more resistant native C may then become dominant and change the characteristics of the N mineralization.

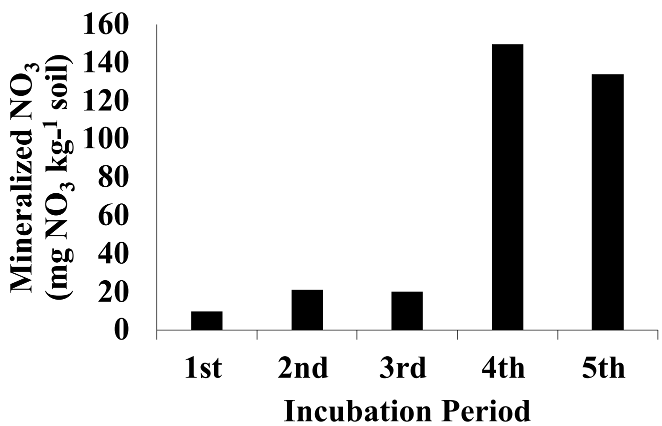

Figure 2. Cumulative N mineralized during each from the untreated control soil during each incubation period.

The soil contains a complex population of microbes, many of which are very adaptable to a variety of food substrates (residues) while others tend to have more specific functions. This study was designed to study the mineralization characteristic of residues applied in a manner that may occur in a no-till production system at realistic field soil temperatures but while maintaining constant favorable moisture conditions for optimum N mineralization conditions. It should be understood that under field conditions, moisture, temperature and residue composition and cover vary across the growing season and even on a day-to-day or over a day-night period. Under field conditions, the magnitude of mineralization would likely be somewhat more erratic and lower than we have observed under laboratory conditions.

This research shows that most high C:N ratio crop residues will immobilize (tie up) mineralized soil N or available soil N and make it unavailable to a growing crop. This research generally supports the concerns reported by Aher et al. (2016) and Chatterjee et al. (2016) that high levels of residue accumulation may limit N availability to subsequent crops. This work shows immobilization of N from relatively high rates of common North Dakota crop residues under "ideal" conditions, that is, realistic ideal moisture and temperature to promote surface residue to break down. Residue remaining on the soil surface will decompose much more slowly due to limited availability to decomposing soil microorganisms provided by soil contact along with highly variable soil moisture conditions and limited availability of soil and fertilizer derived N needed by the microorganisms to be able to function properly. One of the advantages of no-till cropping systems is that they conserve soil moisture in regions of limited rainfall. Often apparent crop growth responses may appear to be responses to more efficient use of N (which does occur in more consistent soil moisture environments) but is in reality a response in better moisture availability. The dearth of research information on residue contributions to nutrient availability to crops in no-till systems is due to researchers focusing on either soil processes or plant processes but not on the integration or soil, plant and microbial processes due to difficulty in measuring changes and dynamics across physical interfaces. Further integrated research is needed to understand nutrient cycling in long-term no-till cropping systems.

The results of this study have led us to undertake a new set of incubations simulating three growing seasons with crop rotations similar to those found across North Dakota. We will be focusing on continuous corn, corn-soybean, wheat-soybean and corn-soybean-wheat systems. Each crop will be present in each phase of a three year rotation in the laboratory. In addition, we will be adding radish to selected soybean and wheat residues to simulate the occurrence of a cover crop seeded into the system. The information from this set of incubations will help inform us about how we can reduce N immobilization in these systems.

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IN-FURROW PLACEMENT OF DRY UREA PRODCUTS WITH WINTER WHEAT

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ABSTRACT

Previous research has shown that the application of some nitrogen fertilizer prior to or at the time of wheat seeding can positively affect the initiation of fall tillers and thus yield potential. However, there are logistical challenges in placing that nitrogen in no-till production systems. Traditionally, the placement of urea-based fertilizers in-furrow with wheat seed has not been recommended. The objectives of this project were to evaluate stand reduction and associated potential yield losses from the in-furrow placement with seed of urea, NBPT treated urea, and a polymer coated slow-release urea at varying rates. This study was conducted across 9 site-years in western and central Kansas. Across most measured parameters, the effects of injury increased with increasing nitrogen rate for all urea products. In general, the level of injury was greatest for conventional urea followed by NBPT+NPPT treated urea, with ESN urea offering the greatest level of safety for in-furrow placement with the seed. Data from this study would suggest that in the silt-loam soils of western and north-central Kansas, 10 lb ac^{-1} of conventional urea may be seed placed when sufficient soil moisture is present and 20 lb ac^{-1} of NBPT+NPPT or ESN may be seed placed.

INTRODUCTION

A great deal of flexibility exists in supplying nitrogen to a winter wheat crop. Essential however, is having nitrogen available in sufficient quantities at times of development for key yield components. In general, it is recommended that some of the crop's nitrogen supply be made available through a planting or pre-plant application. Having nitrogen easily available early in the growth and development of winter wheat can positively effect fall tiller initiation, and thus yield potential. Historically in conventional-till or reduced-till dryland production systems, this was accomplished during one of the pre-plant summerfallow tillage operations, most commonly with anhydrous ammonia applied with a sweep blade plow. With the transition to no-till production systems, producers often inquire about effective methods to efficiently apply nitrogen without the use of tillage. The increased adoption of air-seeder systems with increased bulk commodity capacity over traditional box-type grain drills has provided a less-costly and logistically simpler process to apply dry fertilizer. In addition, the introduction of new dry nitrogen products into the market has many producers asking about their relative safety to urea for placement directly with the seed. Traditionally the recommendation of Kansas State University Research & Extension has been that no urea should be placed with the seed. This is due to the risk of ammonia injury to seedlings as urea undergoes hydrolysis (Bremner and Krogmeier, 1989).

MATERIALS AND METHODS

Field experiment were conducted across three locations in western Kansas over three years and one location in north-central Kansas for two years, for a total of 11 site-years. One site-year was lost due to extremely dry conditions in the fall and subsequent failure of crop establishment. Another site-year was lost due to accidental harvesting by the cooperator. All locations are characterized by relatively flat topography and well drained silt loam soils. At each location, treatments were arranged in a RCBD design with four replications. Plots were generally 5' x 40' in size. Winter wheat was no-till planted into chemfallow at the Tribune, Colby, and Herndon, KS locations where the previous crop was either corn or grain sorghum. At the Hunter location, in north-central Kansas, wheat was no-till seeded into winter wheat stubble. At the Tribune, Colby, and Herndon locations, the variety Byrd (Haley et al., 2012) was used, at the Hunter location the variety Larry (USDA, 2019) was used. Wheat was seeded in 7.5" rows in 2016 and 2017, and in 10" rows in 2018. Seeding rates were 1.1 million seeds acre^{-1} in 2016 and 2018, and 1 million seeds acre^{-1} in 2017.

Three urea fertilizer products: conventional urea, polymer coated slow release urea (ESN, Nutrien), and NBPT+NPPT coated urea (Limus, BASF), were placed in-furrow with the wheat seed at three target rates of applied nitrogen: 10, 20, 30, and 60 lb ac^{-1}. Additionally, two control treatments were also included: a treatment of no fertilizer in furrow and MAP at the rate of 91 lb ac^{-1}, for a nitrogen application of 10 lb ac^{-1}. The key objective of this study was to evaluate potential injury of seed placed nitrogen, not necessarily nitrogen response. Therefore, at all locations, the typical nitrogen fertilization plans for wheat were carried out over the entirety of the plot area.

Fall stand counts were taken at 6 site-years of the study from areas ranging between 3.75 and 7.5 ft^2 depending upon the individual site-year. At 3 site-years (Colby, Herndon, and Tribune in 2016) a spring stand count from an area of 3.75 ft^2 was obtained due to delayed germination caused by dry conditions at seeding. Head number at harvest was obtained at 8 site-years from an area between 2.5 and 7.5 ft^2 depending on site-year. The date on which 50% of the tillers had headed was recorded at 2 site-years. Plots were machine harvested using small plot combines. Seed weight was determined from 300 seeds that were oven dried to constant weight. Data for grain yield, moisture, test weight, kernel weight, and protein content were collected at all 9 site-years.

Statistical analysis was performed using PROC MIXED in SAS 9.4. A one-way analysis of each site-year was conducted for the measured and calculated response variables with replication as a random effect and treatment as a fixed effect. The across-years analysis was conducted with treatment as a fixed effect and site-year and replication nested within site-year as random effects. Means separation was performed used the PDMIX800 macro (Saxton, 1998).

RESULTS AND DISCUSSION

Fall Stand Establishment

Fall stand establishment was affected by treatment at 4 of the 6 site-years where data were collected. In-furrow fertility treatment effected fall stand establishment ($P<0.0001$). In the across years analysis fall stand establishment decreased as nitrogen rate increased (Figure 1). At the 10 through the 30 lb ac^{-1} rates, no significant difference was observed between urea products. However, at the 10 lb ac^{-1} rate, urea resulted in less stand than the control. At the 20 lb ac^{-1} rate, both urea and NBPT+NPPT treated urea resulted in less stand than the control. At the 30 lb ac^{-1} rate, all urea products resulted in less fall stand relative to the control. Differences among products on fall stand establishment were only observed at the highest rate in the study, 60 lb ac^{-1}, in which conventional urea resulted in less stand than either ESN or NBPT+NPPT urea. Conventional urea reduced fall stand establishment at any rate in the study, NBPT+NPPT urea resulted in stand reduction at rates of 20 lb ac^{-1} and above, while ESN urea resulted in stand reductions at rates of 30 lb ac^{-1} and above.

Spring Stand

At 3 of the site-years, extremely dry conditions delayed uniform germination and emergence. Spring stand counts were taken to evaluate potential injury. In an across site-years analysis, in-furrow treatment effected spring stand (P=0.0008). Stands were numerically, but not statistically reduced by any urea product at rates of 10 and 20 lb ac^{-1} (Figure 2). At the 30 lb ac^{-1} rate, stands were reduced relative to the control when conventional or NBPT+NPPT urea was applied. Product differences were further magnified at the 60 lb ac^{-1} rate when both the conventional and NBPT+NPPT urea products resulted in less stand than the control, and the conventional urea treatment resulted in less stand than the ESN urea treatment.

Maturity

Differences in maturity was an unforeseen treatment effect that we recorded with 2 site-years of data. When urea was applied in furrow at any rate, maturity was delayed relative to the control (Figure 3). Maturity was also delayed when rates of NBPT+NPPT urea of 30 lb ac^{-1} and above were applied and at the 60 lb ac^{-1} rate of ESN. The reduction of main stems and tillers due to seedling injury allowed for the initiation of spring tillers, which were later to mature.

Yield Components and Grain Yield

No treatment effect on either yield head^{-1} or kernels head^{-1} was observed. When NBPT+NPPT or conventional urea were placed in-furrow at 60 lb ac^{-1} kernel weight was reduced relative to the control (data not shown). This is likely in part to a larger number of late maturing tillers in these treatments which would be subjected to increased heat stress during grain fill, possibly reducing grain fill rate and/or duration. Heads acre^{-1} were also reduced in these two treatments relative to the control (data not shown).

Grain yields were unaffected by the use of any product at the 10 lb ac^{-1} rate. At rates of 20 lb ac-1 and higher the placement of urea in-furrow reduced grain yields relative to the control. NBPT+NPPT and ESN urea reduced grain yields when applied at the 60 lb ac^{-1} rate.

Discussion

A common occurrence in this study was increasing levels of injury across products in the order of ESN < NBPT+NPPT < urea. This agrees with research conducted in the prairie provinces of Canada (Brandt et al., 2005 and Malhi et al., 2003). The data collected in our study would suggest that for silt-loam soils in western and north-central Kansas it is possible in many cases to place conventional urea with the seed at rates up to 10 lb ac^{-1}, this would concur with recommendations from Montana State Univ. (Olson-Rutz et al., 2011). However, at two of the site-years, Tribune 2016 and Colby 2016, 10 lb ac^{-1} of urea resulted in a yield reduction of 7.8 and 7.2 bu ac^{-1} respectively. In our study, urea treated with NBPT+NPPT appeared to be safe at rates up to 30 lb ac^{-1} although within site-years some numerical reductions in yield were evident. In the across-years analysis for grain yield, ESN was not less than the control at any applied rate. However, in 3 of 9 site-years yield was reduced when 60 lb ac^{-1} of ESN was applied in-furrow (data not shown) while in none of the site years was ESN detrimental to yield at the 30 lb ac^{-1} rate. Work in the prairie provinces has shown plant stands not to be reduced with ESN until rates were above 45 lb ac^{-1} (Brandt et al., 2005). Based on this data, for silt-loam soils in western and north-central Kansas in-furrow application of conventional urea should be avoided in dry soils but may be used up to rates of 10 lb ac^{-1} when sufficient soil moisture exists. Rates of up to 20 lb ac^{-1} appear to be acceptable when using NBPT+NPPT or ESN urea. While higher rates will be safe in the majority of years, the economic costs in a year when injury occurs could be significant.

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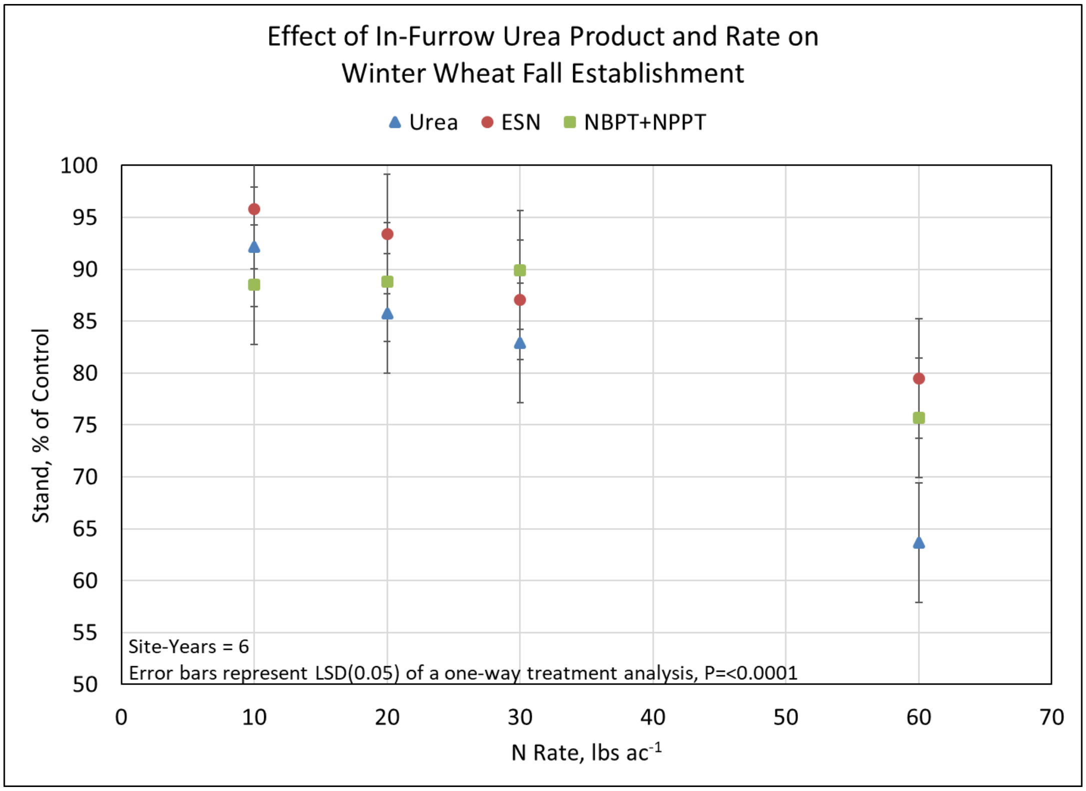

Figure 1. Effect of in-furrow urea product and rate on fall establishment of winter wheat.

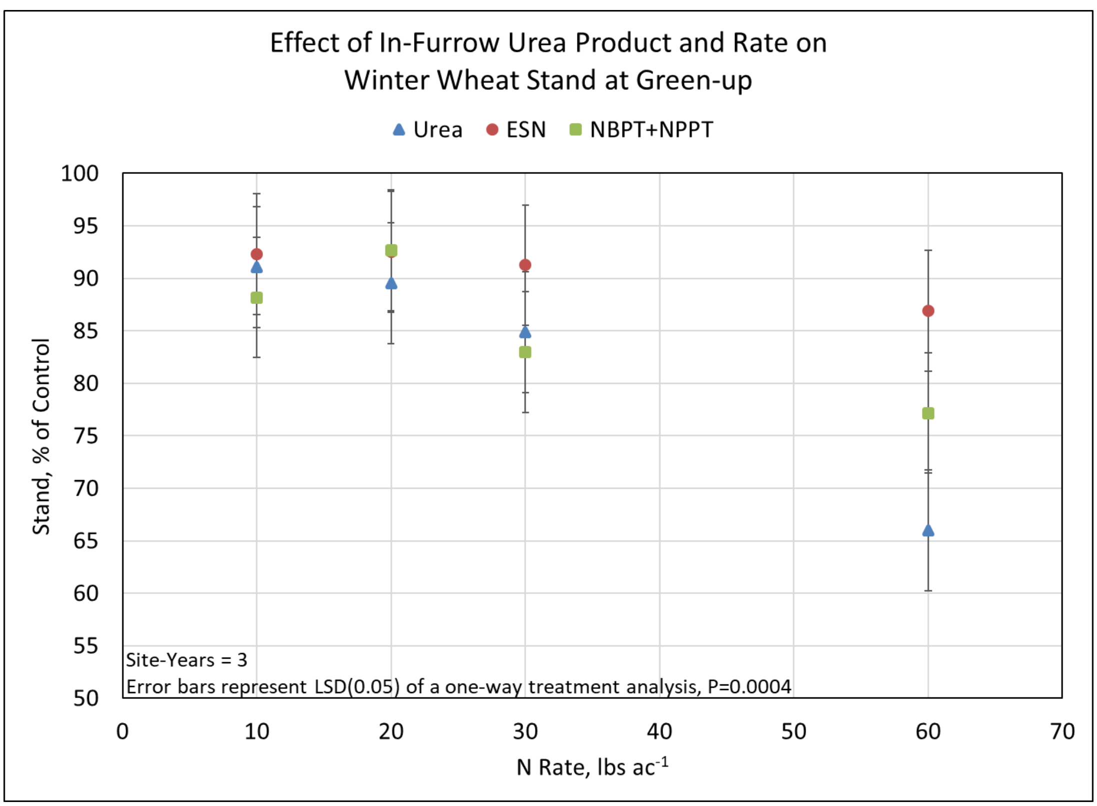

Figure 2. Effect of in-furrow urea product and rate on winter wheat stand at spring green-up.

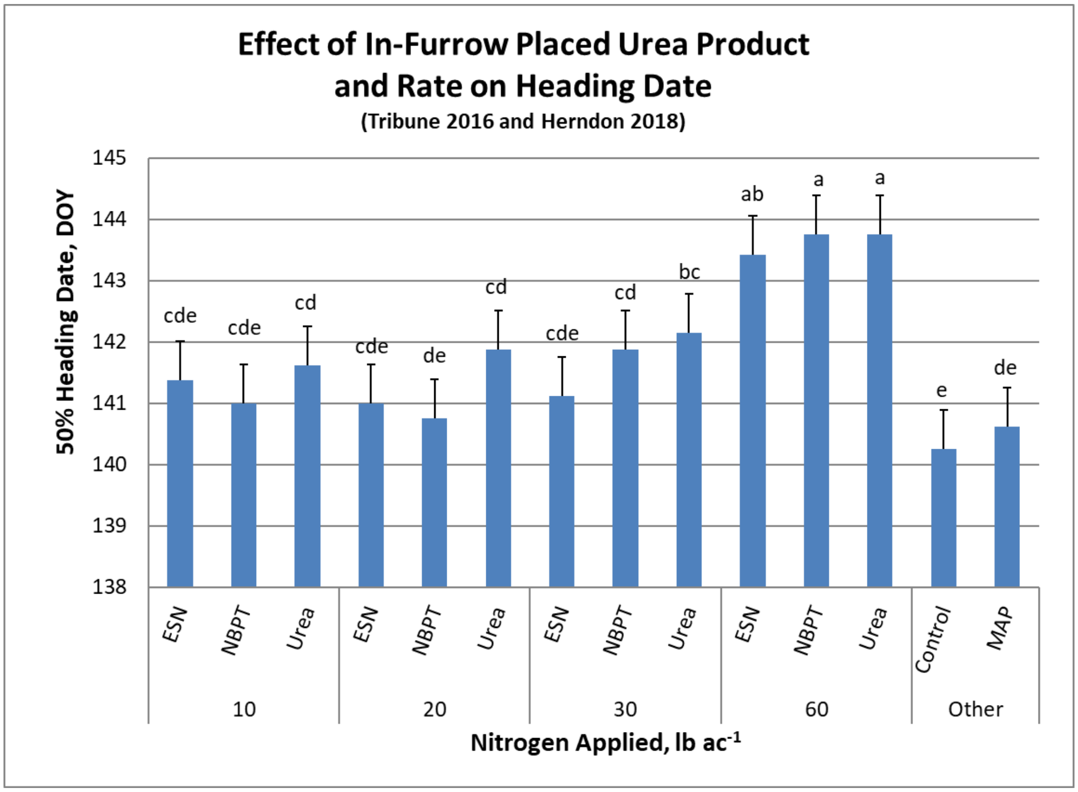

Figure 3. Effect of in-furrow urea product and rate on winter wheat heading date.

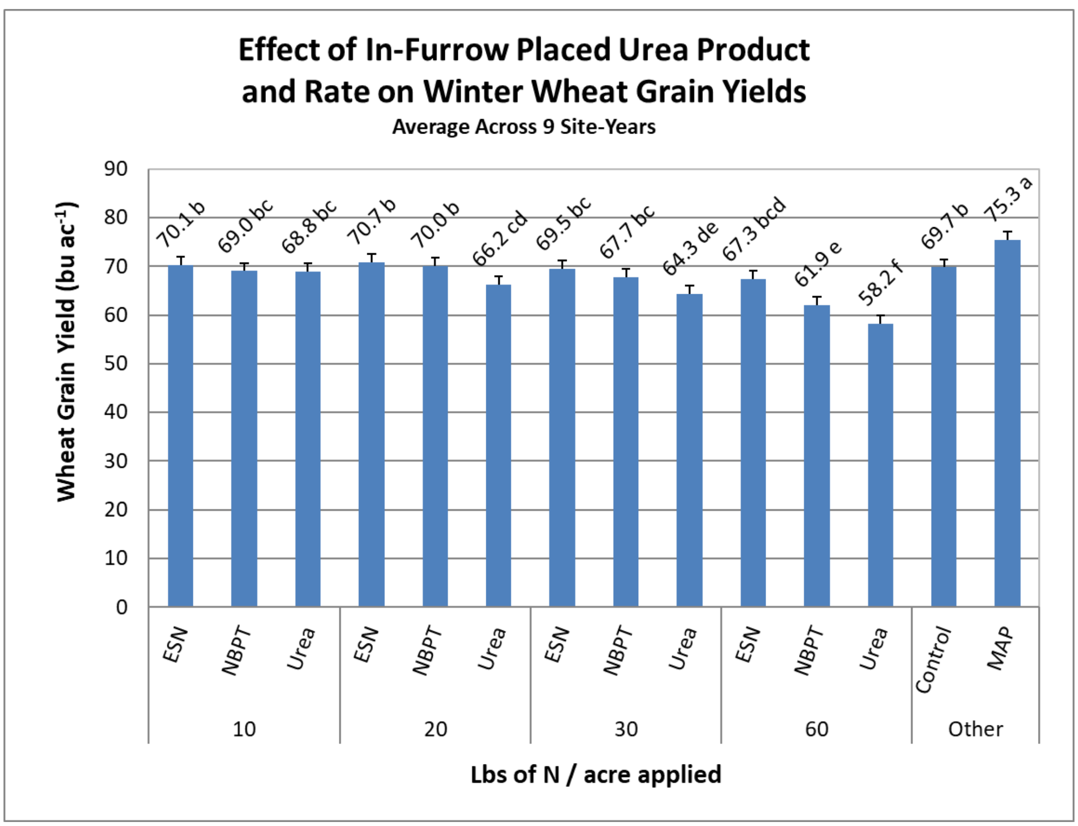

Figure 4. Effect of in-furrow urea product and rate on grain yield.

EXPERIENCES IN THE CANADIAN PRAIRIES WITH ENHANCED EFFICIENCY N FERTLIZERS FOR WINTER AND SPRING WHEAT PRODUCTION SYSTEMS

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ABSTRACT

This presentation summarizes several studies all designed to address knowledge gaps around enhanced efficiency urea fertilizer (EEF) efficacy for nitrogen (N) management in western Canadian winter and spring wheat production systems. Polymer-coated urea was first studied to determine how handling effects can alter the coating integrity of environmentally smart nitrogen (ESN®). While N release rates increased from retail or farm-handling such as transferring product through equipment containing scaly deposits, header-manifold systems with high air fan speeds, or with air boom applicators, the crop compensated to any injury sustained and grain yield was usually unaffected or could be mitigated through proper equipment maintenance and settings. Additional research conducted confirmed the substitution of urea with ESN allows 3x rates of seed-placed N provided N release was ≤ 40%, which is readily achieved through proper handling. Studies exploring winter wheat crop responses to urea type (urea, urea+urease inhibitor - Agrotain®; urea+urease and nitrification inhibitor – SuperU®, polymer-coated urea – ESN®; urea impregnated with a nitrification inhibitor - ENtrench®; and urea ammonium nitrate – UAN) when all applied at planting were compared to split-applications were conducted at study sites across the Canadian prairies representing the main soil zones. The results suggest split applications of N might be most efficient for yield and protein optimization when combined with an enhanced efficiency urea product, particularly with urease or urease+nitrification inhibitors, and if the majority of N is applied in spring. Aside from seed-placed applications, ESN® appears to release too slowly in the northern Great Plains. For example, results from unpublished work report yield results in the following order: SuperU® ≥ ENtrench® ≥ urea ≥ ESN®; the yield response to SuperU® was significantly higher than ESN®. However, proportions of ESN® in side-banded (1:1 ratios with urea) systems improved yield in certain conditions. New studies have been initiated for spring wheat to determine the efficacy of other placement, timing, and rate practices for EEFs in spring wheat.

INTRODUCTION

Aside from water, nitrogen is the major yield-limiting factor in wheat production systems in the Canadian Prairies, and the costliest when considering wheat generally utilizes roughly one-half, or less, of the nitrogen applied. As growers strive for higher yields through intensified practices and new genetics, the knowledge gap around N management systems remains far from closed. One question that arises is the role of enhanced efficiency N fertilizers (EEFs), with respect to greater nitrogen use efficiency through reduced losses and higher overall returns to offset associated input costs. Nitrogen fertilizer management is also complicated by the registration of new extremely high-yielding Canadian Western Red Spring (CWRS) wheat cultivars, with field yields of +100 bu/ac reported by some growers. Moreover, the yield potential for Canadian Western Red Winter generally exceeds CWRS by 20%. For both classes of wheat, however, the trade-off for high yield in some cultivars is a reduction in grain protein concentration. Growers must achieve a minimum protein content of 13% and 11%, respectively for CWRS and CWRS, to avoid price discounts. Some recently registered, high-yielding wheat cultivars struggle to meet these minimum requirements unless nitrogen (N) fertilizer management is focused on simultaneously achieving protein targets. Given the innovations around the introduction of EEFs and significantly higher attainable yield benefits with the latest genetics, a review of N management systems is needed to fully exploit this new Genetics x Environment x Management (GxExM) synergy.

MATERIALS AND METHODS

Handling effects on polymer-coated urea

Separate experiments were conducted for the simulated abrasion and handling studies at each site near Lethbridge, Alberta, Canada. The simulated abrasion experiment (Experiment 1) consisted of 10 kg ESN® lots that were rolled in a cement mixer drum with 2 kg of crushed landscape rocks to create abrasion severity calibrated by increasing the time durations in the drum to achieve lots that differed by 10% in total N release when immersed in water at 23°C for 7d (Table 1). A detailed description of nitrogen release methodology is reported by Zhang et al. (2000). The nine treatments were arranged in a randomized complete block design with three blocks (Table 1). The handling study (Experiment 2) involved three factors that were perceived to potentially affect the integrity of the polymer coating: 1) Retail point handling, which consisted of two loading methods: a) loading the product using a blender that was scaled with fertilizer deposits, or b) loading product after the blender first loaded 10 tonnes of potash for the purpose of de-scaling the blender to minimize abrasion; 2) Farm handling, which consisted of two loading methods: a) loading product into tote or 'mini-bulk' bag (Trimeg holdings LTD, Calgary, AB, Canada) using a 15 cm diameter, steel-flighted auger (Brandt Manufacturing, Regina, SK, Canada), or b) no auger employed – material poured directly into tote bag at retailer and emptied through spout on the bottom of the tote; and 3) Method of application, which consisted of a) control – not handled, b) ConservaPak air drill (Model CP 129A, Vale Farms, Indian Head, SK, Canada) set to high fan speed, c) ConservaPak air drill set to medium fan speed, d) Flexi-Coil delivery system with Easy Flow Header manifold (CNH, Saskatoon, SK, Canada) and John Deere MaxEmerg opener (Moline, IL), e) Flexi-Coil delivery system with product metered to calibration tube, not through manifold, f) 'Barber' drop spreader (Barber Engineering Company, Spokane, WA) set at high rate or wide opening, g) 'Barber' drop spreader set at medium rate or opening, h) Valmar air boom applicator (Model 245, Valmar Airflo Inc., Elie, MB, Canada) set to high fan speed, and i) Valmar air boom applicator set to low fan speed. For implements with more than one exit point, a sample of product was collected by combining equal quantities from each exit point into a composite sample. The three factors (retail handling, farm handling and method of application) were combined into a 36 treatment, factorial randomized complete block design with 3 blocks (Table 1).

To determine crop responses to the variations in abrasion levels and corresponding rates of N release for both experiments, samples were seed-placed with canola (*Brassica napus* L. cv. 'Invigor 5020'), winter wheat (*Triticum aestivum* L. cv 'AC Radiant'), spring wheat (*Triticum* *aestivum* L. cv 'CDC Go'), winter triticale (X *Triticosecale* Wittmack cv 'Bobcat'), and spring triticale (X *Triticosecale* Wittmack cv. 'Pronghorn'). Triticale was not included in the handling study (Experiment 2). The canola and cereal plots were sown at rates of 150 seeds m^{-2} and 300 seeds m^{-2}, respectively. Seed-placed ESN® rates for canola and cereals were 45 kg N ha^{-1} and 90 kg N ha^{-1}, respectively, which would be 3x the safe rate of seed-placed uncoated urea. Plots consisted of 4 rows spaced 23 cm apart with an overall size of 0.92 m wide by 3 m long, and sown in early-spring or late-summer using a self-propelled plot seeder equipped with a cone splitter and zero-tillage double disc openers. The seed bed utilization for this seeder configuration is narrow and would be approximately 10%.

A follow-up study was conducted to determine how upper limits of seed safety using seed-placed ESN® in cereals and canola change with increased N rates and alterations to the coating integrity of ESN®. Alterations to the coating integrity of ESN® were created in the laboratory (consistent within an incremental range of 20 to 80% N release after 7 d immersion in 23°C water) and then arranged in a factorial combination with five rates (30, 45, 60, 75, and 90 kg N ha^{-1}) of the seed-placed ESN lots and urea (100% N release). The same crop responses and varieties used and described above were adopted for this experiment.

Enhanced efficiency N fertilizer management

Although several studies are presented, the following methodology is the general experimental approach that we have designed and followed. Study locations varied but were chosen to represent that major soil zones of the Canadian prairies ie. Lethbridge, Lacombe, Falher, Alberta; Scott, Indian Head, Canora, Saskatchewan; and Brandon, Hallonquist, Manitoba. The N management treatments included the following urea types: 1) uncoated urea (46-0-0), 2) Ammoniacal N stabilized with a urease inhibitor NBPT (Agrotain®), 3) Super-granulated urea with increased N stability derived from urease and nitrification inhibitor (SuperU®), 4) polymer-coated urea – Environmentally Smart Nitrogen® (ESN®), and 5) urea ammonium nitrate (UAN; 28-0-0). We have also recently explored responses with ammoniacal N impregnated with a nitrification inhibitor (ENtrench®). All fertilizer was supplied by Nutiren, Corteva and Koch Agronomic Services. If N rates were not a factor in the treatment structure, rates for all treatments were usually based on 80% soil test recommendation from Western Ag Labs Plant Root Simulator® (PRS; Saskatoon, SK, Canada). Each urea type was applied using the following timing/placement methods: 1) all N side-banded at time of seeding, 2) all N broadcasted in early spring at approximately Zadoks growth stage 30, and 3) half N side-banded and half N broadcasted in spring. The experimental designs were full factorial randomized complete block or designs that utilized a split-plot arrangement, always with four replications. Main effects studies were cultivars and subplots N management treatment combinations. Experimental unit dimensions varied but were usually based on 3.7 m wide by 15.2 m long dimensions. Additional N management treatments have included urea type and various split application time/placement possibilities. For example, 1) all N side-banded at time of seeding, 2) half of N side-banded and the other half was broadcast late fall (i.e., first week of November), 3) half of N side-banded and the other half was broadcast early-spring (Zadoks 30), 4) half of N side-banded and the other half was broadcast mid-spring (Zadoks 40), and 5) half of N side-banded and the other half was broadcast late-spring (Zadoks 45-50). We have also compared split applications of the following to all N side-banded at planting: 1) 30% N side-banded at planting and 70% broadcast in late fall (i.e., first week of

November), and 2) 30% N side-banded at planting and 70% broadcast in early spring at approximately Feekes growth stage 4 at the beginning of stem elongation.

Seeding Operations and Pest Management

For both tests, glyphosate or Pre-Pass® (florasulamSC - 4.95 g ai/ha; glyphosate - 445 g a.e. ha-1) (Dow AgroSciences Calgary, AB, Canada) was applied across the entirety of each site 24 to 48 h prior to seeding using a motorized sprayer calibrated to deliver a carrier volume of 45 L ha-1 at 275 kPa pressure. Seeding was conducted with a ConservaPak™ air drill configured with knife openers spaced 23 cm apart. Winter wheat was sown at a rate of 450 seeds m-2, with a target plant density of 338 plants m-2. Seeding dates for each site in both experiments are summarized in Table 1. All plots, including the control, received blanket applications of other macronutrients based on Western Ag Labs PRS® soil test system.
Weed control was achieved with an application of 2,4-Dichlorophenoxyacetic acid (2,4-D LV ester - 560 g a.e. ha-1; 2,4-D Ester LV 600, Nufarm Americas Inc., Burr Ridge, IL, USA) when average growth was the 3 to 5 leaf stage around mid-October. If necessary, a tax mix of thifensulfuron/tribenuron (15 g a.i. ha-1 - Refine Extra®, Dupont Canada Agricultural Products, Mississauga, ON, Canada) and clodinafop (56 g a.i. ha-1; Horizon® 240 EC, Syngenta Crop Protection Canada, Guelph, ON, Canada) Horizon™ plus Refine Extra™ was applied in the spring for additional weed control. All post-emergent herbicide applications were made using a motorized sprayer calibrated to deliver a carrier volume of 45 L ha-1 at 275 kPa pressure.

RESULTS AND DISCUSSION

Handling effects on polymer-coated urea

There was an inverse relationship observed between most crop response variables and increased nitrogen release treatments (abrasion). Winter wheat compensated through increased tillering and maintained high grain yield regardless of abrasion severity. Acceptable plant populations were maintained up to the 60% release level and crop canopy differences were not as apparent in the latter stages of the vegetative crop phase. With respect to retail and on-farm handling, the most serious abrasion occurred when transferring product in equipment containing scaly deposits; topdress applications with an air boom applicator, or with seeders configured with header-manifold systems operating at high air fan speeds. In most cases, the crop compensated to any injury sustained and grain yield was usually unaffected or could be mitigated through proper equipment maintenance and settings.

The highest and most stable yield for canola and wheat was achieved with 60 to 90 kg N ha-1 with ESN® that had 20 to 40% N release. Triticale appeared to tolerate even greater release rates of N (80%) at the highest N rate. Results from this study confirm the substitution of urea with ESN allows at least 3x rates of seed-placed N provided N release ≤ 40%, which is easily achieved through proper handling. Substitution of uncoated urea with ESN will allow producers to seed-place N in a single-pass with rates that achieve N sufficiency.

Enhanced efficiency N fertilizer management

The wide range of environmental conditions resulted in a fairly diverse set of site-years that was representative of growing conditions for winter wheat in western Canada. Moreover, the range of growing conditions encountered in this study provided an adequate estimate of how N treatments as designed in the two experiments would affect winter wheat responses in western Canada. Of all the factors tested, varietal differences were most variable among sites, suggesting merit for future development of variety specific N management. Also, the control and the most inferior N form, UAN, appeared to be most sensitive to environment variation among sites. With regards to the remaining N treatments, where variety effects, and treatment nor variety by treatment interactions were noted to be deviant at select sites, these deviations were neither frequent nor consistent enough to indicate that average differences among N fertilizer forms and placement/timing would vary among sites. Furthermore, the sites where treatment deviations were detected were not the same sites noted as 'unique' sites from partial least squares analysis (all Lacombe). Productivity levels can vary considerably among soil zone and potentially affect responses to applied treatments. Yields among soils for both tests in this study were as follows: Brown = 2.6 Mg ha-1, Dark Brown = 4.2 Mg ha-1, and Black = 4.5 Mg ha-1. Based on our results, no conclusive evidence suggests that N management with respect to urea type and its placement or timing will differ among soil zones regardless of whether you consider productivity, quality, efficiency, or profitability of winter wheat. Therefore, we can conclude that Agrotain® and SuperU® may be applied during seeding operations and/or broadcast in-crop the next spring with reasonably low risk that there would be any yield-related penalty relative to a more typical urea side-banded at the time of seeding regardless of the winter wheat variety.

Similar results have been observed in unpublished work where yield results were in the order of SuperU® ≥ ENtrench® ≥ urea ≥ ESN®; the yield response to SuperU® was significantly higher than ESN®. For timing and placement, superior yields were observed when N was all-banded and least with a 30% banded/70% late fall in-crop application. A split application of N in-crop at Feekes 4 produced similar yields to all banded. Moreover, Agrotain Ultra® was superior to all other N sources with regards to wheat grain yield and agronomic efficiency.

Aside from seed-placed applications, which is where ESN**®** provided substantial improvements to seed safety, ESN**®** appears to release too slowly in the northern Great Plains. This is somewhat expected given that the specification of the polymer-coating are designed to be optimized for corn production in the Central Plains. However, proportions of it in side-banded (1:1 ratios with urea) systems improved yield in certain conditions.

Protein management for winter and spring wheat remains a concern for the industry. An aspect that warrants further investigation is how the influence of daily minimum temperatures identified by our PLS analysis may be used as a management tool to optimize grain protein concentration.

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An Assessment of Soil Testing as it Relates to Corn Ear Leaf Nutrition in the Midwest

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Abstract

Soil testing for P, K and Zn for corn production the Midwest is based on the probability of crop yield response to an applied fertilizer and not on crop nutritional status. Results of three years of observational data from 98 field sites show soil test M3-K only predicted 26% of the variability in ear leaf K at growth stage R1-R2, whereas K base fraction (K_{BF}) predicted 44% of the ear leaf variability and 56% of the variability in the ear leaf K:Mg ratio. Soil M3-P was inconsistent in predicting ear leaf P, and M3-Zn was not correlated with ear leaf Zn. Over years soil M3-K/Mg ratio was highly positively correlated with ear leaf K, negatively correlated with ear leaf Mg and positively correlated with ear leaf K:Mg ratio. Further subsoil K_{BF} and M3-K/Mg were better correlated with ear leaf K and the K:Mg ratio than M3-K. These results show soil K_{BF} and M3 K/Mg soil test parameters are superior indicators of the nutritional K status of corn ear leaves over current methods. Results support the inclusion of soil K_{BF} and M3-K/Mg in assessing corn K nutrition and response to K fertilizer recommendations.

Introduction

Nutrient management across the Midwest primarily relies on soil testing for generating crop phosphorus (P), potassium (K), zinc (Zn) and lime recommendations. It is based on reference soil test method, field correlation and calibration, and the probability of grain yield response to an applied nutrient based on a measured soil test value (Westerman, 1990). Soil testing in North American as is currently employed, does not address optimization of crop nutrient levels, but is focused solely on the probability of crop yield response to an applied fertilizer nutrient.

A survey of corn ear leaf data 2011-2018 from testing laboratories across the Western corn belt indicates a relatively low occurrence of P deficiencies, but higher frequency of K and Zn deficiencies based on published Land Grant University guidelines. Results have noted ear leaf K deficiencies exceeding 50% of samples tested and values for Zn in ranging 20-30%. The objective of this paper was to assess soil test chemical properties and their relationship to corn ear leaf P, K Mg and Zn nutrition; and corn stalk K nutrition based on observational analysis of data collected from Midwest grower fields 2016-2018.

Materials and Methods

Observational research sites were established in fifty-one grower fields in 2016 and fifty-three in 2017 through 2018 across nine US states. Sites were selected based on a high yield environments, representing a range of soil textures and fertility environments. At each observation site four replicated plots, each six rows width by 30 feet in length, were install at after planting at corn growth stage V2-V3. Composite soil samples were collected representing 0-2", 2-6" and 6-8" from each plot and analyzed for $pH_{(1:1)}$; Sikora buffer pH; Mehlich 3 (M3) P, K, S, Ca, Mg, Na, and Zn; SOM-LOI, estimated CEC (CEC_{Est}), K base fraction (K_{BF}), and calculated soil M3-K/Mg ratio. Composite ear leaf samples based on 30 leaf collection at growth stage R1-R2 and analyzed for N, P, K, S, Mg, Ca, B, Mn, Cu, Zn, N:K, K:Mg and N:Mg ratios by Solum Labs, Ames, IA. At grain black layer grain yield data was collected by hand harvesting twenty feet of the center of the plot and collection of a composite of ten stalk segments 8" segment 6" above the ground. Grain moisture and test weight was determined and yield reported based on 15.5% moisture basis. Corn stalks were analyzed for: N, P, K, S, Mg, Ca, Zn and NO3-N by Sure-Tech Laboratories, Indianapolis, IN. For 2016 four sites were lost, one site in 2017 and two in 2018 due to weather and/or crop damage. Soil analyses, tissue data and yield data was compiled, averages calculated based on four reps, and analyzed using MS Excel and correlation models developed using XLstat software. Observation site data was processed as two data sets 2016 (n=47) and combined 2017-2018 (n=51).

Results and Discussion

Across 2016 observation sites soil pH values ranged from 4.90 - 7.63, M3-P 12.3 -105 ppm, M3-K 71 - 512 ppm, M3-Mg 64 - 1030 ppm, M3-Zn 0.6 - 29 ppm, SOM-LOI 1.40 - 5.35%, and CEC_{Est} 3.9 - 28.2 cmol kg^{-1}. For 2016 ear leaf concentrations for N ranged 2.07 - 3.32 %, P 0.24 - 0.46%, K 1.08 - 3.18%, Mg 0.14 -0.50 % and Zn 21.7 - 53.0 ppm. Similar soil analysis ranges were found for 2017 and 2018 observation sites, however ear leaf N nutrient concentrations were generally lower. Ear leaf P, K and Zn concentration ranges broadened in 2017-2018. Plant harvest populations ranged 26,800 to 34,200 plts ac^{-1} and grain yields ranged 145 - 282 bu ac^{-1} in 2016. Grain yields for 2017 and 2018 ranged from 176 - 292 bu ac^{-1}.

Pearson correlation coefficients for soil analyses and leaf nutrients for 2016 are shown in table 1. Soil $pH_{(1:1)}$ and M3-Zn were not correlated with ear leaf nutrients evaluated. Soil M3-P was significantly positively correlated with ear leaf P ($R = +0.62$, $p<0.0001$) and K ($R = +0.44$, $p<0.001$), whereas M3-K was significantly positive correlated with ear leaf P ($R = +0.48$, $p<0.001$), K ($R = +0.51$, $p<0.0001$) , and K:Mg ratio ($R = +0.67$, $p<0.0001$) and negatively correlated with ear leaf Mg ($R= -0.59$, $p<0.0001$) . Soil M3-Mg was significantly positively correlated with ear leaf Mg ($R = +0.55$, $p<0.0001$) and negatively correlated with the ear leaf K:Mg ratio ($R= -0.59$ $p<0.0001$) . Soil SOM-LOI and CEC_{Est} were both highly negatively correlated with ear leaf K with SOM-LOI values of ($R= -0.70$, $p<0.0001$) and negatively correlated with the ear leaf K:Mg ratios ($R = -0.57$, $p<0.0001$). K_{BF} was highly significant positively correlated with ear leaf P ($R = +0.56$, $p<0.0001$), K ($R = +0.67$, $p<0.0001$) and the K:Mg ratio ($R = +0.74$, $p<0.0001$) and negatively correlated with ear leaf Mg ($R= -0.58$, $p<0.0001$). Soil M3-K/Mg ratio was significantly positively correlated with ear leaf K ($R = +0.70$, $p<0.0001$) and K:Mg ratio ($R= +0.81$, $p<0.0001$) and negatively correlated with ear leaf Mg ($R= -0.64$, $p<0.0001$) .

Observation site results for combined 2017 and 2018 observation sites show similar soil analysis and plant correlations to those of 2016 (table 2). Soil M3-P and M3-K were significantly positively correlated with ear leaf K, with M3-K correlated with ear leaf K ($R = +0.53$, $p<0.0001$) and K:Mg ratios ($R = +0.48$, $p<0.0001$). Soil SOM-LOI and CEC_{Est} were significantly negatively correlated, with SOM-LOI correlated ear leaf K:Mg ratio ($R = -0.44$,

Table 1. Pearson correlation coefficient of nine soil parameters and corn ear leaf nutrients, 2016 observation sites.

Soil Analysis[1]	N	P	K	Mg	Zn	K/Mg
pH	-0.12	0.12	-0.26	0.25	-0.15	-0.27
M3-P	0.30	0.62***	0.44**	-0.17	-0.23	0.30
M3-K	0.10	0.48**	0.49**	-0.59***	0.01	0.67***
M3-Mg	-0.20	-0.04	-0.51***	0.55***	-0.20	-0.59***
M3-Zn	-0.13	0.25	-0.02	-0.20	-0.05	0.05
SOM-LOI	-0.33	-0.41*	-0.70***	0.40*	0.37	-0.57***
CEC_{Est}	-0.34	-0.40*	-0.61***	0.40*	0.37	-0.55***
Soil K_{BF}	0.36	0.56***	0.67***	-0.58***	0.29	0.74***
M3 K/Mg	0.37	0.37	0.70***	-0.64***	0.25	0.81***

1. * , **, *** are different from 0 with a significance level alpha=0.01, 0.001 and 0.0001, n =47 sites

Table 2. Pearson correlation coefficient of nine soil parameters on corn ear leaf nutrients, observation 2017 and 2018.

Soil Analysis[1]	N	P	K	Mg	Zn	K/Mg
pH	0.31	0.09	-0.07	0.25	-0.02	-0.21
M3-P	0.05	0.28	0.44*	-0.27	0.09	0.42*
M3-K	0.01	0.26	0.53***	-0.30	-0.03	0.48**
M3-Mg	-0.42*	0.00	-0.32	0.34	-0.26	-0.49*
M3-Zn	0.20	0.17	0.18	-0.03	0.55***	0.17
SOM-LOI	-0.40*	-0.15	-0.30	0.30	-0.13	-0.44*
CEC_{Est}	-0.53**	-0.10	-0.27	0.29	-0.24	-0.39*
Soil K_{BF}	0.35	0.16	0.66***	-0.52**	0.15	0.76***
M3 K/Mg	0.31	0.13	0.65***	-0.46**	0.16	0.73***

1 * , **, *** are different from 0 with a significance level alpha=0.01, 0.001 and 0.0001, n= 51 sites.

p<0.001). Soil K_{BF} was highly positively correlated with ear leaf K (R = +0.66, p<0.0001) and ear leaf K:Mg ratios (R = +0.76, p<0.0001) , and negatively correlated with ear leaf Mg (R = -0.46, p<0.001). Soil M3-K/Mg ratio was highly significantly positively correlated with ear leaf K (R = +0.65, p<0.0001) and K:Mg ratio (R = +0.73, p<0.0001) and negatively correlated with ear leaf Mg (R= -0.46, p<0.001). Exceptions found for 2017-2018 observations from those of 2016 were a positive correlation of M3-Zn with ear leaf Zn (R = +0.55, p<0.0001) and negative correlation of CEC_{Est} with ear leaf Zn (R= -0.53, p<0.0001) .

Soil depth analysis of the 2016 observation sites indicates correlations of soil tests with ear leaf K, Mg and K:Mg ratios (table 3). Positive correlations of soil M3-K with ear leaf K increased with depth, but were negatively correlated with ear leaf Mg and ear leaf K:Mg ratio. Soil K_{BF} was highly significantly correlated with ear leaf K and K:Mg ratio independent of depth. Soil M3-K/Mg correlations generally increased with depth for ear leaf K, with a correlation of for the 2-6" depth (R = +0.66, p<0.0001). Soil M3-K/Mg correlations with ear leaf K:Mg ratio decreased with depth with the highest value noted for the 0-2" depth (R = +0.82, p<0.0001).

Corn stalk K analyses for 2016 and 2017-2018 observation sites show significant correlations with soil and ear leaf analyses (Table 4). Soil M3-K, K_{BF} and M3-K/Mg were positively correlated with stalk K concentrations for both observation data sets, where as soil CEC_{Est} was significantly negatively correlated only in 2016. Ear leaf K and K:Mg ratios were highly positively correlated with stalk K concentrations, with K:Mg correlations of R +0.73 and R +0.63 for the respective years.

Table 3. Pearson correlation coefficients for soil K and corn ear nutrients by soil depth, 2016.

Soil Analysis	Depth	Ear Leaf K	Ear Leaf Mg	Ear Leaf K/Mg
M3-K				
	0 - 2"	0.17	-0.25	0.33
	2 - 6"	0.35	-0.38	0.49**
	6 - 8"	0.48**	-0.35	0.58**
Soil K_{BF}				
	0 - 2"	0.66***	-0.47**	0.66***
	2 - 6"	0.68***	-0.42*	0.60***
	6 - 8"	0.70***	-0.35	0.58***
Soil M3 K/Mg				
	0 - 2"	0.63***	-0.59**	0.82***
	2 - 6"	0.67***	-0.55***	0.79***
	6 - 8"	0.66***	-0.48**	0.75***

[1] * , **, *** are different from 0 with a significance level alpha=0.01, 0.001 and 0.0001, n= 51 sites.

Table 4. Pearson correlation coefficients, six parameters for corn stalk K, 2016 and 2017-2018.

Analyses	Corn stalk K	
	2016 observation sites[1]	2017-2018 observation sites
M3-K	0.78***	0.52**
CEC	-0.46**	-0.35
Soil K_{BF}	0.73***	0.64***
M3-K/Mg	0.62***	0.54**
Leaf K	0.56**	0.55**
Leaf K:Mg	0.70***	0.63***

[1.] * , **, *** are different from 0 with a significance level alpha=0.01, 0.001 and 0.0001, n= 47 sites 2016 and 51 sites 2017-2018.

Table 5. Soil K_{BF} range, corn ear leaf K deficiency range and ear leaf K:Mg ratios 2016.

Soil K_{BF} Range	Corn ear leaf value	
	Mean percent of observation sites < 2.0% K	Mean ear leaf K:Mg ratio
< 1.5%	100	4.7
1.5 - 2.0 %	70	5.8
2.0 - 3.0 %	54	6.4
3.0 - 5.0 %	33	9.6
> 5.0 %	12	14.6

[1] 2016, 47 field sites, each K_{BF} range represent 7-9 observations sites, soil sample 0-8" depth collected spring 2016, ear leaves collected at GS R1-R2.

Summary and Conclusions

Results show that for ninety-eight Midwest corn grower observation sites M3-P was inconsistent with ear leaf P across the two data sets, but consistently positively correlated with ear leaf K. M3-K had a very significant positive Pearson correlation with ear leaf K and K:Mg ratios and a negative correlation with ear leaf Mg. These results are in agreement with those of Seggewiss and Jungk (1988), that showed that rye grass K deficiencies resulted in increase Mg uptake. Soil M3-Mg, was negatively correlated with ear leaf K, and ear leaf K:Mg ratios indicating high soil M3-Mg was associated with ear leaf K deficiencies.

Correlations of soil M3-Mg and M3-Zn with leaf Mg and ear leaf Zn were inconsistent across the two data sets and likely related to weather differences between years as early growing season rainfall was significantly higher in 2017 and 2018 relative to 2016.

Consistently results indicated positive Pearson correlations of both soil K_{BF} and M3 K/Mg with ear leaf K and ear leaf K:Mg ratios, and a negative correlation with ear leaf Mg. Across the two data sets correlations of either K_{BF} and M3-K/Mg with ear leaf K were higher than those observed for M3-K alone. Further both K_{BF} and M3-K/Mg were significantly correlated with stalk K concentrations across years. In addition high correlations were also noted for both soil K_{BF} and M3-K/Mg with ear leaf K observed across soil depths for the 2016 data set.

These results show soil K_{BF} and M3 K/Mg test parameters are superior in predicting ear leaf K and/or K:Mg ratios than the current M3-K soil test method used for K nutrient management. Further they advance the premise that soils with low K_{BF} values are associated with lower ear leaf growth stage R1-R2 concentrations and lower K:Mg ratios for results from the 2016 observation sites as illustrated in Table 5. Based on a ear leaf K critical deficiency concentration of 2.0%, observation sites with a $K_{BF} < 1.5\%$ had 100% of sites with ear leaf K deficiency and a mean K:Mg ratio 4.8, whereas sites with a $K_{BF} = 5.0\%$ had 12% of sites the ear leaves with < 2.0% K and a mean ear leaf K:Mg ratio of 14.6. Elwali et al. (1985), reported DRIS norms for corn grown in the southeastern US reported a mean ear leaf K:Mg ratio of 9.6 and that ratios < 6.0 were sub optimal and associated with corn K deficiencies. Observation data of 2016 from this study indicated sites with ear leaf K:Mg ratio > 10.0 resulted in a mean grain yield of 244 bu ac^{-1}, whereas those with a ratio < 6.0 had a mean corn yield of 212 bu ac^{-1}.

Overall, these observations indicate an inconsistent correlation of M3-P with ear leaf P and M3-Zn with and ear leaf Zn across years. M3-K as a soil test, only predicted 26% of the variability in ear leaf K, whereas K_{BF} predicted 44% of the ear leaf variability and predicted 56% of the ear leaf K:Mg variability. These results show the need to include soil K_{BF} and M3-K/Mg in the assessment of corn K response research and fertilizer recommendation models.

Acknowledgments

The author thanks the one hundred and four growers for their participation in this study. Special thanks to Dr. Larry May, Mr. Craig Struve, Mr. Tim Smith, Mr. Collyn Miller, and Ms. Irene for their assistance in sample and data collection. Thanks to Winfield United, The Fluid Fertilizer Association, Nachurs and Climate Corporation for providing funding for this study.

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FORGIVEN NOT FORGOTTEN: A SHORT HISTORY OF WIND EROSION ON THE CANADIAN PRAIRIES

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ABSTRACT

Since agriculture arrived on the Canadian prairies in the late 1800s, wind erosion has always been a constant threat. The 1930s saw some of the worst wind erosion but spurred the invention and adoption of soil management techniques to provide better crop residue management, the number one line of defense against wind erosion. The conservation tillage movement of the 1990s saw increased no-till and summer-fallow almost disappeared. However, recent trends of more intensive tillage on the Canadian prairies, the possible attainment of peak soil cover, and the uncertainty surrounding climate change, drought, and extreme weather events remind us that we cannot let down our guard against wind erosion.

BACKGROUND

After the last glaciation 10,000 yr ago, the Canadian prairies did not change much until the 1800s. Large tracts of treeless grassland were grazed by bison, living in harmony with indigenous nations. Pre-1800, there were an estimated 30-60 million bison in North America. The Canadian prairies are mostly semi-arid with annual precipitation increasing from only 10" in southeastern Alberta and southwestern Saskatchewan to about 22" in southern Manitoba. The Palliser Expedition in the 1850s warned that the driest area of the prairies (later known as the Palliser Triangle) would not support agriculture. However, the more expansionist Macoun Expedition of the 1870s promoted the idea of opening up the prairie to agricultural settlement.

By 1880, only 400,000 bison remained, and in 1882, the Canadian Pacific Railway reached Calgary, Alberta, almost at the Rocky Mountains. In the 1880-1900 period, cattle ranching and grazing dominated the prairies. However, in the early 1900s, further waves of settlers broke up the native prairie for agriculture using European farming methods including the moldboard plow, discs, and harrows (Fig. 1).

At first, the rich soils developed under native grasses for centuries, were quite productive. However, they were quickly mined of available nutrients and a lack of surface cover led to the first evidence of wind erosion, euphemistically referred to as 'soil drifting' (Fig. 2). Fairfield (1920) wrote that "*A triangular area beginning at Pincher Creek and extending east for about 100 miles is an area of severe soil drifting. There was not much problem when the land was new but some lands should not have been broken. To control - plow only when the soil is moist, do not disc, maintain cloddiness, strip crop and use winter rye*".

Therefore strip-cropping became the norm with 2-yr rotations of wheat-fallow where upwards of half the land area was fallowed for soil moisture conservation. This system resulted in crop cover for only 4-5 months, followed by a 19-20 month fallow, or an approximate 80:20 fallow:crop split over a 2-yr period.

THE DIRTY THIRTIES AND BEYOND

The 1930s brought an economic-ecological one-two punch to prairie farming. The Great Depression coincided with severe drought for a number of consecutive years. Grasshoppers, cutworm and wheat stem sawfly damage to crops was widespread and wheat yields in 1937 were the lowest in 30 yr. However, there was progress in the 1930s. Firstly, the Prairie Farm Rehabilitation Act (PFRA) was passed in 1935 and staff were hired to combat drought and soil drifting in the prairie provinces. Secondly, the Noble blade cultivator, was invented in 1936 by Charles S. Noble at Nobleford, AB, and is credited with saving vast tracts of prairie land from severe erosion. This tillage implement was able to control weeds on fallow by severing roots just below the soil surface, while at the same time maintaining residue cover to protect against wind erosion.

Fig. 1. *Power machinery breaking virgin prairie sod in the early 20th century. (**Source**: Western Development Museum, Saskatoon, SK).*

Fig. 2. *Hot, drying winds picked up loose topsoil and produced towering dust storms (**Source**: Glenbow Archives, Calgary, AB).*

One of the most famous names in the history of wind erosion research, William S. Chepil, while probably better-known in the US, spent most of his life on the Canadian prairies. He was born at Gimli, Manitoba in 1904 (Smith, 1981). He received a B.S.A. in 1930, and an M.Sc. in 1932, from the University of Saskatchewan. He joined the Canada Department of Agriculture, as Officer-in-Charge of the new substation in Regina, SK, in 1931. In 1936 he transferred to the Soil Research Laboratory at Swift Current, SK, to undertake research on wind erosion and its prevention. From 1937-39, he attended the University of Minnesota, and was awarded a Ph.D. in 1941. In 1946, he took an 18-month assignment in Henan and Anhui provinces, China, as a soil reclamation specialist with the United Nations Relief and Rehabilitation Administration. In 1948, he left Swift Current to take up a position with USDA-ARS in Manhattan, KS, becoming leader of the wind erosion research program in 1953, when he and colleagues set out to develop the Wind Erosion Equation (WEQ) [Tatarko, 2005]. The WEQ led to an understanding of the fundamental factors causing and controlling wind erosion (i.e. soil cloddiness, ridge roughness, field length, climate, and vegetation). However, Dr. Chepil died of cancer in 1963, at age 59, before he could see the first publication of the WEQ in 1965. WEQ was used and enhanced until the official release of the new Wind Erosion Prediction System (WEPS) by USDA in 2005 (Tatarko, 2005).

THE CONSERVATION TILLAGE REVOLUTION

The early pioneers of conservation tillage (minimum tillage, no-till) research in the 1960s and ‘70s in southern Alberta, showed that crop yields were similar with conservation vs. conventional tillage practices, while wind erosion risk was greatly reduced by means of a surface layer of protective residue cover (Anderson, 1961; Lindwall and Anderson, 1977). In the 1980s, a Senate Committee Report (Sparrow, 1984), coupled with drought years in which wind erosion was again prevalent, provided the impetus for grassroots farmer-led organizations which promoted soil conservation practices on the prairies. These groups, active throughout the 1990s and 2000s included the Alberta Conservation Tillage Society, the Saskatchewan Soil Conservation Association, and the Manitoba-North Dakota Zero Tillage Farmers Association. As a consequence, summer-fallow area fell dramatically (to <5% of cropland) across the prairie provinces (Fig. 3). Continuous cropping became the norm.

The other major change was the rapid adoption of conservation tillage. In Alberta, conventional tillage (i.e. tillage incorporating most crop residue into soil) fell from 73% of the seeded area in 1991 to only 12% in 2016 (Fig. 4). In Saskatchewan, the corresponding change was from 64% to 7%, while in Manitoba it was from 66% to 41%. Conversely, the percent of seeded area in no-till or zero tillage increased from 3% to 69% in Alberta, from 10% to 74% in Saskatchewan, and from 5% to 20% in Manitoba during the same time period (Fig. 4).

The last push of wind erosion research on the Canadian prairies occurred in the 1990s and focused on the processes of overwinter change in soil aggregate size distribution as affected by fallow management (Larney et al., 1994a), quantifying soil losses (Larney et al., 1995), the impact of freeze-thaw cycles on soil aggregate breakdown (Bullock et al., 2001), freeze-drying effects on wind erodibility (Bullock et al., 1999), the effect of wind erosion on redistribution of soil nutrients and crop yield (Larney et al., 1998) as well as the phenomenon of herbicide transport on wind-eroded sediment (Larney et al., 1999). By the early 2000s funding for wind erosion research had ceased, largely because the problem was deemed to be solved by the land use and soil management changes outlined above.

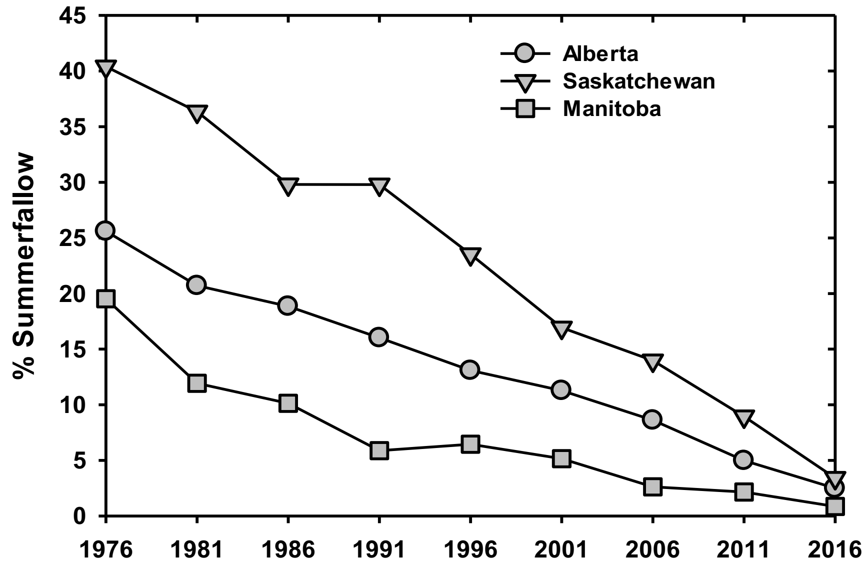

Fig. 3. *Change in summer-fallow area (as a percent of cropland) from 1976 to 2016 in the three prairies provinces (**Source**: Statistics Canada).*

THE RETURN OF TILLAGE?

After close to 30 yr of conservation tillage on the Canadian prairies, there has been an increase in tillage intensity (especially pre-seeding) in recent years. While there are no hard numbers, anecdotal evidence shows the rise of vertical tillage, often called 'tillage for no-tillers'. Vertical tillage systems depend on the manufacturer but generally wavy coulters, or in some cases knives, are mounted on a tool bar to break down crop residue and blacken the soil surface a bit (Hart, 2010). Although the coulters or knives run fairly shallow (2-3 inches), their action fractures the soil profile downward, or 'vertically,' improving moisture infiltration, crop root development and nutrient uptake and alleviating compaction.

As is usual in these scenarios, there is no one reason for the change, rather several overlapping drivers appear to be at play. Vertical tillage is partly fueled by equipment manufacturers trying to re-package existing technology as something new, without the benefit of research (McClinton, as quoted in Hart, 2010). Some of the earliest patents on wavy coulters date back more than 60 years. In addition, younger farmers who have grown up with conservation tillage, do not remember the years prior to conservation tillage when wind erosion was a problem. Another factor has been a series of wetter-than-normal seasons on the prairies which allows surface residue to build-up. Moreover, there are concerns that long-term no-till soils have low pH and high P concentrations (Teboh, 2016) in the shallow surface layer after many years of non-disturbance. 'Strategic tillage' may be promoted to alleviate this 'layering' effect.

HAVE WE REACHED PEAK SOIL COVER?

Huffman et al. (2012) documented increased soil cover on the Canadian prairies between 1981 and 2006. The improvement came primarily as a result of widespread no-till and a decline in summer-fallow. However gains were largely offset by a shift from higher-cover crops such as wheat, oats

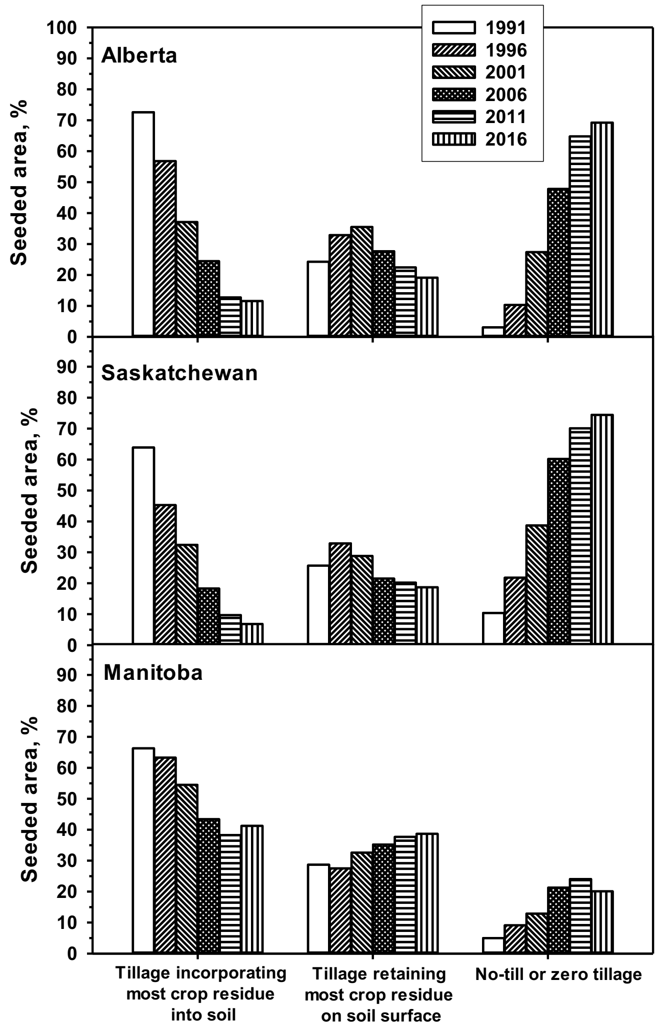

Fig. 4. *Change in tillage practices (as a percent of seeded area) from 1991 to 2016 in the three prairies provinces (**Source**: Statistics Canada).*

and barley to more profitable but lower-cover crops such as canola, soybean and potato. For many years, wheat was king on the Canadian prairies. In 1991, wheat area in the three prairie provinces was 34.3 million acres or 51% of all cropland while canola area was 7.5 million acres or 11% of cropland (Statistics Canada). By 2016, the areas of wheat and canola had converged dramatically, with wheat accounting for 22.1 million acres or 29% of cropland, and canola at 20.6 million acres or 27% of cropland. This trend has implications for soil cover and hence wind erosion risk, as canola produces less residue mass than wheat and decomposes faster (Soon and Arshad, 2002). Huffman et al. (2012) concluded that even though soil protection had improved, soil cover could decline over the next several decades if crop changes continue, the adoption of conservation tillage reaches a peak, or residue harvesting for biofuels becomes more common. In addition, the uncertainty of climate change and more extreme weather events (e.g. prolonged drought) could cause lower net primary productivity and hence residue cover, thus increasing wind erosion risk. Moreover, extreme weather events can lead to wildfires, which may also jeopardize soil surface cover, leading to wind erosion risk (Glen, 2012).

The bottom line is that we cannot become too complacent in the battle against wind erosion. It is always lurking in the shadows waiting to pounce, given the right set of environmental conditions. We can forgive past wind erosion but we should not forget.

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Strategic Tillage Effects on Crop Yield and Soil Properties in Dryland Crop Rotations

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ABSTRACT

This study evaluated strategic tillage (ST) to control HR weeds and improve crop yields in an otherwise long-term no-till (NT) soil. Treatments were five crop rotations: 1) continuous winter wheat (*Triticum aestivum* L.) (WW); 2) wheat-fallow (WF); 3) wheat-sorghum (*Sorghum bicolor* L.)-fallow (WSF); 4) continuous sorghum (SS); and 5) sorghum-fallow (SF) as main plots. The sub-plot were reduced tillage (RT), continuous NT, and ST of NT. Results showed tillage (ST or RT) reduced HR weed density compared to NT. Soil water content at wheat planting was less with RT compared to NT or ST. Strategic tillage did not affect wheat and grain sorghum yield compared to NT. Increasing cropping intensity reduced both wheat and grain sorghum yields. Strategic tillage decreased bulk density and had no negative effect on aggregate size distribution or mean weight diameter (MWD) compared to NT. The MWD of soil aggregates with RT was less than NT or ST. Soil organic carbon (SOC) was not different between NT and ST treatments and both were greater than RT. Soil P was not different among the tillage treatments but RT increased K concentration near the top 0 to 2-inch depth of the soil. The SOC, MWD and micronutrient availability were greatest with WW. Our results suggest ST could provide a mitigation option for HR weeds in NT systems with little impact on crop yields and soil properties.

INTRODUCTION

The increase in soil water storage due to NT adoption has allowed cropping intensification in dryland systems in the central Great Plains (CGP). Benefits of NT include reduced soil erosion, increased soil organic matter accumulation, improved soil structure and increased soil water storage. Stratification of soil nutrients, soil organic matter, and pH tend to develop near the soil surface in long-term continuous NT systems (Baan et al., 2009; Obour et al., 2017). This problem can reduce nutrient availability and uptake by crops and increase the chances of nitrogen and phosphorus losses in surface runoff. In addition, the lack of effective herbicides to control perennial grass weeds such as red three-awn grass (*Aristida purpurea* Nutt.) and tumble windmill grass (*Chloris verticillata* Nutt.) as well as the advent of herbicide resistance weeds such as kochia (*Kochia scoparia* L.) and palmer amaranth (*Amarathus palmeri* S. Watson) pose challenges in NT crop production. Poor control of invasive red three-awn and tumble windmill grass in NT reduced winter wheat and grain sorghum yields compared to clean tilled and RT systems (Thompson and Whitney, 1998), and there are no effective herbicides for managing these weeds.

There is evidence that some producers are reverting to tillage as a cost effective means of controlling herbicide resistant weeds in otherwise NT systems. Strategic tillage of NT cropping systems may be necessary to alleviate herbicide resistant weed issues, redistribute soil nutrients and soil acidification developed because of continuous NT. Baan et al. (2009) showed that imposing a single tillage operation on long-term NT soils had no significant effects on spring wheat yields or soil properties. Similarly, winter wheat grain yield and soil aggregate stability were not affected by one-time tillage of NT soils in eastern Nebraska (Quincke et al., 2007). However, others like Grandy et al. (2006) suggested cultivating NT systems can decrease soil aggregation and increase soil C and N losses so rapidly that all the gains made in soil restoration through NT can be undone within weeks to months after tillage.

Opportunity exists for using strategic tillage operations to correct some of the problems associated with NT without much impact on soil quality. For example, occasional tillage with moldboard plow in a RT or NT dryland cropping system controlled winter annual grass weeds and retained many of the soil quality benefits of NT (Kettler et al., 2000). Few studies have investigated the effects of occasional tillage on soils that have been in continuous NT (> 40-yr) in dryland conditions in the CGP. Our objectives were to determine the effects of ST in long-term NT systems on 1) soil water content and crop yields, 2) the effectiveness of ST to redistribute soil nutrients, soil acidity and control perennial grass and herbicide resistant weeds, and 3) determine soil properties following tillage of an otherwise long-term NT soil.

MATERIALS AND METHODS

This study was conducted using long-term tillage and crop rotation experimental plots established in 1976 at the Kansas State University Agricultural Research Center near Hays, KS. Experimental design was a randomized complete block with three replications in a split-plot treatment structure. Main plots were five crop rotations [continuous winter wheat (WW), wheat-fallow (WF), wheat-sorghum-fallow (WSF), continuous sorghum (SS), and sorghum-fallow (SF)] and two tillage treatments (RT and NT) as sub-plots. Every phase of each crop rotation and tillage combination were present in each replication for each year of the study. The study was modified in the summer of 2016 to implement one-time strategic tillage (ST) to manage perennial grass weeds by splitting the long-term NT plots into two equal plots of 20 ft. wide by 80 ft. long. One-half was left in continuous NT and the other half was tilled. This resulted in three tillage sub-plots treatments of RT, continuous NT, and ST of NT. The ST plots were first tilled to a depth of 3 inches with Quinstar Fallow Master Sweep plow (Quinstar Equipment Company, Quinter, KS) equipped with pickers to ensure complete control of the shallow-rooted tumble windmill grass and other HR broadleaf weeds. This was followed by a second tillage operation 3 days later with the same sweep plow to a depth of 6 inches for soil mixing and redistribution of pH and nutrient stratification. All tillage operations in the wheat rotations were performed in July prior to winter wheat planting in October. For crop rotations without wheat and only sorghum (SS and SF), tillage operations occurred in May before sorghum planting in June. Tillage in the RT treatment was accomplished with residue saving implements including a Minimizer V-blade plow with 5' sweeps (Premier Tillage, Quinter, KS) and the Fallow Master Sweep plow with 24" sweeps. Two to three tillage operations were performed in the RT plots over the fallow period before winter wheat planting in the WF or WSF rotation by using the 5' sweep initially followed by the 24" sweep.

Soil water content at winter wheat planting was determined gravimetrically to 4 ft in 6-inch depth increments in all plots. Two soil cores were taken from each plot and data averaged for a single soil water content measurement. Winter wheat grain yield was determined by harvesting a 5 ft. × 80 ft. area from the center of each plot using a Kincaid 8-XP small plot combine (Kincaid Equipment Manufacturing, Haven, KS). Soil samples were taken from 0 to 2-, 2 to 6-, and 6 to 12-

inch soil depths after tillage operations. These samples will be analyzed for changes in soil quality parameters including bulk density, SOC, aggregate size distribution and soil nutrients.

RESULTS AND DISCUSSION

Weeds and Soil Water Content

In general, broadleaf and grass weeds were significantly less with RT (0.74 plant/ft^2) and ST (0.68 plant/ ft^2) compared to the NT (3.4 plant/ ft^2) treatments. Soil water content measured at winter wheat planting with NT was similar to that of ST and both were greater than that measured with RT in crop rotations that had fallow (Fig. 1). However, tillage operations as either ST or RT decreased soil water content compared to NT at winter wheat planting in WW. Averaged across crop rotations, soil water storage was 13.4 inches with NT or ST, and 12.2 inches with RT over the 2-yr. Averaged across the 2-yr, soil water content with WF was 13.7 inches, which was greater than 13.2 inches for WSF or 12.3 inches with WW.

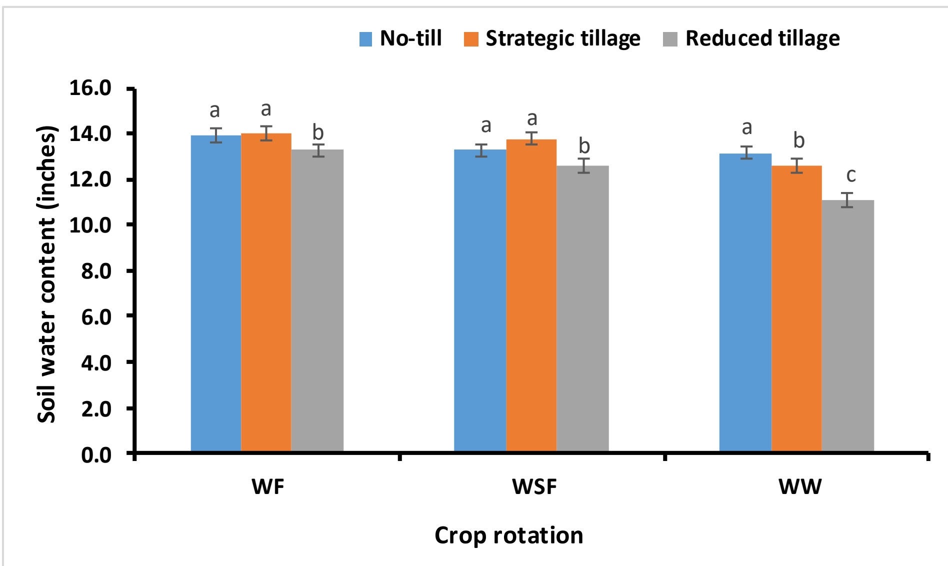

Fig.1.Tillage and crop rotation interaction effects on soil water content within 0 to 4 ft. measured in September 2016 and 2017. Means followed by same letter (s) are not different using the least squares means (LSMEANS) and adjusted Tukey multiple comparison procedure ($P > 0.05$).

Soil Properties and Crop Yield

Soil pH was not different among tillage treatments. However, pH within the top 6 inches was lowest in soils under WW compared to WF or WSF (Table 1), possibly because of annual N fertilizer application. Soil bulk density in the top 6 inches was different among tillage systems and crop rotations. Across crop rotations, bulk density averaged 1.26 g cm^{-3} with NT and 1.19 g cm^{-3} with ST or RT (Table 2). The proportion of water stable aggregates in each size class were similar between the long-term NT and the ST treatments. Mean weight diameter (MWD) of aggregates was 1.05 mm for NT, 1.06 mm for soils under ST and 0.69 mm for RT (Table 2). Similarly, MWD averaged 1.17 mm with WW, 0.93 for WF or 0.72 mm for WSF. The SOC concentration in the surface 2 inches with ST was 1.51 %, similar to 1.67 % measured in soils under NT but were both greater than that with RT 1.32 % (Table 2). Across tillage, SOC measured in the surface 0 to 2 inches for WW was 1.74 %, more than that measured under WF or WSF 1.36-1.37 % (Table 1).

Soil NO_3-N concentration within 2.5 inches in soils under ST was greater than NT or RT. However, beyond this depth, NO_3-N concentration was similar among tillage treatments (Table 2). Tillage (ST or RT) resulted in significantly less NH_4-N accumulation in the top 0 to 2 inch depth compared to NT (Table 2). Tillage had no effect on P concentration that differed only among sampling depth. Across crop rotations, K concentration in the upper 0 to 2 inches under NT (516 mg kg^{-1}) or ST (515 mg kg^{-1}) were less than that measured under RT. Soil K concentration in the upper 0 to 6 inches was greater in soils under WF compared to WSF or WW (Table 1). Averaged across crop rotations and sampling depth, Fe concentration with RT was 36.6 mg kg^{-1} that was less than the 42.8 mg kg^{-1} measured in soils under NT or 41.9 mg kg^{-1} with ST. The concentrations of Cu, Fe or Mn in the surface 0 to 6-inch depth were greater with WW compared to WF or WSF (Table 1).

Over the 2-yr, winter wheat yield with NT was 25 bu/a, which was less than that obtained with ST (31 bu/ac) or with RT (28 bu/ac) (Table 2). Crop rotation × year interaction had an effect on winter wheat grain yield. Regardless of crop rotation, winter wheat grain yield in 2018 was significantly less than that achieved in 2017. Averaged across tillage and crop rotation, wheat yield averaged 33 bu/a in 2017 and 23 bu/a in 2018. The differences were due to spring drought conditions in 2018. Winter wheat grain yields decreased with increasing cropping intensity, WF > WSF > WW irrespective of year. Sorghum grain yield varied over the 2-yr study. Average sorghum yield in 2017 was 47 bu/a, less than the 72 bu/a obtained in 2018. Sorghum grain yield with ST (63 bu/a) was not different from that of NT (61 bu/a), but were both greater than that of RT (54 bu/a) (Table 2). Similarly, increasing cropping intensity reduced sorghum grain yield

Table 1. Soil organic carbon, pH, potassium, iron, manganese, and copper concentrations as affected by crop rotation and soil sampling depth.

Rotation /depth	0-2 in.	2-6 in.	6-12 in.	0-2 in.	2-6 in.	6-12 in.	0-2 in.	2-6 in.	6-12 in.
		Soil pH			Soil organic carbon %			Potassium ppm	
WF§	5.71 a‡	6.17ab	6.89 a	1.36 a	1.14 a	8.9 a	558 a	559 a	544 a
WSF	5.87 a	6.29 a	6.86 a	1.37 a	1.12 a	9.2 a	539 ab	511 b	523 a
WW	5.27 b	6.06 b	6.99 a	1.74 b	1.22 a	10.0 a	516 b	528 b	544 a
		Iron			Manganese ppm			Copper	
WF	53.3 b	39.1 b	22.3 a	27.2 b	20.9 ab	11.7 a	1.5 b	1.4 a	1.2 a
WSF	46.8 b	34.6 b	22.2 a	25.8 b	20.1 b	12.0 a	1.5 b	1.4 a	1.3 a
WW	77.3 a	45.7 a	22.2 a	42.6 a	24.6 a	11.5 a	1.6 a	1.4 a	1.2 a

‡Means followed by same letter (s) within columns are not significantly different using the least squares means (LSMEANS) and adjusted Tukey multiple comparison procedure ($P > 0.05$).
§WF = Wheat-fallow; WSF = wheat-sorghum-fallow; WW = Wheat-wheat

SUMMARY

Strategic tillage of long-term NT soil decreased grass and broadleaf weeds and had no negative effects on soil water content at winter wheat planting. Wheat and grain sorghum yields with ST were not different from NT. Strategic tillage decreased bulk density and had no negative effect on SOC concentration, aggregate size distribution or MWD. However, ST did not affect pH and P stratification because of less soil mixing by the ST operation in the current study.

Tillage with disk or moldboard plow that allow soil mixing might help correct stratification of P or pH. Our results showed ST could provide a mitigation option for herbicide resistant weeds in NT crop production systems with little impacts on crop yields and soil properties.

ACKNOWLEDGEMENT

The USDA-NRCS Ogallala Aquifer Grant program and the Kansas Agricultural Experiment Station supported this work.

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Table 2. Grain yield, bulk density, mean weight diameter (MWD) of soil aggregate, soil organic carbon, pH, potassium (K), phosphorus (P), nitrogen (N), iron (Fe), manganese (Mn), and copper (Cu) concentrations as affected by tillage treatments..

Tillage/ depth	0-2 in.	2-6 in.	6-12 in.	0-2 in.	2-6 in.	6-12 in.	0-2 in.	2-6 in.	6-12 in.
	Soil organic carbon			Nitrate-N			Ammonium-N		
	%			ppm					
NT§	1.67 a‡	1.18 a	0.92 a	33.2 ab	16.3 a	7.6 a	13.2 a	3.3 a	2.6 a
ST	1.51 a	1.20 a	0.99 a	37.4 a	16.9 a	9.9 a	8.3 b	3.2 a	2.6 a
RT	1.32 b	1.10 a	0.91 a	30.7 b	15.8 a	11.2 a	4.4 c	2.7 a	2.5 a
		K		P	Fe	Zn	Mn	Cu	pH
	ppm								
NT	516 b	538 a	543 a	22.2a	42.8 a	0.50a	22.9 a	1.40 a	6.19 a
ST	515 b	517 a	535 a	19.1 a	36.5 b	0.42 a	20.3 a	1.35 a	6.30 a
RT	582 a	543 a	535 a	22.6 a	41.9 a	0.49 a	22.3 a	1.40 a	6.20 a
	0-6 in	6-12 in	0-2 in	Grain yield					
	Bulk density		MWD	wheat	Sorghum				
	g cm^3		mm	bu/a					
NT	1.26 a	1.19 a	1.05 a	25.3 b	61.0 a				
ST	1.19 b	1.19 a	1.06 a	30.8 a	63.4 a				
RT	1.19 b	1.18 a	0.69 b	28.3 ab	54.2 b				

†Means followed by same lower case letter(s) within columns are not significantly different using the least squares means (LSMEANS) and adjusted Tukey multiple comparison procedure ($P > 0.05$). Data are averaged across three crop rotations and three replicates ($n = 9$).
§NT = No-tillage; ST= Strategic tillage; RT = Reduced tillage.

OBSERVATIONAL AND MODELING METHODS TO INFORM ECOSYSTEM SERVICE MARKETS

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ABSTRACT

Interest in quantifying the impacts of land management on ecosystem services has grown as governments, environmental organizations, and corporations have pledged to reduce greenhouse gas emissions, nutrient leaching, and other environmental impacts of human activities. Ecosystem service markets were formalized in the 1990s and originally deployed to mitigate point sources of air and water pollution. Associated protocols were fairly simple and easy to implement because quantification of point sources is easy as is verification of mitigation practices. In contrast, protocols to quantify agricultural sinks and sources of pollutants are more complicated because these sources are more diffuse and often cannot be measured directly because required sampling intensity is not economically or technologically feasible. One approach to transcend this limitation is for protocols to employ pay for practice, i.e., land mangers/owners are paid a standard amount per unit of land area enrolled in a specific conservation practice and no attempt is made to quantify outcomes achieved at the entity level. Another strategy is for protocols to imbed models that calculate entity level greenhouse gas, carbon storage, and nutrient loss outcomes. But up to now, estimates generated by these models are not very accurate at the entity level. However, recent advances in data availability, geographic information systems, precision agriculture and remote sensing combined with model applications and ground and atmospheric based measurements can reduce these uncertainties. Protocols that integrate pay for practice and entity and larger scale quantification methods are expected to approach optimal cost:benefit ratios.

INTRODUCTION

Ecosystem services improve air and water quality, sequester carbon, and provide land for wildlife habitat and recreational activities. Although conservation programs that enhance ecosystem services have existed for decades, it was not until the 1990s that market-based payment for ecosystem services mechanisms were formalized (Gómez-Baggethun, et al., 2010). Markets designed to improve air and water quality emerged before markets designed to sequester carbon and reduce greenhouse gas (GHG) emissions (Bayon, 2004; Salzman et al., 2018). One reason for this is that legislation such as the Clean Water and Clean Air Acts include regulations and permitting so some level of compliance is mandated. On the other hand, GHG markets in the US are based almost entirely in voluntary commitments. Lack of a mandates leads to fluctuating and typically low prices for reduction credits and limited participation (Paustian et al., 2019).

Although markets for individual ecosystem services have existed for decades, a recent resurgence of interest has pushed the development of payment programs. Payments for ecosystem service programs are currently estimated at \$36–42 billion in annual transactions at the global scale (Salzman et al., 2018). For the US, a recent report estimated the potential demand for ecosystem service credits at about \$5.2, \$4.8, and \$3.9 billion for GHG, nitrogen, (N), and phosphorous (P) mitigation, respectively (https://ecosystemservicesmarket.org/wp-content/uploads/2019/09/Informa-IHS-Markit-ESM-Study-Sep-19.pdf). Functioning Ecosystem Service Markets (ESM) require various basic components including buyers, sellers, protocols to verify participation and quantify outcomes, and mechanisms to transfer funds. Buyers include governments (California, Alberta) and corporations such as Bayer, General Mills, Cargill, Amazon, and Google. Commitments made by corporations include reductions of GHG emissions, N, P and other pollutants, both directly within their supply chains (insets) and payments to other entities to provide mitigation benefits (offsets). Sellers include property owners and land managers who oversee crop and livestock operations. Various methods and protocols have been developed to quantify services provided (e.g., Niles et al., 2019). In this paper, we explore why some ESM have been more successful than others, summarize current knowledge, and show how currently available conservation programs, measuring and modeling methods can be combined to help landowners and managers exploit market opportunities.

WHY ARE SOME ESM MORE SUCCESSFUL THAN OTHERS?

Markets to improve air and water quality have been more extensively used than C sequestration and GHG reduction markets for various reasons. These include government mandates, availability of dedicated capital, and feasibility of measuring, reporting, and verifying practices and outcomes. For example, a large portion of industrial air and water pollution is from point sources (e.g., exhaust pipes) so can be quantified with high accuracy at reasonable costs. In contrast, agricultural sources and sinks of GHG and pollutants are typically diffuse. Agricultural emissions and sinks also tend to be highly variable in space and time so it is not technically and economically feasible to directly measure emissions from all relevant land parcels (Niles et al. 2019; Tonitto et al. 2018). Consequently, different methods based on models have been developed to quantify the impact of agricultural practices (Tonitto et al. 2018). However, these methods are usually characterized by high uncertainty, so the accuracy of predicted outcomes is compromised. In addition, predicted outcomes depend highly on the choice of method (Schild et al., 2018a; 2018b). In addition to low C prices and lack of accurate quantification methods, poor communication across various stakeholder groups have limited agricultural sector participation in the U.S.

PROTOCOLS FOR AGRICULTURAL SYSTEMS

Protocols have been developed to measure, report, and verify the adoption of different land use practices and the ecosystem service outcomes they provide. The accuracy of these protocols varies widely. At one extreme, protocols for major land use changes such as reforestation can be readily verified using remotely sensed imagery which can be combined with ground truthing to accurately estimate C sequestration in above ground biomass. At the other extreme, it is difficult to quantify how practices such as changes in tillage intensity or use of different fertilizer types affect soil C changes and GHG fluxes. In the middle are water quality protocols. For example, deploying cover crops and buffer strips has been incentivized in the Chesapeake Bay watershed to decrease nitrate and phosphorus loading. This provides an example of pay for practice because land managers/owners are paid a set price for every acre enrolled (Bowman and Lynch, 2019). In this case, it is relatively easy to verify the land area converted cover crops or buffer strips. Similarly, the aggregated outcomes, i.e. NO_3 and P concentrations in the Bay, can be accurately assessed (Woodbury et al., 2018). However, the contributions of individual land managers/owners to NO_3 and P loading cannot be quantified or verified (Bowman and Lynch, 2019).

To address the limitations of pay for practice more complex protocols that imbed empirical and/or process-based models (e.g., Paustian et al., 2018) and sometimes integrate ground-based measurements have been developed. A simple empirical approach is used by the Province of Alberta to estimate the soil carbon change and GHG consequences of different management practices without direct measurements. Modern computing power, user interfaces, and availability of GIS referencing for model inputs allow for relatively cheap and easy calculation of entity level GHG emissions, soil C changes, and nutrient losses using more sophisticated process-based models (Paustian et al., 2019). However, estimates based on these tools, whether empirical or process-based, are characterized by high uncertainty and accuracy cannot be assured, especially without site level validation (Richards, 2018; Tonitto et al., 2018). Uncertainty can be reduced by aggregating outcomes across space and time and taking measurements to increase accuracy of model inputs and/or to validate model outputs (Tonitti et al., 2018). Aggregation is straightforward and inexpensive to achieve but there is a tradeoff between increased accuracy as more measurements are taken and increased costs which could exceed the price of the credit.

CURRENT STATE OF KNOWLEDGE AND WAYS FORWARD

Ass stated above, markets based on point sources or sinks of pollution have the advantage of easy verification an quantification. Although many agricultural sources and sinks of GHG and pollutants are highly diffuse, some are point sources. One example is methane emissions from managed manure systems. Methane that would other wise escape to the atmosphere can be captured with anaerobic digestors and used to offset fossil fuel emissions. The resulting reductions in emissions can be easily verified and quantified with high accuracy but the systems are expensive. However, credits generated by policies in California can be large enough to cover some producer costs and help make anaerobic digesters profitable (e.g., https://www.governing.com/next/Minnesota-Could-Be-Moving-to-Farms-for-Renewable-Energy.htm).

Advances in precision agriculture and precision conservation (Delgado et al., 2019) are leading to some agricultural sources and sinks becoming more point like. For example, data and technologies exist to spatially and temporally target fertilizer and pesticide applications to increase yields while decreasing inputs (Delgado et al., 2019). Mitigation efforts can also be targeted at fine spatial resolution, for example databases for soil properties, topography, and land use have recently been combined identify where saturation buffers should be located to filter out nutrients that would otherwise contribute to water pollution (Tomer et al, 2017; McLellan et al. 2018) and credits can be calculated using available tools (Saleh and Osei, 2017). In addition to GHG and nutrient fluxes, precision conservation can also assess impacts of land use on wildlife habitat (McConnell and Burger, 2017).

To move forward we suggest that formal comparisons of the overhead costs of programs like EQIP (Environmental Quality Incentives Program) should be compared more sophisticated model-based protocols. Producers currently receive about 10-15% on average of every dollar spent on food but this is highly variable depending on commodity (https://www.ers.usda.gov/data-products/price-spreads-from-farm-to-consumer/price-spreads-from-farm-to-consumer/); this portion will likely need to be much higher for ecosystem service credits to have a good chance of widespread adoption. Outcomes quantified by using different approaches also need to be formally compared and uncertainty rigorously calculated. Cost and accuracy information can then be combined to identify the combination of pay for practice, modeling, measuring, and verifying methods that optimize economic and ecosystem outcomes.

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GREAT PLAINS SOIL FERTILITY CONFERENCE

Poster Presentations

P-1

EFFECTS OF RESIDUE PLACEMENT ON CO_2 LOSS IN AN IRRIGATED, NO-TILL CORN SYSTEM

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ABSTRACT

It is well known that residue management practices that leave crop residue on the surface, such as no-till agriculture, promote soil fertility. However, the effects of such practices on carbon sequestration can be highly variable. To better understand how residue management impacts the loss of carbon through mineralization, we investigated the effects of residue location and addition on CO_2 produced from residue decomposition under no-till irrigated continuous corn in Northern Colorado. Over a period of two years, we monitored the CO_2 fluxes of ^{13}C labeled residue treatments (i.e., incorporated vs surface applied) and their respective unlabeled residue controls. In the first year of the experiment, the incorporated residue treatment had greater residue-derived CO_2 loss during the non-growing season, while the surface applied residue treatments lost more residue-derived CO_2 during the growing season. In the second year, surface applied residue had greater residue-derived CO_2 loss than the incorporated residue in both the non-growing and growing season. Ultimately, our surface applied treatment lost more residue carbon as CO_2 (38.06%) than did our incorporated treatment (20.39%) over this two-year period, but still only represented a fraction of the added residue. Our results suggest that there may be more residue lost as CO_2 in irrigated systems practicing no-till agriculture, compared to those that are conventionally tilled, over the long term. However, CO_2 is only one piece of the carbon puzzle and therefore, the efficiency of carbon stock formation in the soil profile must be investigated as well.

INTRODUCTION

As atmospheric CO_2 levels continue to warm our planet at unprecedented rates, it is imperative that we reduce CO_2 emissions as well as draw down atmospheric CO_2. One way this can be accomplished is through soil carbon sequestration. Due to their large global land coverage and depleted carbon pools, croplands have high potential to be used as a soil carbon sink if we alter agricultural management practices (Paustian et al., 2016). Recently, residue management practices that leave residue on the soil surface have been highly advocated to promote soil fertility and soil health (Derpsch et al., 2010). However, the impact of surface placement on residue carbon stabilization is unclear.

When organic matter, such as crop residue or manure, is deposited on or within the soil, it gets broken down and decomposed by soil faunal and microbial communities. Throughout this process, the carbon from the organic matter can become stabilized as soil organic carbon (through microbial assimilation or physical/chemical protection), be lost through leaching, or be lost as CO_2 during microbial respiration (Trumbore, 2009). By monitoring the amount of CO_2 respired from crop residues, we can gage how efficiently the residue carbon is stabilized in soil versus lost into the atmosphere.

Soil CO_2 emissions stem from several different abiotic and biotic sources, including carbonate dissolution, root respiration, rhizomicrobial respiration, microbial decomposition of plant residues, microbial respiration from the priming effect, and basal microbial respiration (Kuzyakov, 2006). By labeling our plant residue with ^{13}C, a carbon isotope rarely found in nature, we are able to trace the portion of CO_2 that was specifically derived from this residue (Soong et al., 2014).

The objective of this research study was to analyze the effects of ^{13}C labeled residue placement (surface applied versus incorporated) on labeled residue-derived CO_2 fluxes in an irrigated, no-till cornfield in Northern Colorado over two years. After one year, unlabeled residue was added to assess the effects of a fresh carbon source on ^{13}C labeled residue carbon loss. We hypothesized that the incorporated residue would have greater CO_2 fluxes than our surface applied residues. This is due to more consistently favorable climatic conditions for the microbes within the incorporated treatment soil, which would allow for more decomposition and microbial respiration. We also hypothesized that fresh residue addition would result in greater ^{13}C labeled CO_2 fluxes due to priming.

MATERIALS AND METHODS

The field experiment was conducted at Colorado State University's Agricultural Research, Development and Education Center (ARDEC) in Northern Colorado. Our research plot was located within an irrigated, historically continuous no-till cornfield, where the soil is classified as a Fort Collins clay loam (fine-loamy, mixed, mesic Aridic Haplustalf).

In November of 2017, PVC collars (15 cm height, 10 cm diameter) were pounded 10 cm into the ground of our research plot, each positioned 0.7 meters apart and within one of four rows. Treatments consisted of surface applied or incorporated (10 cm into the soil profile) residue within the PVC collar. The experiment was a randomized block design with four replicates and described in detail by Leichty et al. (2018).

Residue was ^{13}C labeled *Andropogon gerardii* (Soong et al., 2014), a native C4 grass, and was used to create our three treatments (**Table 1**): incorporated labeled residue (INC), surface applied labeled residue (SA), and surface applied labeled residue without new residue (SA-NR). Our two controls, incorporated control (C-INC) and surface applied control (C-SA), were established without labeled residue; therefore, C-INC was disturbed to mimic the incorporated treatment and C-SA was left undisturbed. In the fall, one year after establishment, unlabeled corn (*Zea mays* L.) stover was collected from the field and added to all treatments, except for SA-NR, to simulate fresh inputs following annual harvest. We only report residue-derived CO_2 data from the ^{13}C labeled treatments (INC, SA, and SA-NR).

Treatment Name	Residue Placement	First Year Residue Addition	Second Year Residue Addition
INC	Incorporated	^{13}C labeled Andropogon gerardii	Unlabeled corn stover
SA	Surface applied	^{13}C labeled Andropogon gerardii	Unlabeled corn stover
SA-NR	Surface applied	^{13}C labeled Andropogon gerardii	No residue
C-INC	Incorporated	No residue	Unlabeled corn stover
C-SA	Surface applied	No residue	Unlabeled corn stover

Table 1. Experimental design and treatments.

Every year in April/May, corn (*Zea mays* L.) was planted along the edge of each row of PVC collars. SuperU, a slow-release fertilizer (polymer-coated urea), was then surface-band applied near the corn row at emergence in May at a rate of 120.5 lb N acre^{-1}. Throughout the growing season, the corn received approximately 35 mm of sprinkler-applied irrigation water once a week. Following the growing season, the corn was harvested annually.

Gas samples of treatments were taken continuously throughout the two years of our study, with the frequency of sampling depending on season. During the non-growing season, treatments were sampled once a week to once a month. During the growing season, treatments were sampled twice a week, once before the weekly irrigation and once following the weekly irrigation. To obtain gas samples, we sealed each treatment collar with a cap and used a syringe to extract 50 mL gas samples from within the sealed collar at 0, 15, 30, and 45 minutes. Each gas sample was then injected into two separate 12 mL Exetainer vials, each vial receiving approximately 25 mL of the gas sample. Back at the laboratory, one of the vials was analyzed on a gas chromatograph to obtain CO_2 concentration and the other vial was run on an isotope ratio mass spectrometer to measure $\delta^{13}C$ values. These two measurements, along with the initial $\delta^{13}C$ of the labeled residue and the $\delta^{13}C$ of the unlabeled controls, were used to construct Keeling plots (a linear regression of $\delta^{13}C$ versus 1/CO_2 concentration) for each 45 minute sampling period for each field replicate (Pataki et al., 2003). A two end-member mixing model was used to partition the total CO_2 flux into residue-derived and soil-derived CO_2 flux. By interpolating between sample points, we calculated cumulative fluxes to understand how much residue carbon was lost as CO_2 over time and between treatments.

RESULTS AND DISCUSSION

First year residue-derived CO_2 fluxes

During the non-growing season of the first year, INC had a higher residue-derived CO_2 flux than both SA and SA-NR (**Figure 1, a**). However, during the growing season, SA and SA-NR had higher residue-derived fluxes than INC (**Figure 1, b**). Overall, fluxes of all treatments were greater during the growing season than during the non-growing season, resulting in SA and SA-NR having greater cumulative residue-derived CO_2 fluxes in the first year, compared to INC (**Figure 1, c**). There were no significant differences between residue-derived CO_2 fluxes of SA and SA-NR at any point during the first year.

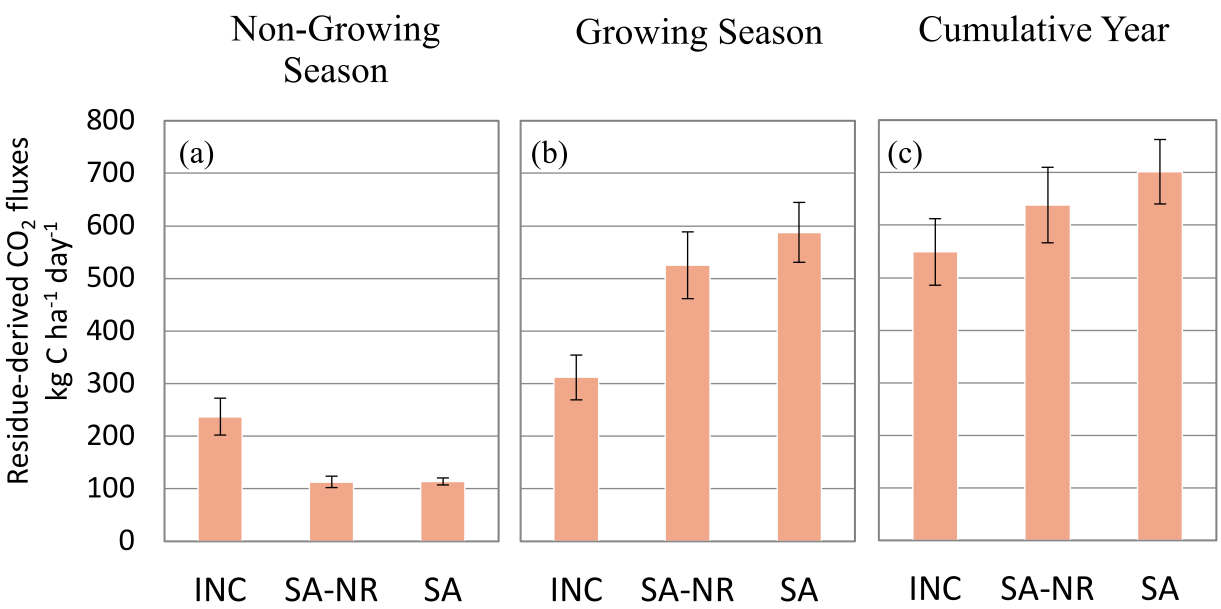

Figure 1. First year residue-derived CO_2 fluxes (kg C ha^{-1} day^{-1}) of incorporated (INC), surface applied without new residue (SA-NR), and surface applied (SA) treatments from the non-growing season (a), growing season (b), and cumulative year (c). Redrawn from Leichty et al. (2018).

Second year residue-derived CO_2 fluxes

Compared to the first year, the second year residue-derived CO_2 fluxes followed a similar pattern during the growing season and cumulatively. There were no significant differences between residue-derived CO_2 fluxes of SA and SA-NR at any point during the second year. The residue-derived CO_2 fluxes of the second year, however, were much lower than those of the first year. During the non-growing season of the second year, SA and SA-NR had greater residue-derived CO_2 fluxes than INC. While the CO_2 fluxes of INC were significantly different from those of SA, they were not significantly different from those of SA-NR (**Figure 2, a**). SA and SA-NR continued to have greater residue-derived CO_2 fluxes than INC through the growing season, although during this period, the difference between CO_2 fluxes of both surface applied and incorporated residue treatments was significant (**Figure 2, b**). Cumulatively, SA and SA-NR had greater residue-derived CO_2 fluxes than INC during the second year (**Figure 2, c**).

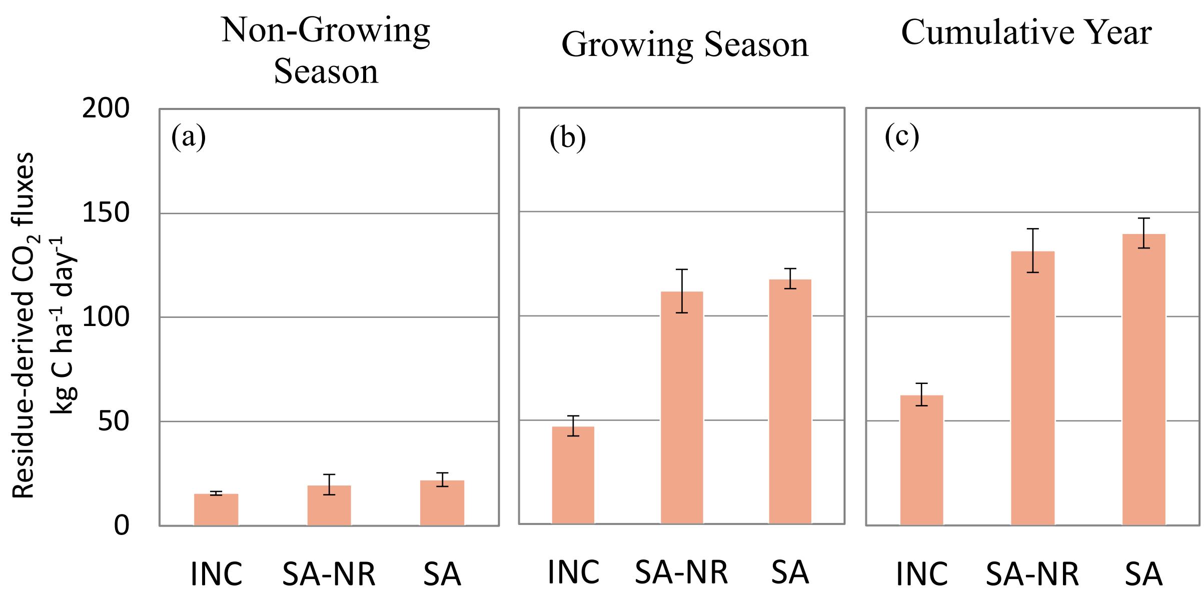

Figure 2. Second year residue-derived CO_2 fluxes (kg C ha^{-1} day^{-1}) of incorporated (INC), surface applied without new residue (SA-NR), and surface applied (SA) treatments from the non-growing season (a), growing season (b), and cumulative year (c).

Two-year cumulative residue-derived CO_2 fluxes

Combined over the two years, SA had the greatest residue-derived CO_2 flux, followed by SA-NR and then INC (**Figure 3**). Accordingly, SA lost 38.06% of residue to CO_2, SA-NR lost 25.67% of residue to CO_2, and INC lost 20.39% of residue to CO_2 (data not shown).

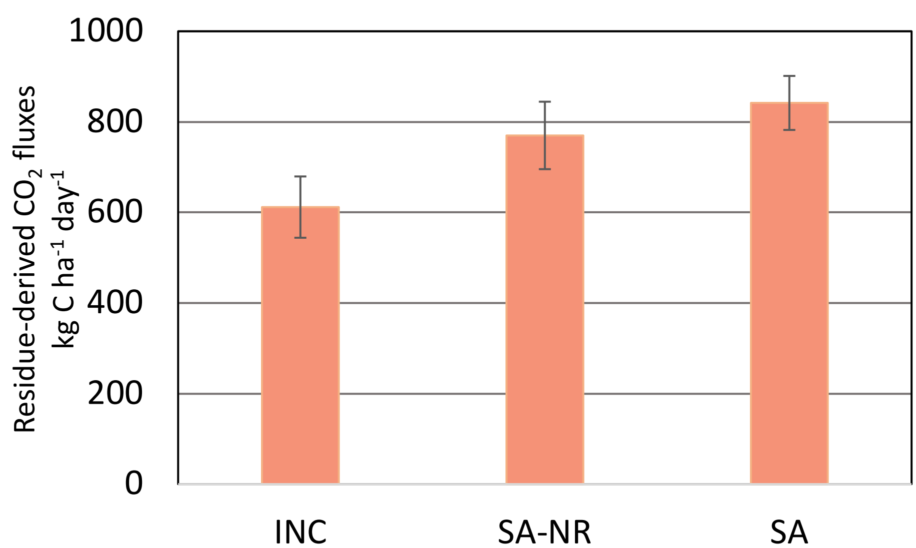

Figure 3. Two-year cumulative residue-derived CO_2 fluxes (kg C ha^{-1} day^{-1}) of incorporated (INC), surface applied without new residue (SA-NR), and surface applied (SA) treatments.

Our results indicate that residue placement has a significant effect on residue carbon mineralization. Contrary to our hypothesis, surface applied residue treatments lost more residue-carbon as CO_2 than did incorporated residue treatments. Additionally, due to the lack of differences found in the SA and SA-NR treatments, our study indicates that priming does not play a large role in the decomposition of residue. Together, our results suggest that, at least in an irrigated, no-till cornfield in Northern Colorado, agricultural practices that incorporate residue may be more efficient in stabilizing residue carbon. Agricultural management practices that promote soil health may not necessarily efficiently store residue carbon.

Our study uses carbon loss as CO_2 as a proxy for carbon stabilization efficiency; however, it is important to also consider the stability of the residue carbon that remains within the soil profile. According to Cotrufo et al. (2015), residue carbon can be transformed into either particulate organic matter (POM) or mineral-associated matter (MAOM). Essentially, MAOM is mostly formed of microbial cell debris and POM is mostly formed of partly decomposed and fragmented plant debris (Miltner et al., 2011). Due to the chemically stabilizing interactions that MAOM forms with minerals, it is considered the most stable pool of organic matter (Mikutta et al., 2006); therefore, it is an important pool to consider for long-term carbon sequestration. In order to more wholly understand the effects of residue placement on our system's ability to stabilize carbon, it would be helpful to additionally analyze the differences between treatments in terms of the allocation of residue carbon between POM and MAOM pools.

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P-2

DO LEGUME COVER CROPS HELP MINERALIZE SOIL NITROGEN?

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ABSTRACT

Nitrogen (N) dynamic is dependent on multiple factor all of which influence in-season plant N availability. Inclusion of a cover crop can have additional impacts on N dynamic by utilizing fall residue soil N, reducing the potential of N leaching. Legume cover crops also have the potential to add additional N to the soil through N fixation. The objective of this study was to evaluate N dynamic of different cover crops (legume and nonlegume) compared to no cover crop (NCC) and the impact on the following corn yield in a three-year field study. The treatments were NCC, sweet clover (*Melilotus officinalis*), winter cereal rye (*Secale cereale*), and hairy vetch (*Vicia Villosa* Roth.) in a randomized complete block design with four replications under no-till condition in a winter wheat/cover crop–corn rotation in Brookings, SD. Soil N mineralization using *in-situ* soil cores with ion exchange resin were measured in three different periods during corn growing season in the field. Results showed rye treatment had the lowest corn yield, however, legume mineralized greater amount of N, especially during the corn V6–R3 growth stage, when crop N demand was high. Nitrogen availability to corn following treatments ranked sweet clover > hairy vetch > NCC > rye depending on weather conditions. Results found that all measured variable were highly dependent on environmental. Hence, to better understand the impact of cover crops on soil N dynamic, additional long-term research is needed to account for yearly variability under different environmental conditions.

INTRODUCTION

In corn production, N is an essential element and one of the most limiting factors in crop growth and yield. Management of N is very challenging because N cycle is dependent on multiple factors in the soil not just a balance of input and output. Cover crops can be grown to provide multiple ecosystems services including, utilizing residual soil N, adding N to the system through fixation, protecting the soil from erosion, feed for livestock and/or weed control.

Utilization of cover crops to influence N dynamic have been evaluated with mixed results, multiple researchers have found that mineralization or immobilization is dependent on residue decomposition and timing of release when synchronizing uptake with the following crop (Wagger, 1989; Sievers and Cook, 2018). So far, no specific cover crop has been shown to consistently achieve both objectives. One common method to estimate soil N mineralization is to use aerobic or anaerobic incubation in the laboratory, but a field incubation (*in-situ*) might have more reliable estimation since N transformation are strongly site-specific (Kolberg et al., 1997; Khanna and Raison, 2013). Our research objective was to evaluate N dynamic of different cover crops compared NCC and the following impact on corn yield after cover crops.

MATERIALS AND METHODS

Research plots were located at three different sites, site 1 (RF) was conducted at the Eastern South Dakota Soil and Water Research Farm and two experiments were conducted approximately 1 mile away at the USDA–ARS North Central Agricultural Research Laboratory

(A2 and A3) near Brookings, SD under no-till soil management. These locations receive an average precipitation of 24-inches and average temperature of 42 °F (1981–2010) (NOAA, 2019). The experiments were a randomized complete block design with four replications. Cover crop treatments included, NCC, white sweet clover, winter cereal rye, and hairy vetch. Planting rate for sweet clover, cereal rye and hairy vetch were 20, 103, and 30 lb ac^{-1}, respectively, and were drilled into wheat stubble. Cover crop were allowed to over-winter and were chemically killed before corn planting. Corn hybrid (DeKalb 44-92) was planted at 20-inch row spacing with a seeding rate of 25,000 seeds ac^{-1} and treated with Trifloxystrobin. Ammonium polyphosphate with 14 lb N ac^{-1}, 16 lb P ac^{-1} and 10 lb K ac^{-1} as dry fertilizer as a starter fertilizer and additional of 50 lb N ac^{-1} as ammonium nitrate was applied sidedress at corn growth stages (GS) V6. Corn yield were harvested using a plot combine (MF8-XP) and yield was adjusted to 15.5 % moisture content (Fig. 2).

The top 6-inches soil has high organic matter (~3.7 %), with 7.3 pH, 1.3 % NO_3–N (2 M KCl extraction), 5 % P ($NaHCO_3$ method), and 2.2 % total C (dry combustion techniques). Cumulative precipitation and weekly averaged soil temperature at top 2-inches with 30-year averages of precipitation and air temperature were presented in Fig. 1(a, b).

Nitrogen mineralization were measured *in-situ* using intact cores deployed with ion exchange resins (DiStefano and Gholz, 1986) as modified by Kolberg et al. (Kolberg et al., 1997) during three periods. Period 1, corn planting until sidedress fertilization at corn GS V6; period 2, V6–R3; and period 3, R3–R6. Two pairs of undisturbed *in-situ* cores (total of four cores) were placed between the corn rows in each plot by driving an aluminum cylinder (4-inches depth, 1.9-inches diam.) into ground. The lower 0.4-inches of the soil cores was excavated and filled with a nylon mesh bag containing approximately 0.5 oz of 50:50 mixture of anion and cation exchange resins (Sybron Ionac ASB-1, C-249, Sybron Chemicals, Birmingham, NJ). This served to capture both NO_3-N and NH_4-N leaching from the soil core which contains equal amount of Na^+ saturated cation and Cl^- saturated anion exchange (DiStefano and Gholz, 1986; Kolberg et al., 1997). The complete assembly was returned to the same hole in each period of incubation. Detailed information regarding the incubation duration of the *in-situ* soil cores incubation were reported in Table 1. Additionally, eight soil cores (diam. 1.3-inches) were collected at the beginning of each incubation to determine the initial soil inorganic N content. After each incubation period, pairs of *in-situ* soil cores and resin were removed and bagged separately in plastic bags and stored at 37 °F. All soil samples were extracted using 2 M KCl method for soil inorganic NO_3–N and NH_4–N within a week. Resin were extracted five times to recover more than 85 % of N. Net N mineralization (Nmin_t) were calculated during each period (t) then normalized into per day basis as follows: $N\text{min}_t = N\text{core}_t + N\text{resin}_t - N\text{soil}_t$; where $N\text{core}_t$ is inorganic N in the soil core at the end of period t, $N\text{resin}_t$ is inorganic N in the resin bag at the end of period t, and $N\text{soil}_t$ is inorganic N in the soil core collected at the beginning of period t (Raison et al., 1987). The total accumulative N mineralized reported in Fig. 3 as multiple 100-day to approximate the growing season for corn in this region.

RESULTS AND DISCUSSION

In general, legume cover crops treatment had better corn yield compared to rye or NCC except at site RF, and rye had the lowest corn yield. Some researchers have found that corn following rye can reduced yield possible due to N immobilization, soil water depletion or allelopathy associated during rye biomass decomposition (Eckert, 1988; Holderbaum et al., 1990; Raimbault and Vyn, 1991; Decker et al., 1994). Sainju and Singh (1997) reported the crop yield and N uptake after nonlegume might be equivalent to or less than without a cover crop, which is similar to what we found at A2 (Fig. 2). The overall corn yield at A2 was significantly lower and only produced about half of South Dakota state 5-yr averages (2005–2009) corn yield (124 bu ac^{-1}) while the other site years were within range of the state average. Precipitation amounts during reproductive stage of corn (Jul–Oct) at RF, A3, and A2 were 124, 113, and 60 inches, respectively, compared to 116 inches on 30-yr averages (1981–2010) which could have reduced over all corn yields. NeSmith and Ritchie (1992) found significant physiological damage and 15–25 % yield loss when long-term (18–21d) water stress is like the conditions during the A2 growing season.

The legume cover crops had greater amount of mineralizable N in the experiment compared to the rye cover crops, but the NCC treatment varied with the different site years (Fig. 3). This could explain why legume cover crop treatments had higher corn yield (Fig 2; two out of three locations) compared to rye treatment. Nitrogen availability was synchronize with the plant N needs. Legume cover crops mineralized more N than rye cover crop but not necessary more compare to the NCC using *in-situ* incubation measurement at all sites.

Interestingly, the relationship between net mineralization rates from *in-situ* incubation was inverse correlation to the N use efficiency of corn (Figs. 3 and 4). This could be explained as the lower N mineralization occurred in the soil after cover crop treatment, the higher of grain produced per unit of input from the soil. Another possible explanation could be as more organic N was available for corn to take up during the growing season, which were not measured in these studies.

CONCLUSIONS

In conclusion, legume cover crop treatments had higher corn yield even in the drought year except RF. *In-situ* incubation data also supported legumes mineralized more N and the total N mineralized from legume were significantly higher than rye. Corn yield were higher at RF due to favorable precipitation during the growing season, however A2 only produced half of SD state 5-yr averages (124 bu ac^{-1}) due to deficit precipitation, especially during the critical reproductive stage in corn (Jul–Oct). Rye cover crop had the lowest corn yield possibly due to low N immobilization.

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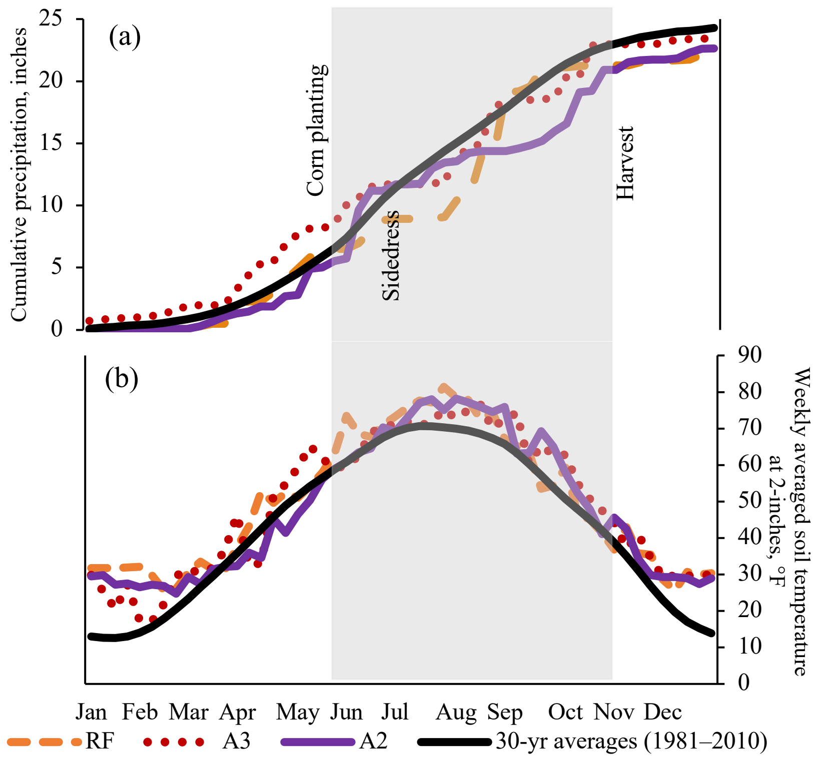
Table 1. The starting and ending date for *in-situ* soil intact cores for nitrogen mineralization measurements at the USDA–ARS NCARL and the Eastern South Dakota Soil and Water Research Farm near Brookings, SD at RF, A3 and A2.

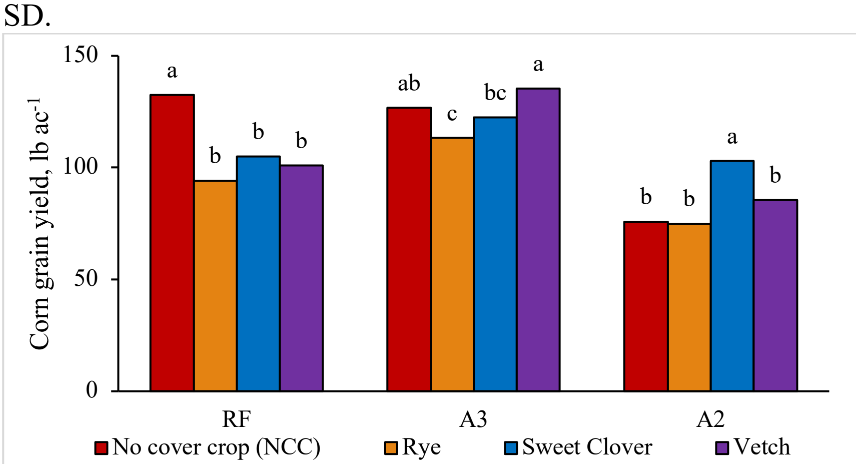
Location	Period 1		Period 2		Period 3	
	Start	End	Start	End	Start	End
RF	6-Jun-06	27-Jun-06	29-Jun-06	10-Aug-06	11-Aug-06	10-Oct-06
A3	31-May-07	20-Jun-07	29-Jun-07	26-Jul-07	26-Jul-07	30-Aug-07
A2	5-Jun-08	30-Jun-08	7-Jul-08	31-Jul-08	31-Jul-08	1-Oct-08

Figure 1. (a) Cumulative precipitation (in) (b) weekly averaged soil temperature (°F) at top 2-in and 30-year averages (1981–2010) at USDA–ARS NCARL and Eastern South Dakota Soil and Water Research Farm near Brookings, SD at RF, A3 and A2.



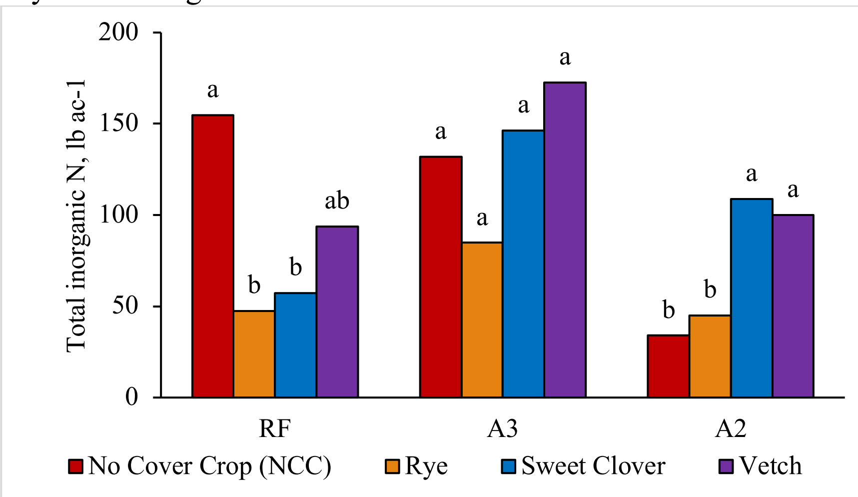
Note: Gray shaded area indicates the time period for corn growing season/*in-situ* incubation; weather data for daily cumulative precipitation (mm) and weekly averaged soil temperature (°C) and 30-yr averages of air temperature and cumulative precipitation (1981–2010) from NOAA (2019).

Figure 2. Corn grain yield (bu ac^{-1}) following cover crop collected at harvest near Brookings, SD.



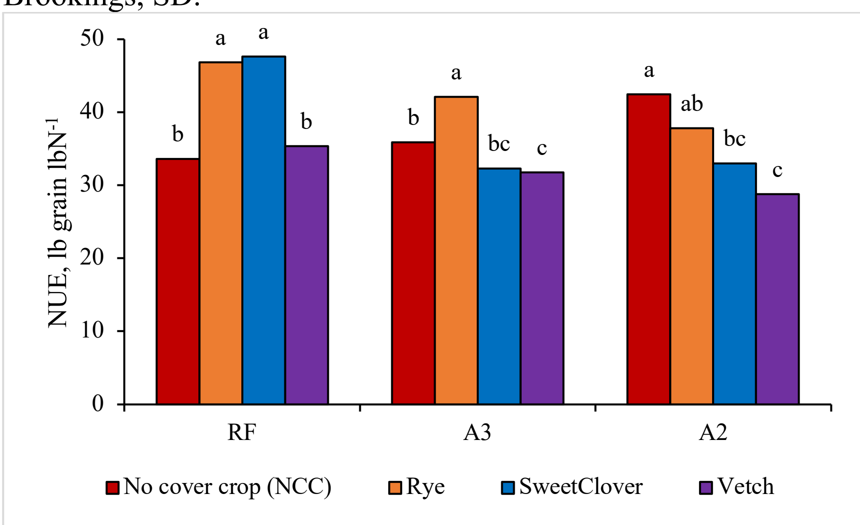
Mean within a site followed the same letter are not significantly different at α = 0.10, PDIFF option.

Figure 3. The accumulative amount of N mineralization from period 1 to 3 (lb N ac^{-1}) for 100-days corn using *in-situ* soil cores incubation measurement near Brookings, SD.



Mean within a site followed the same letter are not significantly different at α = 0.10, PDIFF option

Figure 4. Nitrogen use efficiency (NUE) (lb grain lbN^{-1}) in corn following cover crops near Brookings, SD.



Mean within a site followed the same letter are not significantly different at α = 0.10, PDIFF option

P-3

Mixing Wheat Seed with Fertilizer in the Drill: Seedling Injury and Wheat Response

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ABSTRACT

Mixing dry phosphorus fertilizer with winter wheat seed is common in Kansas to provide a starter fertilizer benefit to the crop. This study was designed to evaluate the effects of dry phosphorus (P) sources, rates and times fertilizer mixed with wheat seed, effects on early growth and overall productivity and yield of the crop. Two winter wheat studies were conducted in the 2018-2019 wheat growing season at Manhattan (Site 1) and Topeka (site 2) in Northeast Kansas. The previous crop for site 1 was soybean, and corn at site 2. The winter wheat was no-till drilled at 70 lbs acre^{-1} and mixed with either diammonium phosphate "DAP" (18-46-0) or Micro-Essentials SZ "MESZ" (12-40-0-10S-1Zn) rates of 30, 60 and 120 lbs P_2O_5 acre^{-1}. Mixing times in which wheat seed was in contact with the fertilizer were 0, 12, 28, and 40 days. The winter wheat was drilled in October and November and top-dressed with 100 lbs N acre^{-1} using UAN 28% at green up in the spring. Normalized Difference Vegetation Index (NDVI) and biomass measurements were taken at jointing in spring 2019. Significant increases in jointing NDVI were observed when overall P_2O_5 rates were increased with both sources, however, no differences were observed when time mixed with seed were compared besides a slight significant decrease at the longest MESZ mixing. Total P in jointing biomass significantly increased with P_2O_5 rates increase with both P sources although time mixed had no effect besides the longer MESZ mixing timings, which observed a significant decrease. Total P removed in grain followed the same trend as total P_2O_5 in the jointing biomass. Yield was significantly increased when rates of P_2O_5 were increased in both P sources analyzed. The time fertilizer P sources were mixed had no effects on yield except for the longer mixed MESZ treatments, which were observed a small significant decrease in yield.

INTRODUCTION

Kansas is one of the leading winter wheat-producing states in the United States. Kansas also has soil testing lower in phosphorus (P). In general, winter wheat is one of the most responsive crops to P fertilizers in Kansas making starter P fertilizer common across the state (Ruiz Diaz and Weber, 2019). Some producers lack fertilizer setups on their drills and commonly blend dry P fertilizers with wheat seed and then drill both together in the same hopper to get a starter fertilizer effect. However, little research has been done to address concerns with potential injury to wheat seed when mixed with different phosphorus fertilizer rates and timings. Thus, increases in nitrogen fertilizer rates (salt) in the seed furrow commonly cause issues with seed germination and fall stand of wheat. This could ultimately decrease fall stands of the crop, which leads to a greater need for fall/spring tillering to recover this reduction in fall stand. In addition, the question "how long can dry fertilizer sit with the wheat seed?" and "will it cause the same damage as a high starter fertilizer rate in-furrow?" This paper will provide a summary of results from an ongoing study evaluating the effect of fertilizer rates and fertilizer time exposure to wheat seed, and effects on wheat grain yield.

MATERIALS AND METHODS

The study was conducted at two locations during the 2018-2019 wheat growing season at Manhattan (site 1) and Topeka (site 2) in Northeast Kansas near Kansas State University **(Table 1)**. The previous crop for site 1 was soybean, and corn for site 2. The trials experiment were set up in a randomized complete block design with four replications. Plots were 45' by 6' for a total area of 270 ft. sq. The winter wheat variety Everest was mixed with diammonium phosphate -DAP (11-52-0) and Micro-Essentials SZ - MESZ (12-40-0-10S-1Zn) fertilizers. The blend of seed and fertilizer was stored in open plastic buckets for 0, 12, 28, and 40 days before drilling. Rates included 0, 30, 60, and 120 lbs P_2O_5 acre^{-1} with 70 lbs wheat seed acre^{-1} (complete combination of P rates and times for two P fertilizer sources). No Nitrogen (N) was applied in the fall except for N present in DAP and MESZ fertilizers. At green up 100 lbs N acre^{-1} was applied to all plots to ensure N was not a limiting factor. NDVI measurements were taken at jointing (Feekes 6) stage with a Holland RapidSCAN CS-45 active sensor ran 35-40 inches above the crop canopy. Averages of NDVI readings were then recorded for each treatment. Biomass samples were collected at jointing (Feekes 6) and were taken from 2.5 feet of row times 2 rows in the backside of the plots. Additional biomass samples were taken at soft dough (Feekes 11.2) in the same manner as the jointing biomass samples. Grain harvest was completed with a plot combine and subsamples were taken from each treatment. All biomass samples and grain were analyzed for P concentrations using the salicylic-sulfuric acid digestion method (Miller and Keeney, 1982). All statistical analysis were completed using SAS Studio (version 9.4; SAS, Institute, Inc, Cary, NC). Analysis of variance (ANOVA) using the GLIMMIX procedure was conducted.

RESULTS

Early Growth

Increases were observed in NDVI when increasing rates of P_2O_5 were mixed with the seed with both DAP and MESZ fertilizer sources **(Figure 1A)**. However, no significant differences were observed when DAP was mixed with increasing time intervals. Although, when MESZ was mixed, the NDVI values at jointing was lower for the longer time interval of 40 days **(Figure 1B.)**. Also, significant increases were observed in total P uptake at jointing when increasing rates of both P fertilizer sources **(Figure 1B.)**. However, there was no significant effects of time mixed and total P uptake at jointing with either P fertilizer sources **(Figure 1D.)**.

Grain yield and P removal

Preliminary results of this study showed that as rates of both P fertilizer sources were increased, significant increases were observed in the total amount of P removed in wheat grain **(Figure 2A.)**. However, when looking at duration of source mixed with seed, no significant results were found for DAP but a slight decrease was observed in P removal for the longest MESZ mixing time of 40 days **(Figure 2B.)**. In addition, yield was significantly increased as rate of both P fertilizer sources increased **(Figure 3B.)**. Also, the time DAP was mixed with seed had no significant effect on grain yield while the longest mixing time using MESZ resulted in a small decrease in wheat grain yield **(Figure 4B.)**.

DISCUSSION

Based on these preliminary results, P rates in-furrow were the primary driver for increasing NDVI at jointing, P uptake at jointing, grain yield and P removal with the grain. This response was significant up to the highest P rate for both fertilizer sources and likely due to the combination of low soil test and late planting date for the wheat (due to unfavorable weather conditions). The time DAP was mixed with wheat seed had no effect on any of the measurements taken which indicates producers have flexibility regarding the time elapsed between mixing the seed and fertilizer, and planting. In this study the storage conditions were in a dry environment to prevent fertilizer from absorbing water, it is possible that conditions of high relative humidity might affect the physical characteristics of the seed-fertilizer blend. When MESZ was mixed with wheat seed for an extended time (approximately 40 days), NDVI, P removal, and yield showed a small decrease. However, the overall trends observed in these prelimiraly resuls sugest that either P fertilizer source can be stored for a prolonged period of time with no negative impact, and producers can avoid the economic expenses of replacing the seed-fertilizer blend.

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Table 1. Sites and soils type information for wheat experimental studies from 2019

					0-6" samples		
Location	County	Soil Type	Soil Texture	Planting Date	pH	P	OM
						ppm	%
1	Riley	Smolan	Silt Loam	11/19/2019	5.75	17	3.2
2	Shawnee	Eudora	Silt Loam	10/19/2019	6.99	18	1.6

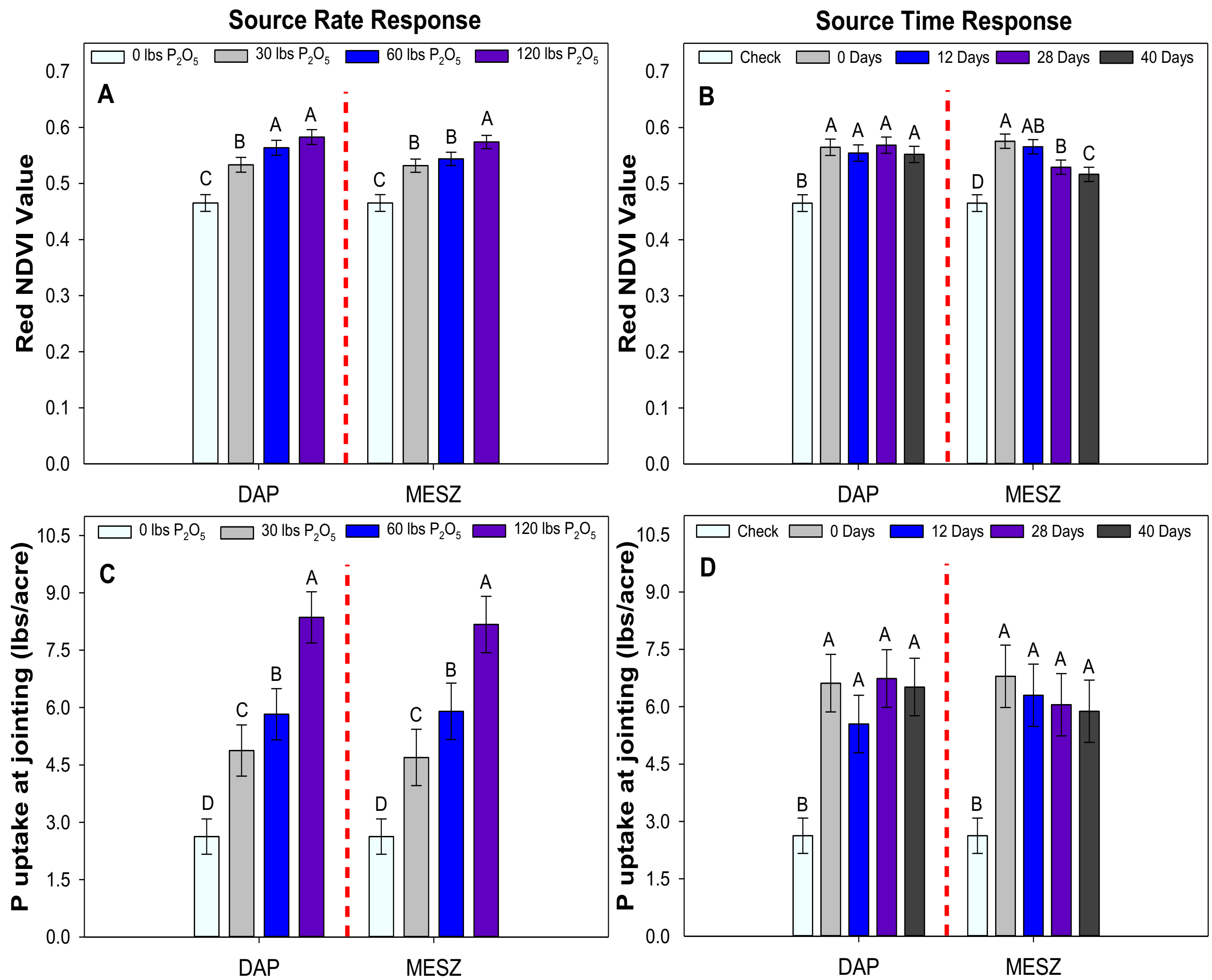

Figure 1. NDVI measurements taken at the jointing (Feekes 6) stage with comparison made between fertilizer source rates mixed with seed (A) and comparison made between fertilizer mixing duration with seed (B). P uptake at jointing lbs acre^{-1} at the jointing (Feekes 6) stage with comparison made between fertilizer source rates mixed with seed (C) and comparison made between fertilizers mixing duration with seed (D).

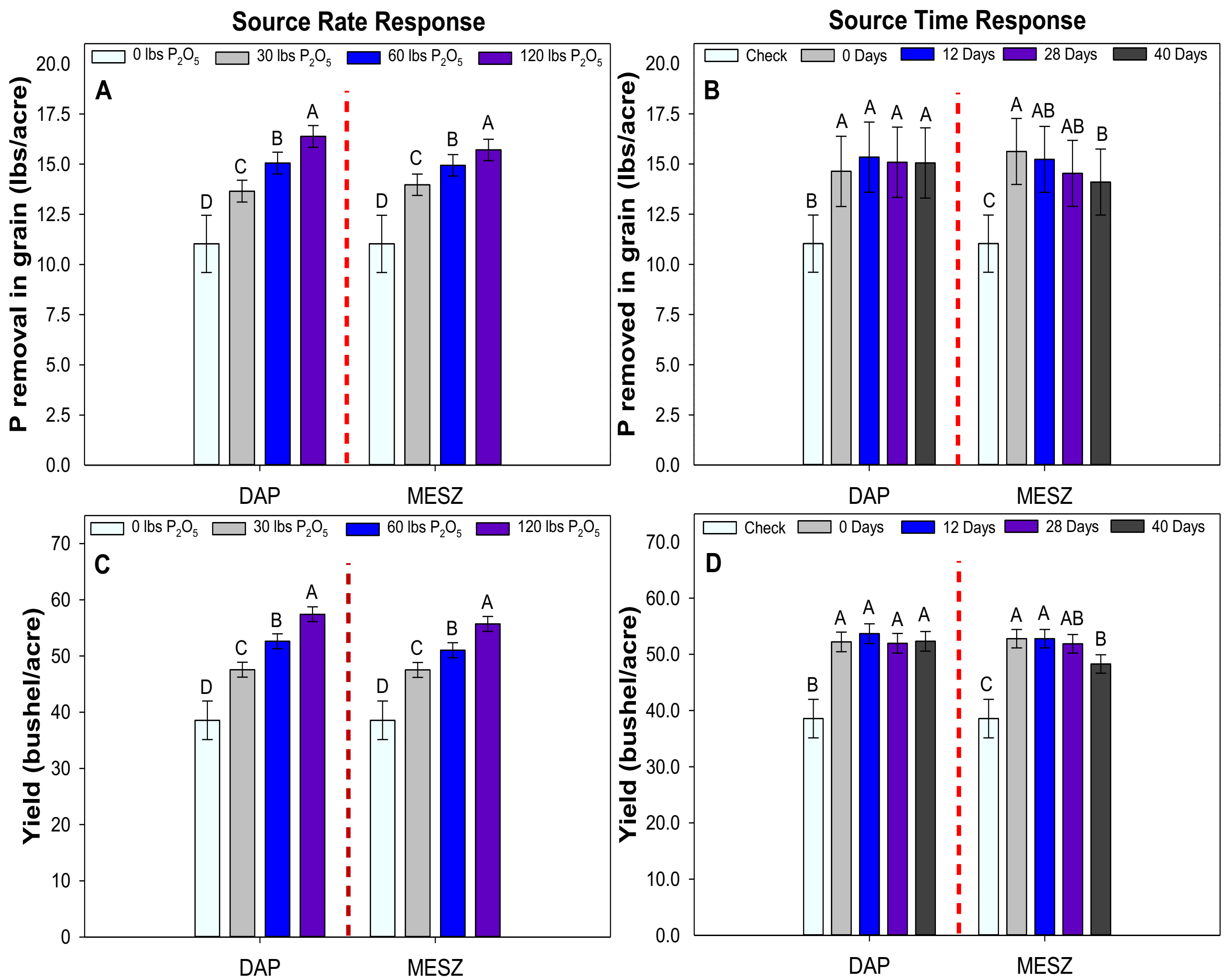

Figure 2. P removed in grain lbs $acre^{-1}$ at grain harvest with comparison made between fertilizer source rates mixed with seed (A) and comparison made between fertilizer mixing duration with seed (B). Grain yield in bushel $acre^{-1}$ with comparison made between fertilizer source rates mixed with seed (C) and comparison made between fertilizers mixing duratio

P-4

DOES CHAR REDUCE AMMONIA VOLATILIZATION BY SLOWING UREA HYDROLYSIS IN SOIL?

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ABSTRACT

Ammonia volatilization due to urea hydrolysis begins immediately after N fertilizer applied in soil and continues up to two weeks. This process might adversely affect N availability in soil/ plant systems and reduce soil fertility and crop yields, as well as bring the negative impact in environment. Char, incomplete burning of coal combustion residue which contains up to 30% total C by weight, is hypothesized to reduce N losses from ammonia volatilization. A 21-day laboratory study was conducted to determine the effects char application on urea hydrolysis in sandy loam soil. Two char rates (0 and 20 t ac^{-1}) and two urea rates (0 and 180 lbs N ac^{-1}) with four replications were arranged in randomized complete block design. Sub-samples from each treatment were collected every other day and analyzed for ammonium, residual N (urea, ammonium, nitrate), and pH. Results from this study will be discussed in conference that how applied N partitions into ammonium, nitrate and/or stays in urea form over time under different treatment combinations.

P-5

PREDICTING CROP YIELD LOSSES DUE TO SOIL-WATER SALINITY: A COMPARISON OF TRADITIONAL AND ALTERNATIVE APPROACHES

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ABSTRACT

It is estimated that 2,000 ha of cropland are taken out of production daily worldwide due to salinization and sodification. Salinity is estimated to result in economic losses of $27.3 billion U.S. dollars annually. Our project aims to jointly develop techniques for quantifying the severity of soil-water salinity and impacts on crop production on surface-irrigated fields in Pakistan's Indus River Valley and the Lower Arkansas River Valley (LARV) in Colorado. The Fairmont Drainage District study site in the LARV is a furrow-irrigated, tile-drained area of about 200 ha that suffers from salt-affected (primarily gypsum) soils due to shallow water tables resulting from inefficient irrigation practices and inadequate drainage. The objective of this study was to model crop relative (Y_r) and absolute yield using two traditional and two alternative approaches with electromagnetic induction derived bulk apparent soil electrical conductivity (EC_a; 0 – 1.5m depth), and saturated paste extract electrical conductivity (EC_e) used as inputs, and compare results. The first method is a traditional piecewise linear approach where EC_e predicts Y_r using a salinity tolerance threshold, and a sensitivity to accrued salinity. The second involved a "modified discount function" that utilized a single empirical parameter to fit a sigmoidal function relating Y_r to EC_e. The third and fourth methods were purely empirical linear and sigmoidal four parameter logistic (4PL) models that used EC_a or EC_e to predict Y_r. Results showed that the empirical sigmoidal 4PL model yielded the greatest accuracy for 190 field data points using EC_a and EC_e as the predictor, with a root mean squared error of ±16.71 % and ±14.37 %, respectively. This suggests that EC_a is an effective predictor of Y_r for this dataset, indicating that it might not be necessary to collect and analyze soil samples for EC_e when trying to map salinity impacts on maize yield when it is known that salinity is the primary yield reducing factor; this would save time, labor, and resources. The fitted Y_r -EC_e regression relationships, however, indicate that the threshold EC_e value at which significant maize yield loss commences for these gypsum soils is markedly higher than the value reported for halite soils by Maas and Hoffman (1977).

INTRODUCTION

Salt-affected and waterlogged soils exist as a growing global problem for agricultural production. These are defined as soils in which salts are in enough quantity to interfere with normal plant growth. The Harmonized World Soil Database (Nachtergaele et al., 2009) estimates the global extent of salt-affected land to be 1128 Mha, 60% of which is saline, 26% is sodic, and the remaining 14% is saline sodic. It is estimated that 2000 ha worldwide are taken out of production every day due to salinization and sodification (Nellemann, 2009; Qadir et al., 2014). This salinity impact was estimated to have an economic impact of $27.3 billion U.S. dollars annually (Qadir et al., 2014). These economic and environmental issues will only be magnified as the area of salt-affected soils expands each year as intensive irrigation practices continue globally.

Salt tolerance of a crop is traditionally described through plotting a crop's relative yield as a continuous function of soil salinity. Relative yield (Y_r) is used to circumvent differences in absolute yield (Y) due to differences in crop species, cultivar, ambient environment, soil fertility, pest damage, and factors other than salinity. The conventional method to convert Y into Y_r involves scaling each observation of Y by the maximum yield observed (Y_m) (Grieve et al., 2013). Various models have been attempted to accurately describe this phenomenon (Steppuhn et al., 2005). Each model, although different in form, require the average root zone salinity (C), where C can be expressed as solute concentration (C_s), osmotic potential (Ψ_o), saturated paste electrical conductivity (EC_e), or the electrical conductivity of irrigation water (EC_w).

One of the most popular methods used for the accurate quantification of soil salinity on field and regional scales is through electromagnetic induction (EMI) techniques that calibrate apparent soil electrical conductivity (EC_a) to other edaphic physical and chemical properties. In cases where EC_a correlates with a soil property of interest, an EC_a – directed sampling strategy has been found successful in quantifying the spatial distribution and variability of that soil property, all while minimizing the number of sample locations, keeping the lab and labor costs to a minimum (Corwin et al., 2003a; Shaner et al., 2008). Furthermore, it has been shown that if EC_a correlates with crop yield, these directed sampling approaches can be used to identify soil properties that are causing yield variability, and thus direct management decisions for remediation (Corwin et al., 2003b).

Correlating yield with EC_a directly has been met with uncertainty, as resulting relationships are often inconsistent due to the plethora of factors influencing the measurement of EC_a, confounding their interpretation (Corwin and Lesch, 2003; Jaynes et al., 1995). This uncertainty is not well understood, however, as previous studies trying to quantify this relationship have had limitations because of crop types (i.e. the crop was too tolerant of the soil properties affecting growth to make a strong correlation), or a mismatch between the dominant factors affecting yield and the dominant factors affecting EC_a readings. The objective of this study was to model crop relative and absolute yield using traditional and alternative approaches, comparing EC_a and EC_e as predictors, observing the potential of each method used as a practical yield prediction tool. To this end, we pursued an observational experiment in Swink, Colorado (United States) where maize yield, and soil salinity data were used with salinity tolerance models to estimate yield over the study region.

MATERIALS AND METHODS

Study Site Description

Soil salinity as an issue in the Lower Arkansas River Valley (LARV) in southeastern Colorado originated in the 1970s due to the increase in river diversions for the use of irrigation water, a lack of efficient irrigation systems (which leads to a severe over application of water), and a decrease in the use of groundwater as a source for irrigation. These practices have led to an increase in the height of the water table within the LARV, pushing salts up into the root zones of many crops (Gates et al., 2002). Salts have negative impacts on crop yields throughout the valley; research and intervention are needed to develop more sustainable water use practices.

A sub-region of the LARV, called the Fairmont Drainage District (FDD), (37°58'56.2" N; 103°38'38.5" W; **Error! Reference source not found.**), was identified as a suitable area of study for observing and quantifying the magnitude of salinity effects in gypsiferous soils. The FDD itself refers to an area of 200 hectares having a drainage tile network installed in the early 20th century as a result of the Colorado Drainage District Act (CO Rev Stat § 37-28-101). The intent of installing drainage tiles in the FDD was to reduce waterlogging caused by a shallow water table. Despite this, salt presence continues to negatively affect the agronomic systems in the region.

The FDD contains approximately 20 different fields averaging 10 ha each. In this context, field is defined as a homogenously managed piece of land devoted to the growth of a singular crop for commercial value. The dominant crops in the region consist of alfalfa (*Medicago sativa* L.) with 65% coverage, maize (*Zea Mays* L.) with 20% coverage, and winter wheat (*Triticum aestivum* L.) with 10% coverage. The remaining 5% of land is fallow or rangeland (not harvested for economic value). Irrigation methods consist of siphon tube irrigation down furrows and center pivot sprinkler irrigation, with application rates varying based on specific field management. Soil textures range from Silty Clay Loam to Clay Loam.

Electromagnetic Induction Surveys for Field Characterization of Salinity and Yield

In 2019, EMI surveys were carried out using mobile equipment (i.e. EM38-MK2, Trimble™ GPS system, and Juniper Allegro CX for datalogging) on 5 corn fields within the FDD prior to corn planting (approx. early May) in order to quantify salinity presence in the region. The EM38-MK2 provided a continuous stream of EC_a measurements (one reading every 4 seconds) at 0-0.75 m (EM_h) and 0-1.5 m (EM_v) depths simultaneously. This averaged to approximately 500 locations of EC_a measurement in each field. Model-based sampling design via the Electromagnetic Sampling Analysis and Prediction model (ESAP, ver. 2.35) was used in each field. ESAP uses a response surface sampling design (RSSD) strategy which, in essence, creates a 3-D surface of the EC_a measurements and, based on the range and variation, selects locations that characterize the EC_a variation while maximizing the distances between adjacent sampling locations (Lesch et al., 2002).

ESAP-RSSD was used to select 6 soil sample locations per field. At each location, soil samples were collected using an 8 cm diameter soil auger at 0.3, 0.6, 0.9, and 1.2 m depths. Gravimetric water content and a saturation extract of each soil sample were prepared to derive EC_e using the method presented by Rhoades (1996). Deionized water was added to approximately 400-500 g of air-dried soil such that a saturated condition was reached. A 50-75 g sub sample of the paste was taken to be oven dried to determine saturation percentage (SP% or $\theta_{g, e}$). Analysis of Covariance (ANOCOVA) linear regression was used to develop a calibration model, converting EC_a into predicted EC_e (Corwin and Lesch, 2017; Corwin and Lesch, 2014).

ESAP-RSSD was used once again in conjunction with EC_a survey data to determine ideal sampling locations for maize yield. 38 locations were identified in each field, resulting in a total of 190 samples. At each location, a one meter by 0.76 m plot was sectioned off for cob selection. This amounted to seven cobs per plot for yield analysis. Samples were oven dried at 70°C for 14 days before being shucked and weighed to determine marketable yield. After yields were determined, Y_r was calculated by averaging the top three yields (to identify a reasonable yield unaffected by salinity), dividing each point by this average, and multiplying by 100.

Model Selection and Goodness of Fit Evaluation

Y_r was predicted using two traditional models: the modified discount function (Steppuhn et al., 2005) and the threshold-slope function (Maas and Hoffman, 1977), as well as two alternative statistical models: a sigmoidal four parameter logistic (4PL) model, and single variate linear regression (Table 1). Furthermore, each model was tested using EC_e and EC_a as the input variable.

Table 1. Summary of salinity tolerance models used to predict relative yield losses in the Fairmont Drainage District using saturated paste extract and soil bulk apparent electrical conductivities (EC_e and EC_a, respectively).

Model	Model Form	Input
Sigmoidal Four Parameter Logistic (4pl) Model	$\hat{Y}_r = d + \frac{a - d}{1 + \left(\frac{x}{c}\right)^{b}}$	EC_e, EC_a
Modified Discount Function	$\hat{Y}_r = \frac{1}{1 + \left(\frac{C}{C_{50}}\right)^{\exp(sC_{50})}}$	EC_e, EC_a
Threshold-Slope Function	$\hat{Y}_r = 1; 0 < C < C_t$ $\hat{Y}_r = 1 - m(C - C_t); C_t < C < C_0$ $\hat{Y}_r = 0; C > C_0$	EC_e
Linear Regression	$\hat{Y}_{r,i} = \beta_0 + \beta_1 C_i + \varepsilon_i$	EC_e, EC_a

Where $\hat{Y}_r$ is model predicted relative yield (%), a, b, c, d, s, β_0, and β_1 are empirically fit shaping parameters, C is average root zone salinity (can be expressed as EC, osmotic potential, or solution concentration), C_{50} is C at $Y_r = 0.5$, C_t is the maximum value of C without yield reduction, C_0 is the lowest value of C where $Y_r = 0\%$, m is the absolute value of the declining slope in Y_r, i is the sample site within a field.

RESULTS AND DISCUSSION

The goodness of fit (GOF) for each model was evaluated in R studio using the HydroGOF package using root mean squared error (RMSE), root mean squared prediction error (RMSPE), and index of agreement (IOA). RMSE and RMSPE were chosen to understand error in terms of yield units, but RMSPE is a measurement of the model's prediction error using a leave-one-point out approach for cross-validation. IOA was chosen to understand model agreement with observations. A value of 0 indicates no fit, while 1 indicates a perfect fit.

GOF evaluation results for each model are summarized in Table 2. EC_a and EC_e were able to predict Y_r with similar accuracies, with EC_e having slightly better predictions when using the 4PL and linear regression models. This might be explained by the susceptibility of EC_a being biased easily by other inter-field variable edaphic properties, such as moisture or texture, whereas EC_e is a more direct measure of salinity. The 4PL model resulted in the best GOF measurements for both EC_a and EC_e, and is shown to be useful in predicting Y_r. Furthermore, it is shown that the RMSE and RMSPE values generated are small enough to indicate that the model could be viable for sub-regional yield mapping and informing management decisions.

Table 2. Summary of goodness of fits results using saturated paste extract and soil bulk apparent electrical conductivities (EC_e and EC_a, respectively) to predict relative yield losses (Y_r; %).

Model	Input Variable	RMSE %	RMSPE %	IOA n/a
4PL	EC_a	16.71	17.02	0.74
Modified Discount	EC_a	21.37	21.48	0.71
Linear Regression	EC_a	18.06	18.29	0.66
4PL	EC_e	14.37	14.70	0.84
Modified Discount	EC_e	24.01	24.12	0.70
Linear Regression	EC_e	15.30	15.47	0.89
Threshold-Slope	EC_e	18.43	n/a	0.75

Where 4PL is sigmoidal four parameter logistic model, RMSE is root mean squared error, RMSPE is root mean squared prediction error, and IOA is index of agreement.

Visual fitting of the 4PL model with both EC_a and EC_e inputs compared to observed Y_r is shown in Figure 1. Although the 4PL model captures the general trend of the data well, much variability exists around each Y_r prediction. This may be due to variability around confounding factors resulting in yield loss outside of soil salinity. Some of these factors include i) differences in maize variety salinity and drought tolerance, ii) differences in field-to-field irrigation and fertilizer management, and iii) spatial differences in soil physiochemical properties. The fitted Y_r -EC_e regression relationships, however, indicate that the threshold EC_e value at which significant maize yield loss commences for these gypsum soils is approximately 2.5 dS/m, which is markedly higher than the 1.7 dS/m threshold reported for halite soils by Maas and Hoffman (1977).

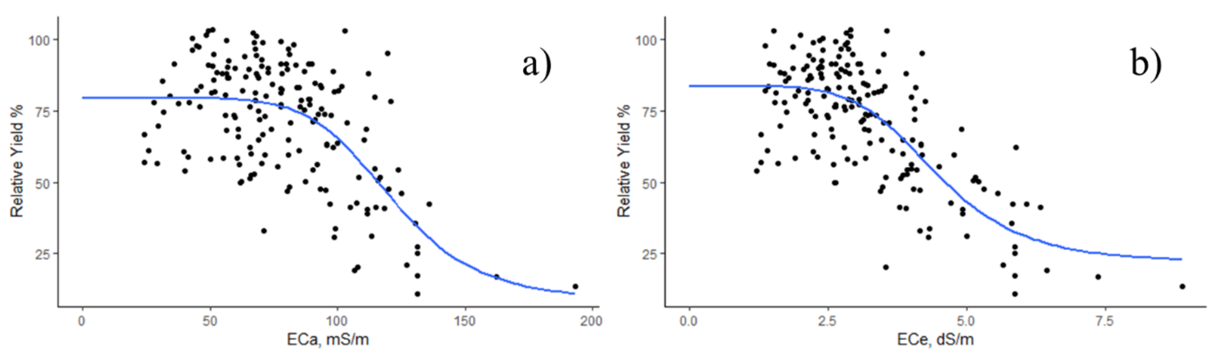

Figure 1.Relationship between a) relative yield % (Y_r) and bulk apparent soil electrical conductivity (EC_a; mS/m) and b) Y_r and soil saturated paste extract electrical conductivity (EC_e; dS/m). Each graph is fitted with a sigmoidal four parameter logistic model, shown in blue.

In summary, this study provides strong evidence to suggest that using EC_a as a predictor for yield losses can be both useful and easily scalable to large areas if it is known that salinity is the dominant yield inhibitor prior to model generation. Additionally, it indicates that EC_e may also be used, but comes with additional labor and cost due to the nature of current soil salinity mapping methods. However, if EC_e can be obtained, it is possible that a calibration might be more temporally stable (unlike EC_a, which would require annual re-calibration) because little changes are seen with EC_e over short periods of time with consistent land management.

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NUTRIENT PARTITIONING CHANGES IN THE PAST 30 YEARS OF COTTON PRODUCTION

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ABSTRACT

Modern cotton (*Gossypium hirsutum* L.) cultivars are more compact and efficient due to optimization of genetics and changed management practices in the past 30 years. The most recent work evaluating nutrient uptake by cotton was done in early 1990s, hence a need to re-evaluate the nutrient accumulation and requirements in modern high productivity cultivars. The objective of this study was to compare the resource allocation of modern cotton cultivars (PM HS26, FM 958, and DP 1646) with older ones based on dry matter production, yields, and nutrient uptake and partitioning to different organs. Results showed that the modern cultivars tested in this study partitioned a greater percentage of dry matter and nutrients into the fruit as compared to older cultivars. The nutrient requirements of these modern cultivars differ from 30 years ago especially during boll development. The nutrient uptake per unit of lint produced increased substantially from 1990 to 2018, which highlights the improved efficiency of the modern cultivars. Overall, the results of this study highlight the remarkable improvements in modern cotton cultivars during the past few decades. The results of this study can be a basis for researchers on how nutrient partitioning should be optimized to be more favorable towards reproductive organ development and subsequently, improved yields. This research is important for re-evaluating the optimal nutrient inputs for farmers and producers, especially since new cultivars are released regularly, and environmental conditions change continuously.

INTRODUCTION

Nutrient uptake and partitioning among plant tissues of cotton grown under dryland and irrigated conditions have been documented in several studies prior to 1990s by Fraps (1919), Armstrong and Albert (1931), Olson and Bledsoe (1942), and Bassett et al. (1970). For cotton cultivars grown in southern USA, the most fundamental and recent report on dry matter and nutrient partitioning was provided by Mullins and Burmester (1990). This study reported on the translocation of nitrogen (N), phosphorus (P), and potassium (K) from vegetative to reproductive tissues. The findings of this study have been the basis of the current fertilizer recommendations for majority of the cotton productions in the Southern High Plains of Texas.

After the 1990s, research efforts on genetic improvement and crop management optimization has greatly improved the lint production efficiency of cotton, thus increasing the yield potential. It is possible that the organ nutrient accumulation and the requirement rates of the modern cultivars have also changed, and these played as factors towards the said improvements.

Since the most recent work was done in the late 1980s, a current investigation on patterns of resource partitioning and accumulation is needed.

We hypothesized that the yield improvements are associated with differences in nutrient allocation and the nutrient partitioning, accumulation, and requirements of the modern cotton cultivars will likely be different compared to older cultivars. The objective of this study is to compare the resource allocation of modern cultivars with older ones based on yields, partitioning of N, P, and K to different organs, as well as nutrient uptake per unit of lint produced in irrigated, fertilized cotton.

MATERIALS AND METHODS

Field experiment was conducted in 2018 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 7 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.

Three cotton cultivars (PM HS26, FM 958, DP 1646) were planted on May 21, 2018. Plots were fertilized with an average rate of 100 lb N A^{-1}, 80 lb P A^{-1}, and 27 lb K A^{-1}. The liquid N fertilizer was split-applied as urea-ammonium nitrate (UAN, 32-0-0), using a coulter applicator, on May 19, 2018 (40% pre-plant) and July 11, 2018 (60% side-dressed). 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 (DAP). 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 analyses. Dry matter fractions were submitted to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory (College Station, TX) for N, P, and K analysis.

Boll distribution was determined using the plant mapping procedure. The number of bolls $plant^{-1}$ at each node was determined by combining the 1st, 2nd, and 3rd position bolls from the corresponding flowering intervals. Mature bolls were harvested within 264 ft^2 area per plot on November 10, 2018. Statistical analysis was performed using the Generalized Linear Mixed Model (GLIMMIX) Procedure in SAS 9.4 (Cary, NC).

RESULTS AND DISCUSSION

At the time period when the maximum crop growth rate was observed, the modern cotton cultivars accumulated more heat units compared to the older ones used in the 1990 study (Table 1). The peak crop growth rate for all the modern cultivars was observed at 800-1100 growing degree days ($GDD_{°C}$), which corresponded to 28-43% of the total dry matter production. In comparison, Mullins and Burmester observed maximum crop growth rate at about 500-800

GDD$_{°C}$, corresponding to 28-38% of the total dry matter production. Growth and development of cotton are temperature-dependent. This difference may be partially explained by the cooler growing environments prior to 1990 compared to recent years. This may have led to greater heat unit accumulation of newer cultivars that in turn may be responsible for optimal biomass production.

In the current study, it can be observed that the partitioning of nutrients varies among developmental stages and different cultivars. For the three modern cotton cultivars, the focus of the plant early in the season is in expansion of vegetative growth. This is reflected in the high nutrient accumulation in leaves and stems. For example, a massive push of N into the leaves and stems was observed (Figure 1). As the plants enter the reproductive stage, there was a decrease in the N content of vegetative parts and a net movement of nutrients to the immature bolls at 90 DAP and then into the seeds at 120 DAP.

Table 1. Comparison of the accumulated heat units, accumulated dry matter at maximum crop growth rate, and seed cotton yields between cultivars developed prior to 1990 and modern cultivars tested in 2018.

Parameters	**1990**	**2018**
Accumulated heat units (GDD$_{°C}$)	500-800	800-1100
Percent of total dry matter	28-38	28-43
Seed cotton yield range (lb A^{-1})	1485 - 2413	3751 - 4058

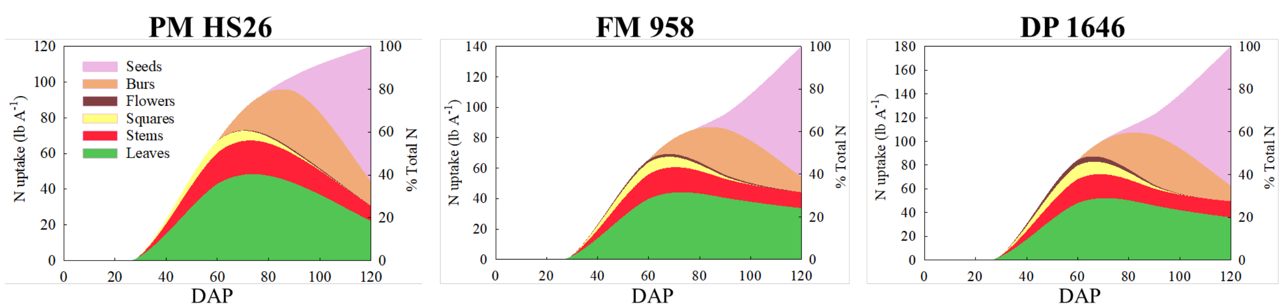

Figure 1. Nitrogen (N) partitioning in the different organs of modern cotton cultivars grown at New Deal, TX in 2018.

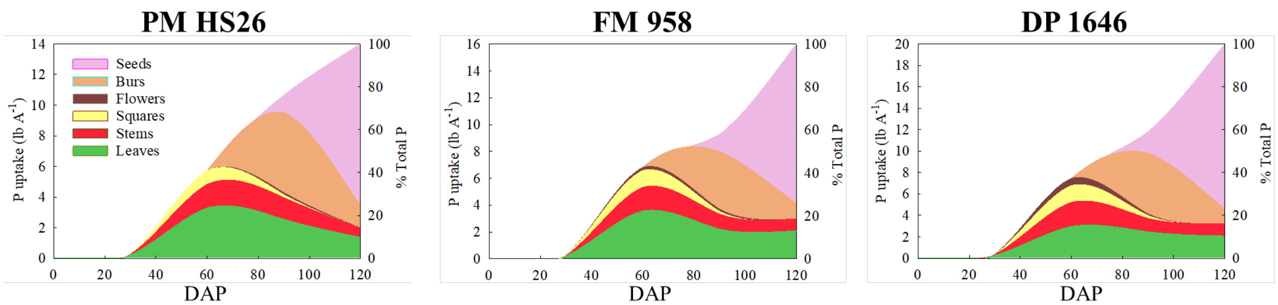

Figure 2. Phosphorus (P) partitioning in the different organs of modern cotton cultivars grown at New Deal, TX in 2018.

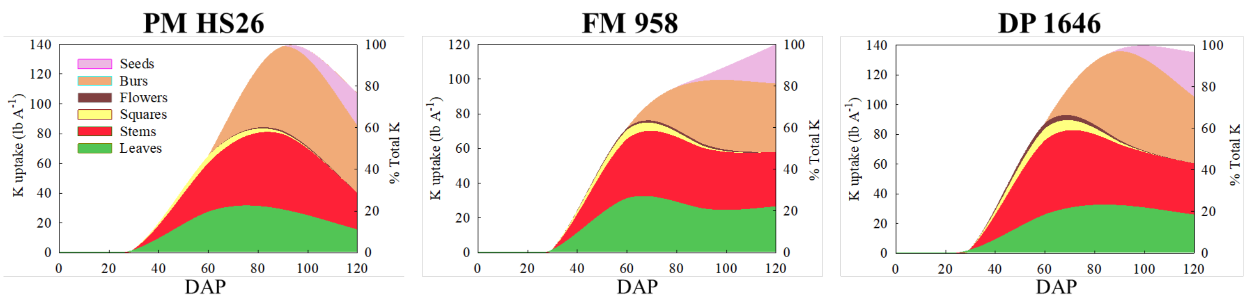

Figure 3. Potassium (K) partitioning in the different organs of modern cotton cultivars grown at New Deal, TX in 2018.

Similar to N, there was a net movement of P into the reproductive parts by the end of growing season (Figure 2). A greater percentage of P was accumulated in the burs at early boll development, which was then later utilized by the developing seed. In young cotton plants, stems and leaves have a high K concentration (Figure 3). As the season progressed, the K content in the stems and leaves decreased or plateaued. Burs, in general, had high K concentration throughout the reproductive stage and had the highest concentration of K among the different tissues at the last sampling date. For all the modern cultivars, the seeds have the lowest K concentration. This was also noted by Mullins and Burmester (1990).

Lint yields of FM 958 and DP 1646 were higher than PM HS26, which is reflected on their higher boll number especially in the middle section of the plants (Figure 4). The improvement of cotton through the years in partitioning its resources towards fruit production can be observed in the trends shown by the three cultivars.

The differences in patterns of accumulation in more modern cultivars reflect the differences in nutrient requirements to produce yield that reaches a cultivar's potential. The noticeable increases in the mean nutrient uptake per unit of lint produced in 2018 compared to 1990 alludes to the enhanced efficiency of modern cultivars in converting nutrient uptake and resource pools to yield production (Table 2).

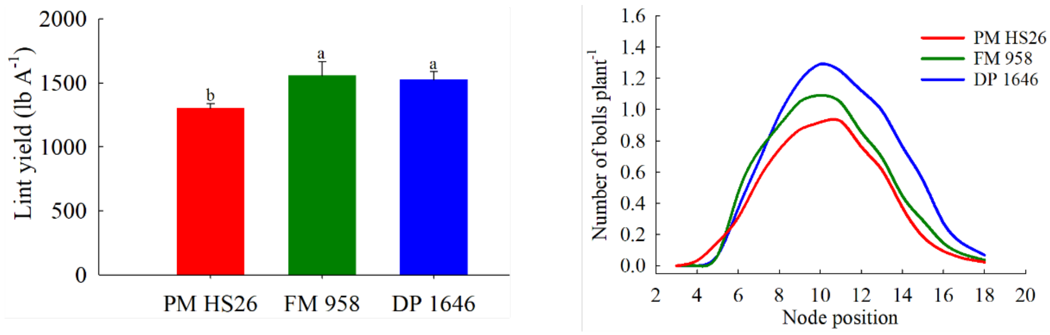

Figure 4. Lint yield and boll distribution of modern cultivars grown at New Deal, TX in 2018. Error bars represent standard error of the mean. Bars annotated by the same letters within the same graph are not different at 0.05 level of significance.

Table 2. Percent increase in the mean uptake of N, P, and K per unit of lint produced of three modern cotton cultivars grown at New Deal, TX in 2018.

Parameter	Increase from 1990-2018, %
Mean N uptake per 220 lb lint	26-47
Mean P uptake per 220 lb lint	4-40
Mean K uptake per 220 lb lint	67-120

CONCLUSIONS

This study provides insights on the remarkable improvements in modern cotton cultivars during the past few decades. Modern cotton cultivars showed a higher accumulation of heat units, increased yields, and significant deviation in nutrient uptake dynamics compared to older cultivars. The last point being the most evident during boll development. Results can provide us with information on how the modernization of cultivars altered their respective nutrient and mineral removal schemes from the soil and how these are distributed to the different organs within a plant. Certain nuances of fertilizer application, such as timing, must be taken into consideration to further increase the uptake efficiency in combination with implementing optimal water and nutrient management strategies to fit any cropping scenario in Southern High Plains of Texas.

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ENHANCED EFFICIENCY NITROGEN FERTILIZER: COATED UREA

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ABSTRACT

Nitrogen (N) is the most common fertilizer. However, a large percentage is lost to the environment—resulting in pollution and depletion of natural resources—representing economic losses. Enhanced Efficiency Fertilizers (EEF) help mitigate these problems by reducing the time N is in forms most susceptible to loss, increasing uptake efficiency and, often, yield and/or crop quality. One example of N EEF are coated urea fertilizers, such as polymer coated urea (PCU). Research studies show reduced loss to the environment and increases in yields and/or crop quality. The delayed release was longer than with sulfur (SCU) and polymer-sulfur (PCSCU) coated urea. The N release is hastened when surface applied. While EEF often cost more, they require can results in less fertilizer use and/or increases in the amount of crop grown per unit of N applied.

INTRODUCTION

Nitrogen (N) is an essential plant nutrient and N fertilizer is an essential component of global food security (Hopkins, 2020). Of all plant nutrients, N is sold in the largest volume because of its large impacts (Geary et al., 2015; Zhang et al., 2015). Nitrogen is needed in relatively large quantities in plants. There is a large store of N in the soil, mostly occurring as a component of soil organic matter (SOM). However, only about 2-5% of this is mineralized to become plant available annually. Given this, and the high demand for N in plant tissues, N fertilizer nearly always needs to be applied to crops in order to achieve maximum economic yield.

The effective use of N fertilizer has been elucidated in a wide body of research for the "4 R's" of fertilizer stewardship to apply the Right source at the Right rate at the Right timing and Right placement. These efforts have resulted in steady improvements in yields and uptake efficiency (Bruulsema et al., 2012). However, N fertilizer impacts the environment through resource consumption and pollution (Bruulsema et al., 2012; Hopkins, 2020).

Pollution is a major concern with N fertilizer use. A large percentage of fertilizer N added to soil is either emitted to the atmosphere as ammonia (NH_3), nitrous oxide (N_2O) or other gaseous forms, or finds its way into surface or groundwater as nitrate (NO_3) (Kibblewhite, 2007).

There is potential for improving N fertilization, as can be seen in a recent review by Omara et al. (2019) who estimated N uptake efficiency in cereals at about 33% with some farmers achieving levels as high as 41%. Significant advances enable growers to simultaneously achieve maximum economic yield while minimizing environmental risks (Bruulsema et al., 2012).

NITROGEN LOSS MECHANISMS

It is vital to understand the N loss mechanisms in order to achieve maximum economic yield and minimize environmental risk. The main loss mechanisms for N fertilizer include: NH_3

volatilization, denitrification/ nitrification of N_2O, and NO_3 leaching (Snyder et al., 2009; Van Groenigen et al., 2010; Venterea et al., 2016; Canter, 2019).

The urea in fertilizers rapidly hydrolyzes when applied to soil, converting it to NH_3 gas. Ideally, this gas quickly converts to ammonium (NH_4) in the soil solution. However, some volatilizes to the atmosphere. Although relatively safe from volatilization, NH_4 can revert back to NH_3, especially in alkaline soils. Otherwise, the NH_4 converts to NO_3 rather rapidly. These NO_3 molecules are subject to denitrification/ nitrification losses, especially under saturated conditions. They are also subject to leaching because they are negatively charged and soluble. Thus, the forms of N most susceptible to loss to the environment are NH_3 gas and NO_3 in soil solution.

The most commonly applied N fertilizer is urea, which is highly soluble and converts rapidly to NH_4 and then NO_3. Traditional NH_4 based fertilizers, such as ammonium sulfate, are also soluble and quickly convert to NO_3. The NO_3 containing fertilizers, such as potassium nitrate, are immediately subject to losses via pathways for which it is susceptible. Timing and placement are critical for improved efficiency for these traditional fertilizers. It is important to understand plant uptake patterns for N and ensure that N in plant-available forms (NO_3 and NH_4) is present when plants need it. In addition to applying at the right rate, timing, and placement; using Enhanced Efficiency Fertilizers (EEF) can positively impact yields and the environment.

ENHANCED EFFICIENCY FERTILIZERS

The N EEFs increase plant N uptake percentage, ideally improving crop yields and/or quality, while minimizing losses to the environment (Hopkins et al., 2008; Hopkins, 2020). These EEFs are divided into slow-/control-released and inhibitors/stabilizers (Fig. 1; Hopkins, 2020).

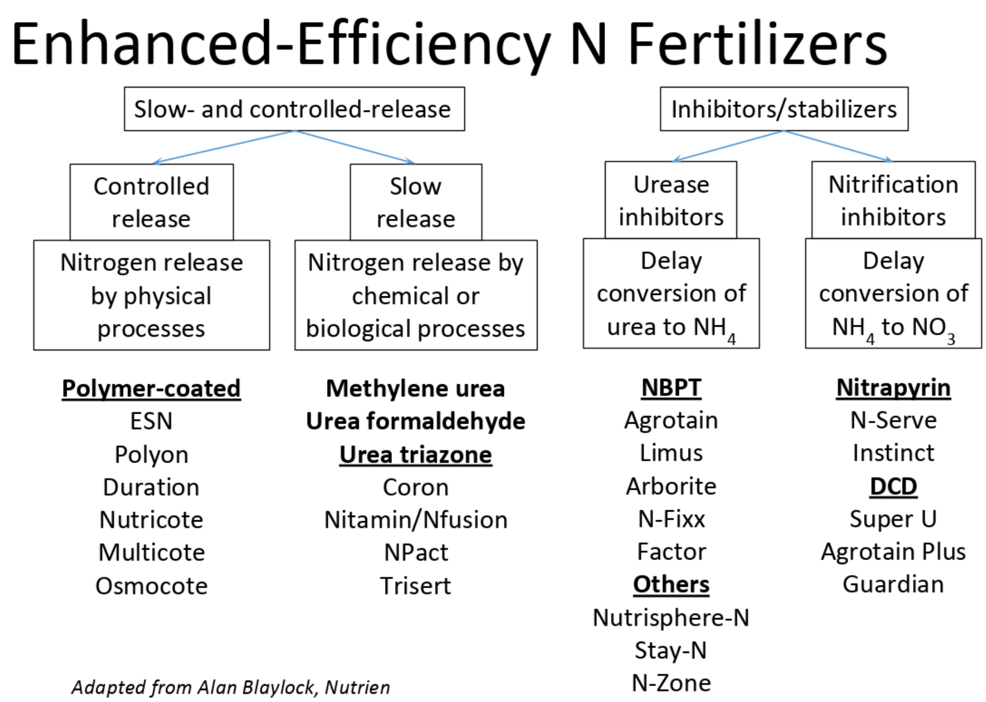

Fig. 1. Enhanced-Efficiency N Fertilizer types (inclusion does not endorse effectiveness)

Slow-release fertilizers involve chemical or biological N release process. For example, urea-formaldehyde, methylene urea and triazone based-fertilizers consist of long chain molecules containing N, which is slowly released with microbial breakdown. This minimizes volatilization, denitrification, and leaching by avoiding a flush of N. These products depend on microbial activity and are affected by factors like extreme soil temperatures. Generally, they do not supply N adequately during cool conditions. And, their breakdown can be slowed after fumigation. These sources tend to not last the entire season, especially in warmer climates with long growing seasons. Some of these EFF are available in liquid form and can be applied via fertigation, foliar applications, and in concentrated fluid fertilizer bands.

Another strategy is applying a sulfur coating on dry fertilizer. Sulfur coatings are used alone or in conjunction with polymer coatings. The N is released as the sulfur coating is oxidized into sulfuric acid by microbial action. They have the additional advantage of releasing sulfur into the soil. Again, release is affected by temperature and fumigation. Sulfur coated products also tend to not last the entire season, especially in warmer climates with long growing seasons.

Control release fertilizers rely on physical processes for N release. As an example, polymer-coated fertilizers (most commonly urea) absorb water through a porous coating. This swells the particle, and eventually the nutrients diffuse through the membrane as molecular diffusion speeds increase with warming temperatures and the sizes of the pores become large enough for passage due to the swelling and/or microbial degradation. The release rate is primarily impacted by temperature and the thickness of coatings. Granules can be designed to release nutrients at differing times, ranging e.g. from 45 to 360 days. As such, polymer coated products can last the entire growing season if conditions are correct and they are handled carefully to avoid cracking the coatings.

Inhibitors increase N efficiency as they slow conversion from one form of N to another. Urease inhibitors [e.g., N-butyl-thiophosphoric triamide (NBPT)] inhibit the urease enzyme, which catalyzes the hydrolysis reaction converting urea to ammonium bicarbonate and then to NH_3 gas and finally to NH_4. The NH_3 gas phase renders the N very vulnerable to volatilization loss if not captured by the soil. This gas loss is greatly minimized if the conversion from urea is slowed by use of an inhibitor, allowing the soil to capture the N more effectively. Although it does nothing to prevent other losses once the transformation takes place.

Urease inhibitors can be effective in all soil types, but especially with high pH soils and/or low cation-exchange capacity (CEC). They are particularly important if urea is not incorporated into the soil using tillage/injection or irrigation techniques, or in conditions which maximize losses to the atmosphere such as open crop canopies, application of liquid urea on thick crop residues or in hot, humid and windy conditions or losses below the rooting zone due to excessive water movement through soil. These inhibitors can be used with dry or fluid fertilizers

Nitrification inhibitors [e.g., Dicyandiamide (DCD), 2-chloro-6 (trichloromethyl) pyridine (nitrapyrin), N-butyl-thiophosphoric triamide (NBPT), 3,4-dimethylpyrazole phosphate (DMPP), and pronitridine] were developed to slow the oxidation of NH_4 to NO_3 by inhibiting the activity of *Nitrosomonas* spp. bacteria responsible for this conversion process. Conversion results in a molecule with a negatively charged ion that is repelled by soil and is thus subject to leaching losses, particularly with excessive precipitation/irrigation. Nitrate is also subject to gaseous loss via denitrification/nitrification. A nitrification inhibitor preserves the N in the NH_4 form which minimizes the period it can be lost in its NO_3 form. Their effectiveness has been evaluated by Burzaco et al. (2014). Inhibitors are especially effective in low CEC soils, soils prone to rapid percolation of water, shallow-rooted crops, and in water-logged or heavily leached soils. These inhibitors can be applied to both dry and liquid fertilizers.

Normally, urea hydrolysis to NH_4 is complete within 2-4 days; a urease inhibitor slows it to about 7-14 days. Conversion of NH_4 to NO_3 normally is complete within 7-21 days; a nitrification inhibitor slows that to about 25-55 days. Using both inhibitors extends the range to about 50-65 days. Slow release products vary widely in their release timing, but generally are released within about 14-50 days. Because they can be more precisely engineered, polymer-coated products vary widely, depending on quality and thickness of the coating, with release timings ranging from 45 to 360 days.

COATED UREA

There is considerable data available on N EEF. Here we focus on the coated urea fertilizers, such as sulfur-coated urea (SCU), polymer-coated sulfur-coated urea (PCSCU), and, especially, polymer-coated urea (PCU). We have conducted many trials on maize, wheat, sugarbeet, dry bean, and other crops with positive results in many circumstances.

Potato is an example of a species that is particularly suited for PCU (Hopkins et al., 2020). Potato is very sensitive to either deficient or excess N, as well as being very sensitive to spikes in availability during the growing season. Most growers apply N in multiple pre-plant and in-season applications, with often weekly applications injected into the irrigation water. Our trials show that a single application of PCU can suffice—often with improvements in yield and/or tuber quality/size because the PCU releases N at a rate that somewhat matches its uptake needs (Hopkins et al., 2008).

In a recent study, all PCU combinations, even at no or reduced in-season applied N, produced yields statistically similar to the grower standard practice with multiple applications, including in-season rates driven by petiole NO_3-N analysis (Carlock et al., 2019). Among the treatments with statistically superior yields, a half rate of N applied as PCU with no in-season N resulted in superior tuber size with no loss of yield or tuber quality. Thus, the PCU treatments, especially with no or lower in-season N, were overall superior to the grower standard practice. Previous trials showed increases in yields and/or tuber quality (Hopkins et al., 2008). These data support other findings that N in the coated urea is protected from loss and, thus, is more efficient. The PCU used in this study, Environmentally Smart Nitrogen (ESN), was an effective enhanced efficiency fertilizer source in these trials. Similar yields with better tuber size was achieved with significantly less N applied. However, previous experience/research shows that it is vital that the PCU is handled carefully to avoid cracking of the coatings. Also, adjustments were required in the interpretation of the petiole analysis (Carlock et al., 2019).

Additionally, based on four years of trials on irrigated barley, a 50%-50% blend of PCU (ESN) and urea significantly increased yield at a moderate rate of N (Fig. 2). The yield increase for this treatment and rate was greater than any other treatment, including those with urea applied alone (Fahning et al., 2019). However, the high rate with this blend resulted in yields decreasing significantly, stressing the importance of realizing that less N is lost and, thus, care needs to be taken to adjust rates downward if excess is a problem. In regards to protein, which was a concern that the PCU would drive it too high, source had no impact on concentration. In summation, these results show that ESN is an effective source of N for barley, although it is seemingly important to avoid blends with too high of a rate or too high of a percentage of PCU.

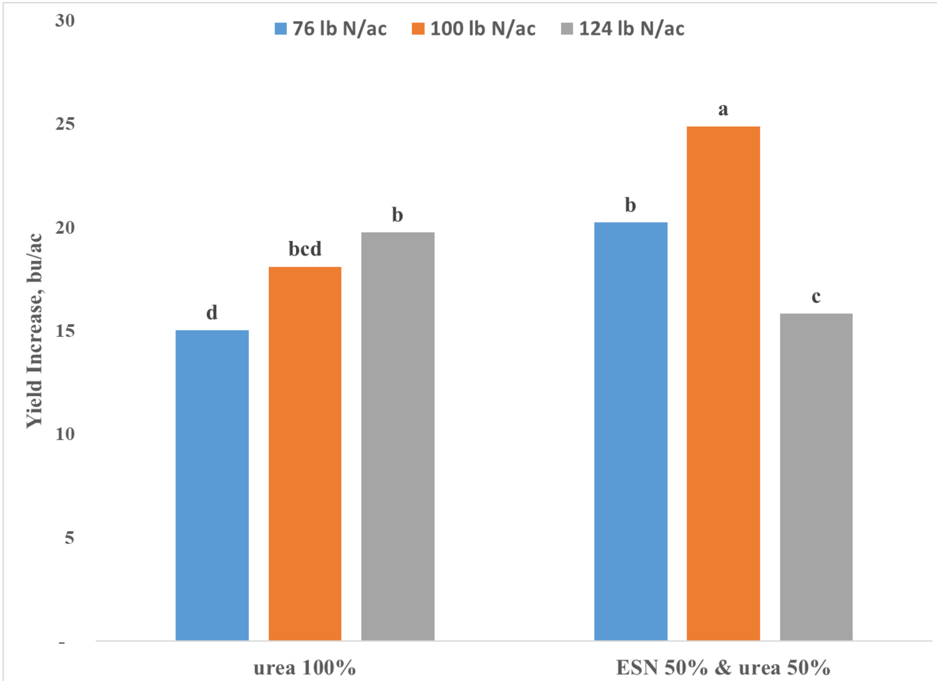

Figure. 2. Barley grain yield increases relative to an unfertilized control averaged over four years (2015-18) for a polymer coated (ESN) urea fertilizer trial in Idaho. Fertilizer was applied at three rates, with each rate applied as 100% urea or 50% ESN & 50% urea. Data bars sharing the same letter(s) are not statistically different from one another. $P = 0.10$

In other studies PCU, applied as Duration, and other coated ureas in Kentucky bluegrass grown as a lawn grass. The PCU was found to reduce NH_3 and N_2O losses to the atmosphere, as well as NO_3 leaching (LeMonte et al., 2016, 2018). The reduced losses enabled lower N rates to be used. We found that two applications (early spring and early fall) were equivalent to spoon feeding monthly when using a 2/3 PCU with 1/3 ammonium sulfate blends. However, we also discovered that the release rates from the PCU were far faster than expected when surface applied because temperature drives release rates and surface soil temperatures are much higher than internal soil temperatures. All of the PCU products applied released >80% of their N within ~40 days—even if they were rated at 180-day release (Ransom, 2014). We also evaluated SCU and PCSCU. The ones we tested did show slow release properties, but they released much faster than PCU with >80% N release in <10 days (Ransom, 2014). The slow release still resulted in reduced loss, but the longevity of availability through the season would be greatly reduced.

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RESULTS FROM THE FIRST YEAR OF ON-FARM N RATE AND TIMING STUDIES

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ABSTRACT

Studies have shown over the past couple of years that utilizing sensor based nitrogen rate calculator (SBNRC) for in-season fertilizer has proven beneficial to yields and protein in the southern Great Plains. However, current SBNRC recommendations and algorithm are based upon trials conducted in central Oklahoma, rather than regionally based. The objective of the larger study is to determine if it is possible to develop a regional dependency component of SBNRC in Oklahoma. For year one of this study, the objective was to employ a nitrogen timing and rate study to assess differences on responses of yield and protein across multiple on-farm locations. In the 2018-2019 growing season, eight locations were established and harvested ranging from the central, north central, and panhandle regions of the state. Each location had a RCBD trial consisting of a check, and a preplant and topdress application of four rates of N fertilizer. Canopeo and NDVI readings were taken in season, with yield and protein being measured post harvest.

INTRODUCTION

Producers aim to maximize production while still staying profitable with inputs. Over the past 15 years, the average price per bushel of winter wheat have been variable, while for the most part, the cost of fertilizer has steadily increased (USDA-NASS, 2019).This charges researchers with providing the information that allows producers to maximize their production, with efficient amounts of nutrients. One option is aiding producers against production cost by increasing nutrient use efficiency.

Nutrient use efficiency is the efficiency of a crop to utilize nutrients that are both from the soil and via fertilizer application, and use those nutrients to produce grain (Raun and Johnson, 1999). Estimation of the world's nutrient use efficiency has shown to be 33, 16, and 19% for N, P, and K, respectively (Dhillon *et al.*, 2019). Though these are estimates, such low use efficiencies are not sustainable at today's standards. Increasing these values has become a mission within the agronomic community, leading to the formation of the 4R Nutrient Stewardship concept (Johnston and Bruulsema, 2014). The 4R's stand for applying the Right source of nutrients, at Right rate, at the Right time, and in the Right place.

One aspect of increasing NUE is by applying fertilizer at the right time. Timing of Nitrogen fertilizer has been looked at by many. Melaj *et al.* (2003), when looking at N fertilizer timing in winter wheat in Argentina, found that lowest values of NUE were found in pre-plant fertilizer applications, and applications around Feekes 3. This is thought to be caused by N immobilization due to the environment and climate. The highest amount of nitrogen uptake was found to be around the time of rapid wheat growth, in the spring during green-up.

Souza (2018) echoed these results, reporting that delaying of nitrogen fertilizer until Feekes 8 did not lead to a loss in yield, and in most cases, protein continued to increase at later fertilizer applications. A significant finding of this study was that the highest usage efficiency of fertilizer applied was found to be when the crop was growing at higher rates, around Feekes 6 and 7.

OSU currently employs the use of the Sensor Based Nitrogen Rate Calculator (SBNRC). Raun *et al.* (2002) observed that the yield potential of winter wheat could be predicted in-season using optical sensor readings. These optical sensor readings taken from an active sensor gives a readout of reflectance, read as Normalized Difference Vegetation Index (NDVI), which is then used to calculate a nitrogen rate. Building the model for this calculation required much data, all of which derived using long term trials in Lahoma and Stillwater, OK across many years and varying conditions (Raun et al., 2005). The SBNRC uses this algorithm as the current sensor based recommendations for N in winter wheat. These current recommendations are based for the entire state of Oklahoma.

Oklahoma's climate can vary greatly across the state. Annual Temperature, precipitation, and growing season changes across the state can affect the phenological growth stages in winter wheat (Porter and Gawith, 1999). Across the state, length of growing season, annual rainfall, and annual temperature can vary from region to region. Oklahoma Climatological Survey divides the state of Oklahoma into 9 climatological zones (Figure 1), each consisting of counties that have average climates similar to their respective group. When looking at regionalizing the state for this study, climatological zones offer distinctions and characteristics between regions that fit well with wheat growth changes in climate.

The objective of this study is to employ a nitrogen timing and rate study to assess differences on responses of yield and protein across multiple on-farm locations.

MATERIALS AND METHODS

This trial was applied in the 2018-2019 growing season to 14 sites, with harvest occurring at 8 sites, across 3 climatological zones. Plots consist of a 2 x 4 factorial plot, 2 timings (preplant and topdress [Feekes 5] fertilizer application) by 4 rates (25%, 50%, 75%, 100% yield potential rate). Rates were determined using the OSU recommendations of 2 lb ac^{-1} N per 1 bu ac^{-1}, using ammonium nitrate (34-0-0) as the source. Site specific rate was determined using the yield potential of the area, considering the productivity of the location, environment parameters, and historical yield. RCBD plot design was utilized, with 4 repetitions. Plot size is 6' x 6', with 4' alleys between repetitions. Canopeo and Greenseeker readings were taken throughout the growing season to monitor growth of plots. At topdress fertilizer application, final NDVI readings were taken for SBNRC calculations. At maturity, 3' x 3' samples were taken from each plot, total biomass removal. Samples are threshed using small grains harvester. Post-harvest grain quality were analyzed using near infrared spectroscopy Diode Array NIR analysis Systems model DA 7000 (Kungens Kurva, Sweden) to measure grain moisture and protein from grain. Statistical analysis was ran in SAS 9.4.

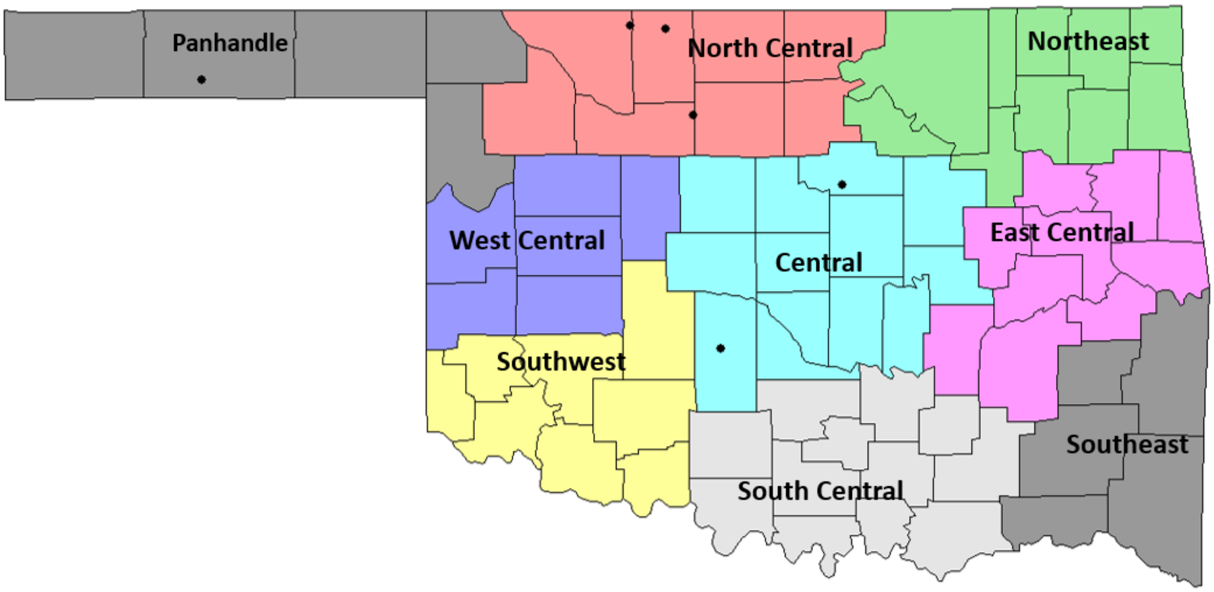

Figure 2 Oklahoma, broken into each Climatological Zone, and all the locations harvested from this trial. The point in Panhandle Zone represents two sites in a similar location. The southernmost point in Central Region also represents two sites in similar location

RESULTS AND DISCUSSION

This trial was applied in the 2018-2019 growing season to 14 sites, with harvest occurring at 8 sites, across 3 climatological zones (Figure 1). Of these 8 sites, two sites had a response in yield, and 7 had a response in protein.

The Byron (North Central) and Perkins (Central) locations had significance for yield and protein (Figure 2). For both of these locations, there was an increase in yield in the preplant applications all the way to the 100% rate (for both locations, 100 lb N ac^{-1}). Bryon maximized its yield (68 bu ac^{-1}) with the pre-plant application with 100 lb N ac^{-1}, while the topdress application maximized yield (73 bu ac^{-1}) with the top-dress application of 75 lb N ac^{-1}. This is attributed to loss of nutrient use efficiency of applying early in season. The proteins at this location increased with the larger applications of N, as expected, but also increased more with the top-dress

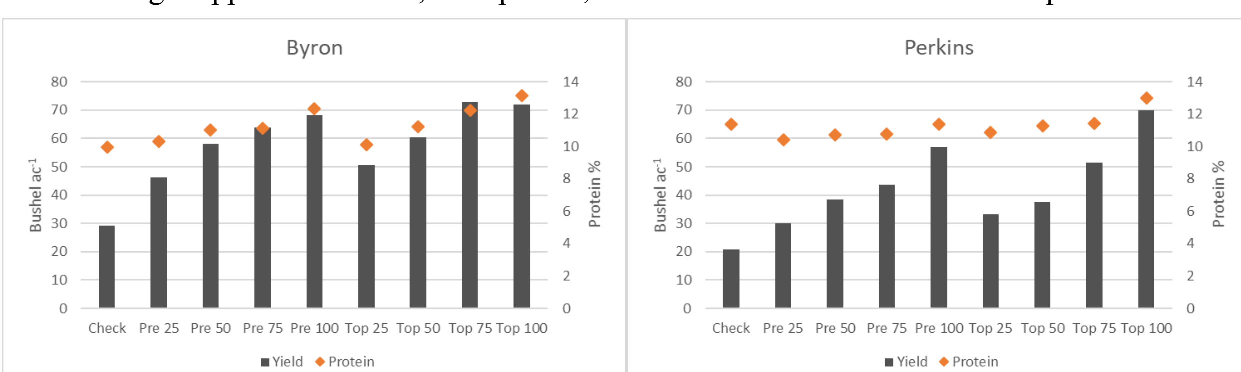

Figure 3 Byron and Perkins locations. These graphs show the yield (represented by bars, left side axis) and protein (represented by points, right side axis) plotted against treatments on the x axis ("pre 25" means pre-plant 25 lb ac^{-1} N application, "top 50" means top-dress 50 lb ac^{-1} application, etc.)

application. This is attributed to the application of N was applied during the time of highest N uptake, allowing more N available to move into protein.

Perkins never plateaued, so it was unknown whether yield or protein was maximized. Yield was increased with the top-dress application, as Byron did. The proteins increased with the larger applications of N, but also increased more with the top-dress application, echoing the Byron location.

Chickasha 1 and Lahoma were two of the 7 locations that did not have a yield response, but had a response in protein. The protein increased with the larger applications of N, and also increased with the top-dress application against the pre-plant application. Again, this is attributed to the application of N being applied during the time of highest N uptake, allowing more N available to move into protein.

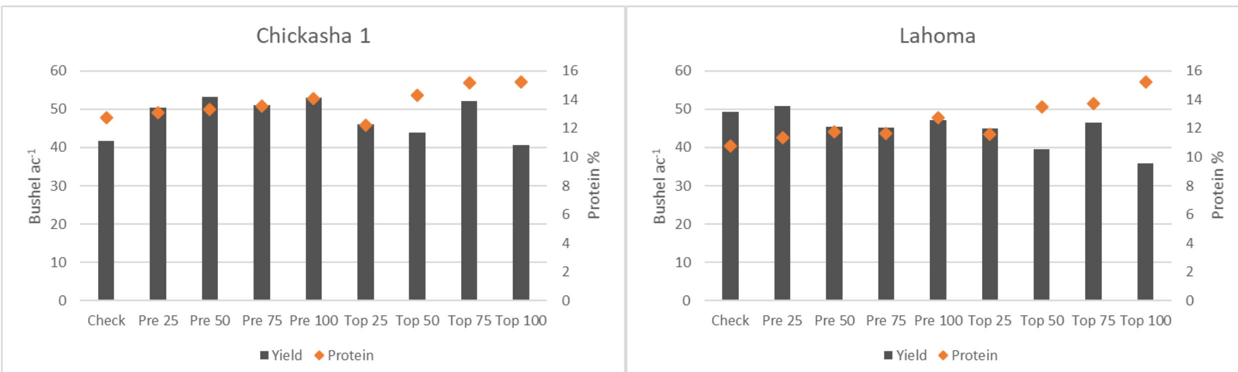

Figure 4 Chickasha 1 and Lahoma locations. These graphs show the yield (represented by bars, left side axis) and protein (represented by points, right side axis) plotted against treatments on the x axis ("pre 25" means pre-plant 25 lb ac^{-1} N application, "top 50" means top-dress 50 lb ac^{-1} application, etc.)

While one portion of this study is to look at regional differences in responses to sensor based management, the lack of responsive locations has resulted in no conclusive answers. However, the responses recorded give further support to using top-dress applications of N for potential increases in yield and protein over pre-plant applications.

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Long-Term Forage Rotation Yields, Soil Water Use, and Profitability

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ABSTRACT

Forages are important for the region's livestock industry and are becoming increasingly important as irrigation capacity and grain prices decrease. Forages require less water than grain crops and may allow for increasing cropping system intensification and opportunistic cropping. A study was initiated in 2012 at the Southwest Research-Extension Center near Garden City, KS, comparing several 1-, 3-, and 4-year forage rotations with no-tillage and minimum-tillage. Data presented are from 2013 through 2019. Tillage generally increased winter triticale yields by 700 lb/a or 30% compared to no-till yields, due largely to increased plant available water. Plant available water at planting winter triticale averaged 5.9 in./a in min-till and 3.9 in./a in no-till. Double-crop forage sorghum yielded 17% less than full-season forage sorghum and yields were not affected by tillage. Oat yields were lower than forage sorghum or winter triticale, averaging 2,100 lb/a across years.

INTRODUCTION

To stabilize crop yields, dryland rotations in western Kansas commonly include fallow to accumulate soil water. Fallow is relatively inefficient at storing and utilizing precipitation when compared to storage and utilization of precipitation received during the growing season. Fallow periods increase soil erosion and organic matter loss (Blanco and Holman, 2012), and represent a large economic cost to producers. Forages are valuable feedstuff to the cow/calf, stocker, cattle feeding, and dairy industries throughout the region (Hinkle et al., 2010). Forages do not require as much water to make a crop as grain crops. Forages grown in place of fallow can increase precipitation use efficiency, improve soil quality, and increase profitability (Holman et al., 2018). This study tests several forage rotations for water use efficiency, forage quality, yield, and profitability.

Annual forages are grown for a shorter period and require less water than traditional grain crops. Including annual forages into the crop rotation might enable increasing cropping system intensity and opportunistic cropping. "Opportunistic cropping" or "flex cropping" is the planting of a crop when conditions (soil water and precipitation outlook) are favorable or fallowing when unfavorable. Wheat yields following spring annual forages such as oat (O) were similar to wheat yields following fallow in a wheat-fallow rotation in non-drought years, but wheat yields were reduced in drought years (Holman et al., 2012). This indicates the opportunity to intensify the cropping system in favorable years. Forage producers in the region commonly grow continuous winter triticale (T), winter triticale or summer crop silage, or forage sorghum (S). However, they lack a proven rotation concept for forages such as that developed for grain crops (e.g. winter wheat-summer crop-fallow). Continuous winter triticale often develops winter annual grass problems, while continuous forage sorghum produces lower quality forage than triticale.

Producers are interested in identifying forage rotations that increase pest management control options, spread out equipment and labor resources over the year, reduce the impact of variable weather risks, and increase profitability. Growing forages throughout the year greatly reduces the risk of crop failure due to variable precipitation.

Growing T or S double cropped (T/S/T), yielded 30% less than non-double crop yields (T-S-O) ($P \leq 0.05$) near Garden City, KS, between 2007 and 2010. Double cropping increased forage production's annual yield 40% more than growing one crop annually (Holman et al., 2012). However, crop establishment was more challenging and crop growth was highly dependent on growing season precipitation in the double-crop rotation compared to annual cropping. Due to the high cropping intensity it was also challenging to implement timely field operations in the double crop system. An intermediate cropping intensity of three crops grown in two years or four crops in three years might be a successful crop rotation in western Kansas.

Recently in western Kansas, glyphosate-resistant kochia (*Kochia scoparia*) was identified, and several other grasses (e.g. tumble windmill grass and red three-awn) are already tolerant of glyphosate and other herbicides. Although continuous no-till was shown to provide better water conservation and crop yields, this result is contingent upon being able to control weeds with herbicides during fallow. Limited information is available on the effect of occasional strategic tillage to control herbicide-tolerant weeds on forage yield. Yield of forage crops following tillage might not be affected as much as in grain crops, since forages require less water. Information is needed on the effects of occasional tillage in forage based cropping systems.

MATERIAL AND METHODS

An annual forage rotation experiment was initiated in 2012 at the Southwest Research-Extension Center near Garden City, KS. All crop phases were in place by 2013, with the exception of T-S-O, which had all crop phases in place by 2015. The study design was a randomized complete block design with four replications. Treatment was crop phase (with all crop phases present every year) and tillage (no-tillage or min-tillage). Plots were 30-ft wide × 30-ft long. Crop rotations were one-, three-, and four-year rotations (see treatment list below). Crops grown were winter triticale (×*Triticosecale* Wittm.), forage sorghum (*Sorghum bicolor* L.), and spring oat (*Avena sativa* L.). Tillage was implemented after spring oat was harvested in treatments 3 and 5, using a single tillage with a Minimizer (Premier Tillage, Inc., Quinter, KS) sweep plow with 5-ft blades and trailing pickers.

Treatments:

1. Continuous forage sorghum (no-tillage): (S-S)
2. Year 1: winter triticale/double-crop forage sorghum; Year 2: forage sorghum; Year 3: spring oat (no-tillage): (T/S-S-O no-tillage)
3. Year 1: winter triticale/double-crop forage sorghum; Year 2: forage sorghum; Year 3: spring oat (single tillage after spring oat, min-tillage): (T/S-S-O min-tillage)
4. Year 1: winter triticale/double-crop forage sorghum; Year 2: forage sorghum; Year 3: forage sorghum; Year 4: spring oat (no-tillage): (T/S-S-S-O no-tillage)
5. Year 1: winter triticale/double-crop forage sorghum; Year 2: forage sorghum; Year 3: forage sorghum; Year 4: spring oat (single tillage after spring oat, min-tillage): (T/S-S-S-O min-tillage)

6. Year 1: winter triticale; Year 2: forage sorghum; Year 3: spring oat (no-tillage): (T-S-O)

Winter triticale was planted at the end of September, spring oat was planted the beginning of March, and forage sorghum was planted the beginning of June. Crops were harvested at early heading to optimize forage yield and quality (Feekes 10.1) (Large 1954). Each year, winter triticale was harvested approximately May 15, spring oat was harvested approximately June 1, and forage sorghum was harvested approximately the end of August. Forage yields were determined from a 3- × 30-ft area cut 3 in. high using a small plot Carter forage harvester from each plot. Forage yield and nutritive value (protein, fiber, and digestibility) were measured at each harvest. Gravimetric soil moisture content was measured at planting and harvest to a depth of 6 ft using 1-ft increments. Precipitation storage efficiency (% of precipitation stored during the fallow period) was quantified for each fallow period, and crop water use efficiency (forage yield divided by soil water used plus precipitation) was determined for each crop harvest. Crop yield response to plant available water (PAW) at planting was used to develop a yield prediction model based on historical or expected weather conditions. Most producers use a soil probe rather than gravimetric sampling to determine soil moisture status, so soil penetration with a Paul Brown soil probe was used four times per plot at planting to estimate soil water availability. Previous studies found a soil moisture probe provided a practical, easy way to determine soil moisture level and crop yield potential. Profitable forage and tillage systems identified in this study will benefit producers in the High Plains region.

RESULTS AND DISCUSSION

Rotation Yield

Annual rotation yield was determined by measuring total yield for the rotation and dividing by the number of years in the rotation. This method allowed for comparing rotations of different years to each other for annual forage production (Table 1). A very dry year in 2013 resulted in low crop yields and no O yield. In 2013, S-S produced the highest annual yield. In 2014, annual yield was comparable across treatments except for T/S-S-O (no-till), which had lower yield than T/S-S-S-O (min-till) and was comparable to all other treatments. The crop rotation of T-S-O was not in phase until 2015, so no comparison was made to that rotation until 2015. In 2015, T/S-S-O (no-till) yielded less than S-S, but more than T-S-O and comparable to all other treatments. The T-S-O annual yield was less than all other treatments in 2015. Between 2016 and 2018, precipitation primarily occurred in late spring and summer, which favored S yield. The highest yielding rotations in 2016 through 2018 were S-S, followed by T/S-S-S-O, and T-S-O yielded the least. In 2019 precipitation was favorable for T and O and T/S-S-O (min-till) had the highest mean yield. Tillage generally increased the yield of triticale and thus the yield of T/S-S-O was improved with tillage but yield improvement in the 4-yr rotation was not as evident due to T occurring less frequently in the rotation.

Forage yield per crop harvest was determined for each rotation since planting and harvesting expenses are the major expenses to growing a crop; yield and value per ton are the major income components. Crop rotations with greater yield per harvest are likely to be more profitable compared to rotations with low yield per harvest since some of the variable and fixed expenses are less. Although O and T yield less than S, they are also higher in crude protein and digestibility and are worth more per unit than S. A full economic analysis of rotations will be completed at the conclusion of this study. In 2013, S-S had the greatest yield per harvest, and all other rotations had similar yields per harvest (data not shown). In 2014, T/S-S-O (no-till) had lower average harvest yields than S-S or T/S-S-S-O (min-till), but was similar to T/S-S-O (min-till) and T/S-S-S-O (no-till). In 2015, S-S had the greatest yield per harvest, and T-S-O had the lowest yield per harvest, which was less than S-S or T/S-S-S-O (no-till), but comparable to the other treatments. Between 2016 and 2019, S-S had the greatest yield per harvest and T-S-O had the least. Sorghum has the greatest yield potential of the three crops investigated, but S-S does not allow for crop diversification, improved weed management, higher forage quality (O and T), the ability to winter graze when native pastures are dormant, or the ability to reduce weather risk by growing a crop during different times of the year.

Crop Yield

Full-season S either grown after T/S or S yielded similarly across rotations (Figure 1). Double-crop S yielded less than full-season S, but varied greatly from year to year based on precipitation during the growing season. Double crop S yielded 70% less than full-season in 2013, 7% less in 2014, 12% less in 2015, 10% less in 2016, 38% less in 2017, and 15% less in 2018. Across all years, double-crop (6,160 lb/a) averaged 17% less than full-season S (7,460 lb/a). The lower yield of double-crop S was due to less available soil moisture at planting. Sorghum yield was not affected by tillage or length of rotation, although there was a tendency for no-till forage sorghum yields to be greater than min-till yields.

Triticale yield was not affected by length of rotation but was affected by tillage. Averaged across years, triticale in min-till (3,260 lb/a) yielded 28% more than no-till (2,550 lb/a). The only tillage in this study occurred in the fallow period before T and, in this study, benefitted the T crop. The exception was in 2017 when no-till (1,869 lb/a) yielded more than min-till (1,518 lb/a). Other studies and producers have found tillage ahead of a winter wheat crop has minimal impact on yield and can improve weed control, but tillage ahead of grain sorghum often reduced grain yield. For these reasons, tillage was only used ahead of T and, similar to winter wheat, did not reduce yields, but actually increased yields in the first 5 years of this study.

Oats failed to make a crop in 2013 due to drought conditions and varied by year due to differences in growing season conditions. Oat forage yield was 400 lb/a in 2014, 4,900 lb/a in 2015, 2,300 lb/a in 2016, 883 lb/a in 2017, 300 lb/a in 2018, and 3,421 lb/a in 2019. Yields in 2015, 2016 and 2019 were higher than other years due to favorable spring precipitation and cool temperatures. Oat yield was not affected by tillage or crop rotation.

Soil Water

Plant available water at planting was measured to a 6-foot soil depth, and soil water content varied by year and planting period. Soil water was greatest for full-season S planting averaging 7.7 in across treatments, which was more than double crop S that averaged 5.6 in. No-till T (3.9 in) was less than min-till T (5.9 in). At oat planting (March) PAW averaged 3.9 in. (Figure 2).

Water use efficiency (WUE) was greatest in S, with full-season averaging 597 lb/a/in. and double-crop producing 555 lb/a/in. Water use efficiency for T averaged 343 lb/a/in., and oat was 250 lb/a/in. The yield potential and thus water use efficiency was greater with S than T or O. However, when precipitation was favorable during a particular growing season, such as O in 2015, the WUE of oat was comparable to forage sorghum. In years with moisture stress, WUE of double-crop S was less than full-season, but in favorable moisture years WUE of double-crop was greater than full-season (data not shown).

Precipitation storage efficiency (PSE) varied by fallow period and ranged from 9% ahead of T to 40% for full-season S. Precipitation storage ahead of double-crop S was 32% and ahead of O planting was 22% (data not shown).

Table 1. Rotation treatment yields across years between 2013 and 2019.

Crop rotation	2013	2014	2015	2016	2017	2018	2019	2015-19 Average†
			Annualized Treatment Yield (DM lbs/acre)					
S-S	4262	7426	10244	8025	5954	5799	7338	7472
T/S-S-O(no-till)	1150	4441	8577	5356	4462	4097	7968	6092
T/S-S-O(min-till)	1340	6710	9581	6135	3897	4849	8023	6497
T/S-S-S-O(no-till)	1926	6815	9523	6830	4845	4817	7389	6681
T/S-S-S-O(min-till)	2224	7566	9099	5958	4353	5113	7775	6459
T-S-O	*	*	6135	3353	3194	2284	6336	4261
$LSD_{0.05}$¶	1508	3038	1488	801	1391	1306	1320	

† Average of years 2015-2019. § T-S-O treatment started in 2015.

SUMMARY

Forages can be grown throughout the growing season (spring, summer, and fall) to diversify rotations. Although T and O have greater forage quality, S produces more yield. Tillage can help manage weeds, alleviate soil compaction from grazing and improved T yield. Growing a combination of cool and warm season forages produces a large amount of forage and offers several advantages. A diverse rotation would reduce risk of crop failure, spread work load, and ensure an annual forage supply throughout the year. Based on an individual operation's forage needs of timing, quality, and yield, a rotation could me modified to include a higher percentage of O, T, and S by changing the length of the rotation growing more of the highest need crop.

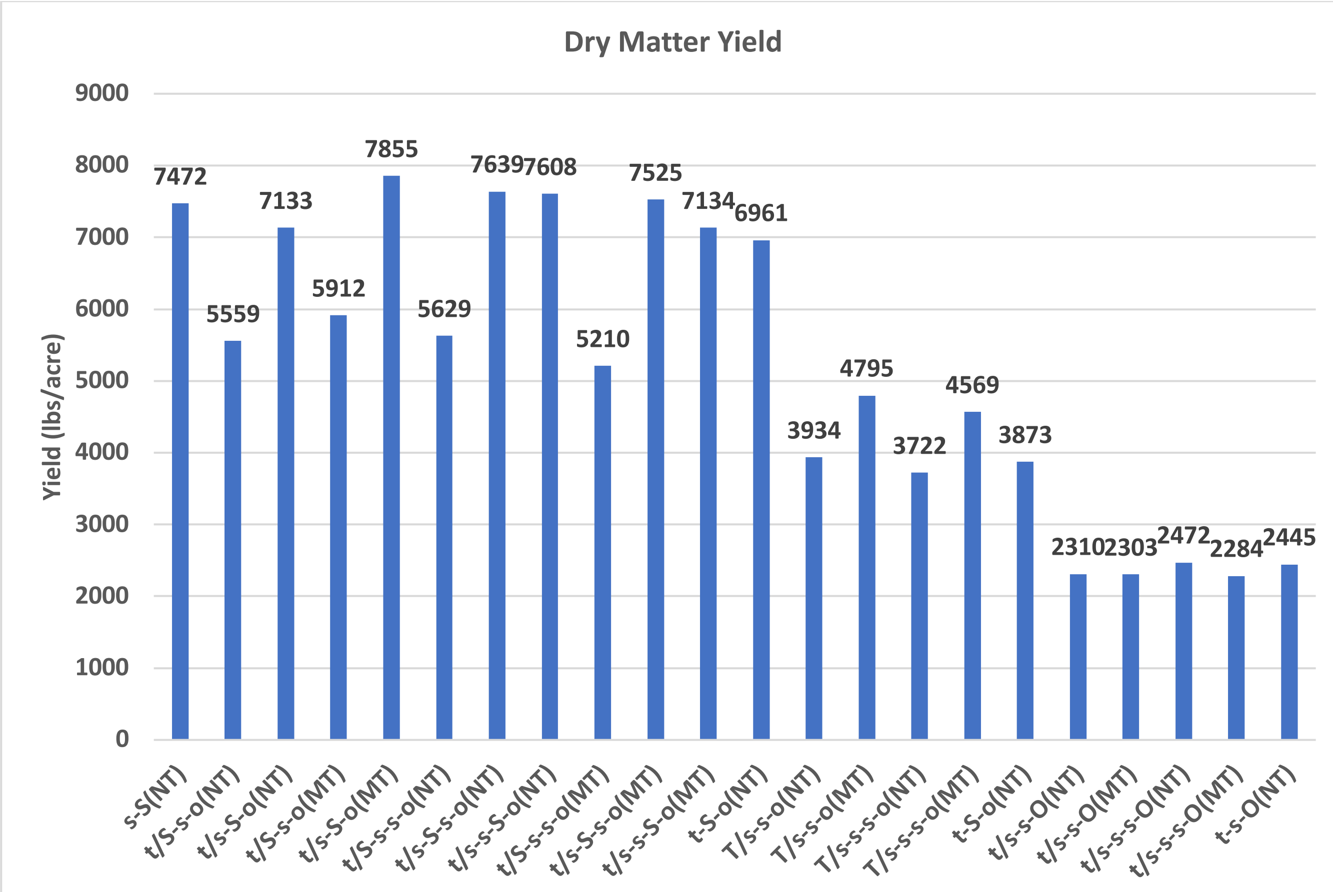

Figure 1. Forage dry matter yield for all crop rotations and phases averaged across years from 2013 to 2018. Crop is identified by capitalization in X axis. S = Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.

ACKNOWLEDGEMENT

The USDA-NRCS Ogallala Aquifer Grant program and the Kansas Agricultural Experiment Station supported this work.

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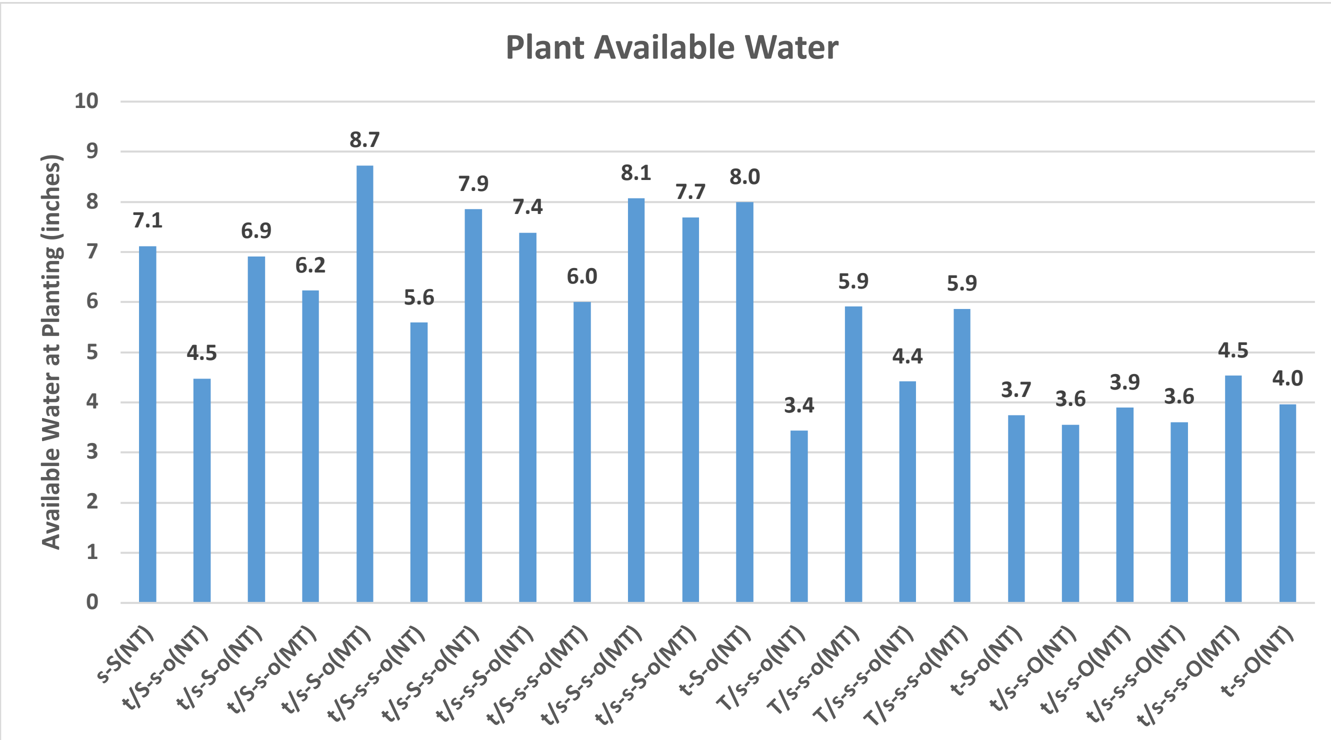

Figure 2. Plant available water in a 6-ft soil profile at planting for all crop rotations and phases averaged across years from 2013 to 2018. Crop is identified by capitalization in X axis. S = Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.

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LONG-TERM CROP ROTATION IMPACT ON SOIL PROPERTIES AND CROP RESPONSE

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ABSTRACT

Crop rotations can be part of sustainable agriculture production by their effectiveness depends on understanding how crop rotations affect above- and below-ground crop characteristics. Objectives were to investigate crop rotation effects on shoot dry weight and root characteristics of cereal and grain legume crops at anthesis as well as on grain yield. Rotations were corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.], (CS); corn-soybean-spring wheat (*Triticum aestivum* L.)-field pea (*Pisum sativum* L.), (CSSwP); corn-soybean-spring wheat-sunflower (*Helianthus annuus* L.), (CSSwSf); corn-field pea-winter wheat-soybean (CPWwS); and corn-oat (*Avena sativa* L.)-winter wheat-soybean (COWwS). Rotations were established in 2000 with plants measured in 2015 and 2016. Rotations had no significant effects on shoot dry weight at anthesis. Small grains had greater root length density than grain legumes between 0-60 cm soil depths. Rotation treatments had significant effects only on soybean root length density at 0-90 cm soil depths. Soybean following winter wheat (CPWwS and COWwS) had significantly less root length density than soybean following corn. Soybean grain yield was significantly greater following winter wheat (CPWwS and COWwS) than other rotations. Thus, smaller root systems at anthesis in soybean following winter wheat were associated with higher grain yield at maturity.

INTRODUCTION

Diverse crop rotations have the potential to facilitate water and nutrient uptake from different soil-profile positions as well as to improve soil health. Cultivation of rotational crops may also improve economic outcomes of farm operations by expanding the time frame of planting and harvest activities as well as by reducing the impact of crop losses to transient weather extremes. In the northwestern U.S. Corn Belt, diversification of the ubiquitous corn-soybean rotation using alternate crops grown in diverse rotations is essential for improving soil health and decreasing yield loss caused by diseases, weeds, and insect pests (Riedell et al., 2013; Riedell and Osborne, 2017). Information on root characteristics of crops that have the potential to diversify the corn-soybean rotation will help when designing these diverse cropping systems as well as assessing their effects on soil health.

Soil physical, chemical and biological properties have a significant impact on root growth, and distribution throughout the soil profile. Researchers have found that soils with a low nutrient supply, and low soil quality produce plants with enhanced root growth compared to soils rich in nutrients (Coutts and Philipson, 1977; Philipson and Coutts, 1977; Garwood and Williams, 1967 and Ma et al, 2001). The impact of crop rotation and crop species on specific soil properties have been the current focus of a number of studies with the recent interest in soil health. Specifically, Maiga et al, 2019 found that in a 4-yr rotation that included small grain had higher particulate organic matter and soil organic matter compared to a 2-yr corn/soybean rotation. Soil water-stable aggregation and microbial biomass was greater following wheat residue (Le Guillou et al.,2012) and Blanco-Canqui and Jasa, (2019) found that grass species (rye) had a positive impact on soil aggregation and organic matter comparted to legume.

The objective of the research presented here was to measure root length density at soil depths to 120 cm for seven crop species (corn, soybean, spring wheat, winter wheat, oat, field pea, and sunflower) that were used to investigate crop rotations that diversify the ubiquitous corn-soybean rotation in the northwestern U.S. Corn Belt. The experimental approach was a 2-yr field study of roots of these seven species of crops that had been grown under rotational treatments since 2001. Root sampling activities, conducted when each crop reached the anthesis stage of development, were repeated over a 2-yr period to enable the potential effect of different growing season environments on root distribution to be assessed. Research focused on root growth characteristics under simple and diverse crop rotations could illustrate the potential contributions of roots to soil ecology and health.

MATERIALS AND METHODS

Experiments investigating simple and diverse crop rotations were conducted at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD. Soils at the research farm are Barnes clay loam soils (fine-loamy, mixed, superactive, frigid Calcic Hapludoll). The field study consisted of 4 replicate blocks of 5 crop rotation treatments arranged in a randomized complete block experimental design: a 2-yr corn-soybean rotation (CS), a 4-yr rotation of corn-soybean-spring wheat-field pea (CSSwP), a 4-yr rotation of corn-soybean-spring wheat-sunflower (CSSwSf), a 4-yr rotation of corn-field pea-winter wheat-soybean (CPWwS), and a 4-yr rotation of corn-oat-winter wheat-soybean (COWwS). Rotation experimental treatments were initiated under no-till soil management with winter wheat being planted in the fall of 2000 and the following crops being planted in the spring of 2001, with all crop present each year. Presented crop data were collected in 2015 and 2016. More information regarding fertilization for each crop during growing season were reported in Lehman et al (2019). During the growing season, weeds were controlled by 2,4-dichlorophenozyacetic acid and glyphosate across the plots.

At anthesis, crop shoots were harvested just above the ground level using shears and pruning tools. Shoots harvested from 0.5 m of crop row were bagged in the field, transferred to a forced air oven maintained at 60 ºC, and dried to constant weight. Shoot tissue was weighed. Root sampling procedures for each crop species were initiated on the same dates as shoot harvests. A 3.175-cm dia. soil probe was positioned as close as possible to the center of the crop row and in-between plants. The probe was pushed into the soil to a depth of at least 122 cm using a hydraulic soil sampler (Giddings Machine Co., Windsor, CO). Two soil cores were taken within each of the crops grown in rotation and within four replications each year. The two soil cores were cut into segments of 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-90 cm, and 90-120 cm. Core segments from the two cores were combined. Roots were separated from the soil with a hydropneumatic root washer and stored in a 30% aqueous-ethanol solution (v/v). Root samples in ethanol solution were transferred to a transparent, 20 X 25 cm2 plastic tray, maneuvered by hand to reduce root overlap on a desktop scanner and scanned at 400 dpi (horizontal and vertical). The resulting images were digitized, and WinRHIZO software (Regent Instruments, CA.) was used to calculate root length present in each sample. Past research by Bauhus and Messier, (1999) found that root detection limit with the RHIZO Image Analysis was 85 µm when the scanner was set at 300 dpi and 42 µm when set at 600 dpi, at a scanned resolution of 400 dpi root detection limit would be 64 μm. Root length density (cm of root length cm^{-3} of soil) was then calculated for each sampling depth segment.

A research plot combine (Massey Ferguson 8-XP; Kincaid Equipment Manufacturing, Haven, KS) equipped with an electronic weigh bucket was used to measure grain yield harvested from research plots. Harvested grain samples were measured for moisture using a grain analysis computer (Dickey-John GAC2000, Johnston, IA). Prior to analysis, grain yields were mathematically adjusted to specific moisture contents: 155 g kg^{-1} for corn, 130 g kg^{-1} for soybean and field pea, 135 g kg^{-1} for wheats, 140 g kg^{-1} for oat, and 100 g kg^{-1} for sunflower.

RESULTS AND DISCUSSION

A significant crop x rotation interaction (statistical results not shown) suggests that grain yields for the crops in this experiment responded differently to rotation treatments. Data analysis suggested that corn, soybean and field pea yields were affected by rotation treatments (Table 1). Differences in corn yield found that corn following field pea in the CSSwP were significantly greater than any of the other crop rotations (Fig 1). There was no significant difference in corn yield when corn was grown in the 2 yr rotation of CS compared to 4 yr rotations of COWwS and CPWwS. In general corn grown following field pea had the greatest yield, corn following soybeans were intermediate, while corn following sunflowers were the lowest (Fig. 1). Differences in soybean yield appear not only to be impacted by differences from the previous crop but also differences in the length of crop rotation. Soybean grown in a 2 yr rotation resulted in lower yield compared to any of the 4 yr crop rotations (Fig. 1). In a 4-yr rotation, soybean yield was significantly greater when soybean followed winter wheat (CPWwS and COWwS rotation treatments) than when soybean was grown after corn (Fig. 1). Additionally, field pea following spring wheat resulted in significantly greater yield compared to following corn (CSSwP vs CPWwS, 3429 and 2673 kg ha^{-1} respectively).

There was no statistical difference between the other rotational crops at the 0-15 and 15-30 cm depth except for the sunflower crop which had significantly lower roots at the 15-30 cm interval compared to corn, field pea and soybeans. Root length density for the 30-45 cm interval found an increase in corn roots equal to that of the small grain crops, while soybean and sunflower had significantly lower root length density. Similar to our findings, Merrill et al. (2002) also found that field pea at anthesis had greater root length density values than soybean at the 0-50 cm soil depth during growing seasons with average and below average rainfall. Taken together, our findings are consistent with those of Hamblin and Tennant (1987) who found that root length densities of small grain cereal crops were substantially and consistently greater than those of grain legumes in the top 80 cm of the soil profile. Root length densities for the 90-120 cm were very low and equivalent for all crops.

Of interest are the significant crop x rotation interactions for root length density at soil depth increments of 0-90 cm (Table 2). These interactions suggest that root length density across crop species responded differently to rotational treatments at these soil depth increments. Soybean grown after cereal grains (COWwS and CPWwS) had less root length density than when soybean followed corn at all sampling depths except for 90-120 cm, but this was not statistically significant (α=0.05) at all depths. Additionally, pea root length density was lower when pea was grown following a small grain compared to following corn although it was not significantly different. Soybean root length density was greatest for the 2 yr CS rotation for sampling depths 15-30, 30-45, 45-60 and 60-90 (Fig 2). These differences suggest that soybean and pea root systems showed phenotypic plasticity in response to rotation treatments. It is likely that the driving forces behind these different soybean root system characteristics were differences in soil physical, chemical or biological properties under the different rotational treatments.

CONCLUSIONS

Soybeans that followed winter wheat had greater grain yield, suggesting that increased root system efficiency carried on past anthesis and continued to crop maturity. The difficulty in this speculation is that soybean root systems at R1 are just beginning to enter a grand phase of growth which results in soybean roots having a two to three fold increase in rooting depth between R1 and R2 (Kaspar et al., 1978). Additionally, Mitchell and Russell (1971) and Coale and Grove (1990) found that soybean root dry matter continued to accumulate throughout flowering, pod formation, and seed fill. However, Izumi at al. (2004) found that there was no correlation between root length density measured at beginning pod developmental stage and soybean grain yield at maturity. Thus, the relationship between differences in root length density at anthesis and final soybean yield needs further investigation to understand the mechanisms that may have resulted in the differences in soybean root systems when grown following winter wheat in 4-year crop rotations, including understanding changes in soil properties and soil processes that are induced by complex rotations.

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Table 1. Crop species means for shoot dry weight and grain yield measured across the rotation treatments near Brookings, SD, 2015–2016.

Crop species	df†	Anthesis shoot biomass	P value‡	Grain yield	P value‡
		------------kg ha^{-1}---------		------kg ha^{-1}-----	
Corn	4	11589 ± 190	0.3770	5911 ± 162	0.0013
Soybean	4	548 ± 24	0.3739	2277 ± 45	<0.0001
Spring wheat	1	2395 ± 88	0.3899	2712 ± 52	0.5224
Winter wheat	1	4261 ± 312	0.9897	3553 ± 239	0.8730
Field pea	1	1796 ± 127	0.0608	3051 ± 110	<0.0001
Sunflower		10348 ± 769§		2775 ± 120§	
Oat		2924 ± 474§		3422 ± 177§	

†df represent the degree of freedom for rotation treatments within crop species.
‡ P value represent the probability due to the crop rotation treatments within each crop species.
§Data from sunflower and oat, which were not included in the original PROC GLIMMIX analysis (see data analysis section in Materials and Methods), are included in this table for the benefit of the reader.

Table 2. Analysis of variance of year, replication, rotation, crop and interactions for root length density, Brookings SD in 2015 and 2016.

Effect	**df†**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**	**60-90 cm**	**90-120 cm**
		Pr < F‡					
Year	1	0.2654	0.0054	0.1230	0.0004	0.0135	0.2938
Replication	3	0.3218	0.6365	0.4232	0.0483	0.4004	0.4494
Rotation	4	0.4027	0.0174	0.6155	0.1956	0.3458	0.7952
Crop	6	<0.0001	<0.0001	<0.0001	<0.0001	0.0049	0.1042
Rotation*Crop	7	0.0008	0.0010	0.0012	<0.0001	0.0058	0.2597
Year*Rotation	4	0.3561	0.2279	0.9193	0.4273	0.1847	0.2854
Year*Crop	6	0.0088	0.0006	0.1625	0.3523	0.0444	0.5726
Year*Rotation*Crop	7	0.8803	0.6843	0.8056	0.3751	0.2556	0.8866

† df represent the degree of freedom for root length density in different soil depth
‡ Probabilities of the main effects for the different soil depth increments.

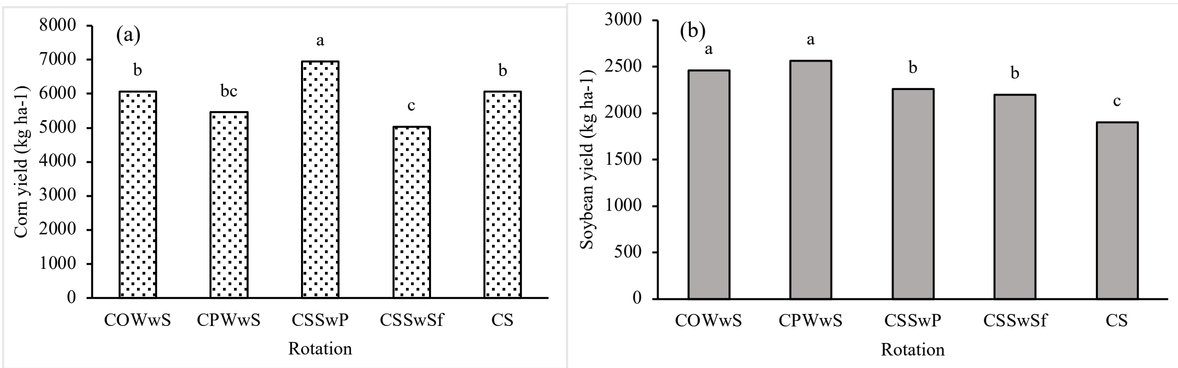

Figure 1. Grain yield of (a) corn and (b) soybean grown under five rotation treatments across the two years of the experiment. Columns marked with the same letter are not statistically different (PDIFF test, α = 0.05).

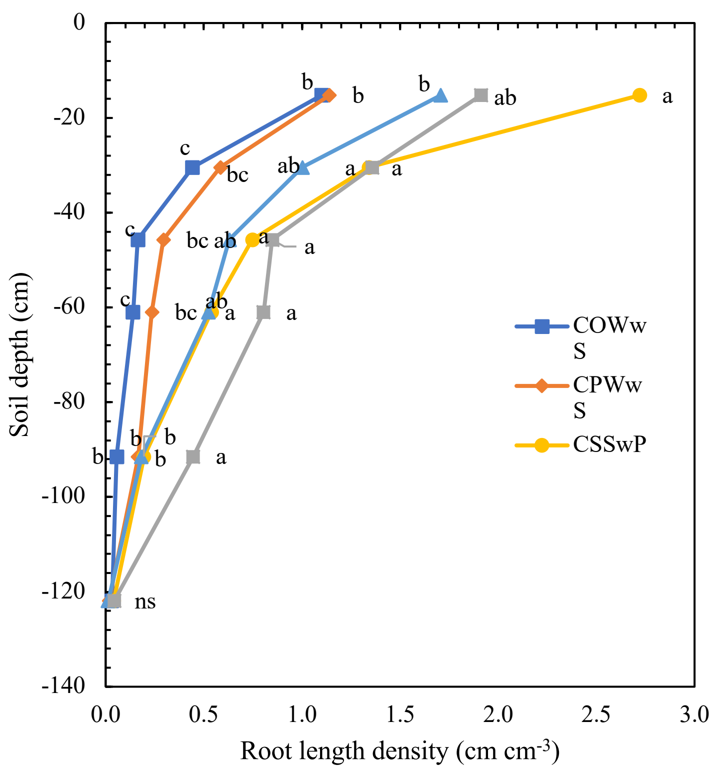

Figure 2. Root length density (cm cm^{-3}) as a function of soil depth for soybean crops within crop rotation treatments at crop anthesis across the two years of the experiment. Symbols denote average root length density values at 0-15, 15-30, 30-45, 45-60, 60-90, and 90-120 cm sampling depths. Symbols followed by the same letter within each soil depth are not statistically different (PDIFF test, α = 0.05).

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Soil Phosphorus Fractions After Long-Term Fertilizer Placement In Different Kansas Soils

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ABSTRACT

Phosphorus fertilizer placement can affect the long-term dynamics and forms of P, and the overall soil P pools. These changes can vary by soil type, and affect P uptake and use efficiency by crops. The objective of this study was to evaluate the changes in the labile P fractions in three Kansas soil under P fertilizer placements (broadcast versus deep band) after 10 years of crop rotation. Three field studies were conducted for 10 years from 2006 to 2015 in three different soils at Scandia, Ottawa and Manhattan. Three treatments were evaluated, including a control with no P fertilizer application and two fertilizer treatments (80 lbs. P_2O_5 acre^{-1}): (1) surface broadcast and (2) deep band at approximately 15 cm depth. All treatments received strip-tillage. After 10 years, soil samples were collected from the row and between the row at two sampling depths (0-3 and 3-6 inches) and soil P pools (inorganic and organic P labile) via sequential P fractionation were measured. Significant changes in soil labile P pools for treatments compared to control were observed due to the long-term effect of P fertilizer placement. The broadcast P fertilizer placement increased the total labile (Pt_{LP}) and inorganic labile P (Pi_{LP}) in the soil surface (0-3 in) and deep band in the subsoil (3-6 in) at all sites studied. However, highest amount of organic labile P (Po_{LP}) was observed for the control broadcast treatments in the subsoil (3-6 in) just at Scandia site. Also, the Pt_{LP} in the soil profile (0-6 in) was affected by maximum P adsorption capacity (MPAC) and P fertilizer placement and was observed the broadcast treatment showed higher amount of Pt_{LP} than deep band and control treatments at Scandia site with low MPAC. However, at Ottawa location with medium MPAD the higher amount of Pt_{LP} was observed for deep band than broadcast and control treatments. In addition, at Manhattan site with the higher MPAC of this study the broadcast and deep band treatments showed the same amount of Pt_{LP} in the soil profile and higher than the control treatment.

INTRODUCTION

Fixation of plant nutrients by soils is a major concern for economical use efficiency of fertilizer. Phosphorus (P) from applied fertilizer can become fixed in some soils, due to conversions into compounds of more limited bioavailability for plant uptake (Stutter et al., 2015), P it is the second macronutrient that most often limits agricultural production (Coelho et al., 2019), and a higher dose is required for optimum crop yield. Phosphorus in the soil exists in inorganic (Pi) as well as organic (Po) forms of comparable solubility, labile, moderately labile and non-labile (Weihrauch and Opp, 2018) and the soil fixation of all these forms depends upon many factors, *viz*., the organic matter content, pH of the soil, soil parent material (type of clay and sesquioxides), soil maximum P adsorption capacity, fertilizer placement etc. Thus, efficient P management in crop production is mandatory to minimize depletion of soil P reserves, environmental issues due to the waste from the higher rates, and production costs. Indeed, fertilizer P placement can affect crop P utilization in the short-term during the growing season. However, the long-term interactions of placement and plant root uptake in different soils can also affect the forms of P and the overall soil P pools, especially the residual labile P concentration at various soil depths and soil-plant interactions. The Hedley's fractionation (1982) is one of the most common methods to identify the redistribution of P applied to the soil its different forms. The objective of this study was to evaluate the changes in the labile P fractions in three Kansas soil under different P fertilizer placements (broadcast versus deep band) after 10 years of crop rotation.

MATERIALS AND METHODS

Field experiments were conducted at the Kansas Research and Extension Centers located in Scandia, Ottawa and, Manhattan. Initial soil samples were collected in April 2006 before initiating the study by collecting a representative sample from the 0-3 and 3-6 inch layers for the characterization of general soil properties of the experimental areas (Table 1). The experiments were arranged in a randomized block design of a corn-soybean rotation with four replications in Scandia and Ottawa, and corn-soybean-wheat rotation with three replications in Manhattan for 10 consecutive years. A strip-tillage operation was performed before planting corn; while soybean and wheat were planted into the corn residue with no prior tillage. Strip-tillage was used for all plots including the control, which received no P fertilizer application. Deep-band P fertilizer application was completed with the strip-tillage operation applied in a concentrated zone spaced at 30 inches and made in the same row location during 10 years. Corn and soybean were planted in the center of the strip in the same row each year. The phosphorus fertilizer source for the broadcast treatment was triple superphosphate (0-45-0) applied broadcast by hand to the soil surface before planting corn. The P fertilizer source for deep banding was ammonium polyphosphate (10-34-0). Treatments included a control with no P application and two treatments involving placements of 80 lbs. of P_2O_5 acre^{-1} as broadcast or deep band. After the last crop harvest for each experiment in 2015, soil samples were collected from 0-3 and 3-6 inches depths from the in-row position. Soil P fractions were determined by the sequential P fractionation method proposed by Hedley et al. (1982) with modifications by Condron et al. (1985). To evaluate maximum P adsorption capacity (MPAC), 2.5g subsamples of air-dried soil were mixed with 11 rates of added P (0, 4, 8, 12, 20, 28, 36, 44, 56, 68, and 80 mg L^{-1}) as potassium dihydrogen phosphate (KH_2PO_4 (p.a.)), in a 25 mL equilibrium solution of calcium chloride (0.01 M $CaCl_2.2H_2O$) and using Langmuir equation. All statistical analyses were completed in SAS Studio (version 9.3; SAS, Institute, Inc, Cary, NC). The GLIMMIX procedure was used for analysis of variance (ANOVA).

RESULTS AND DISCUSSION

After the 10 year period, significant changes in soil P labile pools for treatments compared to the control with interaction between the two factors (treatments and soil depths) were observed due to the long-term effect of P fertilizer placement across locations.

Inorganic Labile P Pool (Pi_{LP})

Overall, the amount Pi_{LP} showed higher amount in the soil surface (0-3 in) for the broadcast treatment compared to the deep band and control treatments across locations, Scandia, Ottawa, and Manhattan (**Fig. 1 D, E and F**). However, the higher amount of Pi_{LP} in the 3-6 in soil layer was observed for deep band treatment compered to broadcast and control treatments. These results suggested that P fertilizer placement for broadcast in the soil surface and deep band for subsoil may contribute to the saturation of adsorption P sites in the soil under reduced tillage with minimal soil disturbance over 10 years. Since the adsorption sites are gradually saturated, the binding energy of P solubilized later is weakly adsorbed and consequently increase P availability (Rheinheimer *et al.*, 2003).

Organic Labile P Pool (Po_{LP})

The P fertilizer placement affected the amount of Po_{LP} just for Scandia with no significant effects for Ottawa and Manhattan sites (**Fig. 1, A, B and C**). The highest proportion of Po_{LP} was observed for control and broadcast treatments at the subsoil (3-6 in). Also, our results showed that treatments with the largest amount of Pi_{LP} showed the smallest amount of Po_{LP}, broadcast in the soil surface and deep band in the subsoil, respectively. The Pi and Po pools act in a similar way in buffering the absorbed P by plants in soils with low or no addition of P fertilizers (Coelho et al., 2019). The Po pool is considered as the main supply of P for plant uptake when no fertilizer is added to the soil (Gatiboni et al., 2007) what may explain these results found in this study.

Total Labile P Pool (Pt_{LP})

In general, the Pt_{LP} showed the same tendency found for Pi with higher amount in the soil surface (0-3 in) for the broadcast and in the 3-6 in soil layer was for deep band treatment (**Fig. 1, G, H and I**) for all locations and could be affected by fertilizer placement as described for Pi_{LP}. In addition, preliminary results of this study suggested that the Pt_{LP} in the soil profile (0-6 in) showed different tendencies across locations (**Fig. 2**) and affected by maximum P adsorption capacity (MPAC). The broadcast treatment showed higher amount of Pt_{LP} (118 ppm) than deep band (112 ppm) and control (84 ppm) treatments at Scandia site with low MPAC (288 ppm). However, at Ottawa location with medium MPAD (348 ppm) the higher amount of Pt_{LP} was observed for deep band (126 ppm) than broadcast (119 ppm) and control (86 ppm) treatments. In addition, at Manhattan site with the higher MPAC (424 ppm) of this study the broadcast and deep band treatments showed the same amount of Pt_{LP} (174 ppm) and higher than the control treatment (84 ppm). The maximum P adsorption capacity of this soils plus the P placement may have affected these results. With lower MPAC the continuum accumulation application of P as broadcasted in a reduced tillage may have contributed to reducing large P sorption reactions and that may have contributed to increasing labile P concentrations near the soil surface (Coelho et al., 2019) plus the presence of low molecular weight compounds present in organic matter near the surface from the crop residues might block P adsorption sites increasing the P availability (Guppy et al., 2005). In addition, the soil with medium amount of P fixing components when P fertilizer is deep banding in the plant row with lower soil volume and minimum disturbance of the soil promoted by reduced tillage, can contribute to reduce the high P sorption reactions, and that may have contributed to increasing the labile P levels. However, in the soil with higher P sorption reactions the effect of P fertilizer placement as broadcast and deep band on TotP are the same in soil profile after 10 years of crop rotations or maybe the 10 years of P application were not enough to saturate the adsorptions P sites of the soil.

Still, broadcast and deep band placements had similar effects over many years and can promote increase and depletion of inorganic and total labile P pools from some soil layers at different locations. Long-term crop production might benefit from combined P placements strategy.

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Table 1. Initial soil parameters for three experimental sites at three Kansas Mollisol soils.

Site	pH	TON[a]	TOC[b]	K	Ca	Mg	Na	CEC[c]	Clay	Silt	Sand	MPAC[d]
		- - - g kg^{-1} - - -		- - - - - - - ppm - - - - - - -				$cmol_c\ kg^{-1}$	- - - - g kg^{-1} - - - -			ppm
					0-3 in							0-6 in
Scandia	6.5	1.8	20	586	2159	371	31	17	210	590	200	288
Ottawa	5.5	1.8	20	311	2003	347	12	24	320	500	180	348
Manhattan	5.7	2.1	23	131	2124	377	15	22	260	600	140	424
					3-6 in							
Scandia	6.5	1.6	14	452	2443	426	45	21	290	550	160	
Ottawa	5.5	1.2	13	192	2309	407	14	26	360	480	160	
Manhattan	5.2	1.9	18	109	2275	344	27	27	320	580	100	

[a] TON, total organic nitrogen; [b] TOC, total organic carbon; [c] CEC, cation exchange capacity; [d] MPAC, maximum phosphorus adsorption capacity

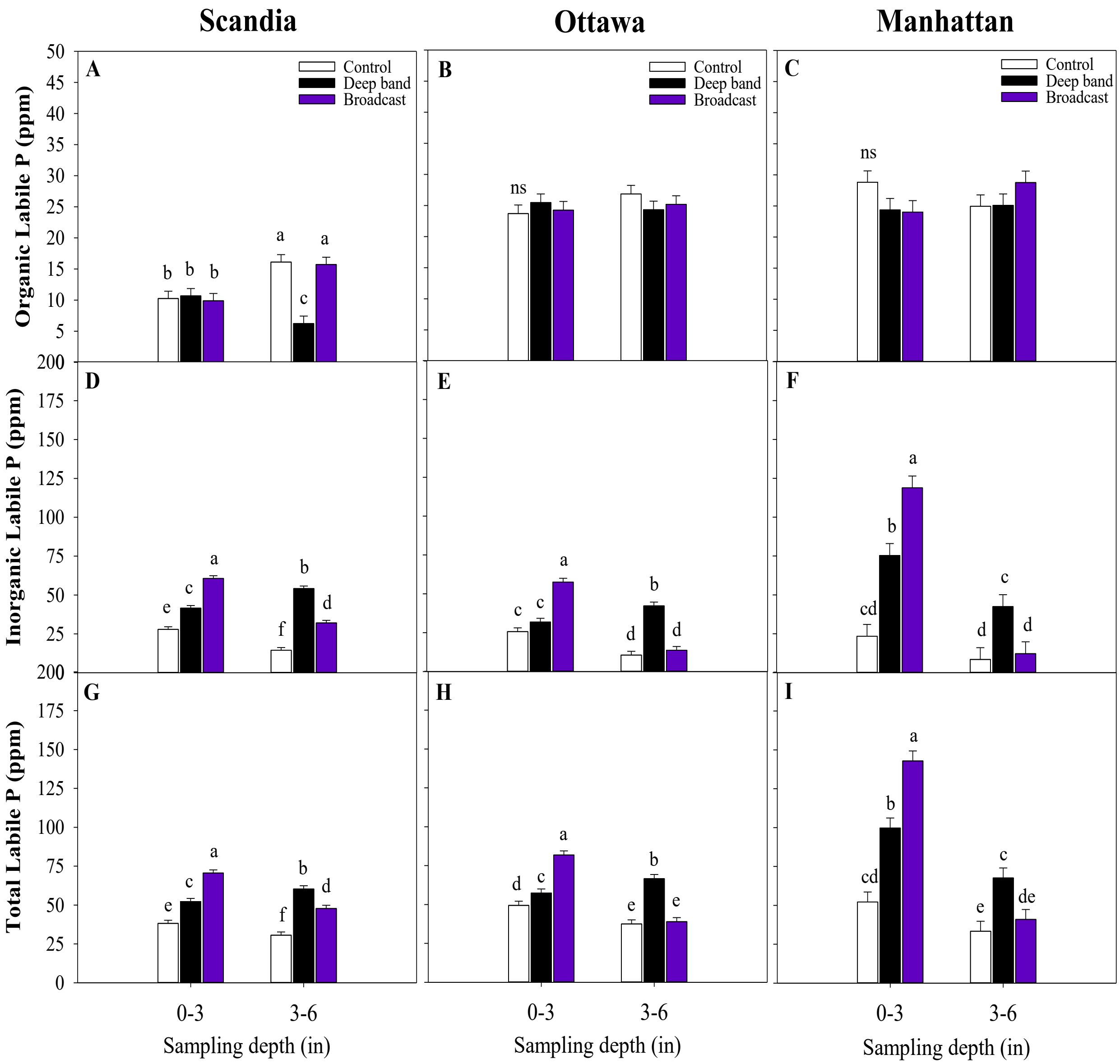

Figure 1. Labile P pool: organic - Po_{LP} (A, B, C), inorganic - Pi_{LP} (D, E, F) and total - Pt_{LP} (G, H, I) for two soil sampling depths for three locations Scandia, Ottawa and Manhattan, respectively, as affected by P fertilizer treatments (deep-band, broadcast, and control) after 10 years of a corn-soybean rotation for Scandia and Ottawa and, corn-soybean-wheat rotation for Manhattan . Error bars indicate the standard error of the mean and mean values followed by the same letter are not statistically different ($p > 0.05$). ns = not significant

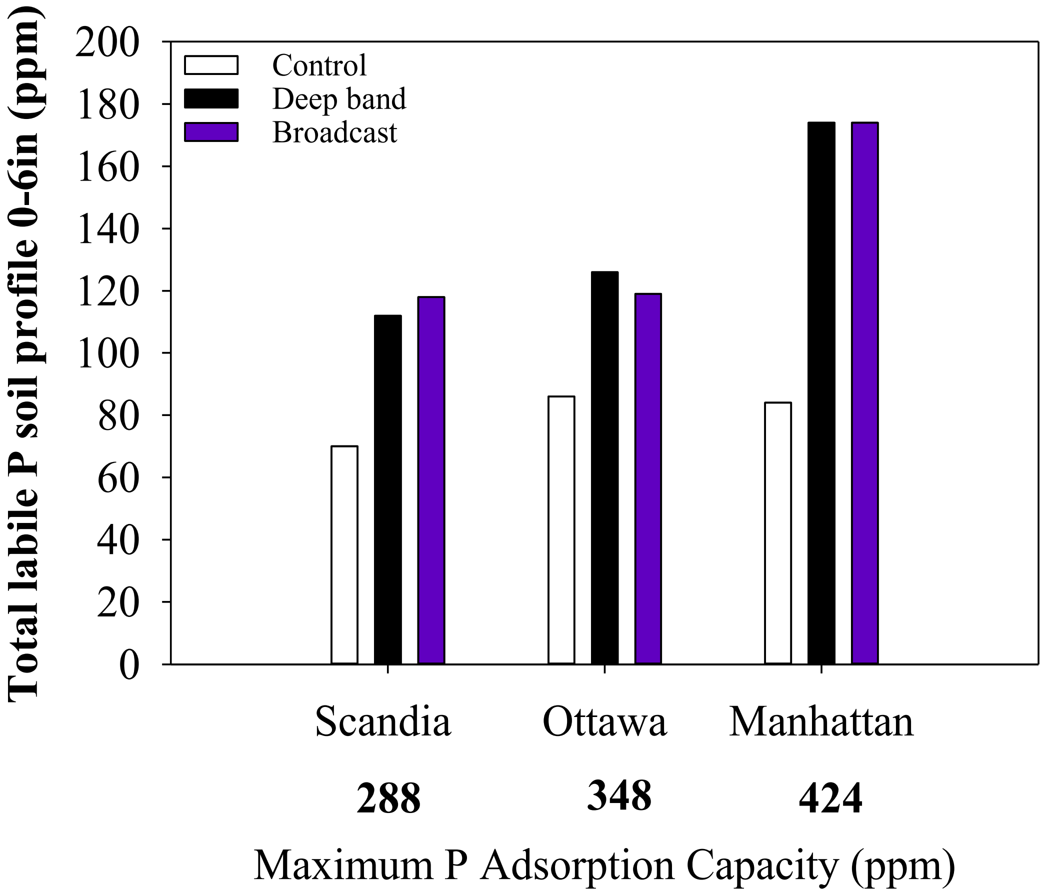

Figure 2. Total labile P in the soil profile (0-6 inches) as affected by P fertilizer treatments (deep-band, broadcast, and control) after 10 years of crop rotation and Maximum P adsorption capacity for three locations Scandia, Ottawa, and Manhattan.

P-12

CHANGES IN SOIL QUALITY DURING THE TRANSTITION FROM IRRIGATED TO DRYLAND CROPPING SYSTEMS

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ABSTRACT

The availability of irrigation water enhances crop productivity and, in turn, increases crop residue inputs and soil quality. With increased pressure on declining groundwater resources, some formerly irrigated lands are being transitioned to dryland management. However, little is known about the shifts in soil quality after conversion from irrigated to dryland cropping systems. The objective of this work was to quantify the effect of irrigation retirement on the early changes in soil quality. In a formerly irrigated field, we installed a 3-year transition experiment with four treatments: irrigated corn, dryland corn, irrigated wheat, and dryland wheat. We quantified crop biomass production and soil properties known to indicate early changes in soil quality: chloroform-extractable microbial carbon (C), phospholipid fatty acids (PLFA) and enzyme activity. Corn production was highly affected by irrigation, with 2- to 6-fold reductions in production on dryland relative to irrigated; irrigation effect on wheat was lower but still significant, and affected grain yield more than biomass production. Treatment effects on chloroform-extractable C varied with sampling time, where irrigated corn generally had higher values than dryland corn. The PLFA analysis at the end of the experiment showed no treatment effects on fungal biomass and weak effects on bacterial biomass ($p = 0.14$), with dryland corn showing the lowest values. Total enzyme activity varied by treatment, with the soil under dryland corn having lower values than all other treatments ($p < 0.05$) and no significant differences between irrigated and dryland wheat. Wheat production, relative to corn, seems to be a viable option to minimize the negative impacts of irrigation retirement on both crop yields and soil quality.

INTRODUCTION

The Ogallala Aquifer is one of the most important aquifers in the world and has a great influence on crop production and social development in the High Plains of the United States. However, due to its intense use, Ogallala´s water reserves are declining at a rate that exceeds sustainable groundwater availability (Richey et al., 2015). To extend the life of the Aquifer and to meet water compacts with neighboring states, water pumping rates for agriculture must decrease (Whittemore et al., 2016) and an increase in irrigation retirement is expected in some regions of the Ogallala. However, little is known about the evolution of soil quality during this transition.

Soil quality can be defined as "the capacity of soil to function" (Karlen et al., 1997), which is similar in definition and proposed indicators to the more recent term soil health (e.g., Doran and Zeiss, 2000). Soil organic carbon (SOC) is accepted as one of the main indicators of soil quality, but it changes slowly and changes in response to management may not be measurable for years. Long-term increases in SOC by irrigation are usually in the range of 11% to 35% for semiarid regions like the Great Plains (Denef et al., 2008; Trost et al., 2013). In general, the effect of irrigation on SOC is much lower than the effect on biomass production, suggesting that irrigation also stimulates SOC turnover (Denef et al., 2008). A faster cycling of SOC occurs because irrigation not only increases biomass production but also soil moisture, which stimulates microbial activity (Trost et al., 2013). Because microbial activity has a great influence on SOC content and its changes are usually faster, measurement of soil microbial properties may help to understand early changes in soil quality (Cano et al., 2018).

The objective of this work was to quantify the effect of irrigation retirement on the early changes in soil quality. We focused on indicators of microbial biomass community size (chloroform-extractable C), structure (phospholipid fatty acids) and activity (enzyme activity) that have been proposed and tested in agricultural systems of the High Plains (Cano et al., 2018).

MATERIALS AND METHODS

To quantify the changes in soil quality during irrigation retirement, an experiment was started in May 2017 at the Agricultural Research, Development and Education Center (ARDEC) of Colorado State University near Fort Collins in a field that was previously managed under full irrigation. The soil is characterized as a Fort Collins loam (Aridic Haplustalfs) (USDA NRCS, 2019), with an annual precipitation of 16.05 inches and annual snowfall of 57 inches (1981-2010 normals average, https://usclimatedata.com/).

A transition experiment was installed with four treatments: (T1) irrigated corn, (T2) dryland corn, (T3) irrigated wheat, (T4) dryland wheat. Thus, the treatments represent the transition from irrigated to dryland and the still irrigated controls under each continuous crop. Prior to the start of the experiment, in March 2017, the site was tilled to homogenize the surface and to incorporate previous crop residue into the soil. During our experiment all the treatments were kept under no till, so the studied changes include both the effect of irrigation retirement and no till. The experiment was finished in November 2019 after three corn crops and two wheat crops.

Corn was planted around mid-May and wheat between late September and early October. For corn, the Producers Hybrids 5218 SSTX was planted at a seed rate of 34,000 and 17,000 seeds/acre for irrigated and dryland respectively. Avery wheat was planted at a seed rate of 90-100 and 50-60 lbs/acre for irrigated and dryland, respectively. Fertilization rates were defined based on soil nutrient concentration, and monoammonium phosphate (11-52-0) and urea (46-0-0) were broadcasted in the initial stages of crop development. Pre- and post-emergence herbicide applications were used for weed control. For the irrigated treatments irrigation was done once per week from May to October. Harvest was done in July for wheat and in November for corn. Total aboveground biomass production and grain yield per plot was estimated at physiological maturity by sampling a total area of 98 and 49 sq. ft for corn and wheat plots, respectively. Grain yield was also determined via mechanical harvesting and the results showed the same trends so only the hand sampling results are presented here.

Soil samples were taken twice a year, at Spring and Fall, to a depth of 4 inches and kept refrigerated between one and two weeks until analyses. A 10-g subsample was dried at 105°C for 48 h to estimate gravimetric water content. Chloroform-extractable carbon was determined by shaking 20-g duplicates of each sample in 100 ml of 0.5 M K_2SO_4 with or without 1 ml of chloroform, centrifuged 10 min and filtered through a 0.45 μm filter (Fierer, 2003). The extracts were analyzed for total organic C and N in a TOC-V-TN analyzer (Shimadzu Corp., Kyoto, Japan). We quantified chloroform-extractable C as the difference between the chloroform-treated and the untreated subsamples and interpreted these values as a proxy for microbial biomass carbon. In the final sampling (Fall 2019) we also quantified phospholipid fatty acid (PLFA) content and extracellular enzyme activity. A subsample of fresh soil was sieved to 2 mm, cleaned from roots, freeze-dried and sent to Ward Labs (Kearney, NE) for the PLFA extraction. We used the PLFA 18:2ω6 as a fungi biomarker and the following PLFAs as bacterial biomarkers: i14:0, i15:0, a15:0, 15:0, i16:0, 16:1ω7c, i17:0, a17:0, 17:0, 17:1 ω8c, 18:1ω7c, 18:1ω5c, 10Me17:0, and 10Me18:0 (Zelles, 1999; Frostegård et al., 1993). Six soil enzymes were assayed following the protocol of Saiya-Cork et al. (2002). Soil slurries were made by homogenizing 1 g of 8-mm sieved, fresh soil in approximately 120 mL of pH 8.1 tris buffer. Then, 200 µL of each slurry was pipetted into a 96 well plate and mixed with 50 µL of substrate. Samples were incubated at 25 °C for 4 h, and the developed fluorescence read in a microplate reader. Enzyme activities were summed based on the nutrient cycle they are mainly involved. Carbon cycling enzymes include β-D-cellubiosidase, and β-Glucosidase. Nitrogen cycling enzymes include Leucine aminopeptidase, Tyrosine aminopeptidase and B-1,4-N-acetyl-glucosaminidase. The only phosphorous cycling enzyme assayed was acid phosphatase.

We conducted analyses of variance to test the treatment effect over each measured variable considering the complete randomized block design of the experiment (n = 4). For the variables measured at several time points during the experiment we used a linear mixed model to consider the covariance structure between measurements taken from the same plot.

RESULTS AND DISCUSSION

As expected, irrigation retirement affected biomass production and soil moisture evolution, but the changes varied with each crop. Corn was strongly affected by irrigation retirement, with 2 to 6-fold decreases in biomass production and even stronger decreases in grain yield (Table 1) confirming the lack of suitability of this crop for dryland production in this area. Wheat was also affected, but irrigation effect on total biomass production was lower (~20%) and not always significantly different. The effect of irrigation on wheat grain yield was higher than in biomass production, explained by late spring irrigation that coincided with the critical reproductive period of the crop and increased its harvest index.

Table 1. Total aboveground biomass production of each crop and grain yield annually from 2017 to 2019.

	Total Biomass			Grain yield		
	2017	2018	2019	2017	2018	2019
Treatment	lbs DM / ac			lbs DM / ac		
IRRI Corn	16,889±410	17,372±691	14,244±557	10,072±222	10,587±396	7,808±304
DRY Corn	6,965±216	3,598±166	2,383±193	4,309±215	1,427±75	433±41
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
IRRI Wheat		8,836 ±907	10,452±771		2,583±280	3,579±289
DRY Wheat		7,277±777	8,677±449		1,949±221	2,717±280
p-value		0.12	0.04		0.02	0.03

Seasonal soil moisture of the dryland treatments shows the growing season of each crop, where water was used, and the moisture recovery during the fallow periods (Fig. 1). Although at the end of the first growing season (Fall 2017) irrigated and dryland corn had the same soil moisture due to rain events after physiological maturity, in Spring 2018 irrigated corn had more GWC than dryland corn. This was probably an effect of the higher soil cover in the irrigated corn that increased water infiltration and decreased evaporation compared to the dryland; in Spring

2018 soil cover was 77% and 25% in irrigated and dryland corn, respectively. Soil moisture in dryland corn decreased sharply during the growing season and tended to recover during late fall and winter, but never reached the GWC of the irrigated treatment. Irrigation had a lower effect on soil moisture in wheat due to fewer irrigation events, usually concentrated in late spring near the end of crop development. However, summer rains were not enough to completely recover soil moisture between harvest and planting of the next dryland wheat compared to irrigated.

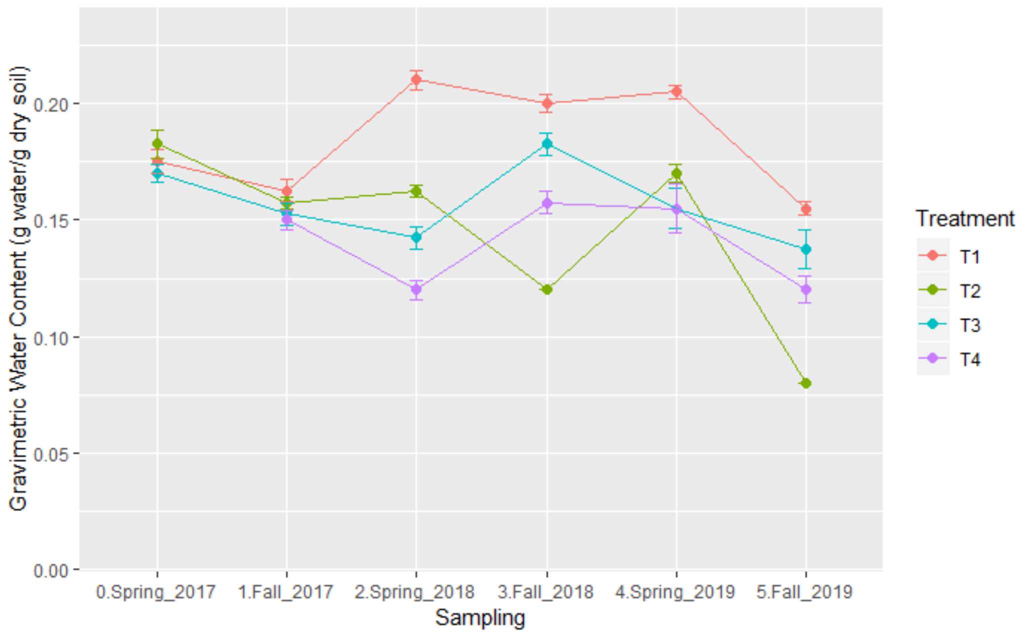

Figure 1. Soil gravimetric water content (0-10 cm) for each treatment at each sampling date. T1.Irrigated Corn; T2.Dryland Corn; T3.Irrigated Wheat; T4.Dryland Wheat

There was a Sampling by Treatment interaction in the evolution of chloroform-extractable C ($p < 0.001$, Fig. 2) indicating that the treatment differences varied with sampling time. The values tended to increase during the first year of the experiment in all the treatments, probably due to the exclusion of tillage (Balota et al., 2003), with a posterior decrease/stabilization. Irrigated corn had the highest values of chloroform-extractable C, while dryland corn usually had the lowest. The recovery in Fall 2019, where biomass production and soil moisture were the lowest for dryland corn, may be a preliminary indication of the soil microbial community adapting to dryland conditions, but more data is needed to conclude about this. This sampling moment corresponds to the analysis of PLFA for the estimation of the microbial community structure (Fig. 3). Total bacteria biomass followed the observed patterns of differences between irrigated and dryland corn with the wheat treatments in the middle and less affected by irrigation, but the treatment differences were not significant ($p = 0.14$). Fungal biomass, indicated by the PLFA biomarker 18:2ω6, was very low and not affected by treatment.

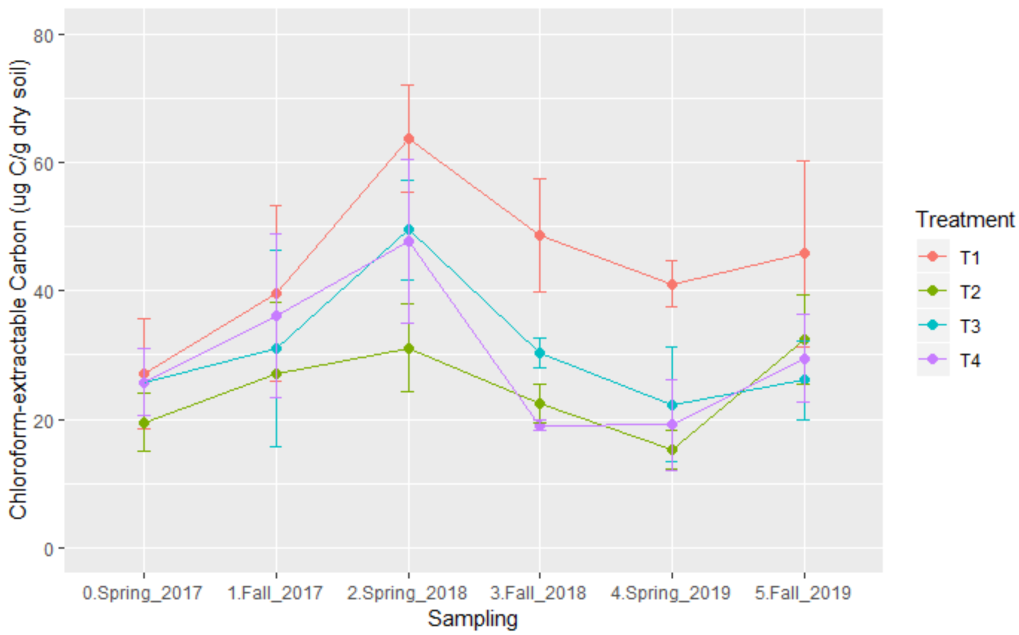

Figure 2. Chloroform-extractable carbon evolution in each sampling for each treatment. Sampling point 0.Spring_2017 corresponds to the baseline before treatment installation.

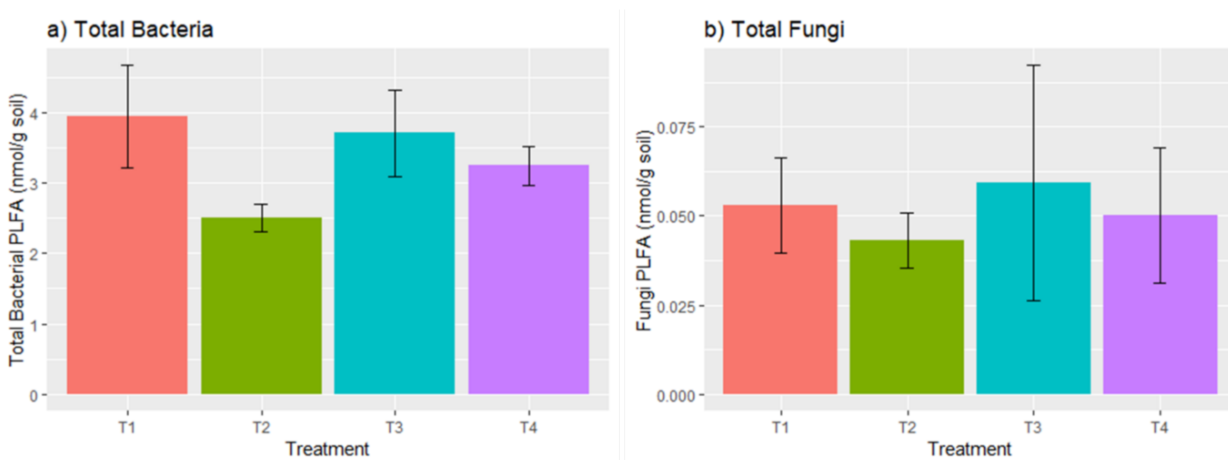

Figure 3. Phospholipid Fatty Acid results for the final sampling of Fall 2019, a) Sum of total bacterial PLFA, and b) Concentration of the fungal PLFA 18:2ω6. T1.Irrigated Corn; T2.Dryland Corn; T3.Irrigated Wheat; T4.Dryland Wheat

There was a significant treatment effect on all the enzyme groups ($p < 0.05$, Fig. 4). Coincident with the tendencies observed in the other variables, dryland corn had the lowest values in overall enzyme activity while wheat treatments were similar to irrigated corn, independent of the irrigation management. Dryland wheat had a lower enzyme activity than irrigated corn only for the phosphorus cycling enzyme. Enzyme activity is often an early indicator of changes in soil health and biogeochemical cycling (Acosta-Martínez et al., 2018), and our results indicate that soils with greater moisture content and more carbon inputs have more biogeochemical cycling activity. Moreover, dryland wheat seems to be a viable option to decrease the negative impacts of irrigation retirement on both crop yield and soil quality.

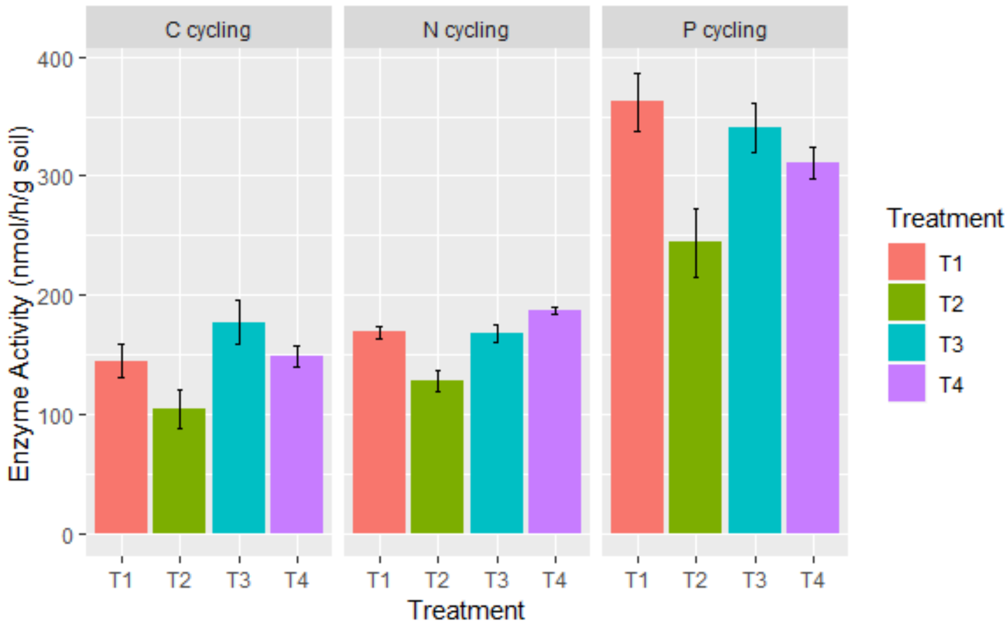

Figure 4. Extracellular enzyme activity for each treatment at the final sampling of Fall 2019. T1.Irrigated Corn; T2.Dryland Corn; T3.Irrigated Wheat; T4.Dryland Wheat

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P-13

OPTIMIZING IRRIGATION AND FERTILIZER MANAGEMENT IN COTTON TO INCREASE NITROGEN USE EFFICIENCY

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ABSTRACT

Nitrogen (N) fertilizer is an important nutrient in cotton production, and if the optimal amount is not applied yield penalty may occur (Hutmacher et al. 2004). A more efficient application of N fertilizer based on plant N requirements, soil texture, and N availability can increase cotton yield and N-use efficiency (NUE). The main objective of this research was to determine the relationship between cotton lint yield and normalized difference vegetation index (NDVI) across multiple irrigation levels, varieties and N fertilizer rates. Urea-ammonium nitrate was applied pre-plant and after emergence by knife-injection at three rates (15, 75 and 135 lb N ac^{-1}) under two irrigation levels (30 and 70% ET), and multiple varieties. Under the low irrigation level in 2018, lint yield of DP 1820 had no statistical response to N application, however, 75-0-0 was greater than all other treatments. Under the low irrigation level in 2019, lint yield of DP 1823 had no statistical response to N application, however, for all other treatments there was a positive response to N application. There was a moderate to poor linear relationship between NDVI and lint yield at different growth stages. The weak relationship may have been due to poor environmental conditions. Further research into NDVI may prove to be beneficial for improved N management.

INTRODUCTION

Nitrogen is required in the largest amount by most plants (Marschner, 2012). Plant available N in soil is limited and can be lost easily depending on environmental conditions (IPNI, n.d.). Pre-plant soil nitrate (NO_3^--N) test levels are often used to determine N fertilizer requirements, however, due to soil N losses within the growing season leaf samples can be used to determine the need for in-season N applications (Sabbe and Zelinski, 1990; Zhang et al., 1998). Normalized difference vegetation index (NDVI) is a tool that can be used to manage water, N, crop development and to predict yield at peak bloom, and may be a non-destructive means to estimate in-season N status of cotton (Li et al., 2001; Bronson et al., 2003; Zhou and Yin 2014). In order to detect N deficiencies within the plant, NDVI is determined via remote sensing equipment by estimating chlorophyll content within the leaves (Thomas and Gausman, 1977; Chappelle et al., 1992; Blackmer et al, 1994). Bronson et al. (2014) reported a strong correlation between NDVI readings and leaf N, plant biomass and yield. However, NDVI readings have also been reported unresponsive to changes in cotton leaf N (Li et al., 2001; Bronson et al., 2003, 2005). The main objective of this research was to determine the relationship between cotton lint yield and NDVI across multiple irrigation levels, varieties, and N fertilizer rates with the overall goal of optimizing cotton production by maximizing NUE.

MATERIALS AND METHODS

A field experiment was conducted in 2018 and 2019 at the Texas A&M AgriLife Research experiment station in Lubbock, TX. There were three main treatment effects, N fertilizer rate, irrigation levels and cotton variety. Treatments were replicated four times. Plots were four rows wide (40 inch spacing) by 50 ft in length in 2018 and four rows wide (40 inch spacing) and 24 ft in length in 2019. The field was arranged in a split-plot design with the whole plot being irrigation level and the subplot treatment was variety. The soil series is an Acuff loam (fine-loamy, mixed, superactive, thermic aridic paleustolls), which is described as a very deep, well drained, moderately permeable soil (USDA, 2017). Cotton varieties DP 1820 B3XF and DP 1823 NR B2XF were planted on 29 May 2018 at 52,775 seed acre^{-1} and 7 June 2019 at 50,000 seed acre^{-1}. The irrigation was applied as sub-surface drip at two levels, a low evapotranspiration (ET) replacement rate of 30% and a high ET rate of 70%. Urea-ammonium nitrate (UAN; 32-0-0) was applied pre-plant, 3 weeks following emergence, and at pinhead square. Different rates included:

1) 15 lb acre^{-1} N applied pre (15-0-0);
2) 15 lb acre^{-1} N pre + 30 lb acre^{-1} N early + 30 lb acre^{-1} N late (75-0-0); and,
3) 15 lb acre^{-1} N pre + 60 lb acre^{-1} N early + 60 lb acre^{-1} N late (135-0-0).

Soil cores were collected and composited by each zone of the drip field, that was divided into eight rows, prior to pre-plant fertilizer application on 5 May 2018 and 8 May 2019 at 0-6 inch, 6-12 inch and 12-24 inch soil depths. Samples were sent to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory. Soil macro and micro- nutrients were extracted using Mehlich 3. The NDVI data was collected using a GeoScoutX data logger and the Crop Circle sensor ACS-211 (Holland Scientific, city, state). There were five sampling dates in 2018, and eleven in 2019. The ACS-211 measures the 670 nanometers (nm) and 780 nm wavelengths and the output is five measurements sec^{-1}. The sensors were mounted to a cart 40 inches above the plant canopy of the tallest plants in the 135-0-0 treatment and high irrigation level and measurements collected from rows two and three. The ACS-211 has a field of view of 40° by 8°.

A Case International Harvester 1400 cotton stripper was used to mechanically harvest the cotton. The harvester was not fitted with a bur extractor, thus bur cotton was collected at harvest. The two center rows were harvested to determine yield at the end of the season on 15 Nov 2018 and 16 Nov 2019. Sample weights were collected in the field. Following harvest samples from each plot were ginned at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX.

For analysis of the NDVI data, ArcGIS 10.5.1 was used. Statistical analysis for all measurements were performed using SAS version 9.4 software (SAS Institute Inc., Cary, North Carolina). Analysis of variance for all parameters were calculated using two irrigation treatments in a split plot design with four replications using PROC GLIMMIX at $\alpha < 0.05$. Means of treatment effects were compared using Fisher's least significant difference (LSD) at $\alpha < 0.05$. Pearson's simple linear regression was used to evaluate the relationship between lint yield and NDVI at $\alpha < 0.05$ using PROC REG. Main effects of N rate, irrigation level, and variety on cotton lint yield were analyzed. The effect of N fertilizer treatment on NDVI and yield were analyzed within irrigation and variety due to significance of these factors.

RESULTS AND DISCUSSION

Soil results in 2018 indicated pH to be alkaline. The nutrients K, Ca, Mg, and S levels were high, while P was low, and Na was very low level according to current Texas A&M AgriLife Extension Soil, Forage and Water testing lab critical values (Table 1). Soil nitrate-N (NO_3^--N) in 2018 ranged from 5 to 9 ppm for 12-24 and 0-6-inch sampling depths, respectively (Table 1). Soil results in 2019 indicated a neutral pH. The nutrient P level was moderate, K was very high, Ca, Mg, and S were high, and Na was very low (Table 2). Soil NO_3^--N ranged from 14 ppm at the shallowest depth to 21 ppm at the deepest sampling depth (Table 2).

Table 1. Characteristics of soil samples collected at three depths (0-6, 6-12 and 12-24 inches) prior to fertilizer application in 2018.

Soil Depth	pH	EC	NO_3-N	P	K	Ca	Mg	S	Na
inch		umhos cm^{-1}				mg kg^{-1}			
0-6	8.0	241	9	23	281	2098	756	14	35
6-12	8.1	183	5	6	228	3010	901	17	51
12-24	8.1	293	5	6	239	6621	864	22	76

Table 2. Characteristics of soil samples collected at three depths (0-6, 6-12 and 12-24 inches) prior to fertilizer application in 2019.

Soil Depth	pH	EC	NO_3-N	P	K	Ca	Mg	S	Na
inch		umhos cm^{-1}				mg kg^{-1}			
0-6	7.6	171	14	59	456	1996	694	21	22
6-12	7.9	134	11	24	299	1948	815	24	40
12-24	7.9	207	21	6	282	4878	861	41	78

Lint yield within variety and irrigation level was significant in 2018 and 2019. Under the high irrigation level in 2018, lint yield of DP 1820 and DP 1823 with the split application treatment (75-0-0) was greater than the pre-plant fertilizer treatment (15-0-0) (Fig. 1A). Under the low irrigation level in 2018, lint yield of DP 1823 with the split application treatment (75-0-0) was greater than the 15-0-0 and 135-0-0 treatments (Fig. 1B). Under the high irrigation level in 2019, lint yield of DP 1820 with the split application treatment (75-0-0) was greater than the 135-0-0 treatment, while lint yield of DP 1823 with the split application treatment (135-0-0) was greater than the pre-plant treatment (15-0-0) (Fig. 2A). Under the low irrigation level in 2019, lint yield of DP 1820 with the split application treatments (75-0-0 and 135-0-0) was greater than the 15-0-0 treatment (Fig. 2B). The lack of yield response to the highest split application treatment (135-0-0) when compared to the 75-0-0 treatment may be due to high levels of N in irrigation water.

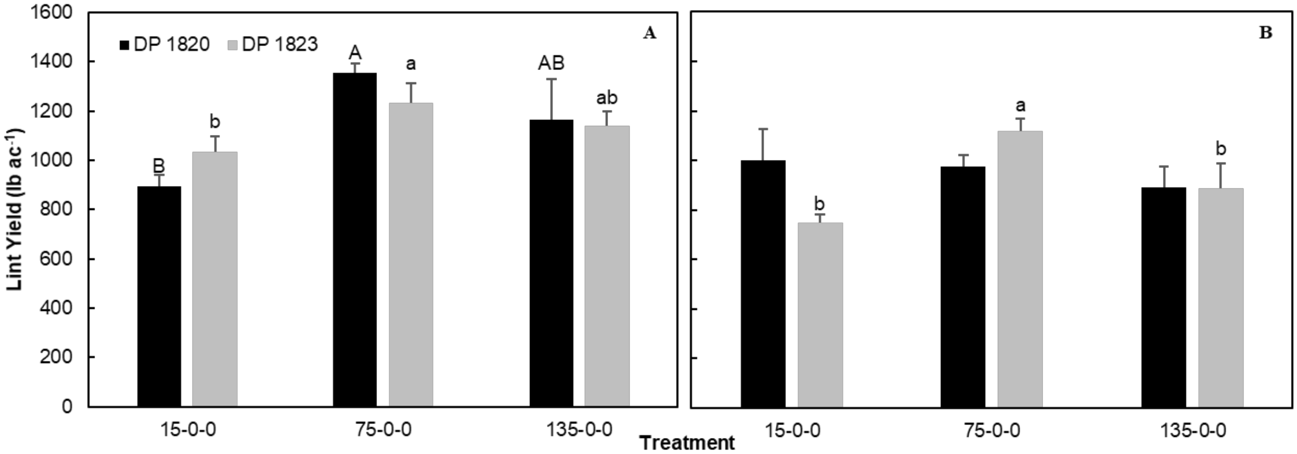

Figure 1. Cotton lint yield in 2018 under the high (70% ET, A) and low (30% ET, B) irrigation levels. The same uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at P<0.05. The vertical bars represent standard error of the mean.

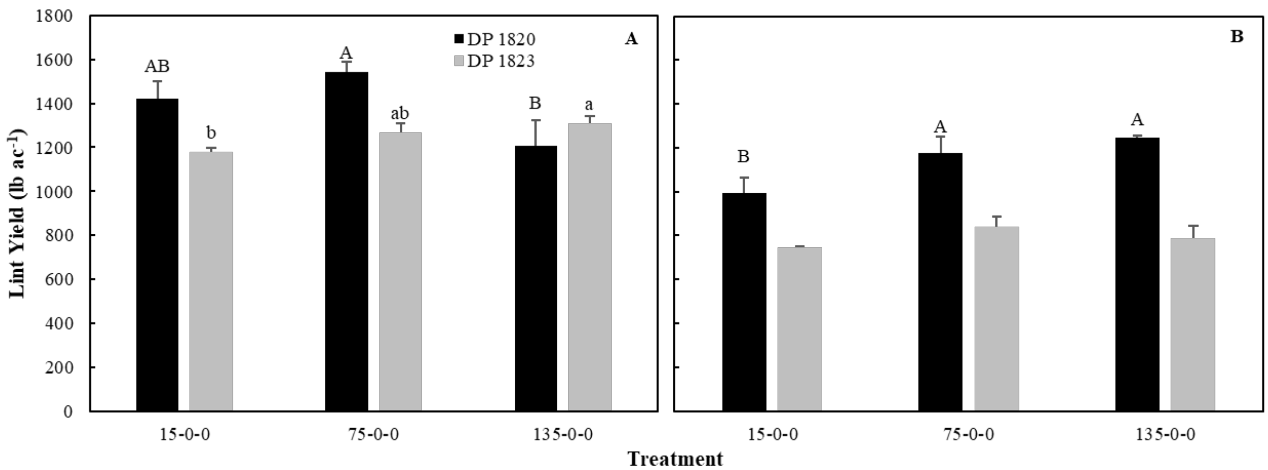

Figure 2. Cotton lint yield in 2019 under the high (70% ET, A) and low (30% ET, B) irrigation levels. The same uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at P<0.05. The vertical bars represent standard error of the mean.

A relatively poor relationship was observed between NDVI and lint yield for both 2018 and 2019. Under the high irrigation level in 2018 NDVI had a stronger relationship with lint yield 51 days after planting (DAP) (R^2=0.791) at squaring/first flower for variety DP 1820, while DP 1823 had a stronger relationship at flowering/boll development stage (91 DAP; R^2=0.486) (Table 3). Under the high irrigation level in 2019 NDVI had a greater relationship with lint yield at the flowering growth stage (56 DAP; R^2=0.616), while DP 1823 had a stronger relationship at squaring (42 DAP; R^2=0.606) (Table 4). Under the low irrigation level in 2018 a greater relationship between NDVI and lint yield was observed at the squaring/first flowering growth stage (51 DAP; R^2=0.292) for DP 1820, while DP 1823 showed a stronger relationship at the open boll stage (126 DAP; R^2=0.380) (Table 3). Under the low irrigation in 2019 NDVI had a stronger relationship with lint yield at the flowering/open boll stage (69 DAP; R^2=0.569) for DP 1820, while DP 1823 had a stronger relationship at squaring (42 DAP; R^2=0.281) (Table 4). The lack of a strong relationship between NDVI and lint yield may be due to the limited range in lint yield across N treatments. Hail damage to the test plots in 2019 is also acknowledged here as a possible confounding effect. Moderate to poor correlation between NDVI and cotton yield have also been reported by Bronson et al. (2005) and Raper et al. (2013).

Table 3. Regression R^2 and p-values for normalized difference vegetation index (NDVI) vs lint yield in 2018.

		DP 1820		DP 1823	
DAP	Irrigation	R^2	p-value	R^2	p-value
51	High	0.791	0.000	0.200	0.145
	Low	0.292	0.070	0.289	0.071
65	High	0.007	0.798	0.177	0.174
	Low	0.260	0.091	0.306	0.062
77	High	0.464	0.015	0.179	0.171
	Low	0.006	0.813	0.009	0.769
91	High	0.006	0.818	0.486	0.012
	Low	0.019	0.669	0.297	0.067
126	High	0.231	0.114	0.178	0.172
	Low	0.030	0.589	0.380	0.033

† DAP, Days after Planting

Table 4. Regression R^2 and p-values for normalized difference vegetation index (NDVI) vs lint yield in 2019.

		DP 1820		DP 1823	
DAP	Irrigation	R^2	p-value	R^2	p-value
26	High	0.431	0.020	0.531	0.007
	Low	0.027	0.611	0.003	0.870
39	High	0.421	0.022	0.031	0.585
	Low	0.007	0.793	0.126	0.257
42	High	0.425	0.022	0.606	0.003
	Low	0.323	0.054	0.281	0.076
49	High	0.028	0.602	0.042	0.522
	Low	0.107	0.299	0.072	0.401
56	High	0.616	0.003	0.134	0.242
	Low	0.163	0.194	0.163	0.193
63	High	0.546	0.006	0.461	0.015
	Low	0.048	0.492	0.193	0.153
69	High	0.393	0.029	0.027	0.610
	Low	0.569	0.005	0.189	0.158
80	High	0.265	0.087	0.004	0.840
	Low	0.056	0.461	0.177	0.173
88	High	0.192	0.154	0.287	0.073
	Low	0.000	0.957	0.181	0.168
101	High	0.004	0.845	0.380	0.033
	Low	0.113	0.285	0.255	0.094
126	High	0.000	0.986	0.001	0.934
	Low	0.003	0.857	0.143	0.225

†DAP, Days After Planting

Future research includes expanding this dataset to examine plant N, boll counts, plant height, soil moisture, and canopy temperature in order to determine if there is a positive interaction between cotton lint yield and NDVI. The study will also include determining if there is a better relationship between red edge and lint yield compared to NDVI.

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P-14

ENHANCED EFFICIENCEY PHOSPHORUS FERTILIZERS

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ABSTRACT

Phosphorus (P) is essential for plants. However, first-year phosphorus fertilizer uptake by plants is low, resulting in economic and environmental impacts. Developments with P Enhanced Efficiency Fertilizer (EEF) sources show improved uptake efficiency and increased yield and/or crop quality, while reducing environmental risk. Research with EEFs (including organic acids, maleic itaconic copolymer, and struvite) all show these improvements, especially when: 1) soil test P concentrations are low, 2) rates are reduced (typically ~50%), and 3) applied to soil with extreme acidity or alkalinity/calcareous. On average, there is a 5% increase in yield/quality over the studies summarized herein. In all cases, if the cost of these materials is too high it may negate any economic advantage with increased yield/quality. Struvite has an added societal advantage in that it is created from recycled materials from wastewater streams, reducing resource consumption. The use of P EEF has potential if used properly and cost is not excessive.

INTRODUCTION

Phosphorus (P) is an essential plant nutrient, second only to nitrogen (N) as a fertilizer and a key to global food security (Hopkins, 2015, 2020; Hopkins and Hansen, 2019). The effective use of P fertilizer has been elucidated in a wide body of research for the “4 R’s” of fertilizer stewardship to apply the Right source at the Right rate at the Right placement and Right timing. These efforts steadily improved yields and uptake efficiency (Bruulsema et al., 2012; Hopkins and Hansen, 2019). However, P fertilizer impacts the environment through resource consumption and pollution (Bruulsema et al., 2012; Hopkins, 2015, 2020; Sharpley et al., 2018).

Some claim the supply of raw phosphate ore will be exhausted in a few decades, although more informed sources estimate several centuries as new mines are located and technology for recovery improves (Hopkins, 2015). Either way, future generations may run out of easily accessible reserves of raw fertilizer materials making conservation a worthy effort.

Environmental impacts are a more immediate concern. The main fertilizer pollutants are N and P (Hopkins, 2015; Sharpley et al., 2018). Unlike N, P is not very mobile in soil and accumulates at the soil surface. As soil erodes and/or surface water flows over P-enriched soil, accumulation of this nutrient in surface waters often occurs. This causes eutrophication and hypoxia as it enriches the nutritional supply for algae, increasing its rate of growth (Sharpley et al., 2018). Enhanced Efficiency Fertilizers (EEF) result in a greater percentage of applied P to be taken up by plants with positive impacts on yields while reducing environmental impacts.

NEED FOR ENHANCED EFFICIENCY PHOSPHORUS FERTLIZER

The most commonly used P fertilizers in the USA are ammoniated phosphates (Hopkins, 2020). The most common dry versions are monoammonium phosphate (MAP) and diammonium phosphate (DAP), which are most commonly broadcast applied to soil. The most common liquid form is ammonium polyphosphate (APP), which is typically used in concentrated fertilizer bands and/or injection into irrigation water.

Most of the P in liquid P fertilizers precipitates as iron/aluminum phosphates in acid soils and calcium/magnesium phosphates in alkaline soils. The dry P fertilizers suffer the same fate after they quickly dissolve after being added to soil. As plants take up dissolved P from the soil solution, the solid-phase P re-dissolves to bring the solution back up to equilibrium. The rate mostly depends on pH and the minerals present. However, in many cases, this process is too slow to match plant requirements at peak demand. There is a wide body of research instructing how to best apply these P fertilizers in terms of correct rates, placement, and timing; relative to the unique root architecture and morphology of various species (Hopkins and Hansen, 2019).

However, first year recovery of applied P remains low. Uptake in the first year for a broadcast placement is 5-10%, although 90% of the P is taken up after a decade (Syers et al., 2008). First year uptake efficiency can increase to about 25-35% when placed in a concentrated band, but use of an EEF could increase efficiency by up to ~50% (Hopkins and Hansen, 2019). Thus, there is significant interest to develop EEF for P (Hopkins et al., 2008, Hopkins, 2020). Our research group evaluated three categories of EEF P fertilizers, namely: organic acids, polymers, and struvite.

ORGANIC ACIDS

One development in EEFs is blending P with various organic acids (humic, fulvic, etc.; Tan, 2003; Hill et al. 2015a and b; Hopkins, 2015; Hopkins and Hansen, 2019; Hopkins et al., 2014; Olk et al., 2018; Summerhays et al., 2017). Soils in arid and semi-arid regions have relatively low P solubility due to alkaline pH and calcareousness. This is especially problematic for crops with high demand for P, like potato (Hopkins et al., 2020). Research done using organic acids blended with ammoniated P fertilizers on a variety of crops shows consistent increases in P uptake, as well as associated increases in yield and crop quality when grown on calcareous soils (Fig. 1).

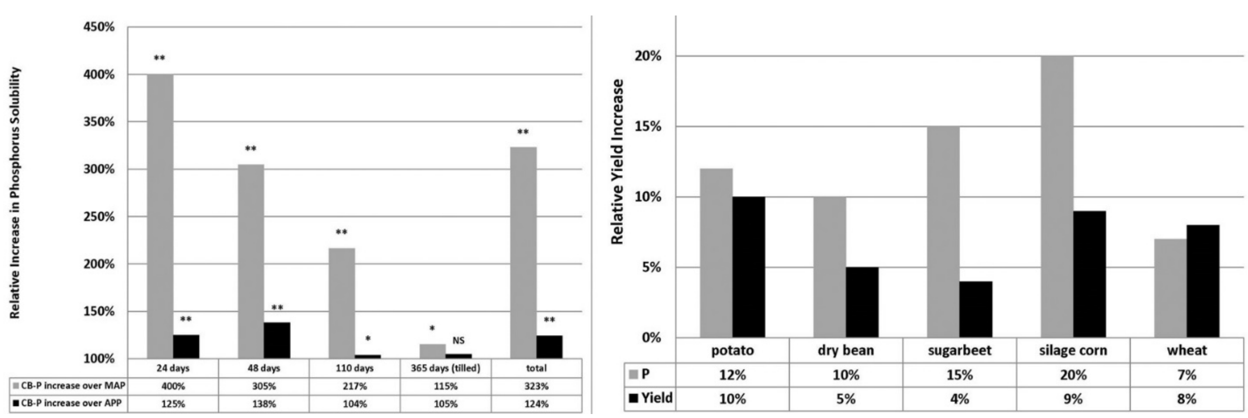

Fig. 1. An organic acid based Enhanced Efficiency Fertilizer, Carbond P (CB-P), has increased solubility relative to monoammonium phosphate (MAP) and ammonium polyphosphate (APP) [graph on left; * = significance at P = 0.05 and ** = 0.01 with NS = not significant], resulting in increased P uptake and yields in several species [graph on right; all bars are highly significant].

However, research in non-calcareous soils with higher amounts of soil organic matter often shows fewer promising results. Soil organic matter contains high concentrations of organic acids, and it has been hypothesized that organic acids blended with P fertilizer are more likely to be effective when organic matter levels are low (Tan, 2003; Summerhays et al., 2015; Olk et al., 2018). Yet positive responses have also been reported in high organic matter soils (Summerhays et al., 2015), with researchers suggesting some type of bio stimulation mechanism rather than a P response (Olk et al., 2018).

POLYMERS

Various polymer coatings have been developed to delay the release of fertilizer into the soil. Although these polymer coatings are more widely studied and used for N fertilizers (Hopkins et al., 2008), they have been evaluated for use with P fertilizers (Sharma, 1979; Nyborg et al., 1995; Yaseen et al., 2017). These coatings avoid the flush of a high concentration of P into the soil solution followed by rapid precipitation. Instead, P is released slowly—replenishing the soil solution P depleted by plant uptake.

Another use of polymers is a maleic itaconic copolymer (AVAIL) sprayed on the surface of dry phosphate fertilizers or blended with liquid phosphates (Stark and Hopkins, 2015; Hopkins et al., 2018). This is not a coating that physically protects the fertilizer, such as with polymer coated urea or blends with P. Rather, it impacts fertilizer chemistry. The mode-of-action is not agreed upon, but studies show it can be effective in soils with low levels of P, achieving yield increases of 5% when compared to traditional fertilizers (Fig. 2; Hopkins et al., 2018).

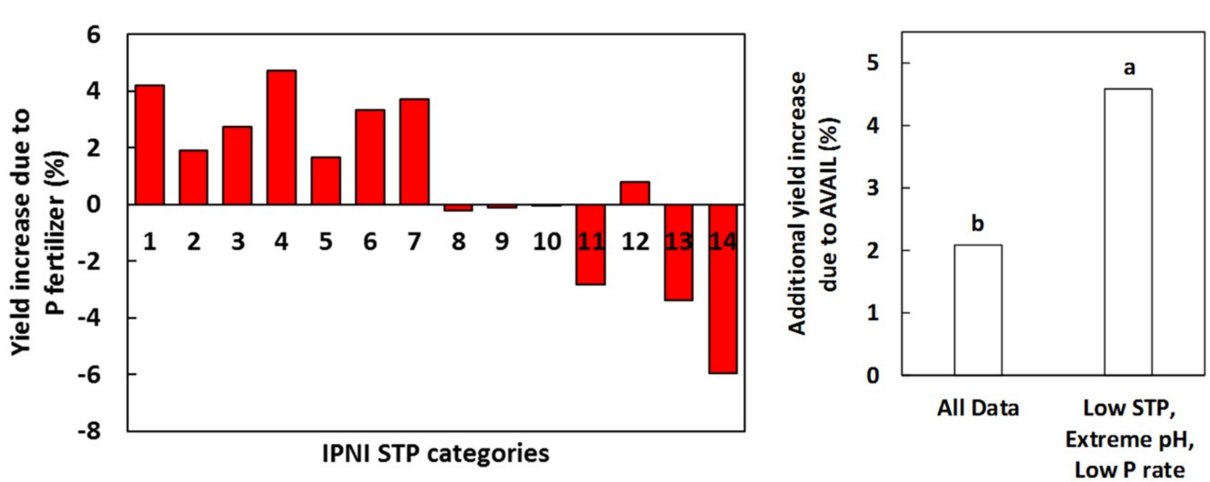

Fig. 2. Yield increase across 503 field sites for P treated with a maleic itaconic copolymer relative to untreated fertilizer for soil test categories ranging from extremely low (1) to extremely high (14) [graph on left] and combined for all data and parsed for just sites with a high probability of response with low soil test P (STP), extreme pH, and with low P rates [graph on right; bars with different letters indicate significant difference].

STRUVITE

Struvite is another example of a P EEF (Hopkins, 2015; Hopkins and Hansen, 2019; Rech et al., 2019). Struvite is a precipitated P material derived from sewage treatment waste streams.

Struvite is not water soluble, with its possible mode-of-action being that it stays protected until roots grow in proximity to the fertilizer. Crop roots exude various organic acids, possibly dissolving struvite and enhancing uptake. Struvite's acid solubility makes it more effective when applied as a concentrated band rather than broadcast. Trials show positive responses in various cropping systems. A recent study on struvite (Crystal Green) in sugar beet found it increased both sugar production and total yield when compared to MAP fertilizer (Fisher et al., 2019). Results have been largely positive in potato as well (Fig. 3). Struvite is appealing because it recycles waste P, reducing the amount of mined P needed for crop production. Struvite is also a slow-release fertilizer reducing leaching. This makes it a more environmentally friendly option (Fisher et al., 2019).

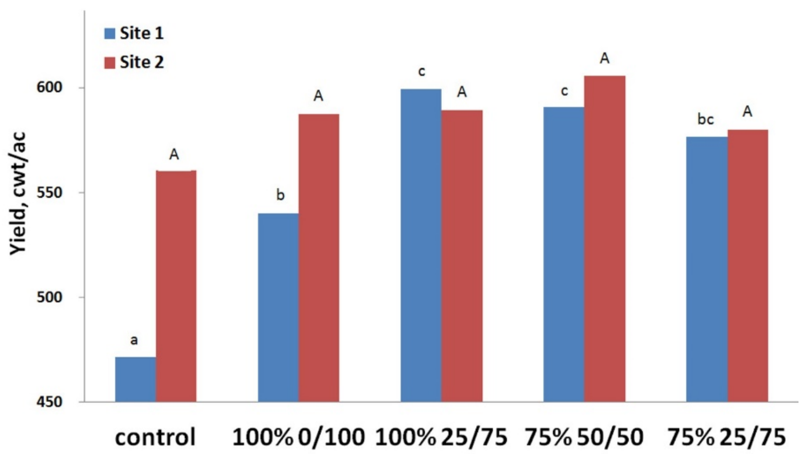

Fig. 3. Potato yield results for two sites with three P rates [0 (control), 75, and 100% of full recommended rate] applied with various blends of struvite/monoammonium phosphate (MAP) [eg. 100% 0/100 = 100% P rate with 0% struvite and 100% MAP]. Bars of each type sharing at least one of the same letter over the top of the bar are not statistically different from one another.

CONCLUSION

Using EEF P fertilizers could solve economic and environmental problems relating to P fertilizer. Three examples of P EEF show positive increases in yield (average of 5% across all types and sites). Studies have had promising results, showing increased yield and P uptake efficiency when applied correctly. These products can be effective if costs are not exorbitant.

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IMPACT OF FERTILIZER MANAGEMENT ON THE STRATIFICATION OF SOIL CHARACTERISTICS IN NO-TILL

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ABSTRACT

The increasing cost of fuel and machinery makes no-till management (NT) a good alternative for producers. With the demanding increase of production, fertilizer utilization efficiency and cycling must be evaluated to address such demand. However, the superficial input of soil amendments under NT may lead to the soil stratification of pH and nutrients and in the first six inches. Three dry-land NT long-term trials located in Perkins, OK (NT since 2005), Stillwater, OK (NT since 2010) and Lahoma, OK (NT since 2010) were sampled after the wheat (Triticum aestivum L.) harvest on 2018/19 growing season at stratified sampling layers of 0-1, 1-2, 2-3, 3-4, 4-5, 5-6 inches. Treatments included a non-fertilized check, half rate, and the full fertility management rate for each location. Nutrients availability (nitrogen (N), phosphorus (P), potassium (K), and organic carbon (OC)) and pH were analyzed at the stratified layers. The results suggest that soil attributes are stratified for all parameters tested in the study. Soil pH, N, and OC were mostly related to N applications, while N is also the most yield-limiting nutrient tested in all trials. The long-term addition of P and K fertilizers on the topsoil increases stratification and nutrients availability when compared to the non-applied plot. Non-fertilized plots were likewise stratified for the tested parameters, which indicates an isolated effect of the NT on the stratification rather than fertilizer addition. Organic carbon and N were highly stratified in the first 2 in and little or no impact was noticed in the subsurface.

INTRODUCTION

No-till management (NT) has increased in agricultural systems over the years. In 1999, areas under NT were 111 million acres around the world while more recently, in 2009, there was an estimation of around 274 million ac. This system can be part of the solution of the increasing demand for food production and fertilizer efficiency. There are many advantages when comparing with a system under conventional tillage practices, including savings on labor, time, and fuel thus being a more profitable economic activity (Derpsch et al., 2010). Moreover, the carbon sequestration is another advantage of the NT and partially solves the anthropogenic carbon dioxide (CO2) emissions responsible for the greenhouse effect and climate change (Lal et al., 1998). However, the superficial nutrient application along with the no soil disturbance under NT may lead to the OC, nutrients and pH stratification in the soil (Crozier et al., 1999; Lupwayi et al., 2006). Although this effect was noticed in previous works, there is still a lack of study considering the depth as an important on the carbon sequestration. No-tillage can avoid and/or reduce erosion, and increase soil OC but, in many cases, some practices could be no cost-effective since reduced tillage increases little or no C in the soils (Manley et al., 2005).

The objective of this study was to evaluate the long-term superficial fertilization effects on nutrient stratification and other soil chemical attributes in three different areas under NT across Oklahoma.

MATERIALS AND METHODS

For this study, soil was sampled after wheat (Triticum aestivum L.) was harvested on 2018/19 growing season from 3 long-term NT trials located in Perkins, OK - Established in 1996 and 2004 become NT; Lahoma, OK - Established in 1970 and 2010 become NT, and Stillwater, OK – Established in 1969 and 2010 become NT. In all locations, treatments were arranged in a randomized complete block design (RCBD) with three replications (n=3) and fertilizer was broadcasted at the pre-plant every year. The size of the plot units was 10 by 20 ft with 10 ft alleys between the replications. Soil sampling was performed utilizing a tubular probe and 25 cores (0 to 6 in depth) were taken from each plot unit. Stratified layers of 0-1, 1-2, 2-3, 3-4, 4-5, 5-6 in were separated by hand utilizing a ruler/knife and prepared for analyses as described by Zhang et al. (2013). The pH was determined using 1:1 soil to deionized water ratio. For bioavailable phosphorus (P) and potassium (K), Mehlich 3 (M3) was used as extractant and their determination was by inductively coupled plasma spectroscopy (ICP). Soil OC and total nitrogen (TN) were determined using a dry combustion carbon/nitrogen analyzer (Zhang et al. 2018). Trials have several treatments although, for the purpose of this study, only two were selected as representative to evaluate the long-term effect on soil attributes (Table 1). Treatments selected for this study was based on their influence on each of the parameters evaluated.

Table 1 - Treatments analyzed for each parameter in all three locations

Location	……………Parameter……………				
	pH	P	K	OC	TN
Lahoma	0-40-60	60-0-60	0-40-60	0-40-60	0-40-60
	60-40-60	60-40-60	60-40-60	60-40-60	60-40-60
Stillwater	0-60-40	80-0-40	0-60-40	0-60-40	0-60-40
	80-60-40	80-60-40	80-60-40	80-60-40	80-60-40
Perkins	50-124-00	100-0-0	0-0-0	100-0-0	100-0-0
	100-124-0	100-124-0	100-0-0	100-124-0	100-124-0

Treatments describe as lb ac^{-1} of applied nitrogen (urea), P_2O_5 (triple super phosphate), and K_2O (potash), respectively.

Statistical analyses were performed utilizing JMP 13 PRO® (SAS institute) for each depth and at location for all of the determined parameters. Data was differentiated using ANOVA methods and least square difference to separate the means (Tukey test, α = 0.05).

RESULTS AND DISCUSSION

pH

pH ranged from 5 to 7, 4.5 to 6.5 and 4.6 to 7.3 in Lahoma, Stillwater, and Perkins, respectively. Results suggest that pH is stratified in all locations (Figure 1). When comparing the treatments by location, it is noticeable that the N fertilization is causing the acidification in the topsoil, and is aggravating the stratification when comparing treatments that received less or no N fertilizer.

The effect on the pH stratification is also clear when no N fertilizer was applied. This indicates an effect of the NT in the stratification. Crop residue accumulation on the surface and its decomposition also appear to influence the pH stratification. Regarding crop yields (data not shown), N fertilization has been proved as the most limiting nutrient in all areas since this nutrient has increased yield more than when other nutrients were added. The increase in biomass and residues accumulation/decomposition due to N fertilization could also cause a higher stratification of soil pH

Phosphorus

Our results show that the distribution patterns of P are highly stratified in NT areas (Figure 1). In Lahoma, Stillwater and Perkins a treatment mean difference of 110, 165 and 121 ppm of M3 extractable P was found between the 0-1 and 5-6 in soil layers, respectively, for the same treatment. This demonstrates that broadcasting the P fertilizer can drastically stratify the extractable P in the soil. Treatments without any P addition were also stratified for all locations. This suggests that crop residues from previous years also had an impact on P stratification, not only the broadcasted fertilization.

Potassium

In the case of K, the treatments evaluated were chosen to show the impact of N fertilization in the K extraction by the crop (Figure 1). In Lahoma and Stillwater, a lower soil K content is observed when there is N fertilization. The difference in the K contents between treatments is apparent in all layers. However, such difference (especially at Perkins) decreases as the subsurface increases from the topsoil. For the treatments used in this study, there was still a difference in the deepest layer analyzed for Lahoma and Stillwater, which indicates a K stratification beyond that depth.

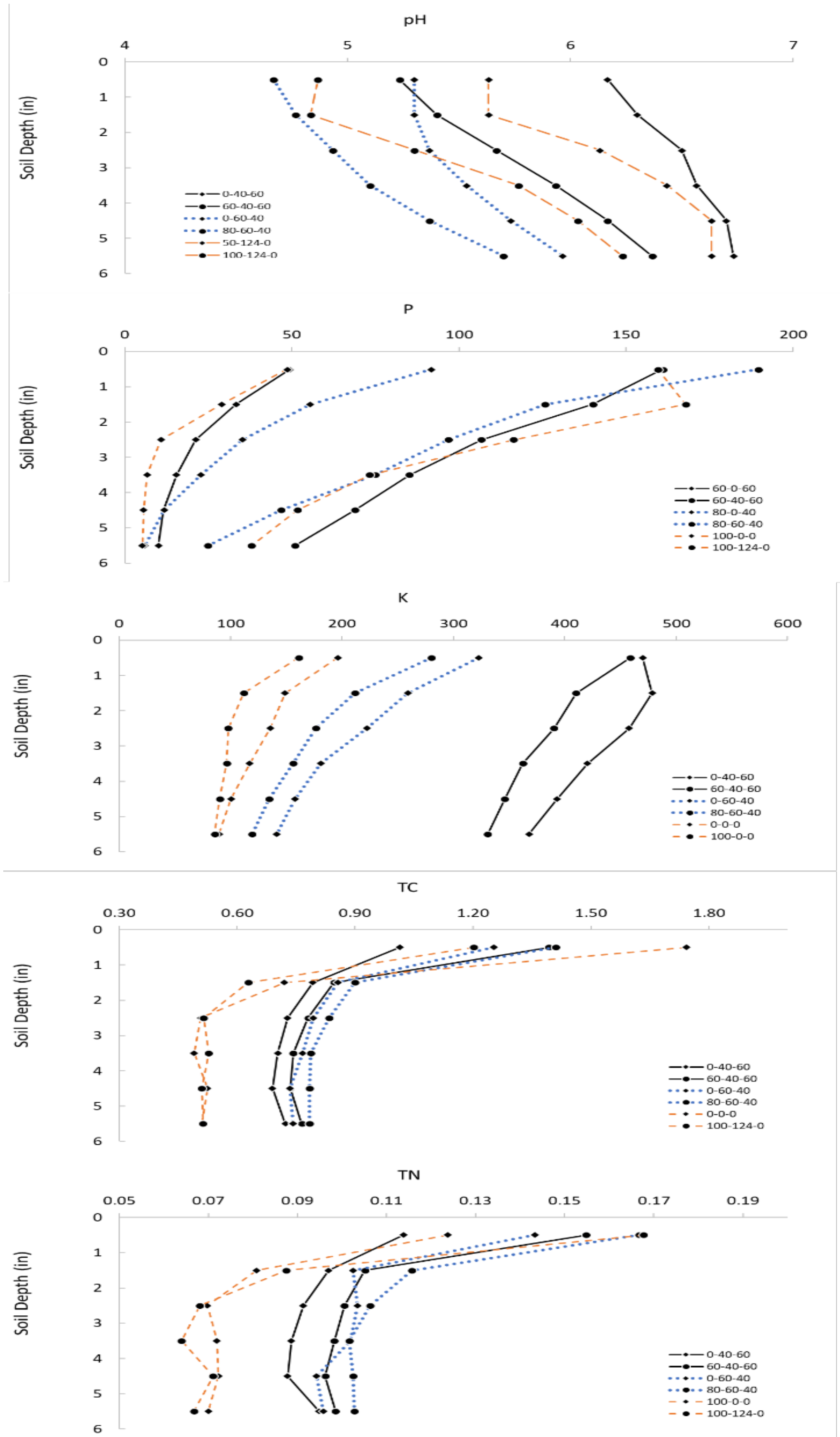
Phosphorus and Potassium build-up

Long-term P and K applications increased the soil available P and K (Figure 1). Since the establishment of the trials in Lahoma, Stillwater, and Perkins (only P), the successive application of P and K fertilizer brought up their bioavailable contents in soils. The results also suggest a reduction in soil P when N is applied at higher rates demonstrating the relation between N with P and K extraction.

Organic Carbon and Total Nitrogen

Differences in OC and TN were found only in the first 2 in regardless the location and appear to be mostly driven by N application.

Our partial results indicate that acidification due to ammoniacal fertilizers application is stratified in the long-term trials under NT. Long-term K and P application result in soil K and P build-up and stratification. Potassium and P removal is increased by N fertilization due to increase in yield. The increase in OC and TN re mostly related to the N fertilization. The stratification effect is more evident in the topsoil (0 to 2 in) and is due to the NT. This might be a consequence of the N being the most limiting nutrient in these areas. High P availability in low stratified pH could be caused by the organic anions produced from the organic matter (OM) and their aluminum (Al) and iron (Fe) complexation.



Figures 1. pH, phosphorus (P), potassium (K), total nitrogen (TN) and organic carbon (TOC) concentrations from stratified soil samples as a function of fertilizer application in 3 long-term NT trials (after at least 9 years under NT). Different lines and colors are locations. (Black=Lahoma, OK; Blue=Stillwater, OK; Orange = Perkins, OK). Different symbols are fertilizers rates within each location.

Table 2 - Least significant difference (LSD) of stratified soil attributes as a function of fertilizer application (Tukey test, α = 0.05).

Depth (in)	pH	P	K	TN	TC
		……ppm……		……%……	
	……………………...Lahoma ……………………..				
0 - 1	0.29	41	52	0.027	0.44
1 - 2	0.29	44	55	0.017	0.10
2 - 3	0.34	52	64	0.005	0.06
3 - 4	0.45	60	85	0.009	0.08
4 - 5	0.28	57	65	0.009	0.06
5 - 6	0.41	50	75	0.012	0.12
	……………………...Stillwater……………………..				
0 - 1	0.54	54	64	0.021	0.19
1 - 2	0.28	49	58	0.018	0.16
2 - 3	0.34	37	66	0.023	0.06
3 - 4	0.26	23	61	0.017	0.07
4 - 5	0.60	32	59	0.015	0.10
5 - 6	0.60	28	50	0.021	0.10
	……………………...Perkins……………………..				
0 - 1	0.53	25	64	0.039	0.46
1 - 2	0.59	14	48	0.016	0.24
2 - 3	0.41	11	45	0.011	0.12
3 - 4	0.75	16	52	0.016	0.18
4 - 5	0.45	12	58	0.011	0.18
5 - 6	0.60	28	50	0.021	0.10

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LONG-TERM COVER CROP AND ANNUAL FORAGE EFFECTS ON SOIL ORGANIC CARBON, NITROGEN STOCKS, AND WATER STABLE AGGREGATES IN THE SEMIARID CENTRAL GREAT PLAINS

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ABSTRACT

Growing cover crops (CC) in semiarid dryland cropping systems in the central Great Plains (CGP) may provide several benefits to soil health. This study examined long-term CC management effects on soil health in a no-till winter wheat (*Triticum aestivum* L.)–grain sorghum (*Sorghum bicolor* L.)–fallow (WSF) cropping system in southwestern Kansas. The experimental design was a split-split-plot randomized complete block with four replications. Main plots were crops in each phase of WSF, and sub-plots were CC treatments including fallow, grain pea, triticale in monoculture, a three-species mixture of oat/triticale/pea, and a six-species cocktail mixture of oat/triticale/pea/buckwheat/turnip/radish. Half of each CC treatment was harvested for forage with the remainder left as cover. Soil samples were collected from the 0 – 6 in depth in 2012 and 2018. Haying of CCs as forage had no effect on soil health indicators compared to when CCs were left standing. Soil organic carbon (SOC) in 2018 showed no significant change with CCs compared to fallow, but was greater compared to 2012. This lack of differences compared to fallow was possibly due to recent periods of drought reducing total carbon inputs compared to earlier periods of relatively greater precipitation. Grain peas or CCs did not increase soil N compared to fallow. Mean weight diameter of wet aggregates was not different between CCs hayed (0.042 in.) and CCs left standing (0.044 in.) but both were greater than fallow (0.033 in.) or spring pea (0.030 in.). Growing a CC significantly increased proportion of larger (2 – 8 mm) aggregate (36%) size fractions compared to spring peas (22%) but not compared to fallow (25%). Our findings suggest SOC gains made in semiarid environments could be sustained even during sustained periods of drought that reduce total carbon inputs from lower crop yields when CCs or annual forages are grown under very dry conditions.

INTRODUCTION

Growing cover crops (CC) in semiarid dryland cropping systems in the central Great Plains (CGP) has potential to provide several benefits to soil health in the region. These include reduced susceptibility to wind and water soil erosion as well as improved nutrient cycling (Blanco-Canqui et al., 2013, 2015). However, even with these potential benefits and an increasing interest among CGP crop producers, CC adoption has been slow in the region. This is mostly due to the fact that CCs will deplete vital soil water, which can result in reduced yields of subsequent cash crops compared to chemically-controlled summer-fallow, where herbicides are used to manage weed growth to store soil moisture for the next crop.

Past research efforts in southwest Kansas have shown that replacement of fallow with CCs or forage crops resulted in increased soil organic matter (SOM) content and stability of wet soil aggregates, as well as reduced soil wind-erodible fraction and run-off (Blanco-Canqui et al., 2013). These results indicate that CCs in semiarid regions have the potential to improve soil health similarly to those reported in more humid regions, at least in the short-term (<10 years), despite limited rainfall and high evaporative demand. However, information is lacking regarding the long-term (>10 years) soil health effects of integrated cover crops in dryland crop production.

Increased adoption of CC by dryland producers in the semiarid CGP can enhance residue cover to reduce the susceptibility of the soil to erosion (Blanco-Canqui et al., 2011, 2013, 2014). Reducing erosion is particularly important in semiarid dryland crop production systems where residue levels are often low, and fallow fields are left exposed. Grazing and or haying of CC for forage can provide an economic benefit to offset potential lost revenue associated from decreased crop yields when CC are grown ahead of a cash crop in dry years (Holman et al., 2018). However, there is concern that harvesting CC as forages and the resulting reduction in residue left on the soil surface may negate the beneficial effects of CC for soil conservation.

With all things considered, there is great motivation for researchers and others involved in production agriculture to develop and evaluate new and innovative crop production strategies and technologies to boost profitability and sustainability of dryland, wheat-based crop production systems in the CGP. Our objectives were to assess the long-term impacts of CCs on 1) soil organic carbon and nitrogen stocks, 2) soil susceptibility to erosion, as well as to 3) quantify the effects of haying cover crops as annual forages upon soil health.

MATERIALS AND METHODS

This study was conducted in a long-term experiment of fallow replacement (cover crops, forage crops, and grain crops) at the Kansas State University Southwest Research-Extension Center near Garden City, KS. The soil is a Ulysses silt loam with 1 to 3% slope. Cover crops included spring triticale (×*Triticosecale* Wittm.), a three-species mixture of oats (*Avena sativa* L.)/triticale/pea (*Pisum sativum* L.), and a six-species cocktail mixture of oats/triticale/pea/buckwheat (*Fagopyrum esculentum* Moench)/turnip (*Brassica rapa*)/radish (*Raphanus sativus* L.). Cover crops plots were split with half of each plot harvested for forage. Additionally, spring peas were harvested for grain. Treatments with crops grown in place of fallow were compared with WSF for a total of 8 treatments. All phases of each crop rotation were present every year. The study design was a split-split-plot randomized complete block with four replications. Crop phase was the main plot, crop species or mixture was the split plot, and termination method (cover, forage, or grain) was the split-split plot. Main plot was 250 ft wide by 120 ft long, split plot was 30 ft wide and 120 ft long, and split-split plot was 15 ft wide and 120 ft m long.

All soil sampling occurred shortly before wheat planting in fall 2018. Soil cores were taken from the 0 to 2, 2 to 6, and 6 to 12-inch depths for determination of bulk density as well as SOC and inorganic nitrogen (NO_3 and NH_4) stocks. Briefly, the samples taken at each depth were dried at 220 °F for 48-hr, and bulk density was determined by mass of oven dry soil divided by volume of the core. Subsamples from each depth were air-dried and ground to pass through a 0.08 in. sieve. Soil nitrate-N (NO_3-N) and ammonium-N (NH_4-N) concentrations in samples were determined colorimetrically after the soil samples were extracted with 2 M KCl. A portion of the samples were ground with a mortar and pestle to pass through a 0.01 in. sieve, and SOC concentration was determined by dry combustion using a CN analyzer after pretreating samples with 10% (v/v) HCl to removed carbonates. Additional samples collected from the 0 to 2 in. soil depth with a flat shovel were air-dried and passed through sieves with 0.185 to 0.30 in. mesh to obtained air-dry aggregates of 0.185 to 0.30 in. diameter. These samples were used to estimate water-stable aggregates by the wet-sieving method. Sand correction was done for each aggregate size fraction, and the data was used to compute aggregate size distribution and mean weight diameter (MWD) of water-stable aggregates.

RESULTS AND DISCUSSION

Soil Organic Carbon and Nitrogen Stocks

Treatments of differing CC species diversity were not significantly different for any observed soil health parameter. Soil organic carbon stocks (Fig. 1) in 2018 showed no significant differences compared to fallow, but were greater than SOC values determined in 2012. This suggests SOC gains made in semiarid environments could be may not be increased, but may be maintained, even with sustained periods of drought that reduce total carbon inputs from lower CC biomass and wheat and grain sorghum yields that result under very dry conditions. Grain peas and CCs did not increase soil N (Fig. 1) compared to fallow. However, recommended rates of N applied to both wheat and sorghum crops may have masked any potential differences.

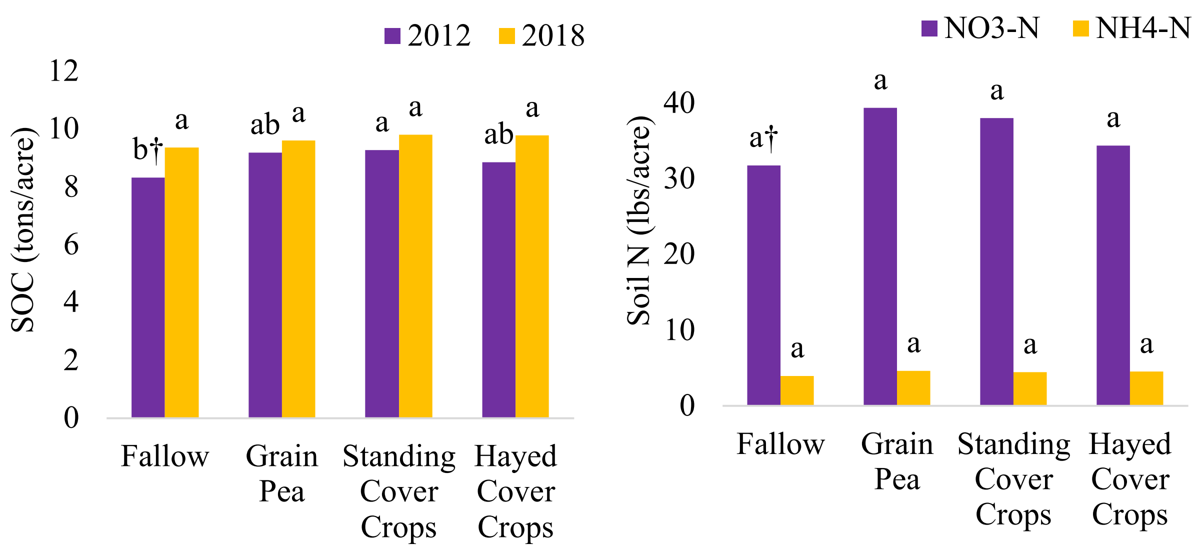

Figure 1. Impact of cover crops on the (a) soil organic carbon (SOC) pool in tons/acre from the 0 – 2 in. soil depth in 2018 and 2012 and (b) soil nitrate (NO_3) and ammonium (NH_4) in lbs/acre from the 0 – 6 in. soil depth.
†Means with the same lowercase letter are not significantly different among treatments within years.

Bulk Density and Water Stables Aggregates

Soil bulk density (BD), a common measurement of soil compaction, was decreased with CCs (1.36 g cm^{-3}) compared to fallow (1.62 g cm^{-3}), but was similar to grain pea (1.47 g cm^{-3}). Water stable aggregates are measured as an indicator of soil erosion. Larger aggregates are less susceptible to erosive forces. In this study, the proportion of larger (0.08 – 0.30 in.) aggregate size fractions (Fig. 2) was increased with CCs (36%) compared to grain pea (22%), but was similar to fallow (25%). The proportion of smaller (0.01 – 0.04 in.) aggregates was decreased with CCs (32%) compared to fallow (45%) but was similar to grain pea (41%). Mean weight diameter of wet aggregates (Fig. 2) was not different when CCs were left standing (0.044 in.) versus when they were hayed as an annual forage (0.042 in.), but both were greater than fallow (0.033 in.) or grain pea (0.030 in.).

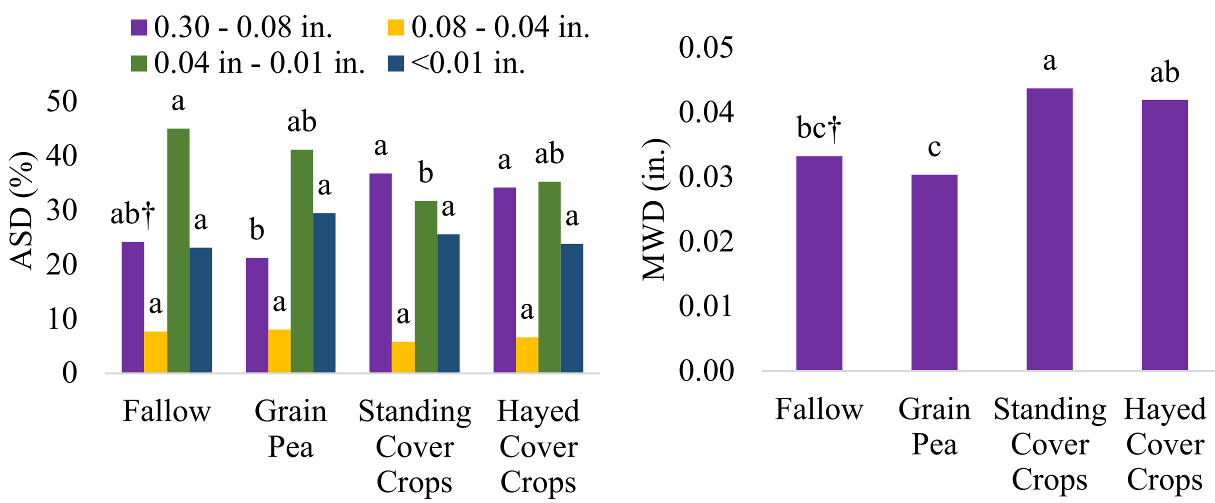

Figure 2. Impacts of cover crops on (a) aggregate size distribution (%) and (b) mean weight diameter (in.) of wet aggregates from the 0 – 2 in. soil depth.
†Means with the same lowercase letter are not significantly different among treatments within each aggregate-size fraction.

SUMMARY

Eleven years of growing a CC or forage crop in place of fallow in the semiarid CGP generally increased aggregation and reduced soil bulk density but had little impact on SOC and N stocks. Treatments of differing CC species diversity did not significantly differ for any observed soil health parameter. Interestingly, haying of CCs as annual forage also had little effect on soil health indicators compared to when CCs were left standing. Similar results were observed by Blanco-Canqui et al (2013) six years earlier in this same experiment. Intensification of cropping systems with CCs, annual forages, or grain crops under no-till management may be a good means of improving soil health in semiarid drylands.

ACKNOWLEDGEMENT

This work was supported by the USDA North Central Region Sustainable Agriculture Research & Education Grant Program, the USDA-NRCS Ogallala Aquifer Grant Program, and the Kansas Agricultural Experiment Station.

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P-17

Evaluation of Cation Exchange Resins as Indicator of In-Season Potassium Supply to Soybean

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ABSTRACT

The use of ion-exchange resins to measure soil nutrient availability has potential applications for fertilizer recommendations. The objective of this study was to evaluate the relationship between potassium (K) adsorption by cation exchange resins (CER) and K uptake by soybean (*Glycine max*) in field conditions. The study was conducted at two locations in Kansas during 2019. Two treatments were selected to evaluate the CER. Treatments included a check (0 lbs K_2O acre^{-1}) and a high K rate with 150 lbs K_2O acre^{-1} applied pre-plant and incorporated. The Plant Root Simulator® (PRS®) was used as an indicator of in-season K supply to soybean. Number, length, and time between burial periods were defined in order to cover most of the soybean growing season. In addition, whole plant samples were collected at V4, R2, R4, and R6 stages to measure plant K uptake. Soil moisture content was calculated based on soil samples collected at the beginning and end of each burial period. CER were able to adsorb more K (measured as cumulative adsorption) when K fertilizer (150 lbs K_2O acre^{-1}) was applied. Data showed a positive relation between CER values and soil moisture content. Preliminary results from this study suggest that CER can be used as an indicator of K supply, particularly in soils with low soil test K levels.

INTRODUCTION

Some soil test methods used to estimate K availability (e.g. 1 M NH_4OAc) are not always good indicators of K uptake by plants. Since the 1950s, synthetic ion exchange resins have been used for assessing the bioavailable fraction of soil nutrients (Qian and Schoenau, 2002). Compared to soil test methods, ion exchange resins can be used to measure nutrient supply rates during specific adsorption periods. Therefore, soil processes such as nutrient release and transport can be considered. In CER, membranes are negatively charged in order to adsorb positively-charged ions, like K^+. Exchange membranes were capable to assess immediate nutrient supply rate by selecting short burial periods (1 hour) (Qian et al., 1996). Also, long periods are used to capture nutrients released from mineral and non-exchangeable forms (Cooperband and Logan, 1994). This technology has potential applications in numerous areas (including agronomic research) because of its ability to simulate plant root activity in undisturbed conditions. However, there are still limitations such as unfamiliarity of units used to express results (Qian and Schoenau, 2002), and reduced calibration studies related to crop response. Commonly, K management is based on pre-plant soil sampling to assess nutrient supply for the entire season. Finding an indicator that considers the kinetics of K release from the soil could be useful to improve future management. The objective of this study was to evaluate whether K adsorbed by CER could be used as an indicator of in-season K supply to soybean (*Glycine max*) in field conditions.

MATERIALS AND METHODS

Field experiments were conducted at two locations throughout eastern Kansas during 2019 (**Table 1**). Sites were located at Ashland Bottoms Research Farm (Manhattan, KS) and East Central Experimental Field (Ottawa, KS) under a conventional tillage crop system. The experiments were a randomized complete block design and two treatments and two replicates were selected to evaluate the CER. Treatments included a control (check) with no K application and one with application of 150 lbs K_2O acre^{-1} (high K rate). Both treatments had an application of 80 lbs P_2O_5 acre^{-1}. The fertilizer applications were a surface broadcast at pre-plant using triple superphosphate (TSP) and potassium chloride (KCl) as a P and K sources, respectively. For this study, we used a commercial CER (Plant Root Simulator® (PRS®, Western Ag Innovations, Saskatchewan, Canada) as an indicator of in-season K supply to soybean. This product consists of an exchange resin membrane held in a plastic frame that is inserted into the soil to measure *in situ* ion supply. Variables such as number, length, and time between burial periods were defined in order to cover most of the soybean growing season (V4 to R7). Ottawa location had six burial periods compared to Ashland that had seven. Burial length consisted of 7 days with a time between burials of 15 days. A total of 4 probes were distributed within the plot to obtain a composite sample. The CERs were inserted vertically into the soil (facing plant row), between 2-4 inches soil depth at a distance of 3 inches from the soybean row during all the sampling season. For every new burial period, the CERs were buried 5 inches apart from the previous period (parallel to the row) to avoid sampling the same portion of soil. Aboveground plant samples were collected at V4, R2, R4, and R6 stages in order to measure plant K uptake. The samples were dried at 140°F, ground to pass through a 2 mm screen, weighed and digested by nitric-perchloric acid digestion. Total K concentration of the extractant was determined by inductively coupled plasma (ICP) spectrometry. Soil samples were taken at pre-plant (one per replicate), air dried at 104 °F, and ground to pass through a 2 mm screen. All samples were analyzed for soil pH (soil:deionized water; 1:1), Organic Matter (OM) (loss on ignition method), extractable P and K (Mehlich-3), exchangeable cations (1 M NH_4OAc pH 7.0, Flame Atomic Absorption), and Cation Exchange Capacity (CEC) (displacement method). Soil samples were taken at the beginning and end of each burial period to calculate soil moisture content (air-dried at 104 °F). Statistical analysis (ANOVA) was performed using the GLIMMIX procedure in SAS 9.4.

RESULTS AND DISCUSSION

Plant K uptake measured at reproductive stages (R2, R4, and R6) was increased by K fertilization in both locations. However, differences were not statistically significant ($p < 0.05$) at location 1 (**Fig. 1**). This result was likely due to its high soil K levels. Based on Kansas State University recommendations, this location had soil K levels that was above the critical level of 130 ppm, and no K fertilizer was needed (**Table 1**). In contrast, location 2 had significantly higher plant K uptake measured at R2 ($p < 0.05$), R4 ($p < 0.10$), and R6 ($p < 0.05$) stages when 150 lbs K_2O acre^{-1} was applied (**Fig. 2**). At the R6 stage, fertilized plots had 50% more K uptake and 40% more K adsorption (cumulative) by CER compared to the control. This observation suggests the potential use of CER as indicator of K supply to soybean in field conditions, but further research is needed to confirm these findings. In both locations, CER were able to adsorb more K (measured as cumulative adsorption) at high K rate. The amount of K that was adsorbed by the CER was influenced by soil moisture content, particularly in location 1 (**Fig. 3**). A similar trend was observed between these two variables. Plots without K fertilization were less affected and minor fluctuations were measured compared to those with high K rate. However, data from location 2 did not show a clear pattern (**Fig. 4**). Preliminary results from this study suggest that CER can be used as an indicator of K supply particularly in low K soils.

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Table 1. Selected soil properties for 0-6" samples

Location	County	Soil texture	pH	OM	P-M	K-M	K	Ca	Mg	Na	CEC
				%	------------------ppm					----------------------	(meq/100g)
1	Riley	silt loam	7.7	3.2	55	350	324	2749	117	11	14.6
2	Franklin	sandy clay loam	5.7	3.4	14	102	94	2399	322	29	20.9

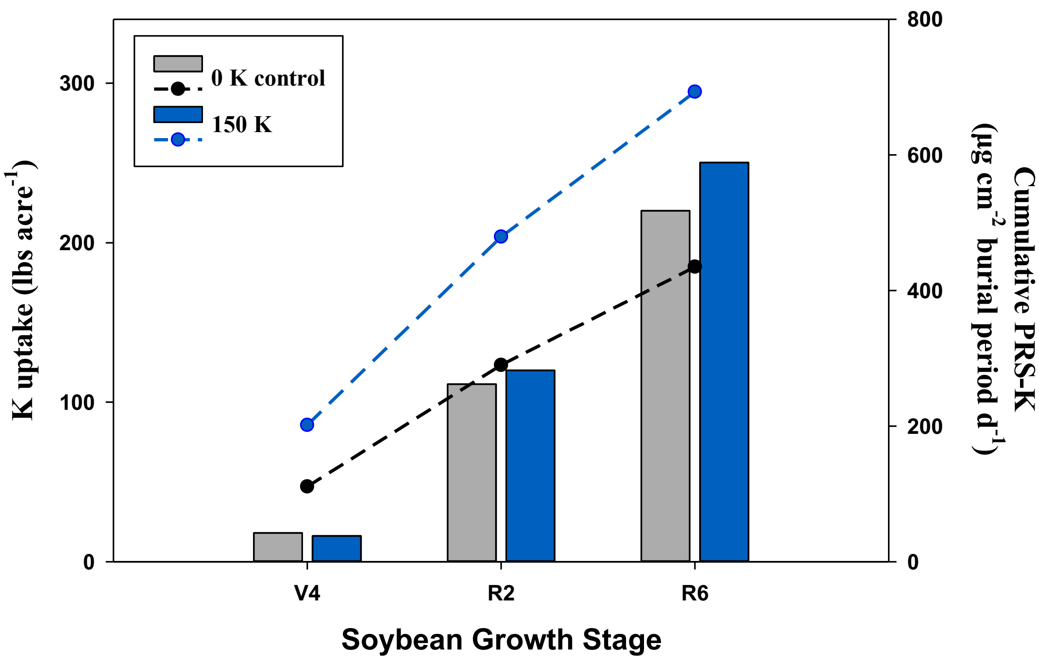

Figure 1. Soybean plant K uptake (represented by bars) and cumulative PRS K adsorption as affected by two levels of K application at Location 1. Pairwise comparisons of K fertilizer application rate within each stage are indicated by "*" when statistically significant at the $p<0.05$.

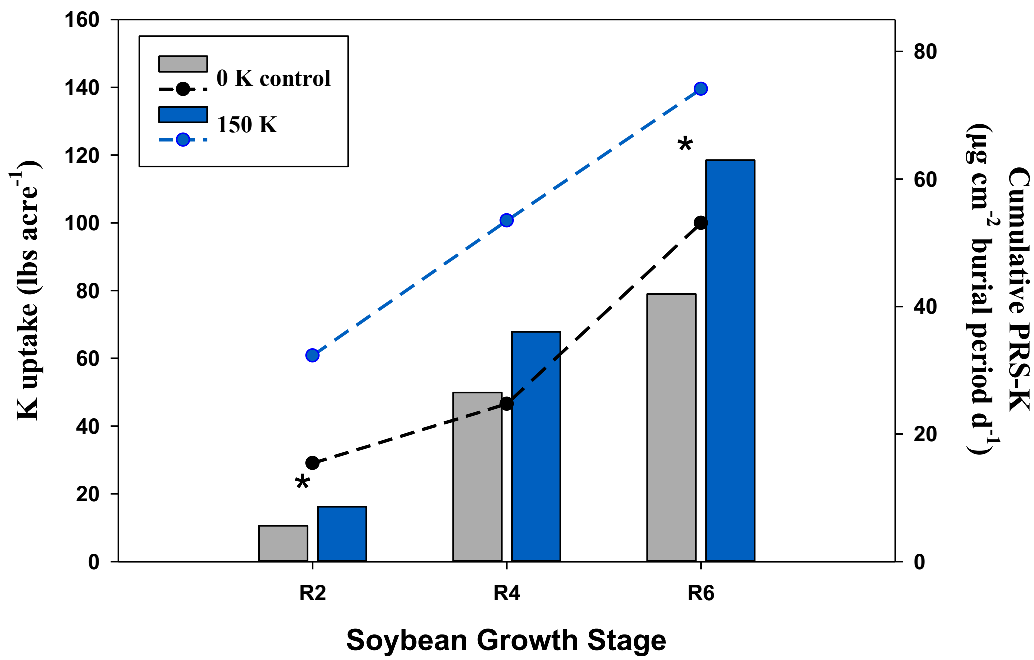

Figure 2. Soybean plant K uptake (represented by bars) and cumulative PRS K adsorption as affected by two levels of K application at Location 2. Pairwise comparisons of K fertilizer application rate within each stage are indicated by "*" when statistically significant at the $p<0.05$.

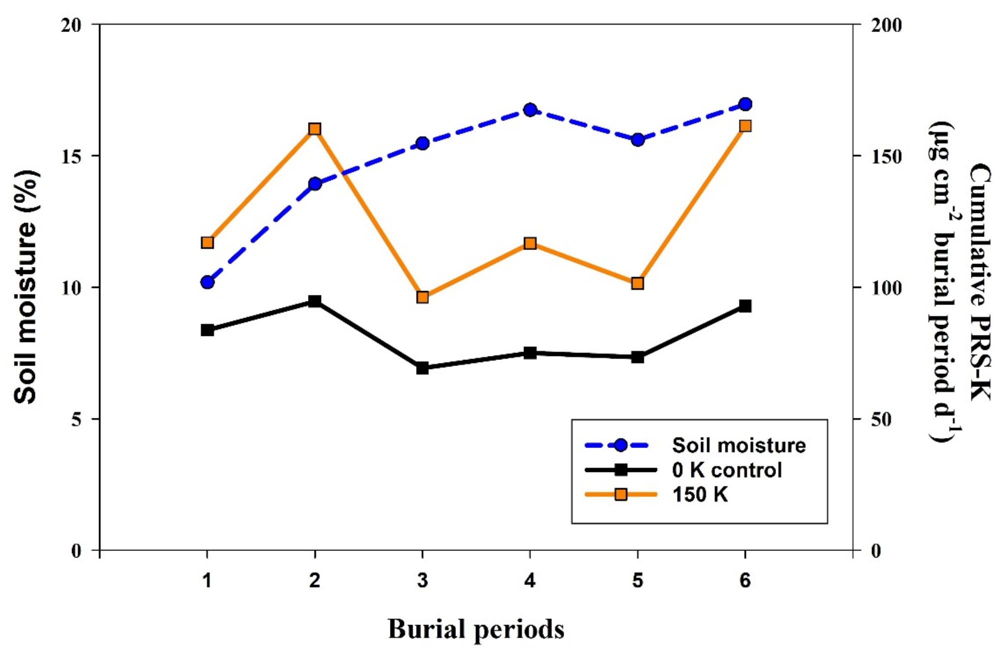

Figure 3. PRS K adsorption as affected by two levels of K application compared to soil moisture content at Location 1.

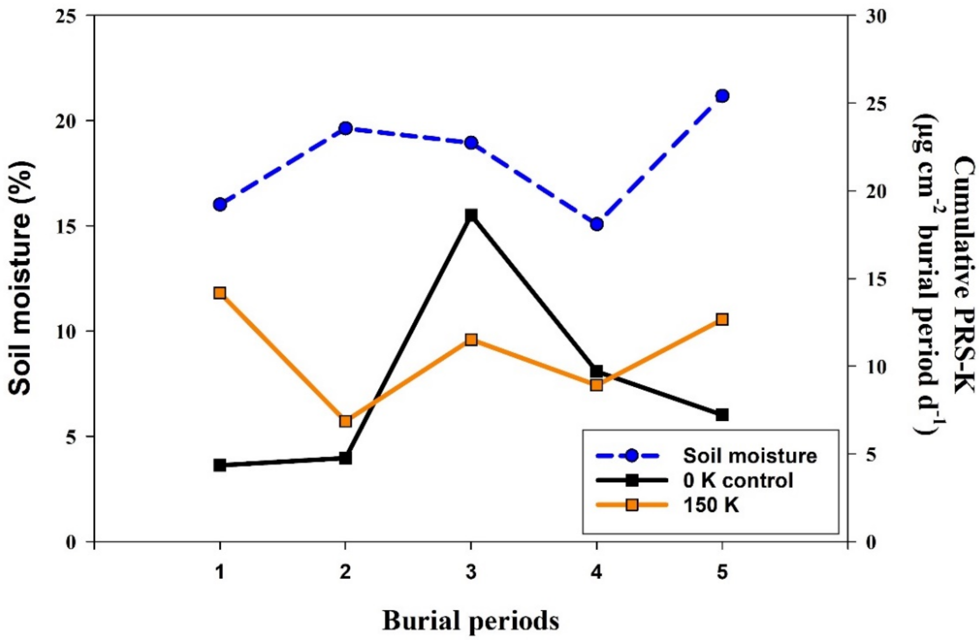

Figure 4. PRS K adsorption as affected by two levels of K application compared to soil moisture content at Location 2.

P-18

EVALUATING THE TRADE-OFFS OF COVER CROPS IN DRYLAND WHEAT SYSTEMS OF THE COLORADO PLATEAU

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ABSTRACT

On the semi-arid Colorado Plateau, dryland farmers are challenged by severely degraded soils and low and increasingly unreliable precipitation. Cover crops have been shown to improve soil fertility and mitigate soil erosion in many regions, but are also associated with use of limited soil moisture, a cost that could mean decreased cash crop productivity for farmers. Most literature on cover crops comes from relatively humid climates, where crop yield penalties due to cover crops may be less pronounced. Our research seeks to assess the viability of cover crops as a solution to soil degradation and erosion in dryland systems on the Colorado Plateau, through the implementation of two field experiments at the Southwestern Colorado Research Center in Yellow Jacket, CO starting in 2015. The yield penalties of winter wheat following cover crop growth ranged from 22% to 78% and varied according to year and the amount of cover crop biomass produced in the year prior to wheat planting. The wheat yield penalty was likely due to lowered soil moisture content and nitrogen availability observed in cover crop treatments as compared to the fallow controls. However, increasing trends in soil carbon and aggregation in plots that had received two cycles of cover crops show the potential for cover crops to improve soil fertility in these dryland systems, though these changes in soil health typically occur over a longer time frame. These experiments will be continued and changes in soil health and wheat productivity will be monitored to assess the potential for cover crops to improve soil health in the long-term.

INTRODUCTION

The high desert region of the Colorado Plateau is characterized by high elevation (1800-3000 m) and low and increasingly unreliable precipitation (180-300 mm yr^{-1}). To minimize transpiration and recharge soil moisture, dryland producers typically leave land fallow for 14-month periods and rely heavily on tillage and herbicides to control weeds. Soils in these systems have consequently experienced severe degradation associated with wind erosion and low organic matter/nutrient inputs, and producers in the region are becoming increasingly concerned with the long-term maintenance of soil fertility and productivity on their farms.

Cover crops have been put forth as a potential solution to increase soil water capture, while also reducing erosion, sequestering soil carbon and improving overall soil health (Snapp et al., 2005; Schipanski et al., 2014). By decreasing runoff, cover crops may allow soils to better retain rainfall from intense storms and increase cropping system resilience in drought years. However, tradeoffs are inevitable and cover crops can also compete for water with cash crops. Cover crop impacts on soil health and cash crop yields are context-dependent and vary according to climatic conditions as well as local management practices. While cover crop impacts are better understood in wetter climates, data for the Colorado Plateau and similar semi-arid regions are notably lacking.

This research aims to assess the viability of cover crops as a means to address soil degradation on the Colorado Plateau by quantifying impacts on both cash crop yields and soil health metrics over time. Data from field experiments will help assess how cover crop management practices- including planting window, cover crop mixture, and tillage- contribute to these impacts.

MATERIALS AND METHODS

Two field trials were established on the Southwestern Colorado Research Station (SWCRC) in Yellow Jacket, CO to evaluate various cover crop mixtures in a controlled setting. The first field trial (SWCRC1) was established in August 2015 and compared three cover crop mixtures vs. a fallow control in a randomized complete block (RCB) design with three replicate plots. Plots followed a two-year cycle with 10 months in cover crops, a 2-month fallow period, 10 months in winter wheat, and another 2-month fallow period.

In August 2016 a second replicated trial (SWCRC2) was established with nine cover crop mixtures including both spring- and fall-planted mixtures. The experiment also examined these cover crop treatments within two tillage regimes (no-till vs. conventional tillage) and employs a RCB design. All cover crop mixtures were followed by winter wheat, which was harvested in July 2018.

Cover crop biomass data were collected at cover crop termination using a 75 cm dia. range hoop and returned to the lab for sorting by plant functional group, oven-drying at 60 °C and weighing. Wheat yield and quality were measured following wheat maturity. Bulk density and aggregate stability were measured at cover crop termination in the top layer (0-5 cm) of soil to evaluate soil compaction and structure. Soil moisture was evaluated using soil cores, taken to a depth of 1 m at cash crop planting. Soil fertility was assessed for total organic C and N, pH, and available N.

All data were analyzed in R statistical software (R Core Team, 2017). Cover crop production, wheat yields, and soil health metrics were analyzed using a multifactor ANOVA, with cover crop treatment included as a fixed effect and block included as a random effect. Tukey-adjusted pairwise comparisons, generated by the emmeans package in R (Lenth, 2018), were used to estimate the difference between treatments.

RESULTS AND DISCUSSION

Cover Crop Biomass

Average cover crop biomass varied by year, according to differences in precipitation patterns. Biomass produced ranged from an average of 5020 ± 418 kg/ha in 2016 to 1510 ± 110 kg/ha in 2018, when the region experienced severe drought (Fig. 1). In SWCRC2, the planting window of the cover crop significantly impacted total biomass, with fall-planted mixtures producing significantly more total biomass than spring-planted mixtures. Within planting window, however, mixtures did not significantly differ in terms of total biomass produced ($p>0.05$).

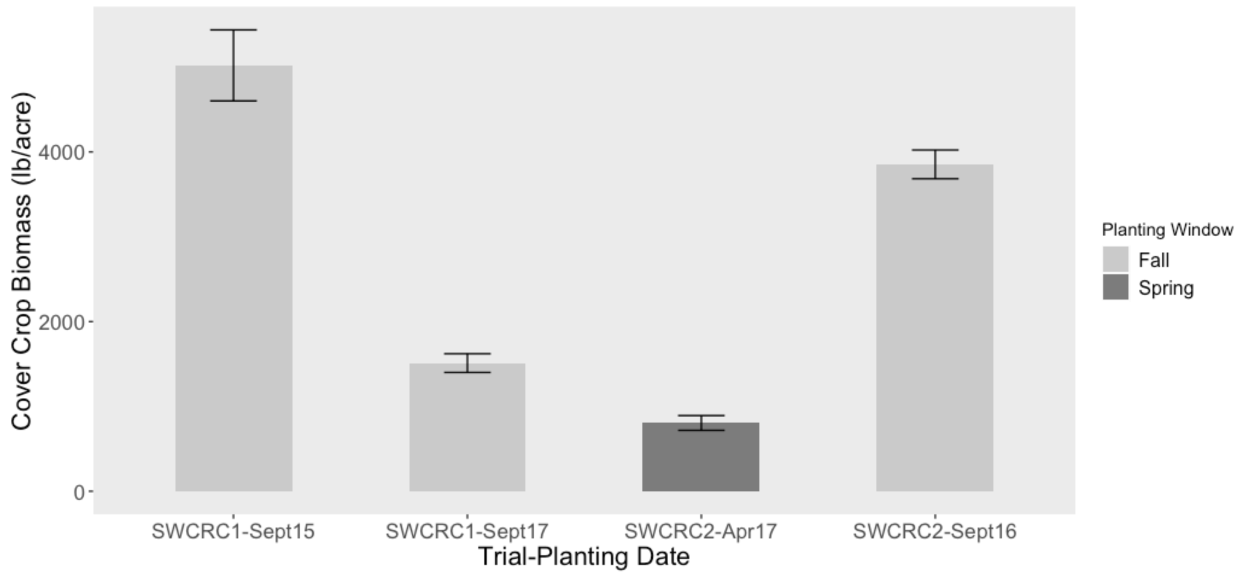

Figure 1. Cover crop biomass in two field experiments located at the Southwestern Colorado Research Center in Yellow Jacket, CO over three growing seasons with both fall- and spring-planted cover crop mixtures. Error bars represent standard error of the mean.

Winter Wheat Yields

In SWCRC1, the wheat yield penalty, or percent decrease in wheat yield following the cover crop treatment as compared to the fallow treatment, was on average 27% in 2017. The wheat yield penalty in SWCRC2 was dependent on the planting window of the cover crop, and was less in the spring-planted cover crop plots (22%) compared to fall-planted cover crop plots (78%; $p<0.0001$). Wheat yields following the fallow treatment had the highest average yield, but did not significantly differ from the spring-planted treatments ($p=0.12$). The amount of cover crop biomass produced was a main driver in subsequent wheat yields, as evidence by the linear regression between 2017 cover crop biomass and 2018 wheat yields in SWCRC2 (Fig. 2; $R^2=0.53$; $p<0.001$).

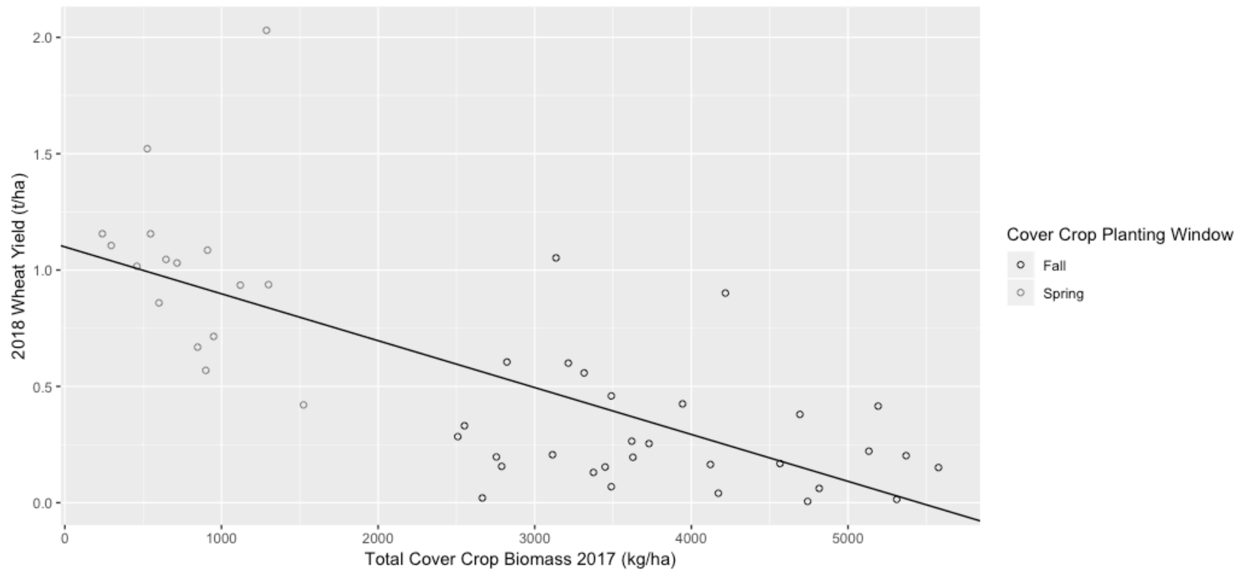

Figure 2. Correlation (R^2=0.53 p<0.001) between cover crop biomass (2017) and subsequent winter wheat yields (2018) in a field experiment (SWCRC2) located at the Southwestern Colorado Research Center in Yellow Jacket, CO.

Soil moisture and soil nitrate levels were both lowest in fall-planted cover crop treatments, highest in the fallow, and intermediate for the spring-planted treatments (Table 1). Soil moisture in particular is widely accepted as the main limitation to crop production on the Colorado Plateau and could explain the lowered wheat yields following cover crop growth. However, available nitrogen is also a known limiting factor to wheat production, especially since dryland systems in this region are not customarily fertilized. Nitrogen immobilized in cover crop biomass is not lost from the system, but will take time to be mineralized back into the soil and made available for cash crop use.

Table 1. Moisture content at 0-30, 30-60, and 60-90 cm and soil nitrate levels between fall-planted cover crop mixtures, spring-planted cover crop mixtures, and a fallow treatment in a field experiment in Yellow Jacket, CO. Measurements were taken at winter wheat planting in September 2017. Values in parentheses represent standard error of the mean.

	Fall-Planted	Spring-Planted	Fallow
Moisture Content at 0-30 cm (g g^{-1})	0.12 (0.0054)	0.12 (0.0054)	0.16 (0.0076)
Moisture Content at 30-60 cm (g g^{-1})	0.11 (0.0060)	0.16 (0.0060)	0.17 (0.0080)
Moisture Content at 60-90 cm (g g^{-1})	0.11 (0.0042)	0.16 (0.0034)	0.17 (0.0044)
Soil Nitrate (kg ha^{-1} N)	13.8 (0.85)	19.7 (0.85)	34.4 (1.1)

Soil Health Metrics

Soil health metrics such as total carbon and aggregate stability were measured in SWCRC1 in July 2018. Though not significant at an alpha level of 0.05 (p=0.10), cover crop treatments show a higher average total soil carbon content (0.76% total C ± 0.02) relative to the fallow treatment (0.72% total C ± 0.03). Mean weight diameter of aggregates in cover crop treatments (399 um ± 67) is also slightly greater than that of the fallow treatment (374 um ± 100). Though these metrics typically take some time to change, it seems that there are soil health increases associated with cover crop treatments after two full cover crop cycles.

CONCLUSIONS

In dryland systems such as on the Colorado Plateau, cover crops can often negatively impact cash crop productivity, presenting a trade-off in terms of productivity and soil health. Early results from the field experiments presented here clearly highlight this trade-off, particularly following fall-planted cover crops, which tend to produce the most biomass (and thus use the most water). As precipitation is extremely low in the region and water is considered to be a major limitation to production, this cash crop penalty is likely due to lower soil moisture observed in cover crop plots. However, lower available nitrogen assimilated to cover crop biomass could also be limiting wheat yields following a cover crop.

Nonetheless, as soil degradation becomes a greater concern on the Colorado Plateau and farm longevity is threatened, soil health benefits (including those for water capture and storage) could justify this decrease in cash crop productivity. After only two cover crop cycles, there are promising trends in soil health metrics such as aggregation and total soil carbon. Improvements in soil structure and fertility such as these could have important implications for water capture, nutrient retention, and erosion control in the long-term, and could potentially help reduce the yield penalty observed here. Field experiments will be continued at least through 2021, and we will continue to monitor these metrics to assess the potential for cover crops to improve soil health in the long-term.

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P-19

NITROGEN MANAGEMENT IN CONSERVATION SYSTEMS TO INCREASE USE EFFICIENCY AND COTTON PRODUCTION

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ABSTRACT

Conservation management practices like no-tillage and cover crops have the potential to reduce wind erosion and stimulate ecosystem service, but lingering doubts regarding nutrient immobilization and water usage may limit their adoption on the Texas High Plains. A study was initiated at the Agricultural Complex for Advanced Research and Extension Systems (AG-CARES) in Lamesa, TX to examine the impact of supplemental nitrogen (N) fertilization on cotton yields and nitrogen use efficiency (NUE) in two cotton cropping systems. The continuous cotton cropping systems included: 1) conventional tillage, winter fallow (CC), and 2) conservation tillage with rye cover (CCRC). The N fertilizer treatments included: 1) farm practice, 2) additional N applied preplant, 3) additional N applied at emergence plus three weeks, and 4) additional N applied at pinhead square plus two weeks. Results indicate cotton lint yield and NUE were greater following a rye cover crop compared to monoculture cotton when additional N was applied preplant or at emergence plus three weeks in both cropping years. Applying additional N at pinhead square plus two weeks resulted in a significant reduction in yield and the lowest NUE in both years.

INTRODUCTION

The semi-arid Texas High Plains is one of the largest cotton producing regions in the world and contributes a significant amount to the regional economy; however, the extreme environmental conditions of the region can lead to wind erosion. Conservation management practices, like no-tillage and cover crops, can reduce wind erosion and stimulate ecosystem services. The use of these practices can result in yield deficit which might be caused by reduced water availability or nutrient immobilization (Lewis et al., 2018; Burke et al., 2019). Cover crops production can range from 1798 to 4654 lb dry matter A^{-1} on the Texas High Plains which results in substantial amounts of organic materials for microbes to decompose. Questions remain whether the decomposition of this organic material will align with peak cotton nutrient demands. The purpose of this research was to determine if and when supplement N applications in cotton cropping systems can reduce the yield drag associated with conservation management practices.

MATERIALS AND METHODS

A trial was initiated in 2018 to evaluate the effect of N fertilizer application timing on lint yield of cotton (DP 1522 B2XF) following a rye cover crop/conservation tillage (CCRC), and in a conventional tillage/winter fallow system (CC). The N treatments were replicated within each cropping system, and included: 1) check, AG-CARES practice (120 lb N A^{-1} applied via fertigation); 2) additional 30 lb N A^{-1} applied at preplant; 3) additional 30 lb N A^{-1} applied three weeks after emergence; and, 4) additional 30 lb N A^{-1} applied at pinhead square plus 2 weeks. The source of the N was urea ammonium nitrate (UAN, 32-0-0). All subsequent N fertilizer applications were knifed injected. Cotton in this trial was planted on 16 May 2018 and 19 May 2019, defoliated on 3 October 2018 and October 2019, and harvested 17 November 2018 and 18 November 2019. Statistical analyses for all measurements were performed using SAS version 9.3 software (SAS Institute Inc.). Analysis of variance was conducted for all parameters using a generalized linear mixed model (PROC GLIMMIX). Means of treatment effects were compared within sample time using Fisher's least significant difference (LSD) at $P < 0.05$. Nitrogen use efficiency was calculated as:

$$Nitrogen\ use\ efficiency\ (lb\ lint\ lb\ N^{-1}) = \frac{lint\ yield\ (lb\ lint\ A^{-1}) - check\ lint\ yield\ (lb\ lint\ A^{-1})}{Nitrogen\ applied\ (lb\ N\ A^{-1})}$$

RESULTS AND DISCUSSION

In 2018, cotton lint yields ranged from 605 to 808 lb lint A^{-1} and 683 to 975 lb lint A^{-1} for CC and CCRC systems, respectively (Table 1). For the CC system, a preplant application of 30 lb N A^{-1} resulted in significantly greater yield compared to the other treatments, while an additional application of N at emergence plus three weeks resulted in significantly greater cotton lint yield in the CCRC system. As with lint yield, NUE was greatest following a preplant application in the CC system and emergence plus three weeks in the CCRC system. In the CC system, the later application of 30 lb N A^{-1} at pinhead square plus two weeks resulted in decreased NUE compared to the check or farm practice. Cotton lint yields and NUE were greater in the CCRC system compared to the CC.

In 2019, cotton lint yields ranged from 776 to 872 lb lint A^{-1} and 913 to 1118 lb lint A^{-1} for CC and CCRC systems, respectively (Table 2). For the CC system, there were no significant differences between treatments and NUE was generally reduced with supplemental N fertilization except following a preplant application of N. Cotton lint yields and NUE were greater in the CCRC system compared to CC. For the CCRC system, cotton lint yield was greatest with the preplant application followed by emergence plus three weeks compared to the farmer practice and pinhead square plus two weeks. Nitrogen use efficiency in CCRC was improved in the preplant and emergence plus three weeks applications compared to the pinhead square plus two weeks application.

The addition of rye cover increased lint yield compared to CC with the addition of supplemental N in 2018, but increased yield regardless of N application in 2019. The 2018 cropping season was initially warmer than average but had adequate rainfall during the cropping season, while the 2019 cropping season began with adequate rainfall, but nearly no precipitation during the growing season. The rye cover may increase soil moisture storage which could explain the yield increases in 2019 even under limited precipitation.

Table 1. 2018 cotton lint yield and nitrogen use efficiency (NUE) of two cropping systems in Lamesa, TX. Mean values with the same letter within year are not significantly different at $P <$ 0.05.

Nitrogen Management	**Cont. Cotton (CC)**	**CC, Rye Cover**
	-----------------Lint yield (lb A^{-1})----------------	
Farm Practice (120 lb N/A)	641 bc	683 c
Preplant (+30 lb N/A)	808 a	830 b
Emerg + 3 wks (+30 lb N/A)	686 b	975 a
PHS + 2 wks (+30 lb N/A)	605 c	786 bc
P-value	0.001	0.009
	--------NUE, over check (lb lint lb N^{-1})-------	
Farm Practice (120 lb N/A)	---	---
Preplant (+30 lb N/A)	5.59 a	4.90 b
Emerg + 3 wks (+30 lb N/A)	1.52 b	9.73 a
PHS + 2 wks (+30 lb N/A)	-1.18 c	3.44 b
P-value	0.0001	0.009

Table 2. 2019 cotton lint yield and nitrogen use efficiency (NUE) of two cropping systems in Lamesa, TX. Mean values with the same letter within year are not significantly different at $P < 0.05$.

Nitrogen Management	Cont. Cotton (CC)	CC, Rye Cover
	----------------Lint yield (lb A^{-1})---------------	
Farm Practice (120 lb N/A)	845	924 b
Preplant (+30 lb N/A)	872	1118 a
Emerg + 3 wks (+30 lb N/A)	790	1001 ab
PHS + 2 wks (+30 lb N/A)	776	913 b
P -value	0.208	0.005
	--------NUE, over check (lb lint lb N^{-1})------	
Farm Practice (120 lb N/A)	---	---
Preplant (+30 lb N/A)	0.90	6.47 a
Emerg + 3 wk (+30 lb N/A)	-1.85	2.57 ab
PHS + 2 wks (+30 lb N/A)	-2.30	-0.38 b
P -value	0.121	0.021

CONCLUSIONS

The inclusion of a rye cover crop into a cotton monoculture system will result in the need for supplemental N fertilization to reduce the yield drag associated with N immobilization. Timing of that application is essential to increase yield, as our results indicate supplemental N fertilization preplant or at emergence plus three weeks will significantly increase yield compared to the control in conservation management systems. Traditional extension recommendations suggest supplemental N fertilization should be applied later in the growing season, generally around pinhead square, but our results indicate that would be too late in the growing season to see the benefit. Questions remain regarding the benefits of supplemental N fertilization in conventional cotton cropping systems without a cover crop. Additional research regarding the economics of these supplemental N fertilizations should be evaluated to determine if economic benefits exist given the yield increases.

ACKNOWLEDGEMENTS

This work was partially supported by Texas State Support – Cotton Incorporated and the Texas A&M AgriLife Strategic Initiative Fellowship in Water and Soil Health. The authors are grateful to Dustin Kelley, and Drs. Lewis and Keeling Research Groups for their assistance.

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IMPACT OF POST-FEEKES 6 NITROGEN APPLICATION IN WINTER WHEAT FORAGE PRODUCTION.

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ABSTRACT

Producers have options when choosing how to utilize their wheat acreage in Oklahoma. These include, grain harvest only, dual-purpose grazing and grain, and graze-out where the wheat crop is used solely for grazing cattle. Many producers take advantage of graze out wheat as a forage for cattle during the winter season. With acreages of approximately 400,000 acres of winter wheat grown for graze out production in the state of Oklahoma in 2018, many questions regarding management of wheat for grazing purposes have arose. This study, in conjunction with the Noble Research Institute, attempts to answer these question. Graze-out winter wheat trials were established in three locations across the state of Oklahoma. Each of these trials were planted to Gallagher variety, developed by Oklahoma Wheat Research Foundation, with three nitrogen treatments at 60 lb N ac^{-1}, 120 lb N ac^{-1}, and a 60 lb N ac^{-1} split application (60 lb N ac^{-1} pre-plant and 60 lb N ac^{-1} top-dress) applied following Feekes 6. Grazing management was simulated mechanically with two harvests at Chickasha and Lake Carl Blackwell locations and Dupy Farm only being harvested once. Final grazing of all locations was conducted at Feekes 11.1 with biomass and quality samples taken from each plot for protein, moisture, acid detergent fiber (ADF), total digestible nutrients (TDN) and, energy content analysis. Biomass yield increases were observed for with both the increase of pre-plant nitrogen and the delay of top-dress application. This study aims to evaluate the effect of a late season, post Feekes 6, application of nitrogen on wheat forage production. Another objective of the study was to evaluate management strategies for maximizing forage production and crop sustainability.The Chickasha and Lake Carl Black Well locations reported yield increases of 8% and 19%, respectively, when pre-plant nitrogen application was increase to 120 lbs N ac^{-1} as compared to the 60 lb N ac^{-1} application. A 29% and 60% increase was observed when the additional 60 lbs N ac^{-1} application was delayed until after Feekes 6 for Chickasha and Lake Carl Blackwell, respectively. Nitrogen uptake of wheat biomass followed a similar trend at all locations, with the exception of the 60 lbs N ac^{-1} and 120 lb N ac^{-1} pre-plant rates at the Dupy Farm location. The results from one year of this study demonstrates the impact of nitrogen application on the forage biomass yield of winter wheat, and provides insight on the impact of delaying N top-dress applications beyond the Feekes 6 stage of winter wheat.

INTRODUCTION

Large amounts of the winter wheat acres planted in the southern Great Plains is utilized for cattle grazing, and much of that land is grazed completely instead of being harvested for grain yields. On an annual basis in the southern Great Plains approximately 30% to 80% of planted wheat acreage is grazed with 10 to 20% grazed out completely, rather than harvested for grain(Pinchak et al., 1996). In the state of Oklahoma, it is reported that 9% of all wheat acreage is used for grazing only purposes(Epplin, True, & Krenzer Jr, 1998). Oklahoma wheat acres for 2018 were reported as having approximately 4.4 million acres planted, which would result in almost 400,000 acres being used solely for grazing purposes(NASS, 2018). Many producers have taken advantage of the opportunity to utilize wheat for winter grazing, leading to much interest in management strategies to improve their graze out system. Epplin et. al (1996) also report the state average application rate for nitrogen on forage only wheat is 78 lbs N ac^{-1}. A study conducted in Texas reported the greatest yield response occurs with the top dress of 45 lbs N ac^{-1} of nitrogen was applied to pre-plant applications of 0 and 30 lbs per acre(Sij, Belew, & Pinchak, 2016). This study, in conjunction with Noble Research Institute, is evaluating the effect of a late season, post-Feekes 6, application of Nitrogen on the production of winter wheat forage production, management strategies to improve crop yield and sustainability.

MATERIALS AND METHODS

This trial was conducted over the 2018-2019 winter wheat growing season in no-till dryland conditions, as a portion of a larger on going trial evaluating winter wheat forage management strategies for improving crop yield and sustainability. The trials were established at three locations spanning the central region of Oklahoma at Lake Carl Blackwell (LCB) near Stillwater, the South Central Research Station in Chickasha, and the Noble Research Dupy Farm (DUPY) near Gene Autry. A three by four by two factorial was established with the primary factor, wheat nitrogen application, of three applications of nitrogen (N) in the form of urea (46-0-0) at 60 lbs N ac^{-1} and 120 lbs N ac^{-1} and a split application of 60 lbs N ac^{-1} at pre-plant and 60 lbs N ac^{-1} top-dress application. The secondary factor treatments were summer rotation crops, with a cow pea (*Vigna unguiculata*) planted at 60 lb ac^{-1}, pearl millet (*Pennisetum glaucum*) planted at 20 lb ac^{-1}, a mixture of Cow pea at 30 lb ac^{-1} and Pearl millet at 10 lb ac^{-1}, and an unplanted summer fallow. The tertiary factory of the trial was summer nitrogen application of no nitrogen or 30 lb N ac^{-1} in the form of urea-ammonium nitrate (UAN, 28-0-0).

Soil samples were taken to 6 inch depth in each plot to evaluate the soil nutrient levels for nitrogen, organic matter content and total carbon content at prior to each wheat season, with 18 inch samples collected for soil physical properties. Gallagher variety was planted at all locations at a rate of 116, 120, 130 lbs ac^{-1} for Dupy Farm, Lake Carl Blackwell, and Chickasha locations, respectively. The planting dates for the LCB and Chickasha locations was mid-September, and mid-November for the Dupy Farm. Pre-plant fertilizer was applied prior to planting, while top dress nitrogen application was delayed until spring green-up was visually detected. In the 2018-2019 winter wheat season top dress applications were applied in the form of urea following the Feekes-6, or “first hollow stem”, stage due to increased precipitation preventing an ideal application timing.

An initial in-season harvest was taken for the LCB and Chickasha locations, by simulated grazing using a Carter Manufacturing flail-type 3 ft harvester, over both halves of the primary factor plots in preparation for tertiary factor implementation. A final harvest was collected at the end of the season prior to heading stages of maturity, near Feekes 10, at all locations. All winter wheat biomass greater than two inches in height was harvested for yield by weight. Grab samples were collected for moisture content and quality analysis from each sub-plot. Wheat forage collected was analyzed by Oklahoma State University Soil Water and Forage Analytic Laboratory for protein, moisture, acid detergent fiber (ADF), total digestible nutrients (TDN) and, energy content. For the purpose of these proceeding the primary factor treatments were analyzed statistically, using SAS 9.4, which resulted in three treatments with thirty-two replicates.

RESULTS AND DISCUSSION

Wheat yields from the first year of this trial resulted in minimal significance during the first harvest, with only the Lake Carl Blackwell resulted in 0.3 tons ac^{-1} increase in forage biomass yield from the increased 60 lbs of nitrogen application. Final harvest results in significant nitrogen application response at two, with yields being increased with the increase in nitrogen application as well as with the delay of the increase to an in-season application (Figure 1). Chickasha and LCB resulted in a 0.4 and 0.9 tons ac^{-1} biomass yield increase with increased rate,respectively, however the split application with the delay of the addition 60 lbs further increased yields of the two locations. Yield increases from the delayed top dress application resulted in 0.8 and 1.7 tons ac^{-1} for Chickasha and LCB, respectively. The Dupy location resulted in no significant yield differences in biomass production for the 2018-2019 wheat growing season.

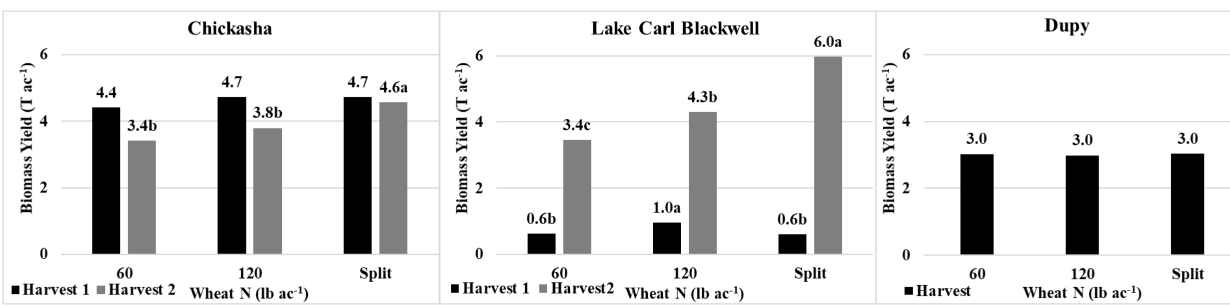

Figure 5. Dry matter harvest results (T ac^{-1}) for each of the harvest dates at each location. Wheat nitrogen rates 60lbs N ac^{-1}, 120lbs N ac^{-1}, and a split application of 60 lbs N ac^{-1}at pre-plant and 60lbs N ac^{-1} applied as top-dress. Dupy location only received a final harvest.

The Chickasha and Lake Carl Blackwell locations increased total yield with the increase in pre-plant nitrogen as well as with the delay of the additional 60 lbs nitrogen application (Figure 2). The additional 60 lbs at pre-plant resulted in a 0.7 and 1.2 ton ac^{-1} yield increase in biomass over the 60 lb pre-plant application at Chickasha and Lake Carl Blackwell, respectively. When the application of the additional 60lb nitrogen was delayed until after the achievement of Feekes 6 stage; forage biomass yields were increase over the 120 lb application by 0.8 and 1.3

tons ac^{-1} for Chickasha and LCB, respectively. Chickasha produced over greater biomass production than LCB due to increased residual N present in the soil.

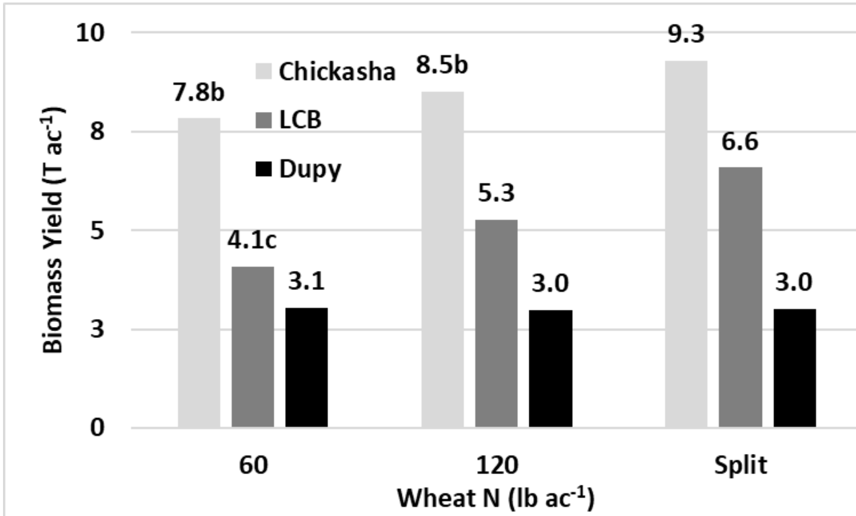

Figure 2. Total dry matter (T ac^{-1}) harvest results for each location. Wheat nitrogen rates 60lbs N ac^{-1}, 120lbs N ac^{-1}, and a split application of 60 lbs N ac^{-1}at pre-plant and 60lbs N ac^{-1} applied as top-dress.

Nitrogen uptake also revealed increases with the increased application as well as delayed addition of N fertilizer. Evaluation of the nitrogen uptake (%) as a factor of nitrogen content of the biomass by the amount of biomass harvested resulted in a 20% or greater N uptake at Chickasha and LCB with the additional 60 lbs of pre-plant nitrogen. Delay of the additional 60 lb N increase resulted in 3, 27, and 27 percent increases in uptake for Chickasha, LCB, and Dupy, respectively, over the 120 lb pre-plant application (Figure 3).

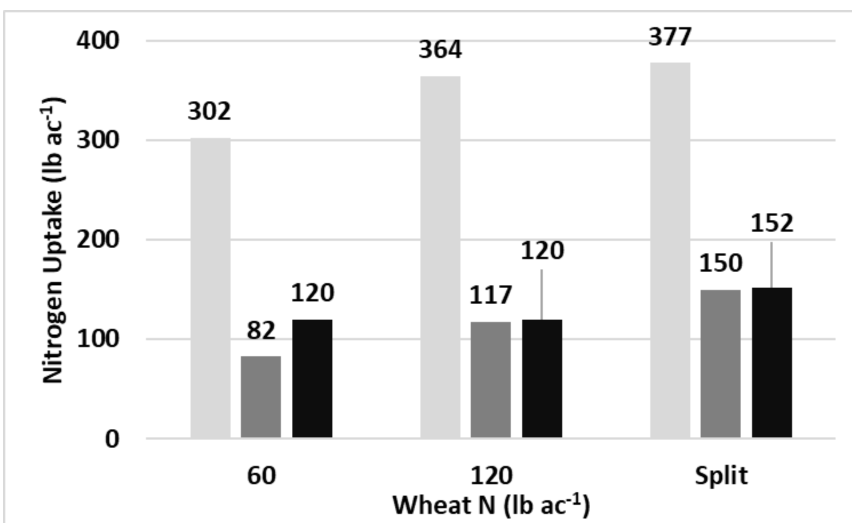

Figure 3. Nitrogen uptake (lb ac^{-1}) results for each location. Wheat nitrogen rates 60lbs N ac^{-1}, 120lbs N ac^{-1}, and a split application of 60 lbs N ac^{-1}at pre-plant and 60lbs N ac^{-1} applied as top-dress. Nitrogen uptake is nitrogen content of biomass by the amount of biomass harvested.

Year one results provide insight to the potential increase in forage biomass yields from the increase in nitrogen application. These increases in nitrogen application rate resulted in up to a 52% increase in forage biomass yield when applied as a pre plant application. The additional 60 lbs of nitrogen delayed until after Feekes 6 produced up to 95% increase in biomass production. These results support the finding of Belew et. al (2016) that state the addition of top-dress nitrogen increase biomass yield most effective and efficiently. While these results are only a portion of a larger study evaluating systems for winter wheat forage management, they can stand alone in showing the impact of nitrogen on the forage production yield potential.

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P-21

Investigating Relationships between Haney H3A-4 And Conventional Soil Tests For Plant Nutrients In Kansas Soils

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ABSTRACT

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

INTRODUCTION

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

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

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

MATERIALS AND METHODS

Field studies were initiated at multiple sites across the state of Kansas during the 2017, 2018, and 2019 corn growing seasons, 14 site-years in total (Table 1). Treatments consisted of N, P, and K fertilizer combinations applied at rates ranging from 0 to 200 lbs N ac^{-1}, 0 or 80 lbs P_2O_5 ac^{-1}, and 0 or 100 lbs K_2O ac^{-1}. These treatments were applied to 10 ft wide by 40 ft long plots. Plots were arranged as a randomized complete block design with four replications at each site. Measurements collected include whole plant dry biomass at R6 growth stage, R6 biomass and grain NPK content, and harvest grain yield. Soil samples were collected from each plot using a hand probe to a depth of six inches prior to treatment application. Soil measurements include soil pH, M3 and H3A-4 extractable P, K, Ca, Mg, Al, Cu, Fe, Mn, and Zn.

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

Relationships between Mehlich-3 and H3A-4 extractable nutrients were evaluated using linear regression models. Relationships between relative nutrient uptake and soil test P and K were investigated using linear plateau and quadratic plateau models. Data analyses were performed in R version 3.6 (R Core Team, 2019) and evaluated at the 95% confidence level.

RESULTS AND DISCUSSION

Mehlich-3 and H3A extractable P and K were highly correlated (r = 0.90 and 0.91, respectively) and exhibit a linear relationship in combined data (Figures 1, 2). On average, M3 extracted approximately 25% more P and 250% more K than H3A-4 (Figures 1, 2). The RMSE of these regression models (15.4 mg P kg soil^{-1} and 83.4 mg K kg soil^{-1}) is too large to allow for estimation of M3 P or K from H3A-4 P or K for the purposes of fertility recommendations. Existing calibration curves for soil test P and K for Kansas soils are based on either Mehlich-3 or Bray-1. These data clearly illustrate that separate calibrations would be required to make fertilizer recommendations from H3A-4 P or K soil tests.

Relative total P and K uptake (RTU_P and RTU_K) were calculated based on above ground biomass production, grain production, and P and K contents of these biomass. Relationships between RTU_P and RTU_K and soil test P and K were not significant (Figure 3,4,5,6). The critical soil test P and K values for corn in Kansas are 20 mg P kg^{-1} and 130 mg K kg^{-1}. This lack of response was consistent across N application rates, and is likely the due to relatively high soil test concentrations of P and K in these soils (Table 1, Figure 3,4,5,6). Future studies should target low P and K soils.

Mehlich-3 and H3A-4 extractable P and K appear highly correlated in Kansas soils. However, RMSE values of regression models indicate that these relationships are not strong enough to simply convert H3A-4 soil test values to M3 values for fertilizer recommendations. Existing calibration and correlation data relating conventional soil tests to relative yield and nutrient uptake are likely not appropriate for use with the H3A-4 soil test.

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Table 3. General site descriptions, and soil chemical and textural parameters for 14 experimental sites included in the study. All sites were located across Kansas. Soil parameters were measured from composite soil samples representing the site. Phosphorus (P) and potassium (K) were determined using Mehlich-3 soil test.

SiteID	Year	County	Tillage	pH	OM	P	K	CEC	Sand	Silt	Clay
					%	- - - soil ppm - - -		$cmol_c\ kg^{-1}$	- - - - - % - - - - -		
1	2017	Riley	Conv.	6.7	2.8	41	250	-	16	60	24
2	2017	Riley	Conv.	6.9	2.9	41	260	-	8	54	38
3	2017	Mitchell	No-till	5.8	3.0	26	430	-	18	60	22
4	2017	McPhers.	Conv.	7.7	3.4	83	718	-	26	44	30
5	2018	Franklin	Conv.	6.1	3.0	15	96	22.2	14	62	24
6	2018	Mitchell	No-till	5.7	2.7	56	520	27.7	16	52	32
7	2018	Mitchell	No-till	5.2	3.2	30	234	27.1	26	44	30
8	2018	Mitchell	No-till	5.6	3.9	23	463	24.7	22	48	30
9	2019	Mitchell	No-till	4.9	3.4	68	368	25.7	16	56	28
10	2019	Mitchell	No-till	5.4	3.3	75	534	25.5	8	60	32
11	2019	Riley	Conv.	5.8	1.8	32	270	13.8	34	52	14
12	2019	Shawnee	Conv.	6.7	1.6	42	140	8.0	52	38	10
13	2019	Republic	Conv.	5.7	3.6	6	408	22.2	20	56	24
14	2019	McPhers.	No-till	6.2	3.4	139	560	21.3	24	52	24

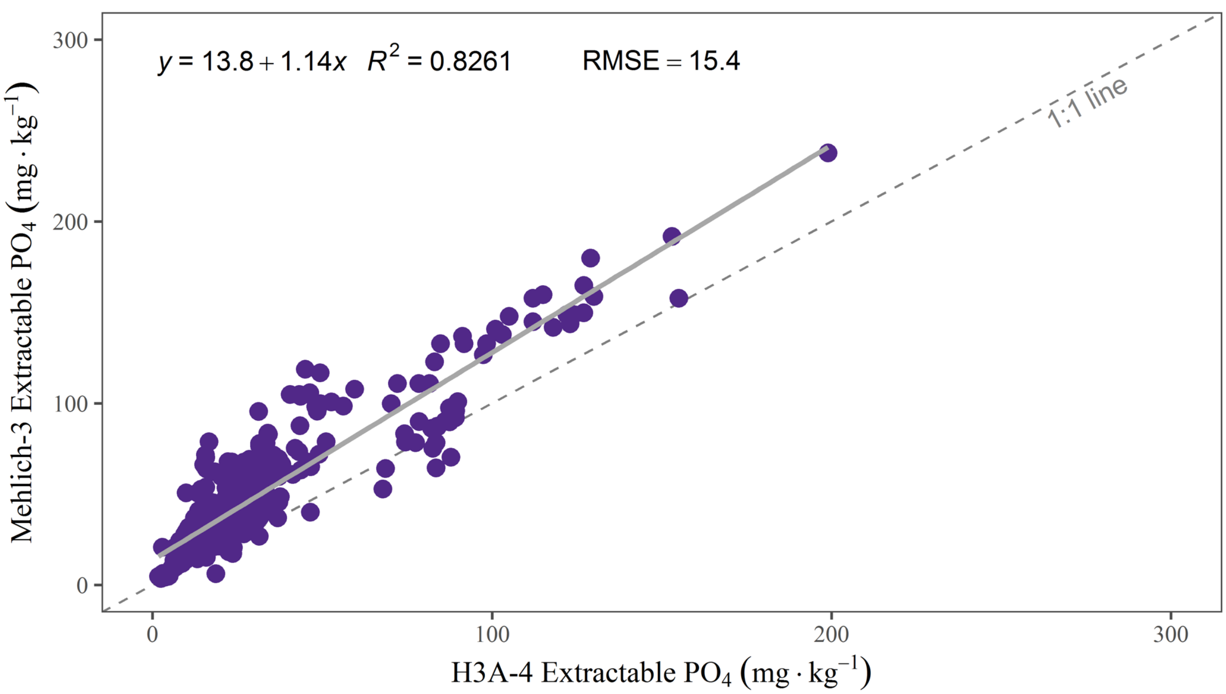

Figure 6. Mehlich-3 (horizontal axis) and H3A-4 (vertical axis) extractable orthophosphate from soils collected from plots at each site. The combined data show a positive linear relationship between the two soil test methods for P, with M3 extracting approximately 30% more P than H3A-4.

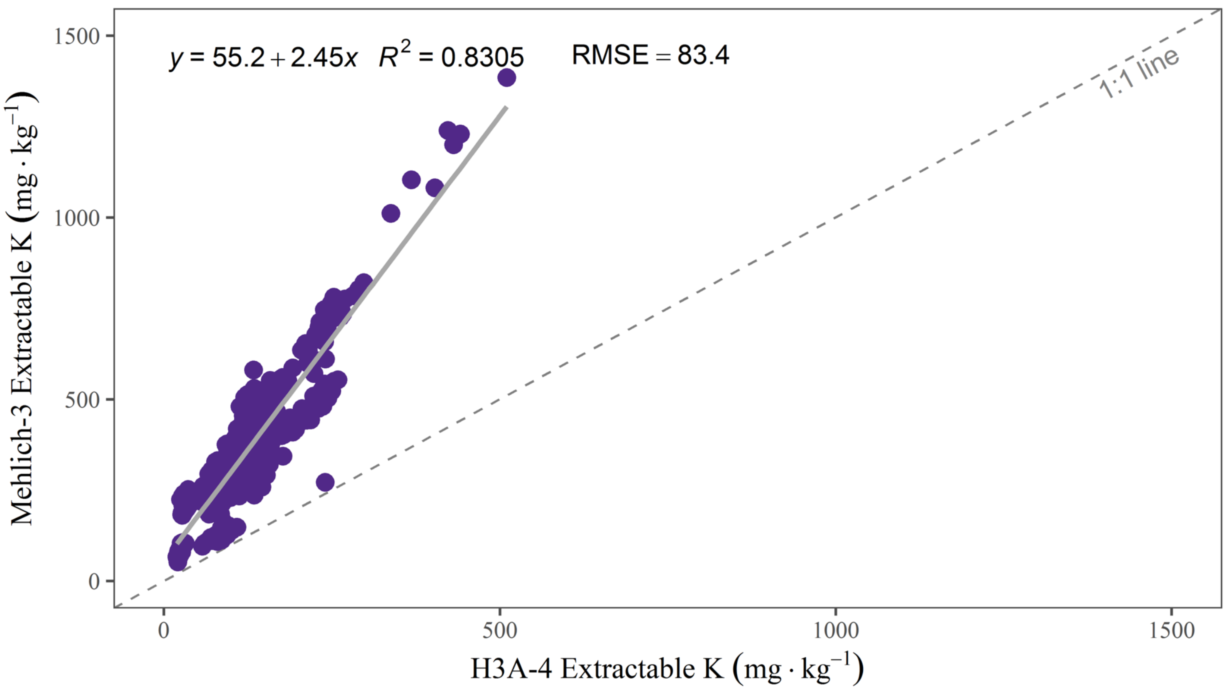

Figure 7. Mehlich-3 (horizontal axis) and H3A-4 (vertical axis) extractable potassium (K) measured from soil samples representing the 0-6 in (15 cm) soil layers. M3 K and H3A-4 K exhibit a positive linear relationship in these combined data, with M3 extracting approximately three times more K than H3A-4.

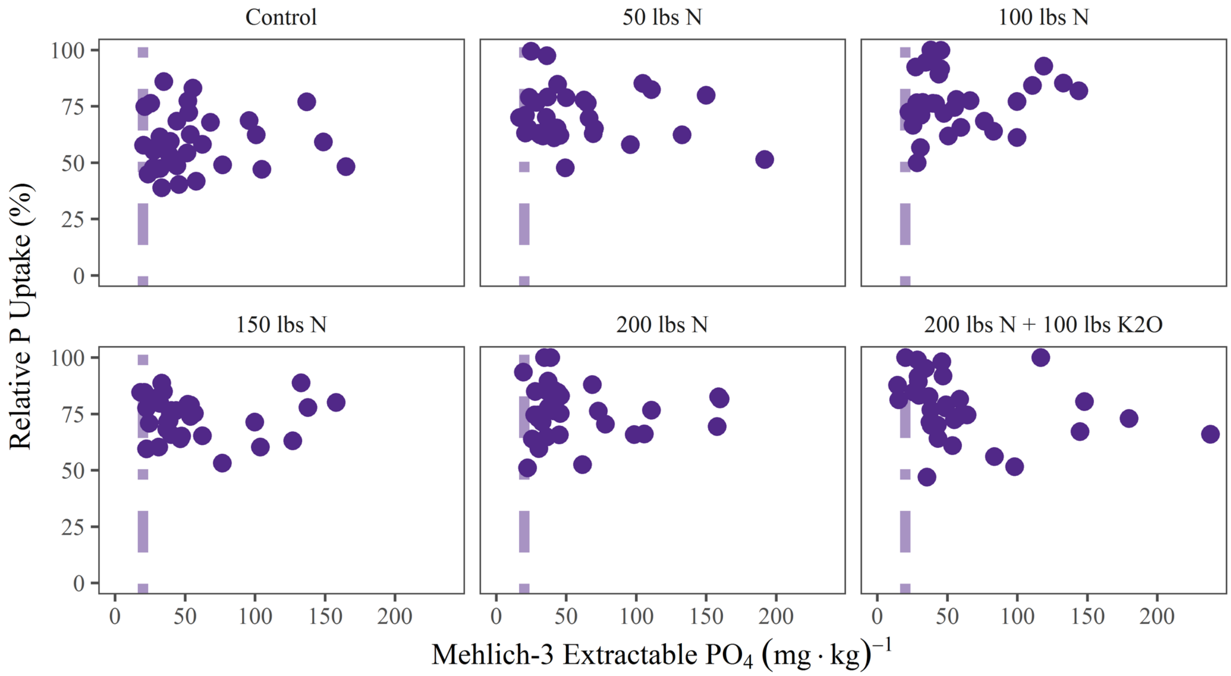

Figure 8. Mehlich-3 extractable orthophosphate (horizontal axis) vs. relative total phosphorus (P) uptake (vertical axis) for all sites combined. Data were grouped by fertility management practice. Facet labels indicate the amount of N, P, or K fertilizer added on a per acre basis, where the "Control" plots received zero added nutrients.

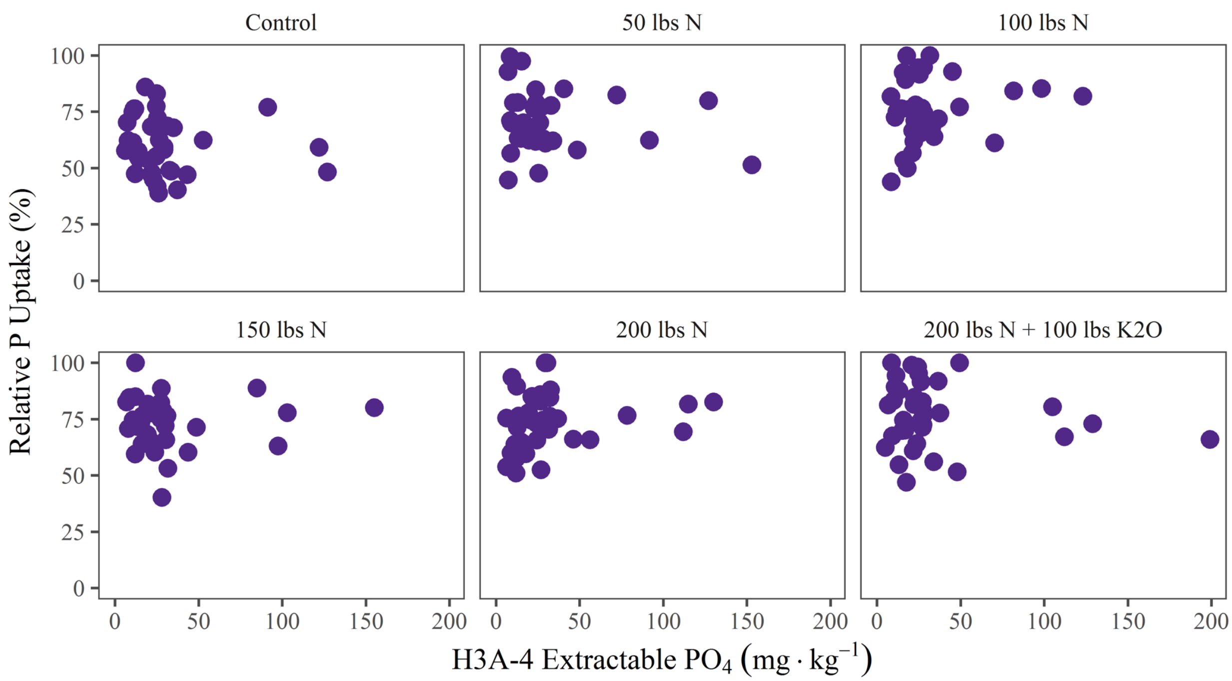

Figure 9. Haney H3A-4 extractable orthophosphate (horizontal axis) vs relative total phosphorus (P) uptake (vertical axis) for all sites combined. Data were grouped by fertility management practice. Facet labels indicate the amount of N, P, or K fertilizer added on a per acre basis, where the "Control" plots received zero added nutrients

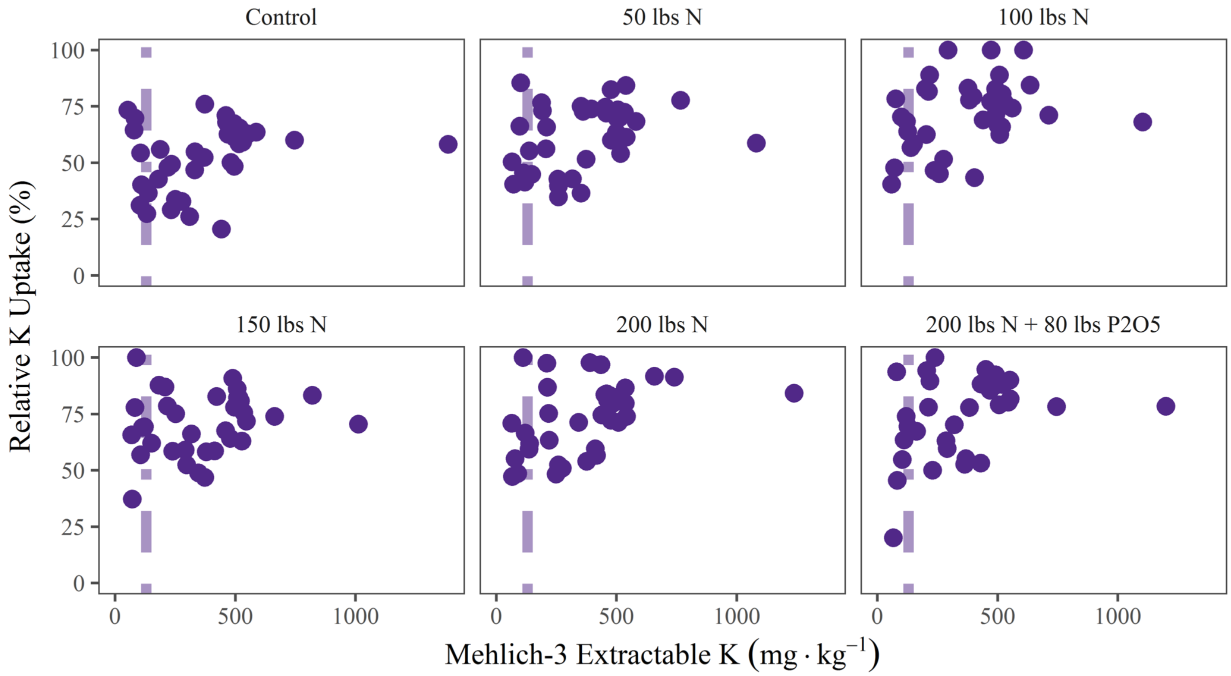

Figure 10. Mehlich-3 extractable potassium (horizontal axis) vs relative total K uptake (vertical axis) for all sites combined. Data were grouped by fertility management practice. Facet labels indicate the amount of N, P, or K fertilizer added on a per acre basis, where the "Control" plots received zero added nutrients.

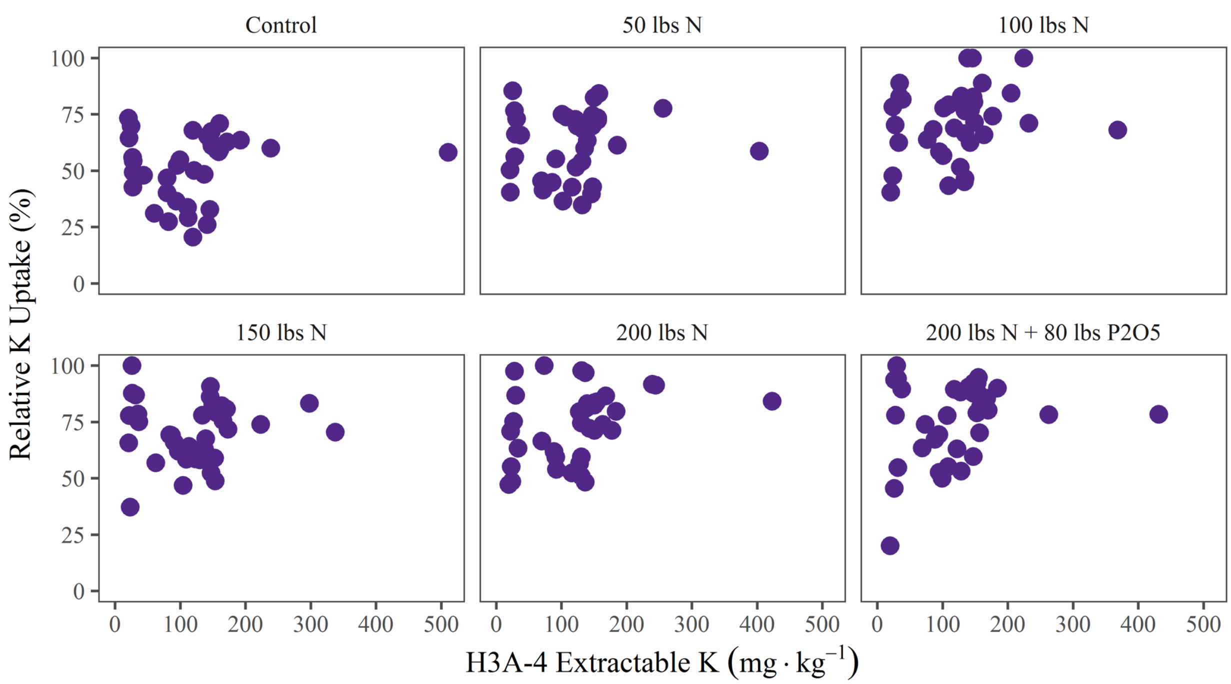

Figure 11. Haney H3A-4 extractable potassium (horizontal axis) vs. relative total K uptake (vertical axis) for all sites combined. Data were grouped by fertility management practice. Facet labels indicate the amount of N, P, or K fertilizer added on a per acre basis, where the "Control" plots received zero added nutrients.

P-22

UTILIZING LONG-TERM ORGANIC AMENDMENTS TO IMPROVE SOIL HEALTH IN SEMI-ARID, GRAZED GRASSLANDS

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ABSTRACT

Determining soil health changes associated with long-term land application of organic amendments, such as biosolids, is important for understanding and improving overall environmental health. In 1991, a single application of biosolids were surface applied (treatment rate: 0, 2.5, 5, 10, 21, or 30 Mg ha^{-1}) to a semi-arid grazed grassland. In 2002, a repeated application of biosolids were surface applied at the same rate to ½ of all plots. In 2018, soil samples were obtained from 0-15 cm depths in all plots. The Soil Management Assessment Framework (SMAF) was used to provide a foundation for quantifying soil health by utilizing soil physical, biological, chemical, and nutrient health indicators, in conjunction with soil management practices, climatic conditions, and taxonomy. Results showed that there was no significant changes in soil physical and nutrient health indices. However, biological soil health was positively affected by increasing application rate or the repeated application as compared to the single application. Chemical soil health was greater with lower biosolids application rates and the single compared to repeated applications. When all indices were combined, overall soil health was "best" at all biosolids application rates except the 30 Mg ha^{-1} rate. A 'sweet spot' exists when applying organic amendments to land by which the material is not under or over-applied, causing no changes or deficiencies, or causing excesses in various soil characteristics.

INTRODUCTION

Biosolids are nutrient-rich organic materials that are a byproduct of municipal wastewater treatment. Once treated and processed, these residuals are often recycled and applied to agricultural lands as an amendment to improve various soil properties and encourage plant growth. The controlled land application of biosolids completes a natural cycle in the environment and is preferable to taking up space in a landfill or other disposal facilities. Paramount to any land application program is the understanding of how biosolids may affect soil health.

Soil health is an assessment of how well soil performs all of its functions now and how those functions are being preserved for future use (Doran et al., 2000). Soil health cannot be determined directly by measuring only a single outcome such as crop yield or water quality. Instead, soil health is evaluated from physical, biological, chemical, and nutrient indicators. Years of scientific research support that fact the organic amendment applications, like biosolids, have a positive impact on disturbed lands, which may then directly or indirectly affect the overall soil health (USEPA, 2017). The objective of this study was to determine the long term effects on soil health properties in response to single or repeated, low to excessive biosolid applications, on semi-arid (over) grazed grasslands.

MATERIALS AND METHODS

Experimental Site Design

This study was conducted on long-term experimental research plots within the Meadow Springs Ranch, Larimer County, CO (40 53'46"N, 104 52'28"W). The ranch (1,750 m elevation) is owned by and located north of the City of Fort Collins, which uses it for the city's land-based biosolids recycling program. The study site is a semi-arid, shortgrass steppe rangeland community dominated by perennial grasses. In 1991 plots (15x15 m) were originally established (Harris-Pierce 1994) and arranged in a randomized, complete block design with four replicates and application rates equal to 0, 2.5, 5, 10, 21, or 30 Mg ha^{-1}. In 2002, each plot was divided in half (7.5x15 m) and a second application equaling the first application was applied to the eastern ½ of each plot (Sullivan et al., 2006). In September 2018, a hydraulic Giddings probe was used to collect four soil cores (0-15 cm depth) from each plot. Three cores were composited and then placed in Ziploc bags, while the fourth core was used for bulk density and soil water content determination. Composite soils were passed through an 8mm sieve, a representative sub-sample (~150 g) of 8 mm sieved field moist was stored in a Ziploc bag at 4º C, another sub-sample (~300 g) of the 8 mm sieved soil was passed through a 2 mm sieve and allowed to air dry, and the remaining 8 mm sieved soil was also allowed to air dry. Once dry, a small sub-sample (~5 g) of the 2 mm sieved air dry soil was powder ground.

Soil Health and Laboratory Soil Analysis

The Soil Management Assessment Framework (SMAF) is an assessment tool that provides a foundation for quantifying soil health by utilizing 11 soil indicators, in conjunction with soil management practices, climatic conditions, and taxonomy (Andrews et al., 2004). These soil indicators include: 1) soil physical health indicators: bulk density and water stable aggregates; 2) soil biological health indicators: soil organic carbon, microbial biomass carbon, potentially mineralizable nitrogen, and beta-glucosidase activity; 3) soil chemical health indicators: pH and electrical conductivity (EC); and 4) soil nutrient health indicators: plant-available potassium and phosphorus. The SMAF utilizes clay content, determined by the soil texture analysis, in the background due to the influence clay content has on most other indicators for soil health quantification. Once all information has been entered into the SMAF, individual indicators are grouped into physical, biological, chemical, nutrient, and overall soil health indices (SHI). To create an output that reflects the specific limitations and needs of the soil to function at its fullest potential, the SMAF takes into account the soil's quantified properties, climatic conditions, how it is utilized, and the management practices performed.

Statistical Analysis

The Meadow Springs Ranch site is a split-plot design (with time) containing four replicates. Utilizing SAS 9.4 (SAS Institute, Inc., 2012), we performed ANOVA using PROC GLM and if significant differences were present (at an α of 0.05) within treatments or time, we determined mean separation using Tukey adjusted pairwise comparisons. The interaction between treatment and time was also taken into consideration.

RESULTS AND DISCUSSION

Soil Physical and Nutrient Health Indices

There was no significant change in physical soil health indices between treatments, application times, or interactions of treatment and time (data not shown). In fact, soil physical health was maximized in this system. There was no significant change in nutrient soil health indices between treatments, application times, or interactions of treatment and time. A trend did exist, however, with nutrient soil health tending to decrease with increasing biosolids application (Figure 1).

Soil Biological Health Indices

There was a significant change ($p < 0.05$) in biological soil health indices between treatments (Figure 2), application times (Figure 3), and interactions of treatment and time. This result is likely due to the combination of all four biological health indicators. There was a significant change ($p < 0.05$) in soil organic carbon between treatments, application times, and interactions of treatment and time. There was no significant change in microbial biomass carbon or potentially mineralizable nitrogen between treatments, application times, and interactions of treatment and time; but there was a positive trend with increasing application rate. There was no significant change in beta-glucosidase activity between treatments, application times, and interactions of treatment and time; but there was a negative trend with increasing treatment rate. When this aforementioned data is combined, it affected the soil biological health index as described above.

Soil Chemical Health Indices

There was a significant change ($p < 0.05$) in chemical soil health indices between treatments (Figure 4) and application times (Figure 5), but no significant interactions existed. Specifically, a significant change existed ($p < 0.05$) in pH between treatments, but not between application times and interactions of treatment and time. There was a significant change ($p < 0.05$) in EC between application times, but not between treatments and interactions of treatment and time.

Overall Soil Health Index and Conclusions

There was a significant change ($p < 0.05$) in the overall soil health index (Figure 6) between treatments. However, there was no significant change in overall soil health indices between application times and interactions of treatment and time. The end result is that a 'sweet spot' exists whereby biosolids over-application has detrimental effects on soil health. Based on the overall soil health index, it is suggested to apply no more than 21 Mg biosolids ha^{-1}, at least when applying repeated applications over time. More research is obviously required to better match what the city of Fort Collins, CO and other municipalities perform.

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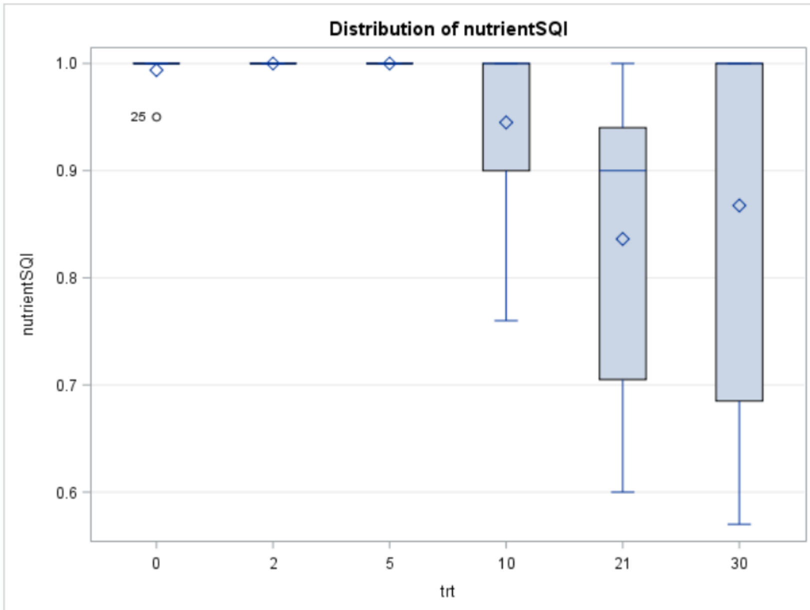

Figure 1. Changes in the soil nutrient health index (scored from 0 to 1, with 0 being ‘worst’ and 1 being ‘best’) with increasing biosolids application rate. Although no significant differences existed between treatments, a trend existed with increasing biosolids application rate. Diamonds = mean, while horizontal dark lines = median (n=8).

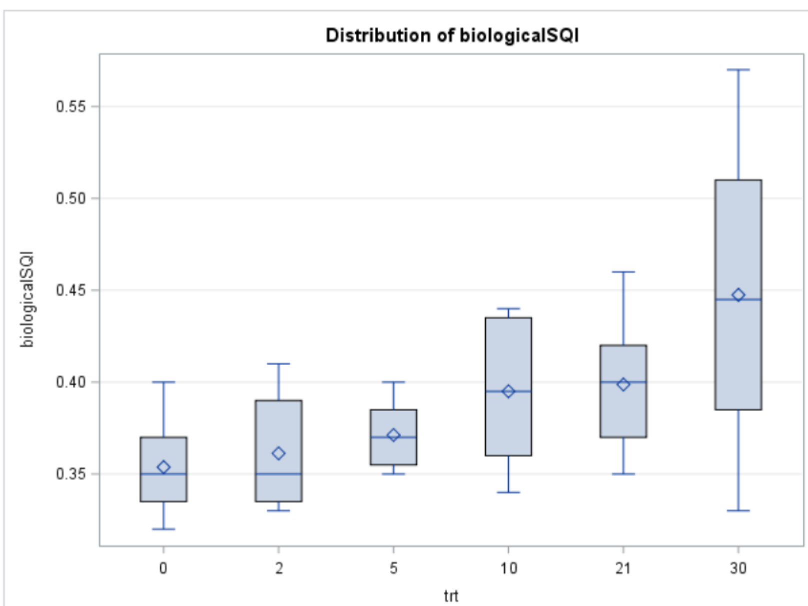

Figure 2. Changes in the soil biological health index (scored from 0 to 1, with 0 being ‘worst’ and 1 being ‘best’) with increasing biosolids application rate. Significant differences (α<0.05) existed with increasing biosolids application rate. Diamonds = mean, while horizontal dark lines = median (n=8).

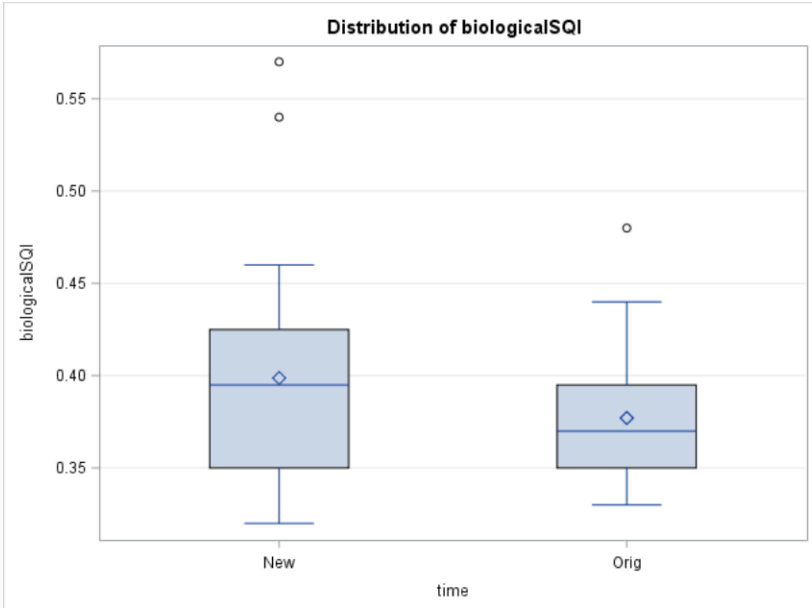

Figure 3. Changes in the soil biological health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') based on original (i.e., one time biosolids application) or new (i.e., repeated biosolids application). The new biosolids application had significantly greater (α<0.05) biological soil health as compared to the original application. Diamonds = mean, while horizontal dark lines = median (n=24).

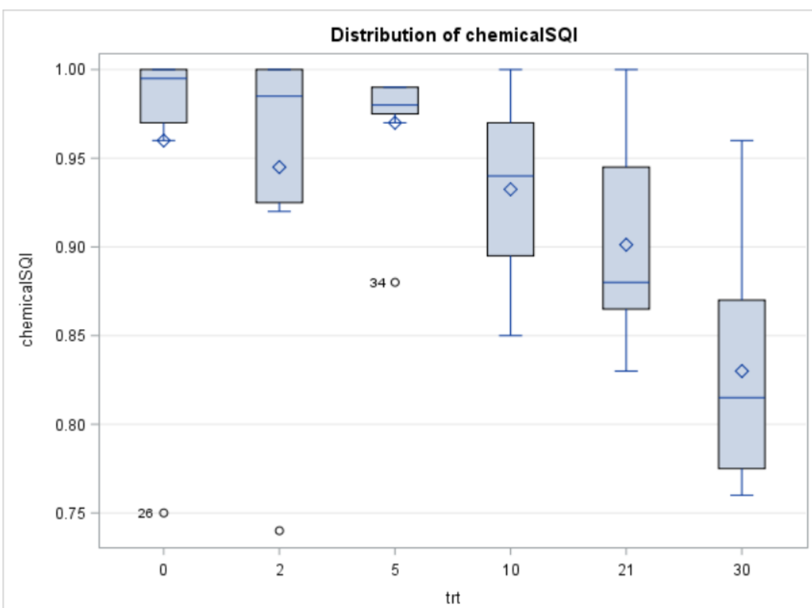

Figure 4. Changes in the soil chemical health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') with increasing biosolids application rate. Significant differences (α<0.05) existed with increasing biosolids application rate. Diamonds = mean, while horizontal dark lines = median (n=8).

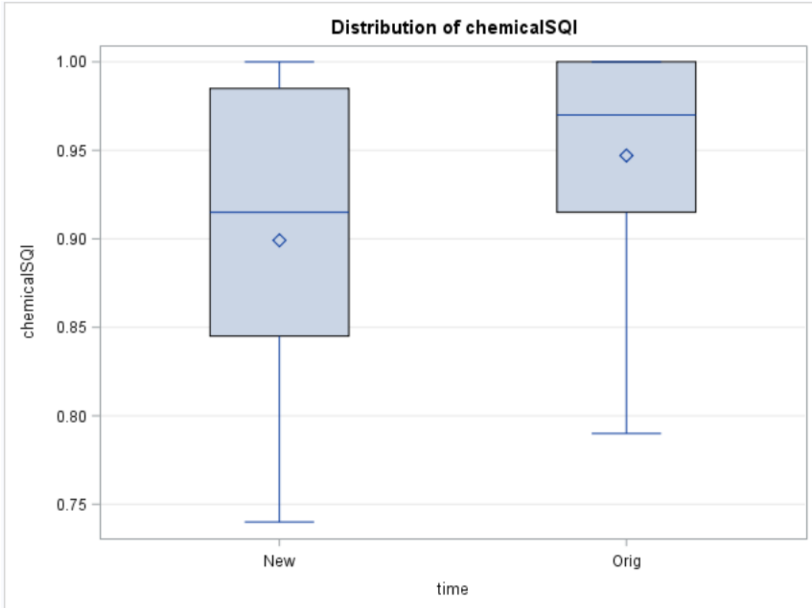

Figure 5. Changes in the soil chemical health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') based on original (i.e., one time biosolids application) or new (i.e., repeated biosolids application). The new biosolids application had significantly lower (α<0.05) chemical soil health as compared to the original application. Diamonds = mean, while horizontal dark lines = median (n=24).

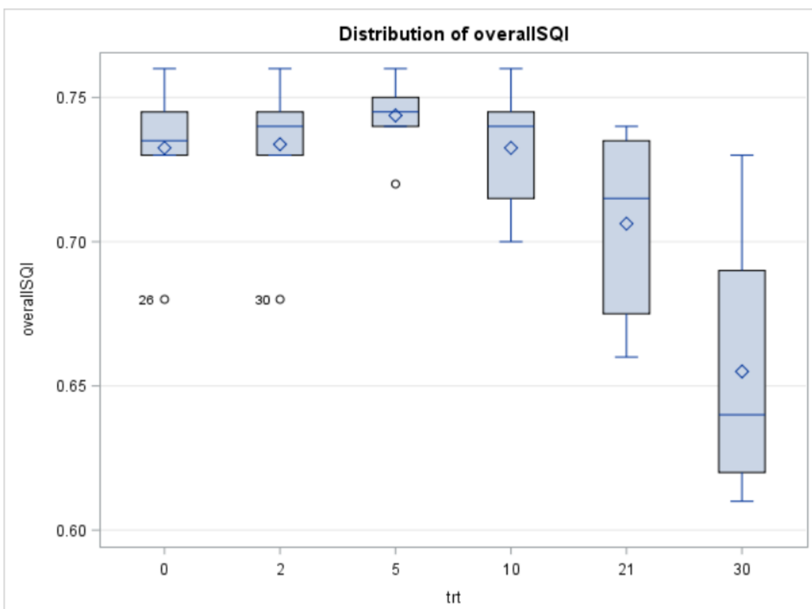

Figure 6. Changes in the overall soil health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') with increasing biosolids application rate. Significant differences (α<0.05) existed with increasing biosolids application rate. Diamonds = mean, while horizontal dark lines = median (n=8).

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CONSERVATION MANAGEMENT AND NITROGEN FERTILIZATION TO ENHANCE SOIL CHEMICAL AND BIOLOGICAL PROPERTIES

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ABSTRACT

Cover crops and no-tillage are increasing in use across Texas. On the Southern High Plains (SHP) these practices are important mitigators of wind erosion and are suggested to increase soil health and other positive soil attributes. This study aimed to monitor and evaluate the soil chemical and biological changes that occur shortly after implementing conservation practices and nitrogen management strategies on the SHP. It was determined that in the short term some soil chemical and biological changes may be attributed to cover crop and no-tillage implementation. In addition, cotton lint yield was increased with no tillage and cover crop compared to conventional till three years after implementation.

INTRODUCTION

The Southern High Plains (SHP, MLRA 77C) are an intensively cropped semi-arid region surrounding Lubbock, TX. The major crop on the SHP is cotton (*Gossypium hiristum* L.), which comprised about 3.1 million acres in in 2019 (NASS, 2019). Over the last century, much work has been done to reduce wind erosion across the region resulting in a significant reduction in erosion (Zobeck & Van Pelt, 2011). In the last few decades, these efforts have increased due to increasing encouragement for producers to adopt soil health promoting practices through government assistance and cost-share programs aimed at increasing the use of winter cover crops in the area. However, there isn’t much data regarding the short-term impacts of these conservation systems on cotton production on the SHP.

The main objective of this study was to evaluate soil chemical and biological properties at major points in the cotton growing system 3 years after implementing soil and N management practices. In addition, cotton lint yield was evaluated to increase our knowledge about how these practices and soil health factors impact cotton lint yield on the SHP.

MATERIALS AND METHODS

This study was conducted at the Texas A&M AgriLife Research and Extension station in Lubbock, Texas (33.68767°, -101.827696°) during 2018. The soil in this area is an Acuff loam and was evaluated for macronutrient composition prior to beginning the study in 2016 (McDonald et al., 2019). Rainfall for this area averages about 19 in, and this study was irrigated as needed using furrow irrigation.

A randomized complete block arranged as a split plot was used in order to make tillage practice consistent through the entire length of the field. The main-plot was tillage system including no-tillage with a triticale (*Triticale hexaploide Lart*) cover crop (NTW), no-tillage winter fallow (NT), and conventional tillage winter fallow (CT). The split-plot for this study was the timing of N fertilizer application including: 100% pre-plant application (PP), 100% mid-season application applied at pinhead square (MS), 40% PP and 60% MS application (SPLIT), 100% PP with N stabilizer (urease inhibitor, STB), and a no N control. Plots were 50 ft in length by 4 rows wide (40” spacing) and all tillage and treatment combinations were conducted in triplicate. The wheat cover crop was drilled (8” spacing) several times before a successful establishment of triticale (Trical 813) was planted on 15 February 2018 at 60lbs/acre. The cover was terminated on 22 May 2018 prior to cotton (Delta-Pine 1518 B2XF) planting on 24 May 2018 at a rate of 53,000 seeds/acre. The late termination was in response to the late planting and the desire to allow the cover crop extra growth time prior to the growing season. Cotton was harvested on 16 November.

Soil samples were collected at major crop growth periods including vegetative growth (Veg, 28 June 2018), peak plant production (Peak, 24 August 2018), and reproductive growth (Repro, 1 November 2018). Soil samples were dried, and a 40 g aliquot was used to determine C mineralization with a 3-day incubation-titration (Franzluebbers, 2016). The remaining soil was ground to pass a 2mm sieve and evaluated for: nitrate-N (NO_3^--N) and ammonium-N (NH_4^+-N) by extracting with 2 N KCl at a 1:10 soil to extraction ratio and analyzing using flow injection spectrometry (FIAlab 2600, FIAlab Instruments Inc., Belevue, WA, Keeney and Nelson, 1982); pH with a 1:2 soil to deionized water slurry and a pH probe (Schofield & Taylor, 1955). In addition, the gravimetric water content (0-4 in, 4-8 in, GWC) of the soil was determined by drying the soil at 140°F for at least three days.

Statistical Analysis of soil characteristics and yield was conducted in SAS 9.4 using the PROC GLIMMIX procedure at a significance level of $a < 0.05$ (SAS-Institute, 2017). In addition, the data was analyzed via principle components analysis (PCA) using the ggbiplot function in the R statistical program (R-Core-Team, 2019; Vu, 2011).

RESULTS AND DISCUSSION

Analysis of soil characteristics determined differences due to the interaction of month and depth with the implemented tillage systems and N treatments. Due to the interactions, all soil characteristics were analyzed within month and depth. Carbon mineralization was affected by tillage system at the 0-4 in depth for the Peak (p<0.001) and Repro (p=0.005) samplings with the NTW and NT systems having greater mineralizable C than the CT system at both samplings (Table 1). No N treatment or interaction of tillage system and N treatment effects on mineralizable C were determined at the 0-4 in depth or at the Veg sampling. At the 4-8 in depth, there were no differences at any sampling for tillage system, N treatment, or their interaction. This lack of effects at the 4-8 in depth is likely due to the depth of tillage implemented in the CT system (2-3 in) and the recentness of the tillage system’s implementation (November 2015) in addition to the majority of microbial activity occurring in the upper layers of the soil.

Gravimetric water content was affected by tillage system at the 0-4 in depth (p=0.027) with the NT and NTW systems having greater GWC than the CT system. Increased GWC in the no-tillage systems is expected at this point in the growing season due to the potential for reduced evaporation from these systems in semi-arid climates (Jones, Hauser, & Popham, 1994). The differences in GWC due to N treatment at Peak (0-4 in: p=0.002; 4-8 in: p=0.003) occur between no application and early-season N applications compared to the treatments with mid-season applications. When N is not applied till the first reproductive growth, the plant may be behind in growth stage and an application of N may spark rapid growth and thus increased the water demand within those treatments. At the Repro sampling, GWC was affected by tillage system at the 0-4 in depth (p=0.006) with the NTW system having greater GWC than the CT system (Table 1). This would be expected as late season rains would have increased GWC across all tillage systems, but with reduced evaporation and the NTW system is expected to have greater GWC.

Nitrate was affected by N treatment at the Veg sampling at 0-4 in (p=0.050) and 4-8 in depths (p=0.019) with the PP treatment having greater NO_3^--N concentrations than the control and MS treatment at both depths (Table 1). In addition, the concentration of NO_3^--N was greater for the STB treatment compared to the control and MS treatment at the 4-8 in depth. This difference in NO_3^--N concentration is expected at this sampling point due to the pre-season application of N within the PP and STB treatments and no N addition in the control and MS treatment at this point. The concentration of NO_3^--N was determined to be affected by tillage system at the Peak sampling (p<0.001) with the CT system having greater NO_3^--N concentrations than the NTW and NT systems. This could be due to greater plant growth in the NTW and NT systems which would reduce NO_3^--N for those systems. The concentration of NH_4^+-N was affected by N treatment at the Veg (p<0.001) and Peak (p<0.001) samplings at the 4-8 in depth. The PP treatment had a greater NH_4^+-N concentration at 4-8 in than the SPLIT treatment and the control for the Veg sampling. This difference, like the differences determined for NO_3^--N at the Veg sampling, is expected due to the application of N as UAN, and only the PP and STB treatments receiving the full rate at this point in the growing season. For the Peak sampling, the MS treatment had a greater concentration of NH_4^+-N than the rest of the N treatments and the control. As mentioned before, the MS treatment received all its N during the month of July, so a greater concentration of NH_4^+-N is expected compared to the rest of the N treatments. The lack of differences in NO_3^--N concentration compared to the differences seen for NH_4^+-N can be attributed to the mobility of NO_3^--N in the soil and other loss pathways of NO_3^--N.

Nitrogen treatment affected soil pH at all sampling points for all depths. At the Veg sampling the control had a greater pH than the SPLIT, PP, and STB treatments at the 0-4 in (p=0.003) and 4-8 in (p<0.001) depths (Table 1). In addition, pH was greater in the MS treatment compared to the PP and STB treatments at both depths and the split treatment at the 4-8 in depth. A similar trend occurred at the Peak sampling, with the control having a greater pH than the rest of the N treatment, and the MS treatment having a greater pH than the PP treatment at the 0-4 in depth (p<0.001). At the 0-4 in depth, pH was greater in the control compared to all N treatments at the Peak sampling (p=0.002). At the Repro sampling, the control had a greater pH than all N treatments except the MS treatment, and the MS treatment had a greater pH than the STB treatment at the 0-4 in depth (p=0.035). At 4-8 in, the pH of the control was greater than that of all the N treatments for the Repro sampling. It is expected that pH would be decreased following N application early in the season accounting for the reduced pH in the treatments with PP applications at the Veg sampling. The pH also consistently increases throughout the year which is likely due to the pH of the irrigation water at this location.

Cotton lint yield was affected by tillage system (p=0.016) with the NTW producing greater cotton lint (1018.7 lb ac^{-1}) than the CT system (598.2 lb ac^{-1}). This yield increase may be due to the early season protection of the cotton seedlings from harsh environmental conditions including 100^{o}F temperatures and average wind speeds of about 14.5 mph. Nitrogen uptake was also affected by tillage (p=0.014) with the NTW system having greater N uptake (101.5 kg ha^{-1}) than the CT system (65.2 kg ha^{-1}). Greater N uptake is likely due to greater plant growth in the NTW system.

To better understand how soil characteristics discussed above affected cotton lint yield during this growing season, a principle components analysis was conducted (Fig. 2). It was determined that the first component (PC1) was a measure of soil C for the Veg sampling at 0-4 in in depth (Fig. 2a). the first component (PC1) was a measure of soil C for the Veg sampling at

Table 1. Soil chemical characteristics at 0-4 in and 4-8 in for the vegetative growth stage, peak plant production, and reproductive growth stages in 2018.

0-4 in

Stage	Soil Chemical Characteristic	Unit	NTW[a] Control[b]	NTW PP	NTW MS	NTW SPLIT	NTW STB	NT Control	NT PP	NT MS	NT SPLIT	NT STB	CT Control	CT PP	CT MS	CT SPLIT	CT STB
Vegetative Growth	pH		7.84	7.44	7.73	7.65	7.51	7.80	7.43	7.84	7.67	7.62	7.80	7.60	7.68	7.61	7.53
	GWC[c]	%	13.7	13.3	13.6	14.5	13.3	13.2	13.3	13.4	16.4	15.1	11.1	13.8	13.6	13.6	13.9
	Mineralized C	ppm	135.0	120.0	122.8	151.0	177.0	155.3	77.9	133.5	141.4	123.0	123.3	141.0	99.0	139.8	107.3
	NO_3^--N	ppm	5.16	15.34	2.80	8.49	5.95	1.46	10.10	1.49	5.53	10.45	9.89	9.34	28.91	22.71	52.25
	$NH4^+$-N	ppm	26.61	1.37	1.01	13.08	0.00	13.44	17.11	0.00	13.71	19.53	19.13	0.00	27.26	13.39	0.00
Peak Plant Production	pH		10.28	6.74	8.71	11.27	7.17	6.99	8.37	11.20	12.11	5.50	11.60	6.46	11.01	7.11	7.43
	GWC	%	9.4	9.6	8.7	8.6	8.9	8.6	9.5	8.2	8.9	10.2	9.0	8.7	7.3	8.4	8.9
	Mineralized C	ppm	87.0	84.5	87.5	96.8	66.0	85.5	82.0	90.5	70.5	70.5	41.0	48.3	54.3	58.9	54.7
	NO_3^--N	ppm	5.16	15.34	2.80	8.49	5.95	1.46	10.10	1.49	5.53	10.45	9.89	9.34	28.91	22.71	52.25
	$NH4^+$-N	ppm	26.61	1.37	1.01	13.08	0.00	13.44	17.11	0.00	13.71	19.53	19.13	0.00	27.26	13.39	0.00
Reproductive Growth	pH		8.35	7.89	8.26	8.00	8.04	8.27	8.10	8.19	8.03	7.91	8.37	8.18	8.34	8.24	8.13
	GWC	%	17.4	16.7	17.4	17.3	16.8	16.0	16.0	17.8	16.0	16.3	15.2	15.9	15.3	15.7	15.8
	Mineralized C	ppm	144.8	143.8	151.8	165.3	101.8	102.0	136.0	105.3	161.8	108.0	87.8	105.0	100.8	101.0	99.0
	NO_3^--N	ppm	5.16	15.34	2.80	8.49	5.95	1.46	10.10	1.49	5.53	10.45	9.89	9.34	28.91	22.71	52.25
	$NH4^+$-N	ppm	26.61	1.37	1.01	13.08	0.00	13.44	17.11	0.00	13.71	19.53	19.13	0.00	27.26	13.39	0.00

4-8 in

Stage	Soil Chemical Characteristic	Unit	NTW Control	NTW PP	NTW MS	NTW SPLIT	NTW STB	NT Control	NT PP	NT MS	NT SPLIT	NT STB	CT Control	CT PP	CT MS	CT SPLIT	CT STB
Vegetative Growth	pH		7.85	7.82	7.77	7.85	7.64	7.85	7.63	7.82	7.81	7.96	7.68	7.71	7.76	7.65	7.51
	GWC[c]	%	15.5	15.8	15.6	15.6	15.6	15.6	15.2	14.5	15.1	15.3	11.5	15.4	16.0	15.3	15.9
	Mineralized C	ppm	91.5	54.8	96.7	129.0	131.0	105.0	76.9	94.1	112.5	90.5	60.8	84.4	108.0	67.4	86.6
	NO_3^--N	ppm	3.72	2.06	5.59	8.16	5.30	2.27	7.77	3.17	4.11	2.27	5.71	2.16	5.25	8.73	14.69
	$NH4^+$-N	ppm	0.00	8.21	1.68	4.03	0.00	5.07	0.00	0.00	3.52	4.72	0.02	0.00	0.00	0.00	21.39
Peak Plant Production	pH		8.00	7.74	8.01	7.92	7.76	7.91	7.89	7.92	7.83	7.92	7.92	7.73	7.86	7.85	7.88
	GWC	%	11.1	10.5	9.1	9.3	9.6	10.7	10.6	9.0	9.6	10.7	10.3	9.2	10.2	8.9	9.7
	Mineralized C	ppm	40.5	58.5	89.3	71.0	65.3	84.8	53.3	63.0	47.2	76.0	52.3	43.0	65.0	51.5	39.5
	NO_3^--N	ppm	3.72	2.06	5.59	8.16	5.30	2.27	7.77	3.17	4.11	2.27	5.71	2.16	5.25	8.73	14.69
	$NH4^+$-N	ppm	0.00	8.21	1.68	4.03	0.00	5.07	0.00	0.00	3.52	4.72	0.02	0.00	0.00	0.00	21.39
Reproductive Growth	pH		8.37	8.23	8.31	8.28	8.37	8.21	8.13	8.06	8.19	8.43	7.95	8.08	8.30	8.28	8.24
	GWC	%	15.6	16.0	17.2	16.0	16.5	15.2	17.1	15.9	16.2	15.3	15.0	15.1	15.5	16.4	15.7
	Mineralized C	ppm	88.3	97.3	106.9	90.0	92.0	89.0	75.3	97.8	95.0	106.5	85.8	94.3	115.0	107.3	103.8
	NO_3^--N	ppm	3.72	2.06	5.59	8.16	5.30	2.27	7.77	3.17	4.11	2.27	5.71	2.16	5.25	8.73	14.69
	$NH4^+$-N	ppm	0.00	8.21	1.68	4.03	0.00	5.07	0.00	0.00	3.52	4.72	0.02	0.00	0.00	0.00	21.39

[a] NTW, no-till with winter wheat cover; NT, No-till winter fallow; CT, conventional tillage winter fallow

[b]Control, no added nitrogen (N) fertilizer; PP, 100% pre-plant N fertilizer application; MS, 100% mid-season N fertilizer application; SPLIT, 40% PP 60% MS N fertilizer application; STB, 100% PP N fertilizer application with N stabilizer product.

[c]GWC, gravimetric water content

0-4 in depth (Fig. 2a). Greater soil C during vegetative growth likely indicated increased soil health and was also positively associated with yield at this point in the growing season. The second component (PC2) was a measure of pH, and its contrasting relationship with NO_3^--N. As NH_4^+ is converted to NO_3^--N, the soil can be acidified through the release of hydrogen ions during this process so it was expected that increased soil pH would be associated with decreased NO_3^--N. At the 4-8 in depth (Fig. 2b), PC1 was also largely a measure of nitrification with the same contrasting relationship as seen at the shallower depth. In addition, PC2 at the 4-8 in depth was a measure of soil C (Fig. 2b).

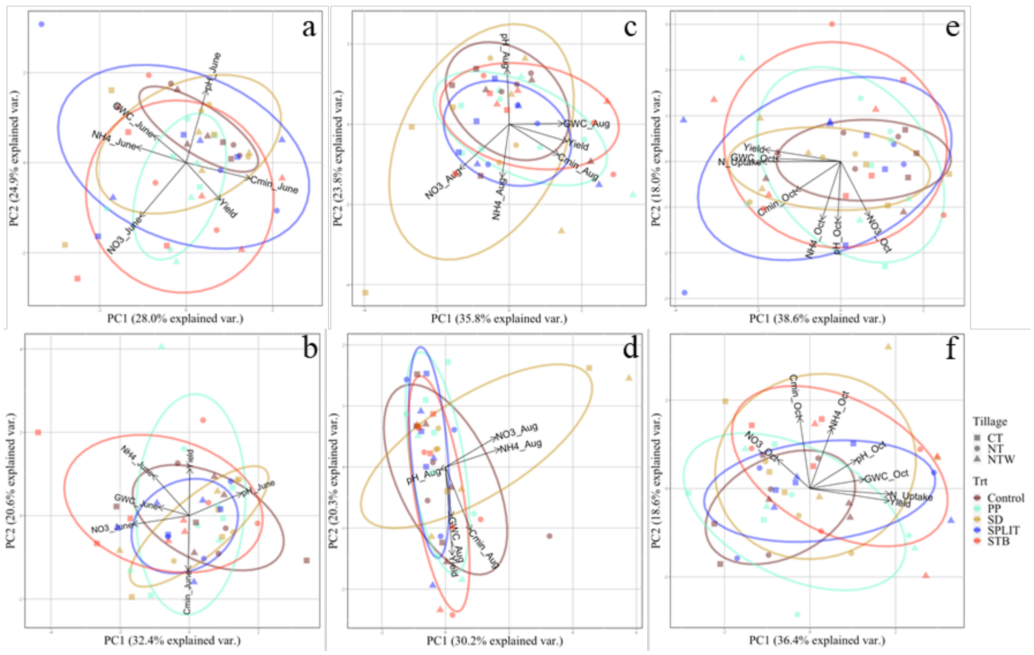

Figure 2. Principle components analysis of yield and soil characteristics at a) vegetative growth (Veg) 0-4 in; b) Veg 4-8 in; c) peak plant production (Peak) 0-4 in; d) Peak 4-8 in; e) reproductive growth 0-4 in (Repro); f) Repro 4-8 in. for 2018. NTW, no-till with winter wheat cover; NT, No-till winter fallow; CT, conventional tillage winter fallow; Control, no added nitrogen (N) fertilizer; PP, 100% pre-plant N fertilizer application; MS, 100% mid-season N fertilizer application; SPLIT, 40% PP 60% MS N fertilizer application; STB, 100% PP N fertilizer application with N stabilizer, Cmin, mineralizable C; GWC, gravimetric water content.

At 0-4 in for the Peak sampling PC1 was a measure of the positive relationship between GWC and yield at peak plant production (Fig. 2c). This was expected due to greater transpiration demand at the Peak sampling time. Yield and GWC had a contrasting relationship with NO_3^--N concentration at this point in the growing season, which occurs after all N applications have occurred for the year. This negative relationship was likely indicating reduced yield where the plant has taken up less NO_3^--N and thus may be N limited. Soil pH was the measure of PC2 and was likely due to the negative association with increasing NO_3^--N and yield as a measure of plant production (Fig. 2c). At 4-8 in for the Peak sampling, PC1 was a measure of soil N content where NO_3^--N and NH_4^+-N were positively correlated together, and the variability likely was the result of overall reduced nutrient uptake (Fig. 2d). The PC2 for the 4-8 in depth at Peak sampling was a measure of decreasing yield although there were no other associations with this variable (Fig. 2d).

The PC1 at 0-4 in for the Repro sampling was a measure of plant production and its main drivers as yield, GWC, and N uptake were all correlated negatively suggesting that reduced GWC and N uptake would decrease yield, which was expected (Fig. 2e). No variable was associated with PC2 although there might have been a slight relationship between decreasing inorganic N and decreasing pH, although this relationship is not understood at this time. For the 4-8 in depth at the Repro sampling, PC1 was a measure of the positive relationship between N uptake and plant production/yield (Fig. 2f) Mineralizable C was the variable most associated with PC2 at the 4-8 in depth at the Repro sampling and had a slight association with NH_4^+-N (Fig. 2f).

CONCLUSION

Cotton lint yield is affected when conservation tillage systems are implemented likely due to one of the inherent benefits of implementing cover crops on the SHP reducing wind erosion that can damage a cotton crop early in the growing season. In addition, 3 years after implementation, mineralizable C was increased in cover crop systems at peak plant production. As an indicator of soil health, a mineralizable C increase indicates an improvement in soil health and with this indicator also being strongly related to yield at Peak and Repro, it is likely that this parameter is a good indicator of agronomic productivity as well. Overall, the soil characteristics measured in this study are good indicators, whether by positive or negative association, of yield at different time points throughout the growing season. This study will continue through 2020 and should help indicate longer-term changes expected when converting to conservation systems on the SHP.

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NITROGEN FERTILIZER SOURCE AND TILLAGE IMPACTS ON SURFACE AND SUBSOIL C UNDER RAINFED CORN

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ABSTRACT

Soil organic carbon (SOC) increases with organic fertilizer and the adoption of no-till. Soil organic C improves the ability of agricultural systems to mitigate and adapt to climate change. This study was conducted to determine the long-term effects of fertilizer type and tillage on profile SOC. The experimental site was a rainfed continuous corn (Zea mays *L.*) system with fertilizer treatments (150 lbs N a^{-1}) of composted organic waste (OrgF), urea (MinF) and no fertilizer addition (Ctrl) and tillage treatments of no-till (NT) and conventional till (CT). Change in SOC and $\delta^{13}C$ was measured through the soil profile after 22 years. The change in SOC was calculated from a baseline sampling at the start of the experiment using equivalent soil mass to determine soil profile changes over time. Long-term addition of OrgF reduced profile C loss (0-60 cm), -1.12 tons C a^{-1} in comparison to Ctrl and MinF where ΔSOC was -8.12 and -13.8 tons C a^{-1}. In the surface 0-15 cm, OrgF increased ΔSOC from the baseline the most (8.11 tons C a^{-1}). No-till sequestered more C in the 0-5 cm layer than CT, while CT sequestered more C than NT in the 5-15 cm layer. The compost $\delta^{13}C$ signature was also evident with depleted soil $\delta^{13}C$ from 0-15 and 30-45 cm. Within the 30-45 cm depth, NT OrgF decreased losses of SOC (-1.70 tons C a^{-1}) compared to CT OrgF (-5.75 tons C a^{-1}). Although $\delta^{13}C$ was elevated with OrgF in the 15-45 cm depths, this did not result in gains in soil C. Although not significant, soil profile C to 45 and 60 cm depths showed greater net gains in soil C with NT OrgF (6.42 and 0.29 tons C a^{-1}) than CT OrgF (1.41 and -3.34 tons C a^{-1}). In summary, surface management effects on soil C were confined to the surface 15 cm even with additional C inputs after 22 years. In these annual cropping systems, considerations need to made for deep-rooted crops and rotations to deliver C inputs into the subsoil; however, this must include no-tillage as tillage loses the benefits of additional C inputs.

INTRODUCTION

The increased concentration of greenhouse gases in the atmosphere has increased the global mean annual temperature since the pre-industrial era and is projected to continue. Efforts to reduce greenhouse gas emissions in the atmosphere are required to mitigate these effects. The largest terrestrial pool of C is the soil with approximately 1550 Pg C in the upper 1 m of soil (Batjes, 2014). It is estimated that over 50% of native SOC has been lost when converted to agricultural systems (Sanderman et al., 2017). Thus, practices that increase SOC in agricultural systems have a significant potential to store C through soil C sequestration which occurs when C replenishment is greater than C loss.

Organic fertilizer addition, such as composted organic waste is known to increase SOC in annual cropping systems (Lynch et al., 2006). In a recent meta-analysis, cattle manure increased SOC stocks compared to an unfertilized control by 3.6 to 7.6 tons C a^{-1} in the upper 20-30 cm

(Maillard and Angers, 2014). This increase in SOC stocks with manure was also greater than mineral fertilizer additions by approximately 1.8 to 4.5 tons C a^{-1} (Maillard and Angers, 2014).

Historically, research has focused on the upper 20-30 cm of soil; however, there is interest in soil C deeper in the soil profile. Over 50% of C in the soil profile is located within 25-100 cm (Batjes, 2014). Further, tillage has less effect on profile SOC stocks, despite widely reported surface SOC gains (Angers and Eriksen-Hamel, 2008). Other research suggests that agricultural practices can alter deep soil dynamics that either increase (Halvorson et al., 2016) or decrease (Stewart et al., 2017) profile C stocks. This study builds on this research and specifically focuses on the relationship between management practices and deep soil carbon in a corn system. There is comparably little known about deep profile effects of manure addition and tillage in rainfed systems.

MATERIALS AND METHODS

The experimental site was located at Kansas State University's North Farm in Manhattan, KS (39° 12' 42"N lat, 96° 35' 39"W long; elevation 1020 ft). Annual mean precipitation was 31 inches and mean annual temperature was 53 °F. The soil was a moderately well-drained Kennebec silt loam (fine-silty, mixed, superactive mesic Cumulic Hapludoll). Plots were established in 1990 as split-plot randomized block design with four replications under continuous corn (Zea mays *L.*). Tillage systems were the main plots and N source was the subplot. Tillage systems were conventional tillage (CT) and no-till (NT). Corn was planted through the previous crops' standing residue in the NT plots with minimal soil disturbance. The CT operations consisted of preplant offset disk set to 10 cm depth and postharvest chisel plow to 15 cm.

The subplot treatment, fertilizer source, was applied at a rate of 150 lb N a^{-1}. Mineral fertilizer (MinF) was applied as broadcast urea. The second N treatment was sourced from various types of organic sources high in C. From 1990 to 2001, the original organic fertilizer (OrgF) treatment was fresh beef cattle manure. Each year, the manure was analyzed for total N, NH_4^+, and NO_3^- and application rates were calculated assuming 100% of NH_4^+ and NO_3^- and 35% of organic N was available. Since 2001, mixed source compost (food waste, hay waste, and cattle manure) has been applied (Nicoloso et al., 2018). Prior to application each year, compost was analyzed for total N, organic N, NH_4^+, and NO_3^-. Compost application rate was then calculated assuming 50% of organic N and 100% of mineral N was available during the growing season. A control (Ctrl) treatment consisted of no N application (0 lb N a^{-1}).

Soil cores were collected in fall 2012 with a Giddings Soil Exploration probe (Windsor, CO) to a depth of 120 cm (5 cm diameter). Five cores were collected per plot. Three cores were collected from each plot for lab analyses. Two additional 120 cm cores were collected for bulk density analysis. All undisturbed soil cores were separated into layers 0-5 cm, 5-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-75 cm, 75-90 cm, 90-105 cm, and 105-120 cm in field and stored in bags. Bulk analysis cores were composited into one bag by layer and bulk density cores were bagged individually.

Soil bulk density was determined by gravimetric moisture analysis. Bulk density measurements were averaged by depth for each plot. For analysis of SOC, a subsample was taken from the composited cores and air-dried. Visible roots were removed from the sample and discarded. The soil was then passed through a 2 mm sieve and finely ground with a mortar and pestle.

Soil samples were analyzed for total soil C by dry combustion with a C elemental analyzer (Flash EA 1112 Series, ThermoScientific, Waltham, MA). Soil organic carbon changes were determined on equivalent soil mass to account for soil differences across a landscape or soil bulk density changes induced by management (Ellert and Bettany 1995). The 1992 equivalent soil mass was calculated using bulk density data from 1990 and C treatment data from 1992 (Nicoloso et al., 2018). Change in SOC was measured to 60 cm due to the baseline sampling depth of 90 cm and adjustment in the equivalent soil mass calculations.

Carbon isotope analysis was performed at the KSU Stable Isotope Mass Spectrometry Laboratory on the air-dried, picked and ground subsamples. The analysis was done with a ThermoFinnigan Con Flo III interface and ThermoFinnigan Delta-plus Continuous Flow Stable Isotope Ratio Mass Spectrometer (ThermoFisher Scientific, Waltham, MA).

The main effects of tillage and N management on ΔSOC (1992-2012) were assessed using a repeated measures analysis of SOC stocks with tillage and N management as main effects with plot as a repeated unit. An analysis of variance (ANOVA) was performed, data were checked for normality and transformed as necessary with the ΔSOC analysis log-transformed. The SOC stock change per layer was log-transformed due to non-normal distribution. An ANOVA was used to assess the main treatment effects of tillage and N management and interaction between tillage and N management. Statistics were analyzed on all response variables measuring SOC change and stocks (ΔSOC, bulk density, $\delta^{13}C$) by using SAS PROC MIXED (SAS 9.4). Differences were analyzed with Bonferroni's adjustment and are reported with letters to denote significance. Results were considered statistically significant at $P < 0.10$.

RESULTS AND DISCUSSION

Soil organic C change

The OrgF significantly increased SOC stocks in the 0-5 and 5-15 cm layers (Table 1). Here, OrgF increased SOC by 4.36 and 3.75 tons C a^{-1}, respectively. Soil organic C in the Ctrl and MinF treatments were relatively unchanged and were not significantly different in this layer. In the 15-30 cm depth, no significant differences were detected by N source or tillage. All treatments lost SOC at depths greater than 30 cm. At the 30-45 cm depth, the Ctrl fertilizer treatment lost the least amount of C, approximately -1.13 tons C a^{-1}. The OrgF and MinF lost similar amounts of SOC, -3.72 and -4.04 tons C a^{-1}, respectively. In the 45-60 cm layer, MinF lost the greatest amount of C at -9.37 tons C a^{-1} where OrgF changed by -5.44 tons C a^{-1}. The Ctrl treatment was statistically similar to both the OrgF and MinF treatments, which lost -6.78 tons C a^{-1}. In considering the full profile, 0-60 cm, all treatments lost SOC where OrgF lost the least C, -1.52 tons C a^{-1}, Ctrl changed by -8.12 tons C a^{-1} and MinF changed by -13.8 tons C a^{-1}.

The adoption of NT increased SOC in the surface 0-5 cm by 2.26 tons C a^{-1} above the baseline ($P = 0.052$). This was nearly twice as much SOC as CT, which only accumulated 1.19 tons C a^{-1}. However, SOC increased in the 5-15 cm layer with CT by 1.79 tons C a^{-1} compared to ($P = 0.061$). Inversion of surface soil and residue into the subsurface causes this increase in CT systems (Angers and Eriksen-Hamel, 2008). An interaction between tillage and N management was noted at the 15-30 cm depth, but results were inconclusive after Bonferroni's adjustment. A significant interaction occurred at 30-45 cm. In general, NT MinF and CT OrgF lost the most C within this layer, -4.91 and -5.75 tons C a^{-1}, respectively ($P < 0.001$). The NT Ctrl and OrgF and CT Ctrl and CT MinF were statistically similar, varying between -3.19 and 0.26 tons C a^{-1}.

Table 1. Change in SOC (tons C a^{-1}) for main effects of N management and tillage by soil layer and full profile (0-60 cm) analysis (1992-2012).

		ΔSOC (tons C a^{-1})					
		depth (cm)					
Effect	Treatment	0-5	5-15	15-30	30-45	45-60	0-60
N source	Ctrl	0.05 a	-0.60 a	0.33	-1.13 a	-6.78 ab	-8.12 a
	OrgF	4.36 b	3.75 b	-0.47	-3.72 b	-5.44 a	-1.52 b
	MinF	0.76 a	0.24 a	-1.45	-4.04 b	-9.37 b	-13.8 c
Tillage	NT	2.26 a	0.47 a	-0.71	-3.04	-7.72	-8.74
	CT	1.91 b	1.79 b	-0.34	-2.89	-6.65	-6.91
Effect	df	P-value					
Tillage (T)	1	0.052	0.061	0.669	0.992	0.419	0.319
N source	2	<0.001	<0.001	0.230	0.004	0.015	<0.001
T × N source	2	0.498	0.244	0.076*	<0.001	0.229	0.084

N management: Ctrl: Control, OrgF: Organic fertilizer, MinF: Mineral fertilizer
Tillage: CT: Conventional tillage, NT: No-till
**No significance detected after Bonferroni's adjustment*

The C isotope data support the integration of OrgF into SOC up to 45 cm in depth. The OrgF (C3-C) treatment significantly depleted $\delta^{13}C$ in the 0-5 cm, 5-15 cm, 30-45 cm and 105-120 cm depths (Table 2). The Ctrl and MinF treatments were not significantly different within these layers and retained a stronger C4-C isotopic signature. The OrgF was depleted in $\delta^{13}C$ in the 0-5 cm layer, -20.7 ‰ ($P < 0.001$). The Ctrl and MinF averaged -17.1 and -17.6 ‰, respectively in this layer. In the next layer, 5-15 cm, OrgF had a significantly depleted $\delta^{13}C$ value of -18.7 ‰ ($P = 0.043$). The Ctrl and MinF treatments were more enriched in $\delta^{13}C$, averaging -17.1 and -17.4 ‰, respectively. Neither N source nor tillage significantly affected $\delta^{13}C$ in the 15-30 cm depth. In the 30-45 cm depth, OrgF was again significantly depleted in $\delta^{13}C$ from Ctrl and MinF ($P = 0.013$) averaging -16.2 ‰. The Ctrl and MinF treatments were not significantly different, with values of -14.8 and -14.9 ‰, respectively.

Tillage had a significant influence in the 30-45 cm layer ($P = 0.026$). No-till was slightly more depleted (-15.8 ‰) than CT (-14.8 ‰). At the 120 cm depth, OrgF averaged -20.0 ‰ ($P = 0.059$) where Ctrl and MinF were -16.2 ‰ and -15.9 ‰, respectively. No-till had significantly depleted $\delta^{13}C$ values (-15.8 ‰) at the 30-45 cm depth ($P = 0.025$). This was more depleted than CT, which averaged -14.9 ‰.

Table 2. Soil $\delta^{13}C$ (‰) for 2012 through the soil profile for the main effects of N management and tillage.

		Soil $\delta^{13}C$ (‰)								
		depth (cm)								
Effect		0-5	5-15	15-30	30-45	45-60	60-75	75-90	90-105	105-120
N source	Ctrl	-17.1 a	-17.1 a	-16.1	-14.8 a	-14.7	-14.6	-15.2	-15.1	-16.2 a
	OrgF	-20.7 b	-18.7 b	-16.7	-16.2 b	-14.8	-15.5	-15.1	-15.5	-20.0 b
	MinF	-17.6 a	-17.4 a	-16.7	-14.9 a	-14.8	-14.9	-15.4	-15.3	-15.9 a
Tillage	NT	-18.7	-17.3	-16.6	-15.8 a	-14.8	-15.1	-15.0	-15.1	-16.2
	CT	-18.2	-18.1	-16.3	-14.9 b	-14.7	-14.9	-15.4	-15.5	-18.6
Effect	df	P-value								
Tillage (T)	1	0.159	0.143	0.544	0.025	0.695	0.659	0.308	0.268	0.165
N source	2	<0.001	0.043	0.470	0.013	0.964	0.334	0.789	0.670	0.059
T × N source	2	0.852	0.414	0.834	0.158	0.143	0.685	0.581	0.218	0.902

N management: Ctrl: Control, OrgF: Organic fertilizer, MinF: Mineral fertilizer
Tillage: CT: Conventional tillage, NT: No-till

An increase in SOC with OrgF was primarily confined to the surface 15 cm. Although not significant, NT OrgF increased SOC by 0.71 tons C a^{-1} in the 15-30 cm depth, while CT OrgF lost 1.64 tons C a^{-1}. In a previous study at this site, Nicoloso et al. (2018) reported that SOC had saturated in the NT with OrgF in the 0-5 cm layer with subsequent translocation into the underlying 5-15 cm layer. They also found no significant accumulation of SOC below 15 cm with either tillage system. The $\delta^{13}C$ from this study confirms the stabilization of C from OrgF up to 15 cm in depth. The OrgF depleted $\delta^{13}C$ in the 30-45 cm but no significant change in SOC was observed within this layer, though not enough C from OrgF has become stabilized to detect.

No-till over 22 years increased SOC in the surface 0-5 cm by 2.26 tons C a^{-1} while CT only increased surface SOC by 1.91 tons C a^{-1}. On the other hand, CT significantly increased SOC within the 5-15 cm layer so that cumulative SOC from 0-15 cm was not different between tillage systems.

Within the profile 60 cm, all treatments lost SOC except NT OrgF (0.29 tons C a^{-1}). Although not significant, soil profile C to 45 and 60 cm showed greater net gains in SOC with NT OrgF (6.42 and 0.29 tons C a^{-1}) than CT OrgF (1.41 and -3.34 tons C a^{-1}). Considering the main effects through the profile (0-60 cm), the MinF and Ctrl changed by -13.8 and -8.12 tons C a^{-1}, respectively, while OrgF changed by -1.52 tons C a^{-1}. In the 30-60 cm layers, all OrgF and MinF treatments lost SOC regardless of tillage treatment; however, in the 30-45 cm layer, NT was able to significantly reduce C losses (-1.70 tons C a^{-1}) compared to CT (-5.75 tons C a^{-1}). This is similar to another maize tillage and N rate study where NT and N application maintained SOC in the surface but lost SOC below 30 cm (Stewart et al., 2017). It appears that C from OrgF, residue or root decomposition was not able to sustain SOC to this depth in this cropping system.

In summary, surface management effects on soil C sequestration were confined to the surface 15 cm even with additional C inputs. Annual cropping systems, such as this, must consider deep-rooted crops and rotations to maintain deep soil C. However, this must include no-tillage as tillage loses the benefits of additional C inputs.

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TILLAGE AND NITROGEN RATES INFLUENCED WHEAT AND SORGHUM PRODUCTIVITY

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ABSTRACT

Reduced tillage (RT) or no-tillage (NT) practices and reducing fallow frequency can both decrease soil losses from wind erosion and conserve soil water in the semiarid regions of the US Great Plains. This study evaluated sorghum grain yield in 2013 and wheat grain yield in 2014 and 2015 as influenced by long-term nitrogen (N) fertilizer application rates (0, 20, 40, and 60 lb N ac^{-1}) and tillage intensity [clean tillage (CT), RT, and NT] in dryland winter wheat–sorghum-fallow (W-S-F) cropping system. Tillage treatments had no effect on sorghum or wheat grain yields, but the yields were influenced by N treatments. Grain sorghum yield in 2013 and winter wheat yield in 2014 increased with the addition of N fertilizer compared with the unfertilized control. Regardless of tillage practice, grain sorghum yield with 40 lb was similar to that of 60 lb N ac^{-1}. Doubling the amount of N addition (0, 40, 80, and 120 lb N ac^{-1}) in 2015 was partially related to increase wheat yield by 37% for 80 lb N ac^{-1} and 46% for 120 lb N ac^{-1} compared with 2014. In general, precipitation timing influenced wheat grain yields more than tillage or N fertilizer application rate.

INTRODUCTION

Conservation practices have been widely adapted in the semi-arid environments of the Great Plains region since the devastating event of the historic Dust Bowl in the 1930s (Stewart, 2004; Hansen et al., 2012). These conservation practices include the adoption of RT or NT, reducing fallow frequency, and residue management to maintain soil sustainability and reduce soil losses by erosion (Stewart, 2004; Mikha et al., 2010). The combination of continuous cropping and minimizing fallow frequency with NT or RT has become a successful practice (Smika and Wicks, 1968; Anderson et. al., 1999) because of increased precipitation storage efficiency. However, the residue decomposition process and lack of residue returned during the fallow period could cause reduction in soil organic carbon (SOC) (Peterson et al., 1998; Mikha et al., 2010).

In general, low precipitation inputs and drought conditions common to the Great Plains region is expected to reduce plant residue and the decomposition of soil organic matter (SOM), decrease nutrient movement through the soil profile, and reduce nutrient availability for crop production (Mikha et al., 2014). Using conservation tillage in this semi-arid region, specifically NT, can benefit soils by promoting SOC accumulation, increasing water storage, enhancing microbial activity, improving grain yield, and reducing soil wind erosion compared to more intensive tillage practices (Nielsen et al., 2005). Furthermore, increased soil water conservation with NT makes it possible to adopt continuous cropping systems or reduce the fallow frequency in the Great Plains region. Nielsen et al. (2005) documented that with NT, grain production per unit of soil water increased with reduced fallow frequency when compared with other tillage practices. In contrast, surface residue incorporation and soil mixing associated with tillage increased residue decomposition rates, reduced SOC, and enhanced soil erosion potential (Blanco-Canqui et al., 2009).

The objective of this study is to evaluate the long-term tillage effects on grain yields in a dryland wheat-sorghum-fallow (W-S-F) cropping system. We also examined whether tillage practice enhances or has no effect on yield response to nitrogen (N) fertilizer application rate. We hypothesize that long-term NT will improve grain yield compared with CT and RT.

MATERIALS AND METHODS

The study was established in 1965 at the Kansas State University, Agricultural Research Center near Hays, Kansas with three tillage practices in a winter wheat-sorghum-fallow (W-S-F) cropping system. The soil series is Harney silt loam (fine, montmorillonite, mesic Typic Argiustoll) and field slopes of 0 to 1%. Mean annual temperature is 54 °F and mean annual precipitation **(Table 1)** is approximately 22 inches (144-year average). Surface soils (0-6 inches depth) range from 32 to 56% sand, 18 to 43% silt, and 24 to 36% clay. Approximately 77% of annual precipitation falls within April to September each year (~17 inches) **(Table 1)**.

Since 1965, the study site has been maintained in W-S-F rotation. Each phase of the W-S-F crop rotation was present in each year of the study. Winter wheat was planted at ~ 60 lb/ac seeding rate and Grain Sorghum by an average of 3 lb/ac. Three tillage treatments were arranged in a randomized complete block design with four replications as the main plots, and N rates were considered the sub-plot factor. Plot sizes for individual tillage treatments were 67 ft by 100 ft. Tillage treatments were no-tillage (NT), reduced tillage (RT), and clean tillage (CT). Details of all field operations and crop management were reported in Thompson and Whitney (1998) and Thompson et al. (2000). The CT plots were plowed and disked to 6-inch depth with a tandem disk, a one-way plow and a mulch treader for crop residue incorporation. The RT tillage operation was implemented with a V-blade or sweep plow. The residue was left on the soil surface with the RT operation. During the fallow period and before winter wheat planting, approximately 3 to 4 tillage operations were made in CT while 2 tillage operations were made in the RT plots. Before sorghum planting, one tillage operation was done in the CT and RT plots to control weeds. With NT plots, weeds were controlled using herbicides only. During the growing season and fallow period, herbicides were used as needed to control weeds with all tillage practices. Two to four applications of glyphosate [isopropylamine salt of *N*-(phosphonomethyl) glycine] and 2, 4-dichlorophenoxyacetic acid were applied to kill emerged weeds before winter wheat planting.

In the 1975, fertilizer N was applied at five N rates (0, 20, 40 and 60 lb N ac^{-1}**)** as sub-plots. In fall 2014, the N rates were further modified to 0, 40, 80, and 120 lb N ac^{-1}**.** Ammonium nitrate was used from 1975 to 2002, and urea was used from 2002 to present. The N fertilizer was broadcasted in the fall before wheat planting and either incorporated in the RT and CT treatments or left on the soil surface under the NT treatment.

Grain yields were evaluated by harvesting an area of 49.2 ft × 100.02 ft of each plot with a plot using a plot combine. In this study, we are only reporting the sorghum yield of 2013 and the wheat yield of 2014 and 2015. Tillage treatments and N rate effects on wheat and sorghum grain yields were tested with F-tests by fitting a linear mixed model appropriate for a split plot experiment with the PROC MIXED procedure. All results were considered significantly different at $P < 0.05$.

Table 1. Annual and long-term precipitation inputs at Hays, Kansas. Highlighted months represent the winter wheat growing season, and asterisks (*) represent the sorghum growing season.

	---------- Year ----------			
Months	**2013**	**2014**	**2015**	**Average 1868-2012**
	---------- Inch ----------			
January	0.70	**0.16**	**0.46**	**0.44**
February	1.19	**0.92**	**0.71**	**0.72**
March	0.78	**0.17**	**0.09**	**1.24**
April	1.06	**0.91**	**0.96**	**2.07**
May	2.16*	**0.82**	**6.44**	**3.18***
June	2.73*	**9.45**	**0.76**	**3.33***
July	7.08*	2.36	4.11	3.22*
August	0.59*	1.64	0.46	2.91*
September	2.98*	5.94	0.42	2.15*
October	**0.99***	**2.15**	1.75	**1.41***
November	**1.16***	**0.05**	1.83	**0.83***
December	**0.05**	**0.73**	1.77	**0.65**
Yearly Total	**21.53**	**25.30**	**19.76**	**22.15**
Wheat Growing Season		**14.63**	**12.35**	**16.33**
Sorghum Growing Season	**17.69***			**17.03***

RESULTS AND DISCUSSION

Total precipitation received during the 2013 sorghum growing season was not different from the long-term average **(Table 1)**. Sorghum grain yield **(Fig. 1A)** was significantly influenced by N-rate and tillage × N-rate interaction, but tillage effect was not significant. Sorghum grain yield was greater in the NT and CT with N fertilizer rate of 60 lb N ac^{-1} compared with lower N-rate (0 or 20 lb N ac^{-1}), and yield with 40 lb N ac^{-1} was in between. However, the greatest sorghum grain yield was achieved in RT with 40 lb N ac^{-1}. In general, differences in sorghum yield among the N-rates were less pronounced with RT than NT and CT **(Fig. 1)**.

The precipitation throughout the wheat growing season of 2014 was 10% lower than the long-term average precipitation (~1.7 inches less) **(Table 1)**. Winter wheat grain yield measured in 2014 was only influenced by N-rate **(Fig. 2)**. Applying N fertilizer increased winter wheat yield irrespectively of tillage **(Fig. 2)**. However, there was no wheat yield response to N fertilizer addition beyond 20 lb N ac^{-1} **(Fig 2)**. Limited response to N fertilizer in 2014 could possibly be related to low precipitation amounts or to other soil nutrients that are necessary for crop production.

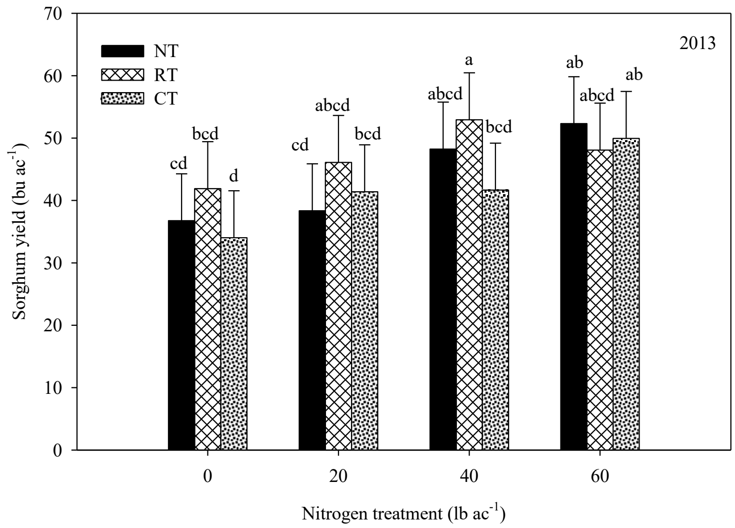

Figure 1. Sorghum grain yield as influenced by tillage practices and N rates (0, 20, 40, and 60 lb N ac^{-1}). The NT represents no-tillage; RT represents reduce tillage; and CT represents clean tillage. The bars represent standard errors of the mean. Different lowercase letters represent significant ($P < 0.05$) differences with tillage × N-rate interaction.

In 2015, the annual precipitation throughout the wheat growing season was 25% lower than average (~4 inches less) **(Table 1)**. Tillage treatment did not influence wheat yield, but N rates increased wheat yield compared with control. Doubling the N rates in 2015 could have some benefits for increasing wheat grain yield **(Fig. 3)**, but the precipitation amount and timing remained the major factor influencing yield in this semi-arid region. In May of 2015 **(Table 1)**, the 6.44 inches of precipitation could have contributed to the increase in wheat yield despite the management practices. Across tillage treatments, wheat yield in 2015 associated with 0 and 40 lb/ac N fertilization were greater than the wheat yield in 2014 by an average of 37.5% (12 bu/ac).

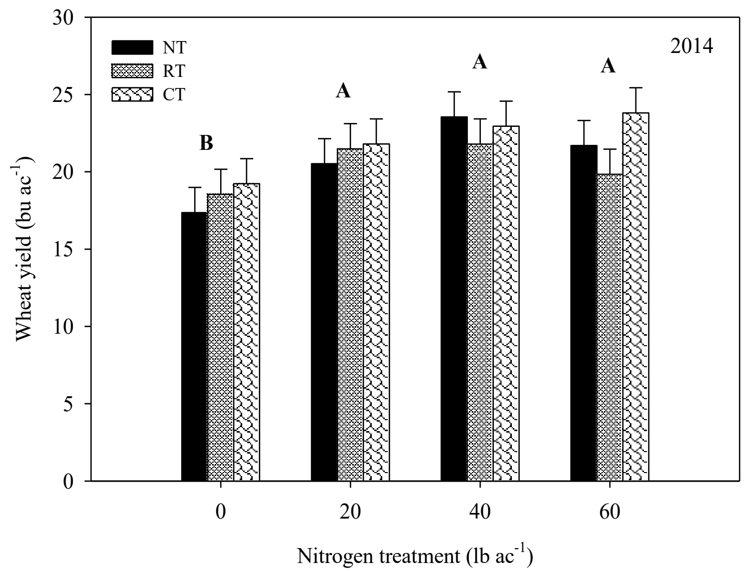

Figure 2. Wheat grain yield as influenced by tillage practices and N rates (0, 20, 40, and 60 lb N ac^{-1}). The NT represents no-tillage; RT represents reduce tillage; and CT represents clean tillage. The bars represent standard errors of the mean. Different lowercase letters represent significant ($P < 0.05$) differences with N-rate.

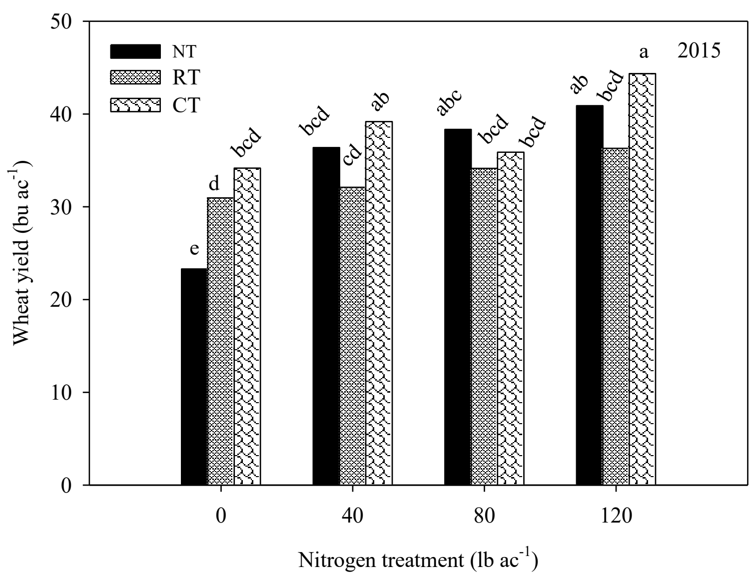

Figure 3. Wheat grain yield as influenced by tillage practices and N rates (0, 40, 80, and 120 lb N ac^{-1}). The NT represents no-tillage; RT represents reduce tillage; and CT represents clean tillage. Different lowercase letters represent significant ($P < 0.05$) differences with tillage × N-rate interaction.

Precipitation from planting to May in 2014 was approximately 5.18 inches, which was less than the 11.6 inches recorded for that same growing period in 2015 **(Table 1)**. The low precipitation amounts in 2014 was the major factor contributing to the low wheat crop regardless of the management practices.

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P-26

INTERSEEDING COVER CROPS INFLUENCE ON OPTIMAL CORN NITROGEN RATE IN NO-TILL

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ABSTRACT

Moving from conventional to no-till with the inclusion of cover crops may change the amount and timing of nitrogen (N) provided to corn (*Zea mays* L.) from mineralization, which may increase or decrease needed N fertilizer to optimize corn grain yield. This study evaluated the effect of cover crop composition on corn N fertilizer requirement and corn grain yield. The effect of three cover crop treatments (no cover crop, single grass species, and grass/broadleaf mixture) on corn N fertilizer requirement and grain yield were evaluated at Beresford and Brookings, South Dakota (SD). Corn biomass at an early reproductive stage and physiological maturity was similar regardless of cover crop treatment and N fertilizer rate applied. Within each N fertilizer rate, the addition of either cover crop mixture did not influence corn grain yield. The fertilizer-N rate needed to obtain optimal corn grain yield was not influenced by the addition of either cover crop mixture. Results from the first year of this long-term study indicate that a single grass species or grass/broadleaf cover crop mixture can be interseeded into corn without significantly affecting corn biomass, corn grain yield, or N fertilizer requirement for optimal grain yield.

INTRODUCTION

No-till and planting cover crops are recommended practices compared to conventional tillage because of their potential to improve organic matter and soil structure leading to a greater capacity to hold water and nutrients needed for plant growth (Dapaah and Vyn, 1998; Nielsen and Vigil, 2010; Blanco-Canqui et al., 2015; Blanco-Canqui and Jasa, 2019). Cover crops can also take up nutrients and excess water in the fall and spring that may otherwise be lost from the root zone due to erosion, leaching, or volatilization (Tilman et al., 2002; Snapp et al., 2005). Inhibitions to planting cover crops in SD are the short amount of time between harvest and the first killing frost that is available for cover crops to grow and the high seeding rate required to establish an optimal stand when seeds are broadcast planted. Using an interseeder to plant cover crops overcomes these impediments because the seeds are placed in the soil and not on top after corn and soybean are established enough that cover crops will not decrease yield but before a planter cannot get into the field. This innovative method of planting cover crops lowers seeding rate requirements and increases the time cover crops are growing.

The cover crops farmers' plant vary extensively from single grass species to mixtures of multiple grass and broadleaf species, depending on weather conditions and the cover crops intended use. The chosen cover crop can influence N mineralization as cover crops take up water and nutrients and ultimately add organic material to the soil when terminated (McVay et al., 1989; Nielsen and Vigil, 2010; Wortman et al., 2012; Blanco-Canqui et al., 2015). Dominantly grass based cover crop mixtures normally have a greater C:N ratio, which may slow N mineralization initially during the growing season while broadleaf dominant mixes tend to have lower C:N ratios, promoting N mineralization sooner (McVay et al., 1989; Fageria et al., 2005). The amount and timing of N mineralization during the growing season may change based on planted cover crop composition, subsequently influencing the N fertilizer amount required to optimize corn grain yield. The objective of this project was to compare the effect of N fertilizer on corn production with no cover crop versus single- and multiple-species cover crops in SD.

MATERIALS AND METHODS

This study was conducted at the Southeast Research Farm in Beresford, SD and at the USDA-ARS research fields in Brookings, SD. Both study locations have been under no-till management for >5 years and receive an average annual rainfall of 24–26 in. The mean temperature and growing degree-day (GDD) accumulation were greater at the Beresford site (47°F and 2750 GDD) compared to the Brookings site (43°F and 2390 GDD). At each location, a corn and soybean block were planted in adjacent fields to minimize soil variation. The experimental design within each corn and soybean block was a randomized complete block in a split plot arrangement with four replications. The whole plot consisted of one of three cover crop treatments (no cover crop, single grass species, and grass/broadleaf mixture). For the single grass species, annual rye grass (*Lolium spp.*) was interseeded at 20 lbs ac^{-1}. The grass/broadleaf cover crop mixture consisted of annual ryegrass, crimson clover (*Trifolium incarnatum*), turnip (*Brassica rapa*), and radish (*Raphanus sativus*) planted at 5, 3.5, 1, and 2 lbs ac^{-1}, respectively. Cover crops were interseeded into corn at the V6–V7 growth stage and into soybean at the V4–V5 growth stage using a high clearance planter. Subplots consisted of N rates ranging from 0–250 lbs ac^{-1} in 50 lb increments at the Beresford site and ranging from 0–225 lbs ac^{-1} in 75 lb increments at the Brookings site. Ammonium nitrate (34-0-0) was broadcast applied near planting only on the corn plots. All other fertilizers were applied to ensure optimal soil fertility for corn and soybean based on university guidelines (Clark et al., 2019). Corn was planted in 30-in. rows at Beresford and 20-in. rows at Brookings at 31,000-corn seeds ac^{-1} and 130,000-soybean seeds ac^{-1}. Corn was planted on 15 May in Beresford and 23 May in Brookings. Soybean was planted 23 May in Beresford and 14 June in Brookings. Recommended practices were followed for all other weed, pest, and disease control.

Plant Sampling and Analysis

Whole corn plant samples were obtained in the zero, low (75–100 lbs ac^{-1}), and optimal (150–200 lbs ac^{-1}) N fertilizer rate treatments within each cover crop treatment at the R1 and R6 growth stages. Corn samples were collected by clipping six plants at ground level. At R6, corn plant samples were separated into ears (grain and cob) and above ground vegetative matter (stover). Plant materials were dried at 140°F until constant mass. Ears were shelled and then the weights of the whole plants (R1), dried stover, grain, and cob were determined separately. Harvest yields were determined by harvesting the center two rows of each corn plot. The moisture-adjusted grain weight from the R6 corn samples were added to the harvest weight of each plot to determine final corn grain yield. Corn grain yield was adjusted to 15.5% moisture.

Statistical Analysis

Data was analyzed within each site using box and whisker plots in Excel to test for differences among the range and mean among N rate and cover crop treatments.

RESULTS AND DISCUSSION

Corn Biomass and Grain Yield

There were marginal corn biomass differences between sites at each plant sampling but only minor differences among the cover crop treatments within each site (Fig 1 and 2). Corn biomass was on average greater at Beresford compared to Brookings regardless of cover crop treatment likely because the warmer temperatures and longer growing season of the Beresford site. The variability of the effect of cover crop treatments on corn biomass varied between the two sites. However, cover crop treatments did not significantly affect corn biomass within each N fertilizer rate. Further, corn biomass was similar across N fertilizer rates and cover crop treatments. Except for the R6 corn sampling at the Brookings site where N fertilization of 75 and 150 lbs ac^{-1} substantially increased biomass over the zero-N control treatments. The lack of R6 biomass increase with greater N fertilizer rates at the Beresford site is likely due to stalk breakage due to high winds. Overall, these results indicate that cover crops regardless of composition can be interseeded into corn without significantly changing corn biomass.

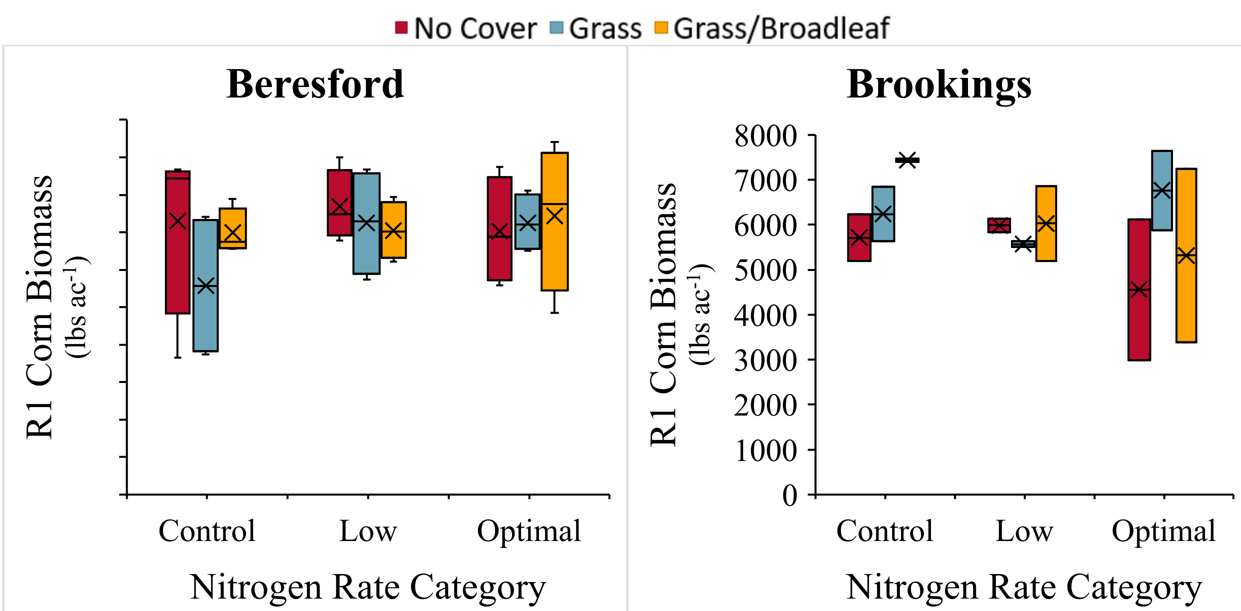

Figure 1. *The influence of three N fertilizer rates within three cover crop treatments (no cover crop, annual rye grass alone, and a grass/broadleaf mixture) on R1 whole corn plant biomass at Beresford and Brookings, SD in 2019. The box midline represents the median, the 'x' marks the mean, the upper and lower edges of the box represent the 25th to 75th percentiles, and the whiskers represent the range.*

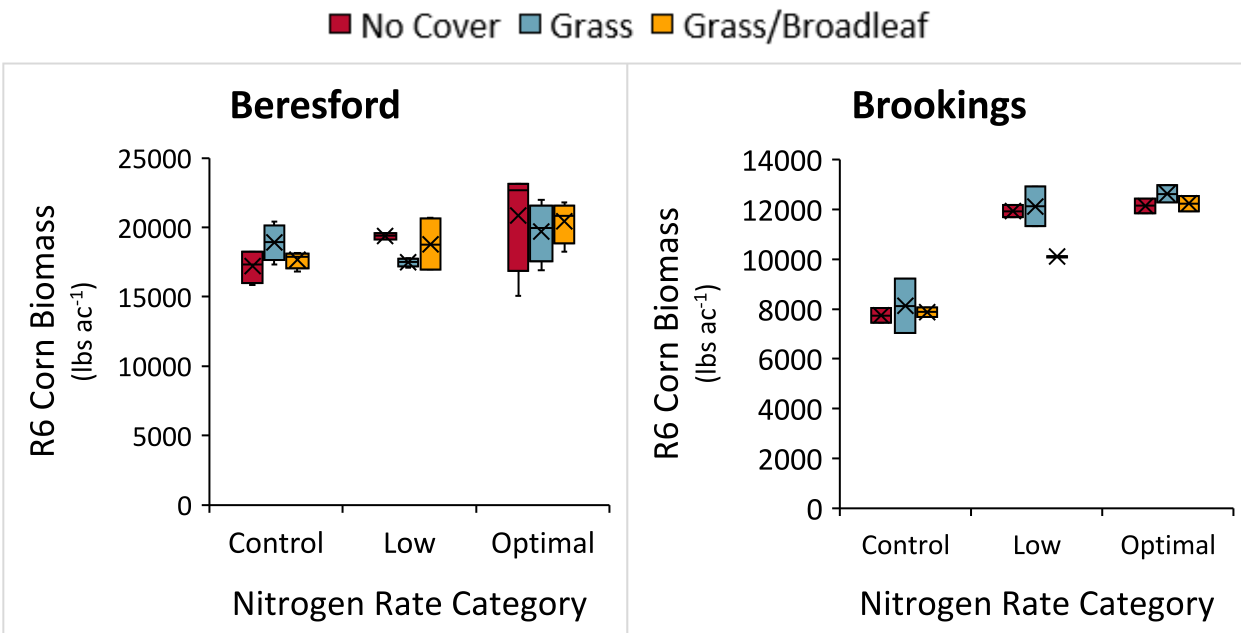

Figure 2. *The influence of three N fertilizer rates within three cover crop treatments (no cover crop, annual rye grass alone, and a grass/broadleaf mixture) on R6 corn biomass at Beresford and Brookings, SD in 2019. The box midline represents the median, the 'x' marks the mean, the upper and lower edges of the box represent the 25th to 75th percentiles, and the whiskers represent the range.*

For the Beresford site, corn grain yield ranged from 142 to 235 bu ac^{-1} with a mean yield of 180 bu ac^{-1} across all treatments (Fig. 3). The zero-N plots grain yield averaged 168 bu ac^{-1} regardless of cover crop treatment. The addition of N fertilizer (50–250 lbs ac^{-1}) increased mean corn grain yield 7–30 bu ac^{-1} for no cover crop, 1–17 bu ac^{-1} for the grass cover crop, and 6–33 bu ac^{-1} for the grass/broadleaf cover crop. Overall, grain yield did not increase substantially with added N fertilizer as it would it most years. Therefore, we were not able to calculate an optimal N rate at this site. This lack of greater increases in yield with more N fertilizer applied may have been due to high winds causing some stalk breakage during the growing season. In addition, within each N fertilizer rate there was no significant difference in grain yield among the three cover crop treatments.

For the Brookings site, corn grain yield ranged from 83 to 162 bu ac^{-1} with a mean yield of 132 bu ac^{-1} across all treatments (Fig. 3). The zero-N plots grain yield averaged 92 bu ac^{-1} across cover crop treatments. The addition of N fertilizer (75–225 lbs ac^{-1}) increased mean corn grain yield 49–53 bu ac^{-1} for no cover crop, 60–66 bu ac^{-1} for the grass cover crop, and 38–59 bu ac^{-1} for the grass/broadleaf cover crop. Corn grain yield plateaued near 75 lbs N ac^{-1} for all three cover crop treatments. Further, grain yields were similar among the three cover crop treatments within each N fertilizer rate. These results from the first year of this study indicate that grass or grass/broadleaf cover crop mixtures can be interseeded into corn without reducing yield or affecting N fertilizer required to obtain optimal yield. As this study continues, we will determine whether the cumulative effects of planting cover crops over several years will influence corn grain yield or N fertilizer required to obtain optimal yield.

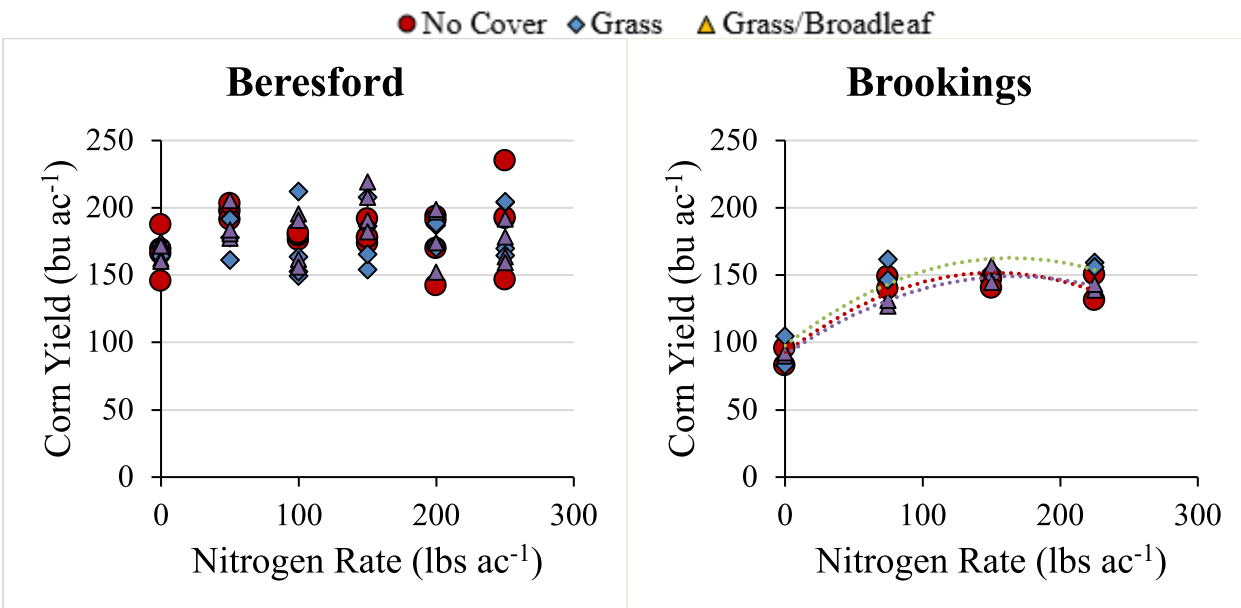

Figure 3. *Corn grain yield response to N fertilizer for three cover crop treatments (no cover crop, annual rye grass alone, and a grass/broadleaf mixture) at Beresford and Brookings, SD in 2019.*

ACKNOWLEDGEMENTS

Research funded by the SD Nutrient Research and Education Council. Authors appreciate the support of the SD Agricultural Experiment Station and USDA-NIFA. Nitrogen fertilizer provided by LSB Industries.

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P-27

SULFUR UPTAKE AND YIELD RESPONSE IN CORN AS AFFECTED BY FERTILIZER SOURCE AND RATE

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ABSTRACT

With sulfur deficiencies being found throughout Kansas, the evaluation of sulfur fertilization and plant uptake are vital to optimize corn production. The objective of this study was to evaluate the effect of application rates of sulfur on yield and uptake in corn. Nutrient concentrations in corn, biomass, and grain were evaluated at the Kansas River Valley Experiment Field at Rossville, Kansas in 2019. Five treatments were evaluated, including a control with no sulfur and no nitrogen, and four fertilizer treatments with 180 lbs of nitrogen and four rates of sulfur fertilizer (0, 30, 50, and 200 lbs. S acre^{-1}). The nitrogen source was urea and balanced for all treatments at 180 lbs. N acre^{-1}. The sulfur-containing fertilizers applications were at the time of planting corn. Whole corn plant biomass and grain samples were taken at physiological maturity and analyzed for nitrogen and sulfur concentrations. Results for the study show that sulfur application rates have a significant yield response in corn likely contributing to increased uptake of nitrogen. Moreover, high yielding environments increased whole plant sulfur uptake and removal.

INTRODUCTION

With the current lower commodity prices for corn, producers are looking to optimize nutrient inputs to enhance returns. Until recent years, sulfur is a nutrient that has often been overlooked. Increasing crop removal due to higher yields, decreased atmospheric deposition, and a greater amount of crop residues have increased the likelihood of sulfur deficiency (Camberato and Casteel, 2017). With decreasing soil test sulfur comes the need to replenish sulfur, however, the uptake and yield response of sulfur needs further research and is receiving increased interest from producers. Sulfur application is economically feasible in soils that have a severe sulfur deficiency, but not all fields respond to sulfur applications (Sawyer et al., 2011). Moreover, nitrogen application rates play a significant role in the response to sulfur application rates (Steinke et al., 2015). This study used Kansas State University's recommended rate for nitrogen for the Kansas River Valley Experiment Field and applied four different rates of sulfur.

MATERIALS AND METHODS

The Rossville field study was completed in September of 2019, initial soil samples were collected 0-6 in soil layer and analyzed for various soil parameters (Table 1). The experiment was in a randomized block design with four replications. Five treatments were evaluated, including a control (No N/ No S) and four rates of sulfur fertilizer (0, 30, 50, and 200 lbs. S acre^{-1}) which will be called control, low, medium, and high, respectively. The fifth treatment solely utilized urea served as the sulfur control treatment. (Table 2). Sulfur sources include Urea Calcium Sulfate (27%), Urea Calcium Sulfate (33%), and Ammonium Sulfate. The nitrogen source for the S control was urea following at Kansas State University's recommended nitrogen rate (180 lbs. N acre^{-1}). The Kansas River Valley Experiment Field used center pivot irrigation 6 times during the 2019 growing season. Whole plant biomass and grain samples were collected at physiological maturity in the corn crop. Whole plant biomass samples were gathered, weighed, and dried at 60°C and then reweighed to attain dry matter content. Corn was harvested, and yield was calculated and corrected to 15.5% moisture. After corn harvest, soil samples were collected from 0-24 in depth. All the soil samples were dried at 40°C, and nitrate and ammonium were measured utilizing a 1N KCl extraction, and sulfur was measured by a monocalcium phosphate extraction. All statistical analyses were completed in SAS using generalized linear mixed model (GLIMMIX) procedure was used for analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Preliminary results for this study showed significant differences in yield between sulfur fertilization rates for both nitrogen and sulfur plant total uptake. Whole plant sulfur uptake significantly increased when sulfur was applied. An increase in the uptake of sulfur with a high application rate more than likely resulted in higher lability of sulfur. Increasing the rate of sulfur showed no significant difference between sulfur rates (Figure 1), suggesting a rate of 30 lbs as sufficient for the corn crop. Increases in nitrogen uptake were seen when sulfur was applied (Figure 2). A substantial increase in nitrogen uptake is likely linked to keeping the balance of nitrogen to sulfur within the plant at approximately 16-25:1 (Steinke et al., 2015). Nitrogen uptake is indicative of increased yield and sulfur uptake suggesting that a higher yielding environments will also have elevated levels of sulfur removal (Figure 3). Soil sulfate levels in the 0-24" soil profile post-harvest was only significantly different at the high sulfur rate (Figure 4). This is likely due to excess S applied at the rate related to corn total need. Preliminary results show the highest sulfur application rate significantly increased yield compared to the urea-only application (Figure 5). This suggests sulfur applied at the lowest rate may have not been sufficient for maximum yield. An increase in nitrogen provided significantly more yield gain over the control when compared to sulfur. Further research is needed to see how sulfur and nitrogen interact to impact yield in corn.

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Table 1. Soil test parameters for 0-6" pre-plant samples

P	K	Zn	Ca	Mg	Na	Fe	Mn
--ppm---							
31	148	1.7	1194	123	11	21	8
pH	Sikora	OM	Sand	Silt	Clay	CEC Sum.	EC
------pH------			------------%------------			Meq/100g	mS/cm
6.5	7.3	1.5	55	37	9	7	0.42

Table 2. Nitrogen and sulfur rates for each treatment

Treatment	Source	Nitrogen rate	Sulfur rate
		(lbs N ac^{-1})	(lbs S ac^{-1})
1	Ammonium sulfate	180	200
2	Urea + Calcium sulfate	180	50
3	Urea + Calcium sulfate	180	30
4	Urea	180	0
5	Control	0	0

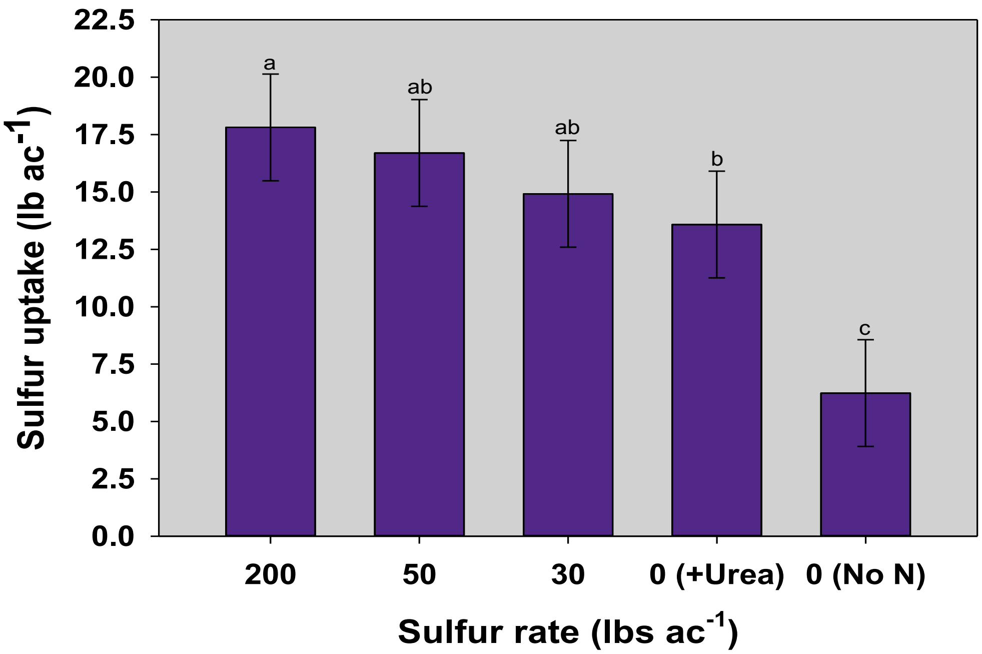

Figure 1. Whole plant sulfur uptake response at different levels of sulfur application in corn. Letters represent significant differences between treatments at $p<0.05$.

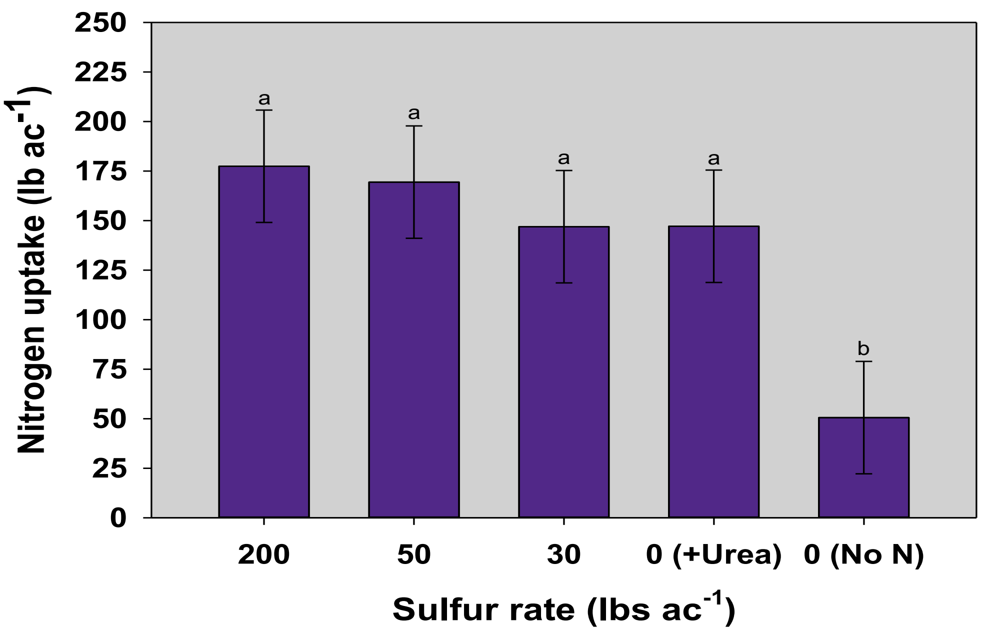

Figure 2. Whole plant nitrogen uptake response at different levels of sulfur application in corn. Letters represent significant differences between treatments at $p<0.05$.

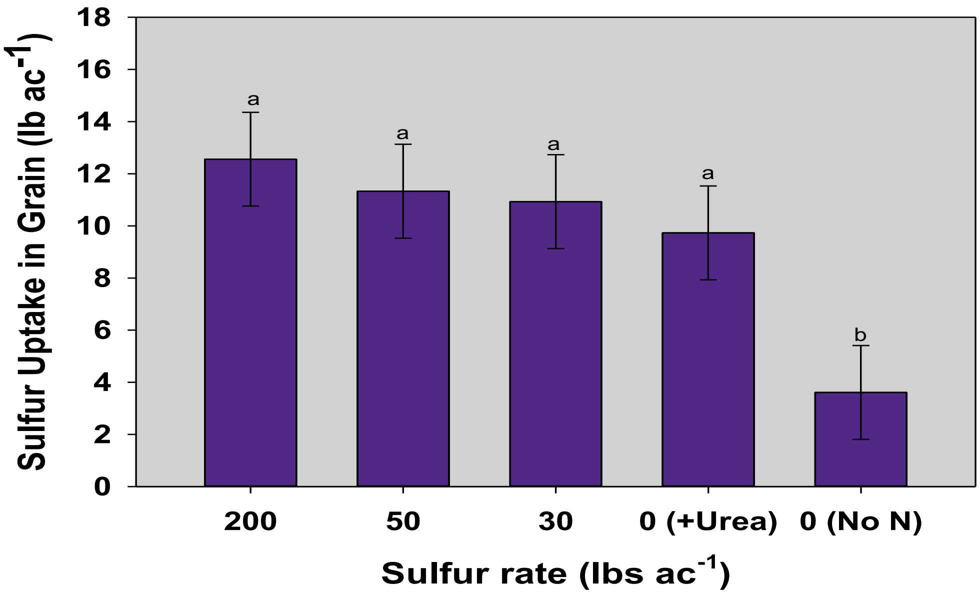

Figure 3. Sulfur removal in grain at physiological maturity in corn. Letters represent significant differences between treatments at $p<0.05$.

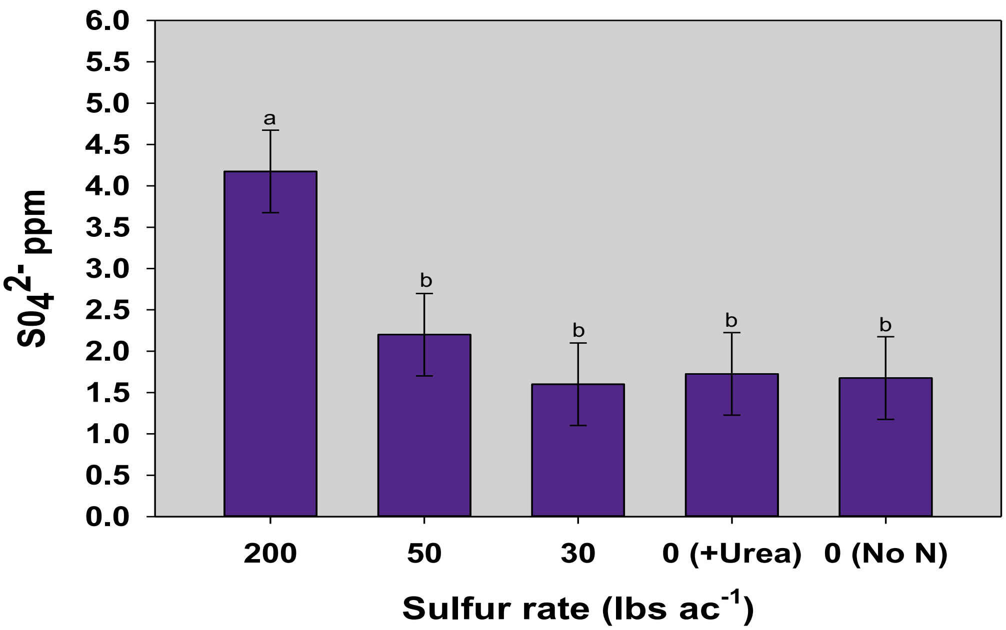

Figure 4. Corn post-harvest sulfate levels in the 0-24" soil profile samples. Letters represent significant differences between treatments at $p<0.05$.

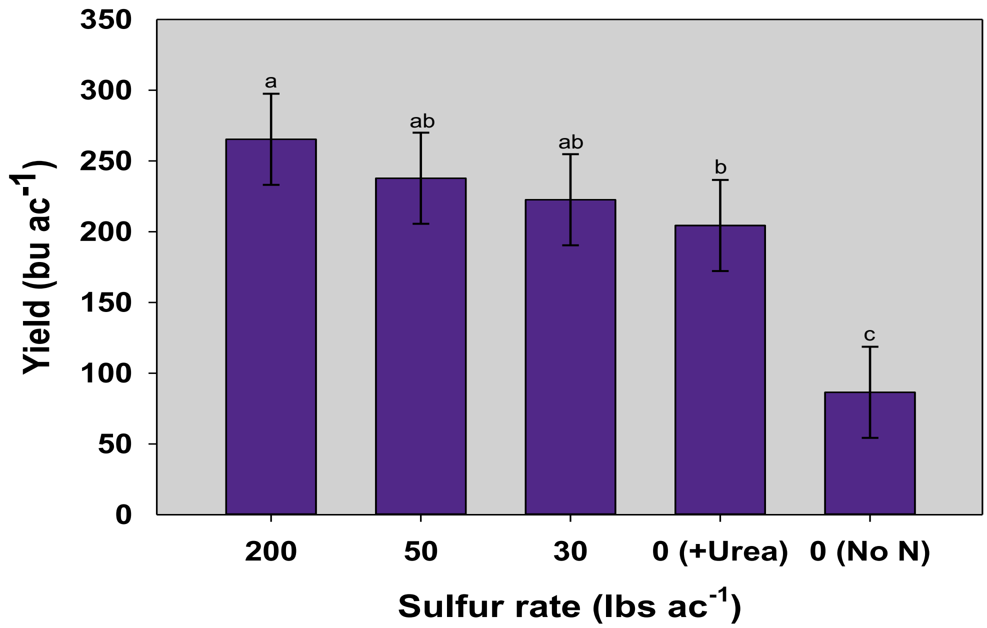

Figure 5. Corn yield response as affected by different rates of S application. Letters represent significant differences between treatments at $p<0.05$.

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Speaker Presentations