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SOIL HEALTH AND COTTON PRODUCTION IN THE SEMI-ARID TEXAS HIGH PLAINS

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ABSTRACT

Soil health has become a ubiquitous term in agriculture, but little is known about the impact of cropping system management on soil health metrics in semi-arid regions because of the majority of research has been conducted in humid or sub-humid regions of the United States. As a leading commodity of the semi-arid Southwest, cotton is an ideal candidate for soil health review. The purpose of this study was to assess a proposed set of soil health metrics in cotton production on the semi-arid Texas High Plains. The proposed metrics included soil C pools (soil organic C and permanganate oxidizable C), microbial biomass (phospholipid fatty acids), and microbial activity (mineralizable C, β-glucosidase and β-glucosaminidase). The metrics were evaluated at two locations: a native rangeland (NAT) near Wellman, TX and the Agricultural Complex for Advanced Research and Extension System (AG-CARES) near Lamesa, TX. The AG-CARES location included three continuous cotton (*Gossypium hirsutum*) cropping systems: 1) continuous cotton with fallow during winter (CT); 2) no-tillage with rye (*Secale cereal*) cover (R-NT); and 3) no-tillage with mixed species cover (M-NT). Results indicated most soil health metrics were reduced in the CT treatment compared to the NAT, M-NT and R-NT treatments. Mineralizable C was not impacted by treatment. There was no relationship between cotton yield and biological indicators of soil health. Conservation management practices in cotton monocultures exhibited soil health characteristics similar to a native rangeland, indicating intensive conservation can yield similar ecosystem services to native sites when compared to conventional cotton cropping. Further research is necessary to understand the relationship between cotton lint yield and biological indicators of soil health.

INTRODUCTION

Soil health can broadly be described as the continued capacity of a soil to perform a function that sustains humans, animals, and plants. The Natural Resources Conservation Service identified four methods for promoting soil health: 1) manage more by disturbing less, 2) diversity with crop diversity, 3) keep living roots throughout the year, 4) keep the soil covered as much as possible, 5) integrate livestock (NRCS, 2012, 2015). In agricultural production, the primary function of the soil is to produce a marketable crop. When coupled with the principles of soil health, there are several management practices to support this goal, including reduced tillage and cover cropping. The adoption of these practices can be impeded by the farmer's perception of how these practices can impact yield. Lewis et al. (2018) reported that conservation management practices increased soil organic C (SOC) but reduced yield in a semi-arid cotton (*Gossypium hirsutum*) cropping system. Most of the soil health research has focused on carbon (C) management as it is a driver of soil biology and nutrient cycling (Follet at el., 1987; Nelson and Sommers, 1996). Due to the important role of soil biology, several soil health metrics have been proposed to relate their function in agricultural productivity (Haney et al., 2006; Nakajima et al., 2015; Moebius-Clune et al., 2016). These metrics have not been thoroughly evaluated in semi-arid ecoregions like the Texas High Plains where biological C pools are relatively small (Blair et al., 2001; Bronson et al., 2004). To this end, a project was implemented to determine how a set of proposed soil health metrics could be useful in cotton (*Gossypium hirsutum*) production on the semi-arid Texas High Plains. The objective of this study was to assess the usefulness and repeatability of proposed soil health metrics on the semi-arid Texas High Plains.

MATERIALS AND METHODS

Site description and experimental design

Two research sites were used for the soil health evaluation. The first was a native rangeland (NAT) located near Wellman, TX (33^{o}3' N, 102^{o}24' W) that has not been plowed in at least 80 years (K. Attebury, personal communication, 31 May 2018). The second was a continuous cotton cropping system located at the Agricultural Complex for Advanced Research and Extension Systems (AG-CARES) near Lamesa, TX (32^{o}46' N, 101^o 56' W) which contained three treatments with a randomized complete block design and three replications, including: 1) continuous cotton with winter fallow (CT); 2) no-tillage with rye (*Secale cereal*) cover (R-NT); and 3) no-tillage with mixed species cover (M-NT). The mixed species cover included hairy vetch (*Vicia villosa* Roth), Austrian winter field pea (*Pisum sativum* L.), rye and radish (*Raphanus sativus* L.). Both cover crop treatments were planted using a grain drill at 40 lb acre^1 with the mixture comprised of 50% rye, 33% winter field pea, 10% hairy vetch, and 7% radish by weight. Cotton was planted annually as the main crop.

Soil characterization

Soil samples were collected to a 100-cm depth using a hydraulic soil probe (Giddings Machine Company, Windsor, CO) on 31 May 2019 and 1 June 2019 for the NAT and AG-CARES locations, respectively. Soil cores were subdivided into 0-5, 5-10, 10-35, 35-75, and 75-100 cm depths. Depths were selected because they correspond to the major soil horizons. For this report, we will only be presenting the results for the 0-5 and 5-10 cm depths. The soil at both sites was classified as an Amarillo series, a benchmark soil of the Southern High Plains of Texas with significant distribution in the region (3.04 M acres) and is described as a fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) with a pH of 7.5 (USDA-NRCS, 2016).
Soil organic carbon (SOC) was determined using instrumental combustion (Schulte and Hopkins, 1996). Potassium permanganate oxidizable C (POXC) was determined by reaction with dilute permanganate according to Weil et al. (2003). Mineralizable C was determined following a re-wetting of air-dried soil as described by Franzluebbers (2016). Total phospholipid fatty acids (PLFAs) were determined by the Soil Health Assessment Center at the University of Missouri. Two enzymes were analyzed during this study, β-glucosidase which is responsible for hydrolyzing complex sugars (Eivazi and Tabatabai,

1988) and β-glucosaminidase which is responsible for the degradation of chitin (Parham and Deng, 2000).

Statistical analysis

Analysis of variance for all parameters was calculated using a randomized complete block design with three replications (PROC GLIMMIX, SAS 9.4, 2015). Means of treatment effects were compared among treatments using Fisher's least significant difference (LSD) at alpha level = 0.05 for all analyses. Pearson correlation coefficient was utilized to determine the relationship between all treatments at P<0.05. Principle component analysis (PCA) was determined using JMP Pro 12 (SAS, 2015).

RESULTS AND DISCUSSION

Soil carbon

At the 0-5 cm depth, SOC was significantly greater in the R-NT, M-NT and NAT plots compared to the CT plots; however, at the 5-10 cm depth, SOC was greatest in the M-NT followed by R-NT, NAT, and finally CT (Fig. 1a). Tillage in the CT plots speeds the decomposition of organic material, resulting in less SOC. At the lower depth, SOC generally builds up from root C inputs into the soil (Neumann and Römheld, 2012). Carbon inputs were greatest in the M-NT and R-NT followed by NAT which is managed less intensively than the conservation management practices. There was significantly greater POXC in the R-NT and M-NT plots compared to the CT and NAT plots at both the 0-5 and 5-10 cm depths (Fig. 1b). The increases in POXC in the M-NT and R-NT treatments was likely the result of increased rhizodeposition which results in more bioavailable C compared to CT and NAT (Lucas and Weil, 2012). There was a positive linear relationship between SOC and POXC (R^2 = 0.5196, p<0.0001) which has been reported in other studies (Culman et al., 2012; Lucas and Weil, 2012; Culman et al., 2013; Morrow et al., 2016).

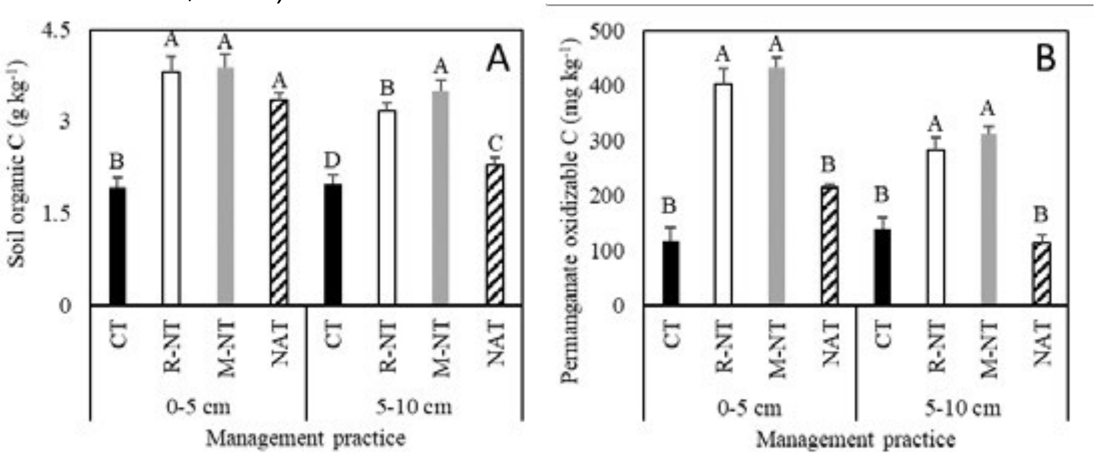

Figure 1. Soil organic carbon (A) and potassium permanganate oxidizable carbon (B) levels under different management practices. Mean concentration followed by the same letter within depth are not different at P<0.05 by Fisher's protected LSD. Conventional tillage winter fallow, no-tillage mixed cover, no-tillage rye cover, and native rangeland treatments are denoted as CT, M-NT, R-NT, and NAT, respectively. The vertical bars represent the standard error of the mean.

Microbial activity

Microbial activity was not significantly different between any treatments at either depths using the 3-day CO_2 flush for mineralizable C (Fig. 2a). However, when examining microbial biomass using Total PLFAs, there was significantly greater PLFAs in the NAT plots, followed by the R-NT and M-NT, and finally the CT plots at the 0-5 cm depth (Fig. 4). At the 5-10 cm depth, PLFAs were significantly greatest in the R-NT, M-NT, and NAT compared to the CT plots (Fig. 2b). In semi-arid soils, the limited microbial activity might not reflect a difference between treatments in a 3-day CO_2 flush, but a longer incubation period might yield significant differences between treatments. While the NAT treatment yielded a greater microbial diversity, as seen with PLFAs, compared to the other treatments, there was generally greater microbial activity as measured by enzyme production in the M-NT treatments compared to the other plots (Fig. 3a and 3b). The increased microbial activity is likely linked to increases in overall primary plant productivity. The increases in plant productivity stimulates microbial activity through C deposition to the root zone (De Nobili et al., 2001; Demoling et al., 2007). These C additions stimulate microbes to increase enzyme production. This is an important distinction for soil health in semi-arid cropping systems. The biological function of soil might not necessarily be limited by the microbes present, but by the quality of the C substances available to the microbes.

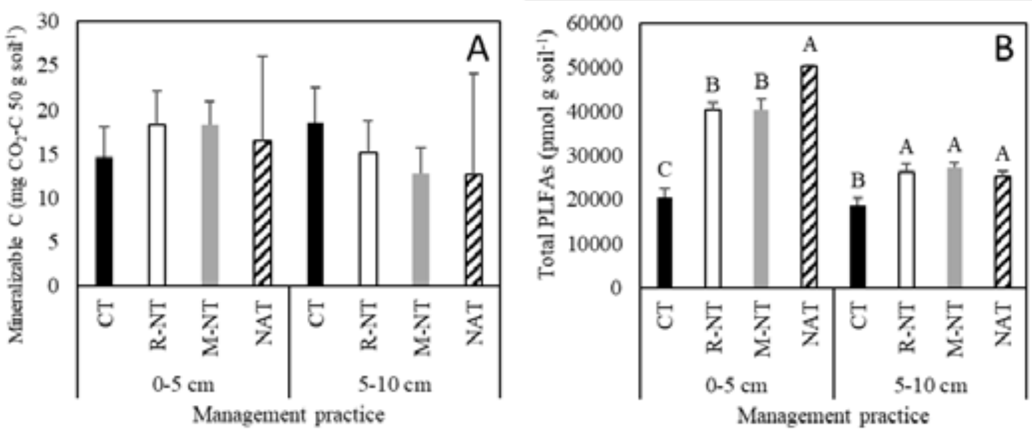

Figure 2. Mineralizable C following a three-day rewetting (A) and Total phospholipid fatty acids (PFLAs) (B)under different management practices. Mean concentration followed by the same letter within depth are not different at P<0.05 by Fisher's protected LSD. Conventional tillage winter fallow, no-tillage mixed cover, no-tillage rye cover, and native rangeland treatments are denoted as CT, M-NT, R-NT, and NAT, respectively. The vertical bars represent the standard error of the mean.

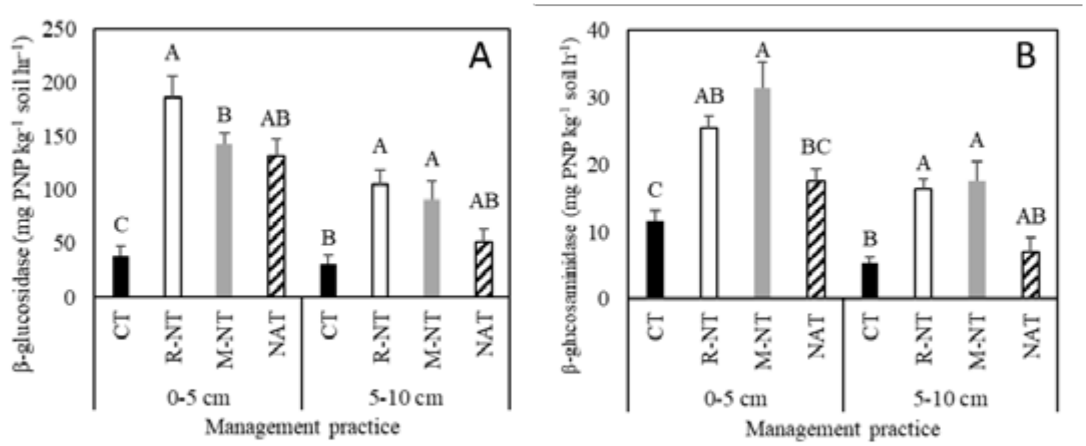

Figure 3. β-glucosidase (A) and β-glucosaminidase (B) activity under different management practices. Mean concentration followed by the same letter within depth are not different at P<0.05 by Fisher's protected LSD. Conventional tillage winter fallow, no-tillage mixed cover, no-tillage rye cover, and native rangeland treatments are denoted as CT, M-NT, R-NT, and NAT, respectively. The vertical bars represent the standard error of the mean.

Yield and soil health

An important component for the adoption of soil health management practices is that they support ecosystem services. The ecosystem service most important for agricultural producers is the maintenance and enhancement of crop production or yield. For this study, we compared the relationship between yield and the soil health parameters measured for biological activity (Fig. 7). Yield was not significantly correlated to any soil health measurements (Table 1). Further research is necessary to determine why there is no relationship between yield and biological indicators of soil health.

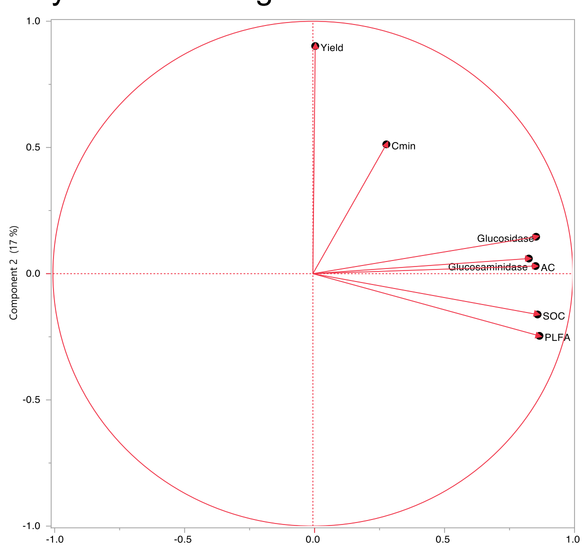

Figure 4. Principle component analysis (PCA) for all treatments. Mineralizable C, B-glucosidase, B-glucosaminidase, permanganate oxidizable C, soil organic C, and phospholipid fatty acids are designated as Cmin, Glucosidase, Glucosaminidase, AC, SOC, and PLFA, respectively.

Table 1. Pearson correlations among yield and soil measurements.

Variables	Yield†	SOC‡	POXC§	C-min¶	Total PLFAs#	β-glucosidase	β-glucosam.††
Yield	1.000	-0.640^{ns}	0.108^{ns}	0.144^{ns}	-0.244^{ns}	0.116^{ns}	0.077^{ns}
Soil organic C		1.000	0.721***	0.112^{ns}	0.747***	0.643***	0.631***
POXC			1.000	0.091^{ns}	0.645***	0.667***	0.682***
C-min				1.000	0.268*	0.272*	0.158^{ns}
Total PLFAs					1.000	0.699***	0.620***
β-glucosidase						1.000	0.657***
β-glucosam							1.000

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; *** Significant at the 0.001 probability level; ns Not significant at 0.05 probability level; † Yield, 2018 cotton lint yield; ‡ SOC, soil organic C; § POXC, potassium permanganate oxidizable C; ¶ C-min, mineralizable carbon; # Total PLFAs, total phospholipid fatty acids; †† β-glucosam. β-glucosaminidase

CONCLUSION

Conservation management practices can significantly increase biological soil health metrics when compared to a conventional cotton cropping system. However, there was no relationship between the proposed soil health metrics and cotton yield which is the primary function of soil in Texas High Plains agricultural production. Microbial activity was greatest in the mixed species cover, although microbial biomass was greatest in the native rangeland. These results indicate that intensive conservation management can build soil health to the same, and even greater extent, than native rangelands in semi-arid ecoregions. Further study is needed to quantify chemical and physical soil health metrics in cotton production to see if this trend continues and identify the relationship with cotton yield.

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SOIL CARBON AND AGROECOSYSTEM BENEFITS OF CONSERVATION MANAGEMENT AND PERENNIAL BIOENERGY CROP PRODUCTION

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ABSTRACT

Conservation agricultural management practices and perennial bioenergy crops can increase soil organic C (SOC) stocks on marginal soils yet the time necessary to observe these benefits, as well as the upper limit of C storage is not known. Co-benefits often associated with SOC accumulation are positive effects on water and nutrient retention, soil microbial biomass (SMB) and diversity and soil structure, resulting in better soil quality. We measured a variety of soil properties and soil quality indicators including SOC, aggregate stability, SMB-C, bulk density (BD), soil volumetric water content (θ_v) at field capacity (FC) and wilting point (WP), and available water (FC – WP) during a 16-year bioenergy study. N fertilizer (0, 60, 120, and 180 kg N ha^{-1}) and harvest management on switchgrass (*Panicum virgatum* L., harvested at Aug. and post-frost) and no-tilled corn (NT-C, *Zea mays L.*, with and without 50% stover removal)) established on a marginal soil in the western U.S. Corn Belt. We present changes in surface (0-30 cm) soil properties after 16 years. Surface soils have not achieved equilibrium and continue to accrue SOC. Soil OC, microbial biomass, and aggregation increased over time. Available water increased with increasing SOC, but the effect was small and unlikely meaningful for plant growth. The impacts of conservation management practices on water capture and infiltration may be much larger than the water storage impact. Our results suggest that perennial systems need long-term measurements to accurately quantify bioenergy impacts on the soil resource and in contrast to model predictions, soil C accrual and soil quality benefits persist for decades post land-use conversion.

INTRODUCTION

Conversion of marginally productive crop lands to perennial biofuel crops has the potential to produce cellulosic biofuel feedstock and increase soil carbon (C) stocks while reducing erosion, fertilizer use, and greenhouse gas (GHG) emissions (Adler et al., 2007; Jin et al., 2019; Mitchell et al., 2016). Switchgrass can increase soil C stocks due to its perennial, deep-rooted growth form (Garten et al., 2010; Stewart et al., 2016) and increase soil aggregation and reduce erosion potential compared to corn (*Zea mays* L.). In this study, we track the impact of N fertilizer and harvest effects on continuous switchgrass (Cave-in-Rock), rotational switchgrass (Liberty), and NT-corn on surface soil properties. We measured several soil quality indicators and properties (aggregate stability, SMB, SOC, available soil water) over the 16-year study.

MATERIALS AND METHODS

Site & Experimental Design

The 16-year rainfed bioenergy experiment is located at the University of Nebraska's Eastern Nebraska Research, Extension, and Education Center (ENREEC) (latitude 41.151, longitude 96.40) in Saunders County, 50 km west of Omaha, NE (details in Stewart et al., 2016, Jin et al. 2019). The mean annual temperature is 9.16°C and the mean annual precipitation is 63.5 cm. The experiment included two similar soils; a Yutan silty clay loam (fine-silty, mixed, superactive, mesic Mollic Hapludalf) and a Tomek silt loam (fine, smectitic, mesic Pachic Argiudoll) with a slope less than 2%.

The study design compares bioenergy crop species (corn and two switchgrass cultivars), N fertilizer rates and harvest practices. It is a randomized complete block split-split plot experimental design that was established with two cultivars of switchgrass (Liberty, Cave-in-Rock), and NT-C.

Three N fertility treatments were randomly assigned within the main plots and were different for switchgrass and NT-corn. Subplots are 30 m long × 18 m wide and are separated by 15 m wide alleys. From 2000-2014, N fertilizer on the CIR switchgrass were 0, 60, and 120 kg N ha^{-1} and on NT-C were 60, 120, and 180 kg N ha^{-1}. For Liberty, in 2014 N fertilizer was the same as for CIR. The 0N rate was used as a low input treatment only for switchgrass. Harvest treatments (no residue removal (NRR) or 50% residue removal (RR) for corn and August or post-frost harvest for switchgrass), were established by splitting plots lengthwise into 9 m wide sub-subplots after the 2001 soil sampling.

Soil Sampling & Analyses

Soils were sampled by excavating the 0–5, 5–10, and 10–30 cm depths using a flat-bladed shovel in July 1998, May 2001, April 2004, May 2007, and April 2014 as described by Stewart et al. (2014). Soils were packed on ice, and transported to Fort Collins, CO and refrigerated or seran coated and shipped to Lincoln, NE. All plant material <2 mm was hand-picked from the soil. Moist subsamples were retained for microbial biomass and soil moisture content (105 °C). An additional subsample was oven-dried at 55 ºC, ground to pass through a 0.2-mm sieve, and stored in glass containers for C analysis.

Soil microbial biomass was determined in duplicate using the incubation-fumigation method on moist soils (Follett et al., 2007). Briefly, soil moisture was adjusted to -0.05 MPa and the soils incubated at 30 ºC for 10 days. Soils were fumigated using distilled chloroform at day 10 and incubated for an additional 10 days. Soil CO_2 was trapped in 1M NaOH base traps and titrated with an excess of HCl.

Soil total C and N concentration and $\delta^{13}C$ were determined using a Europa Scientific carbon nitrogen analyzer with a Solid/Liquid Preparation Module (Dumas combustion sample preparation system) coupled to a Europa 20-20 stable isotope analyzer continuous flow isotope ratio mass spectrometer (Europa Scientific Ltd., Crewe, England). Carbonates were observed in only a few samples and were removed prior to analyses for organic C with addition of 0.03 M H_3PO_4, dried at 55 ºC and ground (Follett *et al.,* 1997). All analyses are expressed as oven dry weight (55°C).

Bulk density, aggregate stability, water content at field capacity (-33 kPa), water content at wilting point (-1500 kPa) were performed at the NRCS Kellogg Soil Survey Laboratory in Lincoln, NE using established methods (USDA-NRCS, 2004). Soil bulk density was determined using the Saran-coated clod method 3B1. Soil clods were cut from the excavated soil material to a suitable size (average of about 210 cm^3), coated immediately with Saran F310, hung to dry, then placed in NRCS chambered boxes and transported to the laboratory. Mass and volume were determined after desorption to 33 kPa, and after drying at 110ºC. A correction was made for mass and volume of rock fragments and the Saran F310 coating with the BD value reported for <2 mm (<0.079 in) soil fabric (NRCS, 2004). Wet soil aggregate stability (method 3F1a1a) was determined on dry soils sieved to 2mm and subsequently wet-sieved on a 0.5 mm sieve and expressed as a percent soil mass (USDA-NRCS, 2004). Available water (AW) was calculated as the difference between FC and WP. Calculations of changes in AW were made on a volumetric (θ_v) basis.

Data were analyzed using a repeated measures design with split-split plot experimental units in SAS version 9.3 (Cary, NC). Fixed main treatment effects were crop, N×crop and harvest×crop with replicate, replicate×crop and replicate×N×crop considered random effects. Variables were tested for homogeneity of variance, normalcy and when necessary, log transformed to meet these criteria.

RESULTS AND DISCUSSION

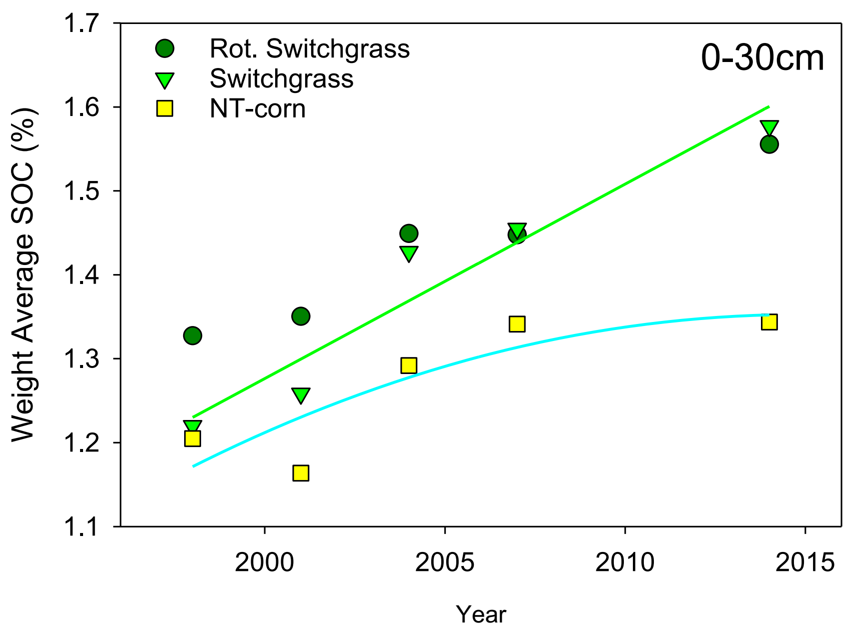

Figure 1. Main crop effects for soil organic carbon (SOC) for two switchgrass cultivars (Liberty, Cave-in-Rock) and NT-Corn in the 0-30 cm depth. Error bars represent standard error of the mean (n=3).

The benefits of best management practices, NT and perennial cropping, were evident in soil quality indicators compared to historic long-term conventional tillage management. Soil OC (Figure 1), microbial biomass (Figure 2), and aggregation (Figure 3) increased over time under all best management practices over the 16-year study. In fact, the greatest increase in SOC content, soil aggregation and SMB-C and the strongest decrease in soil bulk density under switchgrass were observed in the last 7 years of the study, emphasizing the importance of long-term studies in SOC research (Peterson et al., 2012). Main N and harvest effects were not observed, and so we present only main crop effects.

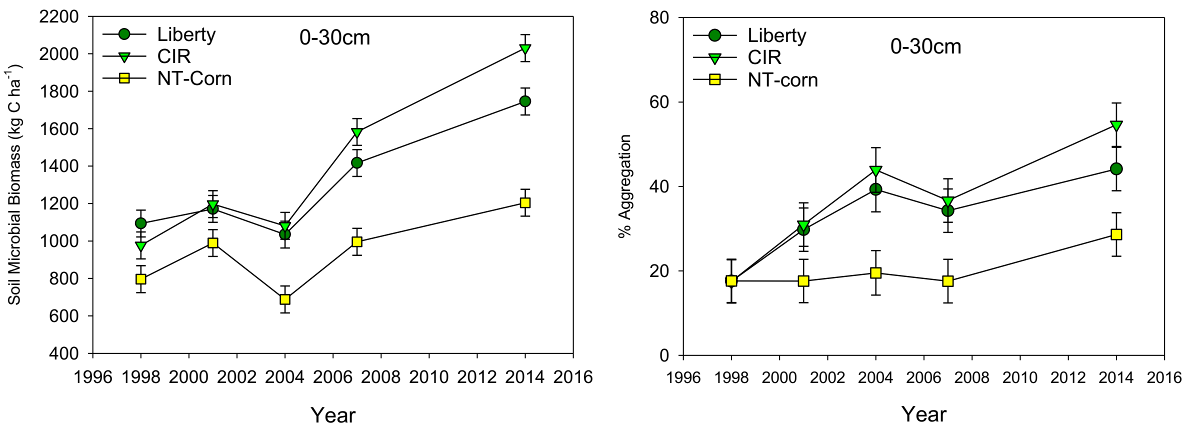

Figure 2. Main crop effects for soil microbial biomass (kg C ha^{-1}) (left panel) and % aggregation (right panel) for two switchgrass cultivars (Liberty, Cave-in-Rock) and NT-Corn in the 0-30 cm depth. Error bars represent standard error of the mean (n=3).

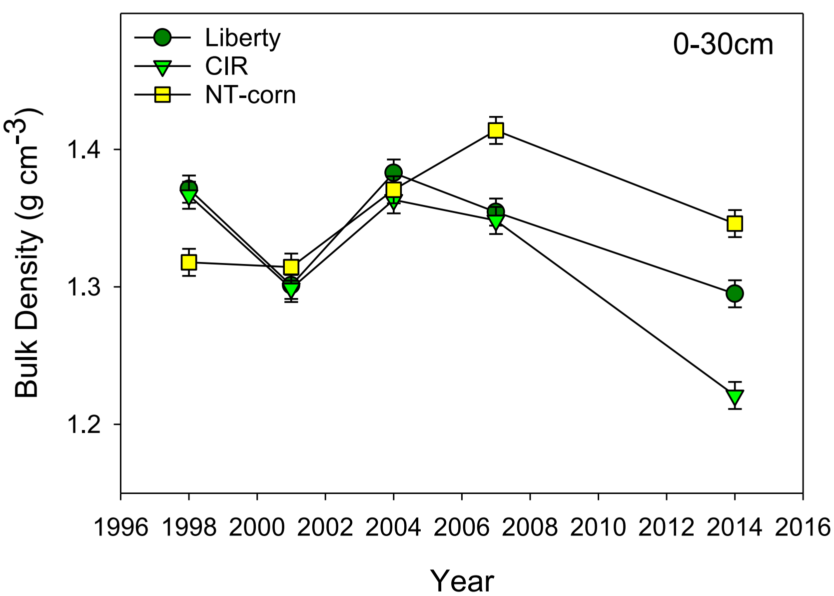

Figure 3. Main crop effects for a) soil microbial biomass (kg C ha^{-1}) and % aggregation b) for two switchgrass cultivars (Liberty, Cave-in-Rock) and NT-Corn in the 0-30 cm depth. Error bars represent standard error of the mean (n=3).

NT-corn increased SMB-C 51%, Liberty 60%, and CIR 108% compared to baseline (Figure 2). The two switchgrass cultivars had more SMB-C in 2014 (CIR 2030.3 g SMB-

C ha^{-1}, and Liberty 1745.1 g SMB-C ha^{-1}) compared to NT-Corn (1204.2, $p<0.0001$, Figure 2). NT-corn increased aggregate stability 62%, Liberty 151%, and CIR 212% compared to baseline for 0-30cm depth (Figure 2). Averaged across N and harvest, switchgrass soils had almost double the aggregate stability (50%) compared to NT–C (27%).

Averaged over depths and N treatments, both cultivars of switchgrass decreased bulk density 10-15% over the 16 years ($p<0.0001$, Figure 3). NT-corn increased bulk density until 2007 and then decreased to slightly above baseline in 2014.

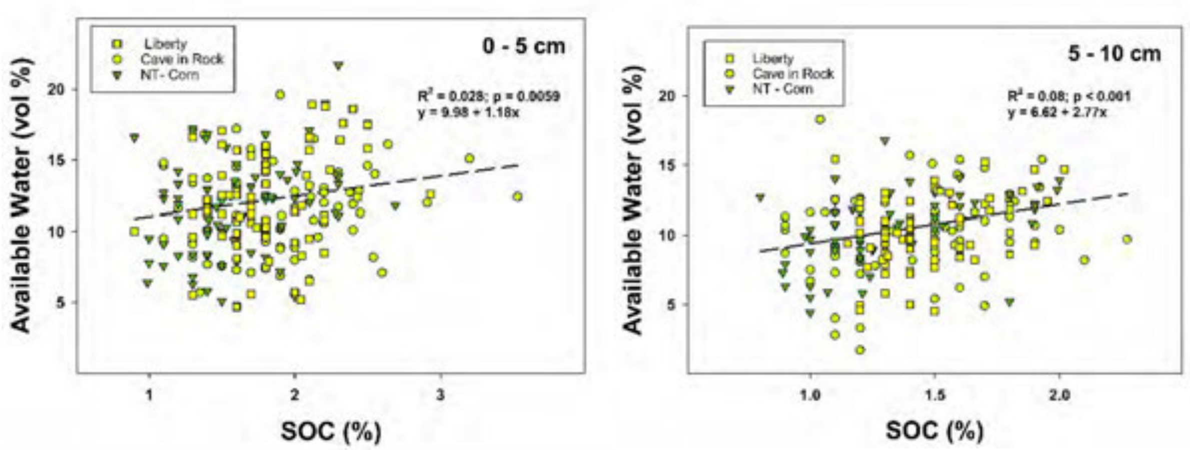

Figure 4. Available soil water (θ_v) versus SOC (%) for the 0 – 5 cm depth (left panel), and the 5 – 10 cm depth (right panel). Slopes and intercepts did not differ between crops. Note the difference of scales for the x-axis.

Due to the increase in SOC %, we expected an increase in available soil water. On average, a 1% increase in SOC increased available water (vol %) by ~ 1.2 in the 0 - 5 cm depth and 2.8 in the 5 -10 cm depth, with no differences in the slopes or intercepts between crop treatments (Figure 4). Although statistically significant, this effect is fairly small (e.g., equivalent to an increase of 1.2 and 2.8 mm of water per 100 mm of soil). These results are similar to those reported by Minasny and McBratney (2018). However, the impacts of conservation management practices on water capture and infiltration may be much larger than the water storage impact.

Switchgrass has the potential for long-term soil C gain due to its large root biomass and slower decomposition compared to NT-corn. Soil quality indicators did show greater increases under switchgrass. Soil microbial biomass increased 3% per year under NT-corn and 7% per year under switchgrass in the 0-30 cm depth. Soil aggregate stability increased 4% per year under NT-corn and 13% per year under switchgrass. Bulk density did not change under NT-corn, but decreased 1% per year under switchgrass in the 0-30 cm depths. Long-term studies will be required to measure these changes, since after 16 years we were only beginning to see crop species differences in SOC storage in the surface soils.

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SOIL PHYSICAL QUALITY EFFECTS OF NOVEL PERENNIAL GRAIN CROPPING AT TWO CONTRASTING SITES IN ALBERTA, CANADA

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ABSTRACT

Novel perennial grain crops have been proposed as a solution to several environmental issues facing modern agriculture, namely the loss of soil quality often associated with annual monocrops. This study evaluated soil physical and hydraulic properties in three cropping systems (perennial forage, perennial grain, and spring grain) at two sites in central Alberta, Canada with contrasting soil types over three growing seasons (2017 to 2020). Soil physical and hydraulic properties were measured during the 2020 growing season for three soil depths (5-10, 15-20 and 25-30 cm). Root samples from 0-60 cm were obtained during crop anthesis in 2018 and 2019. Perennial treatments (forage and grain) showed consistently elevated root density relative to the spring grain treatment.. In general, increases in bulk density in the spring grain treatment were mirrored by relative increases in total porosity of the perennial treatments. Specifically, the perennial forage treatment increased macroporosity in the 25-30 cm at the Edmonton and Breton sites ($p < 0.05$ and $p < 0.001$, respectively). Improvements in S-index materialized at the 25-30 cm depth at the Edmonton site alone, and only in the perennial forage treatment ($p < 0.05$).

INTRODUCTION

Abundant literature has stressed the importance of good soil quality for maintaining and improving ecosystem services provided by agricultural systems including, but not limited to, soil carbon sequestration, disease suppression, water filtration and greenhouse gas mitigation (Kim et al., 2021; Lal, 2016; Palm et al., 2014; Powlson et al., 2011). Conversion of annual croplands to perennial systems has shown improvements, largely attributable to reduced tillage, enhanced root growth and carbon inputs (Culman et al., 2013; So et al., 2009), however, it is unclear if these improvements will manifest in a perennial grain system that only survives 2-3 years (Daly et al., 2021).

The effects on soil physical quality from contrasting cropping systems can be characterized by measuring properties that may be sensitive to management effects, such as total porosity (TP), bulk density (BD), pore volume fractions (PVF) and the S-Index (Hebb et al., 2017). As such, specific objectives of this study were to i) determine the effects of perennial grain, spring grain and perennial forage on soil physical and hydraulic properties in two contrasting soil types, and ii) relate potential differences in physical and hydraulic properties to differences in root density and management between the aforementioned systems.

MATERIALS AND METHODS

Field sites were established in Edmonton, Alberta, Canada (53° 29' 43.33", 113° 31' 59.24") and Breton, Alberta, Canada (53° 5' 16.72", 114° 26' 29.35") in August 2017. Soils at the Edmonton have a long-term management history of continuous barley for silage. Soils at the Breton site were harvested for forage for > 60 years prior to the experiment. Baseline soil chemical and physical properties are summarized in Table 1.

Table 1. Baseline soil properties from the Edmonton and Breton sites.

Soil Properties	**Site** Edmonton	Breton
Canadian classification	Black Chernozem	Gray Luvisol
Total carbon (TC) (g C kg^{-1}) (0-30 cm)	41.6 ± 7.5	19.2 ± 3.9
Total nitrogen (TN) (g N kg^{-1}) (0-30 cm)	3.6 ± 0.5	1.7 ± 0.3
Available nitrogen (NH_4^+ & NO_3^-) (mg N kg^{-1}) (0 – 15 cm)	48.3 ± 4.5	55.5 ± 2.5
pH (1:5 H_2O)	7.3 ± 0.09	6.1 ± 0.08
Bulk density (g cm^{-3}) (5-30 cm)	1.0 ± 0.06	1.1 ± 0.06
Soil texture	clay	loam
% clay	48.3	24.8
% silt	35.7	41.8
% sand	16.0	33.3

Both experimental sites were arranged in identical randomized complete block designs consisting of four block replicates. Treatments consisted of contrasting cropping systems: two analogous grain cultivars, perennial [ACE-1 rye (*Secale cereale L. × S. montanum Guss]* and spring [Gazelle rye (*S. cereale L.*)], as well as perennial forage [(meadow brome (*Bromus commutatus*) and alfalfa (*Medicago sativa*)]. The perennial forage and perennial grain treatments were seeded in late summer 2017. The spring grain treatments were tilled and seeded in spring 2018, 2019 and 2020.

Undisturbed soil cores were collected from the perennial forage, perennial grain, and perennial forage treatments from three depths: 5-10 cm, 15-20 cm and 25-30 cm in May (Edmonton) and July (Breton) of 2020. Two replicates were taken for each depth in each plot and averaged, for a total of 48 cores per site. Soil cores from 0-60 cm were obtained for root density determination using a truck-mounted auger. Two cores were collected and composited for each plot, then separated into 0-15 cm, 15-30 cm, and 30-60 cm intervals.

Soil physical and hydraulic properties were obtained using a HYPROP® instrument system (*Meter Environment, Munich, Germany*) using the simple evaporation method (Schindler and Müller, 2017) in combination with WP4 potentiometer® dewpoint method, for the very dry range (*Meter Environment, Munich, Germany)*. Data was analyzed using the HYPROP-FIT® software, which used measured data values and supplemental WP4® data points to fit the constrained van Genuchten model (van Genuchten, 1980) for moisture retention.

The PVF were calculated using the relationship between points on the water retention curve (kPa) and pore diameters (µm) as follows: macro (0 to -5 kPa, >60 µm), meso (-5 to -33 kPa, 60-9 µm), micro (-33 to -50 kPa, 9-6 µm) and nano (< -50 kPa, < 6 µm) as in Hernandez-Ramirez et al. (2014) and Guenette et al. (2019).

RESULTS AND DISCUSSION

Root Density

Root density differed significantly between treatments at the Edmonton and Breton sites (Figs. 1A-D). At the Edmonton site, root density was consistently highest in the perennial forage, followed by perennial grain, and lowest in the spring grain. Notably, in 2018, in the 15-30 cm depth interval perennial forage root density was significantly greater than the perennial grain, which was greater than the spring grain ($p < 0.001$) (Fig. 1A). Results from the 15-20 cm depth in 2019 were similar. Perennial forage had greater root density than spring grain ($p < 0.001$) (Fig. 1B). Trends at the Breton site mimicked those at the Edmonton site, however, differences between the perennial treatments (forage and grain) and the spring grain were less pronounced at the 15-20 cm depth. Increased root density of the perennial forage compared to spring grain was only evident in 2019 ($p < 0.001$) (Figs. 1C, 1D).

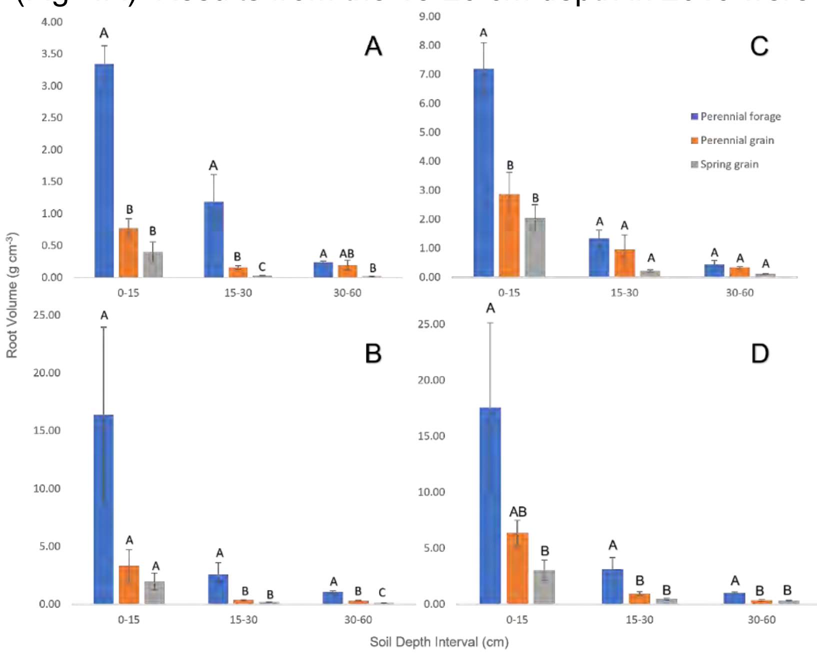

Figure 1. Average root densities for the 0-15, 15-30 and 25-30 cm depth intervals at the Edmonton site in 2018 (A) and 2019 (B) and the Breton site in 2018 (C) and 2019 (D). Uppercase letters denote significant differences between treatments within each depth for each year at each site ($\alpha = 0.05$). Error bars are ± SE (n=4).

Bulk Density and Total Porosity

At the Edmonton site, BD from 5-10 cm was lower in the perennial forage treatment compared to the perennial and spring grain treatments, which did not differ from one another ($p < 0.05$). Statistically significant differences were not detected between treatments in the other depths; however, spring grain BD was consistently higher than the perennial grain and forage treatments. In Breton, the BD trend from highest to lowest in all depths was as follows: spring grain > perennial grain > perennial forage (Table 2).

The TP of the perennial forage at the Edmonton site was greater than the TP of the spring grain in the 5-10 cm depth increment ($p < 0.05$). Neither the perennial forage nor the spring grain differed from the perennial grain, which had a TP that was numerically higher than the spring grain, but lower than the perennial forage. No differences were found for the 15-20 or 25-30 cm depths, but perennial grain and perennial forage had elevated TP relative to the spring grain. In Breton, TP for each depth trended from highest TP to lowest as follows: perennial forage > perennial grain > spring grain, but the treatments did not statistically differ from one another (Table 2).

Reduced BD and increased TP in the no-till perennial treatments (forage and grain) versus the annually tilled spring grain, contrasts with studies that found increased BD with the implementation of no-till practices (Dam et al., 2005; Li et al., 2020). However, these studies did not account for the reduced seeding traffic and elevated root mass in perennial systems, which we hypothesize had an effect on BD and TP.

Macroporosity

At the Edmonton site, macroporosity trends were consistent for the 5-10 and 15-20 cm depths, from highest to lowest: perennial forage > perennial grain > spring grain. Only the 25-30 cm depth showed significant differences between treatments; perennial forage had increased macroporosity compared to the perennial and spring grain treatments, which did not differ from one another ($p < 0.05$). Similarly, macroporosity at the Breton site was consistently higher in the perennial forage treatment. From 15-20 cm, perennial forage macroporosity was greater than the spring grain ($p < 0.05$). From 25-30 cm, macroporosity was greater in the perennial forage treatment than the perennial and spring grain treatments ($p < 0.001$).

Trends in macroporosity generally mimicked those of root density at both sites, as in, perennial forage > perennial grain > spring grain. Roots can amalgamate microaggregates, and in doing so generate macropores (Lu at al., 2020). Specifically, plants with tap roots such as alfalfa, a component in our perennial forage treatment, can generate preferential flow paths and enhance soil macroporosity (Lu et al., 2020; Song et al., 2017). Previous research supports that these changes can materialize over comparable timescales, with McCallum et al. (2004) reporting significantly improved macroporosity in subsoils under perennial rotations after 3 years.

S-Index

At the Edmonton site, significant differences in the S-index materialized at the 25-30 cm depth, where the perennial forage treatment > perennial grain = spring grain (Fig. 2). However, the S-Index for perennial forage was consistently elevated relative to the spring grain treatment for all depths. Differences at the Edmonton site, but no discernable differences at the Breton site, may be due to a combination of factors:

namely, soil properties (texture and organic matter) and land use history. Soils with higher clay and organic matter content, such as those at the Edmonton site, may be more responsive to structural improvements if beneficial management practices are implemented (Denef et al., 2002). Additionally, the Edmonton site may have had more room for soil quality improvements after years of tillage and continuous cropping, as evidenced by S-index values that are collectively less than 0.035, the S-index value proposed as the division between “good” and “poor” soil quality (Dexter, 2004).

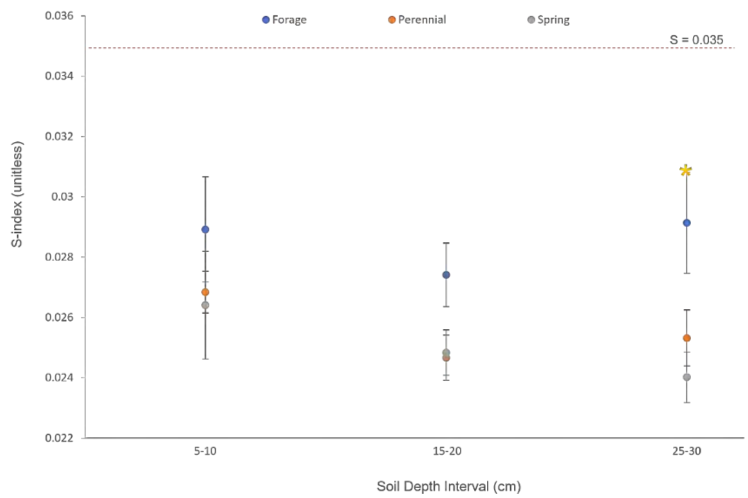

Figure 2. S-Index values for the 5-10, 15-20 and 25-30 cm depth increments at the Edmonton site. The dashed red line at 0.035 indicates the hypothetical division between “good” and “poor” soil quality as proposed by Dexter (2004). The yellow star indicates statistically significant differences between treatments (α = 0.05). Error bars are ± SE (n=8).

Overall, the contrasting effects of contrasting cropping systems on soil physical and hydraulic properties were evident after 3 yrs. Perennial forage had the greatest beneficial impact on BD, TP, macroporosity and the S-index relative to the spring grain, whereas effects of the perennial grain treatment were variable, but often intermediate between perennial forage and spring grain.

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DRAMATIC SOIL HEALTH CHANGES AFTER 18 YEARS OF DIFFERENT NITROGEN RATES AND CROPPING SYSTEMS IN THE NORTHERN GREAT PLAINS

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ABSTRACT

Relatively few long-term cropping and nitrogen (N) rate studies have been conducted in the semi-arid northern Great Plains that assess soil health changes. A cropping system study was initiated in 2002 in Bozeman, Montana (~16 in. annual precipitation) with wheat grown in even years, and either tilled fallow or one of the following no-till systems in odd years alternated with wheat: fallow (NTF-W), wheat (CW), pea grain (Pgrain-W), pea hay (Phay-W), pea green manure (PGM), and an alfalfa-grass until 2012 followed by pea grain (CRP/Pgrain-W). N was applied at either 50% or 100% of the recommended N rate based on soil nitrate levels, yield goals and pulse N credits. After 18 years, pH was nearly 1 unit higher in Pgrain-W and PGM, than CW, likely due in part to much lower N rates in pulse-systems. The fraction of water stable aggregates (1-2 mm) was lower in both fallow systems and PGM than in Pgrain-W and CW, likely due to differences in residue returned. Infiltration rates (double ring) were 7-fold higher in recrop than fallow treatments, likely because of more aggregates in recrop, but possibly due to more permanent root channels in recrop favoring preferential flow. The geometric mean of four enzyme concentrations was higher in the CRP/Pgrain-W than in either fallow wheat system. These results demonstrate the importance of cropping systems and N rates on soil health in a semi-arid region, and the value of long-term studies at detecting soil health changes.

INTRODUCTION

While it is generally understood that cropping systems and N rate can affect soil health for a myriad of reasons, often related to residue quantity (Engel et al. 2017) and quality, it is generally challenging to detect soil health changes in short-term studies especially in semi-arid regions because of low amounts of residue returned. Therefore, it is important to evaluate soil health from long-term cropping studies in semi-arid regions such as the northern Great Plains. A study was commenced in 2002 near Bozeman, Montana to initially assess the effects of cropping system and N rate on greenhouse gas emissions, grain yield, grain quality, and net revenue. For 2009-2012 of this study, Miller et al. (2015) found that net revenue was consistently much higher for Pgrain-W than the other six rotations evaluated, regardless of N rate or assumed protein discount. The perennial system had reduced net revenue for four years after it was converted to an annual system (2012-2016), due to deep water use of perennials combined with excess N that might have resulted in excess water use early in the growing season of annuals (Miller et al. 2019). This study, hereafter referred to the greenhouse gas rotations study (GGRS), has provided an excellent opportunity to also evaluate soil health response to cropping system and N rate.

O'Dea et al. (2015) found that 8-years of cropping in GGRS resulted in 50% higher PMN and 30% higher microbial biomass carbon (MBC) for legume-containing rotations (Pgrain-W and PGM-W) than wheat only systems (NTF and CW). The 1 – 2 mm water stable aggregate (WSA) fraction was nearly 2-fold higher in the higher residue CW and Pgrain-W systems than PGM-W and NTF. Engel et al. (2017) found that soil organic carbon (SOC) pools (equivalent mass in top foot) after ten years were 1-3 ton C ac^{-1} higher in all recrop systems than in tilled fallow. Residue C returned (measured shoot plus calculated root from published root:shoot ratios) was highly correlated ($r^2 = 0.86$) to change in SOC pool over the ten years, despite differences in C:N ratios among residues. This analysis determined that a 'critical' level of 1.2 ton ac^{-1} per year of residue was needed to maintain SOC levels, which is challenging to accomplish in a 16 in. rainfall zone. This critical residue C level was not attained in either fallow system at either N rate in the first ten years of the study but was exceeded in both the CW and Pgrain-W systems when averaged across N rate (residue returned for the CRP system, where roots would have dominated, was not evaluated).

The final year of the GGRS's annual cropping x N rate study was completed in 2020, 18 years after initiation of the study. This provided an excellent opportunity to evaluate long term effects of cropping and N rate on a range of biological, chemical, and physical soil parameters.

MATERIALS AND METHODS

Site

The study is located approximately four miles west of Bozeman, Montana, at the Arthur Post Research Farm. The site receives 16.3 inches of annual precipitation, and soils are Amsterdam silt loams (fine-silty, mixed, superactive, frigid Typic Haplustolls).

Design

The GGRS design is described in more detail in previous studies (Miller et al. 2015; Engel et al. 2017) but the rotations are summarized in Table 1 (next page). The cropping systems that our project focused on included tilled wheat fallow (TillF), and no-till fallow wheat (NTF), continuous wheat (CW), wheat alternated with a pulse (Pgrain, Phay, or PGM), and a mixed perennial/annual system (CRP/ Pgrain-W). The study has 4 blocks in a randomized complete block design. Each plot was split and wheat received either 3 lb available N bu^{-1} or 1.5 lb available N bu^{-1}, where available N = soil nitrate-N to 3 ft + pulse N credit + fertilizer N.

Table 1. Crops grown and total N fertilizer applied in GGRS study near Bozeman, Montana.

Year	Till F	NTF	CW	Pgrain	Phay	PGM	CRP/P
2003	Ftill	Fnt	SWht	WPea	WPha	WPha	Alf/grs
2004	WWh	WWh	WWh	WWht	WWht	SWht	Alf/grs
2005	Ftill	Fnt	SWht	WPea	WPha	WPha	Alf/grs
2006	WWh	WWh	WWh	WWht	WWht	SWht	Alf/grs
2007	Ftill	Fnt	SWht	WPea	WPha	WPha	Alf/grs
2008	WWh	WWh	WWh	WWht	WWht	SWht	Alf/grs
2009	Ftill	Fnt	SWht	SPea	SPhay	SPbm	Alf/grs
2010	SWht	SWht	SWht	SWht	SWht	SWht	Alf/grs
2011	Ftill	Fnt	WWh	WPea	WPha	WPb	Alf/grs
2012	WWh	WWh	WWh	WWht	WWht	WWht	Alf/grs
2013	Ftill	Fnt	SWht	SPea	SPhay	SPbm	SPea
2014	SWht	SWht	SWht	SWht	SWht	SWht	SWht
2015	Ftill	Fnt	WWh	WPea	WPha	WPb	WPea
2016	WWh	WWh	WWh	WWht	WWht	WWht	WWht
2017	Ftill	Fnt	SWht	Lentil	CCMh	CCMb	Lentil
2018	SWht	SWht	SWht	SWht	SWht	SWht	SWht
2019	Ftill	Fnt	WWh	WPea	WPha	WPb	WPea
2020	WWh	WWh	WWh	WWht	WWht	WWht	WWht
Full N (lb/ac)	1496	1547	2840	1426	1336	1115	659
½ N (lb/ac)	516	588	1655	481	340	266	146

Ftill -tilled fallow; Fnt – no till fallow, WP – winter pea, CCMhay – cover crop mixture, hayed, SWht- spring wheat, Wwht – winter wheat, bm – brown manure (sprayed out cover)

Analyses

Biological (Enzymes, Potentially Mineralizable N, Microbial Biomass).

To test the effects of fertilizer N and cropping system on biological aspects of the soil, we measured soil enzyme activity, potentially mineralizable N, and substrate induced respiration (SIR) as an estimate of microbial biomass. Soils were sampled with a hand probe to a depth of 6 inches at the end of May 2020 (a few weeks after fertilization but while the plants were still small) for enzyme activity and subsampled again in in mid-October 2020. We measured activity of soil enzymes associated with N cycling (B-glucosaminidase), P cycling (acid and alkaline phosphatase), S cycling (arylsulfatase), and OM decomposition (B-glucosidase), by incubating 1 g of soil with a dye-labeled substrate. Activity was measured colorimetrically in the lab. Geometric mean was the 4th root of the product of the four enzymes (acid and alkaline phosphatase were summed to created one value). PMN was measured with a 14-d anaerobic incubation (Keeney and Nelson, 1982). Substrate induced respiration was analyzed with additions of autolyzed yeast and reported here as microbial biomass (Fierer et al. 2003).

Wheat was grown across all treatments during 2020, so comparison of spring versus fall measures of soil enzymes will tell us whether the subsequent wheat crop homogenizes any differences brought about by contrasting cropping systems of the previous growing season.

Chemical (pH, SON, SOC).

Soil was sampled with a hydraulic probe truck after harvest in 2020 and analyzed for SOC and SON via combustion on an acidified sample to remove carbonates (0-4, 4-8, and 8-12 in.) and for pH on a 1:1 soil:water (0-4 and 4-8 in.)

Physical (Water stable aggregates, infiltration rates).

Water stable aggregates were analyzed in the top 6 in. of all subplots by air drying and dry sieving to obtain aggregates that were 1 to 2 mm in diameter. These were then subjected to humidification and shaking in a water bath followed by re-sieving to determine the percent of water stable aggregates. Infiltration rate was determined only on the full N treatments given the extensive time involved in infiltration measurements. Three double ring infiltrometers (12 in. outer, 6 in. inner) were pounded into the soil in each tested subplot from Sep 23 to 25, 2020, avoiding noticeable tire tracks, filled with water, and equilibrated until infiltration rate was steady. The rings were then topped with water, and the water level in the inner ring monitored 3 to 5 times until all the water infiltrated. Infiltration rates were determined by linearly regressing water level versus time.

RESULTS AND DISCUSSION

Results for all data are below except for SON and SOC which we hope to have in time for the conference.

Biological

The CRP/Pgrain-W system had 90% higher geometric mean enzyme activity than tilled fallow, and all rotations with pulses had higher geometric means than tilled fallow (Table 1). That pattern roughly follows our hypotheses that including N-fixing crops and increasing biomass available to the soil increases enzyme activities, and hence nutrient cycling rates. Surprisingly, crop rotation did not affect PMN at P=0.05, like it did ten years previously when the two pulse-containing systems had higher PMN than wheat-only systems (O'Dea et al 2015). In both studies, soils were collected for PMN analysis about nine months after crop harvest or PGM termination, although we used a 14-d anaerobic incubation while O'Dea et al. measured PMN with a 112-d aerobic incubation. Interestingly, O'Dea et al. found increasing significance of the pulse-containing v. wheat-only contrast when incubation time increased from 7-d (P=0.38) to 14-d (P=0.08) to 112-d (P=0.01). In addition, N rate did not affect PMN. Substrate induced respiration was 40% higher in the CRP/Pgrain treatment than in tilled fallow (Table 1), demonstrating the benefits of no-till and high amounts of residue, especially roots, on biological activity. The SIRs of all other treatments were intermediate.

Chemical

Soil pH in the CW treatment applied with the full N rate was about 5.8 which was more than 1 unit lower than pH in the Pgrain-W and CRP/Pgrain-W, likely because CW had by far the most N applied (Table 1). The other four treatments had intermediate pH levels. N fixation is reduced below about pH 6, although cereals generally don't exhibit aluminum toxicity symptoms until below about pH 5.2. The pH of Pgrain-W system was only slightly lower than the initial pH level of 7.4 in 2002. Soil pH was about 0.2 units higher in the ½ N rate treatments and soil pH in the 4 – 8" depth was 0.1 to 0.6 units higher than in the 0 – 4" depths (data not shown). Soil pH had dropped by 0.4 units since last measured in 2016 (Engel unpub. data), which is concerning, especially in the CW treatment.

Table 1. Selected soil health parameters for GGRS study near Bozeman after 18 years.

Rotation	Enzyme geometric mean[1,2] (mg PNP g soil^{-1} hr^{-1})	Substrate induced respiration[1] (uL CO_2 g^{-1}-soil hr^{-1})	Soil pH (1:1) for full N rate[3]	Water stable aggregates in top 6 in.[1] (g g^{-1}-soil)
Till fallow	477 c[4]	40.9 b	6.79 ab	0.318 c
NT fallow	563 bc	47.9 ab	6.70 ab	0.375 bc
CW	780 abc	52.3 ab	5.76 b	0.442 a
Pgrain-W	812 ab	50.6 ab	7.15 a	0.438 a
Phay-W	672 ab	41.8 ab	6.37 ab	0.427 ab
PGM-W	812 ab	46.7 ab	6.81 ab	0.376 bc
CRP/Pgrain-W	923 a	57.6 a	6.89 a	0.412 ab
Rotation P-value	0.01	0.10	0.03	0.05
N rate P-value	0.14	0.31	<0.01	0.89

[1]Averaged across two N rates
[2]Fourth root of product of four enzyme concentrations
[3]Soil pH values are for the full N rate
Values that have no matching letters are different with 90% probability

Physical

The range of infiltration rates among treatments was remarkable (Fig 1). Recrop treatments had 7-fold higher infiltration rates than the two fallow treatments, though surprisingly there were no differences between the no till and tilled fallow systems. Higher rates of infiltration in recrop might be due to conditions at the soil surface where the soil is protected for longer periods from rain splash, higher aggregation associated with higher SOC, or producing and maintaining more macropores, and hence increased preferential flow. Higher infiltration rates should decrease runoff and ponding and move water more quickly below the soil surface, which should decrease evaporative losses. The WSA fractions were 20 to 35% higher in the CW and Pgrain-W systems than in the two fallow treatments and PGM treatment with the other two treatments

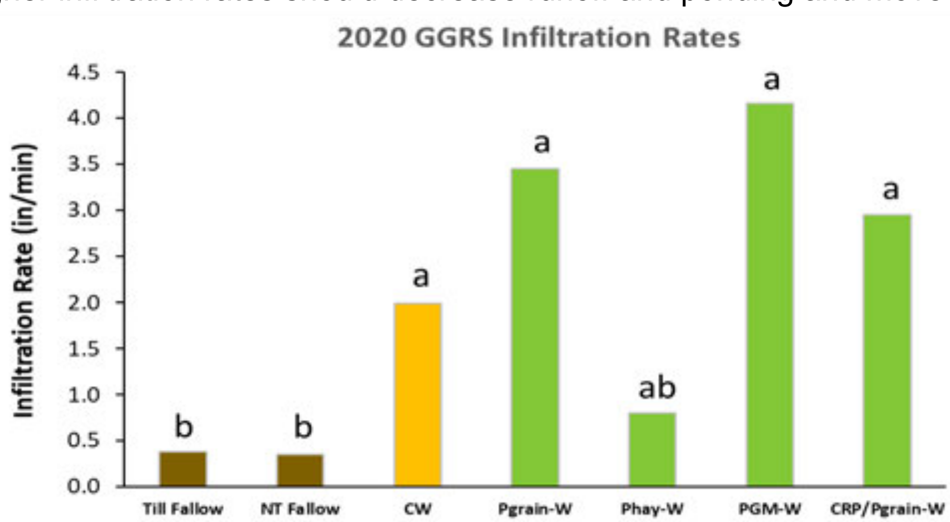

Figure 1. Infiltration rates following 18 years of seven crop rotations (full N rate) near Bozeman. Lack of the same letter above 2 bars indicates that the mean infiltration rates of those treatments are different with at least 90% probability.

intermediate. This is generally in agreement with residues returned (Engel et al. 2017), which makes sense given the importance of SOC and dissolved carbon on promoting aggregation (Schoenau and Campbell 1996); however, given the much smaller differences in WSA than infiltration, the combined results strongly suggest that infiltration rates are controlled by more than aggregate stability.

SUMMARY

In general, recrop systems generally produced higher levels of soil health parameters than fallow, and especially more than tilled fallow. Infiltration rates were dramatically lower for fallow than recrop systems (except Phay). Within the five recrop systems, Pgrain-W and CRP/Pgrain-W had similar levels of soil health parameters as CW, except for pH, which was much higher in the two legume systems than the CW treatment, where pH had fallen 1.5 units in only 18 years due to much higher N rates. Despite increasing popularity in cover crops and annual forages, largely due to connections with soil health, the PGM-W and Phay-W treatments generally did not improve soil health over systems where grain was harvested. Most importantly, this study showed the power of cropping systems to affect soil health in a semi-arid region.

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SNAPSHOT OF CROP NUTRIENT BALANCE WITH USE OF A RYE COVER CROP IN A CORN-SOYBEAN ROTATION UNDER TILE DRAINAGE IN EASTERN SOUTH DAKOTA

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ABSTRACT

The purpose of this study was to evaluate the effect of using a winter rye cover crop within a corn/soybean rotation (rye seeded every fall and burned down each spring) on drainage water quality, crop nutrient status, and grain yield. A three year study was conducted (corn/soybean/corn) starting in 2018 at Beresford, South Dakota, towards this end. There were two treatments in the study, rye cover crop and control (no cover crop), laid out in a randomized complete block design with six replications. Rye biomass and nutrient content were measured near the time of termination of the rye cover crop. Yield differences between treatments were minor. There were trends for greater shoot K levels in the cover crop plots; however, it was not clear if that was an effect of the rye cover crop or an artifact of initial soil K levels being slightly higher in the cover crop plots.

INTRODUCTION

Interest in tile drainage has increased dramatically in eastern South Dakota over the last 15 years. This is due to a complex combination of factors including a long-term trend for increased rainfall, increased crop yields and land value, and economics that favor use of simple rotations lacking perennials or forage sequences. Nationally, concern has grown about the effect of loss of nutrients, particularly nitrate, from fields in drainage systems and its effect on downstream water quality. One simple tool that is practical and within our reach to ameliorate these problems is use of a winter rye cover crop. In order to obtain initial estimates of the effect of a rye cover crop on soil and water quality, and on crop yield and shoot nutrient balance, a replicated study was undertaken where rye was grown every season as a cover crop for three seasons while drainage water, soil quality and crop yields were monitored.

MATERIALS AND METHODS

Winter rye was sown after grain harvest and compared to a no cover crop control in a set of 12 paired plots (six replications) for three seasons in a corn/soybean rotation on a no-till field at the SDSU Southeast Research Farm in Beresford, South Dakota from 2018 through 2020. Detailed results from the water and soil quality aspects of this study are reported in Bawa et al (2021). The shoot nutrient content of the rye cover crop was determined by taking three crop cuts (15 by 22.5") from each plot near the time of burndown herbicide application. Corn and soybean shoot nutrient contents were measured mid-season and near physiological maturity by clipping 6' of row from each plot, determining whole sample fresh weight and immediately chipping a subsample of 3 or more plants for determination of dry matter percentage and to obtain a sample for nutrient analysis. Dried plant samples were sent to Ward Labs (Kearney, Nebraska) for analysis of N by combustion analysis and other nutrients using ICP methods. Yields were measured using a small plot combine (4 rows by 180') in each plot.

RESULTS AND DISCUSSION

Initial soil test values are given in Table 1 and soil K levels (according to the Haney test) over the course of the study are shown in Figure 1. In the first two years of the study, there was a tendency for a small yield bump associated with the use of the rye cover crop (Table 2). In 2018, the corn yield trend ($P < 0.10$) was for a 3.5 bu/ac gain in the rye cover crop plots versus the control plots. In 2019, there was a small, but statistically significant ($P < 0.05$), yield bump of 2.9 bu/ac in soybean yield associated with use of a rye cover crop. In 2020 there was no discernable effect or trend in the plot data on corn yield ($P=0.62$). Even where there appeared to be positive trends on yield in 2018 and 2019, the magnitude of the effect was small. In the years when corn was the grain crop (2018 and 2020), rye biomass was minimal (240 lb/ac in 2018, and 131 lb/ac in 2020 - dry matter basis) because there was not much of a window for growth before the rye was terminated ahead of corn planting. In the year with soybean as a grain crop (2019), the rye had more opportunity to grow and put on biomass (1030 lb/ac dry matter) before the grain crop was seeded.

Pooled analysis across sample dates showed greater microbially active C in the cover crop plots (average of 63.4 vs. 56.2 % for the cover crop and control treatments, respectively ($P<0.05$)), and trends for slightly higher soil organic matter and Haney soil health scores in the cover crop plots, but these latter points were inconsistent (Fig. 2). It appears that the cover crop practice may have to be continued longer than a three year period in order to observe consistent differences in soil health measurements. Measurements of shoot nutrient balance showed a trend for greater K and Zn levels in the cover crop plots (Table 3). Differences in shoot K levels were not significant in the first season of the study, but did show some significant effects in the second and third seasons of the study. Soil K levels tended to be greater in the cover crop plots over the course of the study from beginning to end (Table 1 and Fig. 1). Further work is needed to sort out whether a rye cover crop may contribute to K uptake in the following corn or soybean crop, or if this observation was an artifact of previous differences in soil K levels between plots.

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Table 1. Soil organic matter, Olsen P, K, pH, EC, and Zn from a composite sample taken before the trial started in October of 2017, and average of samples taken from each plot midway through the study in June of 2019. All of these samples were analyzed at the SDSU Soil Testing Lab. Potassium measurement was based on a procedure using an ammonium acetate extract.

Treatment	Date	Organic Matter	Olsen P	K	pH	Salts 1:1	Zinc
		(%)	(ppm)	(ppm)		(mmho/cm)	(ppm)
Composite	10/16/17	5.0	14.9	302	6.6	0.8	1.1
Control	6/4/19	4.9	19.3	258	7.1	0.7	1.1
Rye cover crop	6/4/19	4.9	18.1	266	6.6	0.6	1.3

Note: 'Available K' in the graph below is from the Haney soil test procedure.

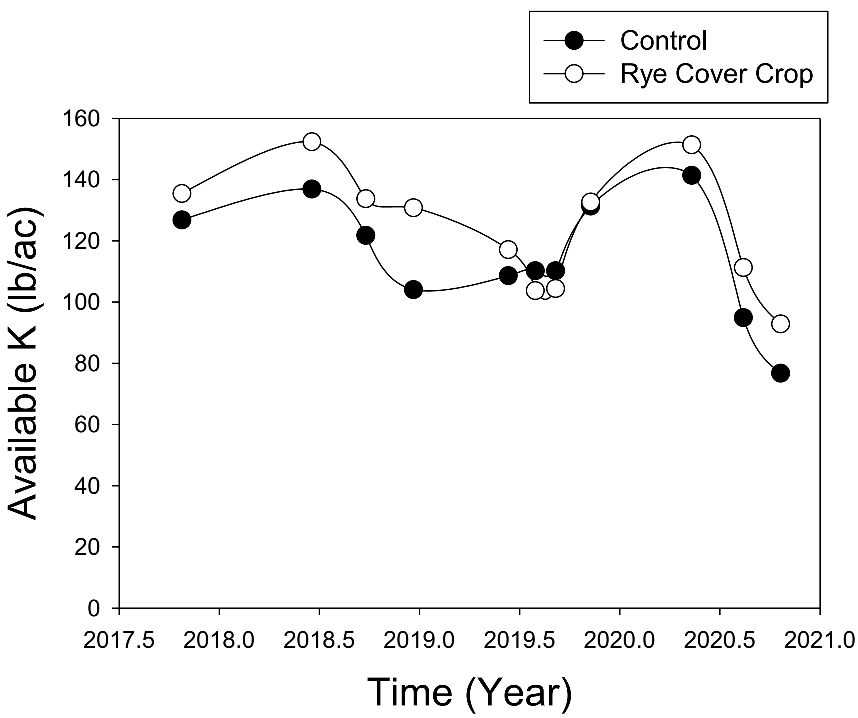

Figure 1. Average levels of available K, as measured from the Haney soil test, from plots raised with and without a rye cover crop in a replicated study at the SDSU Southeast Research Farm in Beresford, South Dakota. The rye cover crop was planted in the fall after grain harvest and terminated in the spring before planting the next grain crop in each year of the study (fall 2017 through 2020). According to this soil test, the cover crop and control plots averaged 124, and 115 lb/ac of available K per acre, respectively, over the course of the study.

Table 2. Average stand, grain moisture, test weight, and yield for corn and soybean plots raised with and without a rye cover crop in a replicated study at the SDSU Southeast Research Farm in Beresford, South Dakota in 2018 (corn), 2019 (soybean), and 2020 (corn).

2018 Corn

Treatment	Stand	Moisture	Test Wt.	Yield
	(plants/ac)	(%)	(lb/bu)	(bu/ac)
Rye Cover Crop	33109	19.4	56.4	207.3
Control	33405	19.5	56.4	203.8
Mean	*33257*	*19.5*	*56.4*	*205.6*
CV (%)	*5.6*	*2.3*	*1.3*	*1.5*
P-value	*NS*	*NS*	*NS*	*P < 0.10*

2019 Soy

Treatment	Height	Stand	100-Seed Wt.	Moisture	Test Wt.	Yield
	(in)	(plt/ac)	(g)	(%)	(lb/bu)	(bu/ac)
Rye cover crop	32.4	98155	19.3	12.3	55.0	61.3
Control	30.8	102221	18.7	12.6	55.7	58.4
Mean	*31.6*	*100188*	*19.0*	*12.5*	*55.4*	*59.8*
CV (%)	*2.2*	*6.3*	*1.1*	*4.3*	*1.4*	*3.2*
P-value	*< 0.01*	*NS*	*< 0.01*	*NS*	*NS*	*<0.05*

2020 Corn

Treatment	Stand	100-Seed Wt.	Moisture	Test Wt.	Yield
	(plt/ac)	(g)	(%)	(lb/bu)	(bu/ac)
Control	26136	29.6	11.9	58.7	182
Rye Cover Crop	26862	29.4	12.1	58.9	179
mean	*26500*	*29.5*	*12*	*58.8*	*180.3*
CV (%)	*9.4*	*5.4*	*2.0*	*1.0*	*5.2*
P-value	*NS*	*NS*	*NS*	*<0.02*	*NS*

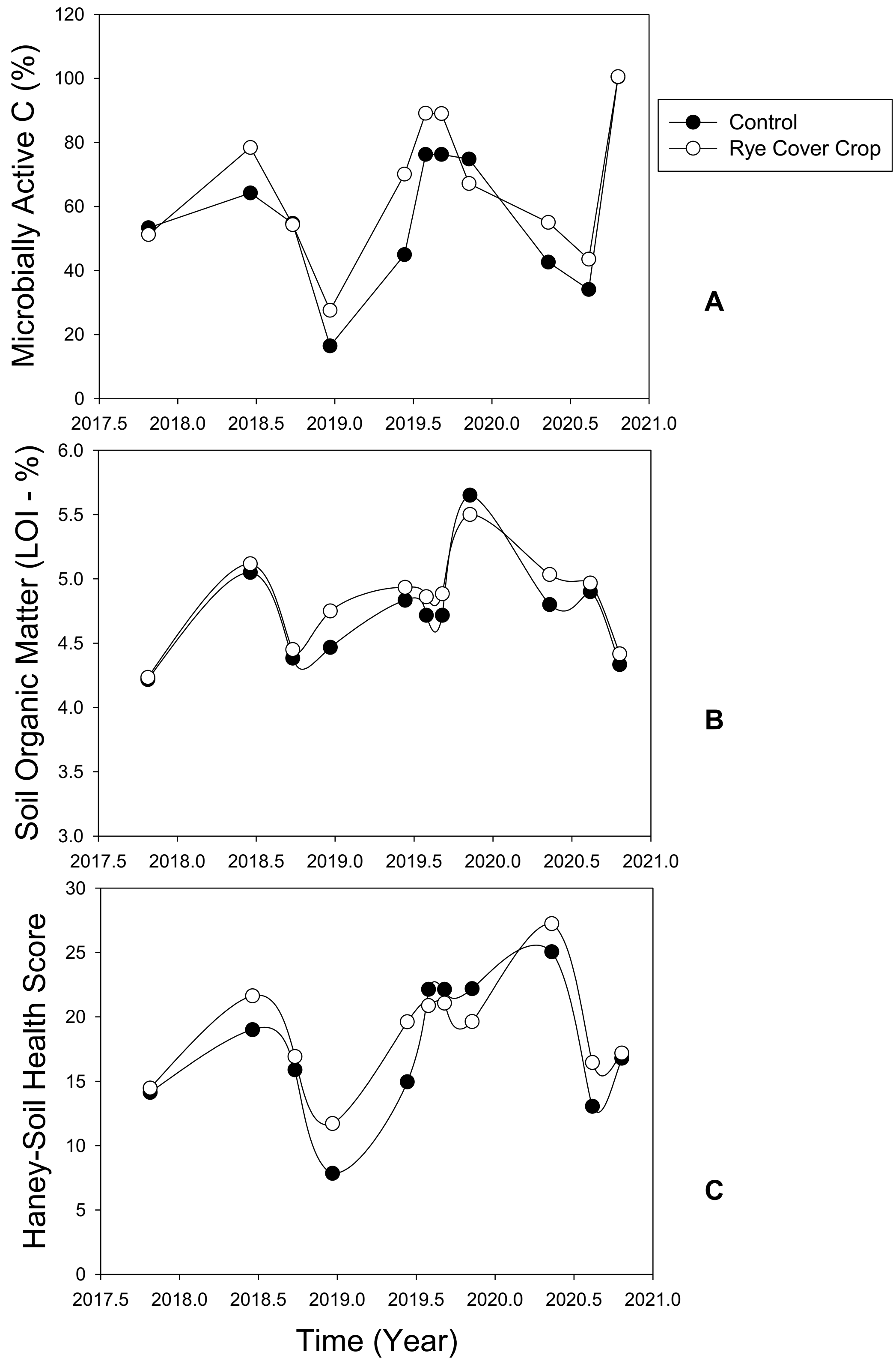

Fig. 2. Microbially active C (A - as measured in the Haney soil test), soil organic matter (B), and the Haney soil health score (C) at different sample times in a study comparing plots that had a rye cover crop versus those that did not over a three year period at the Southeast Research Farm in Beresford, South Dakota.

Table 3. Average whole shoot nutrient content of rye cover crops, and the following corn and soybean crops, as measured in a study conducted at the Southeast Research Farm in Beresford, South Dakota between 2018 and 2020.

Date	Cover Crop	Material	Biomass	[N]	N Content	[P]	P Content	[K]	K Content	[S]	S Content	[Zn]	Zn Content
			(lb/ac)	(%)	(lb/ac)	(%)	(lb/ac)	(%)	(lb/ac)	(%)	(lb/ac)	(ppm)	(lb/ac)
5/24/18	Rye c.c.	RYE	240	3.91	9	0.69	1.7	4.28	10	0.38	0.9	40.0	0.009
7/3/18	Control	CORN	2823	2.52	71	0.30	8.5	3.74	107	0.19	5.5	29.8	0.084
7/3/18	Rye c.c.	CORN	3203	2.58	83	0.30	9.7	4.10	130	0.19	6.1	32.0	0.103
		P-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
9/24/18	Control	CORN	21499	1.13	243	0.17	36.1	1.01	218	0.14	29.7	26.8	0.578
9/24/18	Rye c.c.	CORN	22929	1.14	260	0.18	40.9	1.06	243	0.14	33.1	28.0	0.636
		P-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	***<0.10***
6/4/419	Rye c.c.	RYE	1029	1.55	16	0.40	4.1	2.74	28	0.18	1.8	18.0	0.018
7/30/19	Control	SOY	3809	3.22	122	0.29	11.2	2.53	97	0.22	8.2	30.8	0.119
7/30/19	Rye c.c.	SOY	4520	3.17	144	0.29	13.1	2.60	118	0.21	9.3	38.0	0.185
		P-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
9/6/19	Control	SOY	13050	3.11	406	0.26	33.9	1.73	225	0.19	25.2	20.7	0.270
9/6/19	Rye c.c.	SOY	14097	3.08	434	0.25	35.9	1.87	264	0.19	26.4	21.8	0.306
		P-value	NS	NS	NS	NS	NS	NS	**<0.05**	NS	NS	NS	**<0.10**
5/11/20	Rye c.c.	RYE	131	6.01	8	0.52	0.8	4.31	6	0.40	0.5	41.0	0.006
8/12/20	Control	CORN	13913	1.39	193	0.17	24.2	1.11	154	0.15	20.7	35.8	0.487
8/12/20	Rye c.c.	CORN	13647	1.40	191	0.18	24.3	1.25	170	0.14	19.3	35.8	0.490
		P-value	NS	NS	NS	NS	NS	**<0.05**	**<0.10**	NS	NS	NS	NS
9/18/20	Control	CORN	16761	0.97	163	0.12	20.3	0.98	164	0.11	19.1	25.5	0.429
9/18/20	Rye c.c.	CORN	17944	0.97	174	0.12	21.4	1.09	195	0.11	19.1	23.8	0.427
		P-value	**<0.10**	NS	NS	NS	NS	NS	**<0.05**	NS	NS	NS	NS

POST-WHEAT SUMMER COVER CROP EFFECTS ON CROP YIELDS AND SOIL PROPERTIES IN A NO-TILLAGE DRYLAND CROPPING SYSTEM

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ABSTRACT

Traditional dryland cropping systems in the semi-arid central Great Plains include long fallow periods of up to 14 months to conserve soil moisture. However, precipitation capture and storage with fallow is inefficient even under continuous no-tillage (NT). As less water is needed to produce forage compared to grain, cover crops (CCs) could be integrated for increased soil cover and potentially greater income when grazed or hayed for forage. An experiment was initiated in 2016 near Brownell, KS to investigate the effect of post-wheat summer CCs on crop yields and soil properties in a NT winter wheat (*Triticum aestivum* L.)-grain sorghum (*Sorghum bicolor* Moench.)-fallow cropping system. Cover crops were grazed, hayed, or left standing (no forage removal) and compared to fallow. A second experiment was initiated in 2019 on producer fields near Hays and Alexander, KS to further quantify the effect of grazing CCs on soil properties in NT fields. At these sites, grazed CCs were compared to un-grazed CCs (no forage removal). Across years, CCs produced 3446 lb/ac dry matter (DM) at Brownell. Haying removed 62% of the available DM while grazing removed only 39%. Grain sorghum yields were 11% less following standing or grazed CCs compared to fallow (74 bu/ac) but yields following hayed CCs were similar to fallow. Soil organic carbon concentration in the 0- to 2- inch soil depth was about 8% greater with CCs (hayed, grazed, and standing) compared to fallow (1.24%) through there were no treatment differences in the 2- to 6-inch soil depth. Soil bulk density was marginally greater (4%) with hayed and grazed CCs compared to standing CCs (1.16 g/cm^3) though all were similar to fallow. Soil properties at Hays and Alexander were unaffected by grazing CCs compared to un-grazed CCs at either soil depth. Results showed post-wheat summer CCs can produce considerable DM with more residue retained following grazing compared to haying. However, grain sorghum yield following CCs can be reduced compared to fallow when all or most of the CC DM is retained, possibly due to nitrogen immobilization. Using CCs for forage can compensate for reduced grain yields and potentially increase cropping system profitability without negative impacts on soil properties.

INTRODUCTION

Integrating cover crops (CCs) to replace portions of the fallow periods in semi-arid dryland cropping systems has the potential to improve soil health by increasing soil organic carbon (SOC), reducing compaction, and enhancing soil structure. Previous research has emphasized the fallow period following summer crop [corn (*Zea mays* L.), grain sorghum (*Sorghum bicolor* Moench.), or proso millet (*Panicum milliaceum* L.)] harvest before winter wheat planting in the three-year winter wheat (*Triticum aestivum* L.)-summer crop-fallow cropping system of the semi-arid central Great Plains (Nielsen et al., 2015; 2017). However, less attention has been paid to the fallow period following wheat harvest. As this region has a summer-dominant precipitation pattern, the months following wheat harvest has a high likelihood for rainfall and could provide an opportunity for warm-season CCs to be incorporated (Mahama et al., 2016). Although the benefits that CCs provide for soil health have been widely recognized, their adoption in semi-arid dryland crop production remains limited due to subsequent grain yield penalties when soil moisture is reduced following CCs (Holman et al., 2018). However, utilizing CCs as an annual forage for livestock could offset losses in subsequent crop yield to balance goals of environmental and economic sustainability in dryland crop production. Still, concerns with grazing CCs include reduced SOC accrual, increased soil compaction, and degraded soil structure compared to ungrazed CCs especially in NT production systems. The objectives of this study were to determine the dry matter (DM) accumulation of post-wheat summer CCs as well as effects on subsequent grain sorghum yields and soil properties in a NT dryland cropping system.

MATERIALS AND METHODS

The first experiment was conducted from 2016 to 2021 near Brownell, KS to investigate the effect of post-wheat summer CCs on crop yields and soil properties in a NT wheat wheat-grain sorghum-fallow cropping system. Cover crops were either grazed, hayed, or left standing (no forage removal) and were compared to traditional fallow. A second experiment was conducted from 2019 to 2021 on two cooperative producer fields near Hays and Alexander, KS to further test the influence of grazing CCs on soil properties in NT dryland cropping systems. Annual precipitation in the study region is summer-dominant and averages 22 inches annually at these three sites.

The experiment at Brownell was arranged in a split-plot randomized complete block design. Main plots were the three crop phases of the wheat-sorghum-fallow crop rotation and split-plots (600 ft^2) included three CC treatments as well as fallow. Cover crops were a mixture of forage sorghum, pearl millet (*Pennisetum glaucum* L.), sunn hemp (*Crotalaria juncea* L.), and cowpea (*Vigna unguiculata* L.) at seeding rates of 7.5, 2.5, 5, and 20 lb/a, respectively. Cover crops were planted into wheat stubble each year shortly after harvest (approximately July 1) using a Great Plains no-till drill (Great Plains Manufacturing Inc., Salina, KS) and were either harvested as hay, grazed, or left standing (no forage removal). No fertilizer was applied to CCs in this study.

Prior to grazing, aboveground DM was determined from samples that were hand-clipped to ground level in two areas of 3 ft × 2 ft from each plot. Fresh weights were recorded and samples were oven-dried at 122°F until a constant weight was reached. Grazed CCs were stocked with yearling heifers (1500 lb/ac live weight) which were moved daily for four days. Following grazing, the retained CC residue was measured as previously described. Hayed CCs were harvested at a 6-inch cutting height from a 3 ft × 100 ft strip in the middle of each plot using a small-plot forage harvester (Carter Manufacturing Company, Brookston, IN). Whole plot weights were recorded with sub-samples collected and weighed. Sub-samples were oven-dried at 122°F until a constant weight was reached to determine DM yield. Termination with herbicides was not needed as CC species were selected to be terminated by frost (approximately October 15).

Grain sorghum was planted the following June at a rate of 35,000 seeds/ac with 15-inch row spacings using the same planting equipment as used for CCs and harvested in October using a Massey-Ferguson 8XP plot combine (Kincaid Equipment Manufacturing, Haven, KS). Following a 12-month fallow period, winter wheat was planted in the fall (approximately October 1) at a seeding rate of 60 lb/ac with 7.5-inch row spacing and harvested in June using the same planting and harvesting equipment as used for grain sorghum. For both grain crops, 18 lb/ac P_2O_5 and 5 lb/ac N was applied as monoammonium phosphate (11-52-0) with the seed. Additionally, 75 lb/ac N was applied as broadcasted urea (46-0-0) for a total of 80 lb/ac N for both grain crops.

Whole fields at Hays and Alexander were 50 and 80 acres, respectively. Four areas within each field were assigned as fenced zones to exclude grazing (un-grazed treatment) and cattle were allowed full access to the adjacent unfenced areas (grazed treatment). Cover crops were a mixture of forage sorghum, German millet (*Setaria italica* L.), sunflower (*Helianthus annuus* L.), sunn hemp, and radish (*Raphanus stivus* L.) at seeding rates of 7.5, 5, 1, 1, and 1 lb/ac, respectively. At Hays, CCs were grazed with cow-calf pairs (278 lb/ac live weight), and at Alexander, CCs were grazed with yearlings (459 lb/ac live weight) for a target duration of 35 days.

Soil samples were collected in the spring around sorghum planting in 2020 at Hays and in 2021 at Alexander and Brownell. At each site, two intact soil cores of 6 inches in depth and 2 inches in diameter were randomly taken from each plot to determine soil bulk density. Samples were dried at 221°F for a minimum of 48 hours and bulk density was computed as the mass of oven-dried soil divided by the volume of the core. Ten additional 6-inch cores were collected randomly from each plot to determine SOC and nutrient (NO_3-N and P) concentrations. Additional soil samples were collected from the 0- to 2-inch soil depth with a flat shovel for the determination of water stable aggregates. Samples were gently passed through sieves with 0.32- to 0.19-inch mesh and allowed to fully air-dry. Two sub-samples from each replicate were used to estimate mean weight diameter (MWD) of water stable aggregates by the wet-sieving method. Statistical analyses were completed using PROC GLIMMIX of SAS ver. 9.4 (SAS Institute, 2012, Cary, NC) with year and treatment considered fixed and replication considered random. Differences were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

On average, post-wheat summer CCs produced 3446 lb/ac DM at Brownell. However, CC productivity varied substantially from a high in 2018 (4593 lb/ac) to a low in 2019 (1714 lb/ac; Figure 1a). Cover crops failed in 2017 due to extended summer drought conditions. On average, haying removed 62% of the available DM while grazing removed only 39%. Grain sorghum yields following CCs were 11% less with standing or grazed CCs compared to fallow (74 bu/ac) but yields following hayed CCs were similar to fallow (Figure 1b). Reductions in grain yield following CCs were observed three out of

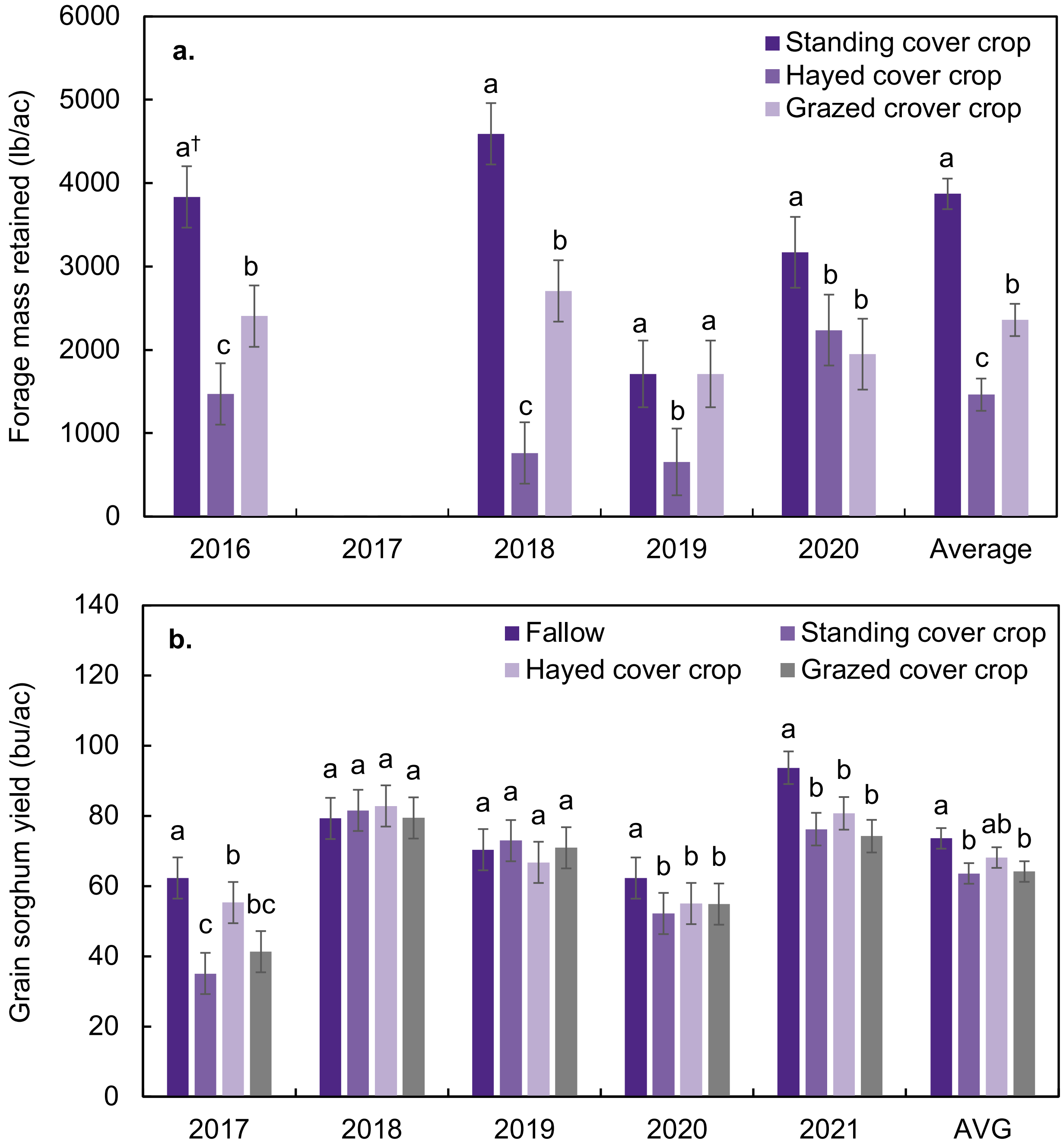

Figure 1. Cover crop residue retained following forage harvest (a.) and effect on subsequent grain sorghum yields (b.) near Brownell, KS.

†Error bars indicate standard error (α =0.05) and bars with the same letter are not significantly different (α =0.05) among treatments within the same year.

five (2017, 2020, and 2021) when sorghum experienced summer drought conditions, but not in 2018, when sorghum followed the failed CC of 2017, or in 2019, when precipitation was 36% above average. The yield of wheat following grain sorghum and a 12-month fallow period was generally unaffected by CCs and averaged 46 bu/ac.

At Brownell, SOC concentration in the 0- to 2-inch soil depth was about 8% greater with CCs (hayed, grazed, and standing) compared to fallow (1.24%) (Table 1). Also, in the 0- to 2-inch soil depth, bulk density was marginally greater (4%) with hayed and grazed CCs compared to standing CCs (1.16 g/cm^3) though all were similar to fallow. No treatment differences in SOC or bulk density were observed in the 2- to 6-inch soil depth. Soil NO_3-N concentration were not different across treatments for either soil depth. However, soil P concentration in the 2- to 6-inch soil depth was about 49% greater with grazed CCs compared to all other treatments (7.7 ppm) though no differences were observed across treatments in the 0- to 2-inch depth. At both cooperative producer locations, Hays and Alexander, soil bulk density, SOC, NO_3, P, and MWD were unaffected by grazing CCs compared to ungrazed CCs (Table 1).

Table 1. Effects of post-wheat summer cover crop management on soil physical and chemical properties in the 0- to 2- and 2- to 6-inch soil depths across three sites in western Kansas.

			BD†	SOC	NO_3-N	P	MWD
Location	Depth	Treatment	g/cm^3	%	ppm	ppm	inch
Brownell	0- to 2-inch	Fallow	1.17ab††	1.24b	18.0	29.7	-
		Standing	1.16b	1.31a	20.6	29.8	-
		Hayed	1.21a	1.35a	18.8	30.9	-
		Grazed	1.21a	1.37a	19.2	31.5	-
	2- to 6-inch	Fallow	1.43	1.24	8.9	7.9b	-
		Standing	1.40	1.22	9.4	7.6b	-
		Hayed	1.39	1.22	8.8	7.6b	-
		Grazed	1.42	1.28	10.6	11.5a	-
Hays	0- to 2-inch	Ungrazed	1.25	2.05	14.4	48.3	0.077
		Grazed	1.32	1.89	16.4	45.2	0.057
	2- to 6-inch	Ungrazed	1.38	1.89	5.2	24.6	-
		Grazed	1.41	1.53	8.7	23.8	-
Alexander	0- to 2-inch	Ungrazed	1.36	1.24	7.0	33.7	0.063
		Grazed	1.24	1.40	9.7	42.0	0.056
	2- to 6-inch	Ungrazed	1.46	0.90	3.5	15.2	-
		Grazed	1.41	0.93	3.6	8.27	-

†BD, bulk density; SOC, soil organic carbon; NO_3-N, nitrate-nitrogen; P, phosphorus; MWD, mean weight diameter of water stable aggregates.
††Means with the same letter are not significantly different (α =0.05) among treatments within the same location and depth.

In conclusion, post-wheat summer CCs can produce considerable DM with more residue retained with grazing compared to haying. However, subsequent grain sorghum yields can be reduced compared to fallow when all or most of the CC DM is retained (standing or grazed) but not when CCs are removed as hay. Soil organic carbon can be increased with CCs compared to fallow in shallow soil depths (0- to 2-inch). Soil chemical and physical properties when CCs are grazed on NT fields are similar to when CCs are left standing. These findings indicate that such CCs can be integrated after wheat in the NT cropping systems of the semi-arid central Great Plains to supply forage for livestock to compensate for reduced subsequent grain yields and potentially increase cropping system profitability without negatively impacting soil properties compared to standing CCs.

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SOIL PHOSPHORUS FORMS AND CYCLING ARE ALTERED BY ACIDIFICATION FROM NITROGEN IN LONG-TERM WHEAT PLOTS IN SWIFT CURRENT, SASKATCHEWAN

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ABSTRACT

Nitrogen (N) fertilization is widely recognized as a contributor to soil acidification. This in turn can alter soil phosphorus (P) cycling, because P is optimally soluble in soils within a limited pH range. This study used continuous wheat plots in Saskatchewan Canada to determine the effects of N and P fertilization or cessation on soil P cycling. The +N+P and -N+P plots were established in 1967, while subplots of +N-P and -N-P were established in 1995 by stopping P fertilization. Long-term NH_4-N addition produced a pH change equivalent to 0.5 pH units per 1000 kg NH_4-N ha^{-1}; in 2016, pH in water ranged from 5.6 (+N+P) to 6.7 (-N-P). This pH change altered aspects of both the biology and chemistry in these soils, and both N and P addition or withdrawal altered soil P cycling. Acidification affected exchangeable cations, and shifted P pools from P associated with calcium (-N-P) to P associated with aluminium and iron (+N+P, +N-P). Phosphorus addition or withdrawal significantly affected soil test P (Olsen, Mehlich, $CaCl_2$-extractable) and soil total P, while soil pH and P addition/withdrawal affected soil organic P concentrations and phosphatase activities.

INTRODUCTION

It has long been recognized that nitrogen (N) fertilization can decrease soil pH (acidification), particularly products containing ammonia (NH_3) or ammonium (NH_4), such as ammonium nitrate, urea, monoammonium phosphate (MAP) or ammonium sulphate (Darusman et al. 1991; Bouman et al. 1995; Barak et al. 1997; Guo et al. 2010). Soil acidification can affect many aspects of soil and plant health. Acidification reduces soil cation exchange capacity and decreases the concentrations of calcium (Ca), magnesium (Mg) and potassium (K). Acidification will also increase other cations, such as aluminum (Al), iron (Fe) and manganese (Mn), some of which (e.g. Al) can be toxic to crops such as wheat. Soil phosphorus (P) cycling is particularly vulnerable to acidification, because P is optimally soluble in soils within a limited pH range (Barrow 2017; Penn et al. 2019).

In SK, Canada, concerns about pH changes from N fertilization have existed for decades. Campbell and Zentner (1984) reported acidification in continuous wheat in long-term plots established in 1967 at the Agriculture & Agri-Food Canada (AAFC) Swift Current Research and Development Centre (SCRDC). These plots were fertilized with P, and with or without N. In 1995, P fertilization ceased in sub-plots established on these main plots. The objective of this study was to study changes in P pools in these long-term plots, with and without N and P fertilization.

MATERIALS AND METHODS

Samples were collected from an experiment established in 1967 on Orthic Brown Chernozem (Aridic Haploboroll, USDA; Haplic Kastanozem, FAO) soils at the AAFC SCRDC in Saskatchewan, Canada (latitude 50º170′N, longitude 107º480′W). This study used two treatments, each with three replicate plots: continuous wheat receiving 10 kg P ha^{-1} yr^{-1} (monoammonium phosphate, MAP) and either a) no N fertilizer (the -N+P treatment); or b) 32-50 kg N ha^{-1} yr^{-1} (ammonium nitrate, NH_4NO_3 from 1967-2007, urea from 2008; the +N+P treatment). In 1995, subplots without P fertilization were established on all plots for both treatments, hereby designated as the +N-P and -N-P treatments. More details are available in Selles et al. (1995, 2011), Liu et al. (2015), and Li et al. (2020). For this study, crops were seeded on June 13, 2016, and soil samples were collected at anthesis (August 15, 2016) and after crop harvest (November 14, 2016) at 0-7.5 cm depth. At each sampling date, three separate samples were collected from each plot. These were kept separate for analysis, giving nine samples per plot per collection date. A subset of soils was refrigerated for enzyme assays; the remainder was dried and ground (< 2 mm).

Using dried soils, pH was measured in water saturation paste, total P (TP) was determined by digestion and total organic P (TP_o) was determined by the ignition method (O'Halloran and Cade-Menun, 2008), with colorimetric analysis (Murphy and Riley, 1962). Samples were extracted with 0.5 M bicarbonate (Olsen-P; Olsen et al., 1954), and 0.01 M $CaCl_2$-P (Self-Davis et al., 2009), followed by colorimetric analysis. Mehlich 3 extraction (Mehlich 1984), followed by inductively coupled plasma optical emission spectroscopy (ICP-OES, Thermo Scientific ICAP 6300 Duo) was used to determine the concentrations of Mehlich-P and Mehlich-Fe, -Al, and -Ca.

Using refrigerated surface soils within five days of sampling for both sampling dates, the potential activities of acid and alkaline phosphomonoesterase were assayed with *p*-nitrophenyl phosphate at pH 5.5 and 11, respectively (Tabatabai, 1994).

Dried soils from the anthesis samples were sequentially extracted (Zhang & Kovar 2009) into the fractions NH_4Cl-P (soluble and loosely bound P), NH_4F-P ("Al-P"), NaOH-P ("Fe-P"), citrate-bicarbonate dithionite P ("CBD-P"; reductant-soluble P), and H_2SO_4-P ("Ca-P"). Extracts were analyzed colorimetrically without digestion for molybdate-reactive P (MRP) concentration or following persulfate digestion in an autoclave for TP concentration. Molybdate-unreactive P (MUP) was calculated as the difference between TP and MRP for each extract. Residual P and P recovery were calculated from the sum of TP in each fraction compared to soil TP concentrations. For this study, MRP is P_i and MUP is P_o, although MUP could also contain complex P_i forms such as polyphosphates. The fraction identifications ("Al-P", etc.) are from the fractionation protocol (Zhang & Kovar, 2009); however, sequential fractionation is not precise, and each fraction likely contains a range of P compounds.

Two-factor analysis of variance (ANOVA) was conducted (treatment, date and the treatment*date interaction) with a standard least squares model, followed by Tukey's highest significant differences (HSD) tests.

RESULTS AND DISCUSSION

There were no significant treatment*date interactions for any of the parameters shown here. As such, data from both sampling dates was averaged together to give a single mean for each treatment.

Soil pH was significantly affected by N fertilization (Table 1), with a pH change equivalent to 0.5 pH units per 1000 kg NH_4-N ha^{-1}. Stopping P fertilization also significantly affected pH, which was highest in the -N-P plots compared to other treatments. This is due to the reduction in NH_4-N from not applying MAP fertilizer. Soil exchangeable cations were also significantly affected by N fertilization. Mehlich-Ca was significantly reduced in the +N plots compared to the -N-P plots, while Mehlich-Al and –Fe were significantly increased.

Stopping P fertilization significantly affected all analyzed P pools. Concentrations of total P, Olsen P, Mehlich P and $CaCl_2$-P were greater in -N+P soils, and were significantly greater than in treatments not receiving P (+N-P and -N-P). Olsen P and $CaCl_2$-P concentrations were also significantly higher in the –N+P treatment compared to the +N+P treatment. Yields in these plots were significantly lower in treatments without N in these plots, which decreased plant uptake of these labile P pools and thus increased their soil concentrations. Organic P, both concentration and as a percentage of total P, was significantly higher in the treatments with N than without N, regardless of P fertilization, with no significant differences with and without P within each N treatment. This suggests that organic P inputs are related to crop yields and to soil pH, rather than organic P mineralization with P fertilizer cessation. This is supported by the increase in organic P as percentage of total P for the +N-P treatment, which indicates a drawdown of inorganic P.

Table 1. Soil pH, Mehlich-extractable aluminum (Al), calcium (Ca), iron (Fe) and phosphorus (P), soil total P, total organic P, Olsen (bicarbonate-extractable P) and $CaCl_2$-extractable P in samples collected in 2016 from long-term plots (0-7.5 cm depth). Values are means ± standard error (n=18), in mg P kg^{-1} soil unless otherwise indicated.

	+N+P	+N-P	-N+P	-N-P
Soil pH (in water)	5.58 c ±0.04	5.74 c ± 0.08	6.26 b ± 0.07	6.72 a ± 0.11
Mehlich Al	1026 a ± 54.7	899 a ± 64.8	718 ab ± 52.9	477 b ± 53.3
Mehlich Ca	1215 b ± 56.4	1299 b ± 54.9	1533 ab ± 61.7	1849 a ± 141
Mehlich Fe	277 a ± 13.4	232 a ± 17.9	193 a ± 13.9	127 b ± 14.2
Total P	656 ab ± 7.1	556 c ± 12.0	667 a ± 9.3	607 bc ± 11.8
Organic P	323 a ± 4.3	312 ab ± 10.0	292 bc ± 11.0	262 c ± 16.5
Organic P/TP (%)	49.3 ab ± 0.82	56.1 a ± 1.34	43.6 b ± 1.21	43.1 b ± 2.30
Olsen P	44.6 b ± 1.24	15.8 d ± 1.26	64.7 a ± 2.00	33.1 c ± 3.02
Mehlich P	98.7 a ± 4.57	44.4 b ± 5.32	114.1 a ± 7.24	58.9 b ± 6.50
$CaCl_2$-P	44.6 b ± 1.24	15.8 d ± 1.26	64.7 a ± 2.00	33.1 c ± 3.02

Sequential fractionation (Table 2) shows an increase in fractions with Al- and Fe associated P (NH_4F-P and NaOH-P) in the treatments with lower soil pH, and an higher

Table 2. Data from sequential phosphorus (P) fractionation and enzyme (phosphomonoesterase) assays for soils samples collected in 2016 from long-term plots (0-7.5 cm depth) from 0-7.5 cm depth. Values are means ± standard error (α = 0.05)

			+N+P	+N-P	-N+P	-N-P
NH_4Cl-P	MRP	mg kg^{-1}	2.8 b ± 0.1	1.6 c ± 0.2	5.1 a ± 0.6	4.0 ab ± 1.5
(loosely bound)	MUP	mg kg^{-1}	0.2 ± 0.0	0.4 ± 0.1	0.4 ± 0.3	0.1 ± 0.1
NH_4F-P	MRP	mg kg^{-1}	62.5 a ± 2.1	25.0 b ± 7.4	78.1 a ± 7.3	41.5 b ± 9.0
(Al-P)	MUP	mg kg^{-1}	72.6 a ± 5.6	55.0 ab ± 14.5	43.2 ab ± 19.5	40.7 b ± 13.1
NaOH-P	MRP	mg kg^{-1}	95.1 a ± 1.5	64.3 b ± 9.0	101.2 a ± 10.5	63.7 b ± 22.0
(Fe-P)	MUP	mg kg^{-1}	154.9 a ± 4.9	143.7 ab ± 8.3	87.8 b ± 36.2	94.5 b ± 20.9
CBD-P	MRP	mg kg^{-1}	35.7 a ± 1.8	27.8 b ± 8.2	36.4 a ± 1.4	38.3 a ± 0.3
(reductant soluble)	MUP	mg kg^{-1}	61.6 ab ± 18.8	37.6 b ± 13.0	113.3 a ± 29.3	112.9 a ± 18.9
H_2SO_4-P	MRP	mg kg^{-1}	146.9 ± 8.2	146.5 ± 15.9	163.6 ± 20.8	193.4 ± 42.0
(Ca-P)	MUP	mg kg^{-1}	2.0 b ± 0.3	1.8 b ± 1.1	8.5 a ± 3.6	8.0 ab ± 3.0
Total MRP		mg kg^{-1}	342.6 b ± 9.2	265.2 c ± 9.1	384.4 a ± 3.6	340.9 b ± 14.6
		%	54.2 ± 1.8	52.8 ± 2.2	58.6 ± 0.9	59.5 ± 5.7
Total MUP		mg kg^{-1}	291.3 ± 17.5	238.5 ± 15.4	253.0 ± 25.6	256.2 ± 45.6
		%	45.8 ± 1.8	47.2 ± 2.2	38.7 ± 3.5	41.7 ± 5.4
Total P recovery, % of TP		%	96.8 ± 3.9	89.1 ± 2.0	98.1 ± 5.1	97.7 ± 3.4
Residual P		mg kg^{-1}	29.4 ± 11.6	61.5 ± 12.0	33.0 ± 11.5	47.3 ± 17.9
Acid Phosphomonoesterase		μg mL^{-1} g^{-1} h^{-1}	20.5 a ± 1.13	21.2 a ± 1.17	16.7 ab ± 0.27	11.7 b ± 2.43
Alkaline Phosphomonoesterase			3.76 b ± 0.21	4.25 b ± 0.58	2.98 ab ± 1.08	10.1 a ± 1.98

concentrations of H_2SO_4-extractable P, representing relatively insoluble P associated with Ca. This is consistent with the Mehlich-extractable cation results, and suggests that acidification is influencing soil chemical P pools. Activities of acid phosphomonoesterase were highest in treatments with the lowest pH (+N+P, +N-P) and while the reverse was true for activities of alkaline phosphomonoesterase. This suggests that pH changes will influence organic P mineralization, and is consistent with changes in the microbial community reported for these soils (Li et al. 2020).

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LENTIL NITROGEN FIXATION RESPONSE TO FERTILIZER AND INOCULANT IN THE NORTHERN GREAT PLAINS

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ABSTRACT

Lentil production in the semi-arid northern Great Plains has increased dramatically over the past two decades, providing agroecosystem benefits of efficient water use, pest cycle disruption, and biological nitrogen (N) fixation. Through N fixation, lentil may help alleviate soil acidification and groundwater contamination by reducing N fertilizer needs. Despite widespread farmer adoption of lentil in the region, little is known about the benefits of fertilizer or inoculant type on N fixation. The aim of this study was to determine how different nutrients (potassium, sulfur, and foliar-applied micronutrients), as well as *Rhizobia* inoculant types (seed-coat and granular), influence N fixation of lentil. The study was conducted at two field sites in Montana from 2019 to 2021. Fixed N amounts were calculated using both an N difference approach and the ^{15}N natural abundance method. N fixation proved to be highly responsive to climatic conditions and soil characteristics. The amount of N fixed did not respond to potassium fertilization. In a moderately dry year at a site with low soil sulfate levels, sulfur fertilization increased N fixed by 40 percent. No differences in N fixed between inoculant types were found, and inoculated lentil fixed more N than uninoculated lentil in two site-years. The study's findings reveal that sulfur fertilization and rhizobial inoculation have potential to significantly increase lentil N fixation amounts in the northern Great Plains.

INTRODUCTION

The prevalence of cereal crop monoculture and summer fallow in the northern Great Plains (NGP) presents several challenges to the region's agricultural industry. Reliance upon N fertilizers causes soil acidification (Brown et al., 2008; Engel unpub data) and elevated nitrate concentrations in groundwater (John et al., 2017). Summer fallow is known to be destructive to soil quality (Carlyle, 1997). Pulse crops, including lentil, a common summer fallow replacement, can reduce N fertilizer inputs through N fixation. As a result, lentil has experienced rapid growth over the past 20 years and was planted on 368,000 ac in 2020 in Montana (USDA-NASS, 2020). While phosphorus is understood to limit N fixation, there has been no research on how other nutrients, such as potassium (K), sulfur (S), or micronutrients impact lentil N fixation in the NGP. Additionally, the effect of inoculant type on lentil N fixation is unknown despite granular inoculant being 3 to 4-fold more costly than seed-coat inoculant per acre. The objective of this study was to evaluate if fertilizer (K, S, and foliar-applied micronutrients) and inoculant type (seed-coat or granular) influence N fixation amounts of lentil.

MATERIALS AND METHODS

Field Descriptions and Experimental Design

Field experiments were conducted at Montana State University's Arthur H. Post Agronomy Research Farm (PF) near Bozeman, MT and at Northern Agricultural Research Center (NARC) near Havre, MT from 2019 to 2021. Soils at PF were Amsterdam silt loams (Typic Haplustolls), and soils at NARC were Telstad and Kenilworth loams and sandy loams (Aridic Argiustolls). Site selection at PF and NARC was based on soil sampling for a range of parameters including nitrate-N, sulfate-S, and exchangeable K to identify locations within suitable fields that had relatively similar nutrient levels.

Treatments included the following eight combinations of inoculant and fertilizer formulations.

1. Control
2. Granular inoculant w/o K or S
3. Seed-coat inoculant w/o K or S
4. Granular inoculant w/ K (15 lb K_2O/ac)
5. Seed-coat inoculant w/ K
6. Granular inoculant w/ K + S (5 lb S/ac)
7. Seed-coat inoculant w/ K + S
8. #6 w/ foliar micronutrients (Micro1000, by AgroLiquid, at 0.25 gal/ac)

The foliar micronutrient treatment was not included in 2019 trials. The experiment was conducted in a randomized complete block design with five replicates.

Plot Management

Avondale lentil, a medium green variety, was seeded at a rate of 11 plants/ft^2 in 6x25 ft plots. Seeds were inoculated with commercial granular and seed-coat inoculants following manufacturer labels. A non N-fixing reference crop of flax was seeded in a 2-m perpendicular strip adjacent to the lentil plots. Monoammonium phosphate (MAP, 11-52-0) was applied in furrow at a rate of 45 lb/ac to provide 5 lb/ac of starter N and 23 lb P_2O_5/ac of starter P. Appropriate pest management practices were conducted throughout the growing season.

Data Collection

A representative area of each lentil plot was sampled for aboveground biomass around early to late pod fill. A corresponding flax sample was taken for every three lentil plots, except in 2021 when a flax sample was taken for each lentil plot. All biomass samples were dried (120°F, 72 h), weighed, and ground (<0.5 mm). Tissue subsamples were analyzed for total N via combustion (LECO, St. Joseph, MI, USA). Isotope ^{15}N was analyzed with a continuous flow isotope mass spectrometer (Stable Isotope Facility, UC Davis, USA). After lentil was harvested, one 3 ft soil sample was taken from each lentil plot. Soil was also sampled from each location where flax biomass was harvested. The soil samples were split in the field into three 1-ft subsamples. Soils were dried (120°F, 72 h), weighed, and bulk density was calculated. Soils were ground (<2 mm), extracted using 1M KCl, and analyzed for nitrate-N. Total N pool for each 3 ft sample was calculated.

Measuring N Fixation

The amount of N fixed by lentil was calculated using two methods: an N difference approach (ND) and the ^{15}N natural abundance (NA) method. The ND approach used the following equation as reported by Unkovich et al. (2008):

$$N\ fixed = \left(Biomass\ N_{lentil} - Biomass\ N_{flax}\right) + \left(Soil\ N_{lentil} - Soil\ N_{flax}\right) \quad [1]$$

Biomass N is the product of dry aboveground biomass and biomass N concentration. Soil N is the total nitrate-N in the 90 cm soil sample taken shortly after lentil harvest.

For the NA method, the fraction of N derived from the atmosphere (fNdfa) was calculated using the following equation from Shearer and Kohl (1986):

$$fNdfa = \left(\frac{\delta^{15}N_{reference} - \delta^{15}N_{legume}}{\delta^{15}N_{reference} - B}\right) \quad [2]$$

Where $\delta^{15}N$ is:

$$\delta^{15}N\ (‰) = \left(\frac{atom\%N_{sample} - atom\%N_{atmosphere}}{atom\%N_{atmosphere}}\right) * 1000 \quad [3]$$

B in Eq. 2 refers to the $\delta^{15}N$ of a pulse crop grown in the absence of soil N, meaning it reflects conditions in which all plant N is fixed from air. A B value of -0.99 was determined by growing Avondale lentil in a greenhouse using a perlite/vermiculite growing medium and N-free nutrient solution. In the NA method, total N fixed is the product of pulse biomass N (lb/ac) and fNdfa.

Statistical Analyses

All statistical procedures were conducted using R (R Core Team, 2021). Analysis of variance (ANOVA) was performed for response variables of biomass N, fNdfa, post-harvest soil nitrate-N, and N fixed (calculated using both the ND and NA methods). Treatment was treated as a fixed effect and block was treated as a random effect in a linear mixed model. Site-years were analyzed independently for treatment effects. Treatment differences were further evaluated using pre-planned orthogonal contrasts and Tukey-Kramer familywise comparisons of means with a 90% confidence level.

RESULTS AND DISCUSSION

There was substantial year-to-year variation in precipitation over the course of this study. Weather data, along with notable N fixation findings discussed below, are summarized in Table 1. The 2019 growing season (April to July) was wetter and cooler than normal, and N fixation at PF was high (90-140 lb N/ac). At both sites, precipitation over the growing season in 2020 and 2021 was low, and N fixation amounts were lower as well. It was particularly hot and dry in June 2021. At PF, N fixed amounts calculated with the ND method ranged from ca. 75 to 115 lb N/ac in 2020 and 35 to 70 lb N/ac in 2021. Overall, N fixation was lower at NARC than at PF, reflecting its drier and hotter climate. The field at NARC in 2020 had high and variable nitrate-N and N fixation was not able to be calculated with confidence; therefore that site year was excluded here.

Table 1. Summary of climate and major N fixation findings for PF and NARC, 2019-2021.

Site	Year	Growing Season (Apr-Jul)		Major Findings	
		Total Precipitation (in)	Mean Temperature (°F)	ND method	NA method
PF	LTA*	8.7	54.9		
	2019	9.8	54.0	No effects	No effects
	2020	5.9	54.9	S fertilizer increased N fixed by 34 lb N/ac	S fertilizer increased N fixed by 29 lb N/ac
	2021	5.8	57.7	No effects	No effects
NARC	LTA	7.4	58.3		
	2019	6.2	55.8	Inoculation increased N fixed by 33 lb N/ac	Inoculation increased N fixed by 21 lb N/ac
	2021	4.1	58.5	Inoculation increased N fixed by 12 lb N/ac	Inoculation increased N fixed by 8 lb N/ac

*Long-term average, 1981-2010 from the Western Regional Climate Center, Desert Research Institute, Reno, NV

Inoculant Effects on N Fixation

Inoculated lentil fixed more N than non-inoculated lentil in two out of five site-years. At NARC in 2019, inoculated lentil fixed on average 33 lb N/ac (ND method) and 21 lb N/ac (NA method) more than non-inoculated lentil (Table 1). Inoculating lentil increased N fixed by 12 lb N/ac (ND method) and 8 lb N/ac (NA method) at NARC in 2021. Early in the 2021 growing season, non-inoculated lentils were visibly less green than inoculated lentils at NARC, but this became less obvious as the season progressed. The N fixed differences were more modest in 2021 due to drought, but they are still notable given that drought can limit N fixation. Inoculation did not influence N fixation in any year at PF, suggesting adequate *Rhizobia* populations in the soil. This is especially interesting in 2020, because that field to our knowledge had no history of pulse crops. The 2019 field at NARC, where a large inoculant effect was observed, had a recent history of pulse crops. This could suggest that *Rhizobia* persistence is lower at NARC, where soil organic matter is lower and climate is drier, or that there are more native *Rhizobia* at PF. There were not significant differences in N fixed amounts between inoculant types (granular and seed-coat) for any site-year, but Miller et al. (2022; in these Proceedings) found an inconsistent effect of inoculant type on lentil yield.

Fertilizer Effects on N Fixation

In 2020 at PF, we observed much darker green and more robust plants in all the +S treatments. Tissue concentrations of both N and S were generally higher in the K+S treatments than in the +K only treatments, implying that the darker green foliage was due not only to more S, but also greater N content presumably from increased N fixation. Treatments with K+S fertilizer fixed approximately 34 lb N/ac (ND method) and 29 lb N/ac (NA method) more N than corresponding +K only treatments. Sulfur is directly needed in the N fixation process, but given smaller S needs of *Rhizobia* than of plants, it's likely that the S effect was indirect, meaning S fertilization increased plant growth, which allowed the plants to send more carbon to the root nodules, boosting N fixation. This is supported by a study on peas in which S-deficient plants had low carbohydrate levels and fixed less N than S sufficient plants, likely due to high carbohydrate demand of N fixation (Scherer et al., 2006). Given that only a small minority of Montana producers fertilize lentil (Warne et al., 2019), it's likely that insufficient S is limiting lentil N fixation in certain Montana regions that are prone to S deficiency.

At PF, the 2019 field had similar sulfate-S levels (around 4 ppm in the top 6 in) to the 2020 field, yet an N fixation response to S fertilizer was not observed in 2019. There was far more precipitation in 2019, and more S may have mineralized with the extra moisture. At NARC, fields in 2019 and 2020 were high in sulfate-S (>14 ppm) and no S response was observed. For both sites in 2021, sulfate-S was low, but drought substantially limited lentil growth and consequently N and S demand. Soil exchangeable K levels were high across site-years, and no N fixation response to K fertilizer was observed. Foliar micronutrients did not influence N fixation.

CONCLUSION

This study found that S fertilization and inoculation have the potential to increase N fixation of lentil in the NGP. This was the first study to investigate lentil N fixation response to S and inoculant in the region. Given the considerable growth in lentil production and current lack of research in the NGP, the findings are valuable for lentil producers to better manage their crops. More research would help us better understand lentil S response, because our results were inconsistent as climate and sulfate-S levels varied. Further research is also needed on inoculant types, as lentil yield and N fixation responses were not similar nor consistent across site-years.

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SOIL TEST METHODS ACCURACY AND PRECISION COMPARISON: HISTORICAL NORTH AMERICAN PROFICIENCY TESTING (NAPT) PROGRAM RESULTS

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ABSTRACT

The SSSA-NAPT Program provides open access to soil, water, and plant laboratory data. This data is collected quarterly from about 150 participating laboratories. For soil data, five samples are sent to participant laboratories for them to submit data for any or all of the 99 accepted methods. Our objective was to evaluate data precision from 43 soil samples (2019-2021). A measure of precision was made by dividing the Median Absolute Deviation (MAD) by the Median for each of the 43 samples evaluated for each analyte. The average precision score across all data was 8.3%, with a range from <1% to 34% (21% was the upper end if only including analyses with the minimum of eight laboratories submitting data). Precision for pH was exceptionally good and, in general, carbon and the primary macronutrients had relatively better precision than the secondary macronutrients, micronutrients, etc. These and other data presented aid in understanding precision across laboratories and show that these participating laboratories, on average, are capable of precise analysis; although some methods are inherently better than others. The NAPT database is an excellent open resource for evaluating the quality of data generated by agricultural laboratories.

INTRODUCTION

Soil test data precision helps us understand the value and limitations of this data (https://acsess.onlinelibrary.wiley.com/doi/pdf/10.1002/crso.20048). The Soil Science Society of America (SSSA) has a vast expertise from its over 6,000 member scientists. The North American Proficiency Testing (NAPT) Program is operated as an activity of the SSSA and governed by an oversight committee comprised of some of these experts as representatives of Regional Soil and Plant Analysis Workgroups; Scientific Organizations; State/Provincial Departments of Agriculture; and private and public laboratories (https://www.naptprogram.org/). The NAPT program furnishes laboratories with quality control and quality assurance tools through quarterly statistical evaluation of soil, plant, and water samples. These tools assist laboratories in generating accurate and precise analyses, as well as leveraging their participation in assuring clientele and other consumers that their data meets high standards.

This valuable program, with the collective wisdom and expertise found in the credibility of SSSA, not only provides resources to laboratories, but also to consumers of the data they generate. The aggregated soil, water, and plant data generated by these laboratories is openly available at https://www.naptprogram.org/content/laboratory-results. We have open access to the collective data provided by the lab community, such as that previously explored for plant tissue (https://acsess.onlinelibrary.wiley.com/doi/abs/10.1002/crso.20113). Herein, we provide an assessment for soil analyses.

MATERIALS AND METHODS

From the database described above, a subsample (43 soil samples) from the library of soil data available from various quarters of 2019-2021. A measure of precision for each method was made by dividing the Median Absolute Deviation (MAD) by the Median for each of the 43 samples for each analyte.

RESULTS

These precision scores had an: average = 8.4%, median = 7.3%, standard deviation = 5.5%, and minimum = 0.6% and maximum = 34% (if only including analytes with at least 8 laboratories submitting data, the maximum value is 20%). The median data is shown in Figures 1-4. These values give a sense of the precision of the data generated collectively across labs (note: these are not measures of correlation to any measure of plant response). There is much data to parse in this analysis, which will be the subject of a future, in-depth publication. However, there are some important preliminary points to glean for those using soil analysis in their management.

The combined pH methods were relatively the most precise methods with a median of 1.0% for pH and 0.7% for buffer pH (Fig. 1-top). In general, the measures for nitrogen (N) were reasonably precise (Fig. 1-bottom), with both methods of total N at 5% and all but the saturated paste method for nitrate-N at ~7%. Ammonium-N and the saturated paste nitrate method were relatively imprecise when evaluated across laboratories in this analysis. When evaluating the commonly used (those with $\geq$8 laboratories submitting data) phosphorus (P) methods (Fig. 2-top), the precision scores were again relatively precise with an average score of 7%. All of the potassium (K) methods were relatively precise (Fig. 2-bottom), with an average score of 6%.

With exception of the saturated paste extraction data and the phosphate based sulfur (S) extractant, the secondary macronutrients had reasonable precision at 6% for calcium (Ca) and magnesium (Mg) and 7% for S (Fig. 3-top). The beneficial nutrient sodium (Na) and its measures for sodicity were disappointingly imprecise—ranging from 11-15% (Fig. 3-top). Another non-essential, but important component of soil chemistry, aluminum (Al) had good precision with Mehlich 3 extraction, which is the primarily used method (Fig. 3-top). For the micronutrients (Fig. 3-bottom), the precision was relatively poor with the exception of zinc (Zn) and the Mehlich extractions for iron (Fe), manganese (Mn), and copper (Cu) with a range of 6-8% for these analytes. The DTPA extraction had poorer precision than the Mehlich extractions in every case. The measures for boron (B) and chloride (Cl) were poor, with average precision scores of 14-15%.

The measures for total carbon (C) and its derived “organic matter (OM)” were relatively precise with an average of 4% (Fig. 4-top). The relatively new Solvita soil health test, with an aim of evaluating microbial use of carbon—measuring respiration of carbon dioxide, had very poor precision (Fig. 4-top). The remaining soil tests of cation exchange capacity (CEC), carbonates, salts, and texture were relatively imprecise with scores that were generally in the double digit percentages, although the pipette method of texture had good precision for silt and clay (Fig. 4-bottom).

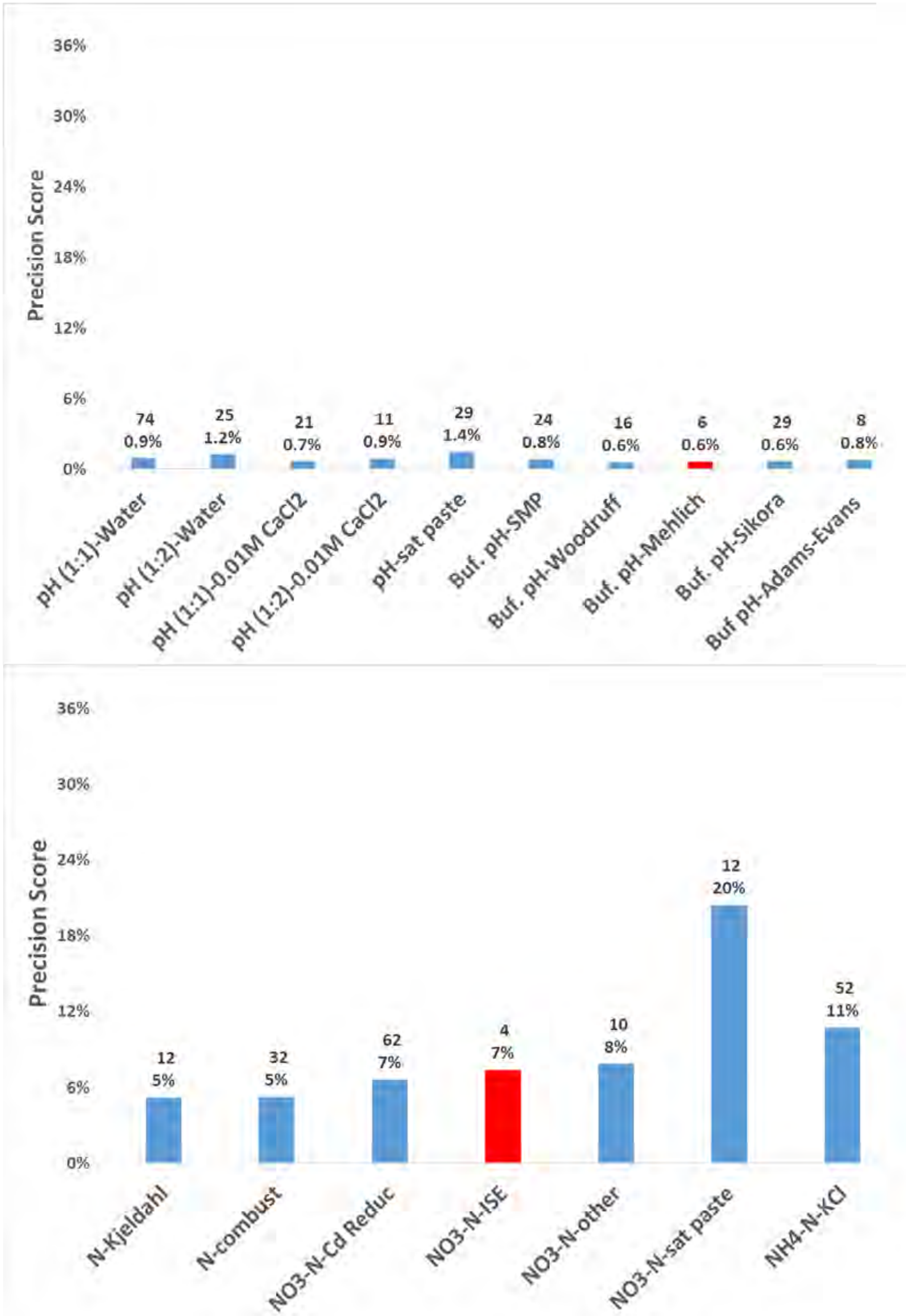

Fig. 1. Precision scores for various soil pH (top) and nitrogen (N) (bottom) analyses calculated from 43 samples tested by participating NAPT laboratories with the median absolute deviation (MAD) divided by the median for each and then averaged for each analyte. Value above the percentage listed at the top of each bar is the number of labs that submitted data for each analyte (those in red signify too few labs to generate statistics within the NAPT program).

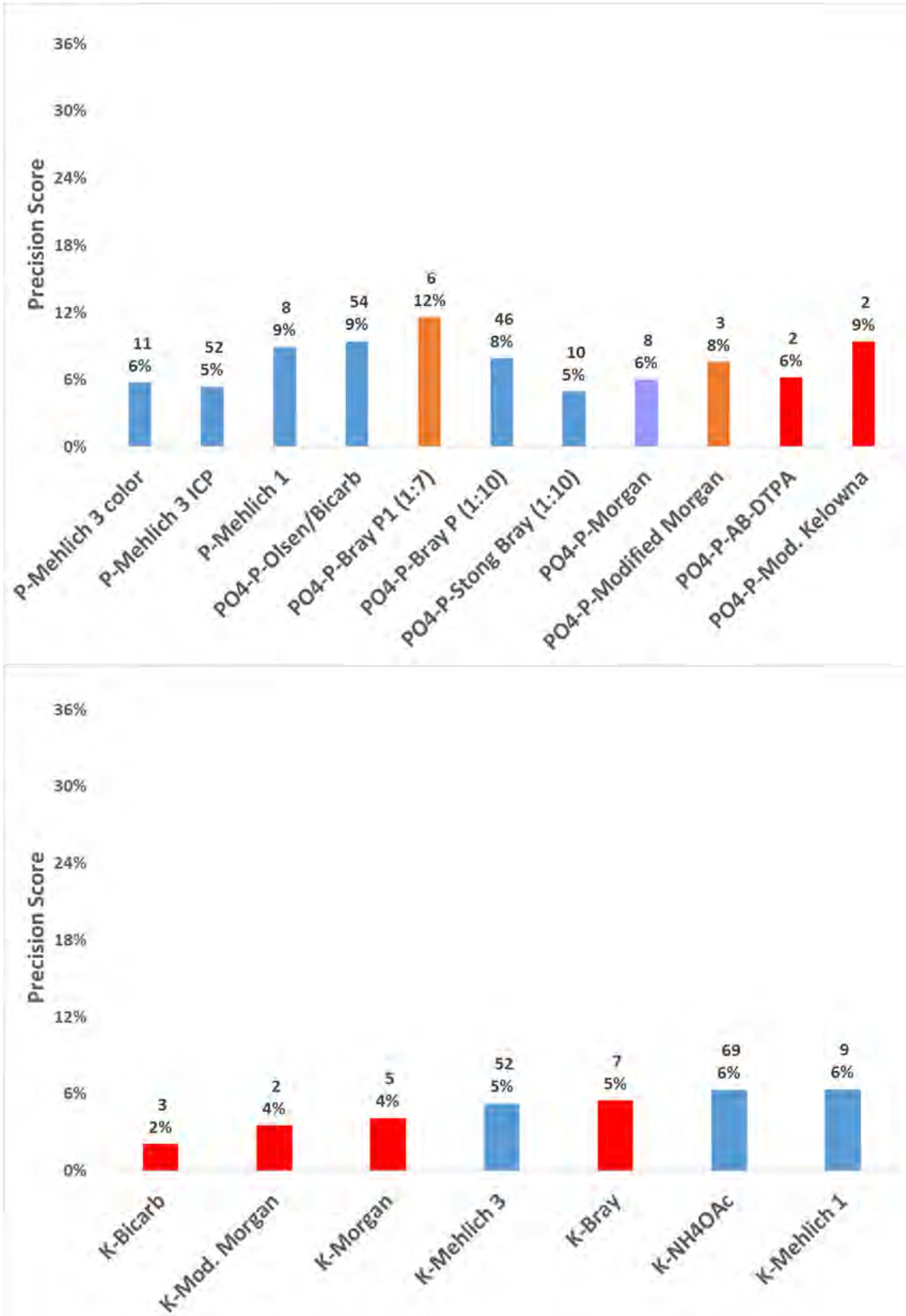

Fig. 2. Precision scores for various soil phosphorus (P) (top) and potassium (K) (bottom) analyses calculated from 43 samples tested by participating NAPT laboratories with the median absolute deviation (MAD) divided by the median for each and then averaged for each analyte. Value above the percentage listed at the top of each bar is the number of labs that submitted data for each analyte (those in red signify too few labs to generate statistics within the NAPT program).

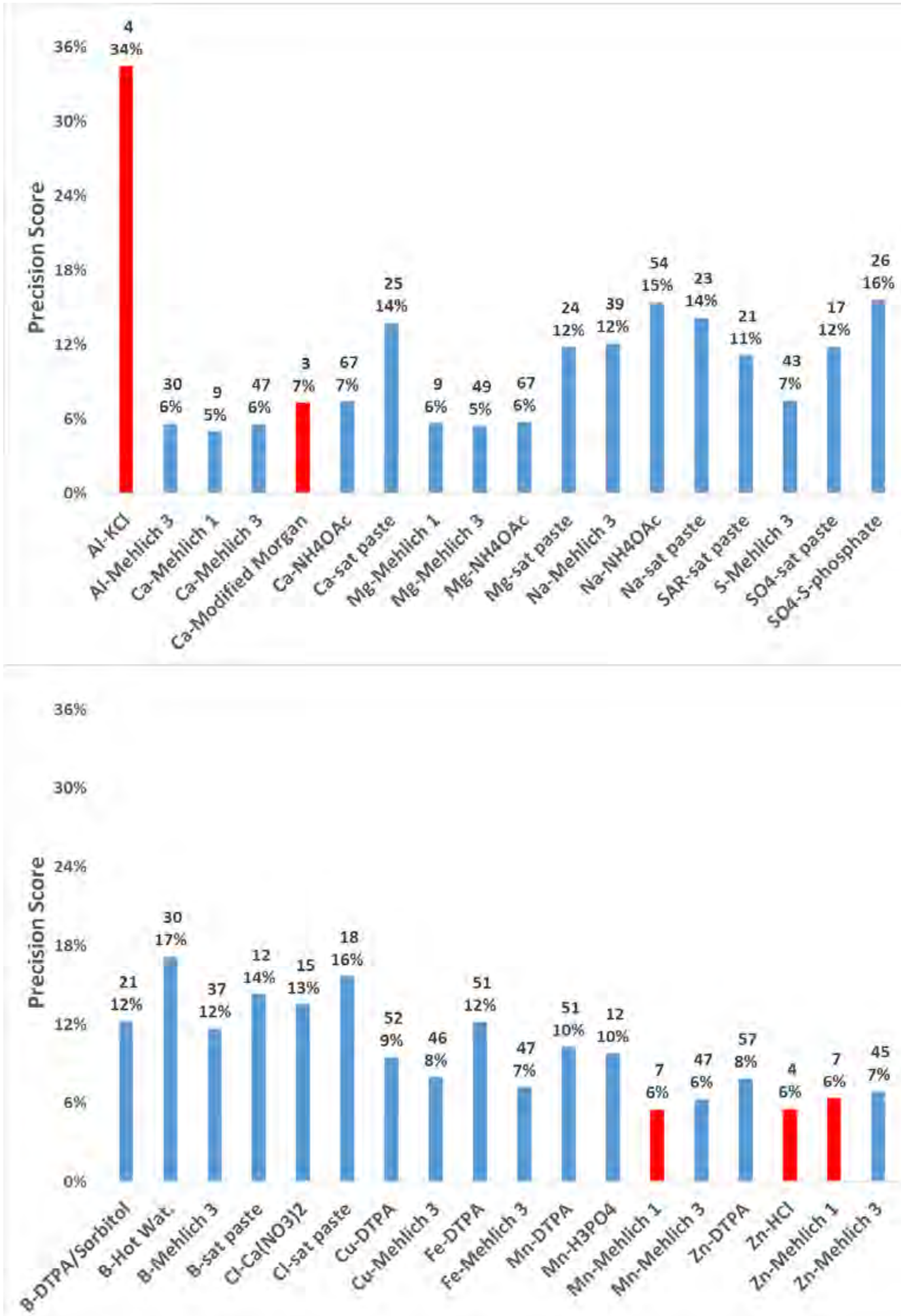

Fig. 3. Precision scores for various soil secondary macronutrients and aluminum (Al) (top) and micronutrients (bottom) analyses calculated from 43 samples tested by participating NAPT laboratories with the median absolute deviation (MAD) divided by the median for each and then averaged for each analyte. Value above the percentage listed at the top of each bar is the number of labs that submitted data for each analyte (those in red signify too few labs to generate statistics within the NAPT program).

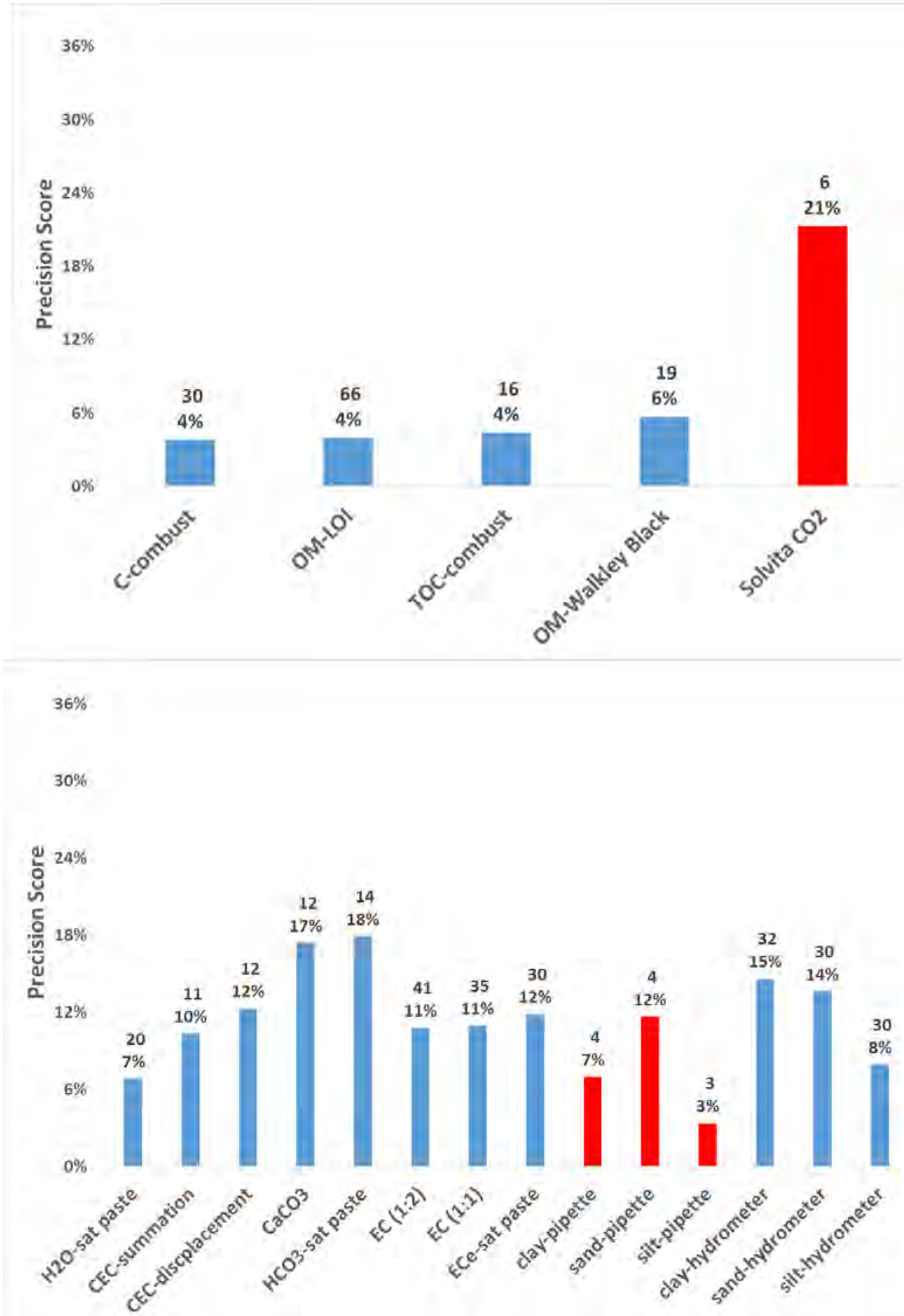

Fig. 4. Precision scores for various soil carbon related measures (top) and miscellaneous (bottom) analyses calculated from 43 samples tested by participating NAPT laboratories with the median absolute deviation (MAD) divided by the median for each and then averaged for each analyte. Value above the percentage listed at the top of each bar is the number of labs that submitted data for each analyte (those in red signify too few labs to generate statistics within the NAPT program).

LEGACY IMPACTS OF CATTLE GRAZING ON SOIL N_2O AND CH_4 FLUXES IN SHORTGRASS STEPPE: A CASE STUDY

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ABSTRACT

Grazing cattle directly emit CH_4 from enteric fermentation and contribute to soil nitrogen (N) gas emissions related to N and organic matter additions from urine and manure deposits. Grazed soils can be sources or sinks of CH_4, depending on moisture levels and localized manure patches. N_2O emissions are related to availability of water as well as mineral N and labile C substrates in soil. Previously, we observed higher N_2O and NH_3 losses from fresh patches of urine and manure compared to controls receiving no waste inputs. In this paper we investigate legacy impacts of more than 75 years of cattle congregating in pasture hotspots near corners and water tanks on soil N_2O and CH_4 fluxes. To minimize the effects of fresh excreta deposition, exclosures were installed around the gas sampling chambers to keep cattle off the experimental plots during grazing periods. We hypothesized that hotspots have higher soil mineral N concentrations, more N_2O emissions, and less CH_4 uptake compared to pasture centers. Soil NO_3 was indeed elevated in hotspots but not NH_4. We also observed consistently higher N_2O emissions from hotspots over all three years of the study (2015-2017) but CH_4 uptake was less than pasture centers only during 2015. N_2O emissions on average were an order of magnitude higher in hotpots than centers. Consequently, although hotspots make up a small portion (e.g., 1-4%) of total pasture area, they were responsible for about 23% of emissions at the pasture level.

INTRODUCTION

Grasslands comprise approximately 40% of the terrestrial land surface area, with the majority of this area under grazing management (Cai and Akiyama, 2016). Grazing animals contribute to soil nitrous oxide (N_2O) emissions related to nitrogen (N) additions associated with animal waste deposition. While methane emissions from cattle are primarily due to enteric fermentation and manure management systems, anaerobic fermentation occurs within feces patches as they dry. In arid rangelands, feces patches act as a source of CH_4 for approximately a week until the patch has dried out (Nichols et al., 2016). In contrast to localized patches, bulk soil is typical a CH_4 sink in arid grasslands

Grazing cattle redistribute approximately 70-95% of N consumed in forage through urine and feces patches (Oenema et al., 2005; van der Weerden et al., 2011. While areas near pasture corners and water tanks comprise a relatively small proportion (1-4%) of the total pasture area in arid rangelands, cattle spend a significant amount of time (about 27%) in these areas (Augustine et al., 2013) creating hotspots with enhanced soil mineral

N concentrations due to a high portion of urine and feces patches deposited at these locations. In addition, these areas also experience soil compaction from cattle treading, resulting in reduced soil pore diameter and increased water-filled pore space (WFPS) which increase the prevalence of anaerobic microsites. Nitrous oxide emissions also tend to be greater from compacted soils (Bhandral et al., 2007).

Previous work quantified N_2O and CH_4 emissions from freshly deposited urine and feces patches for a shortgrass steppe system in northeastern Colorado (Nichols et al., 2016). In this paper, we investigate legacy impacts of more than 75 years of cattle congregating in pasture hotspots near corners and water tanks on soil N_2O and CH_4 fluxes. We hypothesize that hotspots will have higher soil mineral N concentrations, more N_2O emissions, and less CH_4 uptake compared to pasture centers.

MATERIALS AND METHODS

The study was conducted in northeastern Colorado at the USDA-Agricultural Research Service Central Plains Experimental Range (CPER), located approximately 12 km northeast of Nunn, Colorado. The soil types of the experimental sites are Ascalon fine sandy loam and Cascajo gravelly sandy loam. Climate at the region is semi-arid with a mean annual precipitation (1939 – 2016; n = 78) of 341 mm. The typical growing season is approximately 133 days with the dominant vegetation being the C4 perennial grass, blue grama (*Bouteloua gracilis*). Randomized blocks were established in a130-ha pasture that had been moderately grazed since 1939 near a water tank, “hotspot” and at the center of the pasture. The pasture center site was located approximately one km from the hotspot location. To isolate legacy impacts from fresh excreta deposition, exclosures were installed around the randomized blocks to keep cattle off of the experimental plots during grazing periods.

Trace gas sampling was conducted using rectangular aluminum chambers. Anchors (8 per block) were installed in designated trace gas sampling plots and were left for the duration of the study, April 2015 to November 2017. Chambers were deployed for 30 minutes with samples collected at 0, 15, and 30 minutes. Trace gas sampling was conducted once or twice per week between 0900 and 1200 hours, the air temperature during this period has been found to approximate the daily average. Trace gas samples were analyzed for CH_4 and N_2O on an automated gas chromatograph (Varian model 3800, Varian Inc., Palo Alto, CA) equipped with a thermal couple detector (TCD), flame ionization detector (FID), and electron capture detector (ECD). Nitrous oxide and CH_4 flux rates were calculated using the linear equation with gas concentrations taken at three time points. Cumulative emissions were calculated by linearly interpolating between sampling days and summing for the year. Soil core samples for the top 20 cm were collected frequently (every five to six weeks) throughout the spring, summer, and fall to measure soil mineral N (NH_4^+ and NO_3^-). Statistical differences in the annual gas flux rates and mineral N between the hotspot and pasture center were determined using the GLIMMIX procedure with repeated measures for location in SAS (SAS Institute, 2013).

RESULTS AND DISCUSSION

Cumulative N_2O emissions from the pasture hotspot were significantly greater ($P < 0.0001$) than the center during all three years of the study. On average, emissions were approximately 10 times greater from the pasture hotspot than the center (Figure 1). Consequently, even though hotspots comprise a relatively small proportion of the total pasture area, 1.1 – 3.9%, depending on pasture size (Augustine et al., 2013), these regions have an important effect (~23%) on the overall pasture level emissions. Strong positive correlations were observed between soil WFPS and N_2O flux on the pasture center ($r = 0.33$; $P = 0.002$) and hotspot ($r = 0.30$; $P = 0.005$). While positive correlations between soil temperature and N_2O flux were also observed, the relationships were not significant.

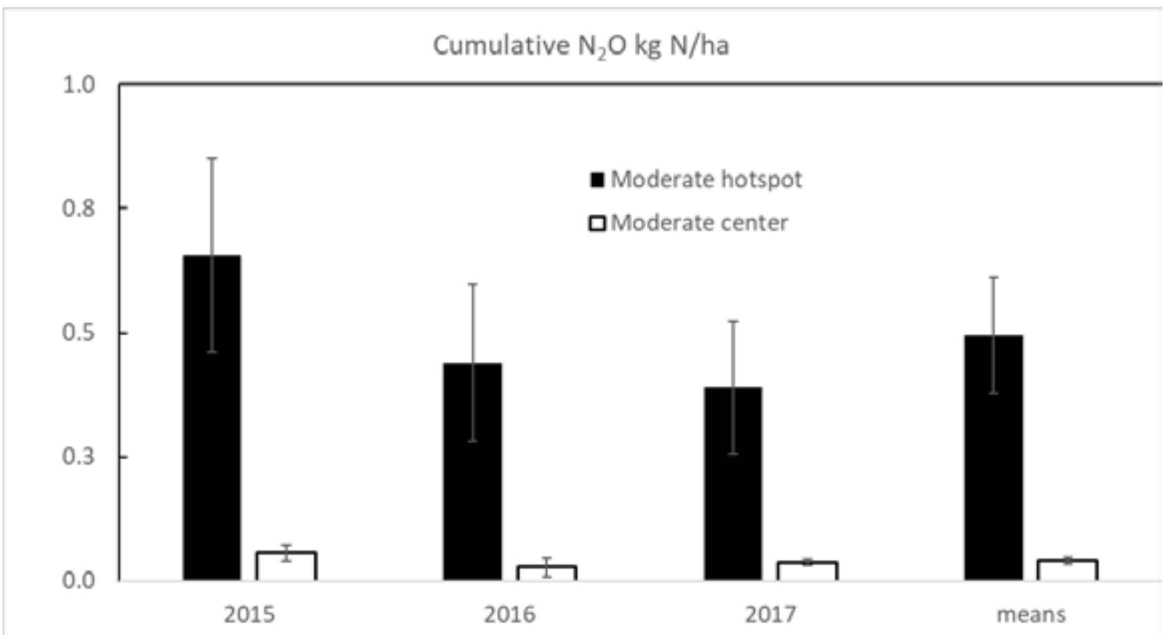

Figure 1. Cumulative annual N_2O emissions from moderately grazed pasture hot spots near water tank vs. pasture center. Bars are standard deviations.

Cumulative CH_4 uptake from the pasture hotspot was significantly less than the center during the first year of the study but not different the subsequent two years (Figure 2). This observation may result from recovery of the methanotroph population and increased soil gas diffusion due to the absence of disturbances in enclosures by cattle treading (i.e., soil compaction and vegetative growth) (Liu et al., 2007).

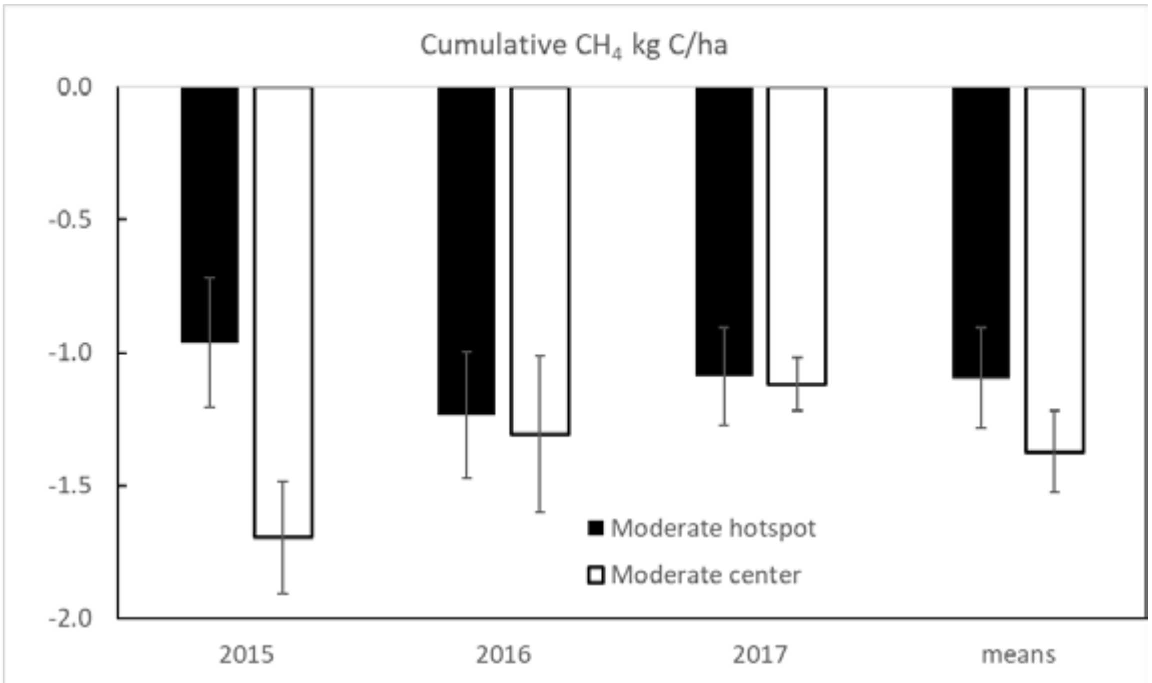

Figure 2. Cumulative annual CH_4 uptakes from moderately grazed pasture hot spots near water tank vs. pasture center. Bars are standard deviations.

As expected, average NO_3 in 0-20 cm layer was substantially (5.6-fold) greater in the hot spot (34 kg N/ha for hotspot vs. 6 kg N/ha for center). In contrast, NH_4 in the 0-20 cm layer did not differ on average (10 kg N/ha for center, 11 kg N/ha for hotspot). However, NH_4 levels were significantly higher for the initial sampling at the beginning of the study in spring 2015.

Hypotheses regarding N_2O emissions and NO_3 levels were supported, but those related to CH_4 uptake and NH_4 levels largely were not; only the first year of the study showed lower CH_4 uptake and higher NH_4 levels in the hotspot. Figure 1 suggests that the ability of hotpots to absorb CH_4 recovers quickly when cattle traffic and waste deposition are prohibited by enclosers. This finding contrasts with an earlier study by Mosier et al. (1996) who found that plots amended with urea to simulate urine patches had lower CH_4 uptake than control plots > 5 years after treatment. Enhanced N_2O emissions persisted for three years from the hotspot, although there is some evidence of a gradual decline across years suggesting that fresh manure and urine inputs contribute to emissions (Figure 2).

The patterns we observed are consistent with those from a study in Australia where Mitchell et al. (2021) found that N_2O emissions and NO_3 levels were much higher in hotspots. Only one of three sites analyzed in their study showed differences in CH_4 fluxes and no sites showed differences in NH_4 levels. Although trends were similar, N_2O emissions from their more mesic system (MAP = 854-1133 mm for the three sites) were much greater than our values. It is also interesting that although hotspots occupied a small portion of pasture area (~3 %) they were responsible for a significant potion (~27%) of pasture level emissions which is similar to our estimation of hotspots being responsible for ~23% of pasture level N_2O emissions. Further research is required to better assess how important hotspots are for pasture level emissions across climate and stocking rate gradients and if the IPCC (de Klein et al. 2006) soil N_2O emission factors commonly used to calculate emissions reported in national greenhouse gas inventories should be adjusted.

ACKNOWLEDGEMENTS

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EFFECTS OF CLIMATE CHANGE AND NARROW ROWS WITH HIGHER PLANT DENSITIES ON YIELDS OF IRRIGATED CORN

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ABSTRACT

Climate change is significantly impacting agricultural systems worldwide, and although there are reports of these impacts contributing to higher yields in some regions, the general consensus is that there will be negative impacts on yields and soil quality across large regions.

Management practices that can contribute to higher yields and adaptation to a changing climate will be important during the 21st century. This presentation will cover results from two manuscripts. One (in peer review) assesses the long-term effects of climate on irrigated yields of corn using data from the Halvorson plots, which are unique long-term irrigated studies that were established in Fort Collins, Colorado. The other (just published) assesses the effects of narrow rows on corn yields with new studies conducted from 2018 to 2020 at the same location. Climate change is occurring at the site and higher yields were correlated with higher average minimum temperatures and growing degree days. Narrow rows (38.1-cm spacing) had 42.5% higher silage production and 9.5% higher harvested grain. Additional information about the results from these studies will be presented. These two sets of studies suggest that climate change is occurring and irrigation is an adaptive practice that could contribute to higher yields, and that management practices such as narrow rows with higher plant populations could contribute to higher silage and grain production. However, the results also suggest that the dryland corn in the region will be significantly negatively impacted.

PRECISION MAPPING TECHNOLOGY IN DRYLAND CROPPING SYSTEM

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ABSTRACT

Increasing availability of cropland geospatial data are providing farmers with opportunities but also challenges in interpreting these data for precision cropland management decisions. The objective of this study is to evaluate spatial variability and precision management decisions using mapping technology in dryland cropping system. The study was initiated in 2018 in Akron, Colorado on field size plots ranged from 2.4 to 4.5 ha (6-11 acres) with substantial production variability. The cropping system consists of (i) Business-As-Usual (BAU) management with wheat-fallow cropping under reduce tillage (WF-RT) and (ii) Aspirational (ASP) with four-year cropping of winter wheat-corn-millet-flex under no tillage (WCMFlex-NT). Each phase of each rotation was included in each year of the study with three replications. Soil samples in each field were taken in a 30-m (100-ft) georeferenced grid. Two or three management zones were defined in each field by yield, soil properties, and elevation. Veris-EC/pH was used as a tool to evaluate some aspects of soil properties. Two eddy covariance towers were installed to estimated carbon and water fluxes. High-resolution topographical maps reveal elevation changes of more than 2 m (6.5 ft) in some fields. Yield differences between high and low yielding zones within each field varied by as much as 135 bu ac^{-1} (8.5 Mg ha^{-1}) for corn and 85 bu ac^{-1} (5.3 Mg ha^{-1}) for wheat. Preliminary geospatial analyses are showing promise in guiding precision farming decisions and could provide a unique opportunity to dryland farmers for optimizing crop production, reducing inputs, and enhancing economic return in the central Great Plains Region.

INTRODUCTION

Precision Agriculture is a farming concept that accounts for spatial and temporal variability in crop production and soil resources. This can be done by using global positioning system (GPS) to coordinate collection of soil, site, and plant information; generating maps and relationships between spatial variability of soil and site properties in correlation with crop yield; and applying those relationships to guide variable-rate inputs for seed, fertilizer, and pesticides. The increase in world's population and the demand for food and fiber challenge the agriculture industry to increase food production, maximize profits, and conserve available resources. Adaptation of precision farming strategy may help increase food production, reduce inputs, enhance resource use efficiency, and improve economic return (Franzen and Mulla, 2016).

The usage of Unmanned Aerial Vehicles (UAV) technology with high resolution imaging equipment assists researchers and producers to identify spatial variability of key factors in the field and apply appropriate management strategies. The UAV provides assessments of crop yield, crop water and nutrient stress, weed problems, insect and pathogen infestation, soil characteristics, and other field conditions, all of which can contribute to maximize land sustainability (Olson and Anderson, 2020). The spectral cameras in these UAV can be used to identify crop stand count (Torres-Sánchez et al., 2015), weed detection (Hansen et al., 2013), and biotic stress detection (Bock et al., 2008). The incorporation of remote sensors and UAV technology allow plant breeders and researchers to gather phenotypic information quickly and efficiently for making management decision that enhance production (Yang et al., 2017). Crop yield and quality assessment, for a specific year, can be influenced by crop genetics, weather pattern, soil nutrients, and land management decisions (Raun et al., 2001). The usage of UAV-based imagery have enhanced crop assessment accuracy (Mekonnen et al., 2020) due to real time evaluation of crop progress though the life cycle (Ballester et al., 2017).

Soil water is the most limiting factor for crop production in dryland agricultural systems. Monitoring crop water stress with UAV technology can assess fluctuations in crop water needs throughout the season (Santestaban et al., 2017) and allow for improved irrigation scheduling (Crusiol et al., 2019) Crop nutrients such as nitrogen (N), phosphorus (P), and potassium (K) are essential for crop production and are applied regularly to soil. Crop nutrient-use efficiency could vary from year to year depending on water availability and ambient temperature. Insufficient synchronization between crop nutrient needs and available soil nutrients may cause deficiencies or lead to leaching of nutrients with harmful effects on the environment (Olson and Anderson, 2020). The UAV can be equipped with spectral sensors for crop nutrient assessments to indirectly assess real-time nutrient deficiencies (Liu et al., 2018). This also could improve estimates of fertilizer requirements and associated costs (Olson and Anderson, 2020).

In precision agriculture, mapping soil characteristics is important for management decisions due to spatial soil heterogeneity (Govers et al., 2013). The UAV provides precise and high-resolution soil mapping, which helps with enhanced input efficiency. Veris instrument that use measured soil electrical conductivity (EC) to estimate soil properties that can be transferred into maps (Pei et al, 2018; Azhar et al., 2021). Soil properties informed by Veris data may include soil organic carbon (SOC), total nitrogen (TN), moisture, soil texture (clay, silt, and sand), cation exchange capacity (CEC), calcium (Ca), magnesium (Mg), potassium (K), and pH (Pei et al., 2018).

The semiarid region of the Great Plains exhibit erratic weather patterns with low precipitation, high evaporation, and high temperature during summer months. The production in dryland cropping systems of this region depends on soil water storage that is influenced by land topography, cropping intensity, and tillage practices (Kühling et al., 2017). There is an information gap linking land topography, soil water storage, crop soil water availability, soil properties, and crop yield (Brown et al., 2020). The objective of this study is to evaluate precision management decisions for enhancing land productivity in dryland cropping system in Akron, Colorado. In this report we will focus on precision technologies in relation to productivity.

MATERIALS AND METHODS

The precision management approach initiated in 2018 at Akron, CO on field size plots that exhibited high degree of variability in crop production, soil nutrients, and soil water content. Two management practices have been implemented: (i) Business-as-

Usual (BAU) that consist of wheat-fallow rotation with reduce tillage (WF-RT) and (ii) Aspirational (ASP) that consist of a four-year rotation with winter wheat-corn-millet-fallow/flex (WCMFlex) and no-tillage. The choice between fallow and an appropriate crop (flex) in the fourth year will depend on the available soil moisture at planting for that year. Each phase of rotation is included in each year with 3 replications. The field plots size ranged from 6-11 acres (2.4-4.5 ha). Average annual precipitation over the previous 29 years (1991-2020) was 16.2 inches (410.5 mm). In 2018, soil samples were taken using a gridded sampling design of 100 ft x 100 ft equidistant spacing with georeferenced grid points to generate field maps (Figure 1). Soil samples were taken from 0-6 inches (0-15 cm) and 6-12 inches (15-30 cm) depth.

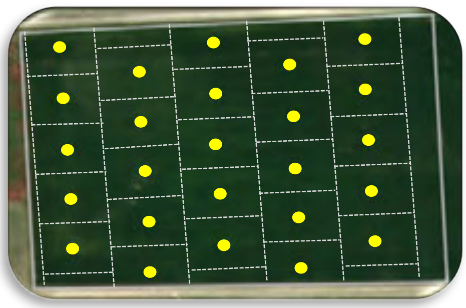

Figure 1. Soil sampling points diagram. Soil samples were taken using grid of 100 ft x 100 ft equidistant spacing and georeferenced each grid point.

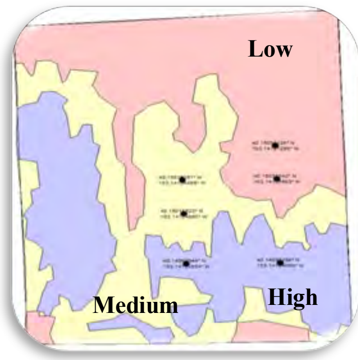

Figure 2. Diagram of the neutron tubs installed in each field plots at low, medium, and high yield zones.

Soil samples were analyzed for chemical properties such as EC, pH, N, P, K, organic matter. Crop yield was evaluated using yield combine harvester equipped with georeferenced instrument to establish yield maps. Crop yield in each field plot was organized in three zones (High, Medium, and Low) by yield, soil properties, and elevation. Soil moisture is being evaluated using neutron probe measurements from two tubes installed in each zone within the same field (Figure 2). Correlation among different parameters (yield, soil nutrients, soil water content, etc.) and crop yield was evaluated using Random Forest models.

RESULTS AND DISCUSSION

Field plots varied in land elevation (Figure 3). The differences in elevations within the same field plot ranged between 7-10 ft (2.1-3.0 m) with BAU and ASP. In 2019 corn and wheat yield ranged from 25.0 bu/ac in the low yielding zone to 160 bu/ac in some high yielding zone for corn and 110 bu/ac for wheat (Figure 4). The yield differences between the high and the low yielding zones was about 135 bu/ac (8.5 Mg ha^{-1}) for corn and 85 bu/ac (5.3 Mg ha^{-1}) for wheat. This represents about 8.5 Mg/ha differences with corn yield and 5.3 Mg/ha for wheat yield within the same field plot. Yield in each field plot exhibited 7 zones blended with each other (Figure 4) which could cause some management challenges regarding inputs. Therefore, organizing the field plot into three management zones may help with improving field management efficiency.

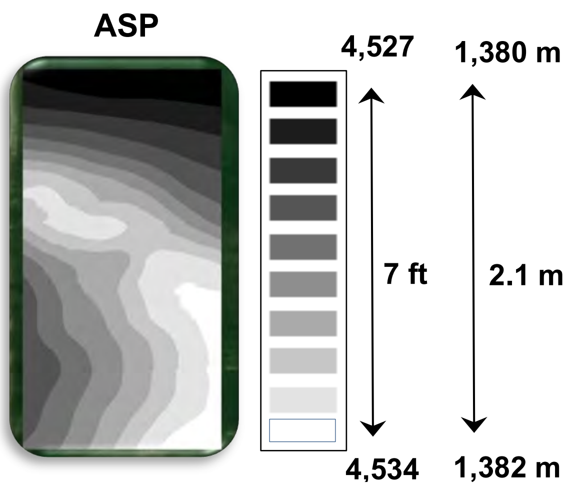

Figure 3. Variability in some field plot elevation associated with Business-as-Usual (BAU) and Aspirational (ASP) management

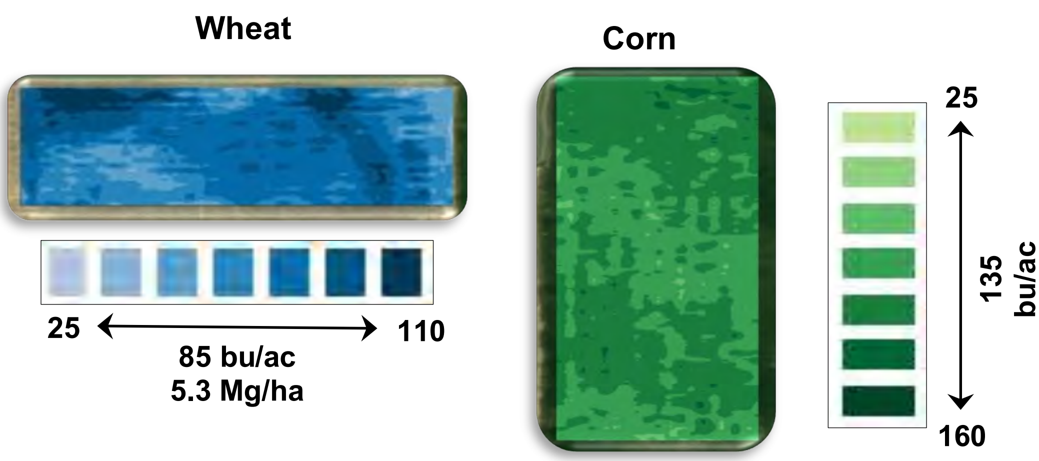

Figure 4. Wheat (blue color) and corn (green color) yield variability within the field plot associated with Business-as-Usual (BAU) and Aspirational (ASP) management decisions.

The 2019 yield data were correlated with field elevation (Figure 3 and 4). The higher elevation areas of the field exhibited lower yield, while the yield decreased with elevation. The yield dynamic for corn and wheat was expected because soil water is the most limiting factor in dryland system. Land topographies contribute to soil differences, soil water differences, and nutrients differences, as nutrients are transported from higher elevation to lower elevation area of the field. This process can translate into enhanced yield in the low elevated section of the field plot compared with high elevated section of the field. Topography is just a surrogate parameter, however, so the next step is to differentiate the contribution of each of these factors, and others, to the observed yield differences.

The influence of different parameters studied on crop yield were evaluated using Random Forest models (Figure 5). These preliminary data showed elevation to be the most influential factor on crop yield. This could be related to soil water and nutrient availability in this dryland cropping system.

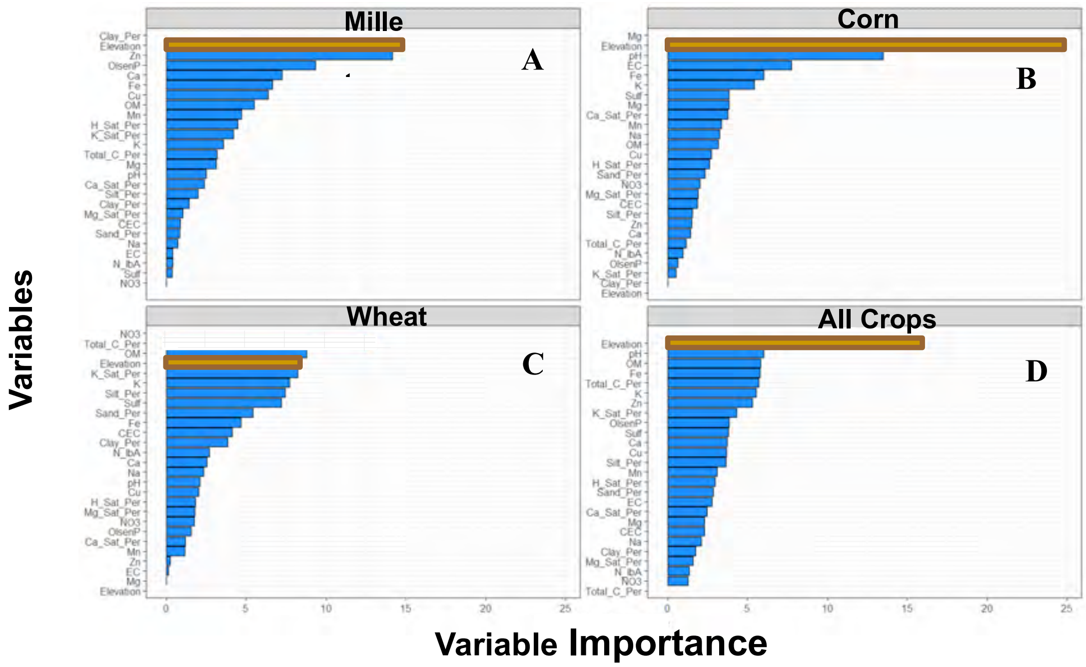

Figure 5. The influence of different studied parameters on crop yield (A, B, and C) individually and on all crops combined (D).

CONCLUSIONS

The data collection and usage of precision technologies and analyses for soil nutrients, crop monitoring, and field mapping will be continued till 2023. This information could improve the application of precision farming in this region. Overall, this project provides a unique opportunity to evaluate precision farming practices for the dryland cropping system in the Central Great Plains Region.

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MEASURING N2O EMISSIONS FROM DRYLAND SORGHUM PRODUCTION USING GAS CHAMBER AND EDDY COVARIANCE FLUX METHODS

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ABSTRACT

Nitrous oxide (N_2O) emissions are not well quantified in the dryland production systems of the Great Plains. Lack of field-based data has led to the use of questionable assumptions in various life-cycle analyses when dryland grain production is a feedstock. A field-scale trial of 81 acres was established within a 160 acre production field of dryland grain sorghum in northwest Kansas in 2021. Grain sorghum was no-till seeded into wheat stubble. Grower practices for nitrogen management were utilized, with UAN streamed on the soil surface immediately following planting. Nitrous oxide fluxes were measured using two methods, one of which provided values at discrete times and the other providing a continuous dataset. To obtain the continuous measurement, an eddy covariance system, consisting of a closed-path gas analyzer and sonic anemometer were used to derive field-scale half-hourly N_2O fluxes. In addition to the continuous monitoring instrumentation, soil gas chambers were installed at 8 locations in a perimeter around the eddy covariance instrumentation at an average distance of 252 ft. At a sampling event, chambers were sealed and a gas sample was extracted from the chamber headspace at 0, 20, 40, and 60 minutes post seal. Samples were collected at 24, 48, and 72 hours after N application and generally weekly thereafter. Gas sampling campaigns were conducted in the mid-morning hours. This presentation will present initial findings of this project as well as a comparison of estimates of N_2O flux from the discrete and continuous measurement approaches.

REVISING THE IMPACTS OF LATE SEASON NITROGEN FERTILIZATION ON WHEAT CROPS

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ABSTRACT

Late-season applied N is a challenging practice that when used correctly can contribute to the sustainability of grain production systems by maintaining grain yield and improving grain quality. A systematic assessment of the effects of late-applied N across multiple environments and agronomic practices is currently lacking. Therefore, our goals were to determine the impact of late-season N application on wheat grain yield and protein concentration (GPC) through the utilization of meta-analytic models; and to determine which fertilizer management scenarios were moderating these effects. A systematic literature search was performed for articles reporting grain yield and grain protein, biomass and N uptake at plant maturity. Across studies, grain yield was unaffected by late season nitrogen; however, the effect on grain protein concentration was significantly positive with a pooled estimate of 3.7%. Significant heterogeneity (I^2 = 78%) for grain protein concentration suggested the need for further exploration of potential moderators. Increasing the proportion of late season N rate over the total N available for the crop in the season was positively related to protein gains, decreasing the I^2 to 54%.

INTRODUCTION

Synchronizing N supply and demand can a tactical strategy for further improving N use efficiency and reducing losses in wheat production systems (Foulkes et al., 2009; Hawkesford, 2014). Through management, this can be achieved by delaying N applications until a moment in which (i) crop yield (being one of the main drivers of N requirements) could be more accurately predicted (Raun and Johnson, 1999); (ii) allows to detect N deficient zones through ground-based reflectance sensors and thus adjust spatially variable rates as a function of crop needs (Raun et al., 2005); (iii) the root system is fully developed and thus positively correlates with higher N uptake efficiency (Foulkes et al., 2009). Therefore, it is crucial to assess late-season N relevance on grain quantity and quality, underpinning its constraints and synergies with management, physiological, and environmental factors.

Across the literature, there is a strong agreement on lack of yield response when N is applied surroundings anthesis(Altman et al., 1983; Woolfolk et al., 2002; Blandino et al., 2015, 2020; Lollato et al., 2021). Nonetheless, there are particular situations in which there is still place for improving yields. For instance, Rossmann et al. (2019) reported yield increases when N was applied at anthesis only for two particular genotype × N regime combinations.

Even though late-season N fertilization has extensively demonstrated clear benefits on wheat protein and quality (Blandino et al., 2015; Cruppe et al., 2017; Lollato et al., 2021), no attempts have been made to quantify its impact on a wide range of environmental conditions.

Furthermore, literature highlights variable response to late season N depending upon management practices adopted (Finney et al., 1957; Woolfolk et al., 2002; Bly and Woodard, 2003; Cruppe et al., 2017), plant N status at anthesis (Varinderpal-Singh et al., 2012) and at a greater extent the environmental conditions explored during the post anthesis period (Bogard et al., 2010).

Therefore, our objective was to perform a comprehensive literature synthesis of N applications post Zadoks 3.7 to: (i) quantify the its overall impact on wheat grain yield and protein concentration and; (ii) to compare whether these effects are affected by different late-season N fertilizer management practices (rates, timing, placement, source).

MATERIALS AND METHODS

A literature search was performed to assess the effect of late-season N application in wheat. We screened articles published in *Agronomy Journal, Crop Science, European Journal of Agronomy, and Field Crops Research.* Data from thesis, dissertation, or unpublished trials were also considered to avoid publication bias (McLeod and Weisz, 2004). The search terms included the word *'wheat'* and any of the following words: *'nitrogen', 'yield', 'protein'* in the article title. The search resulted in 1,672 publications (294-637 per journal), all of which were scanned seeking for specific criteria as requirements for manuscript inclusion in the database. Criteria was fulfilled when: (i) Studies were reporting N applications before and after GS 37 (flag leaf visible); (ii) Either grain yield or grain protein concentration values were reported directly or indirectly (iii) Data were collected only when individual environments were reported (not aggregated across environments); (iv) control (Zero N) and Basal N treatments were reported; (v) when timing of application was not clearly defined and not explicitly determined in any of the well-known Zadoks (1974) or Feekes (Large, 1954) wheat development scales; (vi) data included were considered only from field studies.

Different late-season N management scenarios were defined: (i) timing of application, as indicated in articles expressed in Zadoks growth stage units (Zadoks et al., 1974); (ii) source; (iii) placement; and (iv) rate. Together with the late N rate (LNR), we also collected the early N application rate (ENR) and total $N - NO_3$ at sowing. Subsequently, the total nitrogen available for the crop was calculated as:

$$TN(kgN\ ha^{-1}) = N - NO_3(kgN\ ha^{-1}) + ENR(kgN\ ha^{-1}) + LNR(kgN\ ha^{-1}) \quad \textit{Eq. 1}$$

Derived from Eq. 1 we calculated the Ratio, as the proportion of late season N rate over the total N available for the crop during the season. Nitrogen sources were categorized into five categories: (i) foliar sources, (ii) dry ammonium nitrate, (iii) diluted ammonium nitrate, (iv) dry urea, and (v) diluted urea. Nitrogen placement groups were defined as "soil" and "foliar".

Late-season N effects on grain yield and GPC were calculated as the natural logarithm of the response ratio between treatments that received late-season N and the corresponding control treatment that received otherwise the exact same previous agronomic management. For the easiness of interpretation, we calculated the aproportional effect in the fertilized group relative to the control group as *Eq. 3.* Effects were weighed according to the inverse of the pooled sampling variance between the two groups being compared.

$$Effect\ (\%) = \left\{\frac{\bar{X}_{fertilized}}{\bar{X}_{control}} - 1\right\} * 100 \quad Eq.3$$

RESULTS AND DISCUSSION

Late season N did not affect grain yield across a wide range of environments and management practices (Table 1). Analysis of residual heterogeneity showed that these effects were very consistent reflected by a low I^2 of 35%. Our results were in line with previous research reporting lack of yield response to different management practices related to late season N even in interaction with genotype (Altman et al., 1983; Bly and Woodard, 2003), environment (Altman et al., 1983; Bly and Woodard, 2003; Dick et al., 2016; Cruppe et al., 2017), genotype × environment (Altman et al., 1983; Bly and Woodard, 2003).

Table 1. Overall effect (mean estimate and its respective 95% confidence interval – lower (LB) and upper bounds (UB) are presented) for grain yield and GPC. Asterisks represent significance of the effects at α = 0.01 (***)

Pooled estimate	Grain Yield Response (%)	Grain Protein Concentration Response (%)
Mean	0.7	3.7 ***
LB 95% CI	-2.19	0.7
UP 95% CI	3.68	6.9
I^2(%)	35	78

Delaying N applications resulted in positive significant impact on protein (Table 1). However, these results were highly heterogeneous (I^2 = 78%), meaning there could be potential factors controlling the magnitude of the response. Ratio positively correlated to protein and reduced the inconsistency up to 54% (I^2) (Table 2). Timing of N application was unrelated to protein response (Table 2). From our data we found that when N was soil placed protein response was greater as compared with foliar N treatments (Table 2). Dry ammonium and foliar fertilizers were sources that resulted in significant protein response ($p > 0.05$; Table 2). Situations in which dry ammonium nitrate and foliars were applied, protein was 8.6% and 4.6% respectively. However, protein was moderately impacted by dry urea (5.8%), diluted ammonium nitrate (3.28%), diluted urea (2.4%). Even though ammonium nitrate had the greatest protein response, results are still heterogeneous when accounting for fertilizer sources single effects (I^2 = 63%).

Table 2. Effect of management practices over GPC response to late season N fertilization. (mean estimate and its respective 95% confidence interval – lower (LB) and upper bounds (UB) are presented). Asterisks represent significance of the effects at α = 0.05 (**) and α = 0.01(***).

			Grain Protein Concentration Response (%)			
			Mean	**LB 95% CI**	**UP 95% CI**	**I^2 (%)**
Management	Placement	Soil	7.09**	3.15	11.17	60
		Foliar	3.94**	0.99	6.97	
	Source	Foliar	4.58**	1.36	7.91	63
		Dry Urea	5.87	-0.35	12.49	
		Dry Ammonium	3.28**	2.49	15.08	
		Diluted Urea	2.38	-3.08	8.17	
		Diluted Ammonium	8.6	-3.24	10.24	
			Slope		**I^2(%)**	
	Ratio		26.1 ***		54	
	Timing		ns		62	

CONCLUSION

Our review remarks late-season N have negligible impacts on grain yield and these effects were highly consistent across the wide range of environments and agronomic practices explored in this analysis. In contrast, grain protein concentration responded positively to late season N and these effects resulted highly heterogeneous. Notwithstanding, late-season N management can provide enlightenment for reducing these inconsistencies. This review provides evidence on how the proportion of N applied late in the season over the total available N for the crop controls grain protein response and thus reduce heterogeneity. Still, the great dispersion of the data, shows how grain protein response to delayed N applications is strongly governed by complex G × E × M interactions, all of which is being addressed in current research.

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ADJUSTING N RATE IS THE FIRST STEP IN N MANAGEMENT INTENSIFICATION

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ABSTRACT

Nitrogen (N) management and sowing date are among the leading causes for winter wheat (*Triticum aestivum* L.) yield gap in Kansas. This research aimed to compare the two most common cropping sequences in Kansas (continuous wheat [Ct-Wt] and double-cropping of winter wheat and soybean (*Glycine max* (L.) *Merrill*) [Wt-Sy]) under two N management (standard and progressive) on wheat production. Standard N management consisted of one single broadcast N application as UAN at 80 lbs ac^{-1} at tillering. Progressive N management differed in terms of all 4R components, including N rates which varied year-to-year (80 lbs ac^{-1} in the first year and 67 lbs ac^{-1} in the second year, based on modeled in-season crop conditions), was applied in two timings (tillering and jointing) as UAN with urease and nitrification inhibitors using a streamer bar applicator. Standard and progressive N management had similar responses on grain yield (64 and 67 bu ac^{-1}), shoot biomass (10900 and 10100 lbs ac^{-1}), number of heads ft^{-2} (90 and 81), and seeds size (18000 seeds lb^{-1}) in the first year, in which the total N applied was the same. In the second year, however, the standard N management had greater grain yield (56 vs. 48 bu ac^{-1}) led by higher number of heads ft^{-2} (80 vs. 67) than the progressive treatment. Continuous winter wheat had greater grain yield than Wt-Sy (60 vs. 45 bu ac^{-1}), likely due to a delayed wheat planting date following soybeans. Preliminary findings from this study suggest that N rate trumps the remaining aspects of 4R, suggesting that it should be the first component adjusted to maximize fertilizer use efficiency.

INTRODUCTION

Nitrogen (N) is part of the composition of amino acids (hence, proteins) in plants (Taiz and Zieger, 2010). Synthetic N fertilizers are the most used source to supply N in plants, and it is estimated that 48% of the global population are fed by food grown using synthetic N fertilizer (Smil, 2004). Increasing food production while respecting environmental concerns requires efficient use of resources due to finite sources to produce synthetic fertilizers (Fischer et al., 2012). Simultaneously, increasing yields to narrow yield gaps is also essential to supply the increasing food demand. Yield gap for winter wheat (*Triticum aestivum* L.) in Kansas is estimated at c.a. 50% (Lollato et al., 2017), and poor N management are among the leading issues causing the gap (Lollato et al., 2019a; de Oliveira Silva et al., 2020; Jaenisch et al., 2021). Still, simply applying more fertilizer may not be the answer due to increasing environmental concerns. The fertilizer industry developed the 4R Nutrient Stewardship guidelines to improve fertilizer management practices worldwide. The approach includes the Right Rate (i.e., enough amount to maximize production), Right Source (i.e., matching fertilizer to the cropping system and its potential losses), Right Placement (i.e., minimize N losses through more precise application), and Right Timing (i.e., nutrients should be available to match the crop's demand) (Johnston and Bruulsema, 2014).

Around 51% of the winter wheat produced in Kansas is monoculture, and 30 to 44% are grown after soybean (*Glycine max* (L.) *Merrill*) depending on region within the state (Jaenisch et al., 2021). Winter wheat grown after soybean is usually sown after the end of the optimum sowing window, resulting in lower yields likely due to drier soils and fewer degree days accumulation (Munaro et al., 2020; Jaenisch et al., 2021). Crop management practices must be adjusted according to previous crop and sowing date for winter wheat to minimize yield losses due to late sowing (Staggenborg et al., 2003). While information on management adjustments for late sown winter wheat exists in terms of seeding rate and N rate (Bastos et al., 2020; Staggenborg et al., 2003), little is known about adjustments of the entire 4R system under these conditions.

Considering that little is known about the interaction between two of the major factors affecting winter wheat yield in Kansas (i.e., N management and sowing date – as affected by cropping system), the objective of this research was to evaluate the effect of improved N management through manipulation of the 4R and its interaction with common cropping sequences for winter wheat in Kansas.

MATERIAL AND METHODS

Field Set-Up

A rainfed field experiment was conducted during the 2019-2020 and 2020-2021 winter wheat growing seasons at the Agronomy Farm in Ashland Bottoms, northeast KS (fine-silty, mixed, mesic Cumulic Haplustoll). The winter wheat variety Zenda was planted both years with a seeding rate of 90 lbs ac^{-1} when sowed at optimum date and 120 lbs ac^{-1} when sowed after soybean, drilled at 7.5 in row spacing using a 9-row Great Plains 506 no-till drill on 2000 ft^2 plots (40 ft wide x 50 ft long). Diammonium phosphate (DAP 18-46-0) starter fertilizer was used in the plots at 50 lbs ac^{-1} in both years. In the first year, winter wheat was sowed and harvested on October 24 and July 7, respectively. In the second year, the continuous winter wheat cropping sequence was sowed on October 15 (optimum planting date), and winter wheat after soybean was sowed on November 7 (later planting date); both were harvested on June 6. Pests, weeds, and diseases were monitored and controlled regularly so they were not limiting factors in this experiment. The center of each plot was harvested for grain (300 ft^2 area) using a Massey Ferguson XP8 small-plot, self-propelled combine.

Experimental Design

A split-plot design with four replications was conducted with two cropping sequences (whole plot) under two N management (subplot). Crop sequences were continuous winter wheat (Ct-Wt) and double-cropping of winter wheat and soybean (Wt-Sy). Nitrogen management hereafter will be defined as Standard and Progressive. Each N management (standard vs. progressive) differed in application timing (single vs. split N application), placement (broadcast vs. streamer bar applicator), source (the absence [standard] or presence [progressive] of urease/nitrification inhibitors), and N rate (80 lbs ac^{-1} vs. in-season N recommendation based on seasonal conditions).

The standard N management consisted of one single application at Zadoks 30 of 80 lbs ac^{-1} of N (UAN 28-0-0), broadcasted with flat fan nozzles. The progressive N management was a split N application during two wheat growth stages (Zadoks 30 and Zadoks 32) using a more precise applicator (streamer bar) and with the presence of urease and nitrification inhibitors (Centuro, Koch Agronomic Services Co., Wichita, KS 67220, at 23 L per ton of fertilizer; and Agrotain Plus SC, Koch Agronomic Services Co., Wichita, KS 67220, at 14 L per ton of fertilizer) along with UAN (28-0-0). The rate of N applied in the progressive treatment varied year-to-year based on in-season crop forecasting models that informed management decisions using novel cropland observation nodes, through monitoring crop conditions and water balance. In the first year, the progressive N management had two N applications of 40 lbs ac^{-1} of N each, while in the second year, the first application was 40 lbs ac^{-1} of N and 27 lbs ac^{-1} of N in the second application (i.e., 13 lbs ac^{-1} of N less than in the first year).

Measurements & Statistical Analysis

Soil fertility levels were based on the first 0 to 6 in depth with a soil pH of 6, and 14.3 and 317 ppm levels of Mehlich-3 extractable phosphorus and potassium, respectively. Shoot biomass was collected from a representative 2.1 ft^2 plot area before harvest, in which total biomass weight, number of heads, and one seeds size were measured. Weather data was retrieved from weather monitoring station from the Kansas Mesonet (http://mesonet.k-state.edu/) in Ashland Bottoms, KS, which provided precipitation and evapotranspiration (grass ET_o).

Statistical analysis was performed using the PROC GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC). Nitrogen, cropping sequence, and replication were treated as a fixed effect, and years were analyzed separately due to the significant main effect of year. Cropping sequence was not included in the model in the first year as it was the establishment year of the study and crop sequences were not yet in place.

RESULTS

Weather Conditions

The 30-year normal average precipitation during winter wheat growing season (Oct-July) is 26-in in Ashland Bottoms, KS. In this study, total precipitation during winter wheat growing season was historically below average in both years. Precipitation was 22-in and 18-in in the first and second year, respectively. In the second year, the Wt-Sy rotation received 1.5-in less rainfall than Ct-Wt (16.5 vs. 18-in, respectively) because of a later sowing date. Seasonal ET_o was 29-in and 30-in in the first and second year, respectively, except for Wt-Sy rotation, which had a 24.5-in ET_o (5.3-in less than Ct-Wt) in the second year again due to the later sowing date. In both years, water supply was lower than ET_o.

Grain Yield

Grain yield results for the first and second year are shown in Table 1 and 2, respectively. Winter wheat grain yield ranged from 58 to 72 bu ac^{-1} and from 40 to 66 bu ac^{-1} in the first and second year, respectively. Nitrogen management had similar grain yield in the first year (64 and 67 bu ac^{-1} for standard and progressive, respectively), and standard N management had significantly greater yield than progressive in the second year (55 vs. 48 bu ac^{-1}). In the second year, Ct-Wt had greater yield than Wt-Sy (60 vs. 45 bu ac^{-1}).

Biomass, number of heads, and seeds size

Results for the first and second year are shown in Table 1 and 2, respectively. In the first year, N management did not induce differences in shoot biomass, number of heads ft^{-2}, and seeds size. In the second year, only cropping sequence effect was significant on shoot biomass, in which Ct-Wt had greater shoot biomass than Wt-Sy (9700 vs. 7600 lbs ac^{-1}, respectively). In the second year, Ct-Wt and standard N had greater number of heads ft^{-2} than Wt-Sy and progressive N (78 vs. 67, and 80 vs. 66 heads ft^{-2}, respectively). The N management was the only significant effect on seeds size in the second year, in which progressive N had greater seeds size than standard N (16650 vs. 18000 seeds lb^{-1}, respectively).

DISCUSSION

Higher yields in the first year were likely due to greater precipitation than in the second year (>4-in greater) and lower ET_o. In the first year, N management treatments differed in application timing, placement, and absence or presence of N inhibitors, but the total N applied in the crop was the same (80 lbs ac^{-1}). Although there was a numerical advantage to the progressive N treatment when rates were the same (3 bu ac^{-1}), this difference was not statistically significant. In the second year, the total N rate also differed between treatments (80 vs. 67 lbs ac^{-1}). This result shows that, although progressive N management had more precise N application and was less likely to N losses, the total N applied still plays a major role for grain yield response (de Oliveira Silva et al., 2020). The yield component modulated here was number of heads ft^{-2}, likely due to more tiller production and maintenance in the high N treatment, which was clearer when the treatments responses were not different when the same amount of N was applied. Despite higher yields, the standard N management had lower seeds size than progressive. This is common in wheat response to N rate studies, as a greater N rate will lead to more kernels ft^{-2} and thus to a greater proportion of distal kernels that are naturally smaller. This also confirms that heads ft^{-2}, acting as a coarse regulator of wheat yield, influences yield more than kernel weight which is a fine regulator of wheat yield (Slafer et al., 2014). Finally, these results also show that modeling for crop yield forecasting to dictate N rates is very incipient, as clearly recommendations for 67 lbs N ac^{-1} were suboptimal. Because the optimal N rate depends on yield environment (Lollato et al., 2019b), more efforts are needed to improve prediction of yield environment to fine tune N rate recommendations.

The difference in grain yield regarding cropping sequences is likely due to optimum planting date for winter wheat under the Ct-Wt (Thompson et al., 1996), and sowing date has shown to be the most important variables affecting grain yield in the U.S. central Great Plains (Munaro et al., 2020; Jaenisch et al., 2021). On Wt-Sy rotation, wheat is not sowed until soybean harvest, which falls in early November, resulting in a later sowing date for eastern Kansas. Consequently, and the critical period for grain number determination is shortened and grain filling is hastened, which translates into less shoot biomass production (Gastal et al., 2015) and fewer heads ft^{-2}.

CONCLUSIONS

Standard N management had similar results as the progressive N management when the same rate of N was applied to the crop. However, when under higher N rates, the standard management had greater yield, suggesting that, although the application of 4R nutrient guidelines is ideal, there are components within the 4R that play a major role. In this case, N rate trumped N application timing, placement, and source when these were applied at a lower N rate. Grain yield was dictated not by intensifying N application but by the scarcest resource (total N applied). Therefore, N management intensification should be applied only when N rates are appropriate.

Table 1. Effect of nitrogen (N) management on winter wheat grain yield, shoot biomass, number of heads ft^{-2}, and seeds size at Ashland Bottoms, KS, during 2019-2020 growing season.

N management[a]	Yield (bu ac^{-1})	Biomass (lbs ac^{-1})	Number of heads ft^{-2}	Seeds size (seeds lb^{-1})
Standard	64 ± 1†	10900 ± 400	90 ± 4	18000 ± 150
Progressive	67 ± 1	10100 ± 400	81 ± 4	18000 ± 150

† Standard error of the mean;
[a]N-management: Standard (single N-application using broadcasting applicator with the absence of N-inhibitors at 80 lbs ac^{-1} of N); and Progressive (split N-application into two timings using streamer bars with the presence of N-inhibitors at 80 lbs ac^{-1} of N).

Table 2. Effect of nitrogen (N) management and cropping sequence (crop. seq.) on winter wheat grain yield, shoot biomass, number of heads ft^{-2}, and seeds size at Ashland Bottoms, KS, during 2020-2021 growing season.

Crop. seq[a]. > N management[b]	Ct-Wt	Wt-Sy	N mean
	Yield (bu ac^{-1})		
Standard	64 ± 1†	45 ± 1	54.5
Progressive	55 ± 1	40 ± 1	47.5
Crop seq. mean	59.5	42.5	-
	Biomass (lbs ac^{-1})		
Standard	10200 ± 400	8200 ± 400	9200
Progressive	9000 ± 400	7000 ± 400	8000
Crop seq. mean	9700	7600	-
	Number of heads ft^{-2}		
Standard	87 ± 3	73 ± 3	80
Progressive	70 ± 3	62 ± 3	66
Crop seq. mean	78	67	-
	Seed size (seeds lb^{-1})		
Standard	17650 ± 1500	17450 ± 1500	17550
Progressive	16650 ± 1500	17050 ± 1500	16850
Crop seq. mean	25975	17250	-

† Standard error of the mean;
[a]Ct-Wt = continuous wheat; Wt-Sy = double-cropping of winter wheat and soybean;
[b]N-management: Standard (single N-application using broadcasting applicator with the absence of N-inhibitors at 80 lbs ac^{-1} of N); and Progressive (67 lbs ac^{-1} of N split into two timings using streamer bars with the presence of N-inhibitors).

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LENTIL INOCULANT, POTASSIUM, SULFUR, AND MICRONUTRIENT EFFECTS ON YIELD AND PROTEIN IN THE NORTHERN GREAT PLAINS

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ABSTRACT

Lentil (*Lens culinaris* Medikus) is an important crop, averaging more than 600,000 ac in MT and ND from 2016-20. However, relatively little is known about inoculant and fertility response in lentil in the U.S. northern Great Plains. The objective of this experiment was to evaluate the effect of rhizobial inoculant formulations (granular and seed-coat) and nutrient additions (K, S, and micronutrients), on lentil growth, yield, and seed protein. This study was conducted at six or seven university research centers in Montana and North Dakota from 2019-21, resulting in 20 site-yr of data. At the time of this report, yield results were fully available, but seed protein results were available for only 2019-20. Inoculant application increased seed yield by an average of 22% in 6 of 20 site-yr (P<0.05), and protein in 2 of 13 site-yr for an average 1.2 %-unit increase. Inoculant formulations affected seed yield in 5 of 20 site-yr and seed protein in 2 of 13 site-yr, but inconsistently so. Yield was greater for the granular formulation in 3 site-yr, but less in 2 site-yr. Pulse crop history among sites was not highly explanatory to inoculant response in lentil. Sulfur fertilizer (5 lb S ac^{-1}) increased seed yield in 4 of 20 site-yr, by an average of 13% in those site-years. Sulfur fertilizer increased seed protein in 3 of 13 site-yr by an average of 0.6 %-units. Potassium fertilizer affected lentil yield in 2 site-yr, but with equally opposing responses. Neither sulfate-S, nor pre-plant soil test K levels, proved highly predictive of lentil response to fertilizer. Micronutrient application was measured in 12 site-yr and had no effect on lentil yield. This research suggests greater understanding is needed for inoculant response and when and where S fertilization affects lentil yield and protein.

INTRODUCTION

Despite lentil recently becoming an important crop in the U.S. northern Great Plains (Fig. 1), little research has been conducted on best fertility management practices within this region. Since a positive response to P fertilizer has been documented in dry pea within the broader northern Great Plains region (McKenzie et al., 2001; Karamanos et al., 2003), we focused on the remaining macronutrients likely to cause a growth response in our region, K and S. The objectives of this study were to: (1) quantify lentil yield and protein response to rhizobial inoculation with granular vs seed-coat inoculant formulation, and (2) determine if K, S, or micronutrients enhance lentil growth, seed protein and yield.

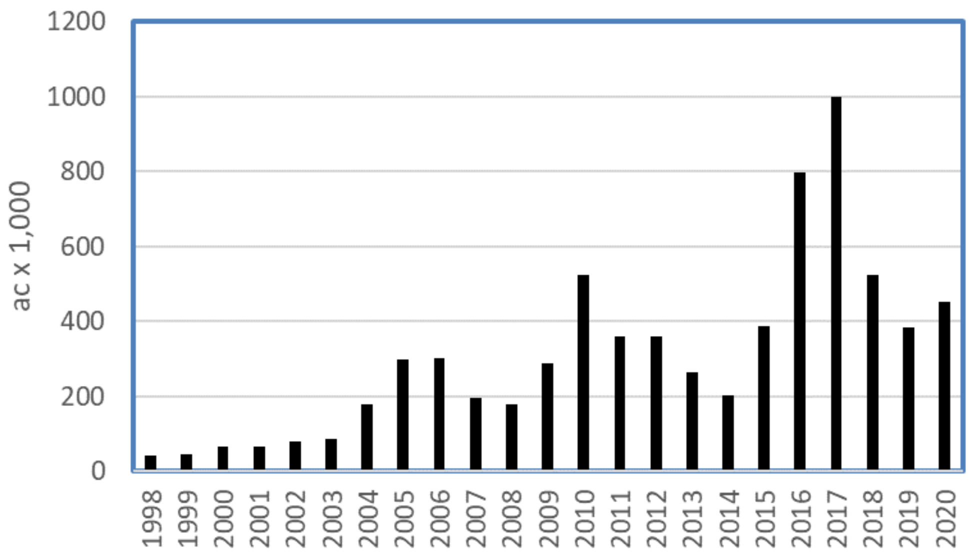

Figure 1. Acreage planted to lentils in Montana and North Dakota, 1998-2020. USDA-NASS 2020.

METHODS

Common experiments occurred at four Montana State University research center locations (Bozeman, Havre, Moccasin, and Sidney) and two or three North Dakota State University research center locations (Carrington, Hettinger, and Minot) from 2019 to 2021. Only 5/20 field sites had no pulse crop history, and another 5/20 sites had grown pulse crops more than 10 yr prior. It was presumed that K would be generally sufficient at all sites (i.e. > 250 ppm); however, the mean K content in the top 6 inches of soil was in the 200-250 ppm range at Moccasin in 2020, and in all 3 yr at Sidney, and was < 150 ppm in both years at Carrington (in 2020, lentils failed to establish). All sites were soil-tested with the aim of finding S-responsive field sites, which was not always possible, especially considering our low level of understanding with respect to measurement of critical S content in soils. The Bozeman sites generally had low soil sulfate-S levels in the top 2 ft, while Havre, Hettinger, Moccasin, and Sidney varied from low to high soil S levels among years, and Carrington and Minot had generally high soil S levels. All sites except Carrington (tilled system) were direct-seeded in cereal stubble, with a popular medium-sized green lentil cultivar (*Avondale*) grown from a common seed source. Soil nitrate-N content in the top 2 ft was consistently low at Bozeman and Sidney, and varied from low to medium among years at the remaining sites. The experimental design was a randomized complete block with eight treatments and five replicate blocks.

Treatments consisted of contrasting peat-based inoculant formulations (granular and seed-coat) with combinations of KCl, K_2SO_4, and a micronutrient fertilizer application (Table 1). Both rhizobial inoculant peat-based formulations were sourced from *Verdesian Life Sciences* (Cary, NC). Granular inoculant application varied from 4.4 to 6.1 lb ac^{-1} (1×10^{8} CFU g^{-1}) in the seed furrow while the seed-coat formulation was applied at 0.31 lb per 100 lb of seed (2×10^{8} CFU g^{-1}). *Micro 1000* (*AgroLiquid*, St. Johns, MI) contains a combination of seven micronutrients essential for plant growth plus cobalt. Although *Micro 1000* contains S, the application rate of S was about 0.3 lb ac^{-1}, and hence we call this a micronutrient solution hereafter. In 2019, *Micro 1000* was applied at well above label rates to increase the chance for a response, but this caused foliar tissue damage, and so data were omitted from 2019 analyses.

Table 1. Lentil fertility treatments.

Treatment	Fertilizer Source	Fertilizer Rate	K_2O	S
		------------- lb ac^{-1}	-------------	
1. Control	-	-		
2. Granular inoculant	-	-		
3. Seed-coat inoculant	-	-		
4. Granular with K	KCl	25.0	12.5	
5. Seed-coat with K	KCl	25.0	12.5	
6. Granular with K+S	Potassium sulfate	30.0	12.5	5.0
7. Seed-coat with K+S	Potassium sulfate	30.0	12.5	5.0
8.Granular+K+S+Micro1000[a]	Potassium sulfate + *Micro1000*	30.0	12.5	5.0

Note. Mono-ammonium phosphate (11-52-0) was used at planting at a rate of 45 lb ac^{-1} to supply 23 lb P_2O_5 ac^{-1} to all treatments, except at Moccasin in 2020.
[a] Micro1000 was applied at first flower at 32 oz ac^{-1}.

The seeding rate at all sites targeted 11 plants ft$^{-2,}$ resulting in seeding rates of 55 - 67 lb ac^{-1} among years. At planting, control plots without inoculant were seeded first, then all treatments containing granular inoculant, and then lastly treatments containing seed-coat inoculant. Treatments with the micronutrient foliar application were applied at late bud or early flowering stage with a backpack sprayer.

All plots were harvested with a combine and lentil seeds were then cleaned and weighed to determine yield. The N concentrations of all 2019 and 2020 grain samples were measured by a Kjeltec 2003 Analyzer Unit (Foss Analytical, Hilleroed, Denmark), except at Bozeman in 2020, lentil grain samples were measured by automated dry combustion analysis (LECO Corp., St. Joseph, MI). A conversion factor of N × 6.25 was used to report ‘protein’ (Coyne et al., 2005). Statistical analyses were conducted with *JMP8*, using a general linear model design, suitable for fully balanced designs. Each site-year was analyzed independently to determine site-specific responses. Linear orthogonal contrasts were used to answer four research questions:

(1) If inoculant (Control vs. Granular, Seed-coat) had an effect when other fertilizer treatments are not present;
(2) If inoculant types (Granular vs. Seed-coat) had an effect, regardless of other fertilizer treatments;
(3) If K had an effect, regardless of rhizobial inoculant;
(4) If S had an effect, regardless of rhizobial inoculant or K fertilizer
The cutoff P-value for declaring a significant effect was 0.05, meaning there is a 5% chance that differences occurred due to chance.

RESULTS AND DISCUSSION

In this study, lentil yielded an average of 1650 lb/ac across 20 site-yr, ranging from a low of <600 lb ac^{-1} at Moccasin in 2021 to two sites that had trial averages of 2610 lb ac^{-1} (Bozeman 2019 and Moccasin 2020). In 2020, lentil yielded an average of 2300 lb ac^{-1} across all sites, while in the widespread drought of 2021, the cross-site average yield was only 1100 lb ac^{-1}. Without the benefit of any formal multi-site analysis, Carrington appeared most dissimilar from the other six sites, posting the lowest ranking yield in the generally wet year of 2019, and the highest yield in droughty 2021.

Inoculant Response

Six of 20 site-yr showed a positive response to rhizobial inoculation, with an average yield increase of 344 lb ac^{-1} at those sites (Table 2). There were zero negative responses. The largest site response occurred in 2019 at Sidney, MT, where the control yielded 50% of the average of the two rhizobial inoculant formulations. At three of the responsive sites, pulses had not been grown before (Sidney 2019, Hettinger 2020, Havre 2021) and at a fourth site (Havre 2019) it is suspected that the only pulse crop grown 3 yr prior was uninoculated. However, positive responses were also observed at Bozeman in 2019 on a site with frequent pulse crop history, and at Moccasin in 2020, where pulses had been grown in 2014. Thus, presence or absence of pulse crop history was not highly explanatory. The effect of inoculant formulation, as applied, was significant at 5 of 20 site-yr. The peat powder seed coat formulation induced higher lentil yields in 2 site-yr, by an average of 107 lb ac^{-1}, while the peat granular soil-applied formulation induced higher lentil yields in 3 site-yr, by an average of 440 lb ac^{-1}. The single most remarkable response occurred at Sidney in 2019 where peat granular inoculant induced yields that were 1110 lb ac^{-1} greater than with seed coat inoculant.

Table 2. Frequency of treatment effects amid 20 site-yr and mean lentil yield response (lb ac^{-1}) for each condition. nd = No Data.

	Ctrl < Inoc	Ctrl = Inoc	Ctrl > Inoc
Frequency	6	14	0
Control	1531	1538	nd
Inoculant	1875	1571	nd
	Gran < SC	Gran = SC	Gran > SC
Freqency	2	15	3
Granular	1619	1547	2261
Seed coat	1726	1552	1821
	K < No K	K = No K	K > No K
Frequency	1	18	1
K	2183	1648	1336
No K	2388	1645	1252
	S < No S	S = No S	S > No S
Frequency	0	16	4
S	nd	1555	2266
No S	nd	1569	2011

Fertilizer Response

Potassium fertilizer increased lentil yield in 1 site-yr and decreased yield in 1 site-yr. The positive response to K was observed at Sidney in 2019, with a mean soil test value of 214 ppm. However, a negative response was observed at Carrington in 2021 with a low mean soil test value of 155 ppm. Sulfur fertilizer showed greater crop response, increasing lentil yield in 4 site-yr by an average of 255 lb ac^{-1}, with zero negative responses. Bozeman had generally low pre-plant soil sulfate-S levels but the S treatment increased lentil yield only in 2020. Notably, N_2-fixation was increased by 30 lb N ac^{-1} in 2020 at Bozeman (Baber et al. 2022). Three other positive S responses occurred at sites where mean soil sulfate-S levels in the top 2-ft of soil were sufficiently high (i.e. Moccasin 2020 = 10.5 ppm, Sidney 2021 = 3.9 ppm, and Carrington 2021 = 5.6 ppm), such that a crop response would not be expected. At Minot in 2019 and 2021, soil-test sulfate-S levels tested high out of measurement range, and yet no negative crop response occurred. Since several positive yield responses were induced by an inexpensive 5 lb S ac^{-1} fertilizer addition it is tempting to recommend this practice broadly. However, further research is needed to make reliable S recommendations for lentil based on soil test values. No effect was observed from micronutrient application.

Lentil Seed Protein

Judging from the 2019-2020 data, protein responses were less frequent than yield responses, and related mainly to presence/absence of rhizobial inoculant and S fertilizer application. Seed protein was increased by inoculation at 2 of 13 site-yr by an average 1.2 %-unit. Seed protein was increased by S fertilizer at 2 of 13 site-yr, but decreased at 1 site-yr.

CONCLUSION

Rhizobial inoculant increased lentil yields at 30% of our site-years, but without clear relation to previous pulse crop history. Peat granular inoculant formulation increased lentil yield over the peat powder seed coat formulation at 15% of our site-years, once remarkably (Sidney 2019), but also reduced lentil yields at 10% of our site-years compared with the seed coat formulation. A low rate of S fertilizer (5 lb ac^{-1}) increased lentil yield markedly at 20% of our site-years, but seemingly without regard to pre-plant sulfate-S levels in the top 2 ft of soil. A focused and well networked research effort is needed to more fully understand the potential benefits of S fertilizer for lentil yield.

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NITROGEN RESPONSE TO 2-ROW BARLEY IN NORTH DAKOTA

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ABSTRACT

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

INTRODUCTION

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

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

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

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

METHODS AND MATERIALS

Site Descriptions

These experiments were conducted over two growing seasons; 2020 and 2021, with two experimental sites each year. In total, four site-years of data were generated at locations in Grand Forks and Barnes Counties in North Dakota. The experiments were located 3 miles southeast of Valley City (VC) and near Logan Center (LC), which is about 10 miles WNW of Northwood. The soil at the VC 2020 site was dominated by Swenoda soils; the 2021 site consisted of Barnes loams (Soil Survey Staff, 2020). The Valley City site has been managed under no-till production for 40^{+} years with the previous crop of the 2020 season being sunflower and previous crop for the 2021 season was corn. At the LC site, the soils in 2020 and 2021 were Barnes loams (Soil Survey Staff, 2020). The LC site was only recently transitioned to a no-till system (< 5 years ago). The previous crop on this site was dry bean (pinto bean) in 2020 and 2021.

Experimental Design

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

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

Crop Management

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

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

Data Collection and Analysis

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

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

RESULTS AND DISCUSSION

Grain Yield and Quality

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

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

Table 1. N rate means combined across varieties and environments.

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

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

Total Known Available N

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

Optimum Nitrogen Rate

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

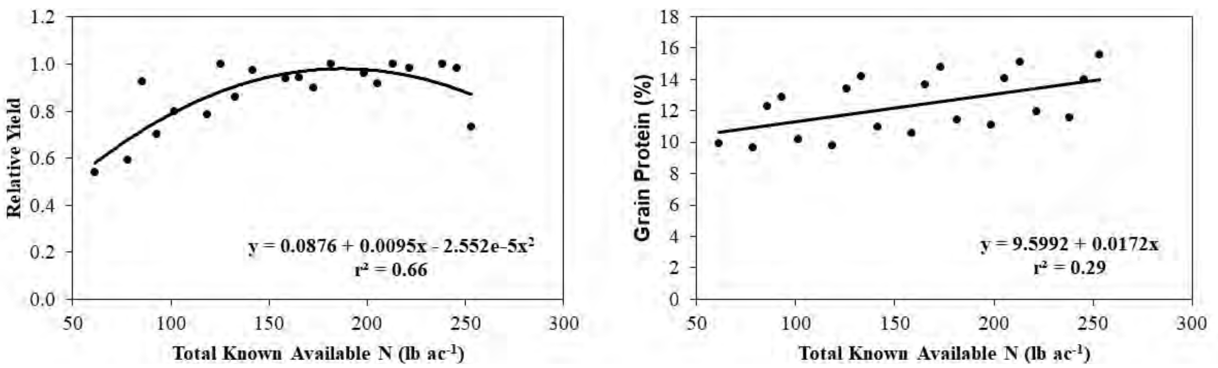

Figure 1. Left: Relative yield data averaged across reps and varieties compared to TKAN, fitted with a quadratic trendline. Right: Grain protein averaged across replications and varieties compared to TKAN fitted with a linear trendline.

CONCLUSION

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

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

ACKNOWLEDGEMENTS

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CO-LIMITATION OF NITROGEN AND SULFUR IN HARD RED WINTER WHEAT

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ABSTRACT

Quantifying the interactions of nutrients in wheat production are essential to reduce the yield gap. Nitrogen and S deficiencies (individually or in combination) reduce wheat yields and increase the yield gap. Our objectives were to quantify the colimitation of N and S in wheat in Kansas. We established an experiment with three N rates (50, 100, and 150% of the N required for an yield goal of 60 bu/a), four S rates (0, 10, 20, and 40 lb S/a), and three genotypes (LCS Mint, SY Monument, and Zenda) in a split-split-plot design across eight Kansas environments distributed on three growing seasons. Grain yields ranged from 12 to 86 bu/a across treatment combinations and environments. Grain yield increased with increasing N rate at all locations (2 to 13 bu/a), while the addition of S increased grain yield at two locations (up to 40 bu/a). Increasing N rates decreased N use efficiency (NUE), and similar results occurred for S. However, S applied at 10 lb/a increased SUE in environments where soil-S content at sowing was limiting. The co-limitation analysis suggested that the optimal N:S ratio for grain was 17.3. Through a field study conducted in eight environments, we demonstrated that N and S interact in the determination of wheat yield and nutrient use efficiencies, and an optimum N:S ratio that decreases the yield limitation by either nutrient exists.

INTRODUCTION

At historical time scales, N has been the most limiting nutrient to crop yields; thus, N fertilizer management has been extensively researched (e.g., Jaenisch et al., 2019; Lollato et al., 2019; 2021). Nitrogen use efficiency (NUE) is the grain yield per unit of available N, and is determined by N uptake efficiency (i.e., the ratio between N uptake and N available) and N utilization efficiency (i.e., the ratio between yield and N uptake) (Moll et al., 1982). NUE is affected by agronomic management, of particular importance to the current study, the availability of other nutrients such as sulfur (S).

Positive agronomic responses in commercial crops to the addition of S fertilizer seem to be more apparent in recent years (Girma et al., 2005; Camberato and Casteel, 2010) due to the decline in organic matter in cultivated soils (Lollato et al., 2012) and the decrease in S dioxide deposition in the rainfall (Ceccotti, 1996). Sulfur is also an essential element to crops, playing variety of roles within the plant (Duke et al., 1986) thus S deficiency can reduce yield (Salvagiotti and Miralles, 2008).

In wheat, S seems to interact with N to determine NUE by impacting soil N recovery rather than increasing N utilization efficiency (Salvagiotti et al., 2009). Sulfur allowed for the production of more shoot biomass which increased root biomass and for greater soil exploration and uptake of N (Salvagiotti et al., 2009). Despite these previous efforts to untangle N and S impacts on wheat performance, to our knowledge, there have been no attempts to understand this interaction from a co-limitation perspective (Sterner and Elser, 2002). Because N and S seem to limit wheat yield in commercial Kansas wheat fields (Jaenisch et al., 2021), our objective was to determine N and S limitation effects on the nutrient use efficiencies and yield on wheat.

MATERIALS AND METHODS

Experimental locations and agronomic management

Field experiments were established in eight Kansas environments (E) resulting from the combination of locations and years. These were Ashland Bottoms during the 2018-19 and 2019-20 winter wheat growing seasons (Belvue silt loam soil); Belleville during the 2017-18 and 2019-20 winter wheat growing seasons (Crete silt loam soil); Manhattan during the 2017-18 season (Kahola silt loam soil); Hutchinson during the 2018-19 and 2019-20 seasons (Funmar-Taver loam soil); and Viola during the 2019-20 season (Milan loam soil). All experiments were conducted under rainfed conditions.

Winter wheat was sown using no-tillage practices following a previous soybean crop at all environments. Plots were seven 7.5-inch spaced rows by 30 ft long. Foliar fungicide was applied at anthesis at all locations so that disease incidence was not a confounding factor. Wheat was harvested using a small-plot Massey Ferguson 8XP combine and grain yield was corrected for 13.5% moisture.

Treatment structure and experimental design

The experiment was arranged in a 3 × 3 × 4 split-split-plot design with four replications. Three wheat genotypes (G) were assigned to whole plots, three N rates were assigned to sub-plots, and four S rates were assigned to sub-sub plots. The three genotypes were SY Monument, LCS Mint, and Zenda. Nitrogen was applied as urea ammonium nitrate (28N-0-0) and rates consisted of 50%, 100%, and 150% of KSU recommendations for a 60 bu/a yield goal. The actual amount of N applied depended on the initial soil NO_3-N in the 0-60 cm profile and ranged from 43 to 73 lb N/ac in the 50% yield goal, and from 110 to 198 lb N/ac in the 150% yield goal. Sulfur was applied as ammonium thiosulfate (12-0-0-26S) at 0, 10, 20, or 40 lb S/a. A pressurized CO_2 backpack sprayer was used to apply treatments at spring greenup.

Calculations and statistical analyses

The N and S use efficiencies were calculated using the definitions provided by Gastal et al. (2015), which takes into account the soil nutrient available at sowing plus the nutrient from applied fertilizer. A limitation in this nutrient use efficiency calculation is that it does not account for the contribution of N and S from the mineralization of soil organic matter during the growing season, potentially overestimating nutrient use efficiency. The N:S ratio were calculated in the wheat grain.

Analysis of variance was performed using “lmerTest” in R software version 3.4.0. Genotype, N rate, S rate, environment, and their interactions were considered fixed effects, while block nested within environment, and genotype nested within block, N rate nested within genotype, S rate nested within N rate were random effects (the latter accounted for the split-split-plot design). For the N:S stoichiometry, a linear-linear model was built using the “segmented” package to determine when either N or S were limiting in the wheat grain.

RESULTS

Across all environments, genotypes, and N and S rates, grain yield ranged from 12 to 86 bu/a with significant three-way interactions for E × N × S, E × G × N, and E × G × S. Increased N increased yields in all environments from 1.5 to 14 bu/a (Figure 1). This benefit of N rate to yield depended on S rate in three environments (AB19, AB20, Sum20) where the presence of S increased grain yield in as much as 40 bu/a. The E × G × N interaction was due to the genotype Zenda yielding the least in six environments at the lowest N rate, and yielding the highest as N rate increased in three environments.

Nitrogen use efficiency varied across environments and treatments (Figure 2). Interactions occurred for NUE among E × N × S and among E × G × S. The average NUE for each N rate across all S rates and environments was 25, 21, 17 lb/lb for the 50, 100, 150% N rate, respectively. Increasing N rate decreased NUE at all environments. In six locations, NUE decreased from 24 to 17 lb/lb as N rate increased from 50% to 150%. In two locations (AB19 and AB20), the zero S rate had significantly lower NUE as compared to treatments receiving a S application. In three environments (Bel18, Bel20, and Sum20), Monument and Mint resulted in a higher NUE than Zenda. Similarly to NUE, three-way interactions among E × N rate × S rate and E × G × S rate occurred for SUE (Figure 3). Across environments, the zero S rate resulted in the greatest SUE which ranged from 73-228 lb/lb, while the 40 lb S/a resulted in the lowest SUE (range: 36-82 lb/lb). The only exception was ASB19, where the addition of 10 lb S/a increased SUE as compared to the zero S rate by 18 and 24 lb/lb for the 100 and 150% N rates. In five environments, the addition of N increased SUE anywhere within the same S rate.

For N and S limited conditions, wheat yield increased with N:S until reaching the 95% maximum value at 17.3 (CI: 17.1-17.5) for the grain, decreasing afterwards ($p<0.001$; R^2=0.65).

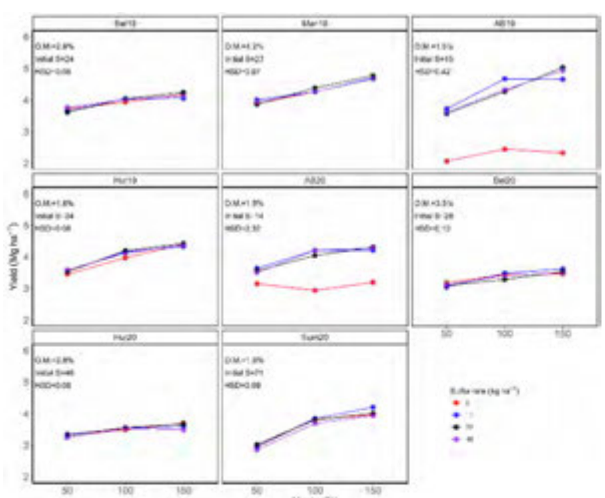

Figure 1. Average winter wheat gain yield affected by N rate (50, 100, and 150%), S rate (0, 10, 20, and 40 lb S/a), and environments (Bel18, Man18, AB19, Hut19, AB20, Bel20, Hut19, and Sum20). The Honest Significant Difference was calculated within

each environment. Soil samples were taken before sowing to determine organic matter (%) and initial plant available S at sowing (kg ha^{-1}).

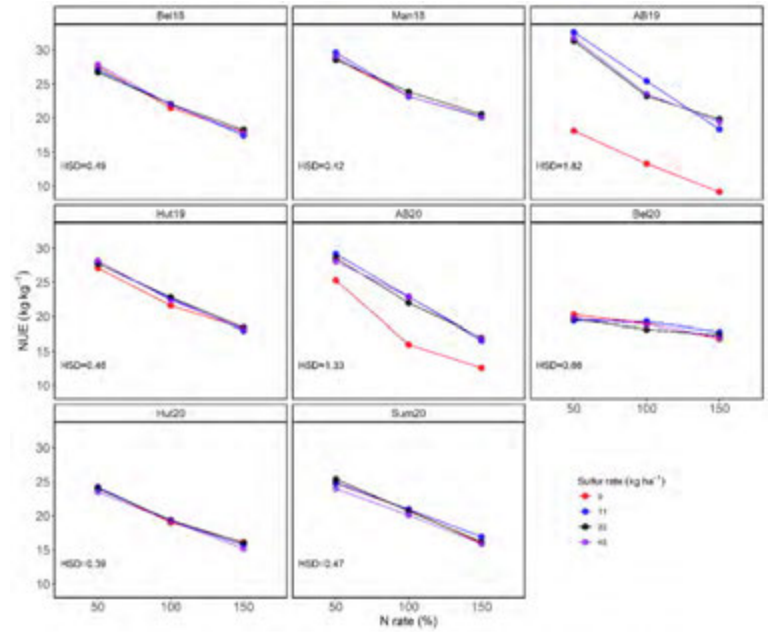

Figure 2. Mean nitrogen use efficiency (NUE) as affected by N rate (50, 100, and 150%), S rate (0, 10, 20, and 40 lb S/a), and environment (Bel18, Man18, AB19, Hut19, AB20, Bel20, Hut20, and Sum20). The Honest Significant Difference was calculated within each environment.

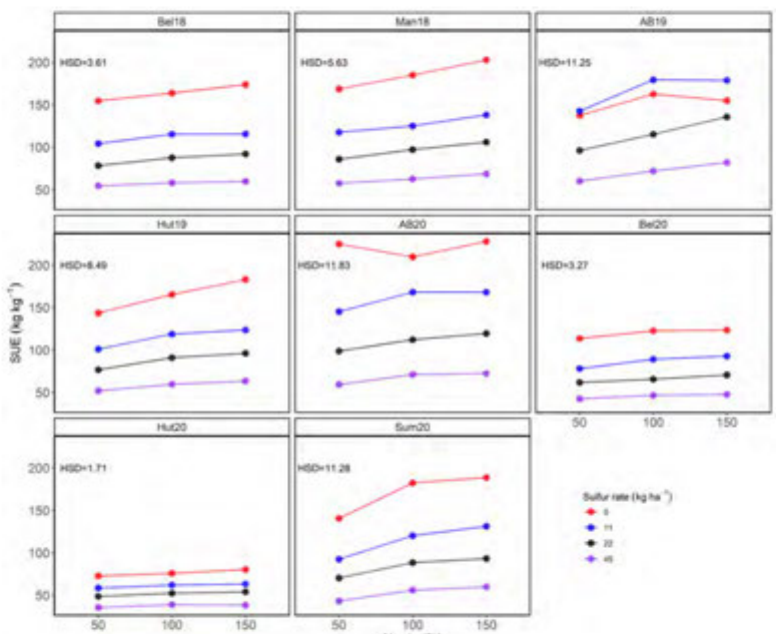

Figure 3. Mean sulfur use efficiency (SUE) as affected by N rate (50, 100, and 150%), S rate (0, 10, 20, and 40 lb S/a), and environment (Bel18, Man18, AB19, Hut19, AB20, Bel20, Hut20, and Sum20). The Honest Significant Difference was calculated within each environment.

Discussion

The range in wheat yield under the experimental conditions evaluated was similar to that reported in this region (Cruppe et al., 2021; Jaenisch et al., 2019; Perin et al., 2020). Wheat grain yield increased linearly with increases in N rate at all locations; however, the presence of S was only significant in two locations. The soil in these two environments were inherently low in plant available S at sowing (<20 kg S ha^{-1}) and had low organic matter (<1.8%) and applications of 10-20 lb S/a maximized yields. Similarly, Ramig et al. (1975) suggested that plant available S at sowing was sufficient at 17 kg S ha^{-1}, and Girma et al. (2005) suggested that yield responses to S fertilizer application are more likely to occur on low organic matter (<2%), coarse textured soils. In the remaining environments with greater soil S available at sowing and/or organic matter content, yield response to S fertilization was not expected.

Increases in NUE and SUE either derive from improved fertilizer recovery or internal efficiency in utilizing the uptake N and S (Salvagiotti et al., 2009). Proposed mechanisms include 1) N and S fertilization increased root growth and the larger explored rooting area allowed for greater uptake of N and S (Salvagiotti et al., 2009), and 2) N and S fertilization increased crop growth consequently increasing the demand of nutrients. Our findings of a N:S ratio of 17.3 in the grain are similar to what has been reported in the literature (Randall et al., 1981; Byers et al., 1987). In S deficient soils, the N:S ratios can be as high as 20:1 or as low as 12:1 which is the minimum N requirement (Camberato and Casteel, 2010). Grain N:S ratio offer a great opportunity to check for nutrient deficiencies at the end of a season (Randall et al., 1981).

CONCLUSIONS

While N and S interacted in the determination of wheat yield, impacting wheat NUE and SUE; the impact of S application was only apparent in coarse textured soils with low organic matter content. This suggests the need for judiciously management of S in winter wheat systems of Kansas. The colimitation approach presented here suggested that wheat yields maximized when N:S ratio in the grain approached 17.3.

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SPATIAL VARIABILITY IN PROFILE SOIL NITRATE, NUTRIENT UPTAKE, GRAIN YIELD, AND NUTRIENT REMOVAL IN A COMMERCIAL DRYLAND GRAIN SORGHUM FIELD

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ABSTRACT

Established relationships exist that describe the confidence interval around a soil test value as a function of cores in the sample for nutrients such as phosphorus. This information is useful for developing economically and agronomically optimal soil sampling strategies. Residual soil nitrate can be a significant source of a crops N needs in dryland cropping systems where N loss is minimal. A common question among producers and consultants is how many profile N cores are required to obtain a reasonable field level estimate of profile N. A field-scale trial was established in a production field of dryland grain sorghum in Northwest Kansas in 2021. Profile soil nitrate was measured prior to planting to a depth of 24” on a 1-acre grid pattern. Biomass accumulation and nutrient update were measured on the same 1-acre grid pattern at V5, G6 (flowering), and physiological maturity. Grain yield and harvest index were measured on the 1-acre grid at physiological maturity via hand harvest as well as across the entire study area using a commercial combine equipped with a calibrated yield monitor system. This presentation will present initial findings of this project with specific emphasis on the spatial variability in profile soil nitrate and the implications to effective soil sampling strategies for determining average profile nitrate levels at the field scale. Additional data exploration will evaluate relationships between yield and nutrient update.

WINTER WHEAT RESPONSE TO ENCHANCED EFFICIENCY FERTILIZERS IN THE CANADIAN PRAIRIES

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ABSTRACT

Optimal nitrogen (N) management can improve agronomic efficiency, and increase winter wheat (*Triticum aestivum* L.) grain yield and protein content. Two experiments were conducted to measure the responses of winter wheat to enhanced efficiency N fertilizers and timing/placements across the Canadian Prairies. Experiment 1 consisted of uncoated urea, urea+nitrification inhibitor (urea+eNtrench®), urea+urease and nitrification inhibitors (SuperU®), and polymer-coated urea (Environmentally Smart Nitrogen®, ESN®). Nitrogen fertilizers were either all side-banded at planting, 30% side-banded at planting + 70% broadcast in-crop in late-fall, or 30% side-banded at planting + 70% broadcast in-crop in early-spring. Experiment 2 compared uncoated urea, urea ammonium nitrate, UAN+nitrification inhibitor (UAN+eNtrench®), UAN+urease inhibitor (UAN+Agrotain Ultra®), UAN+urease and nitrification inhibitors (UAN+Agrotain Plus®), and a 50%-50% mix of ESN® and urea (ESN®/urea). All N sources were 50% side-banded at planting and 50% broadcast in-crop in early-spring. SuperU® and UAN+Agrotain Ultra® split-applied in early-spring produced superior grain yield and N utilization over all other N sources either all applied at planting, split-applied in late-fall or in early-spring. All N sources produced 6.6-9.4% higher grain protein content than the controls, in particular for SuperU®, ESN® and UAN+Agrotain® split-applied in early-spring. The results suggest that split applications of enhanced efficiency N fertilizers is efficient for winter wheat grain yield and protein optimization particularly when the fertilizer includes urease inhibitor or urease and nitrification inhibitors and the majority of N is applied in early-spring.

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) sustainably requires more N supply to maintain high grain yield and protein levels than spring wheat because of its long duration of the vegetative growth stage. However, more N supply has adverse impact on environment due to excessive N will result in significant ammonium emission, denitrification, N leaching and runoff. In addition, winter wheat production includes a period of vegetative dormancy that is characterized by low N requirements during the winter time. The dormant vegetative period and low N requirements will increase the risk of N loss. Optimized N rate, timing and placement or usage of slow/controlled-release fertilizers would be effective strategies to reduce the adverse impact of N on environment. Enhanced efficiency fertilizers (EEF) have coatings that slowly release N, or include additives in their formulation that temporarily reduce urease activity or nitrification rates in soil (AAPECO 2013), and therefore can slow down urea hydrolysis and nitrification process and subsequently synchronize with crop demand. Split N-application is commonly used to harmonize winter wheat N supply with crop demand. Beres et al. (2018) reported that N split-applied at planting and in the spring was most efficient for winter wheat grain yield and protein optimization when combined with an enhanced efficiency urea product under a high-yielding environment.

The objectives of this research are to investigate how fertilizer best management practices, nitrification inhibitors, urease inhibitors, and controlled-release N impact crop N use in dryland winter wheat production systems in the Canadian Prairies.

MATERIALS AND METHODS

Two experiments were conducted at locations representing major dryland agroecosystems across the Canadian Prairies, i.e. Lethbridge, AB, Falher, AB, Indian Head, SK, and Brandon, MB, from 2013 to 2017 with a new site established at each location every year. Besides one dryland site, Lethbridge location also includes an irrigated site. Sites were previously planted with canola (*Brassica napus* L.) except for the Brandon, MB, location in 2013-2014 in Experiment 1, where barley (*Hordeum vulgare*) was previously cropped. A randomized complete block design with four replicates was used for both experiments. Soil nutrient availability were obtained at each site before planting. The N rates were determined based on 80% of the recommended rates targeting a yield of 80 bu ac^{-1}. AC Flourish, a CWRW milling quality variety of winter wheat was used for both experiments.

The treatments in experiment 1 consisted of a factorial arrangement of 14 N management with different N sources and application time/placements. The N sources included: uncoated urea (46-0-0; referred as urea thereafter), urea+nitrification inhibitor (urea+eNtrench®), urea+urease and nitrification inhibitors (SuperU®), and polymer-coated urea (Environmentally Smart Nitrogen®, ESN®). Nitrogen fertilizers were either all side-banded at planting, 30% side-banded at planting + 70% broadcast in-crop in late-fall, or 30% side-banded at planting + 70% broadcast in-crop in early-spring. The N management treatments also included two zero-N controls (one with phosphorus, potassium and sulphur fertilizers applied at the recommended rates based on soil test results; and one with phosphorus only at the recommended rate).

Six N management treatments with different N sources and application timing/placements were used in experiment 2. The N sources included: 1) urea, 2) urea ammonium nitrate (UAN; 28-0-0); 3) UAN+nitrification inhibitor (UAN+eNtrench®), 4) UAN+urease inhibitor (UAN+Agrotain Ultra®), 5) UAN+urease and nitrification inhibitors (UAN+Agrotain Plus®), and 6) ESN® applied at planting + urea applied in-crop. All N were 50% applied at planting (side- or mid-row-banded) and 50% applied in-crop at Feekes 4. The 7th N management treatment is zero-N control (with phosphorus, potassium and sulphur fertilizers applied at the recommended rates based on soil test results).

Herbicide was applied at each site 24-48 hours prior to seeding and in-crop when the average weed growth was the 3-5 leaf stage around mid-October and in spring. Winter wheat was seeded with a ConservaPak™ air drill configured with knife openers spaced 9 or 12 inch apart. The crop was sown at a rate of 45 seeds ft^{-2}, with a target plant density of 34 plants ft^{-2}. Plots were harvested with a plot combine. Grain yield was calculated and corrected to 13.5% moisture. A 4 lb sub-sample was retained to characterize whole grain protein concentration using near infrared reflectance spectroscopy technology (Foss Decater GrainSpec, Foss Food Technology Inc., Eden Prairie, MN).

Three adjacent 2-feet row subsections were harvested in each plot near physiological maturity for straw and grain N determination. Straw and grain N concentration were determined by the Kjeldahl procedure (AACC International 2018). Straw N content (lb ac^{-1}) was calculated by multiplying the %N by the straw biomass (lb ac^{-1}, corrected to 0% relative humidity). Grain N content (lb ac^{-1}) was calculated by multiplying the %N by the grain biomass (lb ac^{-1}, corrected to 0% relative humidity). Total N uptake (lb ac^{-1}) represents the N in aboveground biomass and is the sum of straw N and grain N. Apparent crop recovery efficiency (RE) is the N uptake increase (lb) per lb N applied, which was calculated by the equation below (Fixen et al. 2015):

$$RE = \frac{NF - NC}{NR}$$

where NF (lb N ac^{-1}) is total N uptake in a N fertilized treatment, NC (lb N ac^{-1}) is total N uptake of the control, and NR is N application rate (lb N ac^{-1}). Agronomic efficiency (AE) represents the yield increase (lb) per lb N fertilizer applied, and was calculated by the equation below (Fixen et al. 2015):

$$AE = \frac{Y - Y_0}{NR}$$

where Y is grain yield (lb ac^{-1}) in a N fertilized treatment, Y_0 is the grain yield (lb ac^{-1}) of the control, and NR is N application rate (lb N ac^{-1}).

Data analysis was performed using the SAS platform (Littell et al. 2007; SAS Institute 2011). Homogeneity of error variance was tested using the PROC UNIVARIATE procedure and any outlier observations were removed. Data were analyzed using a two-factor MIXED model and a one-factor MIXED model, respectively, for Experiment 1 and Experiment 2. Nitrogen sources, placements, and N source by placement interactions were treated as fixed effects, and site (combinations of years and locations) and site by treatment (combinations of site by N source and placement for Experiment 1 and site by N source in Experiment 2) were treated as random effects. Effects were considered significant if $p \leq 0.05$.

RESULTS AND DISCUSSION

A notable influence of N source and placement on winter wheat grain yield, protein content and grain N uptake was observed in experiment 1 (Tables 1 and 2). Yields were highest when all N was banded at planting and lowest when N was split-applied in late-fall. Our results in Experiment 1 were in agreement with Adams et al. (2018) and McKenzie et al. (2010) who reported that all N banded at planting produced the highest winter wheat grain yield and grain protein. In this study, banding all N at planting increased grain N by 4.9% relative to a split application in late-fall ($p<0.05$). This may be an indication that banding all N at planting provided plant health benefits resulting in improved abiotic resistance and less winterkill (Beres et al. 2018).

Table 1. Mean responses of yield and protein related variables and agronomic performance to N source and timing/placements in Experiment 1 conducted in MB, SK, and AB, Canada, from 2013 to 2017

Treatment	Grain yield	Protein content	Grain-N	Total N uptake	RE†	AE‡
	Bu ac^{-1}	%	lb N ac^{-1}	lb N ac^{-1}	lb lb^{-1}	lb lb^{-1}
N Source						
Control PKS§	50.6	10.6	72.0	88.4	0.0	-0.7
Control P	43.6	10.0	57.4	83.0	0.0	0.0
ESN®	63.3	11.3	92.5	122.7	0.2	4.1
Urea+eNtrench®	64.7	11.1	93.3	124.5	0.2	4.5
SuperU®	65.7	11.3	96.4	129.3	0.2	4.8
Urea	64.5	11.2	93.4	124.3	0.2	4.1
LSD 0.05	0.1	1.6	2.8	NS	NS	NS
Placement						
100% banded at planting	66.0	11.3	96.0	129.8	0.3	4.7
30% banded/70% in-crop late-fall	63.3	11.1	91.6	122.2	0.2	3.9
30% banded/70% in-crop early-spring	64.2	11.3	94.1	123.7	0.2	4.5
LSD 0.05	0.1	1.4	2.4	4.9	0.0	0.6
p-values						
Fixed effects						
N source	0.011	0.016	0.014	0.065	0.149	0.123
Placement	<0.001	0.001	<.001	0.002	0.005	0.022
N source × placement	0.039	0.975	0.164	0.299	0.758	0.736
Random effects						
Site	0.002	0.002	0.002	0.018	0.090	0.041
Site × treatment¶	<.001	<.001	<.001	<.001	<.001	0.002

† RE = recovery efficiency; ‡ AE = agronomic efficiency
¶ Treatment is combined N source × placement

Significant N source by placement interactions were detected for grain yield. urea+eNtrench® and SuperU® all banded at planting and SuperU® split-applied in early-spring provided the greatest grain yield (Table 2). In the split application regimes, banding small portion of N at planting ensured N availability in soil to support vegetative growth before spring. Nitrogen requirements increase in spring as winter wheat breaks dormancy, actively begins 'green-up' and more N need to be allocated to protein production at booting and flowering stages (Knott 2016; Wuest and Cassman 1992). Therefore, winter wheat tend to be benefited from spring applied N. Campbell et al. (1988) and Gan et al. (2000) have reported that the effect of N application on spring and winter wheat grain yield and protein content depends on environmental conditions, primarily moisture and temperature. In this study, most of the precipitation occurred in the spring and summer at all sites. The co-occurrence of available moisture, warm temperature and N split-applied in early-spring promoted relatively higher grain and protein production compared to N split-applied in late-fall.

All N sources produced 5-13% higher grain protein content than the controls. SuperU®, ESN® and urea produced 1-2% more proteins than urea+eNtrench® (Table 1).

Table 2. Mean responses of yield and protein related variables and agronomic performance to N source by timing/placement interactions in Experiment 1 conducted in MB, SK, and AB, Canada, from 2013 to 2017

Timing/placement	N source	Grain yield Bu ac^{-1}	Protein content %	Grain-N lb N ac^{-1}	Total N uptake lb N ac^{-1}	RE† lb lb^{-1}	AE‡ lb lb^{-1}
	Control PKS*	50.6	10.6	72.0	88.4	---	---
	Control P§	43.6	10.0	57.4	83.0	0	-0.69
100% banded at planting	ESN®	65.9	11.4	95.9	129.3	0.24	4.79
	Urea+eNtrench®	66.3	11.1	95.6	129.7	0.25	4.91
	SuperU®	66.3	11.4	97.2	130.6	0.25	4.96
	Urea	64.8	11.3	94.9	127.8	0.25	4.1
30% banded/70% in-crop late-fall	ESN®	63.3	11.2	92.1	121.5	0.18	3.85
	Urea+eNtrench®	63.8	11.0	90.9	122.0	0.2	4.04
	SuperU®	64.5	11.1	94.1	126.2	0.22	4.53
	Urea	62.6	11.0	89.6	118.1	0.16	3.53
30% banded/70% in-crop early-spring	ESN®	61.7	11.4	90.0	116.4	0.18	4.05
	Urea+eNtrench®	64.2	11.2	93.5	121.0	0.2	4.86
	SuperU®	66.3	11.4	98.2	130.3	0.26	5.07
	Urea	65.7	11.3	95.5	125.8	0.22	4.77
LSD 0.05		0.16	*NS*	*NS*	*NS*	*NS*	*NS*

† RE = recovery efficiency; ‡ AE = agronomic efficiency

*Control PKS = phosphorus, potassium and sulphur fertilizers applied at the recommended rates based on soil test results; § Control P = phosphorus only at the recommended rate

On average, banding all N at planting or split-applied in early-spring provided 2% more protein vs. split-applied in late-fall (p<0.05). Previous researches also indicated that inhibiting nitrification may have created N deficient conditions during heading and flowering, which led to lower protein (Brown et al. 2005; Olson and Swallow 1984; Wuest and Cassman 1992). The low protein content with urea+eNtrench® might be its N release was delayed under the wide range of dry climate conditions in this study.

Total N uptake, RE and AE did not differ among N sources but varied by placements (Table 1). All N banded at planting produced significantly greater total N uptake and RE than when N was split-applied. Agronomy efficiency did not differ between all N banded at planting and split-applied in early-spring; but all N banded at planting and split-applied in early-spring provide significant higher AE than split-applied in late-fall. No significant N source by placement interactions were observed in grain-N, total N uptake, RE, and AE (Table 2).

In Experiment 2, grain yields responded to N sources in the order of UAN+Agrotain Ultra® > urea > UAN+Agrotain Plus® > UAN > UAN+eNtrench® > ESN®/urea > control (Table 3). AUN+Agrotain Ultra® produced significantly higher grain yield than UAN+eNtrench® and ESN®/urea, but no difference was observed between AUN+Agrotain Ultra® and other N sources. Total N uptake from all N sources were

Table 3. Mean responses of yield, protein related variables and agronomic performance to N source in Experiment 2 conducted in MB, SK, and AB, Canada, from 2013 to 2017.

Treatment	Grain yield Bu ac-1	Protein content %	Grain-N lb N ac-1	Total N uptake lb N ac-1	RE† lb lb-1	AE‡ lb lb-1
N source						
Control	50.4	10.6	69.5	98.4	0	-0.2
Urea	65.9	11.5	90.5	138.1	0.22	25.1
ESN®/urea¶	63.6	11.6	87.6	129.8	0.18	54.5
UAN	65.1	11.6	88.8	142.6	0.24	44.9
UAN+Agrotain Plus®	65.3	11.6	89.8	144.3	0.25	34.9
UAN+Agrotain Ultra®	67.5	11.6	93.2	143.7	0.23	15.7
UAN+eNtrench®	63.8	11.3	86.3	134.9	0.2	64.4
LSD 0.05	0.23	3.0	5.91	20.43	0.09	1.2
p-values						
Fixed effects						
N source	<.001	<.001	<.001	<.001	<.001	<.001
Random effects						
Site	0.004	0.004	0.011	0.054	0.084	0.009
Site × N source	<.001	0.002	<.001	0.004	0.005	<.001

† RE = recovery efficiency; ‡ AE = agronomic efficiency

consistently greater than that of the control, with the greatest in UAN+Agrotain Plus®, but no significant difference existed between different N sources (Table 3). Recovery efficiency displayed the same responses to N sources as total N uptake. UAN+Agrotain Ultra®, urea, UAN and UAN+Agrotain Plus® produced greater AE vs. ESN®/urea, UAN+eNtrench® and the control. Agronomic efficiency was 27% and 16% higher (p <0.05) when winter wheat was fertilized with UAN+Agrotain Ultra® compared with ESN®/urea and UAN+eNtrench®, respectively.

In summary, treatments that included a urease inhibitor or urease and nitrification inhibitors, like SuperU®, UAN+Agrotain Ultra® and UAN+Agrotain Plus®, displayed incremental increases in yield and protein relative to other N sources, regardless of application timings and placements. Therefore, including a urease inhibitor in the N fertilizer formulation will improve N uptake and enhance agronomic performance in the winter wheat systems.

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PROCEEDINGS OF THE

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POSTER PROCEEDINGS

CARBON AND NITROGEN CYCLING IN HIGH-ELEVATION HAY MEADOWS: UNDERSTANDING PROCESSES FOR IMPROVED AGROECOSYSTEM PRODUCTIVITY

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ABSTRACT

Irrigated hay meadows are an integral, but often under-performing component of livestock operations in western rangeland ecosystems. Flood irrigation resulting in seasonal saturation, high elevation, and cool temperatures common to these systems result in concentration of organic materials near the soil surface, constraining nitrogen cycling, forage productivity and diversity. Improved understanding of nutrient cycling, soil organic matter processes, and ecosystem services of irrigated hay meadows, as impacted by management, is necessary for improving long-term sustainable production. The goal of this study is to develop process-level understanding in support of management that improves soil health, biodiversity, and productivity of irrigated meadows by sampling four meadow systems in Wyoming and Colorado. At each site, three management scenarios are being compared: fertilized and irrigated meadows, unfertilized and irrigated meadows, and unfertilized and unirrigated rangeland, all on the same soil series. Carbon and nitrogen dynamics are being monitored by sampling the O and A horizons of meadow soils, and the A horizon of rangeland soils. Samples taken in spring and summer of 2021 were analyzed for potentially mineralizable carbon, potentially mineralizable nitrogen, total organic carbon, total nitrogen, microbial biomass carbon, and microbial biomass nitrogen. Results support the hypothesis that carbon and nitrogen dynamics predominate in the O-horizon, with relatively little activity in the A-horizon directly below. Although meadow soils store large amounts of carbon and nitrogen in the O-horizon, this does not translate to mineralization levels that support adequate forage yields in the field, due to limited microbial activity during periods of continuous saturation.

INTRODUCTION

High-elevation hay meadows are integral to the success of ranching operations in the Intermountain West, as they provide critical winter forage for livestock production. Stockpiling adequate stores of hay to overwinter breeding stock and reduce risk of future drought requires ranchers to make management decisions to balance productivity with input costs and productive acres (Taylor et al., 1985). Traditionally, use of nitrogen fertilizer has been one tactic to produce adequate yields in a system where water management and shortened growing season limit productive capacity.

The dependence on nitrogen fertilizer in meadows is somewhat paradoxical considering meadows have an O-horizon at the soil surface containing as much as 1,120-2,464 kg N/ha (Siemer, 1979). This O-horizon develops in meadows as a result of repeated low-efficiency flood-irrigation methods that leave the soil saturated for 6-8 weeks in the growing season (Peck and Lovvorn, 2001). Combined with this, the cold, high-elevation climate in which meadows are found means the soil microbial community has reduced ability to mineralize organic matter for forage production.

With the reoccurrence of drought, increased forage prices, and recently doubled fertilizer prices, ranchers must utilize sustainable management practices to increase productivity of meadow forage systems. Therefore, the objective of this study is to describe soil properties and soil organic matter (SOM) processes that affect nitrogen availability in order to leverage management tactics that make nitrogen more available for sustainable forage production in meadows.

MATERIALS AND METHODS

In spring of 2021, we identified four meadow systems in southern Wyoming and northern Colorado that met the requirements of flood irrigation and elevation greater than 1,980 m. At each meadow system, we further identified three management areas, all on the same soil series: 1) long-term fertilized, irrigated meadow, 2) long-term unfertilized, irrigated meadow, and 3) unfertilized, unirrigated natural rangeland. Three plots were randomly established at each management area for repeated sampling.

Samples were taken in spring 2021, following thaw, and summer 2021, one week prior to hay harvest. In meadows, samples were taken from both the O-horizon (0-5 cm) and the A-horizon directly below (5-15 cm). Because an O-horizon does not exist in the rangeland soils, only the A-horizon was sampled (0-10 cm). Samples were put on ice and transferred to the lab where they were analyzed for potentially mineralizable nitrogen (PMN), potentially mineralizable carbon (PMC), microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), total organic carbon (TOC), and total nitrogen (TN). PMN was analyzed using a 2-week anaerobic incubation followed by colorimetric NH_4^+ analysis (Waring and Bremner, 1964). PMC was analyzed using a 2-week aerobic incubation analyzed for CO_2 evolution (Zibilski, 1994). MBC and MBN were determined using the fumigation method followed by extraction in 0.5M K_2SO_4 and combustion analysis (Horwath and Paul, 1994). TOC and TN were determined using combustion analysis.

Statistical analysis was performed using R 4.1.1. For all soil analyses, an ANOVA was performed with soil horizon, management area, ranch, and sampling date as factors. If sampling date was a significant factor, it was removed from the model and sampling times were analyzed separately. Significance was set at $\alpha=0.1$, as this is an observational study. Following a significant factor or interaction in the ANOVA, means were separated using Tukey's HSD.

RESULTS AND DISCUSSION

Decades of continuous flood irrigation has resulted in the development of a 3-5 cm O-horizon at the surface of meadow soils (Lewis, 1957). Statistical analysis confirms that the O-horizon significantly affects C and N cycling in meadows, as horizon was a highly significant (P<0.0001) model factor for all soil analyses for both spring and summer samplings (Table 1). Meadow soils store large amounts of C and N in the O-horizon, with relatively little C and N in the A-horizon directly below (Table 2, spring sampling & Table 3, summer sampling). This is also true for labile C, N, and microbial biomass (MBC & MBN), where a majority of C and N cycling appears to be occurring in the O-horizon with relatively little activity in the A-horizon for both spring and summer samplings (Table 2 & 3). A potential reason for the lack of activity in the A-horizon is the effect of flood-irrigation on species composition. Long periods of soil saturation common to meadows have been shown to favor rhizomatous grasses with shallow root systems, reducing the amount of organic matter in the A-horizon compared with unirrigated rangeland soils (Table 2 & 3) (Rumburg and Sawyer, 1965).

Table 1: ANOVA p-values for six soil properties on meadow and rangeland soils with soil horizon (O or A for meadow, A for rangeland) as the main factor, and management (fertilized meadow, unfertilized meadow, rangeland) as the sub-factor.

	Horizon		Management		Horizon x Treatment	
	Spring	Summer	Spring	Summer	Spring	Summer
TOC	<0.0001	<0.0001	<0.01	<0.0001	0.09	0.10
TN	<0.0001	<0.0001	<0.01	<0.0001	0.09	0.52
PMC	<0.0001	<0.0001	<0.001	<0.01	<0.01	0.02
PMN	<0.0001	<0.0001	<0.0001	<0.0001	0.41	0.03
MBC	<0.0001	<0.0001	0.54	<0.001	0.63	<0.01
MBN	<0.0001	<0.0001	0.06	<0.01	0.61	<0.01

In the field, it appears mineralization of C and N is limited, as unfertilized forage yields in meadows are commonly low, ranging from 1,700-2,800 kg/ha annually (Rumburg and Siemer, 1975). This is somewhat surprising, considering the C:N ratio of the O-horizon does not exceed 15:1. Our results support that, in ideal conditions, the microbial community is never limited by substrate quality and can mineralize large amounts of C and N in the lab. The reason for the disconnect in meadow nutrient cycling appears to be a result of soil climate. Meadows commonly exist at elevations > 1,980-m, where growing seasons are short and soils remain cold or frozen for long periods of time. When temperatures increase in spring and summer, saturated conditions, as a result of continuous flood irrigation, reduce the ability of the microbial community to mineralize OM (Bossio and Scow, 1995). Considering the need for increased sustainability of western forage systems, ranchers would benefit from improved nitrogen mineralization to support yields without excess dependence on synthetic fertilizer. Research that examines methods to stimulate N mineralization in the field will be critical for improved sustainability of meadows in the future.

Table 2: Average response of meadow and rangeland soils for six soil properties sampled in spring 2021. Different letters within columns denote significant differences at α=0.10

			Analysis					
Location	Management	Horizon	TOC (%)	TN (%)	PMC (mg/kg)	PMN (mg/kg)	MBC (mg/kg)	MBN (mg/kg)
Meadow	Fertilized	O-Horizon	14.77 a	1.13 a	4071 a	61.10 a	3158 a	157 a
Meadow	Unfertilized	O-Horizon	12.75 a	0.94 a	2819 a	31.10 a	3368 a	168 a
Meadow	Fertilized	A-Horizon	1.28 c	0.11 b	172 c	1.22 a	376 a	10 a
Meadow	Unfertilized	A-Horizon	1.47 bc	0.11 c	205 c	1.43 a	359 a	10 a
Rangeland	Unfertilized	A-Horizon	2.34 b	0.17 b	343 b	9.86 a	442 a	18 a

Table 3: Average response of meadow and rangeland soils for six soil properties sampled in summer 2021. Different letters within columns denote significant differences at α=0.10

			Analysis					
Location	Management	Horizon	TOC (%)	TN (%)	PMC (mg/kg)	PMN (mg/kg)	MBC (mg/kg)	MBN (mg/kg)
Meadow	Fertilized	O-Horizon	17.05 a	1.28 a	4216 a	51.93 a	9031 a	290 a
Meadow	Unfertilized	O-Horizon	18.47 a	1.31 a	3243 b	29.06 ab	5424 b	185 b
Meadow	Fertilized	A-Horizon	1.23 c	0.12 a	200 c	1.90 c	408 c	14 c
Meadow	Unfertilized	A-Horizon	2.03 b	0.14 a	222 c	5.26 c	348 c	14 c
Rangeland	Unfertilized	A-Horizon	2.89 b	0.22 a	406 c	19.89 b	580 c	29 c

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ANALYSIS OF 10 YEARS OF N RATE AND TIMING WORK IN OKLAHOMA WINTER WHEAT

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ABSTRACT

Producers face many hurdles throughout the year and with the price of chemical herbicides and fertilizer on the rise, one of the ways producers can mitigate their margins is by perfecting their nitrogen fertilizer rates and timing f applications. In this study that was started in the 2009-2010 winter wheat cropping season, winter wheat was planted in multiple location from the 2009-2010 cropping season to the 2019-2020 winter wheat cropping season. During this time period the study has had 16 different nitrogen application treatments over four replications. During this time period of the 38 site years there was 25 that had reported a response to nitrogen application on winter wheat grain yields.

INTRODUCTION

In the year 2020, the state of Oklahoma planted 4.25 million acres of winter wheat; of those 4.35 million acres, 2.6 million acres were harvested. Those 2.6 million acres produced 104 million bushels of winter wheat, which sold for an average 4.55 dollars a bushel (USDA-NASS, 2020). Producers face many hurdles to make their margins and with the price of wheat varying from year to year and the cost of fertilizers increasing over the years, it’s not getting any easier.

One way a producers can help themselves is to increase their nitrogen use efficiency (NUE). NUE can be defined as the efficiency of a crops to utilize the nitrogen that is already present in the soil as well as the nitrogen applied as fertilizer and is currently 33% for the worldwide (Raun and Johnson, 1999). Raun and Johnson (1999) go on to say that one of the many ways we can increase NUE is to apply fertilizer as a top-dress application. This goes to support the idea of the 4Rs created by (Johnston and Bruulsema, 2014), the 4Rs stand for the Right time, Right source, Right place, and Right rate. The objective of this study was to evaluate and determine the optimum nitrogen fertilizer timing and rate by location and environment so it may be replicated in the future.

MATERIALS AND METHODS

This study has was started in the year 2009 and has continued to be planted to this current cropping season. This study has been conducted in five different locations across Oklahoma over the years. These locations are Lahoma, Hennessy, Lake Carl Blackwell (LCB), Stillwater (Efaw), and Perkins, with the study having multiple locations a year. A RCBD was created originally with ten different nitrogen applications over 4 replications, these ten nitrogen treatments can be seen in the first ten treatments in (table 1). In the 2010-2011 cropping season four more treatments were established adding four pre-plant application rates of 50 lb N ac^{-1}, 75 lb N ac^{-1}, 125 N lb ac^{-1}, and

200 lb N ac^{-1}. An addition two treatments were added to the previous fourteen in the 2014-2015 winter wheat cropping season. These two treatments were sensor-based nitrogen rate applications, where the top-dress nitrogen rate would be determined by the sensor-based nitrogen rate calculator. The sensor-based applications were determined by using a green seeker to establish an average NDVI for a fully fertilized treatment and then the treatments that were sensor-based applications. Averages were input into the sensor-based nitrogen rate calculator which then gave a rate for the treatments. Throughout the season NDVI data was collected with green seekers during feekes 3, 4, 5, and 7 to determine variability in biomass. All applications of nitrogen were in the form of urea-ammonium nitrate (UAN, 28-0-0).

Treatment	N Preplant (lbs N/ac)	N Topdress (lbs N/ac)	N Total (lbs N/ac)	Method of Application
1	0	0	0	Check
2	150	0	150	N Rich Strip
3	25	0	25	
4	25	25	50	
5	25	50	75	
6	25	75	100	
7	25	100	125	
8	25	125	150	
9	50	50	100	
10	100	0	100	
11	50	0	50	
12	75	0	75	
13	125	0	125	
14	200	0	200	
15	0	TBD		SBNRC
16	50	TBD		SBNRC

Table 1. represent the most current up to date treatment table.

Trails were soil sampled each year prior to the application of pre-plant nitrogen and after harvest. Soil samples were taken to a 6-inch depth in each replication to evaluate the soil nutrient levels of total carbon and nitrogen. These soil samples were then ran through a LECO to determine these values.

Harvest was conducted after plant maturity with a small plot combine with a 5 foot header. Moisture content, plot weight, and test weight were collected with an onboard harvest monitor. Grain samples were collected from each plot and analysis. The grain samples later would be dried, ground and then run through a LECO to estimate the percent total carbon and nitrogen. Grain yield was corrected to 12.5% and statistical analysis was ran using SAS 9.4.

RESULTS AND DISCUSSION

Of the 38 site years of this experiment 25 of them reported a response of yield to nitrogen application. In the year 2010 out of the three locations planted 2 locations (Lahoma and Hennessy) reported a response in yield to nitrogen and one location (LCB) did not. Of the two locations that had a response, Hennessy was the only location that had a difference between treatments beyond that of the control. The responsive treatments were 150 lb N ac^{-1} pre-plant application and the split application of 25 lb N ac^{-1} pre-plant followed by 125 lb N ac^{-1} at top-dress. Where the location Hennessy had an average high of 60 bu ac^{-1} in a split application of 25 lb N ac^{-1} pre- plant and 125 lb N ac^{-1} top-dress. In 2010, Lahoma had a highest average yield of 38 bu ac^{-1} in a split application of 50 lb N ac^{-1} at both pre plant and top-dressFinally, the LCB location where it did not show a yield response to nitrogen, had a highest yield of an average of 57 bu ac^{-1} in split application of 25 lb N ac^{-1} pre-plant and 75 lb N ac^{-1} top-dress. These treatments out preforming the other treatments may be attributed to the availability of nitrogen later in the season. In the year 2012 there was a nitrogen response in all three locations (Lahoma, LCB, and Hennessy). In the three locations the highest average yield in Lahoma's was the pre-plant application of 75 lb N ac^{-1} (50 bu ac^{-1}), at the LCB location the application of 25 lb N ac^{-1} pre- plant and 125 lb N ac^{-1} top-dress (46 bu ac^{-1}) had the highest average yield, and in the Hennessy location the pre plant application of 150 lb N ac^{-1} resulted in the highest average yield(70 bu ac^{-1}).

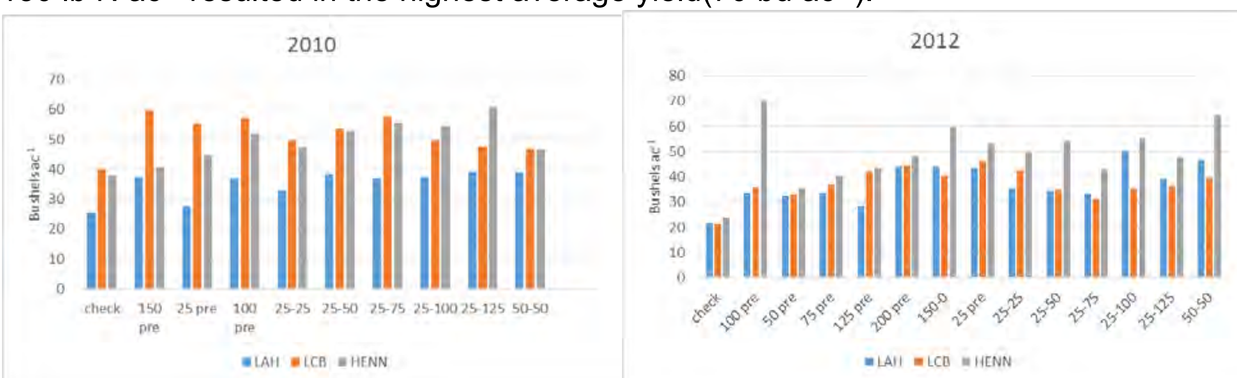

Figure 1.. Average yield (bu ac^{-1}) for the 2009-2010 (left) and 2011-2012 (right) winter wheat growing seasons. Treatments are unfertilized check, 150 lb N ac^{-1} pre-plant, 25 lb N ac^{-1}, 100 lb N ac^{-1}pre-plant, and split applications where the first number is lb ac^{-1} pre-plant and the second number is lb ac^{-1} top-dress.

The year 2014 reported 3 out of 4 locations had no yield response to nitrogen. The Lohoma, LCB, and EFAW locations had no significant impact of the application of nitrogen fertilizers on the winter wheat grain yield, where the check with no N produced yields equal to or greater of the other treatments.(Figure 2). The location of Perkins did however have a nitrogen response, with the an average yield of 30 bu ac^{-1} across all treaments which was greater than the control. In the year 2020, on the other hand, 3 of the 4 locations had a nitrogen response. In this year at the Lahoma, LCB, and Hennessy locations the split application of 25 lb N ac^{-1} pre-plant and 125 lb N ac^{-1} top-dress treatment produce the highest average yields at all locations. Where at the Perkins location that did not have a nitrogen response had an overall average of yeild of 66 bu/ac^{-1} .

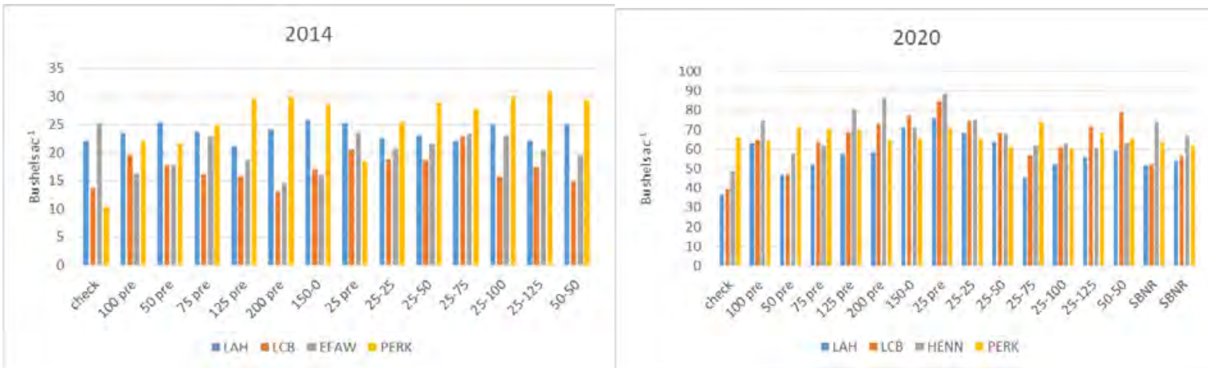

Figure 2. Average yield (bu ac^{-1}) for the 2013-2014 (left) and 2019-2020 (right) winter wheat growing seasons. Treatments are unfertilized check, 150 lb N ac^{-1} pre-plant, 25 lb N ac^{-1}, 100 lb N ac^{-1}pre-plant, and split applications where the first number is lb ac^{-1} pre-plant and the second number is lb ac^{-1} top-dress.

With winters in the state of oklahoma being sporadic, winter rainfall can be attributed to why some years top-dress applications out preform pre-plant and vis versa. In 2010 the state of Oklahoma had a dry winter, with Payne county averaging 3.55 inches over the winter and 1.74 inches in the month of march (Mesonet Long-term). The month of march averaged almost half of the winter average in Payne county, which is a substaincal rainfall during the time of top-dress. Similarly in the year of 2012 where all three of the locations have a nitrogen response Payne county experienced an winter average of 5.44 inches, later in march however, the county received 4.52 inches of rain (Mesonet long-term), which very well could have leached out the top-dress applications. Dissimilarly, in 2014 Payne county averaged 1.39 inches of rain over the winter and averaged 1.11 inches in the month of march (Mesonet Long-term), this lack of rainfall may would have caused fertlizer applications to be volitilized off before it could be pushed into the ground, causing us to see a lack in response to fertilizer in 3 of our 4 locations. The winter of 2020 was a decent winter for rainfall for Payne county, averaging 5.21 inches over the winter, and seeing an average of 5.78 inches in the month of march (Mesonet Long-term). These four years help show that just as weather can vary from year to year so can fertilizer application practices. In years where the state hardly recieves any rain over the winter and rainfall after top-dress applications the expectations are that top-dress applications will preform better than pre-plant applications with an opposite effect when the winter cropping seasons receive higher rainfall.

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ENZYME ACTIVITY AND PEANUT NODULATION WITH THE INCLUSION OF COVER CROPS IN ORGANIC AND CONVENTIONAL AGRICULTURE IN THE TEXAS HIGH PLAINS

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ABSTRACT

Organic farming has been increasingly adopted in the Texas High Plains (THP), but restrictions on synthetic fertilizer use may be problematic if a system cannot mineralize sufficient nutrients from organic matter breakdown to meet crop needs. Cover crops are a tool utilized by both organic and conventional producers for nutrient management, weed control and soil conservation. A one-year study was conducted in organic peanuts in Lubbock and Vernon, TX, to assess the ability of cover crops to increase indicators of organic matter breakdown and nutrient mineralization. Both cover crops and management system impacted activities of N-acetyl-β-D-glucosaminidase and β-glucosidase, as well as carbon mineralization, although results varied by location. Cover crop treatments improved both parameters over fallow, as did organic treatments. These findings suggest cover cropping and other organic farming practices can enhance nutrient mineralization of organic matter in the short-term.

INTRODUCTION

The Texas High Plains (THP) region has long been a major producer of US cotton (*Gossypium hirsutum)* and peanuts (*Arachis hypogea)* (National Agricultural Statistics Service, 2020) and has quickly become a leader in organic production of both crops (Zapata et al., 2022). Restrictions and requirements of organic production make cover cropping an important nutrient management strategy for producers. Past studies on cover crop use in the region have addressed nutrient management challenges associated with cover crops but have focused on their impact in conventional systems (Lewis et al., 2018). Organic production does not allow the use of synthetic fertilizer making organic matter input the main source of nutrients. Measuring activities of enzymes such as N-acetyl-β-D-glucosaminidase and β-glucosidase can indicate a system's ability to breakdown organic matter, and subsequently release nutrients. Mineralizable carbon (CMIN) is another indicator of a system's ability to utilize organic substrates and is an estimator of soil biological activity. The purpose of this study was to investigate the effects of both cover crop use and management strategy on the ability of a system to utilize organic substrates for nutrient acquisition by measuring enzyme activities and carbon mineralization.

MATERIALS AND METHODS

The study was conducted at two locations during the growing season (April-November) of 2020: in the THP at the AgriLife Research Center in Lubbock (33.693, 101.828) and in the Texas Rolling Plains at the Vernon AgriLife Research Center (34.091, 99.365). Peanut variety ACI 236 was planted in Lubbock and Vernon on May 7, 2020 and May 11, 2020, respectively; however, the Lubbock location was replanted on June 10. Conventional peanuts in Vernon were inoculated with Bradyrhizobia while organic peanuts were not. Plots were designed as separate randomized complete blocks for organic (ORG) and conventional no-till management (CONV) and included 4 cover crop treatments, with three replications each. Cover crop treatments were rye (*Secale cereale*) (rye), radish (*Raphanus sativus*) (rad), rye/vetch (*Vicia villosa*) mix (rv), and rye/radish/vetch (rvr) mixes. Fallow, reduced-tillage conventional plots were used as the control (f). Plots measured 35.1 x 13.5 ft with 3.3 ft rows. Termination method differed between ORG and CONV to comply with restrictions on the use of synthetic herbicides in organic systems. ORG cover crops were terminated via stalk cutter in Lubbock and sweep plow in Vernon, in late April 2020. CONV cover crops were terminated in Lubbock using 2,4-D on March 31 and two Roundup applications on April 27 and May 5. In Vernon, CONV cover crops were terminated with a single Enlist Duo application on April 17. CONV plots in Lubbock received urea ammonium nitrate (UAN) at 89 lb. UAN acre^{-1} while ORG received approximately 8,030 lb. compost acre^{-1} during the previous cotton rotation in 2019. In Vernon, CONV plots received fertilizer at 149 lb. ammonium polyphosphate acre^{-1} and ORG plots received 8,800 lb. compost acre^{-1} however, compost was applied just before peanut planting in April. Soil samples were collected at each location prior to peanut planting (pre), during mid-season (mid) and after peanut harvest (post). Cores were collected and divided by depth (0-4 in & 4-8 in), then composited. Samples were air-dried and sieved to 2 mm. Enzyme assays for β-glucosidase (BG) and N-acetyl-β-D-glucosaminidase (NAG) were conducted according to the NRCS colorimetric method (Scott, 2019). Mineralizable carbon (CMIN) was determined during 3-day CO_2 incubations (Franzluebbers, 2015). Results were analyzed in SAS using PROC GLIMMIX. Unless otherwise noted, alpha = 0.05.

RESULTS AND DISCUSSION

Enzyme Activities

No depth interactions were identified for either enzyme at either location, so data for management and cover crop selection were pooled to include both depths. The radish cover crop failed in Lubbock, so it is not included. Results for BG were significant at Vernon only (Figure 1). The presence of cover crops, specifically with rye, rv and rvr, increased BG activity over fallow (Figure 1A). Management effects were observed as well, with BG activity being greater in ORG than CONV (Figure 1B). Significance at Vernon but not Lubbock was likely caused by application of compost just before planting, providing additional substrates for BG to degrade.

NAG activity was more variable and showed significance at both sites. At Lubbock NAG activity was greater in rv treatments compared to r and rvr in post-harvest samples (Fig 2A). The rv treatments showed greater activity in Vernon compared to rye and radish treatments at pre-plant (Fig 2B). Vernon results also indicated significant management effects at mid and post-harvest, with ORG greater at mid-season and CONV greater at post-harvest (Fig 2C).

A. B.

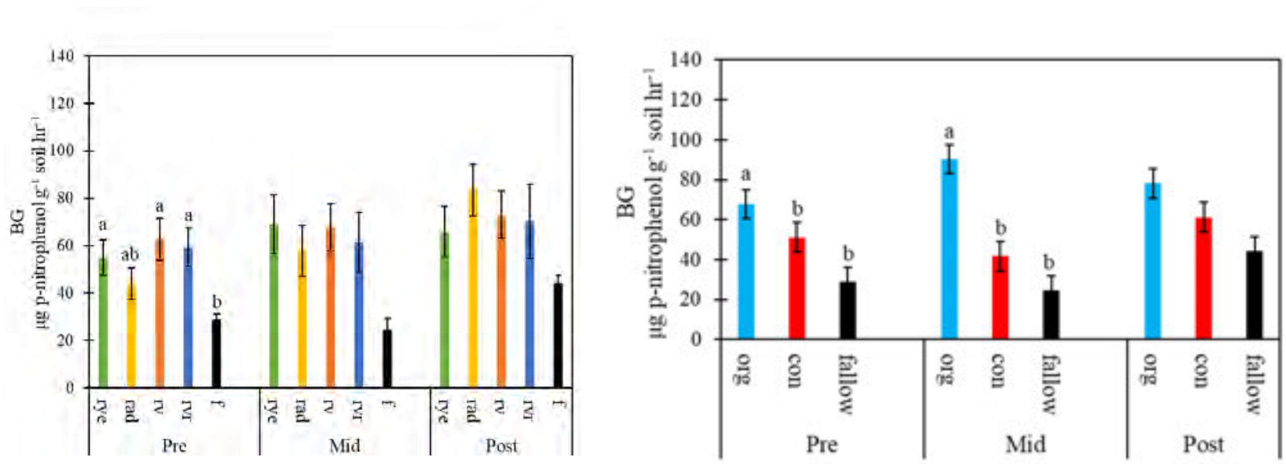
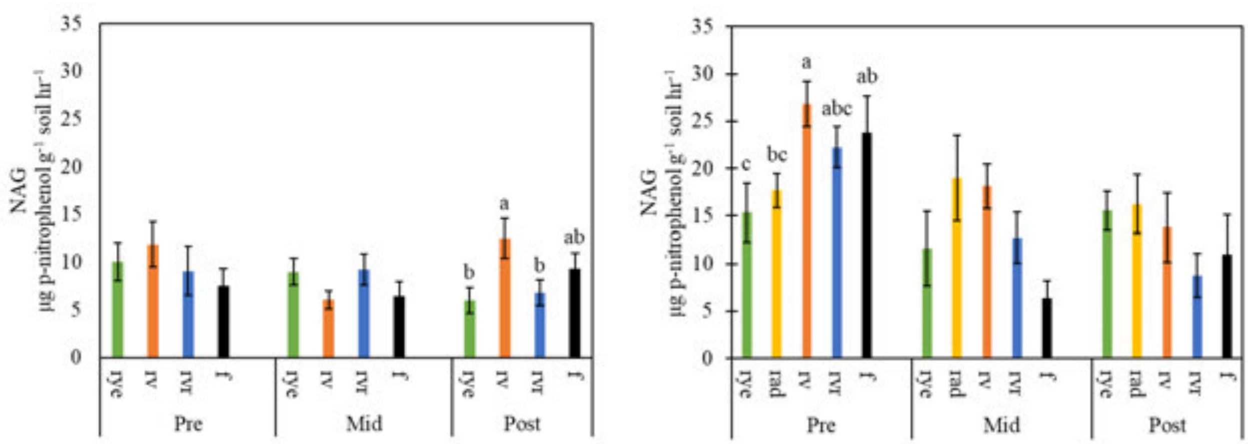


Figure 1. β-glucosidase enzyme activity at Vernon according to cover crop selection (A) and management (B). Bars within sample collection with the same letter are not different at $P < 0.05$

A. B.



C.

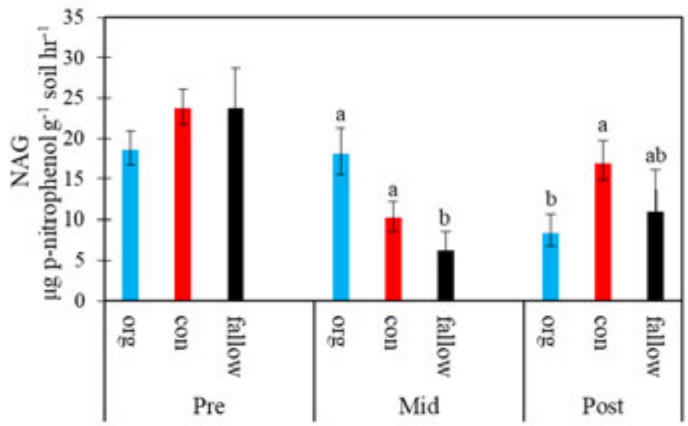
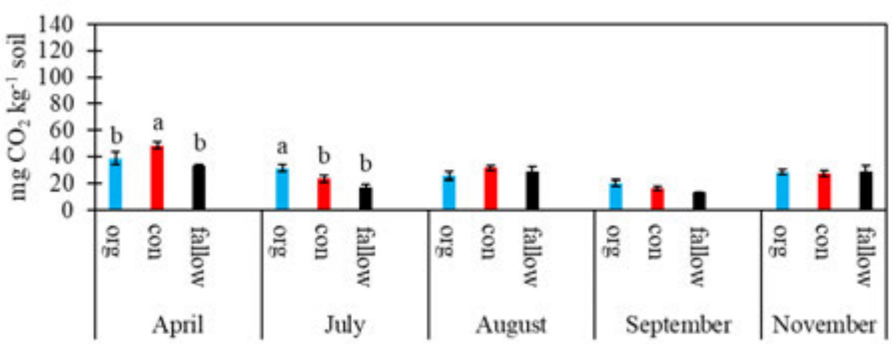


Figure 2. N-acetyl-β-D-glucosaminidase enzyme activity at Lubbock according to cover crop selection (A), at Vernon according to cover crop selection (B) and at Vernon according to management (C). Bars within sample collection with the same letter are not different at $P < 0.05$

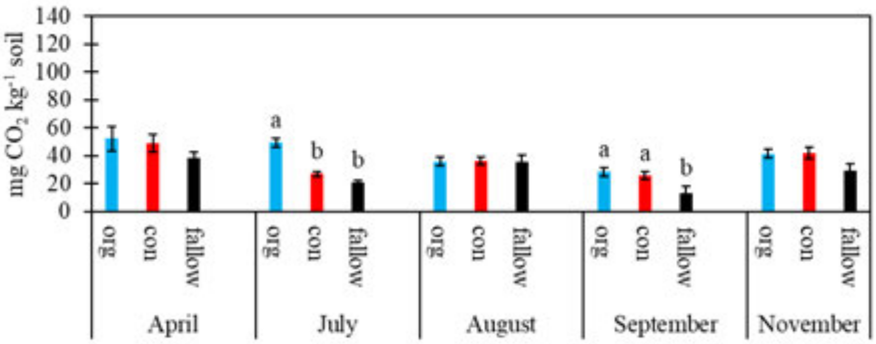
Mineralizable Carbon

Mineralizable carbon was not different at the 4 to 8 inch sampling depth with cover crop selection at either location, so only data from 0 to 4 inches is presented (Fig 3). Total CMIN was greater in Lubbock and no significant cover crop effects were detected in Vernon. In April, at the Lubbock site, rye was greater than fallow, while in September rv was greater than rye and fallow (Fig 3C). While no management effects were observed in Lubbock at lower depths, results indicated increased CMIN in CONV over fallow in April and ORG over fallow in September, at P=0.1 (Fig 3A). CMIN responded to management in three separate months in Vernon. In April, CONV was greater than ORG and fallow, while in July ORG was greater than CONV and fallow at both depth ranges (Fig 3B). In September, both ORG and CONV were greater than fallow but not different from each other.

A.



B.



C.

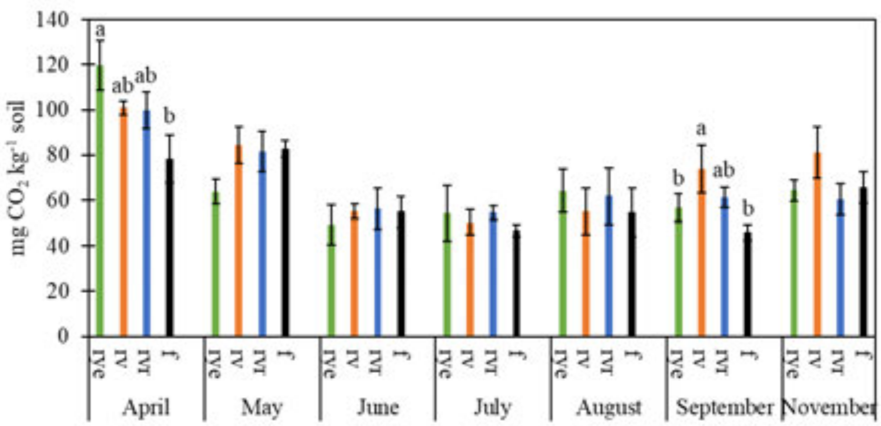


Figure 3. Mineralizable carbon at Lubbock according to cover crop at 0-4 inches (A), management from 0-4 inches (B), and at Vernon according to management at 0-4 inches (B). Bars within sample collection with the same letter are not different at P < 0.1

CONCLUSION

Cover crop presence and management strategy have potential to enhance soil enzyme activities and carbon mineralization, both of which are important for nutrient cycling in systems dependent on organic inputs as nutrient sources. Organic management generally increased both factors over conventional and fallow management, while cover crops, legumes and nonlegumes, also resulted in increased nutrient cycling parameters. Further research should examine the sustainability of organic systems in the THP and evaluate the viability of organic nutrient management strategies relying on factors such as enzyme activity and carbon mineralization to enhance crop nutrient availability.

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ACID SOIL ADAPTATION MANAGEMENT IN WESTERN NORTH DAKOTA WITH HARD RED SPRING WHEAT

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ABSTRACT

Hard Red Spring Wheat (HRSW) yields are decreasing due to acidic soils. No-till practices paired with heavy nitrogen (N) use have lowered the soil pH on many acres of the Northern Great Plains. Acid soil where the pH drops below 5.5 has an impact on nutrient availability, soil microbial activity, stunted roots from aluminum (Al) toxicity and other plant/soil interactions. These areas can be improved from surface liming; however, liming can be costly. For many producers facing this issue, especially those working rented land, there is a search for alternative options to reduce yield loss on acidic ground. Research has been conducted in western North Dakota on adaptive management strategies for mitigating the symptoms of aluminum toxicity and soil acidity including cultivar selection, in-furrow fertilizer application, and seed treatments. Cultivar selection showed a significant difference in yield. Interactions were found among cultivar, biochar application, and in-furrow phosphorus. It was observed that a susceptible cultivar of Hard Red Spring Wheat (SY Soren) had a yield response to in-furrow phosphorus (P), where a tolerant cultivar (Lanning) did not respond to in-furrow P. Calcium in-furrow did not have an impact on yield. Across HRSW cultivars a yield bump of 1.5 bushel was shown from seed placed P (0-45-0) applied at high rates (60 lb P2O5/ac). This mechanism doesn't appear to be as strong for HRSW as shown in similar durum trials. A yield reduction from biochar was identified with the control yielding 24 bushels/ac and a rate of 8 lbs/ac seed placed yielded 17.6 bushels/ac.

INTRODUCTION

North Dakota soils have historically been considered to be alkaline, however with increased implementation of no-till practices along with higher rates of N fertilizer, stratified soil acidity has formed. As the pH drops below 5.5 a variety of issues form including Aluminum toxicity, reduced nutrient availability, reduced microbial activity, and impacts on breakdown of certain herbicides. During the 2021 National Sunflower Association National Sunflower Survey a selection of fields were sampled at 0-3 inches at multiple sites within the field (Figure 1). The extent of fields with a pH below 5.5 was wider than many consultants and producers realized due to lack of precision soil sampling. In 2018 out of all samples sent to AGVISE laboratories, those with either grid or zone soil sampling were as low as 9-19% of samples in regions in western North Dakota (AGVISE, 2019).

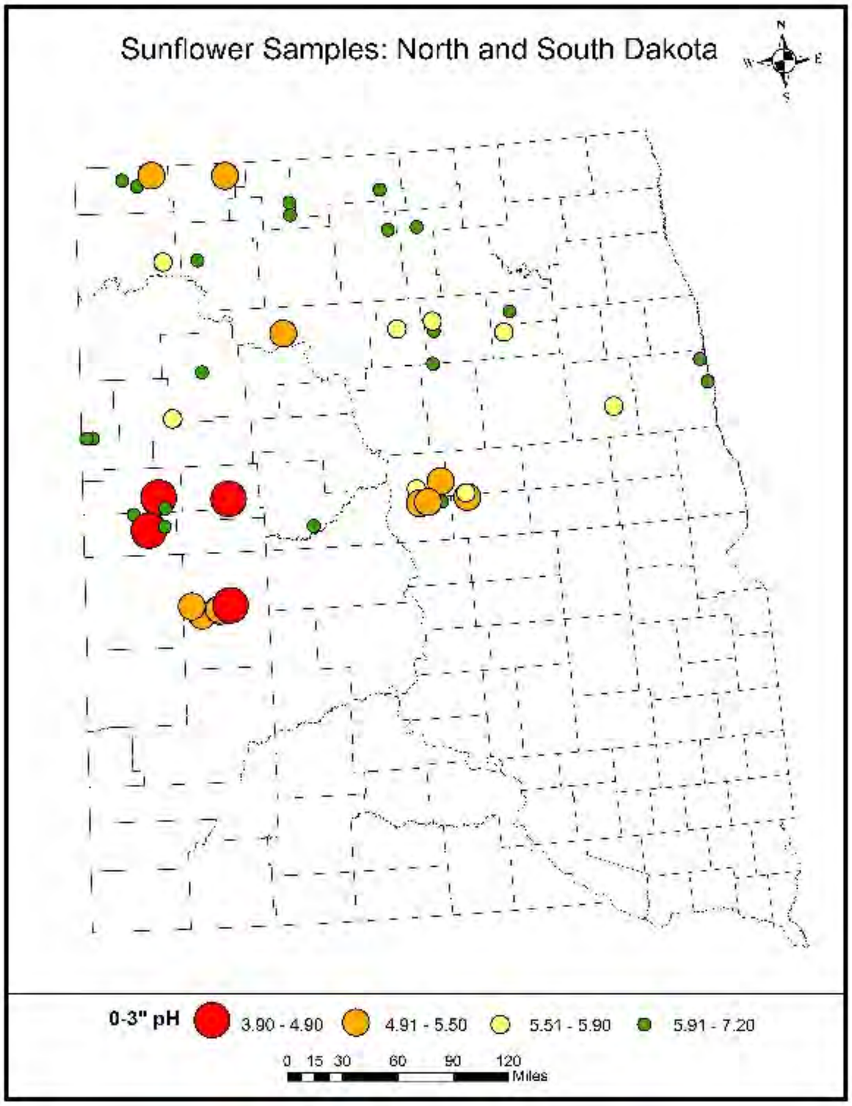

Figure 1. 0-3" soil samples taken in 2021.

Amending soils with agricultural lime is the most common and effective long- and short-term strategy to correct soil acidity. Other short-term strategies that can mitigate the impact of low soil pH on crop yield include planting aluminum-tolerant cultivars of wheat or aluminum-tolerant crops such as triticale (McFarland et al 2015). In the short term, high rates of phosphorus (P) fertilizer placed in seed furrows have been found to reduce the impact of Al toxicity in winter wheat in Oklahoma (Kaitibie et al., 2002) and durum wheat in Montana (Jones et al, 2019).

As producers in North Dakota are not familiar with the need to lime and infrastructure of lime sources and application equipment in the region are in the early stages and considered costly, many are searching for alternative short-term solutions. Even if lime is applied it may take time for the lime to react and often lime application does not have a direct effect on yield (Godsey et al 2007). The objective of this study is to verify short-term strategy effectiveness for the western region of North Dakota.

MATERIALS AND METHODS

Three separate studies were conducted in 2021 in western North Dakota on acidic (pH<5.5) field sites. In all studies soil was sampled in the fall of 2020 and again in the spring of 2019 with a tubular probe at the stratified 0-3”, 3-6” layers and at 0-6” to confirm that the trial areas were acidic. The pH was determined using 1:1 soil to deionized water ratio.

Wheat Cultivar Selection in Acidic Soils

In this study three locations were selected with sites near Minot, Dickinson, and Lefor, ND. At each site Hard Red Spring Wheat (HRSW) was planted and fertilized under best management practices into 5 by 30 ft plot units with 3 replications in Minot and Dickinson and 4 replications in Lefor. The cultivar treatments were arranged in a randomized complete block design (RCBD). Plot units were harvested with a small-plot combine at maturity. A total of 18 cultivars of HRSW were selected as treatments from company entries and public university released cultivars.

Data were analyzed with PROC Mixed with SAS (version 9.4, SAS Institute, Cary, NC). Field experiments were analyzed separately by location. Statistical analyses were performed with type 3 estimation with rep as random and cultivar as a fixed effect.

Biological Plant Growth Regulator Treatments HRS in Acidic Environments

In this study two locations were selected with sites near Dickinson and Lefor, ND. At each site HRSW was planted and fertilized under best management practices into 5 by 30 ft plot units with 3 replications in Dickinson and 4 replications in Lefor. The treatments were arranged in a RCBD. Plot units were harvested with a small-plot combine at maturity. A control, five seed treatments, and a foliar treatment were planted with the HRSW cultivar SY Soren (AgriPro, 2011). SY Soren was chosen as it has consistently shown susceptibility to aluminum toxicity and is otherwise, in neutral pH environments, considered a recommended cultivar for the region. Treatments included plant growth regulators (PGR) and mycorrhizal and bacterial products.

Data were analyzed with PROC Mixed with SAS (version 9.4, SAS Institute, Cary, NC). Field experiments were analyzed separately by location. Statistical analyses were performed with type 3 estimation with rep as random and applied treatment as a fixed effect.

In-Furrow Fertilizer Comparison for HRS in Acidic Soils

In this study one location was selected near Dickinson, ND. At this site HRSW was planted and fertilized under best management practices into 5 by 30 ft plot units with 3 replications. The experiment was a RCBD with a 2 x 2 x 2 x 3 factorial arrangement with two wheat cultivars, with and without 8 lbs/ac of biochar, with and without 60 lbs of P, and three calcium treatments (untreated control, 60 lbs/ac of lime, and 200 lbs/ac of gypsum). Cultivars chosen were SY Soren (AgriPro, 2011) as a susceptible cultivar and Lanning (Montana Ag Exp Station, 2017) as a tolerant cultivar. Plot units were harvested with a small-plot combine at maturity. A control, five seed treatments, and a foliar treatment were planted with the HRSW cultivar SY Soren (AgriPro, 2011). SY Soren was chosen as it has consistently shown susceptibility to aluminum toxicity and is otherwise, in neutral pH environments, considered a recommended cultivar for the region. Treatments included plant growth regulators (PGR) and mycorrhizal and bacterial products.

Data were analyzed with PROC Mixed with SAS (version 9.4, SAS Institute, Cary, NC). Field experiments were analyzed separately by location. Statistical analyses were performed with type 3 estimation with rep as random and cultivar, biochar, P, and calcium as fixed effects.

RESULTS AND DISCUSSION

Wheat Cultivar Selection in Acidic Soils

Drought conditions in 2021 reduced yield potential greatly at the Minot and Dickinson locations. The Lefor location received above average rainfall for the season with 8 inches of precipitation from April through July recorded at the nearest weather station (Mayer Farm, Weatherlink) and the Dickinson location was in severe drought conditions with 6.7 inches recorded at the nearest weather station over the same period (Dickinson, NDAWN). Drought conditions in Minot created a large amount of variability causing a high covariance estimate. Due to high variability, data from Minot was not reported for 2021. Data (Table 1.) shows that some varieties yield significantly higher than others. Yields at Dickinson were highly suppressed due to drought conditions, but differences were still shown.

Table 1. Low pH HRSW variety trial yield results 2021.

Variety	Dickinson	Lefor
	bu/ac	
Bolles	18.0	57.3
CP3099A	**23.0**	-
CP3119A	**22.6**	**69.3**
CP3188	**21.8**	65.4
CP3530	**19.9**	-
CP3915	17.4	64.4
Dagmar	**22.6**	64.2
Duclair	**20.2**	61.5
Glenn	18.6	60.4
Lanning (tolerant check)	**20.5**	64.8
SY Soren (susceptible check)	**19.2**	61.9
TCG Heartland	15.8	62.3

TCG Spitfire	**20.8**	**72.6**
WB9479	12.7	61.8
WB9516	13.1	**68.4**
WB9590	13.2	66.8
WB9606	**21.4**	67.4
WB9719	11.2	**70.8**
LSD (0.05)	3.9	4.2

Average 0-3” soil pH was 4.9 at both the Dickinson and Lefor locations

Data from 2021 shows that multiple cultivars are available that show tolerance to low pH and aluminum toxicity. More data is required due to drought conditions to make specific recommendations as only 2 cultivars, TCG Spitfire and CP3119A were consistently listed as a top yielding cultivar at both locations.

Biological Plant Growth Regulator Treatments HRS in Acidic Environments

As seen in Table 2. no significant difference was found between any of the treatments and the control. At the Lefor, ND location we had above average rainfall conditions, and at the Dickinson, ND location we had extreme drought conditions. According to this data, these types of treatments are not effective at combatting the issue of Aluminum toxicity and yield losses associated with soil acidity.

Table 2. Spring wheat yields across treatments at 2 North Dakota locations in 2021.

	Lefor	Dickinson
Treatment	Yield	
Control	54.8	19.9
Ascend (seed trt PGR)	54.4	20.5
Kickstand (seed trt PGR)	55.6	18.9
Foliar PGR	55.2	20.9
Nutri-cycle (seed trt)	54.3	18.2
MycoApply (seed trt)	55.6	19.0
Humic Acid (granular)	56.4	19.7
LSD (0.1)	ns	ns

Average 0-3” soil pH was 4.9 at both the Dickinson and Lefor locations
Aluminum toxicity susceptible variety SY Soren was chosen.
All seed treatments applied at labeled rate.
Humic acid applied at 10lb/ac with seed at planting.
Drought was a major factor on yield at the Dickinson location however cv was still low.
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In-Furrow Fertilizer Comparison for HRS in Acidic Soils

A significant difference in yield between the susceptible and tolerant varieties was found. We also found significant differences between treatments in biochar, phosphorus, and the interaction between variety, biochar, and phosphorus (Table 3). Biochar showed a negative yield response, this may be due to nutrient tie up or seed moisture loss with drought conditions.

Table 3. In-furrow fertilizer treatments in Dickinson 2021.

In-furrow treatment	Variety	
	Soren (susceptible)	Lanning (tolerant)
Control	21.4bc	25.7a
Control+biochar*	15.3e	18.1d
Phosphorus	25.1a	24.0ab
Phosphorus+biochar*	16.2de	21.0c
LSD (0.05)	2.6	

Phosphorus was seed placed at 60 lbs of P as TSP.
*biochar was placed in furrow at a rate of 8lbs/ac.

The data in the above table suggests that phosphorus (P) in-furrow is able to raise the yield of susceptible varieties, but has no impact on tolerant varieties. When ran across both varieties, however, P showed an overall significant positive impact on yield from the control (Table 4).

Table 4. P fertilizer across all other treatments, Dickinson 2021.

Treatment	Yield
Control	20.1b
60 lbs **additional** P	21.6a

We did not find any significant difference from the control for the various calcium sources, opposing current recommendations from consultants in the region. Due to possible impacts of drought this trial is planned to be repeated in 2022. Yields were compressed by drought conditions, and fortunately covariance estimates were low.

This data suggests that variety selection is an extremely important component of management in acidic soils -- however if a susceptible variety is used -- additonal P fertilizer may be an option, however the price of P fertilizer should be considered in that recommendation. It also shows that calcium products in-furrow do not appear to assist in management of soil acidity.

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RELATIONSHIP BETWEEN PLANT NITROGEN AND NDVI OF COTTON ON THE TEXAS HIGH PLAINS

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ABSTRACT

Nitrogen (N) fertilizer is an important nutrient in cotton production, and if the optimal amount is not applied then it could lead to a reduction in lint yield (Hutmacher et al. 2004). A more efficient application of N fertilizer due to specifics 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 evaluate the interaction of N rate, irrigation level, and cotton cultivar on plant health and cotton productivity by increasing NUE. The project will determine the relationships between end of season N uptake and normalized difference vegetative index (NDVI) to lint yield. Urea-ammonium nitrate (32-0-0) was applied pre-plant and after emergence by knife-injection at three rates of 15, 75 and 135 lb N ac^{-1} under two irrigation levels and two cultivars. Lint yield was greater when the N rate of 75 lb ac^{-1} was applied with either irrigation level, cultivar, and experimental years. 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 N application.

INTRODUCTION

Nitrogen is required in the largest amount by most all plants (Marschner, 2012). Plant available N in soil is limited and can be lost easily due to environmental conditions (IPNI, 2012). Pre-plant soil nitrate-N (NO_3^--N) levels are used to determine N fertilizer recommendations. However, due to N losses within the growing season leaf analysis can be used to determine the need for in-season N applications (Sabbe and Zelinski, 1990; Zhang et al., 1998). Normalized difference vegetative index (NDVI) is a tool that can be used to manage water, N, crop development and to predict yield at peak bloom (Li et al., 2001; Bronson et al., 2003; Zhou and Yin 2014). To detect N deficiencies within the plant, NDVI is calculated 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. (2007) reported a strong correlation between NDVI readings and leaf N, plant biomass and yield. However, NDVI readings have also been reported to not respond to changes in cotton leaf N (Li et al., 2001; Bronson et al., 2003, 2005). The main objective of this research was to evaluate the interaction of N rate, irrigation level, and cultivars on plant health and cotton productivity with the overall goal of optimizing cotton production by maximizing NUE.

MATERIALS AND METHODS

A field experiment was conducted in 2019 and 2020 at the Texas A&M AgriLife Research experiment station in Lubbock, Tx. There were three main treatment effects, N fertilizer rate, irrigation level and cotton cultivar. Treatment combinations were replicated four times (48 total plots). Plots were four rows (40 inch spacing) by 25 ft in length. The field was arranged in a split split-plot design with the whole plot being irrigation level, and within the irrigation levels, there were subplot treatments for cultivar. 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 (DP 1820 B3XF and DP 1823 NR B2XF) was planted on 7 June 2019 at 50,000 seed acre^{-1} and 4 June 2020 at 50,820 seed acre^{-1}. The irrigation levels were a low evapotranspiration (ET) replacement rate of 30% and a high ET rate of 70%. Urea-ammonium nitrate (UAN; 32-0-0) was applied prior to planting (pre), 3 weeks following emergence (PE) and at pinhead square (PHS) at different rates which included:

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

Soil cores were collected and composited by zone prior to pre-plant fertilizer application on 8 May 2019 and 30 March 2020 at 0-6”, 6-12” and 12-24” soil depths. Samples were sent to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory. Soil macronutrients were extracted using Mehlich 3 (Mehlich, 1978; Mehlich, 1984) and micronutrients were extracted using diethylenetriaminepentaacetic acid (DTPA) (Lindsay and Norvell, 1978). NDVI data was collected using the Holland Scientific GeoScoutX data logger and the Holland Scientific Crop Circle sensor ACS-211 (2019) and ACS 435 (2020 & 2021). Data was collected about every two weeks, which totaled 11 sampling dates in 2019, and in 2020 there were 15 sampling dates. The ACS-211 measures at 670 nanometers (nm) and 780 nm wavelengths, and the output is five samples sec^{-1}. The ACS-435 measures at 670 nm, 730 nm, and 780 nm. The sensors were mounted 40 inches above the plant canopy of the tallest plants in the 135-0-0 treatment and high irrigation level of rows two and three. The ACS-211 has a field of view of 40° by 8°, while the ACS-435 has a field of view of 40^{o} by 10^{o}.

A Case International Harvester 1400 cotton stripper was used in mechanical harvest of the cotton in 2019. The stripper was not fitted with a bur extractor, thus bur cotton and not seed cotton was collected at harvest in 2019. A John Deere cotton stripper was used in 2020. The center two rows were harvested at the end of the season on 16 Nov 2019 and 11 Nov 2020. Bur cotton sample weights were collected in the field in 2019 and seed cotton weights were collected in 2020. Following harvest samples of bur cotton and seed cotton from each plot were ginned at the Texas A&M AgriLife Research and Extension Center gin in Lubbock, TX.

Plant samples were collected to determine N uptake prior to harvest by sampling the whole cotton plant at first open boll (Bronson et al., 2018). A 50-cm segment of plants from two rows were cut at ground level. The whole plants are then separated into leaves, bolls, and stems. The plant parts were then dried at 65°C and weighed before grinding on a Thomas Wiley universal mill. The bolls were then separated into seed cotton and burrs. The seed cotton is weighed and then ginned using a small custom-built tabletop ten saw box gin (Dennis manufacturing, Athens, TX). After ginning, the lint and seed were weighed separately, and the seed was acid delinted and then ground. Once the leaves, stems, burrs and seed have been ground to pass a 2-mm mesh sieve, they were shipped to Waters Agricultural Labs in Camilla, Georgia, and N was determined using a high temperature combustion process and was reported on a dry plant basis (Nelson & Sommers, 1973). Nitrogen uptake was calculated by multiplying N concentration by biomass. Internal NUE (iNUE) was calculated by dividing lint yield by total N uptake to determine optimal N fertilization and reduced N export from over-fertilization (Bronson, 2021). Agronomic N use efficiency (ANUE) was calculated to determine the efficiencies with N fertilizer applied at different rates and time periods compared to the pre-season N fertilizer rate.

$$\text{ANUE}=\frac{Y-Y_0}{F}$$

where Y is the yield of harvested portion of the crop with applied nutrient, Y_0 is the yield in the control (PP) and F is the amount of N applied (Snyder & Bruulsema, 2007). Recovery N use efficiency (RNUE) was calculated to determine crop uptake of the applied N.

$$\text{RNUE}=\frac{U-U_0}{F}$$

where U is the total N uptake in aboveground crop biomass with applied N, U_0 is the total N uptake in aboveground crop biomass in the control (PP) and F is the amount of N applied (Snyder & Bruulsema, 2007).

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 was calculated using two irrigation treatments in a split split-plot design with four replications (PROC GLIMMIX) at $\alpha < 0.05$. Means of treatment effects were compared within sample using Fisher's least significant difference (LSD) at $\alpha < 0.05$. Pearson's simple linear regression (PROC REG) was used to evaluate the relationship between lint yield and NDVI at $\alpha < 0.05$. Main effects of N rate, irrigation level, and cultivar on cotton lint yield were analyzed. The effect of N fertilizer treatment on NDVI and yield were analyzed within irrigation and cultivar due to significance of these factors.

RESULTS AND DISCUSSION

Soil results in 2019 indicated an average pH of 7.8 across all depths. Phosphorus ranged from high (59 ppm) at the shallowest depth (0-6") to very low (6 ppm) at the deepest depth (12-24"), while K ranged from very high (456 ppm) to high (282 ppm). Calcium (>750 ppm), Mg (>150 ppm), and S (>13 ppm) were high, and Na (<98 ppm) was very low according to the rating system of the Texas A&M AgriLife Extension Soil, Forage and Water testing lab (Table 1). Soil NO_3^--N ranged from 14 ppm at the shallowest depth (0-6") to 21 ppm at the deepest depth of 12-24" (Table 1). Soil results in 2020 indicated an average pH of 7.6 across all depths. Phosphorus ranged from moderate (43 ppm) at the shallowest depth (0-6") to very low (5 ppm) at the deepest depth (12-24"), while K ranged from very high (385 ppm) at the shallowest depth to high (236 ppm) at the deepest depth (12-24"). Calcium (>750 ppm), Mg (>150 ppm) and S (>13 ppm) were high, and Na (<98 ppm) was very low according to the rating system of the Texas A&M AgriLife Extension Soil, Forage and Water testing lab

(Table 1). Nitrate-N ranged from 23 ppm at the shallowest depth (0-6") to 48 ppm at the deepest depth of 12-24". The nutrients NO_3^--N, P and K decreased deeper into the soil profile, while Ca and Na increased deeper into the soil profile for both years.

Table 1. Soil characterization of samples collected at three depths (0-6, 6-12 and 12-24 inches) prior to fertilizer application in 2019 and 2021.

Year	Depth	pH	EC	NO_3^--N	P	K	Ca	Mg	S	Na
	inch	--	umhos cm^{-1}				ppm			
	0-6	7.6	171	14	59	456	1996	694	21	22
2019	6-12	7.9	134	11	24	299	1948	815	24	40
	12-24	7.9	207	21	6	282	4878	861	41	78
	0-6	7.6	223	23	43	385	1986	664	23	26
2020	6-12	7.7	239	27	12	251	1953	714	26	42
	12-24	7.6	395	48	5	236	4586	733	45	87

Lint yield differences within cultivar and irrigation level were determined in 2019 and 2020. Under the 70% ET irrigation level in 2019, lint yield of DP 1820 with the 75-0-0 treatment was greater than the 135-0-0 treatment, while lint yield of DP 1823 with the 135-0-0 treatment was greater than the 15-0-0 treatment (Fig. 1A). With the 30% ET irrigation level in 2019, lint yield of DP 1820 with the 75-0-0 and 135-0-0 treatments was greater than the 15-0-0 treatment (Fig. 1B). With the 70% ET irrigation level in 2020, lint yield of DP 1820 with the treatments of 15-0-0 and 75-0-0 was greater than the 135-0-0 treatment, while with DP 1823 the 75-0-0 and 135-0-0 treatments were greater than the 15-0-0 treatment (Fig. 2A). Under the 30% ET irrigation level in 2020, lint yield of DP 1820 with the treatments of 15-0-0 and 135-0-0 were greater than the 75-0-0 treatment (Fig. 2B). A possible reason that the highest split application treatment of 135-0-0 was not consistently greater than the 75-0-0 treatment may be due to high levels of N in the irrigation water.

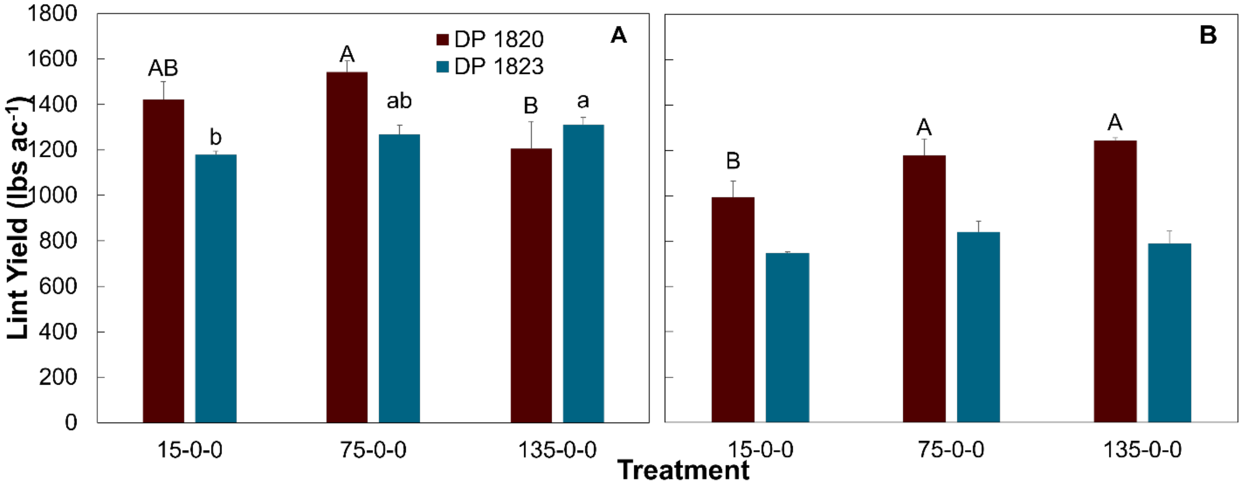

Figure 1. Cotton lint yield determined in 2019 (A) under the 70% ET irrigation level and (B) under the 30% ET irrigation level. Uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at P<0.05 by Fisher's protected LSD. The vertical bars represent standard error of the mean.

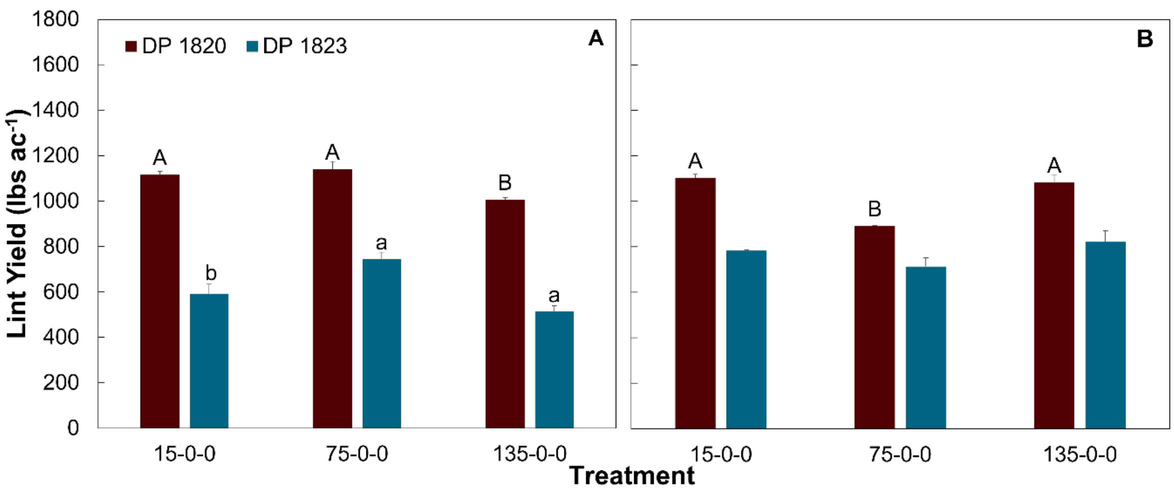

Figure 2. Cotton lint yield determined in 2020 (A) under the 70% ET irrigation level and (B) under the 30% ET irrigation level. Uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at P<0.05 by Fisher's protected LSD. The vertical bars represent standard error of the mean.

Nitrogen uptake was significant in 2020 (Fig. 3). With the 70% ET irrigation level, the 15-0-0 and 75-0-0 treatments were greater than the 135-0-0 treatment for DP 1823. With the 30% ET irrigation level the 135-0-0 treatment was greater than the 15-0-0 and 75-0-0 treatments with the DP 1820 cultivar. The 15-0-0 and 75-0-0 treatments were less than the 135-0-0 treatment within the 30% ET irrigation level and the DP 1823 cultivar. The results within the 70% ET irrigation level were opposite the 30% ET irrigation level.

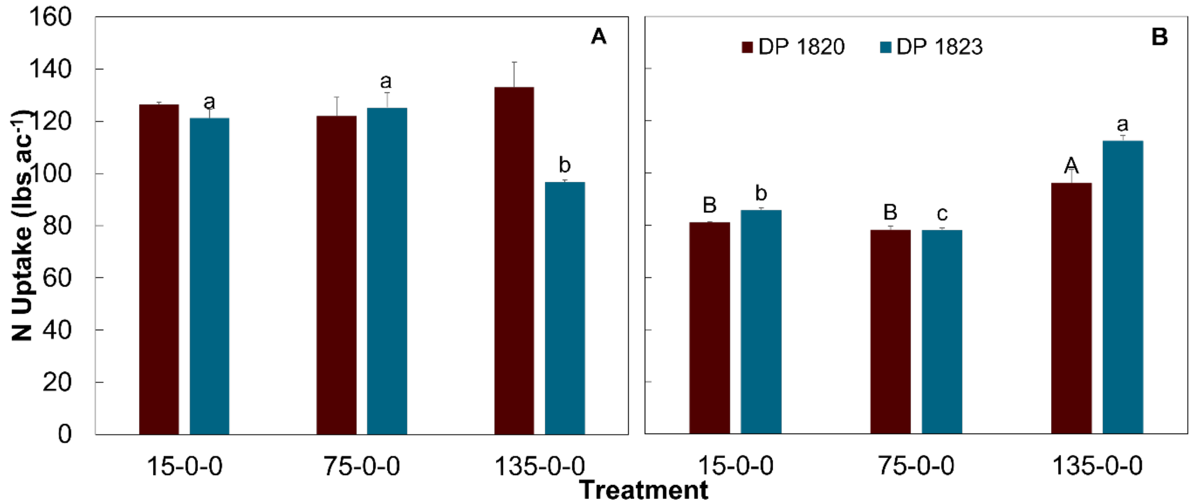

Figure 3. Nitrogen uptake in 2020 under the 70% ET (A) and 30% ET (B) irrigation levels. Uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at α<0.05 by Fisher's protected LSD. The vertical bars represent standard error of the mean.

Recovery NUE was significant in 2020 within the 30% ET irrigation level with the 135-0-0 treatment being greater than the 75-0-0 treatment with DP 1823 (Table 2). Agronomic NUE was significant in 2019 with DP 1820 within the 70% ET irrigation level being greater with the 75-0-0 treatment than the 135-0-0 treatment. In 2020, DP 1823 was greater with the 75-0-0 treatment and the 70% ET irrigation level. With the 30% ET irrigation level, the 135-0-0 treatment was greater than the 75-0-0 treatment with both cultivars (Table 2). Internal NUE was 13.96 lb lint lb N^{-1} for the 135-0-0 treatment in 2019 with the 70% ET irrigation level and the cultivar DP 1823, however it was most likely deficient in N due to it being greater than 11.4 lb lint lb N^{-1} according to Bronson (2021). The 15-0-0 treatment was less than the 75-0-0 and 135-0-0 treatments with the 30% ET irrigation level and the cultivar DP 1820. The cultivar DP 1820 under the 70% ET irrigation level had an optimal iNUE across all treatments. In 2020, the 15-0-0 treatment had the greatest N uptake (13.6 lb lint lb N^{-1}), which was deficient in N, while the 75-0-0 and 135-0-0 treatments had an optimal iNUE according to Bronson (2021) (Table 2). However, N was mostly taken up in excess according to our results. When plant N uptake was the greatest, iNUE was the lowest, which resulted in excess N uptake due to it being less than 10.5 lb lint lb N^{-1} (Rochester, 2011; Bronson, 2021) (Figure 3 & Table 2).

Table 2. Nitrogen use efficiencies in 2019 and 2020 with DP 1820 and DP 1823. Letters within irrigation levels are not different at α<0.05 by Fisher's protected LSD.

Irrigation	Cultivar	N	RNUE 2019	RNUE 2020	iNUE 2019	iNUE 2020	ANUE 2019	ANUE 2020
		(kg ha^{-1})	(lb N lb N applied^{-1})		(lb lint lb N^{-1})			
70% ET	DP 1820	15	---	---	9.757	8.824	---	---
		75	0.002	-0.060	10.708	9.480	1.566 A	0.334
		135	-0.174	0.048	9.780	7.700	-1.317 B	-0.808
	DP1823	15	---	---	11.824	4.859 B	---	---
		75	-0.314	0.053	13.282	5.983 A	1.151	2.053 A
		135	-0.283	-0.182	13.958	5.304 AB	0.952	-0.575 B
30% ET	DP 1820	15	---	---	5.908 B	13.613 A	---	---
		75	-0.038	-0.038	8.300 A	11.411 B	2.391	-2.816 B
		135	-0.042	0.113	9.533 A	11.317 B	1.806	-0.153 A
	DP1823	15	---	---	8.161	9.142 A	---	---
		75	0.120	-0.102 B	8.436	9.144 A	1.511	-0.934 B
		135	0.060	0.198 A	7.991	7.311 B	0.462	0.286 A

A relatively poor relationship was observed between NDVI and lint yield for both 2019 and 2020. Under the 70% ET 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 greater relationship at squaring (42 DAP; R^2=0.606) (Table 3). With the 30% ET irrigation level in 2019 NDVI had a greater relationship with lint yield at the flowering/open bolls growth stage
(69 DAP; R^2=0.569) with the cultivar DP 1820, while DP 1823 had a greater relationship at squaring (42 DAP; R^2=0.281) (Table 3). With the 70% ET irrigation level in 2020 NDVI had a greater relationship with lint yield at the boll development growth stage (92 DAP; R^2=0.389) with the cultivar DP 1820, while DP 1823 had a greater relationship at boll development growth stage (99 DAP; R^2=0.297). The cultivar DP 1820 had a better relationship with NDVI and lint yield during the flowering growth stage of both years, while DP 1823 had a greater relationship during the squaring growth stage in 2019 and in 2020 it was higher during boll filling, but not significant. The poor relationships between NDVI and lint yield may be due to the limited range in lint yield across N treatments. The environmental conditions in 2019 may have affected the interaction between NDVI and lint yield. Similar results to Bronson et al. (2003 & 2005) were determined in which NDVI had a moderate to poor correlation to lint yield.

Table 3. Regression R^2 and p-values for NDVI vs lint yield in 2019.

		DP 1820		DP 1823	
DAP	Irrigation	R^2	p-value	R^2	p-value
26	70% ET	0.431	0.020	0.531	0.007
	30% ET	0.027	0.611	0.003	0.87
39	70% ET	0.421	0.022	0.031	0.585
	30% ET	0.007	0.793	0.126	0.257
42	70% ET	0.425	0.022	0.606	0.003
	30% ET	0.323	0.054	0.281	0.076
49	70% ET	0.028	0.602	0.042	0.522
	30% ET	0.107	0.299	0.072	0.401
56	70% ET	0.616	0.003	0.134	0.242
	30% ET	0.163	0.194	0.163	0.193
63	70% ET	0.546	0.006	0.461	0.015
	30% ET	0.048	0.492	0.193	0.153
69	70% ET	0.393	0.029	0.027	0.610
	30% ET	0.569	0.005	0.189	0.158
80	70% ET	0.265	0.087	0.004	0.840
	30% ET	0.056	0.461	0.177	0.173
88	70% ET	0.192	0.154	0.287	0.073
	30% ET	0.000	0.957	0.181	0.168
101	70% ET	0.004	0.845	0.380	0.033
	30% ET	0.113	0.285	0.255	0.094
126	70% ET	0.000	0.986	0.001	0.934
	30% ET	0.003	0.857	0.143	0.225

Table 4. Regression R^2 and p-values for NDVI vs lint yield in 2020.

		DP 1820		DP 1823	
DAP	Irrigation	R^2	p-value	R^2	p-value
22	70% ET	0.147	0.219	0.083	0.363
	30% ET	0.244	0.176	0.016	0.764
36	70% ET	0.185	0.163	0.02	0.664
	30% ET	0.037	0.619	0.142	0.317
57	70% ET	0.222	0.122	0.009	0.775
	30% ET	0.112	0.378	0.044	0.588
64	70% ET	0.291	0.070	0.003	0.864
	30% ET	0.041	0.600	0.129	0.342
69	70% ET	0.326	0.052	0.030	0.593
	30% ET	0.578	0.017	0.018	0.734
78	70% ET	0.268	0.085	0.021	0.653
	30% ET	0.091	0.432	0.000	1.000
84	70% ET	0.292	0.070	0.172	0.181
	30% ET	0.373	0.081	0.179	0.256
92	70% ET	0.389	0.030	0.076	0.387
	30% ET	0.184	0.249	0.149	0.305
99	70% ET	0.201	0.143	0.297	0.067
	30% ET	0.062	0.518	0.141	0.319
106	70% ET	0.317	0.057	0.047	0.497
	30% ET	0.027	0.670	0.174	0.264
111	70% ET	0.106	0.303	0.174	0.178
	30% ET	0.076	0.474	0.166	0.276
127	70% ET	0.129	0.252	0.007	0.793
	30% ET	0.065	0.509	0.282	0.141
132	70% ET	0.281	0.076	0.066	0.42
	30% ET	0.104	0.397	0.002	0.922

SUMMARY

This research was aimed at evaluating the effects of N rate, irrigation level and cotton cultivar on lint yield and NUE. With N being required in greater quantities than other nutrients in cotton development the lack of yield response to the highest treatment (135-0-0) when compared to the 75-0-0 treatment may be due to high levels of N in irrigation water or residual soil N below the deepest sampling depth. Recovery efficiency was variable. When N uptake was the greatest, iNUE was the lowest, which resulted in excess N uptake (Rochester, 2011; Bronson, 2021). 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. Similar results to Bronson et al. (2003 & 2005) were determined in which NDVI had a moderate to poor correlation to lint yield. NDVI may not be the best predictor of lint yield based on total N uptake in the Texas High Plains since there was not a consistently strong relationship between lint yield and N.

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NUTRIENT CYCLING FOLLOWING COVER CROP TERMINATION IN TEXAS COTTON PRODUCTION

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ABSTRACT

Cotton producers on the Texas High Plains (THP) have not readily adopted conservation practices such as no-tillage and cover crops due to concerns regarding water availability and its subsequent impact on the proceeding cotton (*Gossypium hirsutum* L.) crop. However, prior research in the THP has shown that soil water availability was greater with the inclusion of cover crops compared to conventionally tilled cotton. A study was initiated into an existing experiment at the Agricultural Complex for Advanced Research and Extension Systems near Lamesa, TX. The objective of the study was to determine the decomposition rate and nutrient cycling potential of cover crops following termination. Treatments included: 1) conventional tillage, winter fallow (CT); 2) no-tillage, rye (*Secale cereal* L.) cover crop (NTR); and 3) no-tillage, mixed species cover crop (NTM). Mixed cover crop species included 10% hairy vetch (*Vicia villosa* Roth), 7% radish (*Raphanus sativus* L.), 33% winter pea (*Pisum sativum* L.), and 50% rye, by weight. Litterbags were installed at field-scale into the plots following cover crop termination on 27 March 2020 and collected periodically at 4, 8, 16, 32, 64, and 128 days after termination (DAT) during the growing season to determine biomass decomposition. Soil samples were collected along with the litterbags to determine inorganic nitrogen (N) fractions (nitrate and ammonium) and soil protein concentrations. Results indicated that approximately 75% of the terminated cover crop biomass was persistent in the field 128 days after termination. Soil N followed similar trends to biomass decomposition indicating that N may not immediately be available to the cotton crop following a cover crop in this semi-arid ecoregion. Soil protein and inorganic N concentrations peaked 8 and 16 DAT, respectively, before steadily decreasing for the rest of the study period. These results suggest N immobilization may serve as a viable culprit to the yield reductions observed following cover crops in Texas High Plains cotton production.

INTRODUCTION

Texas is the largest cotton producing state and annually produces approximately 40% of the US cotton crop (USDA-NASS, 2017). Within Texas, the High Plains region produces a majority of that cotton, but THP production can be significantly impacted by limited rainfall and wind erosion. Cotton producers can reduce their susceptibility to wind erosion with no-tillage and cover crops. However, producers are concerned that cover crops will compete for limited soil water and reduce cotton yields. Prior research near Lamesa, TX demonstrated that cover crop water use is likely not the principal factor causing the yield decline in conservation cropping systems (Burke et al., 2021).

Instead, it is likely that N immobilization by microorganisms mineralizing the cover crops is causing cotton yield reductions. The objective of this experiment was to determine cover crop biomass decomposition rates and N cycling following cover crop termination.

MATERIALS AND METHODS

Site description and experimental design

Management practices were demonstrated near Lamesa, TX at the Agricultural Complex for Advanced Research and Extension Systems (Ag-CARES), a cooperative research site between the Texas A&M AgriLife Research and Extension Center in Lubbock, TX and the Lamesa Cotton Growers, and included: 1) conventional tillage, winter fallow; 2) no-tillage, rye (*Secale cereal* L.) cover crop; and 3) no-tillage, mixed species cover crop. Mixed cover crop species included hairy vetch (*Vicia villosa* Roth, 10%), radish (*Raphanus sativus* L. 7%), winter pea (*Pisum sativum* L., 33%), and rye (50%, by weight). Conventional tillage and no-tillage with a rye cover crop were established in 1998 and a mixed species cover was seeded in 2014 by splitting the 32 row plots into 16 rows within the rye cover crop plots. Cover crops were planted using a no-till drill on 21 November 2019 and were chemically terminated 27 March 2020 using Roundup PowerMAX (32 oz/acre). Prior to termination, above ground biomass of cover crops were harvested from a 9 ft^2 area to calculate herbage mass (dry weight basis), N uptake, and C:N ratios. Biomass from an additional 9 ft^2 sampling area was collected and transferred to 6- x 8-cm nylon litterbags at field scale to simulate decomposition *in-situ*. Litterbags were installed in triplicate into the single or mixed species cover crop plots on 27 March 2020 and collected at 4, 8, 16, 32, 64, and 128 DAT. At each collection date, soil samples were collected from directly beneath the litterbags to a depth of 6 inch and analyzed for soil proteins, nitrate, and ammonium (NO_3^- & NH_4^+). Cotton (DP 1646 B2XF) was planted on 19 May 2019 at a seeding rate 53,000 seeds $acre^{-1}$. Cotton was harvested on 31 October 2020. After cotton harvest the no-till plots were drilled with their respective cover crops.

Calculations and statistical analysis

Biomass decomposition was calculated by applying a natural log curve to the average of the litterbag weights by treatment remaining at a specific collection date following cover crop termination. Total inorganic N was calculated as the sum of NO_3^- and NH_4^+. Potential N availability was calculated by multiplying the amount of biomass produced by the percent N of the biomass. Analysis of variance for all parameters was calculated using a randomized complete block design with three replications (PROC GLIMMIX, SAS 9.4, 2015). Means of treatment effects were compared among treatments using Fisher's least significant difference (LSD) at alpha level = 0.05 for all analyses.

RESULTS AND DISCUSSION

Biomass production and decomposition

There were no differences in biomass production, N concentration, potential N, and C:N ratio between the two cover crop systems (Table 1). Cover crop biomass production was consistent with results reported by Lewis et al. (2018) which reported to potentially reduce cotton lint yields. Hypothetically, if 100% of the biomass were to decompose within a given growing season, approximately 126-128 lb N A^{-1} would be available for the subsequent cotton crop. However, decomposition was limited following cover crop termination in 2020, resulting in ~78% biomass remaining 128 DAT (Fig. 1). These results indicate that only 28 lb N A^{-1} would be available for cotton growth during the entire 2020 growing season. This limited biomass mineralization could have resulted in N limitations as soil microorganisms immobilized N to complete their cellular functions.

Table 1. Cover crop biomass production, nitrogen (N) concentration, potential N, and C:N ratio of rye and mixed species cover crops terminated in 2020.

Cover crop	Biomass (lb A^{-1})	N (%)	Potential N (lb A^{-1})	C:N Ratio
Rye	4,131	3.1	128.0	13.3
Mixed	4,068	3.1	126.2	13.3

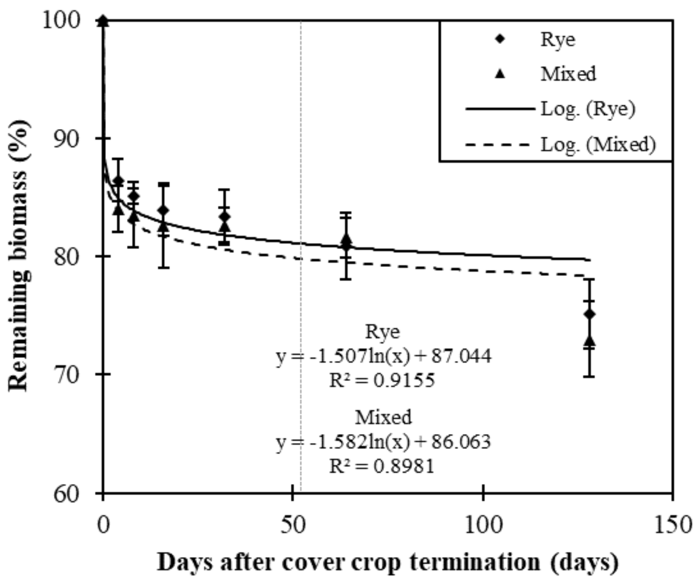

Figure 1. Biomass decomposition following rye and mixed species cover crop termination in 2020. The vertical dashed line represents cotton planting date.

Nutrient cycling

Following cover crop termination, soil inorganic N levels remained constant 0-8 DAT before increasing at 16 DAT (Fig. 2A). This increase in inorganic N at 16 DAT follows increases in soil proteins 8 DAT (Fig. 2B). Following termination, proteins are one of the first products to be released from the biomass, as those proteins are mineralized by soil microbes, they release soil inorganic N resulting in the increase in soil N observed at 16 DAT. After the peak at 8 DAT, soil protein levels decreased throughout the rest of the cotton growing season. Soil inorganic N levels were similar between 16 and 32 DAT, but significantly increased at 64 DAT. The increase in NO_3^--N and inorganic N observed at 64 DAT is likely due to N fertilization shortly after cotton planting. These results indicate that there is likely N immobilization early in the growing season following cover crop termination.

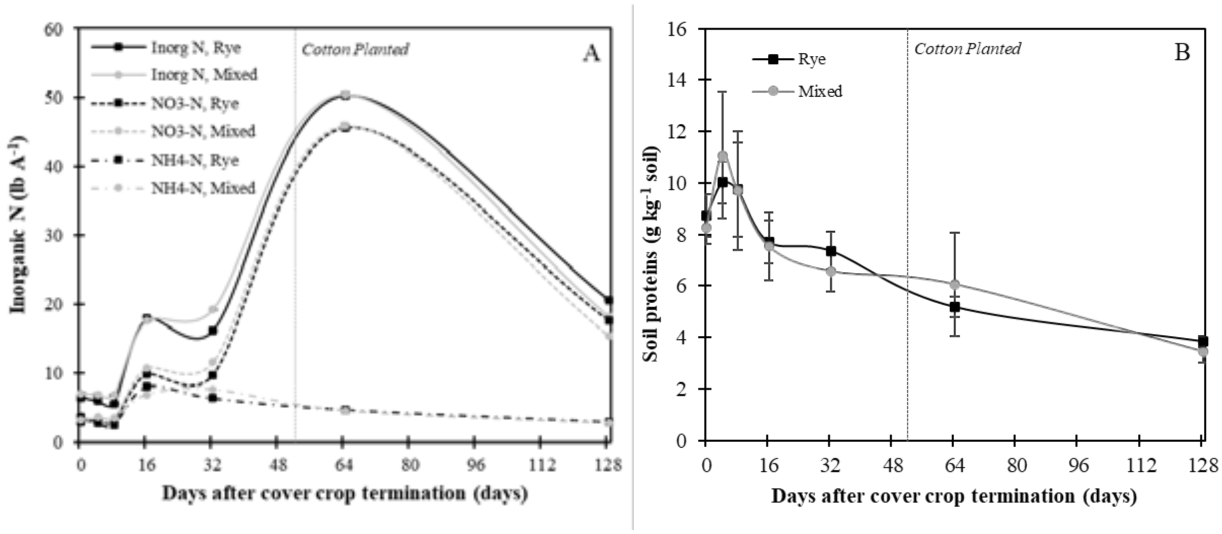

Figure 2. A) Inorganic nitrogen (N) consisting of nitrate (NO_3^--N) and ammonium (NH_4^+-N), and B) soil protein dynamics following rye and mixed species cover crop termination. The dashed vertical lines represent cotton planting.

CONCLUSIONS

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

ACKNOWLEDGEMENTS

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INTESIFIED FORAGE WINTER WHEAT PRODUCITON IMPACTS ON SOIL CHEMICAL AND PHYSICAL PROPERITIES UNDER DIFFERENT TILLAGE MANAGEMENT SYSTEMS

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ABSTRACT

Producers often take advantage of the opportunity to graze livestock on wheat during the winter and spring months, the fields are then left fallow during the summer. Interest has increased into the replacement of summer fallow periods with forage quality crops for livestock grazing. This has resulted in many questions regarding the impacts of intensive forage management on the production and sustainability of the land. This study, in conjunction with the Noble Research Institute, attempts to answer these questions. Established winter wheat grazing paddocks managed under no-till and tillage systems were used to evaluate the impact of intensification of forage cropping on the impacts of soil chemical and physical parameters. The two established tillage management systems were the primary factor of the study, within each of those were a treatment of cropping method of either summer fallow or summer forage cropping. Soil samples collected at the beginning of each winter wheat season were evaluated for the impacts of intensification by summer forage cropping. Soil bulk density and infiltration were often reduced and soluble salts were increased by the intensification of forage cropping. These impacts often decreased as the study progressed, often to a level of non-significance in final wheat season. The soil organic matter was not impacted by either summer cropping method but did show a decline following the first year of the trial. This study tells us the impact of intensive for cropping are minimal when present and become in-significant after the first 3 to 4 years in both tillage management systems.

INTRODUCTION

The common practice for annual winter wheat forage production in Oklahoma is to graze a wheat crop and follow with a summer fallow period. In order to reduce the time in which a field would not be productive, recent research has evaluated the possibility of increasing production by replacing traditional fallow periods with forage quality summer crops (Horn et al., 2020). The introduction of summer into a winter wheat system have shown beneficial for reducing erosion and nitrate losses, with increases in soil carbon, when managed properly (Blanco-Canqui et al., 2013; Blanco-Canqui & Ruis, 2020). However, increasing annual forage production could result in greater nutrient mining of the soil due to the increased biomass removal by grazing livestock. Another common practice among Oklahoma forage producers managing grazed land using traditional tillage practices, such as sweep or disc tillage, for seedbed preparation and weed management. With the increased popularity of no-till management in crop production regions, there has been interest among forage produces about implementing similar no-till management schemes. There have been reports of improvements in soil bulk density (Thomas et al., 2008) and nitrogen (N) concentrations (Franzluebbers & Stuedemann, 2014) following the introduction of no-tillage. However, similar to producing a crop during a normal fallow period, no-till management can also impact soil chemical characteristics of the soil, by introducing stratification due to eliminating soil homogenization by tillage (Crozier et al., 1999). The potential interaction between these two management practices has been investigated little, and has become of concern to researchers, as many producers look to increase production of land while reducing costs by utilizing a no-till management approach. The objective of this study is to determine and compare the soil chemical and physical property impacts of an intensified forage winter wheat grazing system under conventional and no-till management strategies.

MATERIALS AND METHODS

This study was conducted over five years (2015-2020) including both winter and summer cropping seasons near Ardmore, Oklahoma (34° 13’ 0.75” N, 97° 12’ 30.98” W). The trial area was managed as a winter wheat grazing unit for more than 30 years prior to establishment with paddock tillage management strategies in use since the 1990’s. Nitrogen management was done using Urea (46-0-0), with applications of 50 lb N ac^{-1} in the first two years, and 25 lb N ac^{-1} in the final three years of the trial. The trial was established in a winter wheat grazing, summer fallow rotation, as a randomized complete block design with a two-by-two factorial treatment structure with five replications. Treatments factors applied to replicate 5 ac grazing paddocks were the primary factor of crop residue management using either conventional tillage of multiple passes with a disc, or no tillage management system. The secondary factor of summer cropping method of either fallow or a summer crop mixture. Experimental units were managed using the best management practices for the production system, with applications of herbicides and fungicides, and animals provided with water, supplemental feed, and vaccinations as necessary.

Soil water infiltration rates were measured using a mini disk infiltrometer (Meter Group; Pullman, WA.) set at 0.8 in suction at 5 randomly selected locations in each paddock, within a three-day timeframe targeting similar soil moisture contents. Soil infiltration readings were taken in 30 second intervals for a total of 5 minutes. Bulk density measurements were taken prior to each cropping season from each paddock with five samples collected using a 5-cm diameter hammer probe (AMS Inc; American Falls, ID). The samples were then stratified by 0–2 in., 2–4 in., and 4–6 in. and oven dried at 150 °F to a constant weight. A 0–6 in. bulk density was calculated by combining the stratified samples. Standard soil test samples were collected from twelve, 1-inch cores from each paddock at the beginning of each cropping season. Soil chemical analysis was conducted using standard soil testing procedures for organic matter and soluble salt after drying soil at 150°F for up to 12 hours followed by grinding the soil to pass through a 2-mm sieve. Sampling date soil data was analyzed for crop influence within tillage management system at an alpha of 0.05. Statistical analysis was done using PROC GLM in SAS 9.4.

RESULTS AND DISCUSSION

Soil bulk density showed to be impacted by the intensification at the beginning of the 2017/18 winter wheat growing season for both tillage systems as well as the beginning of the 2018/19 winter wheat growing season in the tilled system. The beginning bulk density of the no-till system was decreased by the intensification by 0.05 g cm^{-3} in the 2017/18 and 0.12 g cm^{-3} in the 2018/19 growing season (Figure 1). The tilled system showed an increase in 2017/18 beginning bulk density of 0.22 g cm^{-3} when summer forages were used in place of a summer fallow (Figure 2).

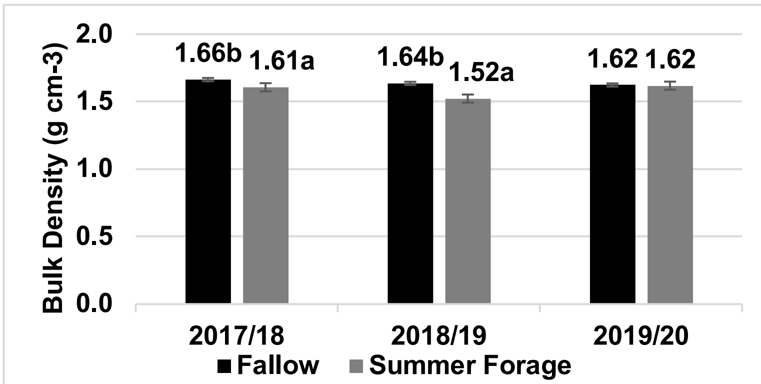

Figure 1. Soil bulk density (g cm^{-3}) taking at the beginning of each no-till winter wheat cropping season. Letters denote significant differences within sampling date.

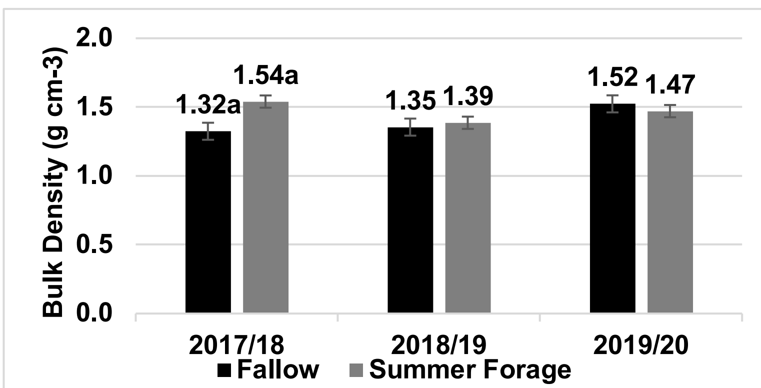

Figure 2. Soil bulk density (g cm^{-3}) taking at the beginning of each tilled winter wheat cropping season. Letters denote significant differences within sampling date.

Soil water infiltration measured at the beginning of each winter wheat season reported a significant impact of intensification in the no-till system in the 2016/17 season. The no-till system in 2016/17 had greater infiltration of surface applied water by 0.98 cm^3 $hour^{-1}$ when the summer season was fallowed compared to cropped (Figure 3). Similar intensification impacts to soil water infiltration were not observed following the 2016/17 season, however the final two no-till winter wheat seasons reported numerically greater infiltration when summers were cropped. The tilled system reported no significant impacts of intensification, but typically had greater infiltration rate when summer periods were left fallow (Figure 4).

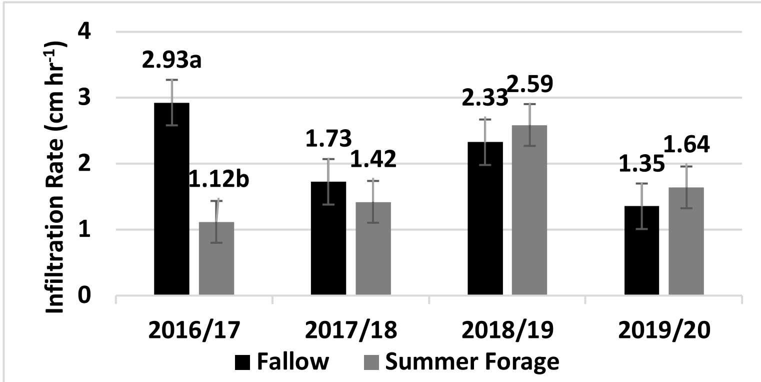

Figure 3. Soil water infiltration (cm hr $^{-1}$) taking at the beginning of each no-till winter wheat cropping season. Letters denote significant differences within sampling date.

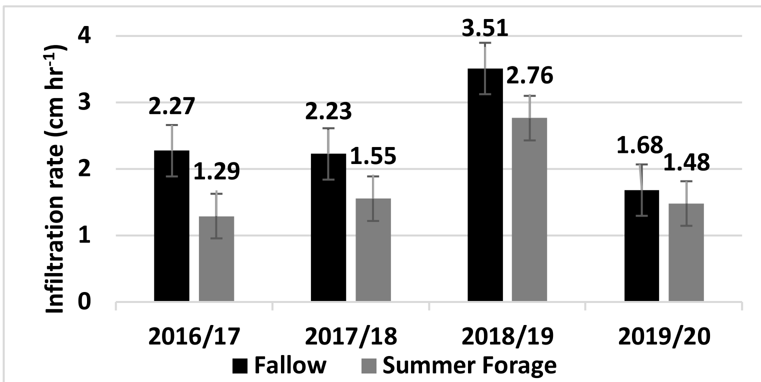

Figure 4. Soil water infiltration (cm hr $^{-1}$) taking at the beginning of each tilled winter wheat cropping season.

Soil organic matter content was not impact by intensification in either tillage system at the beginning of any winter wheat season. There was a decrease from the first recorded sampling, at the beginning of 2015/16, from an average of 2.2% in the no-till and 1.92% in the tilled systems to 1.53 and 1.17%, respectively, in the second sampling (Figure 5; Figure 6). Soil organic matter content stayed similar through the subsequent sampling dates.

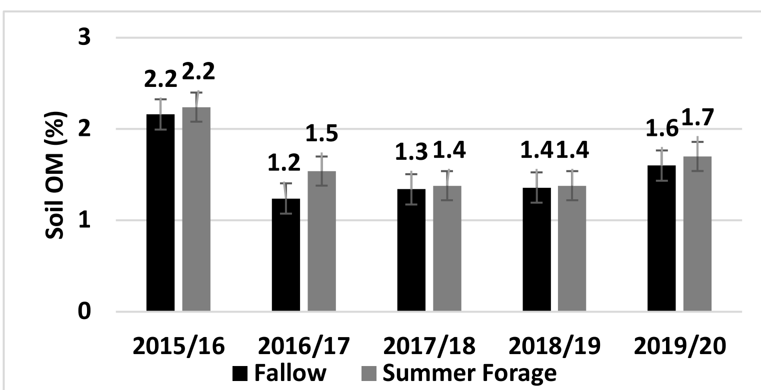

Figure 5. Soil organic matter content (%) taking at the beginning of each no-till winter wheat cropping season.

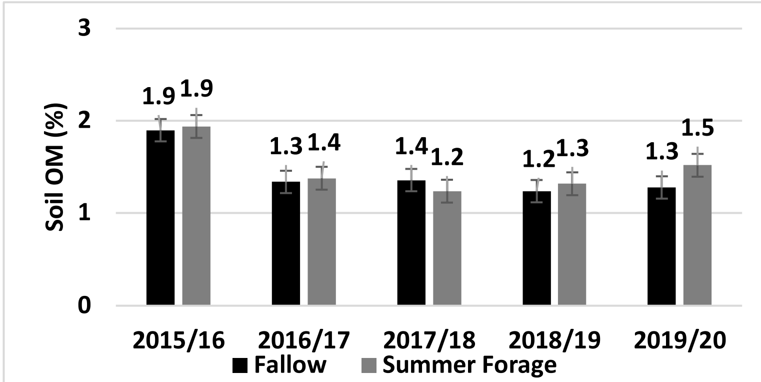

Figure 6. Soil organic matter content (%) taking at the beginning of each tilled winter wheat cropping season

Soluble salts concentration was reported to be significantly different for both tillage systems. In the no-till system were significant different in the 2016/17, 2017/18, and 2018/19 winter wheat seasons. These significant seasons all reported lower soluble salt concentrations when the previous summers were fallowed as compared to cropped with a summer forage by 42 to 63 ppm (Figure 7). Differences in the 2015/16 no-till soluble salts are non-significant (p=0.0506) and due to spatial variability, as no treatments had been applied at the time of sampling. The tilled paddocks reported intensification impacts in the 2016/17 and 2018/19 winter wheat seasons (Figure 8). Both of these seasons had 85 and 70 ppm less soluble salts in the fallow treatments than in treatments that were cropped during the summer in the 2016/17 and 2018/19 seasons, respectively.

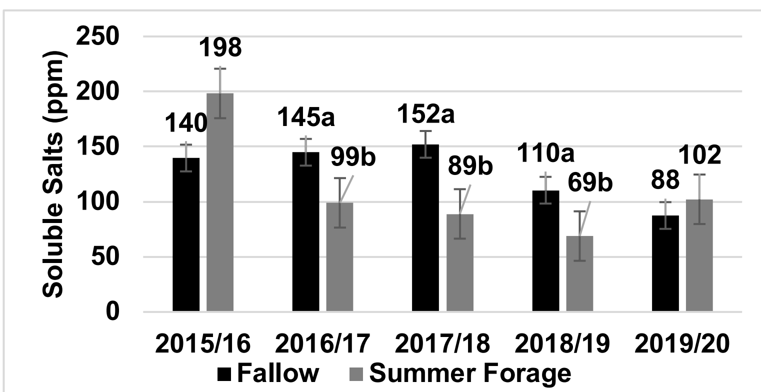

Figure 7. Soil soluble salt concentration (ppm) taking at the beginning of each no-till winter wheat cropping season. Letters denote significant differences within sampling date.

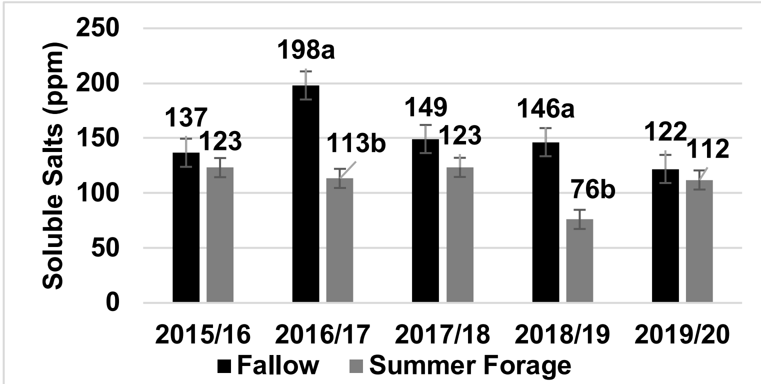

Figure 8. Soil soluble salt concentration (ppm) taking at the beginning of each tilled winter wheat cropping season. Letters denote significant differences within sampling date.

The impacts of intensification on soil properties were observed in the second, third, and occasionally fourth year of the study. As the study progressed toward a conclusion all impacts were found insignificant in the final winter wheat season in both tillage managed systems. These results echo the observations of Blanco-Canqui et al. (2013), who found the impacts of intensive cropping, by replacement of a fallow period, on soil properties to be short lived. Although this data is a small portion of a larger study evaluating the impacts of forage cropping intensification, they stand alone in showing the impacts to soil chemical and physical parameters.

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MICROPLASTICS IN SWEET CORN: POLYMER COATED FERTILIZERS

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ABSTRACT

Polymer coated fertilizers enhance nutrient efficiency and potentially reduce environmental nutrient loss. However, heavy runoff can carry microplastics into waterways and could negatively impact aquatic or terrestrial environments (Alimi, 2018). The objective of this project is to determine the microplastics concentrations in runoff water in sweet corn (*Zea mays* 'sweetness') with various placement methods. The full factorial study design consisted of three fertilizer sources (uncoated dry, coated dry, or liquid slow release) with all combinations of three placement methods (incorporated broadcast, surface broadcast, or subsurface band) compared to an unfertilized control. Two in-season runoff events were simulated and microplastics concentration determined. Although there were no differences in sediment movement, the treatments that received polymer coated fertilizers resulted in significantly higher microplastics with fertilizer placement showing a statistical difference in how many visible fertilizer coatings were found in the runoff water, with the highest at 0.112 lb ac^{-1} when applied to the surface and not incorporated. When the coated fertilizers were placed in the subsoil in a 2x2 band, or broadcast incorporated, the microplastics in the runoff was significantly less at 0.006 and 0.004 lb ac^{-1}, respectively. Both the subsurface band and the incorporated broadcast were effective at nearly eliminating visible microplastic movement in surface runoff. Another year of testing will be done to verify the data.

INTRODUCTION

Whether in large commercial farms or small residential settings, providing nutrition is vital for a sustainable plant system. In general, the law of the conservation of mass requires replenishment of nutrients that are removed (Hopkins, 2020). The development and use of fertilizers as part of the "Green Revolution" greatly improved the availability of food, fuel, and fiber globally, but it has come at great cost of natural resources and nutrient pollution.

Agriculture is the leading cause of water quality problems in developed nations, with nitrogen and phosphorus enrichment resulting in eutrophication. The combined effect of agriculture and urban systems seriously degrades the quality of many lakes and coastal waters. Significant efforts have been made to synergistically allow for efficient fertilization while minimizing negative impacts on water and other natural resources. One of the best solutions has been polymer coated fertilizers. This technology decreased environmental nutrient losses while reducing application rates without hurting growth. However, polymer coatings could negatively impact aquatic and terrestrial ecosystems (Hopkins, 2020).

The objective of this project is to determine the microplastics concentrations in runoff water in sweet corn (*Zea mays* 'sweetness') when fertilized with polymer coated products, compared to uncoated fertilizers and an unfertilized control, using three placement methods (incorporated broadcast, surface broadcast, or subsurface band).

MATERIALS AND METHODS

A field study was conducted in 2021 at Brigham Young University (BYU; 40°16'1.40" N 111°39'28.59" W) in Provo UT to evaluate microplastics loss in sweet corn (*Zea mays* 'sweetness'). The study was conducted on a calcareous sandy clay loam soil. The full factorial study design consisted of three fertilizer sources (uncoated dry, coated dry, or liquid slow release) with all combinations of three placement methods (incorporated broadcast, surface broadcast, or subsurface band) compared to an unfertilized control with four replications. Fertilized plots received 220-80-80-169(S)-3(Zn)-4(Fe)-3(Mn)-0.6(Cu)-1.4(B) in lb/ac. The macronutrients were applied as: 1) Uncoated = urea, monoammonium phosphate, and potassium sulfate; 2) Coated = Environmentally Smart Nitrogen (ESN) (Nutrien, Saskatoon, Saskatchewan, Canada) and Osmocote 14-14-14 (ICL, Dublin, Ohio, USA); 3) Liquid = UFLEXX (Koch, Wichita, Kansas, USA), ammonium polyphosphate, and potassium sulfate. The micronutrients were applied as an elemental sulfur impregnated dry material (Tiger Industries, Huston, Texas).

Each plot was 7.2 foot long by 3.6 foot wide. Plots were built to be gently sloping (~1%) towards the long end where a 9 by 13-inch an aluminum pan with a lid with holes drilled through the tops was buried at the soil surface to allow runoff water collection. Runoff water was collected on July 22 with a simulated large precipitation event until the pan had approximately ~16-32 ounces of water and sediment. The water and sediment was immediately transferred to 32 ounce glass jars and sealed and refrigerated (samples were stored in the dark to avoid microplastics degradation).

The sediment was filtered out (FisherBrand P5 paper, porosity medium, filter rate slow) and measured gravimetrically after drying. A drop of concentrated sodium hypochlorite was added to the remaining water and then a subsample stored for further analysis of nutrient concentrations and non-visible microplastics (data not yet complete).

Visible microplastics coatings were removed manually from the filtered sediment. The coatings were punctured and placed in a vial with deionized water in order to release any fertilizer left in the coatings. After 24 hours, the coatings were removed and rinsed and then dried at room temperature for at least 24 hours. Microplastics concentrations were determined gravimetrically.

Statistical analysis was performed by ANOVA with mean separation by the Tukey Kramer method using SAS software.

RESULTS AND DISCUSSION

Soil sediment loss was considerable, but there were no statistical differences between fertilizer or fertilizer placement treatments (data not shown).

As expected, microplastics were absent from treatments that did not receive polymer coated fertilizer (Fig. 1). Treatments that received polymer coated fertilizers resulted in significantly higher microplastics with fertilizer placement showing a statistical difference in concentration of visible fertilizer coatings found in the runoff water, with the highest when the fertilizer was applied to the surface and not incorporated at 0.112 lb ac^{-1}. When the coated fertilizers were placed in the subsoil in a 2x2 band or broadcast incorporated the microplastics in the runoff with significantly less at 0.006 and 0.004 lb ac^{-1}, respectively. These represent 19 and 28 times decreases in the amount of microplastics that were in the runoff water.

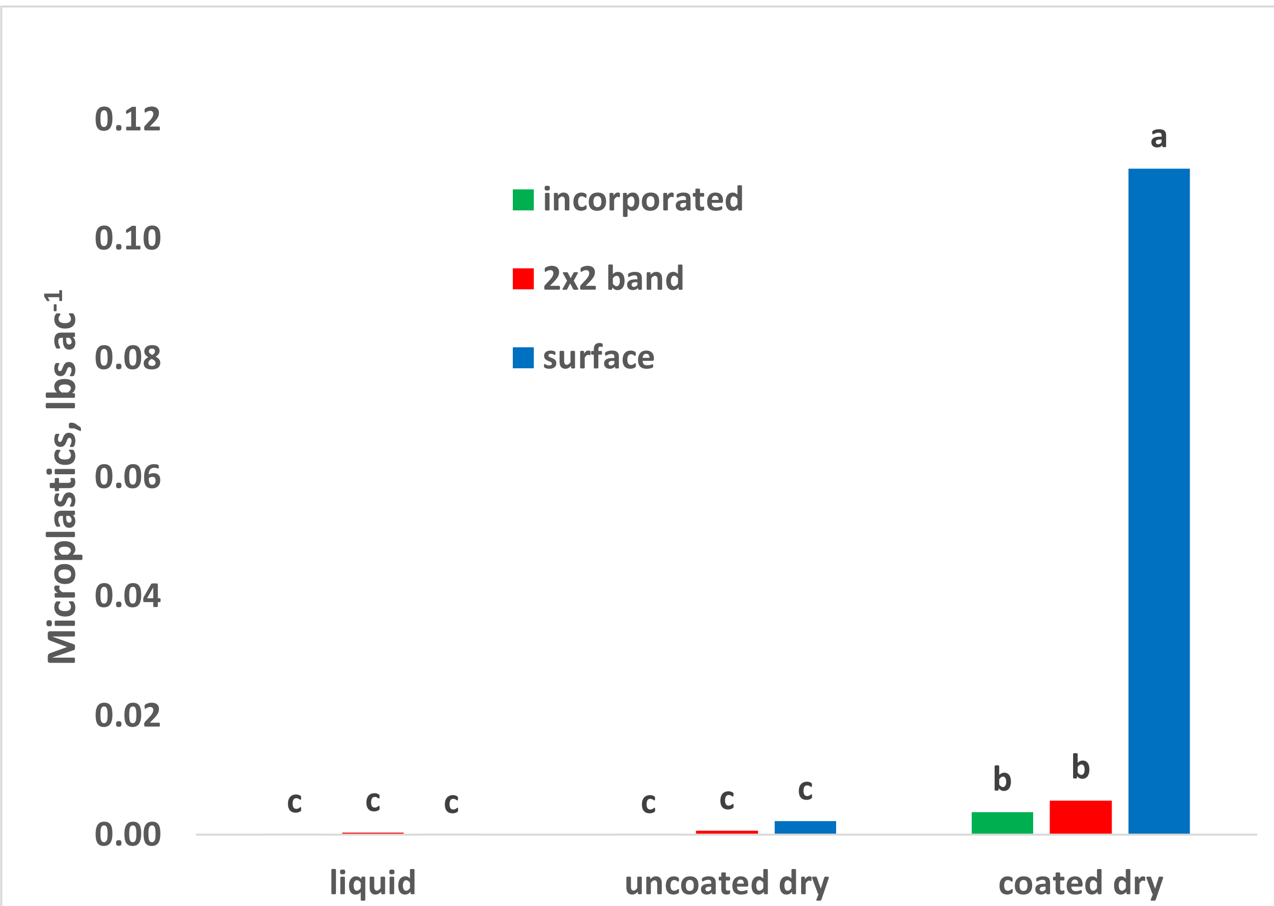

Fig. 1. Microplastics in runoff water for three fertilizer placement methods (broadcast incorporated, surface broadcast not incorporated, or subsurface 2-inch x 2-inch band) with three fertilizer sources (liquid slow release, dry uncoated, dry polymer coated). Bars sharing the same letters on top are statistically identical to one another (P = 0.05).

In terms of quantification compared to the amount of coatings applied, these losses represent 0.62% of the applied polymer coatings for the surface non-incorporated treatment and 0.03% for the 2x2 subsoil band and incorporated treatments. These results show the vast majority of the coatings remained in place, but the losses are nevertheless concerning. From our findings it was clear that both the 2x2 subsurface band and the incorporated broadcast were effective at nearly eliminating visible microplastic transport off site, but that not incorporating the polymer coated fertilizers is not a wise practice.

While more testing needs to be done to further prove these finding, we can assume that correct fertilizer placement greatly prevents movement of microplastics. We will replicate this trial in 2022 and use the data to create a model of polymer coated fertilizer microplastic movement model. We also plan to make a model of microplastic runoff from this data.

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SUGARBEET YIELD RESPONSE AND NITRATE LEACHING AS INFLUENCED BY NITROGEN MANAGEMENT IN SEMI-ARID CLIMATE

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ABSTRACT

Fertilizer nitrogen (N) in irrigated sugarbeet production needs to be optimized to simultaneously increase yield and reduce nitrate leaching. In addition to adjusting N rate and application timing, there are available fertilizer technologies such as controlled- or slow-release N which may be beneficial for beet yield and reducing potential nitrate leaching. However, there are limited studies assessing the effectiveness of such fertilizers for sugarbeet in a semi-arid climate. The two-year experiment was initiated to evaluate the effects of controlled-or slow-release N fertilizer on beet yield and nitrate leaching in irrigated sugarbeet at the University of Nebraska Panhandle Research and Extension Center, Scottsbluff in 2020. Twelve N treatments with four replications were laid out in randomized complete block design. The treatments included three N fertilizers: polymer coated urea (PCU; Duration) and urea with urease and nitrification inhibitors (INH; Uflexx) and granular urea applied at different rates and timings (PCU and INH at 80% and 100% of recommended N rate, both applied all at planting; urea at 50%, 80%, 100%, and 125% of N rate applied all at planting and urea at 100% of N rate split-applied between planting and six weeks after planting). The 100% recommended N rate was 170 lbs N/acre. Water samples were collected periodically using suction-cup lysimeters installed at five feet depth in selected plots and analyzed for nitrate-N. The results showed that there were no significant yield differences among fertilized plots when all N treatments, including N rate, split N, and N fertilizers were compared. Advanced N formulations such as Duration and Uflexx reduced potential nitrate leaching compared to granular urea.

EFFECTS OF A HIGH RATE OF COMPOSTED CATTLE MANURE AND COVER CROPS IN SEMI-ARID DRYLAND WINTER WHEAT CROPPING

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ABSTRACT

Growing dryland winter wheat (*Triticum aestivum,* L.) in the US Northern High Plains (NHP) region is challenged by inadequate soil organic matter (SOM), limited soil water and nutrients, and frequent droughts. A single application of a high rate of composted cattle manure (compost) may help address these issues. Multiple soil health-associated benefits have been observed in different climates, but are still unexplored in the NHP. In order to conserve compost-associated benefits and to prevent compost-amended soils from weed infestation, spring planting of cover crops has been recommended. The synergy between these two practices could help build up SOM, increase soil water-holding capacity, and reduce greenhouse gas (GHG) emissions. The objective of this study was to evaluate the legacies of a single application of compost (0, 15, 30, and 45 Mg ha^{-1}) and annual fallow cover crop planting on soil moisture, inorganic nitrogen (N), and GHG emissions three years after compost application. Unfortunately, results suggested no lasting benefits of the two factors combined. The highest rate of compost showed elevated, yet statistically insignificant soil moisture and inorganic N concentrations in the fallow not planted to cover crops. Nitrous oxide fluxes were comparable to the lower compost rate and the control, suggesting effective soil N conservation. Cover crops alone were not beneficial: they depleted soil moisture and soil inorganic N from the already water and N limited soils.

INTRODUCTION

Consumer demand for organic food has shown double-digit growth in recent years, encouraging the development of a wider range of organic foods (Curtis and Quarnstrom, 2019). Organically certified winter wheat (*Triticum aestivum,* L.) production is on the rise due to greater consumer demand, higher premiums, and better economic returns from grain sales (Curtis and Quarnstrom, 2019).

There is much to be learned about organically certified production of winter wheat in eco-regions like the NHP. Soils are marginally productive, are low in soil organic matter (SOM), alkaline, and often sodic. The climate can be challenging with low, often unpredictable, precipitation and extended periods of drought during the growing season (Hansen et al., 2012). In order to retain the organic certification status, producers are obligated to come up with a SOM building plan. Composted cattle manure (compost) has been widely utilized worldwide as an effective soil amendment with the purpose of improving numerous biological, chemical, and physical properties associated with increasing SOM (Reeve et al., 2012). Used primarily for their within-season fertilizing contribution, composts and raw manures also play an important role in SOM accumulation and long-term improvements in soil quality (Olsen et al., 2015).

Another practice that is not yet well-explored by organic winter wheat producers in the NHP is the inclusion of cover crops planted for a period of time during the fallow phase. Fallow periods are common throughout the region in order to re-charge the soil water profile, which experiences inconsistent precipitation. Planting cover crops for part of the fallow period (either immediately after crop harvest or early the following spring) has a potential to protect the surface soil from erosion during the non-crop periods (Havlin et al., 2014). Other benefits of cover cropped fallows could include competition with weeds species and, if leguminous, contributing additional N atmospheric dinitrogen (N_2) fixation. However, the idea of adding cover crops to the winter wheat-fallow rotation is met with skepticism in the NHP. This is because cover crops compete with winter wheat for abiotic resources such as soil water and plant-available nutrients during the non-crop season.

Greenhouse gas (GHG) emissions are important measurements that help assess sustainability and health of agroecosystems (Bista et al., 2017). The benefits of cover crops in the fallow may translate to lower GHG emissions through decreased N loss as nitrous oxide (N_2O) and increased SOC from organic matter inputs (Grant et al., 2002).

The main objective of this study was to determine the optimal combination of compost application and cover crops planted in the fallow for long-term benefits in dryland organic winter wheat production in the NHP. It was hypothesized that three years after a single application of a large rate of compost followed by cover crops planted in the fallow in the spring, the legacy of high input SOM would continue in the form of increased plant-available nutrients along with decreased losses to the atmosphere in the form of GHG emissions.

MATERIALS AND METHODS

The study was conducted between September 2018 and August 2019 at the Sustainable Agriculture Research and Extension Center (SAREC) near Lingle, Wyoming. The experiment was a randomized complete block design with four replications. Two sets each of winter wheat and fallow strips were divided into eight field blocks. Each field block contained ten plots. Out of the eight field blocks, four blocks were in the winter wheat growing phase and four blocks were in the fallow phase. Within each strip, four rates of locally sourced compost of 0, 15, 30, and 45 Mg ha^{-1} dry weight (control, low, medium, and high, respectively) were applied to the wheat strips during the fall of 2015 and to the fallow strips during the spring of 2016 and incorporated to a depth of 5 cm. Inorganic fertilizer (IF) consisting of mono-ammonium phosphate and ammonium sulfate was applied to the IF treatment plots in the wheat strips during the fall of 2015 and again to the remaining strips during the fall of 2016. Each spring, a cover crop mix of Austrian winter pea (*Pisum sativum,* L.) and oat (*Avena sativa*) was planted to one half of the fallowed plots and allowed to grow for six weeks. After this time, cover crops were terminated by tillage and those plots remained fallow until wheat planting.

Three years after the establishment of the experiment, field soil samples were collected once per month during the non-active growing season (September through

April) and every 2 weeks during the active growing season (May through August) using a soil probe to a depth of 10 cm. Soil was collected out of plots in both the wheat and fallow phases. Soil samples were transported to the lab and processed within 24 hours. Gravimetric water content was determined for each sample by removing a 10-11 g subsample and measuring the difference in mass before and after drying at 105ºC for 48 hours (Gardner, 1986). Samples were sieved through a 2 mm sieve post-drying to assess gravel content. Soil NH_4-N and NO_3-N were determined from 1:2.5 soil KCl (2 M) extracts. Soil KCl extracts were shaken for 30 minutes, stored at 4ºC overnight, and filtered through ashless filter paper (Q5 Fisher Scientific, USA). Soil remaining in specimen cups after extraction was wet sieved to pass a 2.0 mm sieve to determine the gravel weight needed to correct the final gravimetric soil water content. Soil NH_4-N was determined with the Weatherburn method (1967) and sodium salicylate reaction and soil NO_3-N was determined with the Doane-Horwath method (2003) and vanadium chloride reaction. All NH_4-N and NO_3-N samples were analyzed using a microplate spectrophotometer (Bio-tek PowerWave HT: RPRWI, Bio-tek Inc., Winooski, Vermont, USA).

Greenhouse gas (GHG) samples were collected using static closed chambers based on the enclosure technique as outlined by Hutchinson and Mosier (1981). Greenhouse gas samples were analyzed on an automated gas chromatograph (Varian 38001) equipped with a thermo-conductivity detector for CO_2, flame ionization detector for CH_4, and electron capture detector for N_2O analyses (Mosier et al., 1991). The best GHG flux was determined based on four independent linear or logarithmic estimates of the concentration change over time (Hutchinson and Mosier, 1981).

RESULTS AND DISCUSSION

The goal of this study was to assess the potential synergy and determine the optimal combination of compost application and cover crops planted in the fallow for long-term benefits to dryland organic winter wheat production in the NHP. Specifically, if a single application of a high rate of compost would have long-lasting effects on soil parameters and to determine if cover crops planted in the fallow phase of the organic winter wheat-fallow rotation would create any synergistic benefits with compost. Although there were multiple instances where compost and cover crops acted as significant factors alone, there were very few interactions between the two, suggesting that cover crops did not result in a synergy with compost in the third year after compost application (Table 1).

Table 1: Comparisons of compost and cover crop treatments using t-tests among the parameters of gravimetric soil moisture (moisture), inorganic nitrogen (InN), carbon dioxide (CO_2), and nitrous oxide (N_2O). Values in bold with asterisk indicate a significant difference compared with the control/bare treatment at $\alpha < 0.10$.

	Moisture		InN		CO2		N2O	
	cc	bare	cc	bare	cc	bare	cc	bare
	g/g		*ug/g OD soil*		*ugC/m2/hr*		*ugN/m2/hr*	
Control	0.200	0.203	6.03	7.29	39.51	44.39	2.39	3.02

IF	**0.190 ***	0.194	6.33	8.48	35.00	42.68	2.33	3.11
Low	0.195	0.206	5.04	9.29	39.99	30.79	2.17	2.35
Medium	0.193	0.200	**4.19 ***	7.78	44.38	41.73	2.64	2.89
High	0.200	0.210	6.47	7.64	46.23	53.25	2.35	2.71

In general, the wheat phase of the growing cycle resulted in lower soil water content than the fallow phase by 3% (Figure 1A). One of the biggest concerns of dryland winter wheat production is soil water availability during the most critical periods of crop growth.

Inorganic nitrogen (sum of soil NH_4-N and NO_3-N) was also significantly impacted by the phase during the growing cycle (Figure 1B). After planting in the fall and throughout the winter, inorganic nitrogen in the wheat phase was on average 5 times higher than the fallow phase. However, after active wheat growth began in the spring, inorganic nitrogen levels were on average 1.7 times higher in the fallow phase compared to the wheat phase. Fallowing is considered an important management strategy for the restoration of soil productivity due to the replenishment of nutrients removed by crops (Adekiya et al., 2021).

In general, CO_2 fluxes from dryland winter wheat are low compared with other dryland crops (Hurisso et al., 2016). Carbon dioxide emission increased in the spring and summer months when temperatures increased (Figure 1C). This increase could have been a result of wheat root respiration (Larinova et al., 2006). The CO_2 flux in the wheat phase remained relatively constant during the active growing season. The CO_2 flux in the fallow phase experienced a sharp increase after cover crop termination. Vegetated land surfaces play a significant role in controlling carbon dynamics in the global carbon cycle so removal of cover crop residue from tillage can increase CO_2 emissions (Ray et al., 2020).

Since the soil water content never exceeded 0.55 g g^{-1} dry soil in this study, denitrification was not the dominant process that influenced N_2O emission (Bista et al., 2017). Rather, N_2O emission in drylands have been reported to be the product of nitrification of available labile N substrates and dryland soils are reported to have high nitrification potential (Bista et al., 2017 and Norton et al., 2008). Nitrous oxide fluxes in the fallow phase were 1.2 times higher than the wheat phase (Figure 1D).

Cover crop growth in the fallow phase during the active growing cycle (April-August) produced significant differences compared to bare fallow for soil gravimetric moisture and inorganic nitrogen (Table 2). Cover crops decreased soil moisture by 1% compared to the bare fallow. Cover crops increased soil inorganic nitrogen 1.4 times compared to the bare fallow. However, cover crops did not have a significant impact on CO_2 nor N_2O emissions, suggesting nutrient conservation due to higher levels of soil inorganic nitrogen.

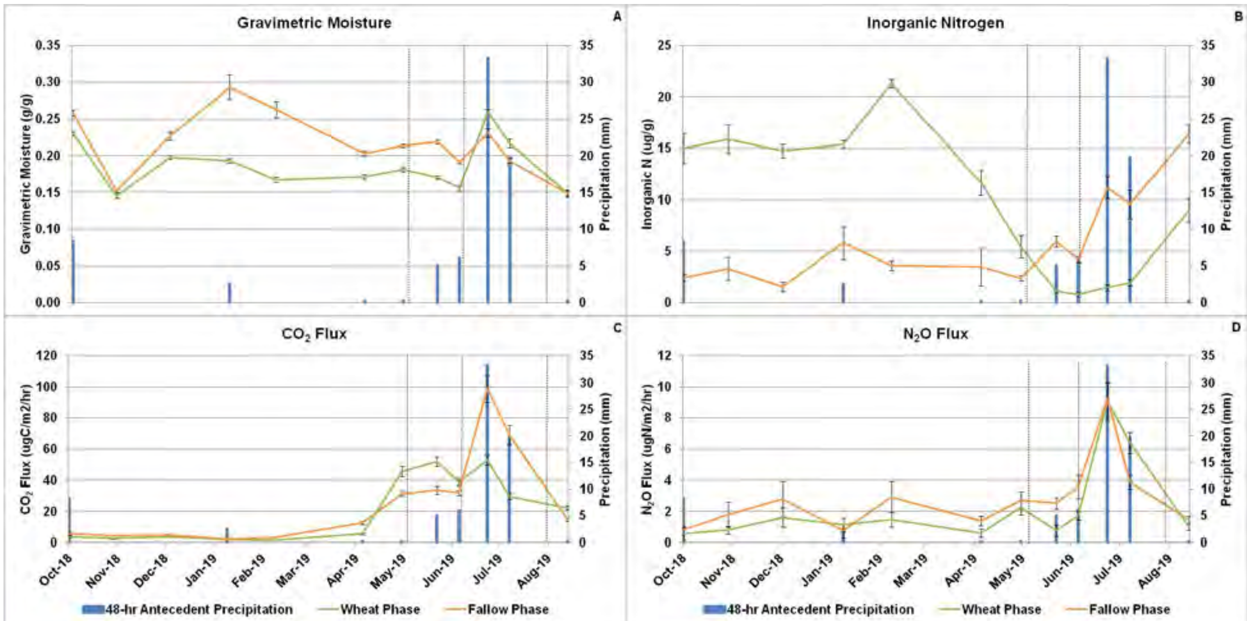

Figure 1: Gravimetric soil moisture (A), soil inorganic nitrogen (sum of soil NH_4-N and NO_3-N) (B), carbon dioxide flux (C), and nitrous oxide flux (D) in the wheat and fallow phases of the growing cycle. 48-hour antecedent precipitation is included on the second axis. Dashed lines indicate tillage events that affected the fallow phase (orange line) only.

Table 2: Cover crop impacts to parameters measured (gravimetric soil moisture (moisture), inorganic nitrogen (InN), carbon dioxide (CO_2), and nitrous oxide (N_2O) during the active growing cycle (April-August). Values in bold with lowercase letter indicate a significant difference within the row at α=0.10.

	Moisture			InN			CO2			N2O		
	Avg	Test Stat	P-Value	Avg	Test Stat	P-Value	Avg	Test Stat	P-Value	Avg	Test Stat	P-Value
	(g/g)			*(ug/g OD soil)*			*(ugC/m2/hr)*			*(ugN/m2/hr)*		
Bare	**0.203 a**	5.770	0.02	**5.62 b**	6.41	0.01	41.02	0.16	0.69	2.38	1.50	0.22
Cover Crop	**0.196 b**			**8.10 a**			42.57			2.81		

CONCLUSIONS

A single application of a high rate (45 Mg ha^{-1}) of compost was shown to have minimal long-lasting benefits in dryland organic winter wheat-fallow rotations in the NHP. However, annual planting of cover crops in the fallow can have the potential to increase carbon and nitrogen conservation due to the absence of increases to CO_2 and N_2O emissions.

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HOMOGENOUS BORON-POTASSIUM FERTILIZER: PLANT UPTAKE

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ABSTRACT

Application of concentrated boron (B) fertilizers is potentially a problem for crops with a narrow root cylinder as some plants may receive the B while others are not in close enough proximity. The objective of this trial was to evaluate a low concentration B fertilizer in a variety of crops. Uptake of B was measured and compared to known B sufficiency levels. Crops with a relatively narrow root cylinder diameter (Kentucky bluegrass turfgrass, onion, carrot, and alfalfa) that were fertilized with the low concentration fertilizer had a significantly higher percentage (15-55%) of plants with B above the sufficiency level when compared with those fertilized with the more concentrated fertilizer. Boron uptake in crops with a wide root cylinder, such as maize and wheat, generally did not show a significant increase in plants above the sufficiency level, although potato did show a benefit with 18% more plants above the critical level for the low concentration B fertilizer. These results exhibit how fusing B into a homogeneous granule at a relatively lower concentration results in better spatial uniformity and improved B nutrition for a larger percentage of plants for plants with narrow root morphologies.

INTRODUCTION

Both potassium (K) and boron (B) are integral in plant growth, development, and health (Hopkins, 2020). Potassium helps plants with synthesis and degradation of carbohydrates and synthesis of proteins, and B is needed for nitrogen fixation in alfalfa, as well as for development of a healthy cell wall etc. (Lissbrant, S., et al., 2009).

The practice of blending dry fertilizers is common and although there are advantages, such as easy customization for specific zones in a field, disadvantages include irregular application due to spatial separation from differences in fertilizer shapes and densities, and a non-ideal uptake of plants from differences in root morphology even when fertilizers are equally spread. The later is especially true for micronutrients needed at very low levels.

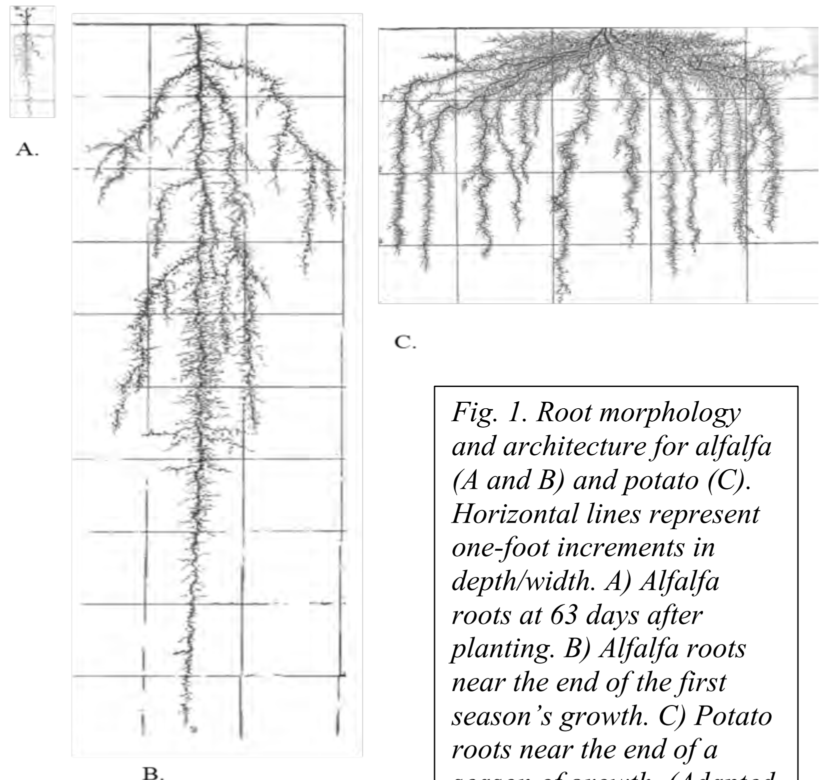

Fig. 1. Root morphology and architecture for alfalfa (A and B) and potato (C). Horizontal lines represent one-foot increments in depth/width. A) Alfalfa roots at 63 days after planting. B) Alfalfa roots near the end of the first season's growth. C) Potato roots near the end of a season of growth. (Adapted from Weaver, 1926.)

An alfalfa plant, for example, has a narrow root system, especially before fully mature (Fig. 1). Assuming a soil test is low in K and B, the most common form of each is muriate of potash (MOP, KCl; 0-0-60) and boric acid (15% B). It would be common to mix these together in a heterogeneous mixture of individual granules. Plants that lie next to where a B fertilizer particle fell will likely have ample, but some plants may receive little to no boron if the distance between their roots and where a B particle fell on the soil is several inches. Other crops with narrow root systems include carrot, onion, and turfgrass. This also potentially poses a potential problem in potato or similar crops with a shallow root system and few root hairs (Fig. 1; Hopkins, 2020).

In order to potentially solve this problem, fertilizers that are a homogeneous blend of K and B are a potential solution for better distribution and uptake. One such fertilizer is Aspire (0-0-58-0.5B; The Mosaic Company, Plymouth, MN, USA). Wooley et al. (2019) reported on a three study with alfalfa having a small, but significant increase in yield compared to traditional K and B fertilizers (Fig. 2.). They also reported on potato that had a significant increase in size of US No. 1 tubers treated with this homogeneous K-B fertilizers over those treated with traditional fertilizers (Fig. 3.). It is theorized that this homogeneous blend results in better distribution uniformity and, thus, improved uptake by a majority of plants.

The objectives of this trial were to Compare Aspire® (0-0-58-0.5B) against traditional K and B fertilizers in alfalfa and potato for uptake of B.

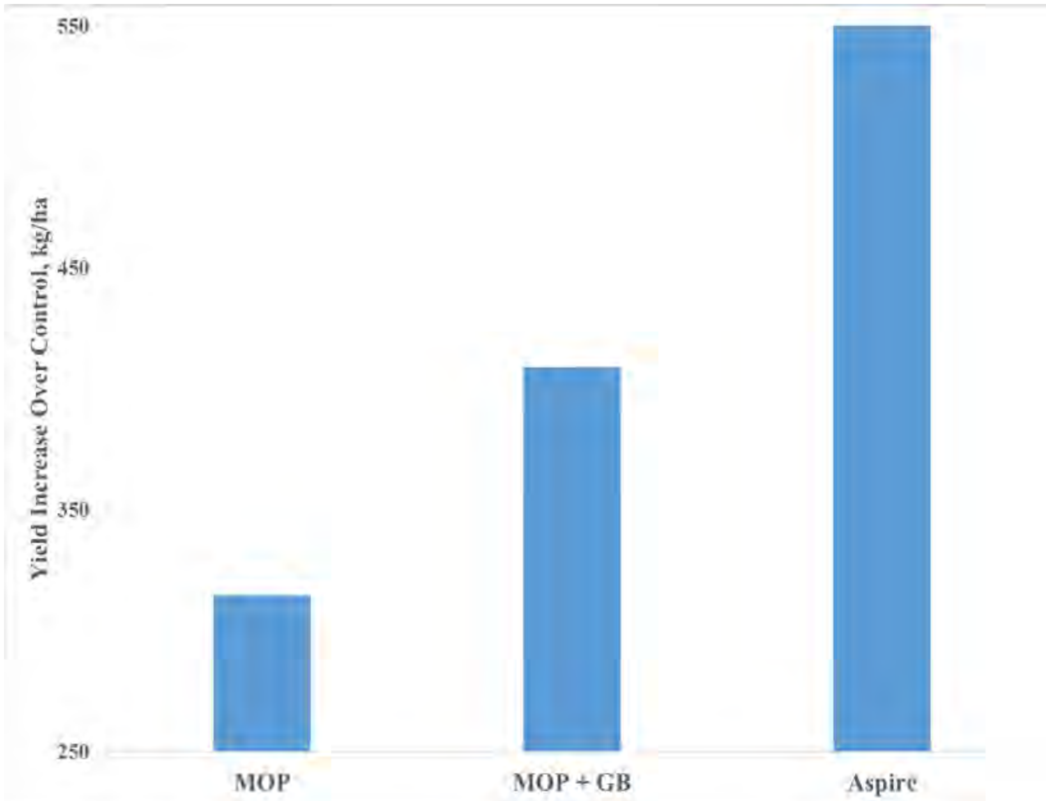

Fig. 2. Orthogonal differences for alfalfa forage yield between combined Aspire vs. muriate of potash (MOP) with or without boric acid (Granubor; GB) averaged over three years of field trials (2016-18). Reported on an "as fed" basis with 15% moisture. Bars sharing the same letters above are not significantly different. P = 0.10

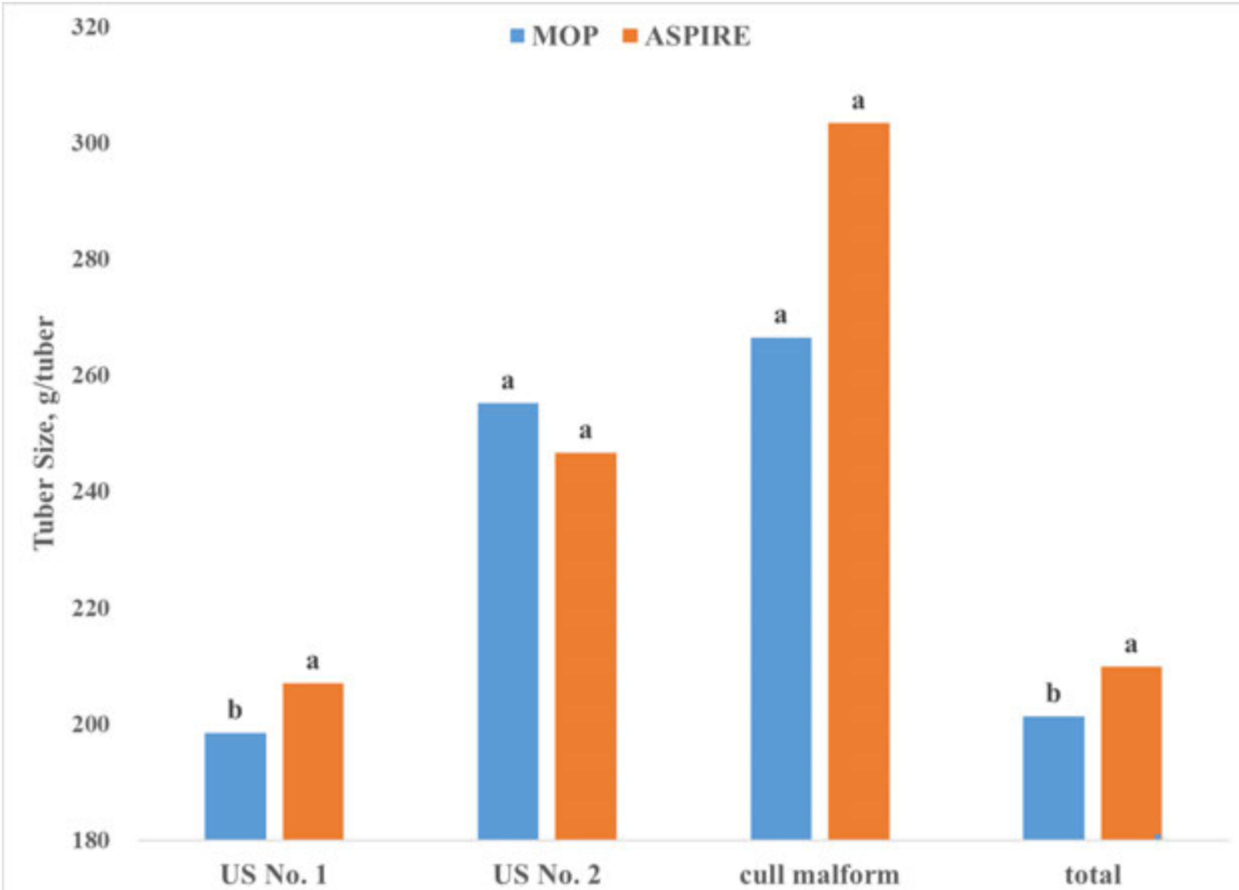

Fig. 3. Differences in tuber size of US No.1, 2, and cull malform Russet Burbank potatoes when treated with MOP or Aspire as a source of boron and potassium. Tuber yield was not impacted significantly. Bars sharing the same letters above are not significantly different. P = 0.10

MATERIALS AND METHODS

Two fertilizer treatments were evaluated with eight plants species with 20 replications in a RCBD in a glasshouse study at Brigham Young University in Provo, UT, (40.2450° N, 111.6412° W). The fertilizer was applied based on soil test at 115 and 1 lb ac^{-1} of K_2O and B, respectively (other nutrients were applied uniformly according to soil test to avoid any deficiencies). Fertilizer treatments included: 1) K applied as muriate of potash (0-0-60) and B applied as Granubor (15% B; Borax, Chicago, IL, USA) or 2) K and B applied as Aspire (0-0-58-0.5B; The Mosaic Company, Plymouth, MN, USA). (An unfertilized control was also included, but is not reported here.) The plant species include: maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), soybean (*Glycine max* L.), potato (*Solanum tuberosum* L.), alfalfa (*Medicago sativa* L.), carrot (*Daucus carota* L.), onion (*Allium cepa* L.), and Kentucky bluegrass (mowed at turfgrass height weekly at 2 inches; *Poa pratensis* L.). Seeds of each were planted in 5 gallon buckets with a 10 inch diameter. The K and B fertilizers were placed by hand, with the B applied uniformly. In the case of the homogeneous blend, the distance between B and seed was short with a range of 0 to 2 inch, but with the more concentrated boric acid the distances were more variable—ranging from 0 to 8 inches. Best management practices were followed in raising the plants. Plants were irrigated as needed to keep the soil moist (surface allowed to dry out after establishment with irrigation occurring when the soil was beginning to dry to a depth of about 1 inch), but avoiding any leaching losses. The hot water extractable B was 0.4 ppm, which is considered low.

Plants were grown for 60 days and then harvested, dried, ground, and analyzed by nitric peroxide digestion with determination of K and B with ICP. Plants in each bucket were separated by distance from B in 1 inch increments, counted and then composited as needed per bucket in order to have enough plant tissue for analysis (eg. corn plants could be analyzed individually, but several dozen Kentucky bluegrass plants were required to composite for analysis). Data was collected on a relative scale by subtracting the average nutrient uptake of plants fertilized with Aspire from the average nutrient uptake of plants fertilized with Granubor and comparing with the published critical level of B in each crop. Statistical differences were determined by ANOVA within each species using SAS software.

RESULTS AND DISCUSSION

Potato, alfalfa, carrot, onion, and Kentucky bluegrass turfgrass all showed a significant increase in the number of plants that were above the established sufficiency levels for each species (Fig. 4). With the exception of potato, each of these was found to have a narrow root cylinder (less than 4 inch diameter at harvest). Potato is known to have a shallow, inefficient root system with few root hairs even though its root cylinder is relatively wide. The maize, wheat, and soybean showed no increase in percentage of plants above the critical level for B.

These results show that some species benefitted at varying levels from improved B distribution uniformity with the low B concentration, homogeneous fertilizer. This appears to be related to root morphology. Crops with root systems having a narrow diameter showed an increased benefit from the use of homogeneous K/B granules as compared to the blended traditional fertilizers. In general, species with wide root systems appeared to see little benefit of one B fertilizer over another due to their ability to collect nutrients from a wider area of soil and subsequently have a greater chance of encountering more individual fertilizer granules. The potato is an apparent exception, being responsive despite its wide root system. This is likely due in some unknown way to its relatively weak root system.

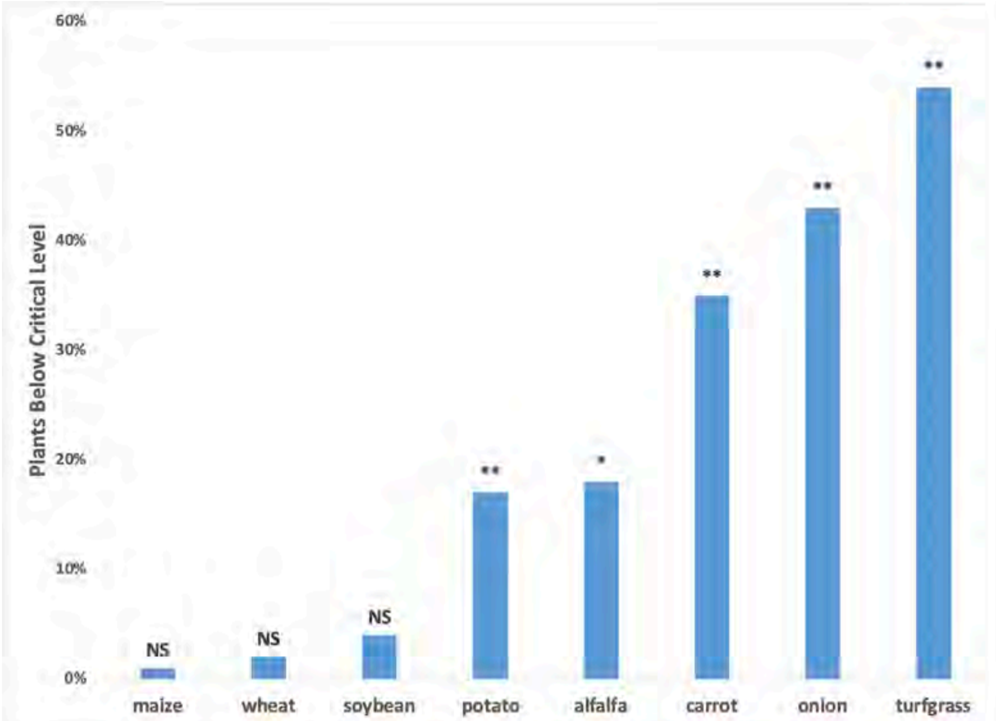

*Fig. 4. Nutrient Uptake and percentage of plants below critical level of B. NS = not significant, * = significant at P = 0.05, ** = significant at P < 0.01.*

SUMMARY

The utilization of fertilizer with homogeneous K/B granules (such as Aspire) provides a better spread of B and allows for better B nutrient uptake (especially in crops with narrow root cylinders) than the utilization of blended fertilizers with B as individual granules (such as Granubor). For crops with wide root systems, there seemed to be no advantage of one fertilizer over another.

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A NEW HYDROPONIC SYSTEM FOR TESTING MINERAL NUTREINT DEFICIENCIES AND ITS APPLICATION TO SOYBEANS

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ABSTRACT

Correlating plant tissue nutrient concentrations with visual symptoms is valuable in combating mineral nutrient deficiencies and toxicities. Due to changing climates and decreasing water supplies throughout the world, agricultural lands need to improve nutrient and water management in crops, including soybeans (*Glycine max* L.). Because nutrient concentrations can be easily controlled, hydroponics effectively demonstrate isolated specific nutrient related symptoms. However, many hydroponic systems present challenges in creating isolated nutrient deficiencies because nutrients are often added as salts with cationic and anionic pairs. For example, if potassium sulfate is used as the potassium (K) source, altering the K level will also impact the sulfur (S) concentrations. This creates the possibility of a dual deficiency and other potential interactions. As a result, a system was developed to create mineral nutrient deficiencies using the following single mineral nutrient sources: ammonium nitrate; nitric, phosphoric, sulfuric, hydrochloric, and boric acids; potassium, calcium, magnesium, zinc, and copper carbonates; manganese acetate; sodium molybdate; iron chelate 6% (EDDHA), along with HEDTA as a chelate. This solution, previously tested in an environmentally controlled growth chamber and now adjusted and improved, was effective in growing plants to maturity and creating multiple nutrient deficiencies in soybeans. Stem size, plant height, and shoot and root biomass was significantly impacted for several nutrients, especially for those with low concentrations of nitrogen (N), phosphorus (P), and K. Unfortunately, some adjustments made to the hydroponic system (based on work from previous studies) were too deficient and healthy plants were not able to grow. Additional nutrient rate adjustments and fine tuning will be required to create all visual nutrient deficiencies. This information, once complete, will be beneficial for farmers and their advisors managing soybean crops, as well as scientists studying these species.

MATERIALS AND METHODS

Growing Environment

Using an environmentally controlled growth chamber, soybean was grown from May to August 2021 at Brigham Young University in Provo, UT, USA (40.245,-111.650, 4550 ft above sea level). Growth chamber lighting was provided by a combination of metal halide and high-pressure Na lamps, with 1800 and 1000 μmol (photons) m^{-2} s^{-1} of photosynthetically active radiation [AccuPAR LP-80, Meter Group, Inc. (formerly Decagon Devices, Inc.), Pullman, WA, USA] at 12 inch and 43 inch, respectively, from the light source. Plants were grown in a 16/8 h light/dark photoperiod. Temperatures were 70 ± 2 ◦F for the dark photoperiod, and 73 ± 2 ◦F during the first 4 h, and 77 ± 2 ◦F for the remainder of the light photoperiod.

Each experimental unit consisted of soybean grown in a 3.7 gal plastic container (11.4 inch inside diameter, 10.6 inch height) filled with a hydroponic solution. The containers were placed into opaque wooden boxes and covered with opaque plastic lids 0.4 inch thick. Each lid had four (2.0 inch diameter) holes for plants that were completely covered by fittings and a smaller diameter access hole in the center that had an oxygen tube running through it which was then completely covered with opaque tape to exclude light from the roots and nutrient solution. The fittings for holding plants were plastic cups (2.0 inch inside diameter at the top, 1.1 inch diameter at the bottom) sitting flush with the top of the plastic lids, and they hang down 1.5 inch into the buckets, with the bottom 0.25 inch sitting in the hydroponic solution. One layer of white nylon matte mesh (0.08 inch × 0.15 inch) netting material was placed into a fitting cup with another fitting cup placed on top of it. Plastic beads (0.15 in diameter) were then placed within the fitting cup, filling 1/3 of fitting cavity. The system in this study was similar to that shown in photographs by Cole et al. (2020), with differences explained above.

Three soybean seeds ("NK S46-A1", Syngenta, Basel, Switzerland), were germinated in each fitting by placing them on top of the beads. The fitting cup was then covered with an opaque plastic that was then covered with opaque tape, so that the seeds were near the surface of the hydroponic solution, receiving moisture, and they were protected from light. The hydroponic solution level was checked daily and refilled as needed so that the seeds were receiving adequate moisture without being saturated. 5 d after planting, slits were cut in the form of an 'X' on the tape and plastic over the fittings, allowing the seeds to grow into the light.

Oxygen was supplied to the solution through PVC tubing passed through the access hole in the center of the opaque lids and then into the nutrient solution. The tubing included a plastic T connector at the bottom of the bucket that split the oxygen supply into two lines. Cylindrical bubbler air stones (0.5 inch diameter with 1 inch length), commonly used in aquariums, were attached to the end of the tubing to diffuse the size of air bubbles. The system was checked for soluble nutrients to avoid contamination.

Treatment and Block Design

Fourteen treatments were established just prior to planting in a randomized complete block design (RCBD) with three replicated blocks. A positive control (Table 1) contained what was estimated to be optimal concentrations of all nutrients based initially on Cole et al. (2020) also considering modifications discussed in Cole et al. (2021). Each of the other 13 treatments had the same concentration of all nutrients as the positive control, apart from a reduced concentration of: N, P, K, S, Ca, Mg, Zn, Mn, Fe, Cu, B, Mo, or Cl. The reduced treatments included 40% of the concentration found in the positive control for N, P, K; 10% of the concentration for S, Ca, Mg; and 0% for all micronutrients. The N, P, and K nutrients were added throughout the growing season, with the amounts in Table 1 added at the initial time of planting, and then again at 25 d after planting. Additionally, all treatments received a total replenishing of their original nutrient concentrations at 58 d after planting.

Table 1. *Hydroponic Nutrient Concentrations (µM) for the positive control*						
			Macronutrients			
N	P	K	S	Ca	Mg	
15,000	750	6,000	2,150	3,960	1,500	
			Micronutrients			
Zn	Fe	Mn	Cu	B	Cl	Mo
4.2	26.8	8.1	1.5	18.1	39.8	0.2
			Chelate and Buffer			
		HEDTA	EDDHA	MES		
		63.8	26.8	4,000		

The nutrient solution was composed of the following: ammonium nitrate; nitric, sulfuric, phosphoric, hydrochloric, and boric acids; potassium, calcium, magnesium, zinc, and copper carbonates; manganese acetate; sodium molybdate; iron 6% chelate (EDDHA); and HEDTA chelate. Each nutrient was added to deionized water (container ~80% full) and stirred in the order of N, K, Ca, Mg, Zn, Mn, Cu, B, Mo, P, S, Cl, Fe, and MES and then brought to volume.

Growth and Harvesting

After seed planting and germination, the number of healthy plants was thinned down to one plant per fitting (resulting in four plants per container as each container had four fittings) at 19 d after planting and then to two plants per container at 25 d after planting. At 35 d after planting, the containers were thinned to 1 plant per container.

Beginning 28 d after planting, visual ratings of plants were taken each week until the final harvest. The visual ratings were done using a scale of 0 to 5, with 0 being a dead plant and 5 being the relatively healthiest plant in the study at that time. Pictures were taken of the plants at 33 d after planting, as well as 65 d after planting. At the time of pictures being taken, both the sitting height and the length of the longest shoot were recorded for each remaining plant. The plants that were thinned at 25 d and 35 d after planting were harvested, and the final harvest of all remaining plants occurred 88 d after planting. The harvesting of the soybeans began with harvesting the bean pods off the plants. Plants were then harvested by separating shoots and roots by cutting the base of the stem immediately above the fitting and cutting the roots off just below the fitting (the minimal plant material interwoven into the mesh was not included in the dry weight measurements as it was impossible to separate the plant tissue from the netting, etc.). Roots were rapidly rinsed by plunging three times in deionized water to remove any loose surface-bound nutrients. Bean pods, shoots, and roots were each placed into separate paper bags and air dried. Dry biomass was determined gravimetrically.

RESULTS AND DISCUSSION

The objective of successfully growing soybean to maturity using this nutrient solution was achieved. However, the measured parameters show that the theorized and adjusted “optimum” nutrient concentrations were not optimum for every nutrient, which will require adjustment in future experiments, as discussed below.

As a general result, the treatments that appeared to be deficient when compared to our positive control were showing signs of deficiency throughout the entirety of the growing process. The visual ratings at the time of the 35 d thinning and the 88 d final harvest showed similar results, indicating that the deficiencies that were successfully induced, were held throughout the entire growing period. Our hydroponic solution was effective at inducing nutrient deficiencies throughout several treatments, though successful deficiencies were not achieved for all nutrients.

Nutrient analysis is not yet complete. There were essentially no differences in visual, shoot length, and biomass for some nutrients (K, S, Ca, Cl, Mo, and B), suggesting that further adjustments are needed in the nutrient solution in order to study these nutrients in soybean. However, there were significant biomass and plant height reductions for N, P, Mg, Zn, Mn, Cu, and Fe compared to the full nutrient solution (positive control), which is an indicator of a successfully inducing nutrient deficiencies (Figure 1).

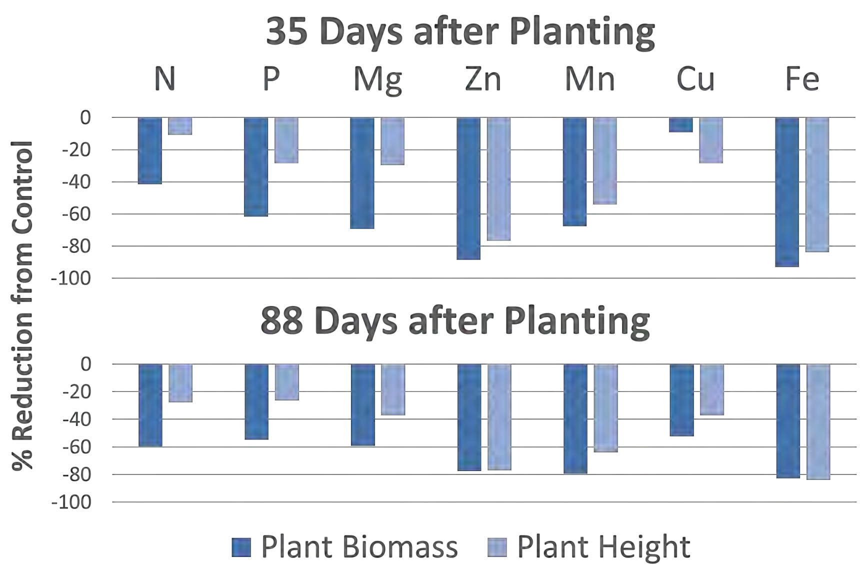

Figure 1. *The percent reduction of plant biomass and plant height in comparison to the control treatment, all percent reductions shown were statistically significant compared to the positive control.*

One of the objectives of the study was to observe the visual characterization of nutrient deficiencies within soybean. Throughout the trial, the treatments shown in Figure 1 all showed significant visual symptoms of deficiency, including, but not limited to, reduced height, wilting, chlorosis, reduced canopy density, and/or reduced greenness. The purpose of photographing the soybean throughout the study was to then connect these visual symptoms with the nutrient deficiency. There is not space here to show all of these, but the N treatment is shown as an example (see Figure 2). Within treatments of reduced N, P, Mg, Zn, Mn, Cu, and Fe, we were able to get clear visual deficiency symptoms, with the prior stated treatments ranging between 1.1-3.3 on average visual ratings, compared to the control treatments which had an average visual rating of 4.1 throughout the study.

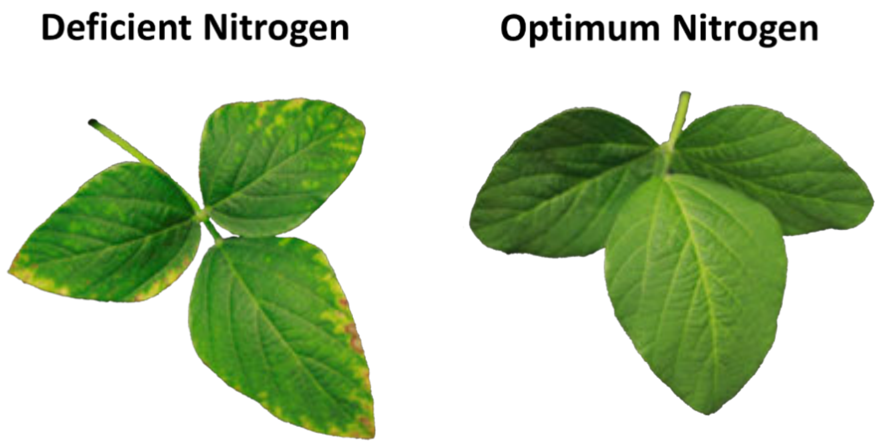

Figure 2. *Comparison of an optimum nutritional leaf and a nitrogen deficient leaf.*

There are several hypotheses connected to why we may not have seen nutrient deficiencies within certain treatments. Compared to previous studies, this is the first time that we have struggled to create a nutrient deficiency for K. Tissue analyses performed from experiments using a previous version of this solution showed possible low levels of K within the positive control and so we raised the total K concentration from 4000 μM to 6000 μM within the positive control. This adjustment, in addition to changing the process for adding the primary macronutrients from providing the full concentration at the time of planting, to an in-season supply of primary macronutrients, could account for the lack of K deficiency within the visual symptoms of the K deficient treatment.

This trial included no adjustments to the concentrations of S or Ca from previous studies by Cole et al. (2020 and 2021). When using this solution with quinoa, Cole et al. (2020) saw that plants visually showed slight deficiencies in biomass, though not enough to be statistically significant, the tissue concentrations could still show nutrient deficiencies. Because we have not completed tissue analysis, we cannot make conclusions on whether treatments that did not show significant biomass differences from the positive control had clear nutrient deficiencies in this study.

For the micronutrients Cl, Mo, and B, tissue analysis is likely to be required to judge whether a deficiency was achieved. We are doubtful of a deficiency within the B and Cl treatments because of biomass and plant height data, which was higher than the positive control, though not statistically significant, at both the 35 d thinning and the final harvest. Previous analysis of the B tissue concentrations showed signs of potential toxicity, and slightly increased height and biomass of the reduced B plants may support that hypothesis by Cole et al. 2021, further tissue analysis on B concentrations will be needed to further understand the potential of B toxicity. The reduced Mo treatment did show an average 30% reduction in biomass from the control at the 35 d harvest and the final harvest, but plant height was statistically the same as the positive control and so these results are not conclusive and further study is warranted.

The reduced Fe treatment was an interesting case. We are confident that an Fe deficiency was induced, though the results are likely insufficient for our study because the deficiency led to significant necrosis throughout all Fe deficient plants and the deficiency did not allow the plants to successfully grow to maturity. In the future, we recommend adding at least a low concentration of Fe into the reduced Fe treatment so that the plants can grow to maturity and show symptoms of Fe deficiency. A similar problem may have been observed within the reduced Zn treatments.

The stability of the pH of the hydroponic solution also remained a concern throughout this study, like that discussed in Cole et al. (2021). The pH of the solution remained primarily between 8 and 9, despite the addition of MES as a buffering agent. Throughout the trial, the pH would fluctuate between 7 and 9 rather rapidly among each treatment, and NaOH and Acetic Acid at small concentrations would be used to try and equalize the pH of the study each week. Despite efforts to create a uniform pH across the study, the pH continued to fluctuate, which is not representative of in-field soil conditions. We are not concerned about the high pH of the study, but further studies are needed to experiment with MES as an effective solution buffer without becoming toxic to the health of the plants.

SUMMARY

The results of this study are a mixed success. The adjusted Hopkins single nutrient source hydroponic solution was still effective at growing healthy soybean plants. Additionally, despite unfinished tissue nutrient analysis, we did see significant reductions in plant height and biomass due to suspected nutrient deficiencies for reduced N, P, Mg, Zn, Mn, Cu, and Fe compared to the positive control. Some nutrients (K, S, Ca, Cl, Mo, and B) likely did not have a nutrient deficiency in their respective reduced treatments, though some nutrients, like B, may have potential toxicity at its concentration within the positive control. Further use of this hydroponic solution will need to consider adjusting the concentrations of the nutrients that did not see clear deficiencies, in addition to adding slight amounts of Zn and Fe to the deficient treatments to ensure mature plants can be grown. Finally, further research is needed to understand the potential of MES as an effective buffer of the Hopkins hydroponics solution without becoming toxic to soybean plants, and still effectively buffering the pH of the solution between a small interval.

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EFFECT OF SOIL AND FOLIAR APPLICATION OF SULFUR, MAGNESIUM, BORON, AND ZINC ON ROOT YIELD AND SUGAR QUALITY IN CONVENTIONAL TILL AND NO TILL SUGAR BEET

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ABSTRACT

Field experiment was conducted at the Eastern Agricultural Research Center in Sidney, MT, to determine the effect of S, Mg, B, and Zn on beet yield and sugar quality under conventional and no-till system. Split-plot design was used with 3.6 x 9.1 m experimental plots and four replicates. Tillage was main plot and micronutrient fertilizer was sub-plot. Tillage treatments included conventional and no-till. Fertilizer treatments included SUL4R-PLUS® (Ca & S), SUL4R-PLUS®B+Zn (Ca, S, B, & Zn), MAX-IN®BORON (B), EDTA-Magnesium (Mg), EDTA-Zinc (Zn), and nontreated check. Field soil samples within 2-ft profile were collected and initial nutrients status was determined. For SUL4R-PLUS® and SUL4R-PLUS®B+Z treatments, their respective products were separately mixed with base fertilizers (Urea and P_2O_5) at 112 kg ha^{-1} and soil-incorporated by irrigation before planting. MAX-IN®BORON, EDTA-Mg, and EDTA-Zn were foliar applied at 1.75, 1.12, and 0.9 kg or L ha^{-1}, respectively. Data were collected for emergence, final stand, root yield, and sugar quality parameters. Conventional tillage had 19% more final stand (plants ha^{-1}) and 7% more root yield (ton ha^{-1}) compared with no-till, but did not differ in sugar content or percent sucrose extract. Micronutrient fertilizer had no effect on response variables regardless of tillage, except for SUL4R-PLUS® and MAX-IN®BORON which have had differential effects on percent sucrose extract between two tillage treatments but did not translate into differences in sucrose yield (ton ha^{-1}). Lower sugar and extractable sucrose yield in no-till compared to conventional was due to difference in final stand. Residue management maybe critical for seedling establishment in no-till sugar beet depending on soil environment and climatic conditions. Further study needed to confirm results.

INTRODUCTION

Sugar beet is a valuable crop that contributes largely to the economies of the sugar beet growing regions in the Upper Midwest (MN, ND), the North West (ID, OR, WA), California, the Great Lakes (MI), and the Great Plains (CO, MT, NE, WY) of the United States. Cash receipts from marketing and sale of sugar beets by US farmers were \$1.184 and \$1.098 billion in 2019 and 2020, respectively (Sowell et al., 2020). Locally, it is a reliable cash crop following wheat rotation in the furrow- and sprinkler-irrigated farms of northeastern MT and northwestern ND. In 2020, a total 38,000 acres of sugar beet was harvested in Montana with an average yield of 31.3 tons/ac (Montana Annual Bulletin, 2021). Cash receipts from marketing of sugar beet in Montana was \$42.4 million in 2020 (Sowell et al., 2020). Despite the viability of sugar beet as a cash crop in the region for many decades, its sustainability is always undermined by the increasing crop production costs, unpredictable weather, damages by resilient pest and diseases, and yearly fluctuation in the commodity price. However, many have shown over the years that sugar beet production with reduced tillage practices have no yield disadvantage compared to its conventional counterpart (Evans et al., 2010; Al-Kaisi and Licht, 2004; Tarkalson et al., 2012; Miyazawa et al., 2004; Jabro et al., 2010; Stevens et al., 2010). Other studies suggested that reduced tillage could maintain sugar beet yields with no compromise to pest control practices and nitrogen fertility programs (Wenninger et a., 2019; Khan and McVay, 2014; Stevens et al., 2010). Reduced tillage systems present an alternative way to minimize cost and maximize net profit by cutting down fuel, time, and labor expenses to the minimum, at the same time offer an opportunity to improve soil microbial activity, increase water infiltration and retention in the soil, and reduce soil erosion to wind and surface runoff without risk of yield drawbacks for preference over conventional sugar beet production system (Lafond et al., 2006; Zenter et al., 2004; Alvarez and Steinbach, 2009; Reeves, 1997). Micronutrients play a huge role in sugar beet growth and development. Studies have shown that soil and foliar applications of Zn, B, Mo, Fe, and Mn in addition to the macronutrients improved sugar beet root yield and sugar quality due to enhanced root and shoot growth (Yarnia et al., 2008; Zewail et al., 2020; Gobarah et al., 2014; Gharib and El-Henawy, 2011). Micronutrients has also been shown to boost plant defenses against sugar beet pathogens. In repeated greenhouse and field studies, micronutrient applications of Zn, Cu, Fe, Mg, Bo, and S not only improved root yield and sugar quality but also reduced the severity of powdery mildew and cercospora leaf spot in sugar beet due to the increased activity of enzymes responsible for the breakdown of free radicals (Shabrawy and Abd Rabboh, 2020; Ghazy et al., 2020). Integration of micronutrient fertilizers into current sugar beet fertilizer program may prove beneficial to sugar beet growers. However, information is limited as to the effect of no-till system compared to conventional in conjunction with micronutrient fertilizer application in sprinkler-irrigated sugar beet. The ultimate goal is to maximize net farm profits through improved sugar beet yield and minimized production costs. We hypothesized that no-till system approach could be a viable alternative to sugar beet production without risking yield and that micronutrient fertilizer application could help improve sugar yield and quality in a sprinkler-irrigated sugar beet. This study aimed to determine the effects of conventional tillage and no-till system in conjunction micronutrient fertilizer application on sugar beet yield and sugar quality.

METHODOLOGY

The field experiment was conducted at the Eastern Agricultural Research Center in Sidney, MT in 2021. The research center was located at 47.729819° latitude and -104.152406° longitude at 1950 feet (594 meters) above sea level. The field was under a linear irrigation system that was previously planted with spring wheat. The field's soil type was a Savage silty clay loam [21% sand:46% silt:33% clay] (Afshar et al., 2019). To achieve uniform Nitrogen (190.5 kg N/ha or 170 lbs N/ac) and Phosphorus (33.6 kg P/ha or 30 lbs P/ac) in all plots, Urea and P_2O_5 were soil-applied as base fertilizers. The experiment was conducted in randomized completed block in split-plot, with main plot size of 22 x 9.1m (72 x 30 ft) and a subplot size of 3.6 x 9.1m (12 x 30 ft). The experiment was replicated four times. Tillage treatment was assigned to the main plot and micronutrient fertilizer treatment was randomly assigned to the subplot. Tillage treatments included conventional (fall and spring tillage) and no-till (stubble left above ground after spring wheat harvest in the previous fall). Micronutrient fertilizer treatments included SUL4R-PLUS® (Ca & S), SUL4R-PLUS® B+Z (Ca, S, B, & Zn), MAX-IN® BORON (B), Magnesium (EDTA-Mg), Zinc (EDTA-Zn), and the untreated check (base fertilizers only). For SUL4R-PLUS® (Ca & S) and SUL4R-PLUS® B+Z (Ca, S, B, & Zn) treatments, each respective micronutrient fertilizer product was separately mixed with Urea and P_2O_5 at a rate of 112 kg ha^{-1} (100 lbs product/ac) and applied to the soil and incorporated through irrigation prior to sugar beet planting. MAX-IN® BORON, Magnesium, and Zinc were dissolved in water and foliar applied at a rate of 1.75, 1.12, and 0.9 kg or L ha^{-1}, respectively (1.5 pints/ac of Max-in Boron, 1 lb/ac of Mg, and 0.8 lb/ac of Zn), when sugar beet was at 8- to 10-true leaf stage. A CO_2 backpack sprayer fitted with four 80015 nozzles calibrated to deliver 140 L ha^{-1} (15 gal/ac) was used for all foliar micronutrient fertilizer sprays.

Prior to sugar beet planting or any micronutrient fertilizer application, composite soil samples that consisted 5 core samples from 0 to 30 cm (0 to 12 inches) and 30 to 60 cm (12 to 24 inches) soil profile depths in conventional tillage and no till plots were taken at random on March 15th, 2021. The soil samples were air dried, packaged, and sent to a soil analysis laboratory in Northwood, ND [AgVise Laboratories, 804 Highway 15 W, Northwood, ND 58267] and the initial soil nutrients status in the field was determined. The sugar beet variety Crystal S696 GEM 100 was planted with a no-till planter in all plots on April 22nd, 2021, at 2.5 cm (1 inch) seeding depth 12 cm apart (4.5 inches) with a 61 cm (24 inches) row spacing. The field received a total of 442 mm (17.4 inches) of linear irrigation from planting to harvest. The accumulated precipitation (snow and rainfall) from October of 2020 to September of 2021 was 164 mm (6.47 inches). Three applications of glyphosate at 0.95 kg ai/ha (24 fl oz roundup/ac) were applied on sugar beet to control weed flushes throughout the growing season. Disease incidence was very minimal and no chemical application for disease control was done. Monthly high temperatures averaged 18.6, 28.5, 32.3, 28.2, and 26^{O}C (65.8, 83.3, 90.3, 82.8, and 78.8^{O}F) and monthly low temperatures averaged 4.5, 11.8, 15.7, 11.8, and 7.05^{O}C (40.1, 53.4, 60.4, 53.4, and 44.7^{O}F) in May, June, July, August, and September, respectively. Sugar beet was harvested on September 20th, 2021.

Data collection and analyses. Data for crop emergence, final beet stand count at harvest, beet root yield, sugar content, and sugar quality (i.e., impurity value, percent SLM, percent extractable sugar) were determined. Seedling stand count was determined one week after crop emergence using a meter stick placed randomly in one of the four center rows of sugar beet, seedlings were counted and the process repeated twice in each plot. At harvest, final stand count and dirty weight of sugar beet harvested from a 30-ft center row in each plot were taken. A sample of 10 to 15 sugar beet roots from the harvested center row were placed in a labeled tare bag. Dirty and clean weights, beet count, and sugar content (with impurities) of the beet samples from the tare bag was determined at the Sidney Sugars laboratory. A 5-ml sample of sugar beet juice extract from the beet samples from the tare bag was collected and sent to a laboratory in Sheridan, WY [AgTerra Technologies, Inc., 212 W Burkitt St, Sheridan, WY 82801] for impurities analysis (i.e., sodium, potassium, amino-N concentration). Impurity, sugar loss to molasses (SLM), and percent sucrose extract values were determined. Extractable sucrose per hectare (or acre) was determined based on sugar beet yield, sugar content, SLM and percent sucrose extract values. All data were subjected to *type 3 split plot analysis of variance test* using *procmixed* in *SAS* (Statistical Analysis Systems®, version 9.2, SAS Institute Inc., SAS Campus Drive, Cary, NC 27513) with alpha set at 0.05. Tillage, micronutrient fertilizer, and interaction were considered fixed effects. Replication and interaction with treatment were considered random effects. *Type 3 test of fixed effects* was used to test for significance of treatment to the response variables. Where treatment effects significant, group means were separated using Fisher's LSD at $P < 0.05$. Data assumptions for normality of residuals and homogeneity of variance were met when tested with shapiro-wilk and levene's test, respectively, using *proc univariate* in *SAS*.

RESULTS AND DISCUSSION

The soil analysis results showed that the experimental field had good nutrient conditions to foster crop growth (Table 1). The CEC and OM values indicated high capacity for exchange and retention of water and nutrients in the soil, and the slightly alkaline pH indicated most soil nutrients were abundant in available forms for plant uptake. Potassium was sufficient in both conventional tillage and no till plots. However, Nitrogen was low in top 30 cm of soil for both and was much lower in the deep subsoil (30 to 60 cm depth). Phosphorus is relatively sufficient; however, literature suggests that an additional P fertilizer (P_2O_5) was needed to ensure availability for plant uptake. N and P issues were addressed when the base blend of Urea and P_2O_5 were incorporated in all plots before sugar beet was planted. Sulfur and magnesium amount in the soil were generally sufficient based on established literature on soil fertility. Soil pH indicated that most of the macronutrients and micronutrients were likely to be more available in the soil solution except for Fe, Mn, B, and Zn which could be less abundant due to the slightly alkaline soil condition but nevertheless still available for plant uptake.

Table 1. Results of soil analysis for initial nutrient status in Conventional (CT) and No till (NT) plots. Values presented were averaged from 5 composite samples taken at 0 to 30 cm and 30 to 60 cm depths.

Tillage	Soil Depth	pH	OM	NO_3-N	S	P-Olsen	K	Ca	Mg	Na	Zn	Fe	Mn	Cu	B	CEC
	cm		%	------------------------------------ ppm -------------------------------------												meq/100g
CT	0-30	8.3	3.2	6.1	25	16	337	5247	767	152	0.60	6.9	2.0	1.2	1.8	34.2
NT	0-30	8.3	3.3	6.0	16	15	340	5321	705	153	0.71	7.6	1.7	1.2	1.8	33.9
CT	30-60	8.4		2.4	51											
NT	30-60	8.3		2.9	32											

Results of analysis of variance showed that neither micronutrient fertilizer nor interaction with tillage had a significant effect on sugar beet stand and yield parameters (Table 2). However, tillage had a significant effect on crop emergence, final stand count, beet root yield, sugar yield, and extractable sucrose but not on sugar concentration (Table 2). Results of the analysis of variance also showed that micronutrient fertilizer alone had no significant effect on sugar quality parameters, but interaction with tillage had a significant effect on potassium concentration, sugar loss to molasses (SLM), and percent sucrose extract from beet root samples (Table 3). Additionally, tillage had no significant effect on sugar quality parameters except for its effect on the amino-N concentration in the sugar beet roots which was significant (Table 3).

Table 2.Results of split-plot analysis of variance showing *p*-values for the effect of tillage, micronutrient fertilizer, and interaction on crop stand, beet root yield, and sugar yield parameters.

Source of variation	Crop emergence	Final stand	Beet yield	Sugar concentration	Sugar yield	Extractable sucrose yield
Tillage	**<0.01**	**<0.01**	**<0.01**	0.27	**<0.01**	**<0.01**
Fertilizer	0.33	0.98	0.97	0.26	0.91	0.90
Tillage*fertilizer	0.84	0.96	0.29	0.59	0.30	032

Table 3. Results of split-plot analysis of variance showing *p*-values for the effect of tillage, micronutrient fertilizer, and interaction on sugar quality parameters.

Source of variation	Sodium	Potassium	amino-N	Impurity Value	SLM	Sucrose extract
Tillage	0.20	0.44	**0.01**	0.19	0.10	0.11
Fertilizer	0.77	0.69	0.83	0.35	0.55	0.55
Tillage* fertilizer	0.12	**0.03**	0.56	0.68	**<0.01**	**<0.01**

Conventional tillage had significantly higher final beet stand count at 112,947 beets/ha (45,708 beets/ac) compared to no till which had 91,644 beets/ha (37,087 beets/ac) (Table 4). The considerable amount of stubble residue cover from the previous year's wheat crop may have had delayed the emergence and made it difficult for seedlings to come out of the residue cover which resulted in lower final stand count in the no-till compared to conventional tillage (Table 4). This was evident when seedlings counted in no-till plots only averaged 6.4 seedlings/m row which was lower compared to 7.6 seedlings/m row in conventional tillage one week after crop emergence (Table 4). However, the stand counts in the no-till plots in this study were considered to be normal. In this study, sugar beet seeds underwent fungicide seed treatment and disease incidence throughout the growing season was very minimal making it unlikely for pathogens to substantially compromise germination, emergence, or final stand count. Additionally, the seeds were planted with a no-till planter and sugar beet seeds were not visible on the soil surface in the no-till plots at the time of planting making it less likely a planter issue. However, the conventional tillage plots were allowed to dry up before chisel plowed with 5-6 passes in the previous fall and another 5-6 passes in the following spring to prepare the seedbed. Higher soil moisture in conservation tillage results in a wetter and cooler seedbed compared to the conventional (Deibert, 1983; Sojka et al., 1980; Overstreet, 2009; Hatfield et al., 2001). Wetter years have been shown to delay seedling emergence in sugar beet following strip tillage (Evans et al. 2010), although the response was inconsistent due to yearly variations in climatic conditions following planting (Wenninger et al., 2019). Although the appearance in top growth were visually the same throughout the growing season, beet root yield was significantly higher in conventional tillage which averaged 92.1 tons/ha (37.3 tons/ac) compared to the 85.9 tons/ha (34.8 tons/ac) in no-till. Similarly, sugar yield averaged 17.5 tons/ha (7.07 tons/ac) in conventional tillage which was higher compared to the 16.2 tons/ha (6.54 tons/ac) average sugar yield in no-till. Although, the beet root yield and sugar yield were significantly higher in conventional tillage compared to no-till, the sugar content of 18.93% (with impurities) from sugar beet samples in conventional tillage did not differ from those in no-till which was 18.77%. This indicates that the significantly increased root and sugar yield observed in conventional tillage compared to no-till was not due to the increased sugar content in sugar beet roots but was mainly a function of the final stand count that was higher in conventional tillage at the time of harvest. The amino-N (impurity) in beet root samples from conventional tillage was 17.8 ppm which was lower than the 20.5 ppm observed from sugar beet samples in no-till (Table 4). Previous studies have associated high soil nitrate levels with crop residue in reduced tillage (Wenninger et al., 2019; Zhang et al. 2016). However, other studies have also shown that no-till system had no effect on nitrogen storage in organic matter and that nitrate leaching into deeper subsoil (root zone) for plant uptake seemed dependent on soil and climatic conditions (Goss et al., 1990; Hansen and Djurhuus, 1997b; Constantin et al., 2010). Although the amino-N impurity in sugar beets from conventional tillage was lower, the percent extractable sucrose was comparable to sugar beet in no-till. On average, the percent extractable sucrose (free of impurities) in sugar beet samples from conventional tillage and no-till was 98.97% and 98.94%, respectively (Table 4). However, the average in extractable sucrose yield was significantly higher in sugar beet from conventional tillage which was at 17.3tons/ha (7.0 tons/ac) compared to 15.6 tons/ha (6.46 tons/a) in no-till (Table 4). The observed difference was again attributed to the higher stand count in the conventional tillage sugar beet compared to no-till.

Treatment	Crop Emergence	Final Stand	Root yield	Sugar content	Sugar yield	amino-N	Sucrose extract	Extractable sucrose yield
	seedlings / m row	beets/ac	ton/ac	%	ton/ac	ppm	%	ton/ac

8.93 a	7.07a	17.8b	98.97a	7.0a
8.77 a	6.54b	20.5a	98.94a	6.4b

Table 4. Effect of conventional tillage (CT) and no-till (NT) treatment on crop emergence, final stand count, beet yield, percent sugar, sugar yield, amino-N impurity, percent sucrose extract, and extractable sucrose yield. Values presented were averaged across micronutrient fertilizer treatments. Means followed by the same letter within a response variable are not significantly different at Fisher's LSD$_{(\alpha=0.05)}$.

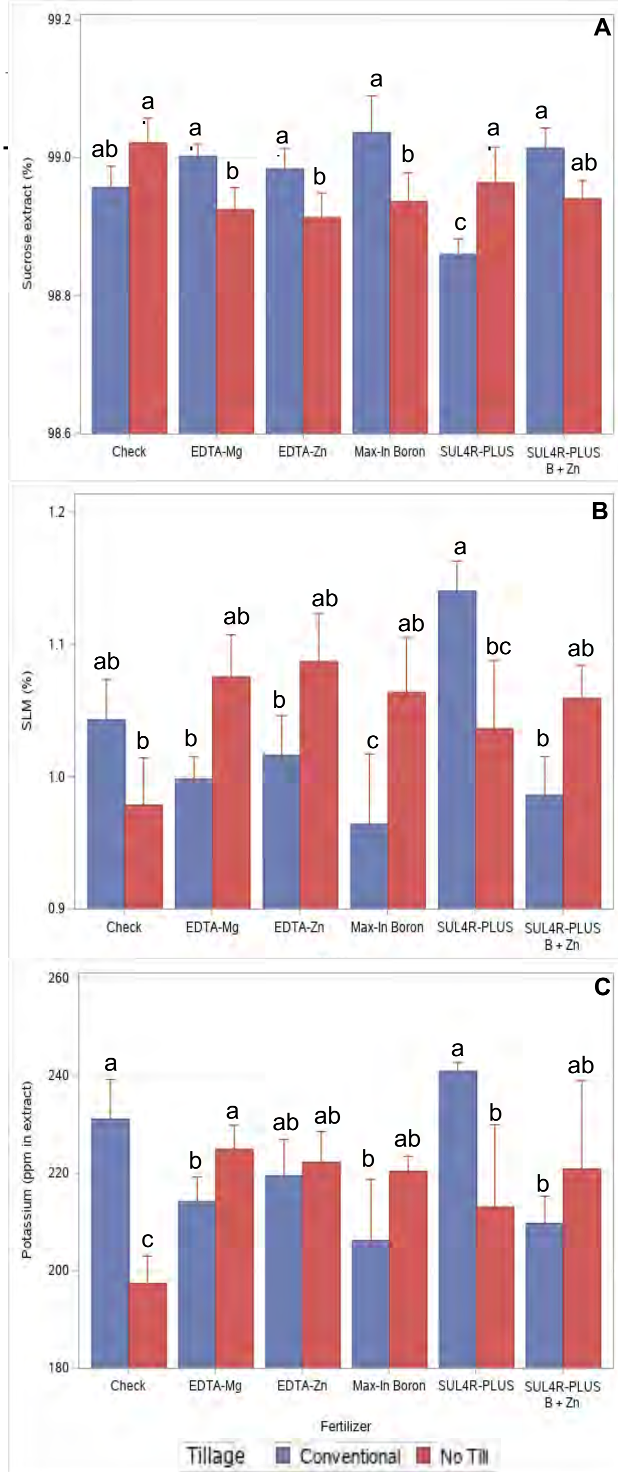

Figure 1. Effect of micronutrient fertilizer treatment on percent sucrose extract (A), sugar loss to molasses or SLM (B), and potassium concentration (C) in sugar beet as affected by conventional tillage and no-till treatment. Presented are mean values (bars) and standard error of the mean (caps). Bars with the same letter are not significantly different from each other as per Fisher's LSD$_{(\alpha=0.05)}$.

Interaction effect of tillage treatment and micronutrient fertilizer treatment was significant for potassium concentration, SLM, and percent sucrose extract (Table 3). Mean response values for each treatment combination were separated and presented in Figure 1. Percent sucrose extract, percent SLM, and potassium concentration values for sugar beet that received the same micronutrient fertilizer treatment were comparable between conventional or no-till, except for SUL4R-PLUS® and MAX-IN®BORON micronutrient fertilizer treatments. Treatment of SUL4R-PLUS® to sugar beet in conventional tillage showed lower sucrose extract (98.85%), due to higher beet root SLM (1.14%) and potassium (241 ppm) compared to its treatment effect in no-till (98.96% sucrose extract, 1.03% SLM, and 213 ppm of potassium) [Figure 1A, 1B, 1C]. The opposite was true for MAX-IN®BORON treatment. On average, treatment of MAX-IN BORON to sugar beet in conventional tillage resulted in higher sucrose extract (99.94%) due to lower beet root SLM (0.96%) when compared to its treatment effect in no-till (99.03% sucrose and 1.06% SLM) [Figure 1A, 1B].

Relative to in conventional tillage, treatment of SUL4R-PLUS® in no-till produced lower potassium and SLM levels, that produced higher sucrose extract in the roots. Conversely, treatment of MAX-IN®BORON in no-till sugar beet produced higher potassium and SLM levels that produced lower sucrose extract in the beet roots, relative to its treatment effect in conventional tillage. However, a *two-tailed pairwise t-test* revealed that the differential effect of CT*SUL4R-PLUS® and NT*SUL4R-PLUS® on sugar beet percent sucrose extract did not translate into a difference in extractable sucrose yield tons per hectare (p=0.26, data not shown), even though the average final stand count between two treatment combinations did not differ from each other (p=0.07, data not shown). The same can be said about MAX-IN®BORON treatment as revealed after the *t-test* (p=0.16 for sucrose yield/ha and p=0.11 for final stand count, data not shown). This suggests that sucrose yield on a per hectare basis will be comparable for sugar beet treated with SUL4R-PLUS® regardless of tillage practice. The same response from sugar beet will be expected following MAX-IN®BORON application.

In this study, the lower root yield (tonnage) in no-till was due to the difference in stand count despite having a normal plant density, however, sugar content and quality were comparable regardless of the tillage practice used. Although the actual cause for the difference in stand counts is not clear, residue management maybe critical for seedling establishment in no-till sugar beet system and could be specific to soil environment and climatic conditions. Micronutrient application using the fertilizer products seemed to have had no effect on yield and sugar quality parameters except for Boron (MAX-IN®BORON) and Sulfur (SUL4R-PLUS®) which have had an effect on percent sucrose extract but did not necessarily translate into a difference in extractable sucrose yield per hectare between conventional tillage and no-till. The field soil had sufficient amounts of micronutrients for sugar beet production that the effect of micronutrient treatments may have not been detected due to the inherent abundance and availability soil residual micronutrients for plant uptake. Additionally, soil and microbial processes associated with different soil management systems can admittedly have had confounded the effects on micronutrient uptake/absorption, translocation, and metabolism. A repeat of the experiment is needed to confirm results.

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EFFECTS OF PHOSPHORUS AND POTASSIUM APPLICATION TIMING ON A WHEAT DOUBLE CROP SOYBEAN SYSTEM

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ABSTRACT

The wheat-double crop soybean system is a popular choice for Oklahoma producers, as it allows for two crops in one year, and therefore, more revenue in less time. With favorable conditions and proper management, double crop soybeans are yielding as well as full season soybeans. Weather pattern shifts over the last few years have raised the question for growers if they should invest more into the summer double crop, as there is growing potential for profit. While attempting to increase yield and profit of the summer crop, it is also important to not limit the potential of the winter wheat crop. This study is designed to evaluate the effects of phosphorus (P) and potassium (K) fertility management for a wheat – double crop soybean cropping system, over three timings, and different rates, to better understand how these effect the wheat and soybean yield. The study also determines if OSU fertilization rates based on soil tests are effective. This study consists of 13 treatments replicated 4 times that were established at planting of winter wheat. A total of 6 site years spread out across eastern and north central Oklahoma over two years made up this research. Oklahoma State University's winter wheat P and K recommendations based on the sufficiency approach maximized yields when P and K where the only limiting factors. As in previous work, locations with acidic soil pH responded to the addition of P fertilizer above sufficiency recommendations. At one location with low P and pH, in season application of additional P at top dress maximized yield in wheat. Pre plant application on soybeans has been found to significantly impact yield in one location, although further investigation of soybean data is needed.

INTRODUCTION

Double cropping soybeans in Oklahoma is becoming a popular option for farmers looking to improve their profits in uncertain economic times. Double cropping can be defined as harvesting two crops from the same field in one year (Borchers, et al., 2014). This system offers several advantages such as improving soil quality, reducing erosion, a more efficient use of land and equipment, and provides more food and feed for an expanding world population (Holshouser, 2015). As double crop soybean (*Glycine max*) production increases, additional questions are being raised as to what is the optimal fertilizer program for a wheat (*Triticum aestivum*) and soybean system. Currently, published literature is lacking as to the optimum nutrient management practice for a winter wheat and double crop soybean system. Currently if producers add nutrients for the double crop it is applied as a single pre-plant application prior to the wheat crop. The proper timing of nutrient application for the double crop has not been documented, much less if additional nutrients are needed above that of the primary cash crop, winter wheat. Therefore, this study will observe the impact of different phosphorus (P) and potassium (K) fertilization timings on a wheat-soybean double crop system focusing on soybeans.

MATERIALS AND METHODS

This trial was established at two locations, Haskell and Ponca City, for the 2019-2020 growing season. For the 2020-2021 growing season 4 sites were established in 2 areas of Oklahoma. Two locations are in Lamont, one location is at Lake Carl Blackwell, and a location at Haskell once again. These locations represent different soil types and rainfall patterns.

The trial is organized as a randomized complete block design (RCBD) consisting of 13 treatments and 4 replications. The treatments were split into 3 separate timings across the combined winter wheat and then double crop soybean growing season. The fertilizer applications were made either pre-plant or top-dress in the wheat season or at planting of the double crop soybeans. Treatments consisted of combinations or single applications of N, P, and K. Multiple P and K treatments were determined using OSU recommendations based on preplant soil tests. Treatments with a "+" next to the letter represent the application of the OSU recommendation for both the wheat and soybean crop.

Treatment	Pre – Wheat	Top – Dress	Pre – DC Soybeans
1	N	N	-
2	NP	N	-
3	NK	N	-
4	NPK	N	-
5	NP+K	N	-
6	NPK+	N	-
7	NP+K+	N	-
8	NPK	NP	-
9	NPK	NK	-
10	NPK	NPK	-
11	NPK	N	P
12	NPK	N	K
13	NPK	N	PK

Figure 1. Treatment structure of the wheat – double crop soybean trial.

Pre-plant wheat soil samples were taken at a 0-15 cm depth with 2.54 cm diameter soil probes in each plot at both locations. The samples were dried and ground to pass through a 2 mm sieve or less. The samples were then analyzed for pH and buffer index using a 1:1 soil: water suspension and glass electrode (Sims, 1996; Sikora, 2006). They were also analyzed for phosphorous and potassium concentration using Mehlich-3 extractant solution (Mehlich, 1984) and analyzed using an ICP spectrometer (Soltanpour, et al., 1996).

Fertilizer was applied almost exclusively by hand in granular form as top-dress. UAN was applied with a John Deere Gator. A constant rate of 67.25 kg ha^{-1} of nitrogen as ammonium-nitrate or UAN was applied on all plots at all trial locations at pre-plant wheat timing. Phosphorus was applied as triple super phosphate (0-46-0) and potassium was applied as muriate of potash (0-0-60

At maturity, 7 of the wheat and double-crop soybean crops were harvested by a Kincaid 8-XP plot combine (Kincaid Equipment Manufacturing; Haven, KS). Yield data was collected by a Harvest Master Yield onboard monitoring computer (Juniper Systems; Logan, UT), and grain samples were collected from each plot. The middle 2 rows of each plot (wheat and double-crop soybeans) were harvested at all locations. The remaining 4 crops were hand harvested due to time constraints and bad field conditions at time of maturity. The 2019-2020 wheat crop at Haskell failed due to freeze and flood damage. Subsequently, the wheat at this location was baled off.

RESULTS AND DISCUSSION

Oklahoma State University's winter wheat P and K recommendations based on the sufficiency approach maximized yields when P and K where the only limiting factors. As in previous work completed in the past, locations with acidic soil pH responded to the addition of P fertilizer above sufficiency recommendations. At one location with low P and pH, in season application of additional P at top dress maximized yield in wheat. Pre plant application on soybeans has been found to significantly impact yield in one location, although further investigation of soybean data is needed.

INFLUENCE OF NITROGEN RATE APPLICATION ON SOIL FERTILITY IN FOUR LONG TERM EXPERIMENTS SITES

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INTRODUCTION

Two major determinants of soil fertility are Soil Organic Carbon (SOC) and Total Nitrogen (TN). These two parameters play an important role in soil fertility management (He et al., 2015; Dai and al., 2022). Fertilization can impact soil productivity by changing the soil's physical, chemical, and microbiological properties (Dong et al., 2014; Herencia et al., 2011). Nitrogen is a fundamental macronutrient that affects plant development. Its application is indeed vital for crop growth, yield, and grain quality. Many long-term studies have been conducted to study the effect of Nitrogen application on soil proprieties. This study focused on Nitrogen fertilization's effect on SOC and TC in four separate long-term sites.

METHODOLOGY

Experiments sites: The four long-term sites were in four different locations in Oklahoma State: Stillwater (STW), Lahoma (LAH), Perkins (PRK), and Carl Blackwell Lake (LCB), established respectively in 1968, 1970, 1998, and 2002. All the sites are characterized by no-tilling and continuous wheat monoculture.

Table 1: Experiment's sites characteristics

	STW	LCB	LAH	PRK
Soil classification	Fine-silty, mixed, thermic, udic paleustoll	Fine-silty, mixed, thermic, cumulic haplustoll	Fine-silty, mixed, superactive, thermic, Udic Arguistoll	Fine-silty, mixed, thermic, Ultic haplustalfs
Location: Longitude latitude	36°7'7'' N 97°5'30''W	36°8'22.97"N 97°16'56.53"W	36°23' 13''N 98°60'29''W	35° 59' 39.12''N 97° 02' 31.83''W
Year established	1968	2002	1970	1998
No till establishment	2010	2007	2010	2005

Experiments designs:

For all the experiments sites, the experiment design is a randomized complete blocks design with one fixed factor: Nitrogen fertilization rate. STW and LCB had four replications. As for LAH and PRK sites, the number of replications was three.

Table 2: N rate applied and replications number for the four sites studied

	STW	LCB	LAH	PRK
N treatments (lbs/ac) Urea	0 40 80 120	0 45 90 135	0 20 40 60 80 100	0 50 100 150
Replications number	4	4	3	3

Soils sampling and analysis:

Soil samples (0.15 m depth) were collected after harvesting in 2020. In each plot, the soil was collected from twenty points randomly and mixed into one composite sample. Soil total organic carbon and nitrogen were determined by high temperature combustion using a LECO Truspec CN analyzer.

Statistical analysis:

The results obtained from the different analyses were processed and analyzed using Microsoft Excel 2010 (graphing) and SPSS Statistics 20 (ANOVA test and simple linear regression).

RESULTS AND DISCUSSION

Total Organic Carbon:

Figure 1 shows that STW, LAH, and PRK fluctuate similarly. By increasing the N Rate, the TOC values raised then fell and eventually increase. However, when raising the N rate at the LCB site , we see an elevation in TOC percentage followed by a reduction.

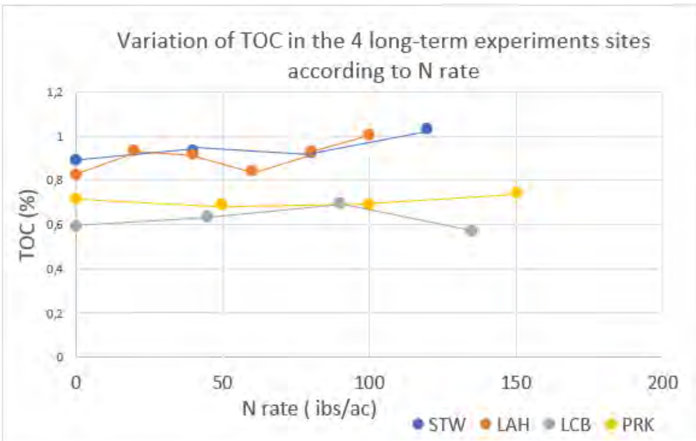

Figure 1: TOC variation according to N rate in the sites studied

The highest TOC values were observed in STW, LAH, and PRK sites when adding the highest value of N fertilization. As for LCB site , the highest value of TOC was observed by fertilizing a quantity of 90 ibs N/ ac (the max n application rate was 135 ibs/ac) .

Although the TOC value varied to the amount of N fertilizer, statistical analysis revealed that the N rate had no significant impact on the TOC value in the soils of the four locations studied. Furthermore, the N rate does not explain much of the TOC variation (the R square of the regression is low for the four sites)(Table 3) . This result was consistent with Raun, and Al's work (1998), who demonstrated increases in soil organic C with increasing N applied in 0-30 cm depth in three of the four sites.

Other research demonstrated that N fertilization affect negatively and significantly TOC. Souza and al., (2021), showed that the nutrient application rate (especially N) significantly affects the content of TC in the soil. In addition, Luo and al., (2019) supported that N fertilization decrease SOC especially the recalcitrant in the surface layer (0–10 cm).

Table 3:Analysis of variance, mean squares and regression R squares for TOC in experiments STW,LAH,LCB and PRK for 0-15cm

Location	N treatments	Mean	Standard variance	ANOVA N rate sig	Regressions R square
STW	0	0,889	0,061	Ns 0,177	0,15
	40	0,934	0,049		
	80	0,927	0,073		
	120	1,032	0,066		
LAH	0	0,828	0,051	Ns 0,093	0,114
	20	0,934	0,081		
	40	0,917	0,115		
	60	0,840	0,031		
	80	0,928	0,092		
	100	1,004	0,253		
LCB	0	0,590	0,061	ns 0,53	0,02
	45	0,632	0,083		
	90	0,696	0,178		
	135	0,568	0,171		
PRK	0	0,713	0,082	ns 0,227	0,18
	50	0,686	0,080		
	100	0,692	0,039		
	150	0,743	0,138		

Total Nitrogen:

Figure 2 shows the TN variation according to N applied. TN values didn't necessarily increase when N applied increase. This is emphasized by the graphs of all the experimental sites. Thus, Except LBC all the others experiment sites had the highest TN concentration while adding the highest N rate.

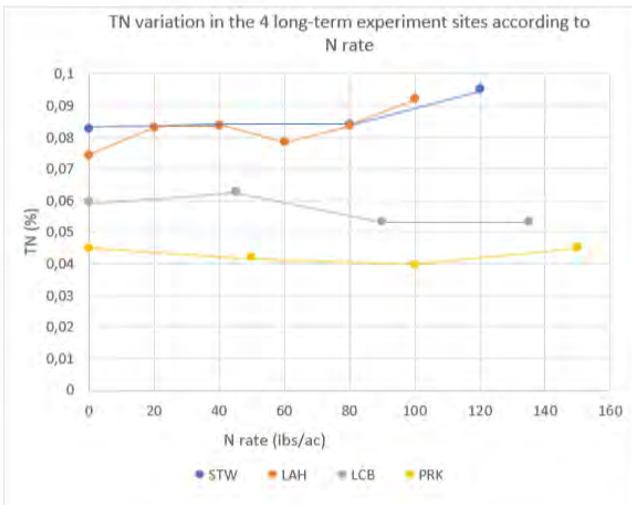

Figure 2 TN variation according to N rate in the studied sites

Similar to observation for Total Organic Carbon, Soil Total Nitrogen didn't significantly change with increasing N applied. Also, all the regression equations where N rate is the explanatory variable and TN is the dependent variable for all the sites don't explain much the variability of TN(Figure 6).

This result disagrees with two scientific researches : Jesmin and al., (2021), and Raun and al., (1998), who illustrated that total N was significantly greater after using fertilizer.

Table 4 Analysis of variance, mean squares and regression R squares for TN in experiments STW,LAH,LCB and PRK for 0-15cm

Location	N treatments	Mean	Standard variance	ANOVA N rate sig	Regressions R square
STW	0	0,083	0,004	ns 0,093	0,384
	40	0,084	0,006		
	80	0,083	0,006		
	120	0,095	0,005		
LAH	0	0,074	0,005	ns 0,126	0,113
	20	0,083	0,009		
	40	0,084	0,007		
	60	0,078	0,004		
	80	0,084	0,007		
	100	0,092	0,019		
LCB	0	0,059	0,004	ns 0,761	-0,068
	45	0,056	0,006		
	90	0,063	0,017		
	135	0,053	0,020		
PRK	0	0,045	0,008	Ns 0,724	-0,99
	50	0,042	0,009		
	100	0,040	0,009		
	150	0,045	0,010		

By calculating the OC/TN ratio for all the sites, the soils of the studied sites have an average decomposition capacity except the LCB site, whose soils are easy to medium decomposable. The C/N for all locations is not significantly changed by the N applied, same to TOC and TN. As illustred in Figure 5, the ratio values increased then decreased in the 4 sites the Ration. Raun and al., (1998) had observed a ratio the same fluctuation: the ratio value increased at the low and moderate N rates then decreased. Jesmin and al., (2021) observed also a declination of C/ ratio but with statically significant difference .

Table 5: TOC/TN ratio and SD for the 4 studied sites

	N rate (ibs/ac)	TOC/TN	SD
STW	0	10,738	0,45749669
	40	11,152	0,5039396
	80	11,052	0,4045208
	120	10,844	0,33929442
LAH	0	11,148	0,63658536
	20	11,286	0,55625162
	40	10,942	0,56377645
	60	10,737	0,56377645

	80	11,062	0,53244261
	100	10,828	0,55422904
LCB	0	9,902	0,43526926
	45	9,763	1,07692187
	90	11,167	1,1717754
	135	10,854	0,75979958
PRK	0	15,975	1,72807028
	50	16,651	2,15182177
	100	17,829	3,30607442
	150	16,550	0,9781694

CONCLUSION

The result of the present experiment can be explained by the research done by Souza and al. ,(2021) who studied the effect of Nutrient management on SOC and TN . Souza and al., (2021) have done their survey in 3 same locations that were studied in this research (LAH, STW and PRK). The time difference between the two researches is about two years. The result of their experiment showed that the impact was mostly found in the first soil layer (0-2.54 cm). From 2.54-10.16 cm and 12.7-15.4 no statistical difference was found in the OC values. Also, no difference was found in the 7.62-12.7 cm considering TN. From this research study, we can suggest the hypothesis that the sampling depth would highly influence the effect of N application on Soil organic matter. In our case, the depth selected had diluted the Carbon and Nitrogen differentiation, which impacted the significance of the Nitrogen application on SOM components. A new research must be made on the same plots in the same conditions but in a smaller depth (0-2,5 and 2,5 to 5 cm) to confirm this hypothesis. A debate should be maintained over the effect of different fertilization treatments on soil fertility because of the differences in soil types, crops, climatic conditions and soil depth.

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FORAGE PRODUCTIVITY, WEED DENSITY, AND SOIL PROPERTIES AFFECTED BY GRAZING AND TILLAGE OF ANNUAL FORAGES

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ABSTRACT

No-tillage (NT) management of annual crop production systems has often been observed to increase precipitation capture and storage. However, long-term NT can lead to decreased water infiltration due to compaction especially when fields are annually grazed. Compaction as well as cooler soil temperatures can inhibit crop establishment and reduce production. Minimum tillage (MT) (one to two operations between crops) could be used to break up surface compaction, increase water infiltration, improve crop establish, and increase production. Additionally, the development of herbicide resistant weeds presents a challenge to long-term NT production systems. An on-farm study was established in 2016 near Jetmore, KS to investigate the effects of annual tillage with a sweep plow compared to NT in a grazed continuous winter triticale (×*Triticosecale*) production system. Stocking rates were adjusted to the amount of plant growth which was dependent on precipitation. Stocking rates averaged 2 acres per 600 to 650 lb in the fall and 1 acre per 850 to 900 lb in the spring with yearling heifers. Forage productivity, weed density, and soil properties were determined in the 2020 and 2021 production years before and after the implementation of summer tillage. Soil properties were compared to an adjacent perennial grass pasture in 2020. Results showed MT increased available triticale forage by 29% compared to NT when measured in March though treatments were similar when measured in June. Averaged across years, tilled plots had 380% less weed density compared to NT before tillage occurred and 1530% less weed density after tillage and herbicide application. Soil chemical and physical properties were unaffected by tillage compared to NT in the 0- to 2-inch and 2- to 6-inch soil depths. However, when compared to an adjacent perennial pasture in 2020, both MT and NT plots had greater soil bulk density (13%), lower soil organic carbon (40%), and lower mean weight diameter of water stable aggregates (69%). These preliminary results suggest MT of grazed annual forage systems reduced weed density and increased fall through early spring forage productivity without affecting soil properties.

INTRODUCTION

Growing annual forages in semi-arid dryland cropping systems in the central Great Plains and increase cropping intensity, benefit livestock production, rest native rangeland, and increase profit (Holman et al., 2020; 2021). No-tillage (NT) management of annual crop production systems has often been observed to increase precipitation capture and enhance soil health (Blanco-Canqui and Ruis, 2018) However, long-term NT can lead to decreased water infiltration due to compaction especially when fields are annually grazed. Compaction as well as cooler soil temperatures can inhibit crop establishment and reduce production. Minimum tillage (MT) (one to two operations between crops) could be used to break up surface compaction, increase water infiltration, improve crop establish, and increase production (Holman et al., 2021). Additionally, the development of herbicide resistant weeds presents a challenge to long-term NT production systems. Across the semi-arid Great Plains, herbicide resistant kochia (*Bassia scoparia*) and Palmer amaranth (*Amaranthus palmeri*) are major challenges to effective NT management (Kumar et al., 2018; 2020). This experiment compared MT and NT management of grazed continuous triticale (×*Triticosecale*) to determine effects on forage production, weed density, and soil properties.

MATERIALS AND METHODS

An annual forage grazing and tillage experiment was initiated in 2016 at an on-farm field near Jetmore, KS. The study was a randomized complete block design with four replications. Two tillage treatments, NT and MT, were implemented in a grazed continuous winter triticale cropping system. Plots were 50 ft wide and 1300 ft long. In this experiment, tillage was implemented twice during the fallow period between winter triticale crops using a Minimizer sweep plow (Premier Tillage, Quinter, KS) between July 1 and August 1. The sweep plow is a minimum disturbance implement commonly used in the region for weed control. Both MT and NT treatments received the same herbicide applications which usually consisted of a mixture of glyphosate, dicamba, and 2-4,D.

Every year, winter triticale was planted between August 15 and September 15 and was grazed through the winter and spring. Stocking rates were adjusted to the amount of plant growth which was dependent on precipitation. Stocking rate averaged 2 acres per 600 to 650 lb in the fall and 1 acre per 850 to 900 lb in the spring with yearling heifers. Livestock were removed to an adjacent native grass pasture either before or soon after heavy rain events (>0.5”) for a few days to allow the soil surface to dry and minimize surface compaction. Otherwise, livestock were left on the field to graze. Grazing ended between May 15 and June 15 either after triticale reached heading stage in wet years or after the crop had been grazed out, in dry years.

In 2021, triticale forage was measured in March and June to estimate early spring and early summer forage availability using two 2.5 ft^2 quadrats. Samples were oven-dried at 122°F until a constant weight was reached to determine dry matter. In 2020 and 2021, weed density was measured before tillage in the month of June and after tillage and herbicide application in July. Weed density was estimated using a 2.5ft^2 quadrat in June and a 100 ft^2 quadrat in August. A larger quadrat was used in August due to low weed density following tillage and herbicide application.

In 2020 and 2021, soil properties were measured before and after summer tillage. In 2020 only, an adjacent perennial grass pasture dominated by buffalograss (*Bouteloua dactyloides*), sideoats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), and little bluestem (*Schizachyrium scoparium*) was also sampled for comparison with the annual triticale. Soil bulk density, organic carbon, and water stable aggregates were measured in two increments of 0- to 2-inches and 2- to 6-inches soil depth at these two time periods. Two intact soil cores of 6 inches in depth and 2 inches in diameter were randomly taken from each plot to determine soil bulk density. Samples were dried at 221°F for a minimum of 48 hours and bulk density was computed as mass of oven-dried soil divided by volume of the core. Ten additional 6-inch cores were collected randomly from each plot to determine soil organic carbon. Soil samples were mixed in the field, allowed to air-dry, and ground to pass through a steel sieve with 0.08-inch openings. Subsamples were ground to pass through a 0.01-inch screen and soil organic carbon was concentrations were determined by dry combustion after pretreatment with 10% (v/v) hydrochloric acid to remove carbonates. Penetration resistance was measured in June 2021 at 5 points within each plot using a hand cone penetrometer (Eijkelkamp Co., Giesbeek, The Netherlands) and readings were divided by the area of the cone (1 cm^2). Values of penetration resistance were adjusted to a field capacity gravimetric water content of 0.35 (g/g) (Busscher and Bauer, 2003). Additional soil samples were collected from the 0- to 2-inch soil depth with a flat shovel for the determination of water stable aggregates. Two sub-samples from each replicate were used to estimate mean weight diameter by the wet-sieving method. Statistical analyses were completed using PROC GLIMMIX of SAS ver. 9.4 (SAS Institute, 2012, Cary, NC) with year and treatment considered fixed and replication considered random. Differences were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Available triticale forage was 29% greater in the MT plots compared to NT when measured in March 2021 (Fig. 1). However, no difference in available forage was present by June. In 2020, MT plots had 130% less weed density compared to NT before tillage occurred and 1840% less weed density after tillage. In 2021, MT plots had 450% less weed density compared to NT before tillage occurred and 1340% lower weed density after tillage (Fig 2.). In June 2020, soil bulk density showed no difference between MT and NT plots in the 0- to 2-, 2- to 4-, or 4- to 6-inch soil depths. However, averaged across soil depths, MT (1.29 g cm^{-3}) and NT (1.32 g cm^{-3}) plots were about 13% greater than the perennial pasture (1.15 g cm^{-3}). Also in June 2020, soil organic carbon showed no difference between MT (1.72%) and NT (1.75%) plots in the 0- to 2-

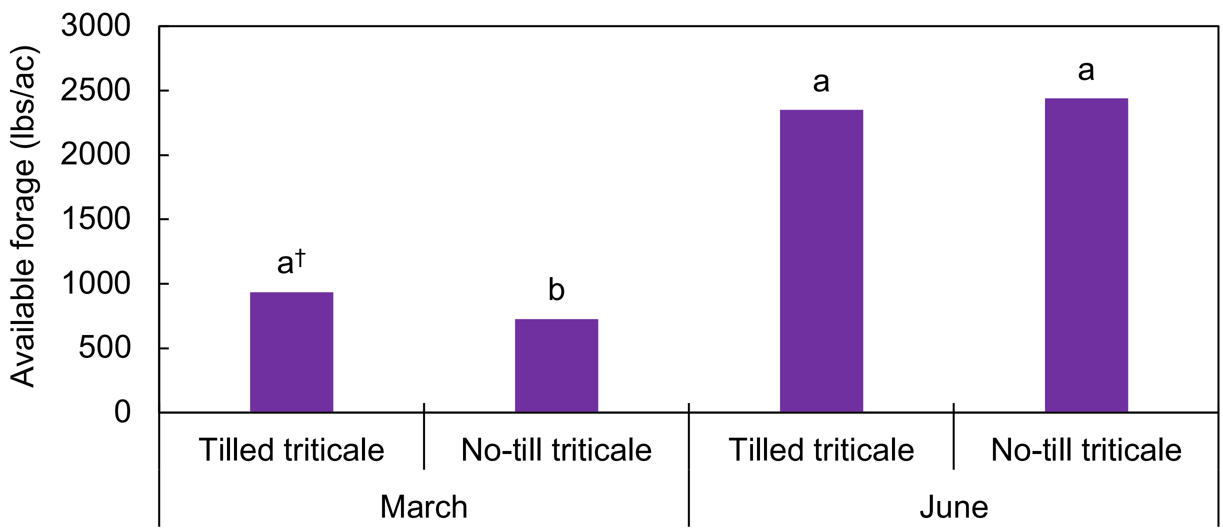

Figure 1. Tillage effects on triticale forage production in 2021 near Jetmore, KS.
†Means with the same letter are not significantly different (P <0.05) among years.

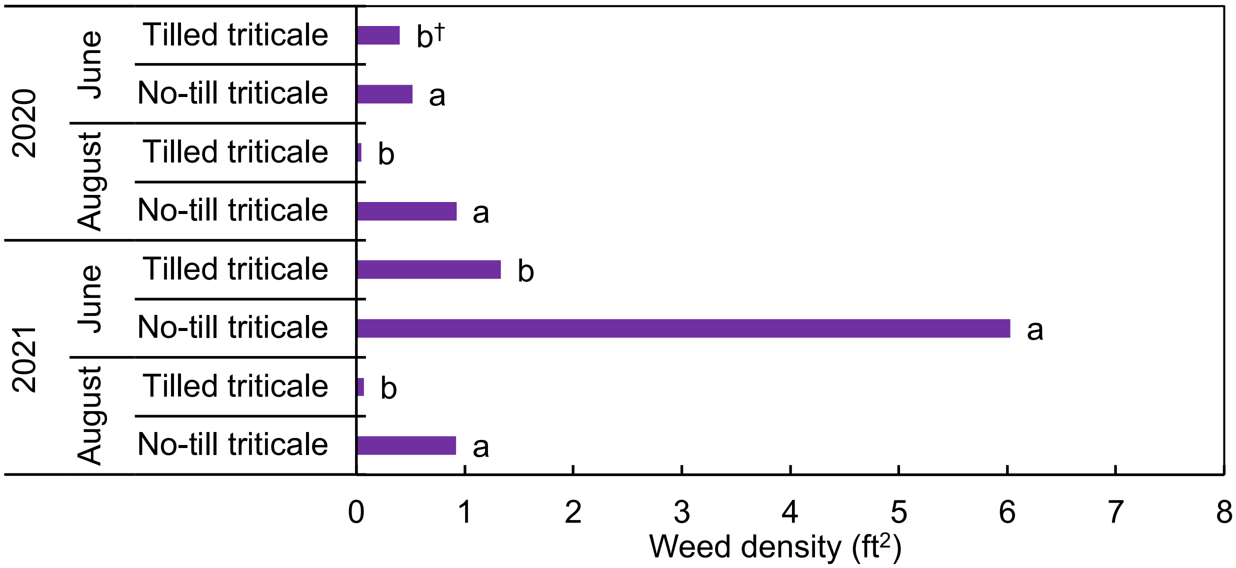

Figure 2. Tillage effects on weed density in a grazed winter triticale system in 2020 and 2021 near Jetmore, KS.
†Means with the same letter are not significantly different (P <0.05) among years.

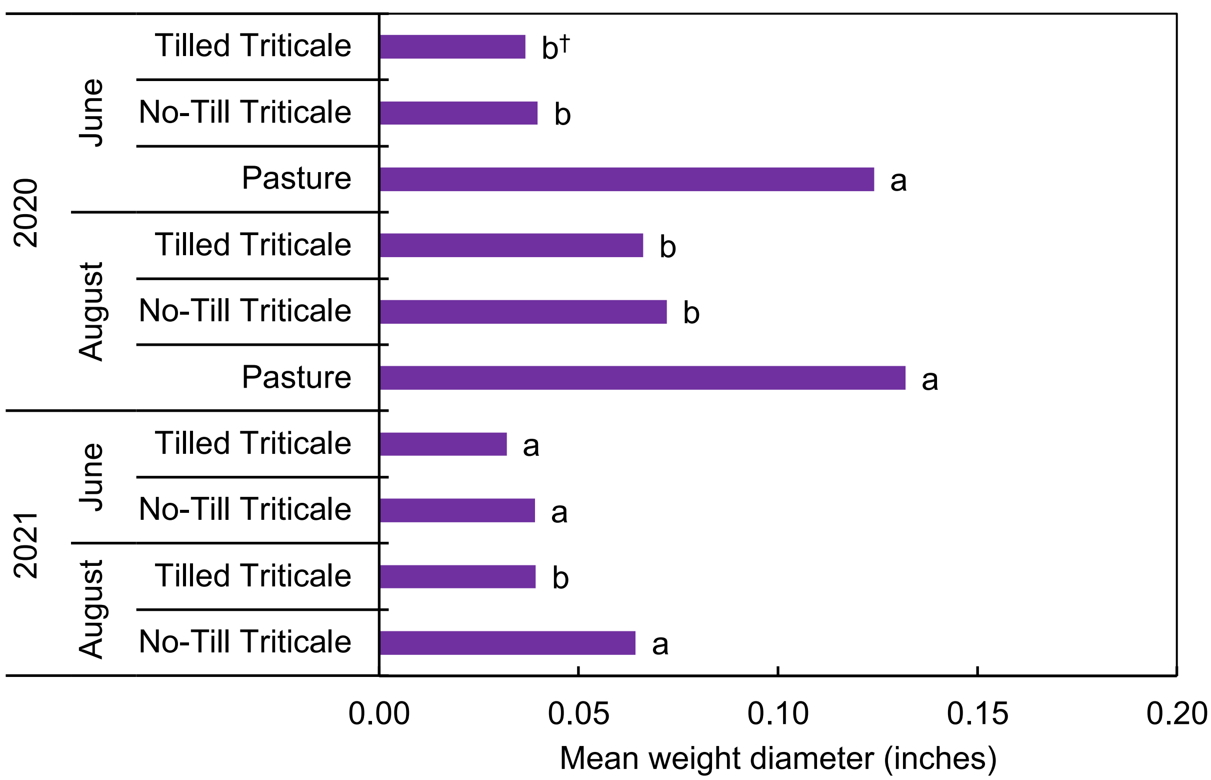

Figure 3. Tillage effects on mean weight diameter of water stable aggregates in the 0- to 2-inch soil depth in a grazed winter triticale system in 2020 and 2021 near Jetmore, KS.
†Means with the same letter are not significantly different (P <0.05) among years.

inch soil depth. However, both tilled and NT plots were about 57% less than the perennial pasture (2.72%). In June 2021, penetration resistance in the 0- to 6-inch soil depth was not different between MT (246 pounds/inch^2) and NT (263 pounds/inch^2).

In June 2020, there was no difference in mean weight diameter of water stable aggregates between the MT and NT plots though both were about 69% less than the perennial pasture (Fig. 3). Similar trends were observed in August 2020 with MT and NT being similar though significantly less than the perennial pasture. In June 2021, mean weight diameter was not different between the MT and NT plots. However, in August 2021, the MT plot was 39% less than NT plot possibly due to a greater tillage intensity compared to 2020 (one tillage operations versus two operations).

In conclusion, MT increased early available forage and substantially reduced weed density compared to NT. Bulk density, soil organic carbon, soil penetration resistance, and mean weight diameter of water stable aggregates were not different with tillage compared to NT, though both were less than the adjacent perennial pasture. Smaller mean weight diameter with tillage in August 2021 is notable. Another sample collection in 2022 will enhance our understanding of tillage effects in this system. Overall, results suggest that shallow tillage can be used to increase yields and reduce weeds with minimal effects on soil properties in grazed annual forage systems.

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COVER CROPS FOR THE IRRIGATED SPECIALTY CROP PRODUCTION IN THE NORTHERN HIGH PLAINS

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ABSTRACT

Irrigated specialty crop growers in the Northern High Plains (NHP) face multiple production challenges. These include low productivity soils, 125-day growing season, and extreme weather. For organically certified producers, additional difficulties include limited weed control strategies, incorporating biodiversity and implementing rigorous soil building strategies. One way to help improve these agroecosystems is to include cover crops as an off-season or relay crop. Cover crops have been widely studied in other climates on large-scale production, but careful design of cover crop mixes for producers facing the abovementioned challenges is needed. The main objective of this study was to evaluate suitability of selected cover crops to effectively compete with weedy species while not compromising plant available soil water needed to grow specialty crops and build up soil plant available nitrogen (N). Two monocultures, berseem clover and phacelia, along with three cover crop mixes (soil building mix, nitrogen fixer mix and mycorrhizal mix) were tested under irrigated conditions at the University of Wyoming Laramie Research and Education Center, in Laramie, Wyoming. Results suggested that large biomass producing cover crops provided an effective smothering of weedy species while not significantly depleting soil moisture. All cover crop mixes performed well but mycorrhizal mix likely provided additional benefits in form of rhizosphere associated simple organic N that facilitated healthy microbial communities.

INTRODUCTION

There is a growing interest in local food production in the Northern High Plains. Urban farmers in small towns of southeaster Wyoming, however, must face multiple challenges associated with very demanding growing conditions such as low precipitation, poor soil quality and short growing seasons. In addition, many farmers are interested in transitioning to organic certified production which brings even greater production challenges. These include chemical-free weed control, diversifying crop production and deploying soil management strategies to improve soil health, protect natural resources and conserve biodiversity (USDA, 2016). One way to help these producers is by incorporating cover crops. Cover crops are monocultures or mixes of fast-growing species, grown during non-crop periods or as a relay crop that can provide multiple benefits, including soil organic matter (SOM) increase, improved soil aggregation, increased plant biodiversity, soil surface cover, and weed competition/smothering (Blesh, 2018). Research has been conducted on the benefits cover crops add to large-scale production world-wide, but cover crop design and incorporation has not been researched on the local organic producer scale. Due to the short growing season present in Wyoming, designing cover crop mixes is of particular importance. These mixes should contain species that germinate quickly at low soil temperatures and produce large amounts of biomass that can smother competing weeds, build SOM, and prevent soil erosion. Designing the correct mixes and sharing that information with producers is a vital need that can be met with this research.

The main objective of this study was to evaluate suitability of selected cover crops to: (1) effectively smother weedy species, (2) not compromise plant available soil water needed to grow specialty crops and, (3) build up soil plant available nitrogen (N).

MATERIALS AND METHODS

The study was done at the University of Wyoming Laramie Research and Education Center Student Farm in Laramie, WY (41° 18′ 4″ N and 105° 35′ 28″ W, elevation 2,184 MASL). Cover crops were planted on May 14, 2020, and terminated on July 21, 2020. The experiment was affected by a June 8th snowstorm. The soil is sandy loam with a pH of 7.6 and an EC of 320 µS cm^{-1}. Seeds from three cover crop mixes and two cover crop monocultures (Table 1), plus a no cover crop control were planted in a randomized complete block design. The cover crops were obtained from Green Cover Seed (Grow Your Future » Green Cover). Each treatment was replicated six times resulting in a total of thirty-six, 6 m^2 plots.

Four 0-15 cm depth soil cores were collected at cover crop termination (July 21, 2020) using a step-down auger probe. Once excavated, soils were homogenized, stored in a plastic zipper bag, sealed, and placed in a cooler with icepacks until processing within 24 hours of collection.

In the lab, soils were sieved through a 2 mm sieve and analyzed for: (1) gravimetric soil water content (Gardner, 1986); (2) electrical conductivity (EC) and soil pH on a 1:2 soil-to-water ratio; (3) inorganic N (sum of NH_4-N and NO_3-N) on an extract obtained from placing 10 g of fresh soil to 25 ml of two molar potassium chloride (2 *M* KCl) and analyzed using Doane and Horwath method (2003) (Doane & Horwáth, 2003) on a spectrophotometer microplate reader (UV-VIS Biotek Instruments, Highland park, USA); (4) total dissolved nitrogen (TDN) on an extract obtained from placing 10g of fresh soil to 25 ml of one half molar potassium sulfide (K_2SO_4) using the Newcomb-Carrillo method (2011).

Plant biomass (cover crops and weeds separately) were collected from a .44 m^2 area within each plot using a PVC quadrat (33cm by 33cm) thrown two times at random and then flipped on one side for a total area measuring .44m^2. The plant biomass was cut at ground level and separated into cover crops and weeds. The plant biomass was then placed in a paper bag and oven-dried at 65°C for 48 hours to determine dried biomass.

All statistical analyses were performed in R version 3.6.2 (The R Foundation for Statistical Computing). The effects of cover crop treatment on soil gravimetric and chemical characteristics along with plant biomass comparisons were assessed using two-way Analysis of Variance (ANOVA) with significance at a minimum of $P \leq 0.05$. Data were tested for normality using the Shapiro–Wilk test. Transformations were used to achieve normality for data that were not normally distributed. If data were unable to normalize, a Kruskall-Wallis rank sum test was used for statistical analysis followed by the Dunn test to determine treatment significance. Regression analyses was performed on plant biomass data to assess weed suppression by cover crop treatment (Kutner, et.al., 2004).

Table 1: Cover crop mixes

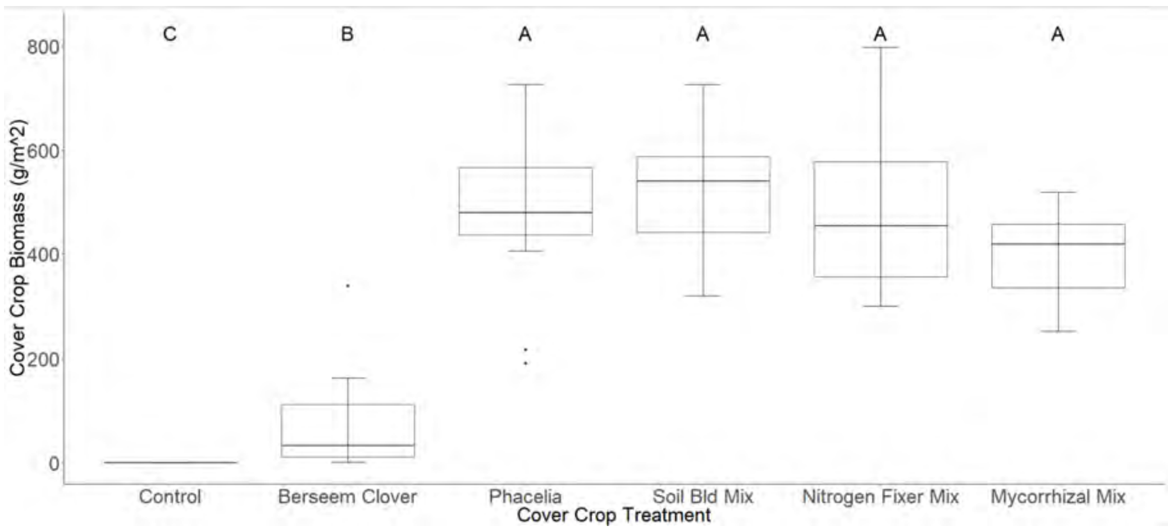
Species	Scientific Name	C3/C4 Plant	Lifeform	Berseem Clover	Phacelia	Soil Building Mix	Nitrogen Fixer Mix	Mycorrhizal Mix
Chick Pea	*Cicer arientinum*	C3	Legume				X	
Spring Pea	*Pisum sativum*	C3	Legume			X	X	
Spring Lentil	*Lens culinaris*	C3	Legume			X	X	X
Chickling Vetch	*Lathyrus sativus*	C3	Legume				X	
Common Vetch	*Vicia sativa*	C3	Legume			X	X	X
Berseem Clover	*Trifolium alexandrinum*	C3	Legume	X				X
Crimson Clover	*Trifolium incarnatum*	C3	Legume			X	X	
Persian Clover	*Trifolium resupinatum*	C3	Legume					X
Mung Bean	*Vigna radiata*	C3	Legume					X
Rapeseed	*Brassica napus*	C3	Broadleaf			X	X	
Sunflower	*Helianthus annus*	C3	Broadleaf			X	X	X
Flax	*Linum usitatissimum*	C3	Broadleaf			X	X	X
Phacelia	*Phacelia tanacetifolia*	C3	Broadleaf		X			X
Safflower	*Carthamus tinctorius*	C3	Broadleaf					X
Barley	*Hordeum vulgare*	C3	Grass			X		X
Oats	*Avena sativa*	C3	Grass			X	X	X
White Wonder Millet	*Setaria italica*	C4	Grass					X
Proso Millet	*Panicum miliaceum*	C4	Grass					X
Brown Top Millet	*Urochloa*	C4	Grass					X

RESULTS AND DISCUSSION

1. Cover crops competition with weedy species

All cover crops except for berseem clover produced biomass large amounts of biomass. Berseem clover is typically grown in warm environments with mild winters (Piano & Pecetti, 2010). A late, June 8th snow prevented a well-established stand of inoculated berseem clover (Figure 1A). This was demonstrated in the reduction of weed biomass in the well-established cover crop treatments (Figure 1B). Phacelia has a cold tolerance of -7.78°C (Kilian, 2016) and develops a dense canopy that made the biomass production of this monoculture similar to the biomass production of the cover crop mixes (Figure 1A) while also providing similar weed suppression (Figure 1B).

A



B

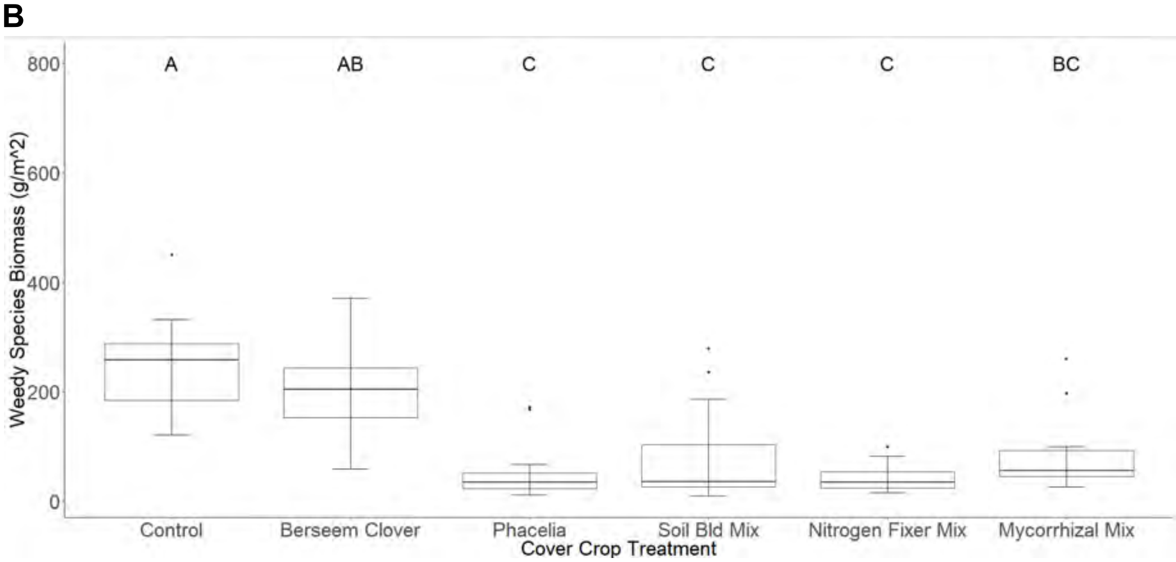
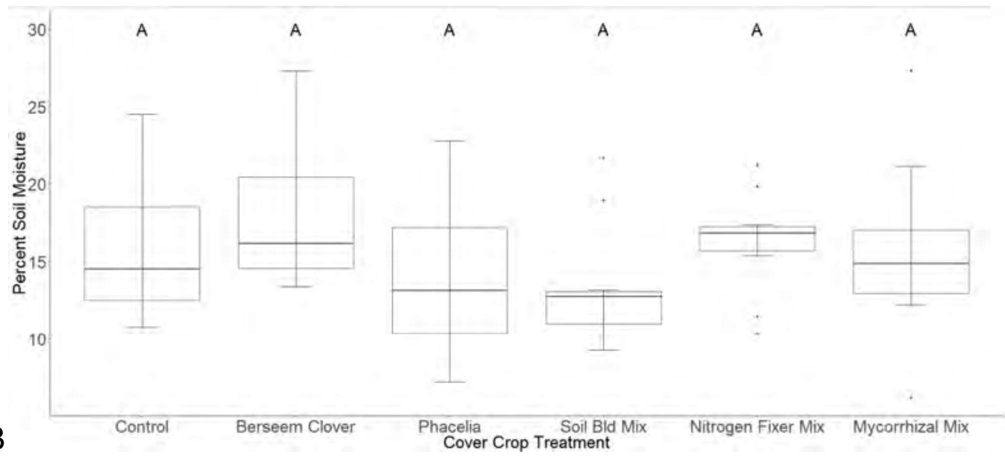


Figure 1: Cover crop (A) and weedy species (B) biomass

2. **Plant available water and nitrogen in soil following cover crops termination.**

A



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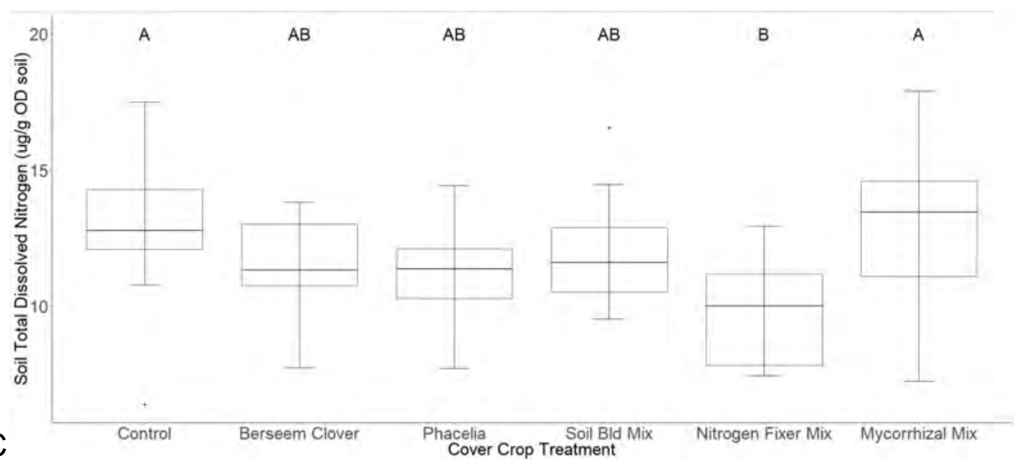

C

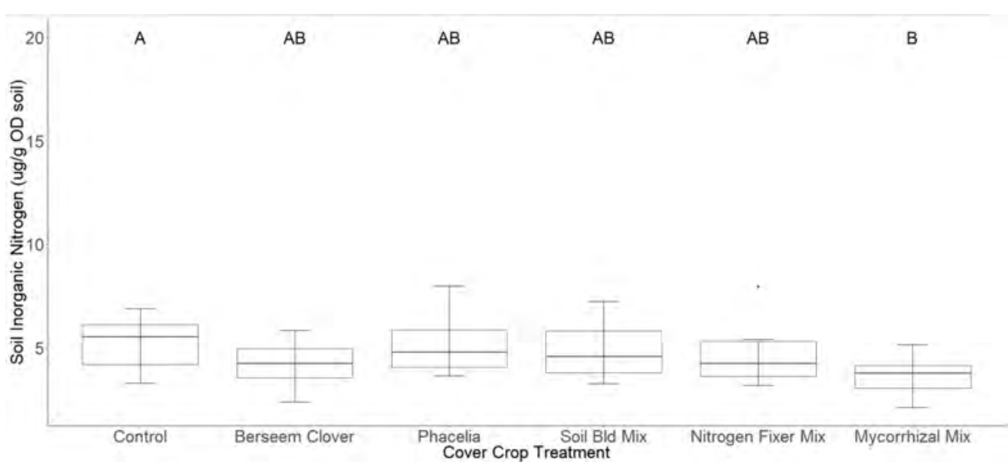

Figure 2. Soil water content (A) total dissolved nitrogen (B) and inorganic nitrogen (C).

Soil water was not significantly reduced by growing cover crops despite greater biomass production compared to weedy biomass produced in the control (Figure 2A). Total dissolved N was the highest in soils beneath mycorrhizal mix while the lowest TDN was in soils beneath N fixer mix (Figure 2B). In contrast, inorganic N was the lowest in soil beneath mycorrhizal mix. Mycorrhizal mix contained the highest number of cover crop species (Table 1) and contained the most grass species. Fibrous roots of grasses acted as good scavengers for inorganic N (Shelton et al., 2018) and successfully competed with weeds for soil N (Finney et al., 2017) (Figure 4B). High TDN and low inorganic N concentrations in mycorrhizal mix also suggested large contributions of simple organic N possibly root exudates, that supported active microbial communities in the rhizosphere.

CONCLUSIONS

Under water unlimited conditions, cover crops were effective at weed suppression in an organic system. Soil moisture was not compromised by growing high biomass producing cover crops. Once incorporated into the soil, cover crop biomass will become a source of plant available nutrients, increase soil organic matter, and improve soil health. Cover crop mixes containing grass species and producing large amounts of biomass effectively smothered weedy species. All cover crops selected for this experiment performed equally well but there were emerging trends that mycorrhizal mix may provide more benefits in the long term. Soil sampling immediately following cover crop termination might not reflect the prolonged benefits incurred by cover crop planting and later soil sampling would be required.

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IN-SEASON CHANGES OF SOIL MINERAL NITROGEN WITH NITROGEN FERTILIZER AND NITRIFICATION INHIBITOR IN CORN

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ABSTRACT

Understanding the role that soil mineral nitrogen (SMN) plays in the growth and productivity of corn is crucial. Nitrogen (N) demands vary during the growing season, and maintaining a sufficient amount of N in the form of ammonium (NH_4^+), or nitrate (NO_3^-) during the peak times of plant N uptake can help support high yields. The objective of this study was to assess changes and the supply of soil mineral nitrogen during the growing season in corn under field conditions in Kansas. This study was carried out in 8 site-years across Kansas during the 2017, 2018, 2019, and 2020. Fertilizer rates included 100, 150, and 200 lbs N acre^{-1} in addition to a control and with and without the use of a nitrification inhibitor at the 150 lbs N acre^{-1} rate. Since the V2 through the R6 grow stage in corn, soil samples were collected every two to three weeks. Samples were collected at 0-12 and 12-24 inches and analyzed for NO_3^- and NH_4^+. Soil NO_3^- concentration showed an initial increase followed by a rapid decrease after the V8 growth stage. This trend was likely due to the initial nitrification process from N fertilizer followed by a rapid corn N uptake. Soil $NH_4^+$was generally higher early in the season, with slightly higher values with the use of nitrification inhibitors. This study indicated that the delayed nitrification process with nitrification inhibitors was detectable with regular soil sampling. However, differences were small, and under regular field production systems is unlikely this small effect will be detectable with soil sampling. Results from this study also provided field values for SMN during the growing season under corn production. Weather and soil variables for each location in this study will be explored to investigate the interaction of soil, weather, and SMN under field conditions.

INTRODUCTION

Once applied to the soil with the fertilizer, nitrogen comes to be part of the soil pool, and changes in forms can occur rapidly. After nitrification, the NO_3^- form can be lost by leaching or denitrification. The amount of NO_3^- that can be lost depends on many variables like the amount of nitrate present in soil solution, the amount of N applied as fertilizer, the nitrification and denitrification rates, as well as weather and soil factors (Cameron et al., 2013).

Corn yield is largely determined by N fertilization and the efficient use of the fertilizer applied. Therefore, developing management and methods to prevent N losses is necessary to improve productivity and avoid possible negative impacts on the environment. Nitrification Inhibitors (NI) were developed to reduce the process of nitrification and keep N in the NH_4^+ form for a longer period of time and available for crop absorption, especially during the highest demands (Corrochano-Monsalve et al., 2021).

The objective of this study was to assess changes and the supply of soil mineral nitrogen during the growing season in corn under field conditions in Kansas.

MATERIALS AND METHODS

Field studies were conducted during the 2017, 2018, 2019 and 2020 corn growing seasons in eight site-years in Kansas. Nitrogen fertilizer was applied in the spring (March) at the rates of 100, 150, and 200 lbs N $acre^{-1}$ using Anhydrous ammonia (AA) with and without the use of a nitrification inhibitor (nitrapyrin) for the rate of 150 lbs N $acre^{-1}$. A control treatment was included with no nitrogen application. The experimental design was a randomized complete block with four replications. Corn was planted from April 23th to May 25th. Composite soil samples were taken at the V2, V4, V6, V8, V12, R1, and R6 corn growth stages at two soil depths, 0-12 and 12-24 inches. Soil NO_3^- and NH_4^+ concentrations were determined using 1M potassium chloride (KCl) extraction. NO_3^- concentration was determined by the cadmium reduction method, while NH_4^+ concentration was determined by the colorimetric reaction. Analysis of variance (ANOVA) and Fisher's least significant difference (LSD) pairwise comparisons at $\alpha < 0.05$ was performed using the R-4.1.2 software.

RESULTS AND DISCUSSION

Soil nitrate (NO_3^-) changes

At the beginning of the corn growth stage, there was no difference in the content of NO_3^- between the N rates, neither with the use of the NI **(Figure 1A & 1B)**. There was only a significant difference due to the application of N to the soil. By the V4 growth stage, there was an increase in the amount of NO_3^- at the 0-12 in depth for the highest rates of 150 and 200 lbs N $acre^{-1}$, however, there was no effect of the inhibitor at this stage **(Figure 1A)**. In the same depth (0-12 in) at V6 stage, a peak was reached and directly proportional to the increment of applied N rates **(Figure 3)**. Even though the concentration was lower and decreased, at V8, the same relationship was observed for NO_3^- **(Figure 4)**. In V8, an increase in NO_3^- content in the 12-24 in depth corresponded with a decrease at the 0-12 in depth, suggesting a leaching process. This time also corresponds with the time of the highest average of precipitation. When the crop reached the reproductive stages, the NO_3^- present in the soil decreased quickly.

Soil ammonium (NH_4^+) changes

The soil NH_4^+ content was generally higher at the beginning of the season, but with no significant differences due to fertilizer rates or the use of inhibitors **(Figure 2A & 2B)**. At the V6 growth stage there was an increase in soil NH_4^+ content with the higher amount of N applied (200 lbs N $acre^{-1}$); this increase occurred in both depths and the trend continued to V8 in the 0-12 depth **(Figure 5)**. After the V8 stage, soil NH_4^+ quickly decreased to background levels until the end of the season.

Results from this study suggest that the increased application of N helps increase mineral soil N content. The use of NI shows lower levels of NO_3^- early in the season, likely due to the reduction in the rate of the nitrification process.

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

					0-6 in		0-24 in	
Sites	County	Soil	Texture	Planting Date	pH	OM	NO_3^-	NH_4^+
						%	lbs acre^{-1}	
1	Riley	Smolan	Silt Loam	4/24/17	7.3	1.8	16.4	42
2	Republic	Hastings	Silty Clay Loam	4/25/17	5.8	3.3	23.6	38.8
3	Riley	Smolan	Silt Loam	4/28/18	8.0	1.9	10.4	0
4	Shawnee	Eudora	Silt Loam	5/07/18	6.9	1.4	105.2	44
5	Riley	Smolan	Silt Loam	05/25/19	5.7	1.6	22.8	16.8
6	Shawnee	Eudora	Silt Loam	04/25/19	6.6	1.5	61.6	16.8
7	Riley	Belvue	Silt Loam	04/30/20	6.5	2.2	7.6	14
8	Shawnee	Eudora	Silt Loam	04/23/20	6.4	1.3	15.2	14.8

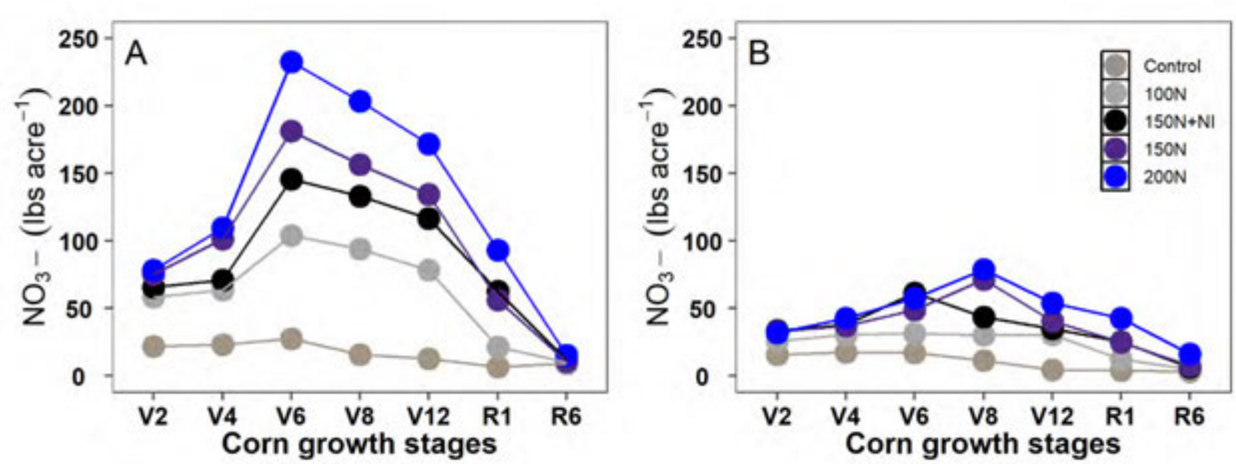

Figure 1. Average soil nitrate (NO_3^-) content throughout the corn growing season as affected by nitrogen fertilizer rates and nitrification inhibitor. **(A)** Soil nitrate (NO_3^-) content at the 0-12 in depth. **(B)** Soil nitrate (NO_3^-) content at the 12-24 in depth.

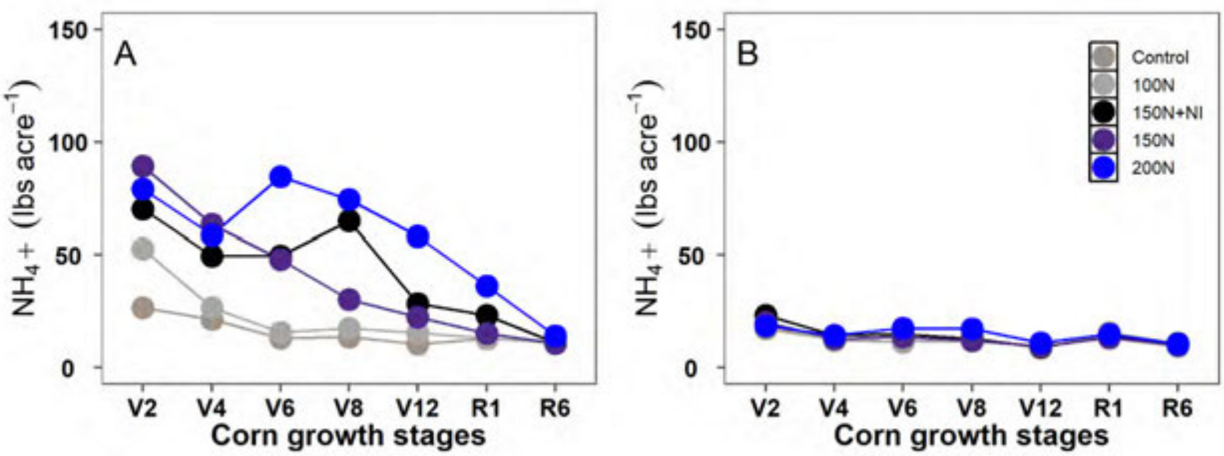

Figure 2. Average soil ammonium (NH_4^+) content throughout the corn growing season as affected by nitrogen fertilizer rates and nitrification inhibitor. **(A)** Soil ammonium (NH_4^+) content at the 0-12 in depth. **(B)** Soil ammonium (NH_4^+) content at the 12-24 in depth.

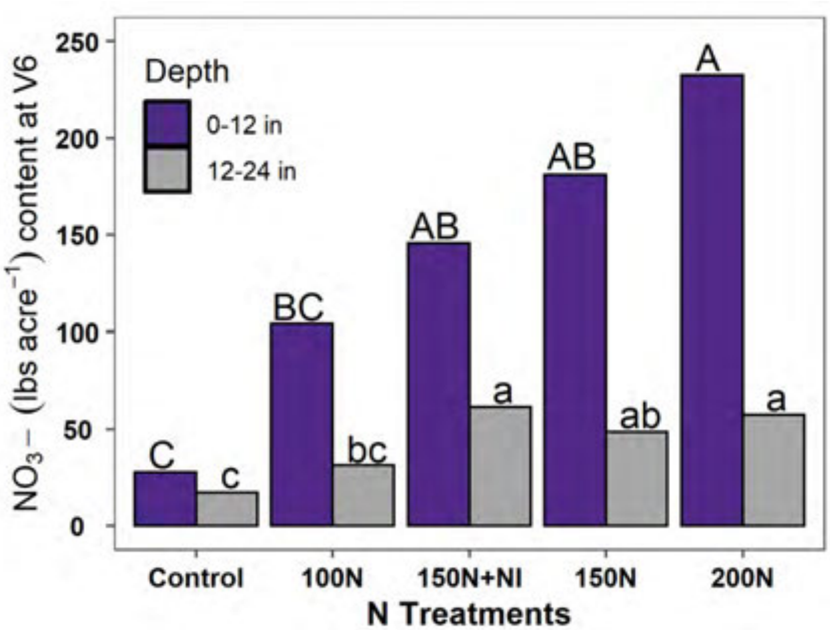

Figure 3. Average soil nitrate (NO_3^-) content throughout the V6 corn growth stage as affected by nitrogen fertilizer rates and nitrification inhibitor. Uppercase letters are used to compare NO_3^- content in the soil at 0-12 in depth ($P < 0.05$). Lowercase letters are used to compare NO_3^- content in the soil at 12-24 in depth ($P < 0.05$).

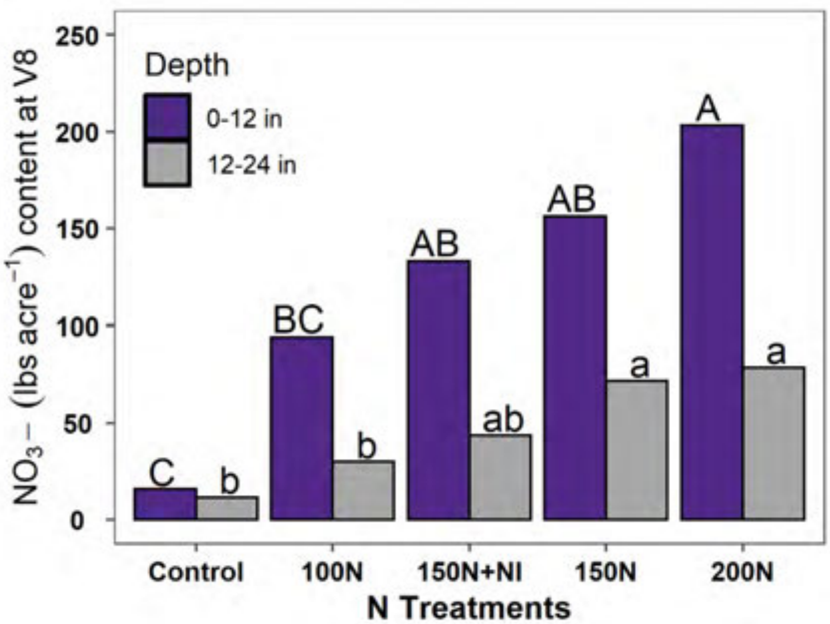

Figure 4. Average soil nitrate (NO_3^-) content throughout the V8 corn growth stage as affected by nitrogen fertilizer rates and nitrification inhibitor. Uppercase letters are used to compare NO_3^- content in the soil at 0-12 in depth ($P < 0.05$). Lowercase letters are used to compare NO_3^- content in the soil at 12-24 in depth ($P < 0.05$).

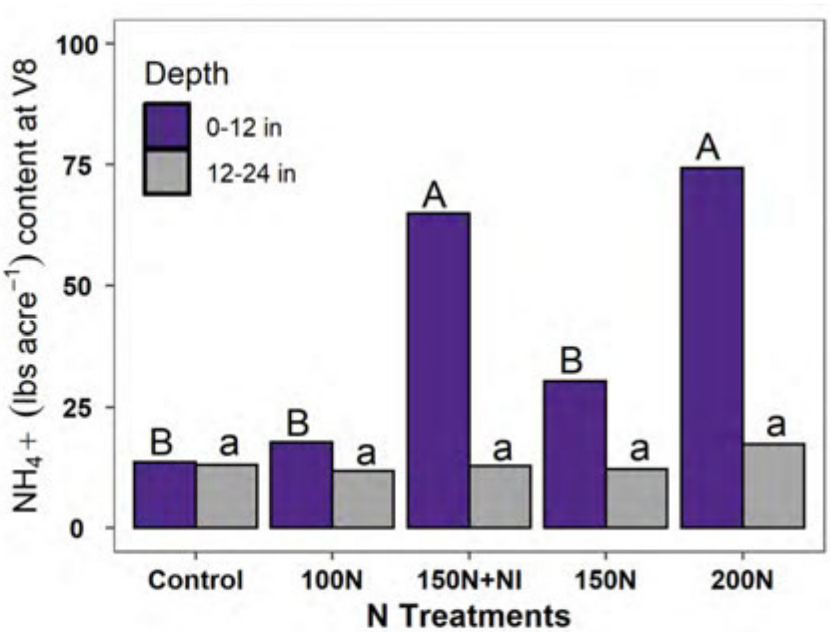

Figure 5. Average soil ammonium (NH_4^+) content throughout the V8 corn growth stage as affected by nitrogen fertilizer rates and nitrification inhibitor. Uppercase letters are used to compare NH_4^+ content in the soil at 0-12 in depth ($P < 0.05$). Lowercase letters are used to compare NH_4^+ content in the soil at 12-24 in depth ($P < 0.05$).

IMPACT OF N FERTILIZER SOURCE ON GRAIN YIELD

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ABSTRACT

Nitrogen (N) is one of the most important and critical nutrient elements in agricultural systems, and its effect directly affects crop productivity and nutrient content.

Our field studies were related to the wheat Crop. They were conducted in four locations to evaluate the effect of various Nitrogen sources (SuperU, Urea, UAN and UAN+Anvol) applied at three different times (pre, greenup and jointing). The experimental design of the four locations was randomized complete with 4 repetitions on each one we have 13 Treatments.

This study was focused on the effect of these variables on the wheat grain yield and also the Protein content and based on the statistics data that we collect, we found that N sources, time of applying and the locations affect the wheat yield, Concerning the protein content, the only significant relation that we found was with the locations.

Also, the objective of this study is to optimize the use of N fertilizers by choosing the best source and time to apply it so we can reduce N losses (economically and in yield) and increase the nutrient quality in the grain and the productivity.

INTRODUCTION

Wheat is the most important crop in Oklahoma, also it’s one of the top states that produce it in the region,

Oklahoma farmers sow each year 4 million acres approximately of winter wheat and that’s make it the largest cash crop, what’s make it play a major role in the US cattle industry. At a larger scale, several studies concerning the food production have shown that our productivity need to be increase so we can to meet the needs of rising population and diet shifts (Bruinsma, 2009; Tilman et al., 2011; OECD and Food and Agriculture Organization of the United Nations, 2012).

Our mean objective is to increase the yield and at the same time the nutrient content in wheat, that’s why fertilization will play a major role to achieve this goal.

In this study, we will be focused on the effect of nitrogen. As we know nitrogen is one of the essential nutrients, and it’s correlated directly to yield, it must be widely available during several growth steps of the wheat crop like formation of the foliage, the growth of the tubers…, also it ensures an optimal production of sugars in the leaves via chlorophyll and the enzymes of photosynthesis.

On the other hand, Nitrogen fertilizer requirements that’s we must apply depend on many factors like yield to achieve, soil type and environmental factors. also, there is several sources of nitrogen that we can use, and the applying time of each one can affect directly on the target yield.

Keeping all these points in view, several trials was implanted on the field with the purpose to evaluate the effect of different nitrogen sources applied on different times on grain yield and protein content at Oklahoma state.

MATERIALS AND METHODS

Our field experiments were conducted in four different locations at Oklahoma state on 2020/2021: Lake Carl Blackwell research farm (LCB), Caldwell, ALVA and Chickasha. The experimental design of the four locations was randomized complete with four repetitions on each one we have 13 Treatments (plots). The experiment comprised 4 different sources of nitrogen applied on 3 dates (pre, January, and march) with an unfertilized check.

Concerning the nitrogen, the sources that we used are Urea, it's a low-cost fertilizer form, after field application it transformed to ammonium bicarbonate. SuperU is stabilized urea-based fertilizer. UAN (Urea Ammonium Nitrate) is fluid fertilizer containing between 28 and 32 percent of nitrogen (N). And finally, we have UAN+Anvol is Urea Ammonium Nitrate plus Anvol is a nitrogen stabilizer that Improve nitrogen use efficiency in the soil. The plots were sown in October and received Nitrogen fertilizers in (pre, greenup and jointing).

At grain maturity, the plots were harvested, and the data that we collected are grain yield, percent moisture content and grain protein that was determined in post-harvest.

Also, an average of the daily temperature and accumulated rain (7 days after each N application) were retrieved from the Mesonet (www.mesonet.org) so we can compart and see how the climate influence on the grain yield.

Concerning the data analysis, we used Microsoft Excel 2019 AND SPSS Statistics 20 to see if there is any significant relation between N sources, time of applying and the locations on crop production factors, such as grain yield and protein. Data was differentiated using ANOVA methods and Dunnett's to separate the means at p = 0.05. Controls utilized on the test were the check

RESULTS AND DISCUSSION

Effect of N source, locations and applied day on grain yield:

Based on figures bellow we can see that the yield increases varied depending on the nitrogen source and other subject effects like locations, applied time and climate factors (Temperature and rain).

Figures 1 to 3 of the yield trend for winter wheat shows a significant difference on the yield what that mean is the location affects directly on the yield. also, Statistical analysis (ANOVA) of the data showed a significant difference in yield from 29.34 (19.16 for check) to 56.57 bushel/acre.

Table1: ANOVA test result of between-Subjects Effects (Locations, Time, N source) on Grain yield

Source		P-value Sig.
Intercept	Hypothesis	.000
	Error	
LOCATION	Hypothesis	**.000**
	Error	
TIME	Hypothesis	**.001**
	Error	
NSOURCE	Hypothesis	**.000**
	Error	
BLOC	Hypothesis	.090
	Error	
LOCATION * TIME	Hypothesis	.774
	Error	
LOCATION * NSOURCE	Hypothesis	**.001**
	Error	
NSOURCE * TIME	Hypothesis	.076
	Error	
LOCATION * NSOURCE * TIME	Hypothesis	.602
	Error	

Table1 contain the results of the ANOVA test, we can see that P-value of Locations, time, N source and also the interaction between location and N source on yield ≤ 0,05, that's mean that these subjects have a statistically significant effect on the grain yield.

However, BLOC and some other interactions between these factors did not show any effect.

Regarding the locations, the highest yield was achieved at Caldwell – TANA using Urea as a nitrogen source in March, it was specifically 61,73 bushel/acre (Figure 1). On the contrary, the lowest yield was Lake Carl Blackwell (LCB, only 29.34 bushel/acre (Figure 3) using UAN + Anvol as a nitrogen source in March. The yield difference between these 2 locations was 32,39 bushel/acre.

Furthermore, based on the climate data that we collect 7 days after each Nitrogen application (Figure5), we have:

- The biggest grain yield was in TANA location, with a height rainfall cumulative of 1,39in divided as follows 0,52in in November, 0,84in in March and 0,02 in April. The difference between the first 2 applying time and N sources wasn't significant, except in April we get the lowest grain yield in this location and coincided also with the lowest rainfall cumulative and highest Temperature 59,6 F.
- The Second average grain yield was in LCB Location using SuperU and Urea applied in March as a N source, with a height rainfall cumulative of 0.67in in March.
- In ALVA Location, the highest grain yield was obtained by using SuperU and Urea as a N source applied in November or March.

For the Chickasha location, it was eliminated it from this study because of the climatic conditions which affected it (Low Temperature), which is directly reflected on the data that we collected (Figure4).

Figure 1: Winter wheat grain yield and protein response to the application of 4 N sources affected by the timing of application at Caldwell, Oklahoma

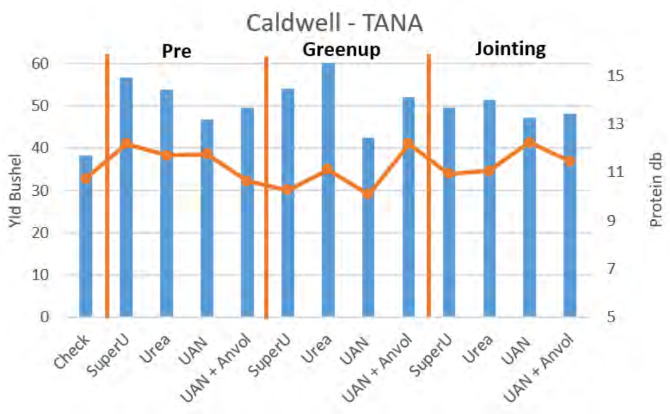


Figure 2: Winter wheat grain yield and protein response to the application of 4 N sources affected by the timing of application at ALVA, Oklahoma

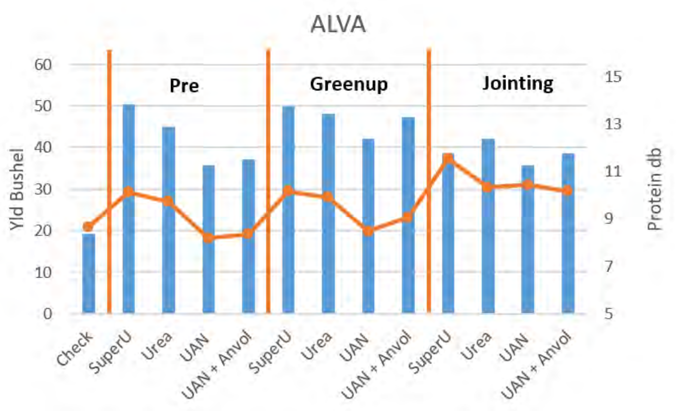


Figure 3: Winter wheat grain yield and protein response to the application of 4 N sources affected by the timing of application at Lake Carl Blackwell (LCB), Oklahoma

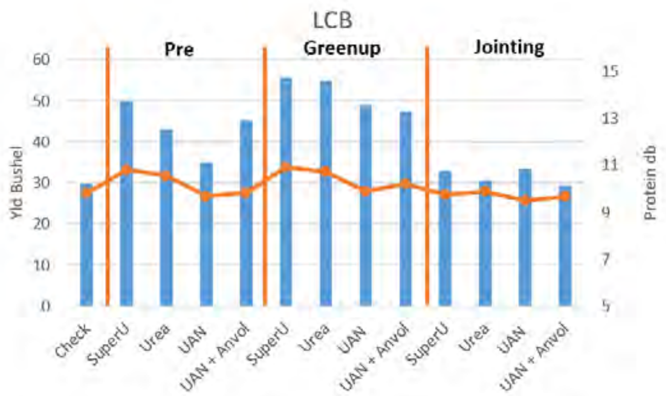


Figure 4: Winter wheat grain yield and protein response to the application of 4 N sources affected by the timing of application at Chickasha, Oklahoma

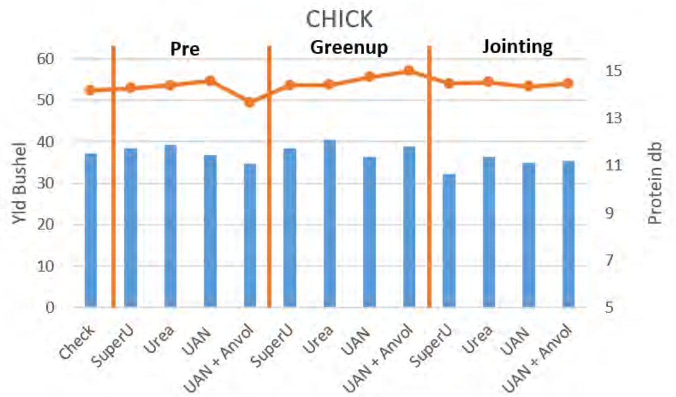
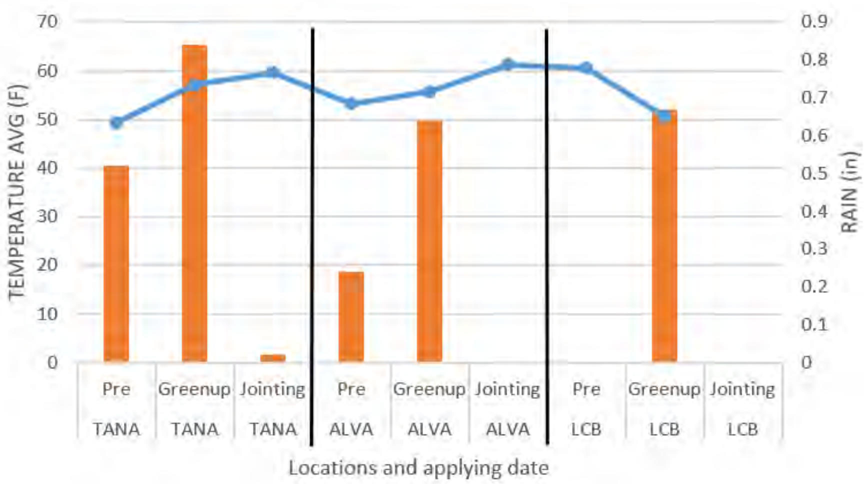


Figure 5: Temperature average and cumulated rain after 7 days of Nitrogen application at 3 locations (TANA, ALVA and LCB), Oklahoma



Effect of N source, locations and applied day on Protein content:

Table2: ANOVA test result of between-Subjects Effects (Locations, Time, N source) on Protein content

Source		Sig.
Intercept	Hypothesis	.000
	Error	
LOCATION	Hypothesis	**.000**
	Error	
NSOURCE	Hypothesis	.101
	Error	
TIME	Hypothesis	.378
	Error	
BLOC	Hypothesis	.109
	Error	
LOCATION * NSOURCE	Hypothesis	.144
	Error	
NSOURCE * TIME	Hypothesis	.101
	Error	
LOCATION * TIME	Hypothesis	**.002**
	Error	

Table2 shows the results of the statistical analysis, based on ANOVA test result between Subjects Effects (Locations, Time, N source) on Protein content, we can see that the location has a significant effect on the protein content also the interaction between location and time.

However, N source, time, bloc, and the rest interactions between these factors did not show any effect.

Based on the locations, the highest protein content was Caldwell – TANA (Figure 1). and the lowest protein content was between LCB and ALVA, what can be related to the climate factors (figure 5),

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NITROGEN FERTILIZER APPLICATION AND DEPTH OF MOIST SOIL AT PLANTING AFFECTED GRAIN SORGHUM YIELD

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ABSTRACT

The depth of moist soil before planting is critical for grain crop production in intensified dryland cropping systems. We investigated depth of moist soil at planting and nitrogen (N) fertilizer application rate effects on continuous grain sorghum yields on a Crete silt loam soil over 32-years in western Kansas. Treatments were four N rates (0, 20, 40 and 60 lb ac^{-1}) in a randomized complete blocks design with four replication and depth of moist soil at planting determined with Paul Brown moisture probe. Grain sorghum yield response to N application was -0.10, 14.4, 29.3, and 36.5 lb grain ac^{-1} for every lb N applied in very low yielding (VLY), low yielding (LY), high yielding (HY), and very high yielding (VHY) environments, respectively. Grain yield increased with depth of moist soil at planting for each N rate, with yield increases of 217 to 461 lb ac^{-1} per inch increase in depth of moist soil at planting for the unfertilized control through 60 lb N ac^{-1}. Regardless of yield environment, net returns were negative when depth of moist soil at planting was below 30 inches. This suggest continuous grain sorghum should not be planted when depth of moist soil is < 30 inches. Results of this 32-year study showed depth of moist soil at planting could be used to fine-tune sorghum N application rates.

INTRODUCTION

The increase in soil water storage due to adoption of conservation tillage has allowed cropping intensification (including continuous grain sorghum) in dryland systems in the central Great (Rosenzweig et al., 2018). Over 5.2 million acres of grain sorghum was produced annually from 2016 to 2020 in the United States, >50% of which was grown in Kansas (USDA NASS, 2021). Storage of moisture is critical to ensure profitable grain sorghum production in water-limited environments. In addition to moisture stress, soil nutrients particularly N availability affect sorghum production. Too much fertilizer could provide good vegetative growth, but, because of limited soil moisture, yield levels could be low. However, too little fertilizer may not use the stored moisture effectively and thus, would not optimize profitable yields. There are limited studies that have attempted to address effect of available soil water at planting and N fertilizer application on grain sorghum production in the semi-arid Great Plains. In dryland systems, measuring the depth to moist soil could provide a measure of water stored at crop planting. The depth of moist soil could be determined using the Paul Brown Moisture probe (Brown, 1960).

The amount of force required to push the Brown moisture probe into the soil is directly related to soil moisture content, with resistance increasing as the soil moisture content decreases. The objective of the current research was to determine if the depth of moist soil at planting measured with the Paul Brown probe could be used to make fertilizer application decisions.

MATERIALS AND METHODS

This study was conducted at Kansas State University Agricultural Research Center near Hays, KS between 1970 and 2002 under dryland reduced tillage operation system with annual cropping of sorghum. Treatments were four N rates (0, 20, 40 and 60 lb ac^{-1}) arranged in a randomized complete block design with four replications. Individual plot size was 40 ft. long × 12 ft wide. Tillage operations were accomplished with a V-blade or sweep plow to about 15 cm depth. Approximately two tillage operations were performed, one in the fall and another in late spring before sorghum planting. Nitrogen, as ammonium nitrate fertilizer was broadcast applied in the fall each year just prior to fall tillage to incorporate fertilizer. Soil test levels for available P were medium to high over the study period and exchangeable potassium (K) are inherently high in this soil, therefore, N was the only fertilizer applied over the 32-year study period. An objective of this study was to determine the influenced of depth of moist soil at planting on grain sorghum response to N fertilizer. The depth of moist soil was determined prior to sorghum planting in each year of the study using the Paul Brown probe (Brown, 1960). Briefly, depth of moist soil was determined by pushing a 0.4 inch diameter rod with a 0.5 inch ball bearing on the end into the soil. The depth to which the rod could be pushed was marked as the depth of moist soil **(**Brown, 1960). Six probe measurements were taken and averaged per plot and the depth of moist soil were converted to plant available water at planting (ASW) using conversion tables based on soil texture.

Grain sorghum was planted in late May through the second week in June and harvested in October. Grain sorghum was planted in 30-inch row spacing at 35,000 plants ac^{-1}. Grain sorghum hybrids used changed occasionally over the course of the study as seed company's replaced discontinued hybrids with newer, better-adapted hybrids. Weed control in grain sorghum was done with a pre-mixture of 25.3% of [alachlor, 2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide] and 15.3% of [atrazine, 2-chloro-4-(ethylamino)-6-(isopropylamino) s-triazine]. Grain yields were determined by harvesting 5 ft × 40 ft long area of each plot with a plot combine harvester (Massey Ferguson, Duluth, GA). The net returns from N fertilizer were computed for each N application rate treatment as the difference between total revenue from grain sales and cost of production (including planting, harvesting, trucking and fertilizer application costs). The total revenue was calculated as the product of grain yield and grain price. Nitrogen fertilization costs included in the calculations were price of fertilizer and spreading costs taken from the Kansas Agricultural Statistics custom rates (https://www.nass.usda.gov/Statistics_by_State/Kansas/). The economic analysis was done excluding government payments and crop insurance.

Data analysis for grain yield and net returns from N fertilizer for the 32-years were done using the PROC MIXED procedure of SAS (SAS Institute, 2012). Descriptive statistics was conducted and based on the results, the data was group into very low yielding environments (VLY), low yielding environments (LY), high yielding environments (HY), and very high yielding environments (VHY). Yield response to N in these environments were regressed using PROC REG procedure of SAS. Nitrogen application rate, depth of moist soil, and their interaction effects on yield and net return was conducted using PROC MIXED procedure. Mean separation of treatment effect was conducted using Tukey's honest significant difference.

RESULTS AND DISCUSSION

Precipitation and Grain Yield

Growing season precipitation (May through September) varied significantly over the study period (data not show). Total average growing season precipitation over 32-years of the study was 15.5 inches. In general, the 1993, 1996 and 2001 growing seasons recorded the highest growing season precipitation amounts. The driest growing season was 1983, with total seasonal precipitation amount of 6.8 inches. In 15 of the 32-year study, the amount of precipitation received was equal or above the 30-year average.

Sorghum grain yield varied significantly over the 32-yr study for each N rate. In five of the 32-years, average yield was below 1133 lb ac^{-1}, significantly smaller than the average yield (VLY). Average yields in twelve years of the study were below the overall average but within the lower portion of the standard deviation (LY). In eleven of the 32-years, annual average yields were above the overall average but within the standard deviation (HY). In four of the 32-years, yields were significantly above the overall mean (VHY). Sorghum grain yield did not respond to N fertilizer in VLY environments. In the LY, HY, and VHY environments, sorghum yields responded positively to fertilizer application rate (Fig.1a). In the LY environment, grain yield increased by 14 lb ac^{-1} for each additional lb ac^{-1} N fertilizer applied. In the HY environment, yield increased by 29 lb ac^{-1} for each lb increase in N fertilizer. Similarly, in the VHY environment, yield increased by 37 lb ac^{-1} for a one lb ac^{-1} increase in N fertilizer (Fig. 1a). Available soil water at planting and in-season precipitation amounts differed significantly among yield environments (Fig.1b & c).

In-season precipitation was generally weak at explaining grain yield response to N fertilizer application rate. However, sorghum gain yields responded positively to ASW at planting, and explained 86 - 98 % of the variation in yield within each N application rate (Fig. 2). Sorghum grain yield increased by 217 lb ac^{-1} for an inch increase in ASW for the unfertilized control. Applying N fertilizer at 20 lb ac^{-1}, grain yield increased by 318 lb ac^{-1} for an inch increase in ASW at planting. Likewise, grain yield increased 317 and

461 lb ac^{-1} with the application of 40 and 60 lb N ac^{-1}, respectively, for an inch increase in ASW at planting (Fig. 2).

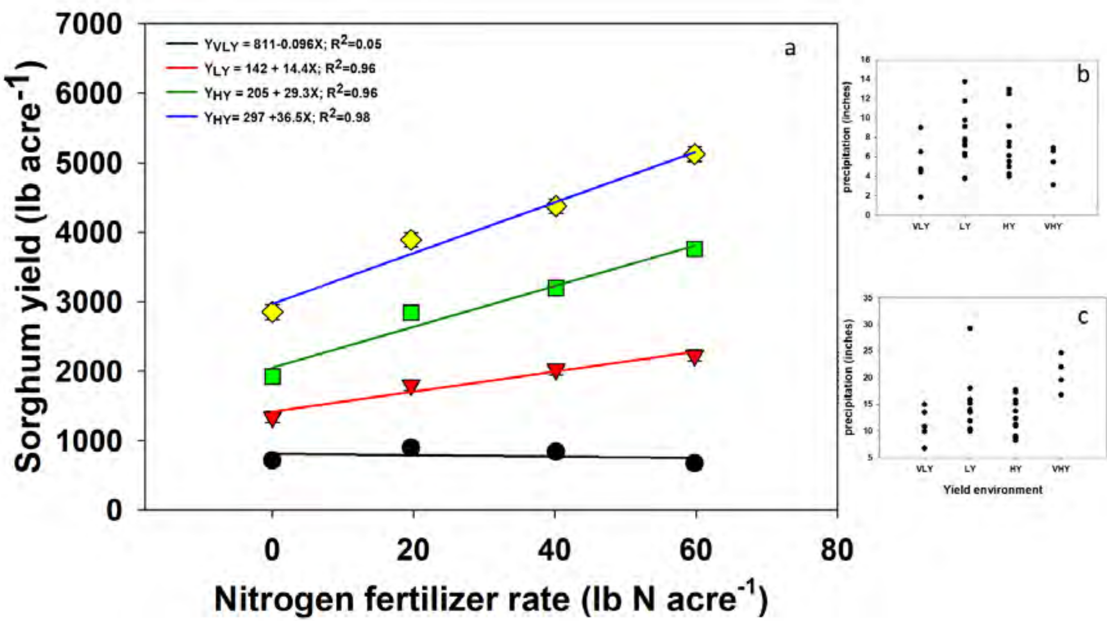

Fig.1. Nitrogen fertilizer rate and sorghum yield relations at four dryland yield environments [years with low yielding (VLY), low yielding (LY), high yielding (HY), and very high yielding (VHY)] and (b) off-season (fallow) precipitation, and (c) in-season precipitation amounts by yield environment from 1971-2002 near Hays, KS.

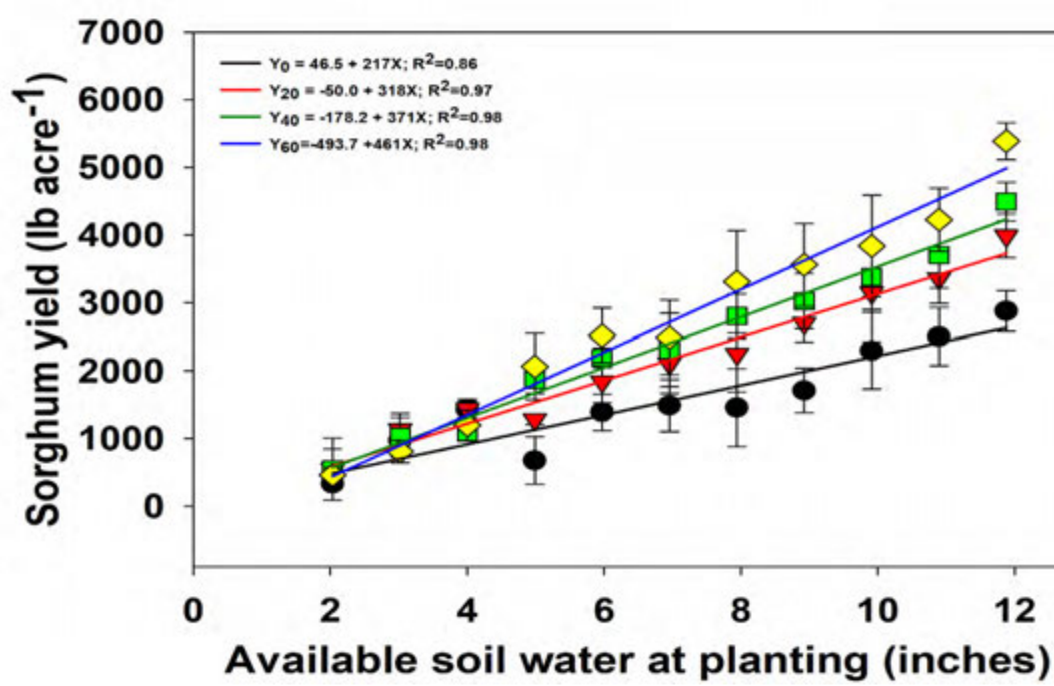

Fig. 2. Available soil water and sorghum yield relations in four N fertilizer amounts over the years from 1971-2002.

Net Return

Regardless of N fertilizer amount applied, net return for continuous sorghum production was negative for all environments when depth of moist soil at planting was below 30 inches. Irrespective of in-season precipitation, net return from N fertilizer application increased with depth of moist soil. For example, when in-season precipitation was < 16 inches, net return averaged $-200 to $-46 when depth of moist soil was ≤ 30 inches compared to net returns of $142 to $355 when depth of moist soil was 48 to 72 inches. In environments with > 16 inches in-season precipitation, net return to fertilizer application increased by $3.4 – $3.6 for each additional increase in depth of moist soil.

Conclusion

Grain sorghum response to N fertilizer application was highly dependent on yield environment. Available soil water at planting explained 86-98% of the variation in yield within N fertilizer rate. However, compared with only 4-18% with in-season precipitation explained only 4-18% of variability in yield with N rate. Net return with fertilizer application was negative for all environments when depth of moist soil at planting was less or equal to 30 inches. We concluded that the depth of moist soil at planting could be used to fine-tune continuous sorghum planting (do not plant sorghum when depth of moist soil < 30 inches) and N fertilizer requirements.

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EVALUATION OF SOIL TEST PHOSPHORUS EXTRACTANTS AND TISSUE ANALYSIS FOR CORN IN KANSAS

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ABSTRACT

Phosphorus (P) is a critical nutrient for corn (*Zea mays* L.) productivity. Determining an appropriate concentration of soil test phosphorus (STP) and P tissue concentrations is a fundamental step needed to make accurate phosphorus management decisions. The main objective of this study was to evaluate the relationship of four different STP methods (Mehlich 3, Bray 1, Bray 2, and H3A) for corn production and determine critical P tissue concentration at different growing stages. The study was conducted in 12 locations across Kansas during 2021. Fertilizer treatment consisted of five phosphorus fertilizer rates and was applied one time by broadcast pre-plant. Soil samples were collected at the 0-6-inch; samples were recollected before treatment application by block. Tissue samples were collected at the V6, and R1 grow stages. The relationship between different STP, model R^2 varies between (0.24-0.93), Mehlich 3 and Bray 1 have the higher correlation, and Bray 1 and Bray 2 have the lower correlation. Linear Plateau determined the critical P levels for V6 at 0.42 %, and for R1 stage was 0.22 %. The relationship between the concentration at V6 and R1 was moderately correlated with R^2 = 0.62, having a higher P concentration in the early stage.

INTRODUCTION

Phosphorus (P) is a macronutrient that plays several essential roles in plants and is required in relatively large quantities. The available fraction of the total soil phosphorus is typically low, and P fertilizer needs to meet crop P needs. Understanding the adequate P rate in corn production is necessary to sustain high yield potentials. Phosphorus fertilizer may not be enough to replace what the crop is removing in the long term if rates are too low. Therefore, soil testing should be performed to determine the correct fertilizer rate for an economic yield response (Mallarino & Blackmer, 1992); Critical concentrations of STP and critical tissue concentrations can be used to identify the response to phosphorus fertilization should be expected.

Critical levels could depend on many factors, including specific crops as well as soil characteristics, environmental, and other factors. Determining an appropriate concentration of STP and their relationships is a fundamental step required in making fertilizer recommendations. Error in determining critical concentration results in an incorrect decision relating to fertilizer application (Mallarino & Blackmer, 1992). New STP methods for corn have not been evaluated recently in Kansas.

MATERIALS AND METHODS

Field experiments were conducted at 12 locations across Kansas in producers' fields and Kansas State University Research and Extension Centers (table 1). The experiment design was a randomized complete block design with four replications; plots were 10 ft width per 40 ft length. Fertilizer treatment were four rates of phosphorus (P) fertilizer (30, 60, 90, and 120 lbs. P_2O_5 acre^{-1}), using mono-ammonium phosphate (MAP) (11-52-0). A total of 5 treatments was established, including one control; all fertilizer was applied one time by broadcast pre-plant. Before treatment application, soil samples were collected, composite by blocks at 0-6-inch depth using a hand probe; soil measurements include pH and different extractants for P (Mehlich 3, Bray 1, Bray 2, and H3A). Corn was harvested, and yield was calculated and corrected to 15.5% moisture.

Soil samples were dried at 40 °C, plant tissue samples were dried at 60 °C, and both were ground to pass a 2 mm sieve. Soil samples were analyzed for pH 1:1 (soil:water) using a pH meter equipped with glass electrodes (Skalar, Inc). Mehlich 3 extraction was performed using solution ratio 1:10 (soil:solution), extraction 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 200 epm (Mehlich, 1984) For Bray 1 (0.03 M NH4F + 0.025 M HCl) and Bray 2 (0.03 M NH4F + 0.1 M HCl) the extraction solution ratio was 1:10 and was shacked for five minutes at 200 opm (Bray & Kurtz, 1945). H3A extractions were collected using a solution ratio of 1:10 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 200 epm. The H3A extracts were centrifuged at 3500 rpm for 5 minutes (Haney et al., 2017). All extracts were filtered through Whatman 2V filter paper. Extractable P was measured at 660 nm using a colorimeter (Lachat QuikChem 8500 Series 2). The plant's tissue samples were digested using Nitric-Perchloric Acid Digestion and analyzed using ICP-OES.

Relationships between different STP were evaluated using linear regression models. Critical levels were performance between relative yield and plant tissue concentrations and relative P uptake at V6 and different STP using linear plateau models. Data analyses were performed in R version 4.1.

RESULTS AND DISCUSSION

Correlations between different STP

Preliminary results showed that Mehlich 3 vs. Bray 1 and Mehlich 3 vs. H3A were highly and well correlated (R^2 = 0.93 and 0.80, respectively) and exhibit a linear relationship (Figure 1a, and Figure 1b). A similar correlation between Mehlich 3 and Bray 1 was reported several times with a range of R^2 values between (0.85-0.99) (Culman et al., 2020). Rutter & Ruiz Diaz (2020) reported a correlation of Mehlich 3 and H3A with an R^2 of 0.83. The Bray 1 and H3A relationship was moderately correlated with R^2 = 0.60 (Figure 1c); this is similar to what has been reported by Dari et al., (2018), a correlation with an R^2 of 0.54. All method correlated with Bray 2 (Mehlich 3 vs. Bray 2, Bray 1 vs. Bray 2 and H3A vs. Bray 2) was poorly correlated with R^2 = 0.31, 0.24 and 0.47, respectively (figure 1d, 1e, 1f). Soil with a pH above 7.0 was shown in red.

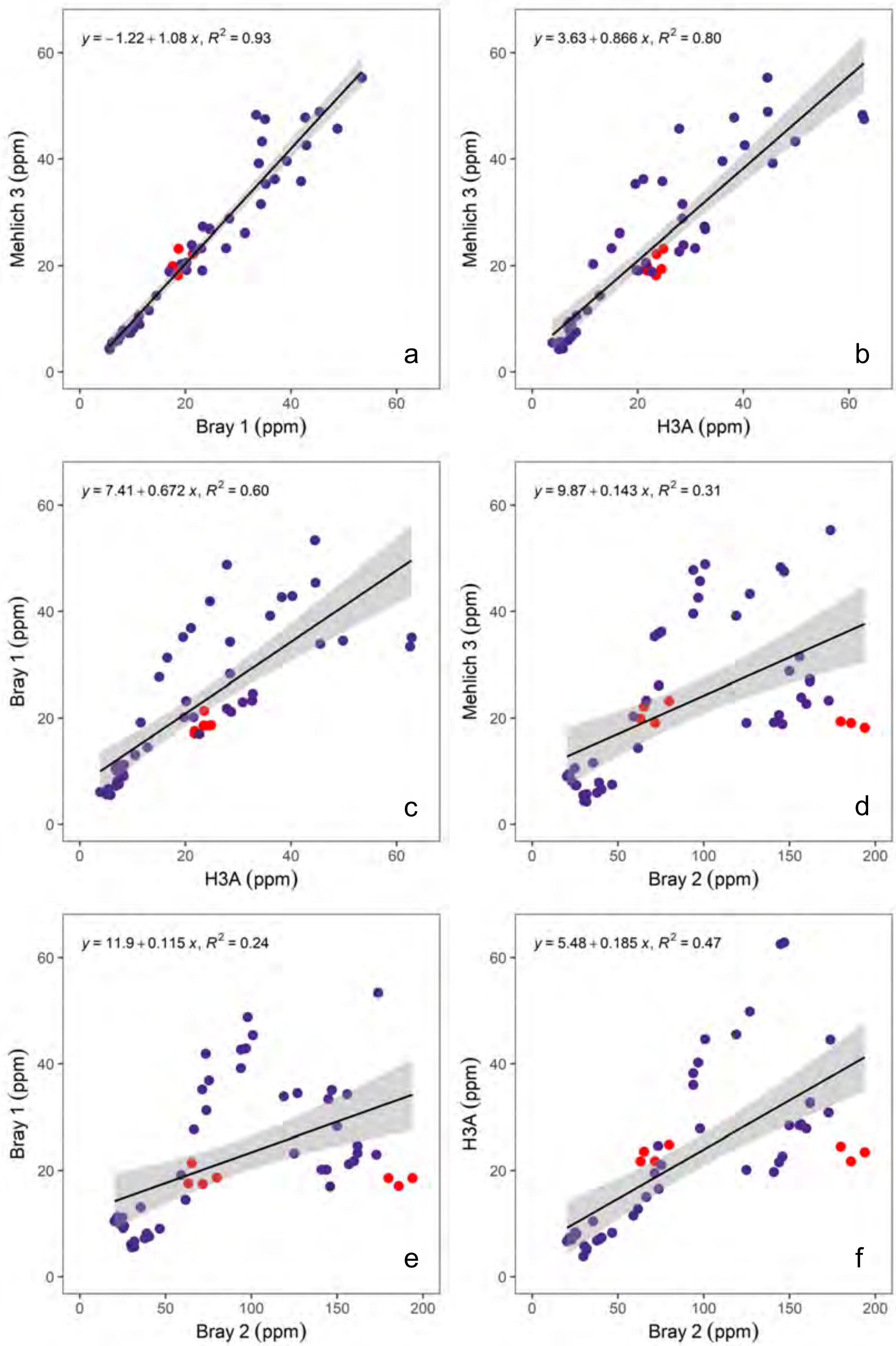

Figure 1. Relationship between different soil test phosphorus methods (a) Mehlich 3 vs. Bray 1, (b) Mehlich 3 vs. H3A, (c) Bray 1 vs. H3A, (d) Mehlich 3 vs. Bray 2, (e) Bray 1 vs. Bray 2 and (f) H3A vs. Bray 2. Soils with a pH > 7.0 are indicated by red points.

Table 1: Study sites, soil properties, and production system information for corn studies in 2021. Samples were collected at 0-6 in depth.

Location	County	Soil Series	pH	Mehlich 3	Bray 1	Bray 2	H3A
				ppm			
1	Republic	Crete	6.5	5	6	31	5
2	Republic	Crete	6.1	7	8	41	7
3	Franklin	Woodson	6.0	9	11	28	9
4	Dickinson	Geary	5.8	21	23	65	14
5	Shawnee	Bismarckgrove	7.6	21	19	70	23
6	Gove	Keith	7.2	20	19	183	25
7	Logan	Keith	6.4	22	21	145	23
8	Gove	Keith	6.6	25	23	160	30
9	Gove	Ulysses	6.2	35	37	148	26
10	Salina	Longford	5.4	38	41	79	23
11	Riley	Bourbonais	6.3	45	34	134	55
12	Brown	Kennebec	6.3	45	43	96	40

Critical Phosphorus concentrations

The critical tissue P levels for the whole plant at the V6 growth stage were determined by linear Plateau was 0.42 %, and model R^2 value was 0.26 (figure 2a). The critical P levels for the ear leaf at the R1 stage were 0.22%, and the model R^2 value was 0.18 (figure 1b). Both R^2 values are low, the ear leaf at R1 having lower than the whole plant at V6. Stammer & Mallarino (2018) found a similar critical P concentration in Iowa for the whole plant V5-V6 with a linear Plateau of 0.48 % (R^2= 0.35), and 0.25 % (R^2= 0.64) for ear leaf blades at the R1.

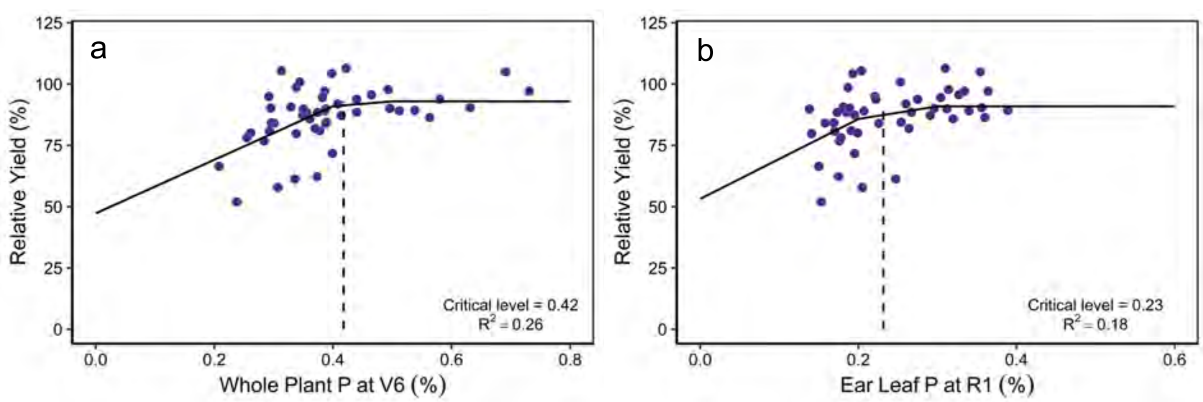

Figure 2. Relationship between relative yield and the P concentration of (a) whole plants at the V6 growth stage or (b) ear leaf blades at the R1 stage. Vertical lines indicate a critical P level with a linear plateau.

Critical soil test P values at the V6 stage was determined for the different P extractants by linear Plateau (table 2), and provided critical levels of 24 and 21 ppm for the Mehlich 3 and Bray 1 methods, respectively, both having an R^2 of 0.50. For the H3A, the critical level was estimated at 13 ppm with the highest R^2 of 0.51. The Bray 2 method has the lowest R^2 value (0.36) and an estimated critical value of 75 ppm. The relationship between the concentration in the whole plant at V6 and in ear leaf in R1 was moderately correlated with R^2 = 0.62 (figure 3). The P tissue concentrations ranged from 0.25 to 0.64 % for V6 and 0.15 to 0.42 % for R1. The tissue P concentrations in the V6 stage were higher than at the sample at the R1 stage; this suggests that the value of tissue testing to assess plant P nutritional status may differ during the growing season.

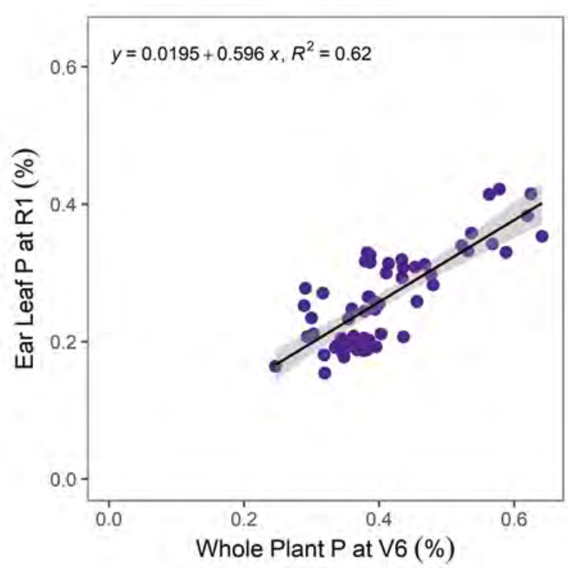

Figure 3. Relationships between P concentrations in-ear leaf at the R1 stage and whole plant at the V6 growth stage.

Table 2: Relationships between relative P uptake at V6 (%) and different soil test P (ppm).

Soil test method	Critical level	Std. Error	R^2
Mehlich 3	24	2.78	0.50
Bray 1	21	2.49	0.50
H3A	13	1.97	0.51
Bray 2	75	11.22	0.36

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KERNZA IN WYOMING: EVALUATING PERENNIAL GRAINS TO REVITALIZE WYOMING DRYLAND AGRICULTURE

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ABSTRACT

Kernza, a perennial grain crop harvested from intermediate wheatgrass, promises to provide a sustainable alternative to wheat-fallow agriculture that can build soil health while producing food for a growing population. Kernza had not previously been planted in Wyoming, where the semiarid landscape presents unique challenges yet stands to particularly benefit from a perennial crop. Kernza is being grown from spring 2021-2024 at several farms in southeast Wyoming using various management strategies. We aim to evaluate Kernza's effects on soil fertility, carbon sequestration, and microbial activity by comparing Kernza fields to both wheat-fallow and perennial grassland. So far, baseline soil sampling has shown differences in soil health indicators between annual and perennial systems. In particular, we found higher surface (0-5cm) microbial enzyme activity and labile organic matter pools, and more stratification between depths (0-5 and 5-15cm) in the perennial system. In future years, we expect that fields transitioning from annual cropping to Kernza will become more similar to perennial grassland in terms of these soil health indicators.

INTRODUCTION

Wyoming Wheat-Fallow

Cereal grains make up the majority of world cropland and fertilizer use, and wheat in particular accounts for one-fifth of the global food supply.[1,2] Winter wheat is the major food crop in the High Plains of Wyoming, yet degraded soils, climate change, and weak markets threaten farming in this region. Additionally, wheat agroecosystems are especially vulnerable to a changing climate.[3] The Western Great Plains is experiencing both land abandonment and land-use change towards Conservation Reserve Program (CRP) land and hay, driven by drought, fluctuating markets, and marginal yields.[4,5] When perennial grassland is converted to annual cropland, even without tillage, root biomass, oxidizable carbon (C), and microbial biomass has been shown to decrease.[6] Though tilled wheat-fallow (W-F) systems in eastern Wyoming have lost 33-63% of their native soil organic C (SOC), converting these systems back to perennials as part of CRP can restore SOC to 90% of that under native grassland after 15 years.[7] Sustaining agriculture in this region will require alternative farming systems that can mimic the native landscape while remaining profitable.[8]

Kernza

Kernza, the first perennial grain crop grown in the US, is harvested from a cultivar of intermediate wheatgrass *(Thinopyrum intermedium)* developed at The Land

Institute. Kernza serves as a replacement for wheat in food products such as cereals, bread, and beer. It grows for three or more years between seedings and can be harvested for both grain and forage. Kernza's deep perennial roots sequester C, curtail soil erosion, and enhance access to water and nutrients. Kernza fields support soil microbial communities more similar to native prairie than to annual wheat, contributing to soil aggregation, microbial C stabilization, and tight nutrient cycling.[9–11] Though Kernza had not been planted in Wyoming prior to this project, it shows promise as a sustainable dryland crop for marginal lands.[12]

We aim to evaluate the effects of Kernza on soil health and C sequestration compared to W-F and CRP. Kernza is being planted at four farms, including the James C. Hageman Sustainable Agriculture Research & Extension Center (SAREC), and yield will be assessed at each. Additionally, we are evaluating soil health and soil microbiology in matched Kernza, W-F, and CRP fields at one farm by analyzing soil physical, chemical, and biological properties. We expect to find that soil properties will become more similar to perennial grassland as W-F fields transition to Kernza. Despite lower yields, higher market prices and soil health benefits could make Kernza a viable option for High Plains wheat farmers.

MATERIALS & METHODS

Site Description & Experimental Design

The High Plains ecoregion that comprises Wyoming's wheat growing region experiences 305-432 mm annual precipitation, 100-125 frost-free days, and a mesic temperature regime (-13/4°C average January min/max, 11/31°C average July min/max). Soils are mainly silty and loamy Mollisols (Agiustolls, Haplustolls) and Entisols (Torriorthents, Torripsamments, Ustorthents).[13]

Ten to twenty acres of Kernza was or will be planted in spring of 2021 or 2022 at each of four farms in southeastern Wyoming, and will be harvested in the summers of 2022, 2023, and 2024 using a plot combine for yield analyses. Winter wheat is grown in a 2-year W-F rotation that includes 14 months of fallow between crops. Perennial grassland is certified CRP land. At SAREC, Kernza was planted in 6 small (5ft x 30ft) irrigated research plots. Half are irrigated up to average precipitation monthly, and half are fully irrigated, in order to evaluate Kernza growth with average and with non-water-limiting conditions. Soil sampling takes place at SAREC and at matched Kernza, W-F, and CRP fields at one farm with three replicate plots in each field.

Data Collection & Analysis

Composite soil samples and bulk density cores are being taken from each plot at two depths (0-5cm and 5-20 cm) in Spring of 2021, 2022, and 2023. In year 3, deeper samples (20-40cm, 40-70cm, and 70-100cm) will be taken at one replicate plot per field for soil characterization (soil texture, soil C, and soil N).

Soil samples are analyzed for the following indicators: total C and N by combustion analysis (Leco Corp., St. Joseph, MI), inorganic C by pressure calcimeter,[14] pH and EC by electrode,[15] aggregate stability using a Yoder-style wet sieving apparatus,[16] bulk density by the core method,[17] gravimetric moisture by oven-drying, dissolved organic C and N (DOC and DON) by extraction with 0.5M K_2SO_4 and the combustion catalytic oxidation/NDIR method (Shimadzu TOC-VCPH with TNM-1, Shimadzu Corporation), microbial biomass C and N (MBC and MBN) by the fumigation-extraction method,[18] nitrate and ammonium (NO_3^- and NH_4^+) by extraction with 0.5M K_2SO_4 and quantification on a microplate spectrophotometer (BioTek, Inc., Winooski, VT),[19,20] mineralizable N (PMN) by 14-day anaerobic incubation,[21] soil protein by autoclaved citrate extractable protein analysis,[16] and active C by reaction with a potassium permanganate solution.[16]

Additionally, we are analyzing potential enzymatic activities by fluorometric or colorimetric reaction with the appropriate substrate and quantification on a microplate reader[22] (Table 1) and microbial community composition using phospholipid fatty acid (PLFA) analysis.[23] Data will be analyzed using ANOVA in Program R to compare soil properties and yield between Kernza, W-F, and CRP land. ANOVAs will be considered statistically significant at p<0.05. Principal component analysis (PCA) will also be used to evaluate differences between soil properties among fields.

Table 1: Enzyme names and functions. Adapted from Boggs Lynch (2020) and Stott (2019).

Abbrev	**Enzyme Name**	**Enzyme Function**
CBH	Cellobiohydrolase	Cellulose degradation
BG	Beta-glucosidase	Cellulose degradation
BX	Beta-xylosidase	Hemicellulose degradation
AG	Alpha-glucosidase	Starch hydrolysis
NAG	N-acetyl-beta-Glucosaminidase/ chitinase	Chitin degradation
LAP	Leucine aminopeptidase	Polypeptide degradation
PHOS	Acid phosphatase	Phosphate ester mineralization
SUL	Arylsulfatase	Ester sulfate hydrolysis

RESULTS

Results of baseline sampling indicate that 17 variables significantly differed (p<0.05) between CRP and farmland (wheat or fallow) at either 0-5 or 5-15 cm. Enzyme activities and organic matter pools were generally higher in CRP at 0-5 cm but lower at 5-15 cm (Table 2). PCA was able to separate samples by field and horizon, with greater separation between the two depths in CRP than in wheat or fallow (Fig. 3).

Using the matched wheat, fallow, and CRP samples, PERMANOVA found significant differences between horizons (p=0.017) and between the three fields (p=0.01), but not between the fields when evaluating horizons separately, likely due to small sample sizes. The variables that contributed most to PC1 were PMN, MBC, MBN, and BG, and the variables that contributed most to PC2 were NO3, SOC, DOC, DON, PHOS (Fig. 1).

Table 2. Mean (and standard deviation) of measured soil properties at the two depths in the farmland and CRP at one farm. All enzyme activities are in nmol/hr/g soil. Values that differ significantly (p<0.05) are bolded.

		0-5 cm				**5-15 cm**		
	Soil Property	**Farmland**	**CRP**	**p val**		**Farmland**	**CRP**	**p val**
	pH	**8.50 (0.10)**	**8.33 (0.08)**	**0.041**		8.55 (0.11)	8.48 (0.08)	0.337
	EC (uS)	123 (11.5)	120 (10.2)	0.751		**113 (14.5)**	**133 (1.56)**	**0.022**

Physical & Chemical Properties	WSA (%)	**35.3 (15.4)**	**53.2 (6.83)**	**0.047**		59.6 (8.54)	50.5 (15.2)	0.414
	Bulk Density (g/cm^2)	2.34 (0.08)	2.23 (0.13)	0.279		2.39 (0.07)	2.45 (0.02)	0.077
Organic Matter Pools	NO_3 (mg/kg)	2.89 (1.94)	2.08 (0.57)	0.379		2.21 1.56	1.27 (0.25	0.352
	PMN (mg/kg)	**4.24 (1.64)**	**9.31 (1.62)**	**0.011**		**2.29 (1.08)**	**3.74 (0.57)**	**0.035**
	SOC (%)	1.24 (0.14)	1.35 (0.10)	0.217		1.15 (0.10)	1.07 (0.07)	0.264
	Total N (%)	0.08 (0.01)	0.09 (0.01)	0.217		**0.08 (0.01)**	**0.07 (0.00)**	**0.012**
	POXC (mg/kg)	311 (118)	288 (76.5)	0.743		299 (117)	295 (50.2)	0.994
	Protein (g/kg)	**3.08 (0.30)**	**3.51 (0.02)**	**0.017**		**2.99 (0.22)**	**2.58 (0.16)**	**0.022**
	DOC (mg/kg)	95.7 (12.0)	62.0 (23.4)	0.116		**82.8 (17.5)**	**55.1 (1.51)**	**0.011**
	DON (mg/kg)	13.6 (3.23)	10.6 (3.97)	0.337		**12.5 (2.76)**	**9.41 (0.67)**	**0.042**
	MBC (mg/kg)	**436 (120)**	**657 (35.9)**	**0.005**		329 (79.9)	361 (47.8)	0.478
	MBN (mg/kg)	**76.4 (14.8)**	**112 (3.63)**	**0.001**		55.6 (7.25)	56.7 (11.5)	0.884
Enzyme Activities	CBH	40.2 (21.9)	51.1 (16.2)	0.436		**13.7 (3.64)**	**6.19 (2.13)**	**0.007**
	PHOS	56.2 (45.0)	23.6 (15.7)	0.157		54.3 (36.9)	19.1 (24.1)	0.135
	NAG	13.4 (5.65)	27.6 (14.5)	0.228		**8.95 (3.87)**	**0.32 (0.50)**	**0.002**
	BX	61.8 (18.4)	78.9 (7.84)	0.092		**31.2 (7.88)**	**16.2 (4.99)**	**0.013**
	AG	48.3 (18.4)	54.0 (12.7)	0.612		**24.2 (4.98)**	**10.8 (3.68)**	**0.005**
	SUL	**10.2 (3.97)**	**14.9 (1.78)**	**0.044**		**7.10 (1.51)**	**4.94 (0.86)**	**0.030**
	LAP	263 (100)	432 (109)	0.093		226 (55.6)	255 (33.7)	0.378
	BG	**137 (43.6)**	**220 (17.3)**	**0.005**		**93.7 (11.9)**	**61.4 (5.22)**	**0.001**

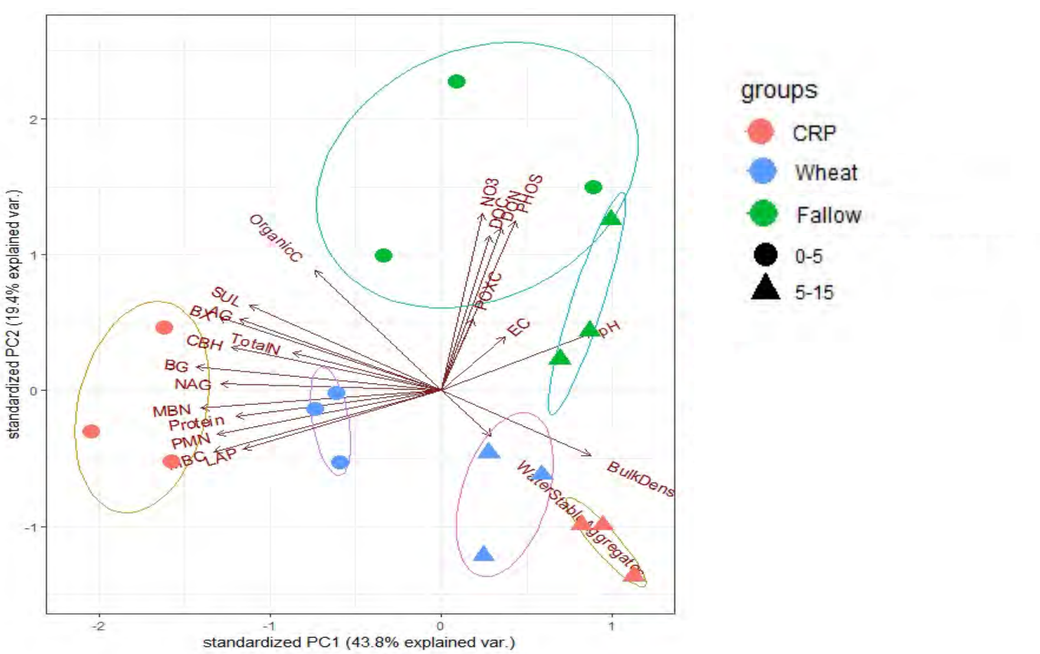

Figure 1. PCA with all measured soil properties (from Table 2) shows the separation between CRP, wheat, and fallow fields at one farm at both depths. The first two principal components explain 62.7% of the variance in the data.

DISCUSSION

Differences Between Annual Cropland and CRP

The clearest difference between CRP and cropland was stratification of enzyme activity and labile organic matter pools in the top 15 cm. The fallow field, which was the most disturbed, was also the most similar between depths (Fig. 1). Microbial biomass and enzyme activities were generally higher in CRP than farmland at 0-5cm but lower at 5-15cm (Table 2). This suggests that in CRP, a higher proportion of microbial activity was occurring near the soil surface. BG and SUL differed between CRP and farmland at both depths, suggesting that these enzymes may be particularly sensitive indicators of soil health change in these systems.

Studies have suggested that stratification of microbial activity and SOC in agricultural fields indicates improved soil health, and that surface SOC can promote functions such as erosion control and nutrient conservation.[24,25] Norton et al. (2012) found SOC accumulation in Wyoming High Plains farmland converted to CRP, as well as higher surface SOC and stratification in perennial prairie than in wheat agriculture.[7]

Future Expectations for Soil Health and Microbial Activity

Though three years will likely not be long enough to observe significant changes in SOC, we expect to find increased labile C pools and microbial activity near the soil surface as fields transition to Kernza. Labile C pools have been shown to be an early indicator of soil health benefit in systems transitioning to Kernza. For example, in Michigan, studies that compared Kernza to annual wheat found 13% higher C mineralization two years after planting,[26]15-18% higher active C during the first three years, and changes in bacterial community in the fourth year.[27]

We expect that microbial indicators (microbial biomass, microbial community composition, and enzyme activities) will be intermediate in Kernza compared to W-F and CRP land. Perennial grain crops support more highly structured and complex food webs relative to annual cropping systems, and the fungal community under Kernza is more similar to native prairie than annual crops.[10,27] PLFA studies comparing Kernza to annual wheat or rye have found increased fungi and AMF (but not bacteria) at 0-10cm after one year, five times greater AMF abundance down to 100cm after two years,[28] and higher total microbial biomass and fungi in 0-15cm after three years.[9] However, further research is needed to evaluate *how* enzyme and SOM stratification may impact soil functions, particularly nutrient cycling, C sequestration, and erosion control.

Overall, this study suggests that stratification of soil enzyme activities and labile organic matter pools could indicate soil change as annual cropland transitions to perennials. Going forwards, this study will help us to better interpret what these various soil health indicators can tell us about land use change and soil health as fields transition from an annual to a perennial grain crop.

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EVALUATION OF SOIL TEST METHODS AND PLANT TISSUE ANALYSIS TO ASSESS SULFUR RESPONSE TO FERTILIZER SOURCES IN WHEAT

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ABSTRACT

Identifying how winter wheat responds to sulfur (S) fertilization through the use of soil test S (STS) methods has been a challenge across Kansas soils. The objective of this study was to evaluate soil test extraction methods for S as well as plant S nutritional status using different S fertilizer sources and rates. Sulfur response trials were established at 24 Kansas locations during two years (2019 and 2020). Fertilizer rate treatments included a control, 10 and 40 lbs S/ acre applied using ammonium sulfate AMS (21-0-0-24S); a blanket application of 100 lbs of nitrogen (N) ac-1 and 40 lbs of P2O5 (P) ac-1 using urea and mono ammonium phosphate. Adding to the control treatment and balancing N fertilizer accordingly. Results indicate STS methods varied in their correlation with one another. The highest correlating methods to one another included the calcium phosphate extraction and the ammonium acetate extraction, which resulted in an R2 of 0.96. While yield and Feekes 6 NDVI showed little impact to S fertilizer rates and sources, most tissues samples saw an increase in S concentration as rates of S increased and a decrease in S concentration when elemental S was used as the source.

INTRODUCTION

Sulfur (S) deficiency in winter wheat has become more common in recent years. Identifying the need for S as fertilizer has typically been done through the use of profile sampling (0-24 in), much like is seen for nitrogen. Since these two nutrients have similar “mobility” in the soil. Applying the correct amount of this nutrient to obtain an economic return is the main driver S fertilization in crops like winter wheat. Identifying how efficiently the crop utilizes this nutrient as well as how effectively the crop can uptake it from the soil is key to understanding how to manage this nutrient. There are many different soil test S (STS) methods being used to identify S deficient soils in Kansas. This makes it a challenge when determining where a response could be seen. This is especially apparent if an STS method has not been well correlated with crop response.

How well a crop responds to sulfur depends largely on which form of sulfur is in the soil at the time of crop S uptake. Sulfur in the sulfate form is readily available to the plant, while other sources such as S in organic matter need to be mineralized to become plant available. This is also relevant for the type of fertilizers that are applied to a growing crop. While many fertilizers contain S in the sulfate form, others contain S in the elemental form, which requires oxidation before becoming plant available. This process depends upon soil moisture and temperature because sulfur oxidation is primarily done by microorganisms. With the transition to no-till, soil temperatures are typically lower in these production practices due to previous crop residue providing a temperature buffer in the spring. In addition to this, wheat is grown during the colder part of the year as well as in drier regions of Kansas. Knowing how much elemental sulfur is converted to the plant-available sulfate form is difficult to tell. The objective of this study was to evaluate soil test extraction methods for S as well as plant S nutritional status using different S fertilizer sources and rates.

MATERIALS AND METHODS

Sulfur response trials were established at 24 Kansas locations during two years (2019 and 2020). Fertilizer rate treatments included a control, 10 and 40 lbs S/ acre applied using ammonium sulfate AMS (21-0-0-24S); a blanket application of 100 lbs of nitrogen (N) ac-1 and 40 lbs of P2O5 (P) ac-1 using urea and mono ammonium phosphate. Adding to the control treatment and balancing N fertilizer accordingly. Fertilizer S source treatments included the application AMS, Micro-Essentials SZ "MESZ" (12-40-0-10S-1Zn), and elemental sulfur (0-0-0-90S). All P and S and 50 lbs N ac-1 of N were broadcast in the fall, followed by 50 lbs N ac-1 topdress application at Feekes 5.

A randomized complete block design was used for the experiment with four replications in this study. Soil samples were taken by replication at depths of 0-6 and 0-24 in and analysis for four different STS methods. At Feekes 6 (jointing), normalized difference vegetation index (NDVI) and tissue samples were taken and analyzed for total S concentration. Soil samples were extracted for S using four methods: calcium phosphate, resin, Mehlich 3, and ammonium acetate. Sulfur was determined with the ICP–OES (Inductively Coupled Plasma Optical Emission Spectrometry) for all extraction methods other soil parameters measured by replication at each site included soil pH, OM, and CEC

RESULTS AND DISCUSSION

When comparing the relationship of the calcium phosphate method (most common;y used) to other methods, the highest R2 (0.96) was with the Ammonium Acetate (AA) extraction (Fig 1). The lowest R2 was with the Mehlich-3 (M3) method with an R2 of 0.31 (Fig 1). The Resin (R) method had an R2 of 0.76 when compared with the calcium phosphate method. The M3 and resin extraction methods showed the lowest R2 and large variability in values.

NDVI measured at jointing showed no significant treatment effects at the $\alpha = 0.05$ statistical level across locations (Fig 2 and 3). Responsive locations to S fertilizer had tissue S concentrations of 0.24% or lower (Fig 2 and 3). Flag leaf tissue samples were also responsive to S fertilizer application rates Tissue analysis (and yield at responsive locations) indicate that fall-applied elemental sulfur was not available to the plant during the growing season, MESZ was plant-available; however, the plant response seems attributable to the sulfate fraction of the total S content in MESZ (MESZ is composed of 50% sulfate and 50% elemental sulfur) (Fig 2)

Table 1. Soil test information from samples collected before wheat sowing and fertilizer application.

Location	pH	OM	S (0-6 in)	CEC	S (0-24 in)
		%	ppm	(meq/100g)	ppm
1	6.5	2.3	3.4	13	23.1
2	7.7	2.5	4.4	25.9	4.5
3	6.2	3.5	2.7	15.1	4.2
4	6.9	2.5	3.6	18.4	4.8
5	6.7	2.6	3.2	17.5	5.7
6	7.6	2.0	2.6	29.1	5.6
7	6.4	2.5	2.5	15.2	7
8	5.7	3.1	2.2	16.1	3.2
9	7.7	2.0	2	21.2	3.2
10	6.2	2.3	0.7	10.7	1.2
11	5.6	2.3	1.1	9.3	1.5
12	7.2	2.3	2.4	21.6	2.5
13	8.3	2.3	2.4	30.5	2.1
14	7.3	2.5	2	20.4	2.8
15	7.6	2.4	1.8	24.3	2.5
16	6.5	2.5	1.4	21.7	2.5
17	5.4	2.7	1.8	11.9	12.3
18	5.6	3.0	1	14.7	2.1
19	6.2	2.9	1.4	13.3	1.6
20	6.6	2.8	1.8	16.6	3
21	6.7	1.8	12.8	6.3	151.9
22	6.8	2.4	2.3	17.4	3.5
23	6.8	2.4	2.6	19.1	2.6
24	5.6	2.8	1.5	13.4	1.9

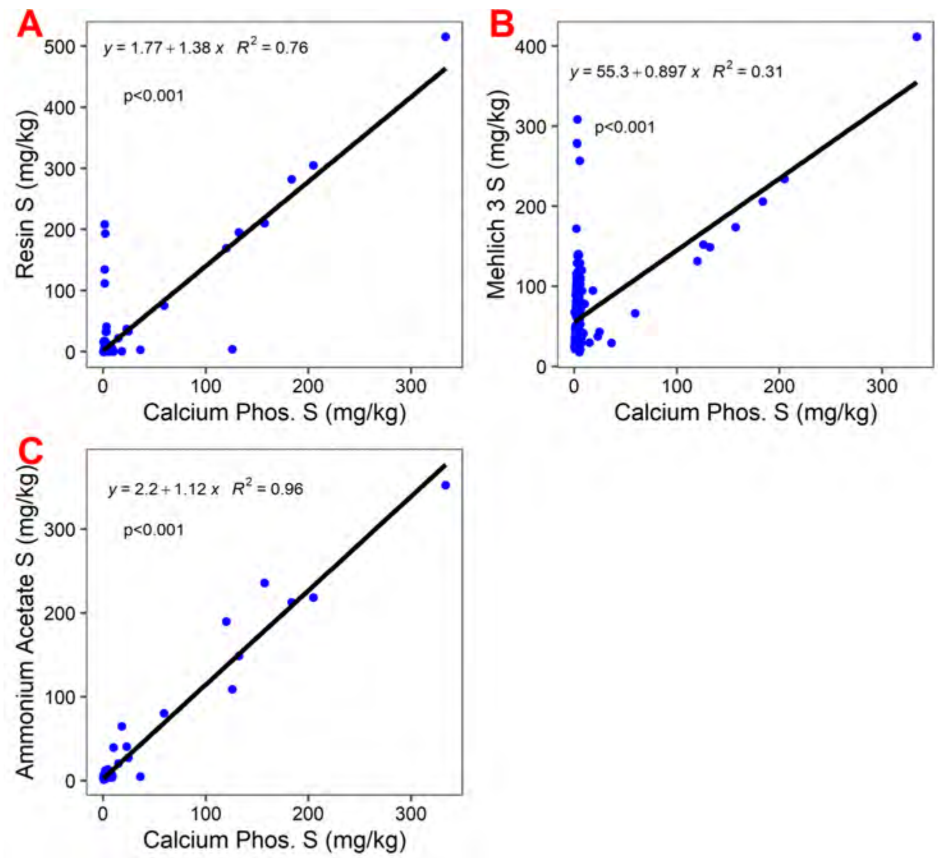

Figure 1. Relationship between four different extraction methods for S.

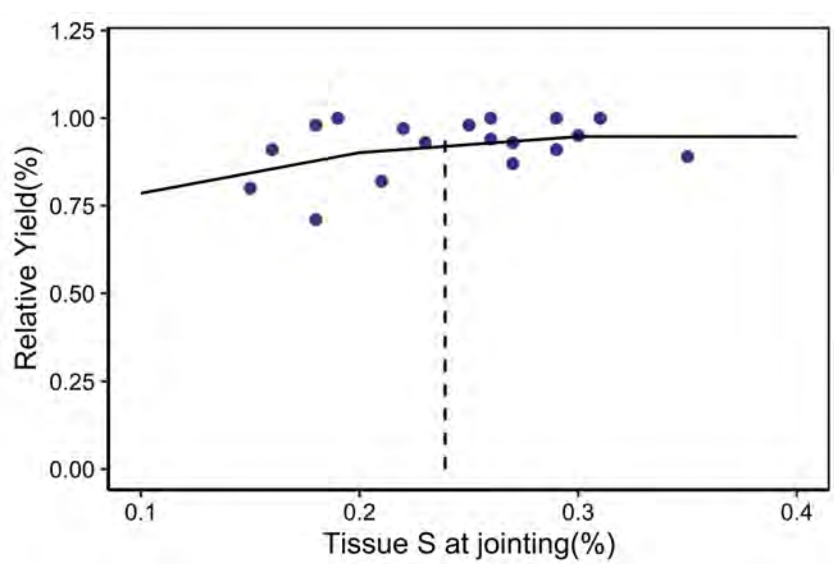

Figure 2. Tissue S concentration at Feekes 6 (jointing) and relative yield response to S fertilization (critical value of 0.24%).

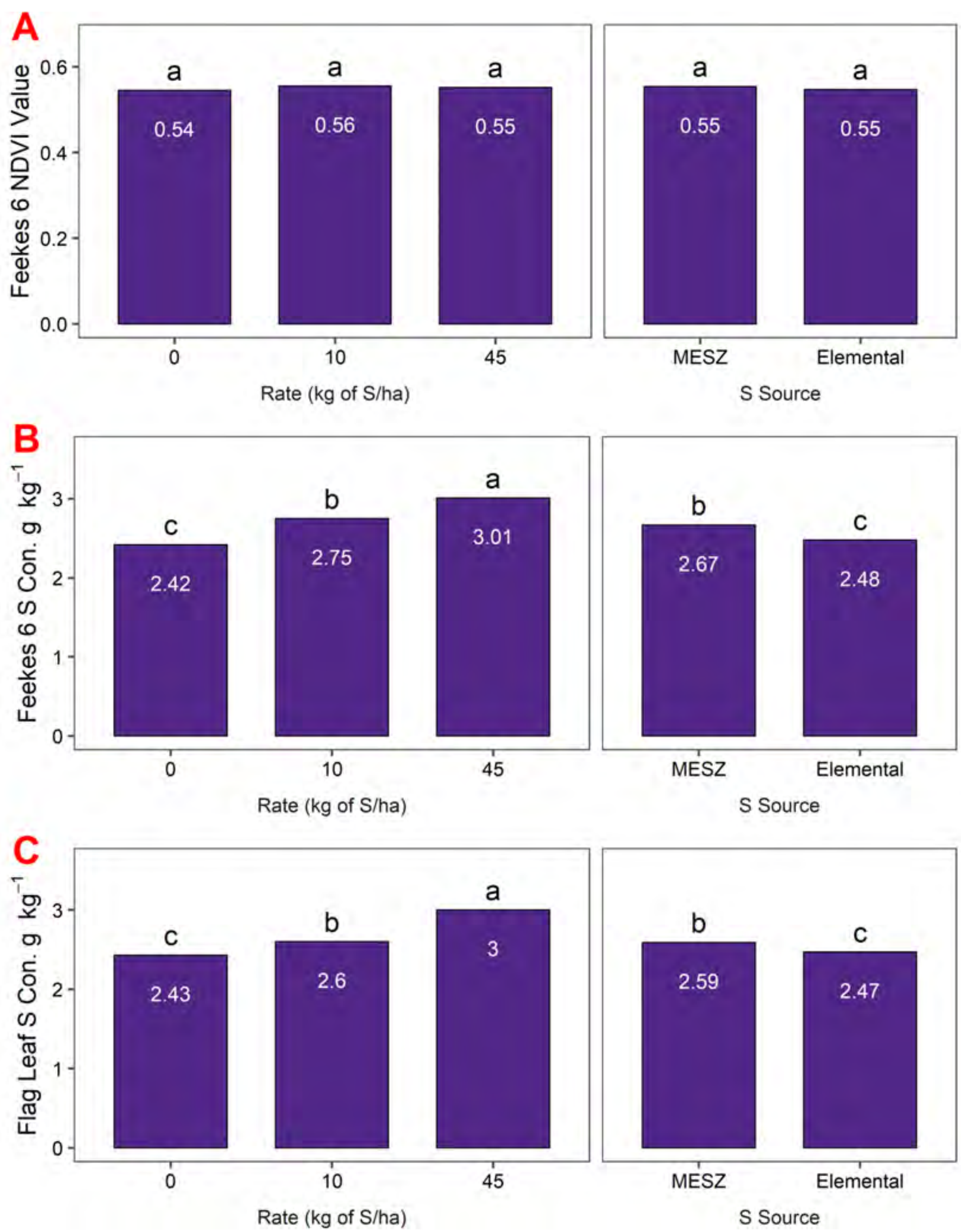

Figure 3. Wheat response to S application rate (as fall ammonium sulfate); and two sources (MESZ and elemental S) with the same application time at 40 lbs S/acre rate (45 kg/ha).

EVALUATION OF MEHLICH-3 FOR THE DETERMINATION OF CATION EXCHANGE CAPACITY IN KANSAS SOILS

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ABSTRACT

Soil testing laboratories across the United States have implemented the Mehlich-3 (M3) extraction method for phosphorus (P) and other nutrients. Though M3 is known to work well as a multinutrient extractant, it raises concerns for measuring exchangeable cations, particularly in calcareous soils. The objectives of this study were (a) to evaluate M3 as an extractant for base cations for Kansas soils, (b) to identify a range of soil pH where M3 may be a suitable replacement for ammonium acetate (AA), and (c) to examine the relationship between cation exchange capacity (CEC) summation and CEC displacement. A study was conducted evaluating 308 soils collected from across Kansas and extracted using both the M3 and AA soil extraction methods. Cation exchange capacity was estimated using the summation approach from measurements of both the M3 and AA, and the displacement method. Results indicate a strong correlation among M3 and AA methods for K, Mg, and Na (R^2 = .98, .96, .97, respectively). However, these relationships were considerably weaker for extractable Ca (R^2 = .78), where extractable Ca was higher in the M3 extracts for high pH soils. Estimated CEC was also affected by soil pH for the M3 method, with an estimated critical pH value of 7.3. Extractable Ca and CEC for soils with a pH below 7.3 showed a strong correlation between M3 and AA methods (R^2 = .9). Using M3 as a multinutrient extractant can improve turnaround time for sample analysis in soil testing laboratories. However, the use of the M3 procedure in soils with a pH of 7.3 or above will likely result in overestimation of exchangeable Ca and CEC.

INTRODUCTION

The Mehlich-3 (M3) soil test procedure allows for the simultaneous measurement of numerous essential plant nutrients in soils, including phosphorus (P), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn), and copper (Cu) (Mehlich, 1984). This has lent to the wide adoption of the M3 procedure by soil testing labs across the United States. Using a single extraction for multiple nutrients helps streamline the daily workflow, reduce labor and operating costs in the laboratory, and improve turnaround times for routine soil fertility analyses. These multinutrient extractions also allow laboratories to take full advantage of modern laboratory equipment's ability to measure multiple elements simultaneously, such as inductively coupled plasma–atomic emission spectroscopy (ICP–AES). In Kansas, the M3 procedure is currently used to assess plant-available P and K, but exchangeable base cations and CEC estimates are determined using a neutral ammonium acetate (AA) extracting solution. This AA procedure is well established for the extraction of exchangeable base cations in soils (Ciesielski et al., 1997; Normandin et al., 1998; Sumner & Miller, 2018) and is a recommended procedure for the North Central Region (Nathan & Gelderman, 2015).

Given its potential cost savings, the M3 procedure is an attractive option for soil testing laboratories. However, data relating M3 extractable base cations to the standard procedures are nonexistent for Kansas soils. This study aimed to (a) investigate the relationship between M3 and AA extractable base cations and CEC in Kansas agricultural soils; (b) identify a soil pH range at which these two methods can be used interchangeably; and (c) examine the relationship between CEC summation and CEC by displacement (not shown, see Rutter et al., 2022).

MATERIALS AND METHODS

Soil samples were randomly selected to represent a range of soils and geographic regions across Kansas, USA. A total of 308 samples were included in this study and selected from field-production soil samples collected from the 0-to-15 cm depth and submitted to the Kansas State University Soil Testing Laboratory from July through December 2019. Samples were dried at 40 °C and ground to pass a 2-mm sieve using a flail-type soil grinder. Dried and ground samples were stored at room temperature until analysis (Gelderman & Mallarino, 2012). All extraction procedures used in this study are described in the Recommended Soil Testing Procedures for the North Central Region handbook (Nathan & Gelderman, 2015).

Relationships between the various soil test parameters were investigated using linear and nonlinear least-squares regression analysis. All statistical analyses were performed using R version 4.05 (R Core Team, 2021) and visualized using the ‘ggplot2’ graphics package (Wickham, 2016) in RStudio (RStudio Team, 2021). Nonlinear regression models were fit using self-starting functions from the ‘nlraa’ package (Miguez, 2021). The significance of all statistical tests and comparisons were evaluated at the 95% confidence level (α = .05). For a more detailed description of the laboratory and statistical methods used in this study please refer to the accompanying paper by Rutter et al. (2022).

RESULTS AND DISCUSSION

Soil pH ranged from approximately 4.4 to 8.2 with a median of 6.67, but followed a bimodal distribution with distinct modes at approximately 6.0 and 7.5 pH. Soil OM contents ranged from approximately 8 to 96 g kg^{-1} with a median of 30 g kg^{-1}. Soil CEC ranged from approximately 9 to 39 meq 100 g^{-1} with a median value of 19.7 meq $100g^{-1}$. The range and distributions of these parameters (Figure 1) illustrate the need for laboratories to use adequate methods and consider the wide range of soils they may receive from this region.

Potassium, Magnesium, and Sodium

Extractable Ca, K, Mg, and Na were compared between M3 and AA procedures. Mehlich-3 and AA extractable K, Mg, and Na were highly correlated with near 1:1 relationship with slope coefficients of 0.99, 1.02, and 1.01 for K, Mg, and Na, respectively (Figure 1). High R^2 coefficients (Figure 1) suggest that M3 and AA extracted these cations from similar soil pools across a wide range of soil pH and SOM contents. Ammonium acetate extractable base cations are commonly interpreted as representing the "exchangeable" pool, and these results suggest that a similar interpretation for M3-K, -Mg, and -Na is appropriate in Kansas soils.

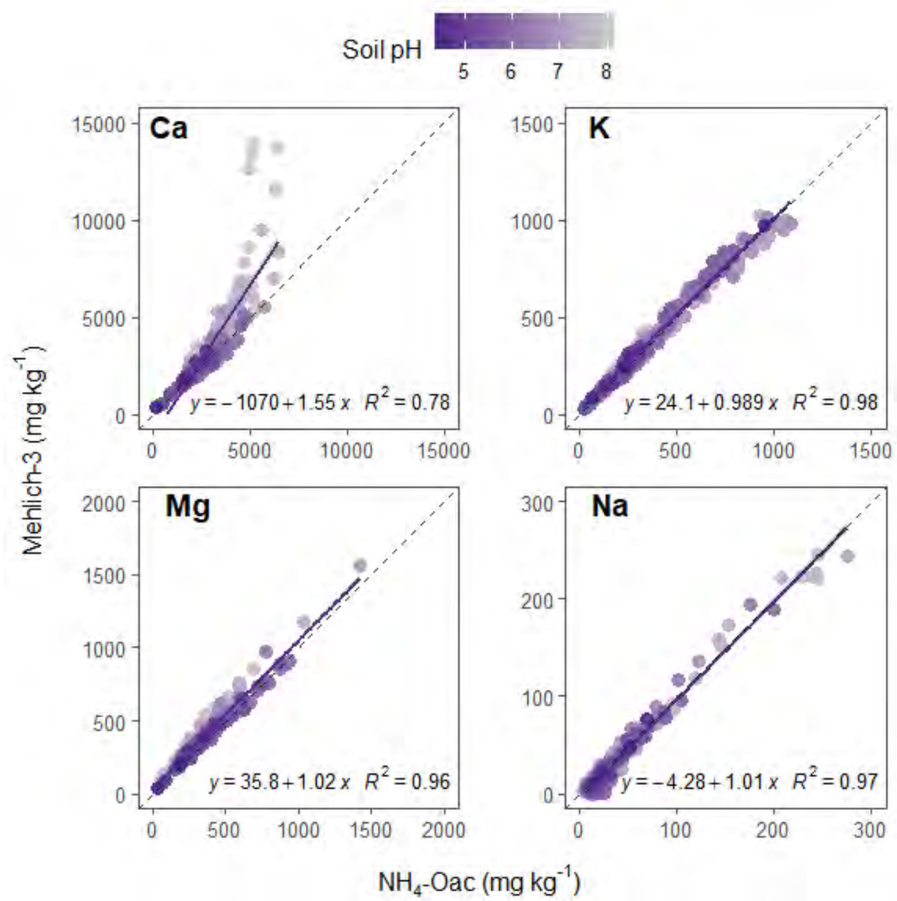

Figure 1. Relationship between Mehlich-3 and Ammonium Acetate extractable calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na). Soil pH is indicated by the color of the dots, where lighter shades denote higher pH values. The dashed line indicates the 1:1 ratio. The fit of a linear regression model is indicated by the solid line and equations in each panel.

However, M3 extracted substantially more Ca than AA in some soils, and the slope (1.55) and R^2 (0.78) of the linear model fit to the Ca data indicate a relatively poor fit between M3 and AA when compared to K, Mg, and Na (Figure 1). Soil samples with high pH generally resulted in higher M3 extractable Ca (Figure 1). The difference between M3-Ca and AA-Ca was further examined as a function of soil pH using nonlinear regression and an exponential plateau model (Figure 2A). This analysis identified a critical soil pH of 7.33; where M3 extracted exponentially more Ca than AA as soil pH increased beyond this critical pH value. Excluding samples with a soil pH greater than 7.33 resulted in a near 1:1 relationship (slope = 1.047) and substantially improved relationship (R^2 = 0.9) between M3- and AA-Ca (Figure 2B).

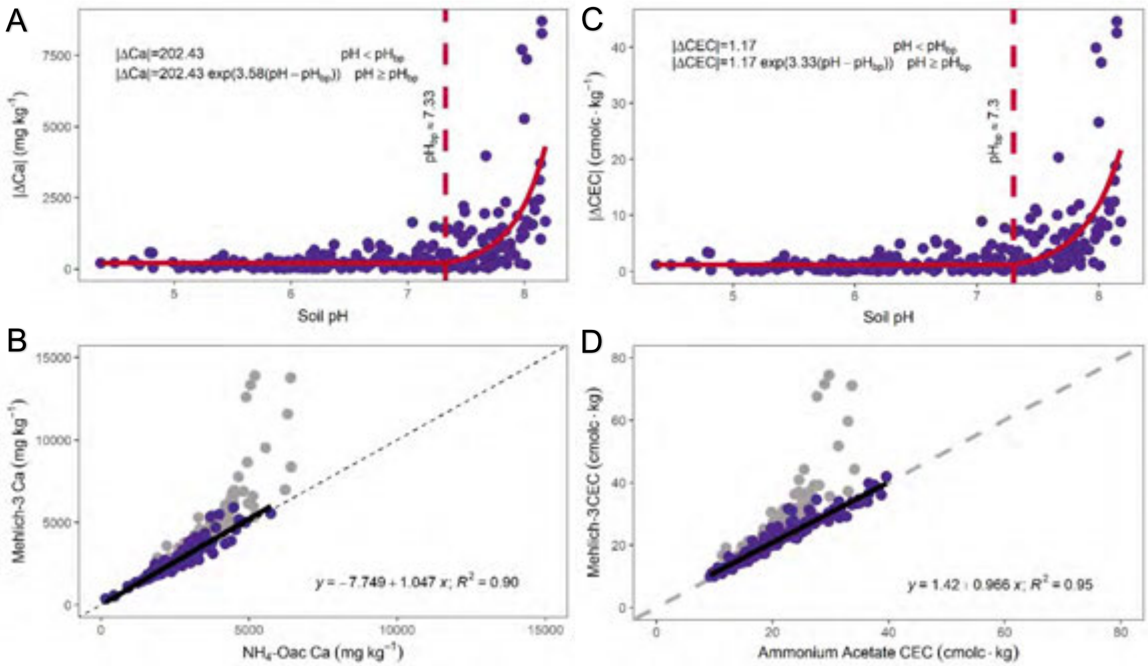

Figure 2. (A) The difference between Mehlich-3 (M3) and ammonium acetate (AA) extractable calcium (ΔCa) as a function of soil pH. The nonlinear model fit is indicated by the solid line. The soil pH breakpoint value is indicated by the dashed vertical line. (B) The relationship between M3 and AA extractable calcium (Ca). (C) The difference in CEC by summation determined from Mehlich-3 and ammonium acetate (ΔCEC) as a function of soil pH. (D) The relationship between CEC determined from Mehlich-3 and ammonium acetate. In panels B and D, the dark points indicate soils with a pH below the critical value, while the grey points indicate soils with a pH above the critical value. The linear models are indicated by solid lines, where samples with pH ≳ 7.3 were excluded (grey points).

This relationship and effect of soil pH on M3 and AA extractable Ca has been documented in previous studies, and is primarily attributed to the presence of calcium carbonates and their dissolution during the extraction process (Michaelson et al., 1987; Ketterings et al., 2014; Rogers, 2019). Soil carbonate measurements were performed on a subset of samples, and regressed against the difference between M3- and AA-Ca and -CEC. A strong linear relationship was observed (R^2 = 0.93), suggesting the increased Ca extracted by M3 is due to dissolution of calcite-like minerals (data not shown, see Rutter et al., 2022 for details).

Cation Exchange Capacity

Cation exchange capacity (CEC) was calculated from both AA and M3 extracts using the summation approach (AA-CEC and M3-CEC, respectively). Linear models fit the raw data poorly and appeared to be influenced by soil pH; where M3-CEC was generally greater than AA-CEC in higher pH samples. Regression analysis indicated a similar trend to that of the Ca measurements, where the difference between M3-CEC and AA-CEC (ΔCEC) increased exponentially as soil pH increased beyond 7.3 (Figure 2C). These results are not surprising given that these CEC values are calculated directly from the Ca, Mg, K, and Na measured from the AA and M3 extracts, but clearly illustrate the effect of extracting nonexchangeable-Ca on CEC estimates. Excluding soil samples with a pH equal to or above this critical pH value (pH = 7.3) resulted in a near 1:1 relationship between M3-CEC and AA-CEC (slope = 0.97; R^2 = 0.94) (Figure 2D). Regression against soil carbonate content also indicates these differences are likely driven by the dissolution of calcium carbonates in the M3 extracts (data not shown; see Rutter et al., 2022).

CONCLUSIONS

Relationships between CEC by summation for AA and various displacement methods have been reported in some studies (Ciesielski et al., 1997; Jaremko & Kalembasa, 2014; Ketterings et al., 2014; Sumner & Miller, 2018). However, M3-CEC by summation is largely ignored in the literature, and many commercial soil testing laboratories in the US currently report these values on a routine basis. Results from this study clearly illustrate the limitations and difficulties of interpreting these values. Ideally, an individual tasked with this interpretation would also have knowledge of soil pH and the soil's carbonate contents. Unfortunately, soil carbonate tests are relatively time-consuming and costly, and are often not included in routine soil tests for farmers. Given the wide range of soils and environments represented in this study, our results suggest a critical soil pH of 7.3 may be appropriate as an alternative to soil carbonate measurements for Kansas soils; where M3-Ca should not be interpreted as “exchangeable-Ca” or used for CEC estimates in soils with a pH at or above this value.

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INCREASING WINTER WHEAT GRAIN YIELD BY REPLICATING THE MANAGEMENT ADOPTED IN HIGH-YIELDING COMMERCIAL FIELDS

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ABSTRACT

Large winter wheat (*Triticum aestivum*) yield gaps between farmer yields and yield potential in the southern Great Plains indicate the need to improve recommendations of best management strategies to profitably bridge this gap. Many studies have been completed on individual management factors pre-determined by the individual researcher, but we are not aware of studies comparing combination of practices that producers are currently using, which would be more relevant for real-world scenarios. Our objective was to determine the yield gains resulting from management intensification using combination of practices currently adopted in commercial wheat fields. Four management intensities (i.e., low, average, high, and top) were derived from a survey of 656 commercial fields, and replicated in trials conducted in four and six locations in western and central Kansas. Management intensities were tested factorially on two adapted varieties. Grain yield in central Kansas ranged from 45.5 bu/a in the low management intensity to 69.3 bu/a in the high and top intensities, with the average management increasing yields by 30% as compared to the low intensity, and the high management increasing yields 18% from the average. The variety WB4269 outyielded Zenda (63.2 and 58.7 bu/a) across central environments. In western Kansas, there was a significant variety by management interaction, where wheat yield increased from the low and average intensities to the high and top intensities (72.8-78.9 to 90.7-96.0 bu/a). WB Grainfield and KS Dallas varieties produced similar yields in the western environments. Managing like high yielding producers in central and western Kansas narrowed the yield gap and further increases in management intensification were not warranted, as managing like the top producers shows no significant increase in yield. Variety selection played an important role either by increase attained yields or by interacting with management.

INTRODUCTION

The adoption of conservative farming practices has led to large (c.a., 55% or more) hard red winter wheat (*Triticum aestivum L.*) yield gaps between actual and potential yields in Kansas and most of the US central Great Plains (Jaenisch et al., 2021; Lollato et al., 2017; Patrignani et al., 2014). While part of this conservative management is justified to harsh weather (Couedel et al., 2021; Lollato et al., 2020), evidence suggests that the highest yielding growers (i.e., those that competed in state and national yield contests) were able to narrow this yield gap to less than 15% (Lollato et al., 2019c). Thus, efforts to improve management practices to narrow this yield gap profitably and effectively are warranted to sustainably increase food production.

Among the most important management practices that can potentially narrow the wheat yield gap in this region are fertilization practices (Lollato et al., 2019a, 2021) and foliar fungicides (Cruppe et al., 2021; Jaenisch et al., 2019), as quantified by de Oliveira Silva et al. (2020). We note, though, that other practices such as crop rotation and sowing date (Munaro et al., 2020), seeding rate (Bastos et al., 2020), fungicide and insecticide seed treatments (Pinto et al., 2019), in-furrow fertilizer (Maeoka et al., 2020), and liming (Lollato et al., 2013; 2019b) have also benefited wheat yields in this region.

Many studies evaluating strategies to narrow the yield gap have treatments originally designed by the researcher him/herself (e.g., de Oliveira Silva et al., 2020; Jaenisch et al., 2019). While these studies can provide valuable information, they usually do not quantitatively reflect practices currently adopted by growers. To our knowledge, that are no studies where the practices (or combination of practices) tested have been quantitatively determined by practices that producers are already using in commercial fields. Still, we argue that using field experiments to replicate the different management intensities adopted in commercial wheat fields can help identify avenues to increase yields while maintaining treatment parsimony and connection to reality. Thus, our objective was to quantify the wheat grain yield gain resulting from adopting the same management practices to those adopted by top commercial wheat growers, as compared to the average- and low-yielding fields using Kansas as a case study.

MATERIALS AND METHODS

Two experiments were conducted in a number of locations in the state of Kansas, one representing growers in the central region and one in the western region of the state. Central Kansas locations included two at Ashland Bottoms (Belvue silt loam and Bismarckgrove-Kimo complex), Belleville (Crete silt loam), Hutchinson (Ost Loam), Manhattan (Kahola silt loam), and Tipton (Harney silt loam). Western Kansas locations included Colby (Keith silt loam), Garden City (Ulysses silt loam), Leoti (Richfield silt loam), and Norcatur (Holdrege silt loam). The study was set up in a two-way factorial experiment in a split-plot design with management intensity as the whole plot, and wheat variety as the sub-plot. Management intensities were based on a survey of management practices adopted in 656 wheat fields (Jaenisch et al., 2021). Fields were categorized by grain yield into low (bottom 30% yielding fields), average, high (top 30% yielding fields), and top (top 5% yielding fields) categories. The frequency of adoption of different management practices was quantified for each group and replicated as treatments. A listing of management practices used in each treatment are provided in Table 1. Two hard red winter wheat varieties were planted at each location, including Zenda and WestBred WB4269 in the central locations, and KS Dallas and WestBred WB-Grainfield in the western locations. Central locations were sown following harvest of a preceding soybean crop while western locations followed a period of fallow, as was regionally common according to the survey of adopted practices.

Table 1. Combinations of management practices adopted in 656 commercial winter wheat fields based on different yield levels in the central and western environments.

Management Practice	Central Kansas				Western Kansas			
	Low	Average	High	Top	Low	Average	High	Top
Yield goal (bu/a)	35	55	75	95	35	55	80	95
Seeding rate (seeds/a)	1,000,000	1,200,000	1,450,000	1,450,000	750,000	900,000	1,050,000	1,050,000
Seed Treatment	No	Yes	Yes	Yes	No	No	Yes	Yes
Split N Application	No	No	Yes	Yes	No	No	Yes	Yes
Nitrogen (lbs N/a)	40	80	120	160	40	80	120	180
Phosphorus (lbs P/a)	0	20	30	35	0	0	30	30
Sulfur (lbs S/a)	0	10	10	20	0	0	10	20
Chloride (lbs KCl/a)	0	15	15	15	0	0	0	0
Micronutrients	No	No	No	Yes	No	No	No	Yes
Jointing Fungicide	No	No	No	Yes	No	No	No	Yes
Flag leaf Fungicide	No	No	Yes	Yes	No	No	Yes	Yes

Treatments were established according to Table 1, either by hand spreading fertilizers or by using a CO_2-pressurized backpack sprayer for application of foliar fungicides. Plots were harvested with a Massey Ferguson 8XP small plot, self-propelled combine. Grain weight, test weight, and moisture content were measured at harvest with an on-board HarvestMaster GrainGage system. Grain yield was calculated with an adjustment to 13% moisture content. Statistical analysis was completed using RStudio v. 2021.09.0. Two-way analysis of variance with environments as the random effect detected the effects of variety, management, and their interaction. Means were separated at the alpha = 0.05 level.

RESULTS AND DISCUSSION

The main effects of management and variety both influenced grain yield in the Central Kansas experiment, however with no significant interaction (Figure 1). The 'Low' management yielded on average 45.5 bu/a across environments and varieties. Increasing inputs to average management increased yield by 29.5% to 58.9 bu/a. High management resulted in a grain yield of 69.3 bu/a, an increase of 17.7% compared to the average level. Further increases in inputs did not significantly increase yield as compared to high management. Across all levels of management intensity, WB4269 produced 7.7% greater grain yield than Zenda (63.2 vs. 58.7 bu/a).

Of the management practices included in the treatments, seeding rate may be amongst the most impactful for increasing grain yield due the previous crop of soybeans. Higher seeding rates are needed in lower yielding environments (Bastos et al., 2020) which often occur when winter wheat is planted following summer crop harvest to compensate for later planting dates (Lollato et al., 2019c; Staggenborg et al., 2003). Consistent with findings from Lollato et al. (2019a) that optimum nitrogen rates to maximize grain yield are about 100 lbs N/a, our study in central Kansas maximized yield when increasing nitrogen from 80 to 120 lbs N/a. The addition of jointing fungicide did not increase yield in the top management, a practice that has been found to be cultivar and environment dependent (Watson et al., 2020).

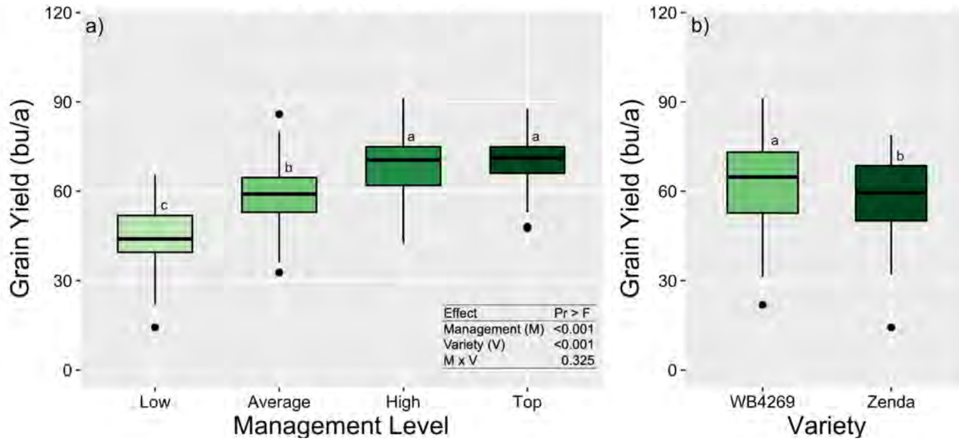

Figure 1. Box plots of wheat grain yield response to (a) management and (b) variety across six experimental locations in central Kansas. Inset table shows significance ANOVA effects. Box-plots followed by the same letter indicate no statistical difference at the 0.05 probability level.

In the western Kansas experiment, there was a significant management by variety interaction on grain yield (Figure 2). General yield trends were that there were no significant increases in grain yield observed between the low and the average management intensities, which ranged from 72.8-78.9 bu/a; and as inputs were increased to the high and top levels of management, grain yield significantly increased to 90.7-96.0 bu/a. Increasing management intensity from the High to the Top level did not further increase grain yield. The significant management by variety interaction was brought about by numerical (though not statistical) differences between varieties as function of management, where KS Dallas had lower numerical yields than WB-Grainfield at the Low and Average treatments, and greater numerical yields at the High and Top treatments (Figure 2).

Although seeding rate increased between low and average management, there was no observed increase in yield, in part due to being planted at optimal timing following fallow. This was also observed by Lollato et al. (2019c) where yield was unaffected by increasing seeding rate when planted at the optimal timing. It also aligns with the findings of Bastos et al. (2020) where wheat yield was less responsive to seeding rates at high yielding environments. The increase of management intensity from average to high input levels is where we see the largest overall increase of input levels with the addition of several factors, which resulted in an increase in grain yield. Of these was the addition of sulfur fertilizer, which is documented to increase the plant's ability to respond to nitrogen applications (Salvagiotti and Miralles, 2008). The addition of fungicide also likely played a role in increasing grain yields, which has observed with the presence of disease pressure (Cruppe et al., 2021; Jaenisch et al., 2019; Lollato et al, 2019c).

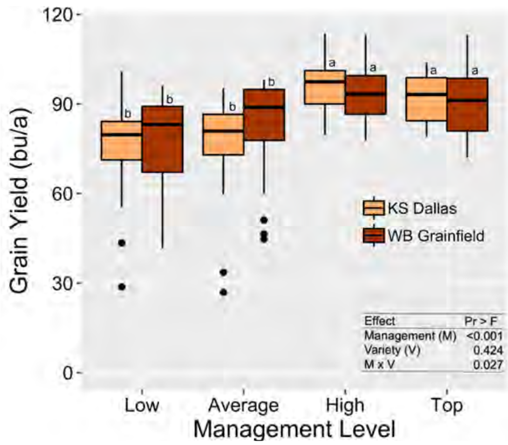

Figure 2. Wheat grain yield response to variety and management interaction across four locations in western Kansas. Inset table shows significance ANOVA effects. Box-plots followed by the same letter indicate no statistical difference at the 0.05 probability level.

CONCLUSIONS

In both central and western Kansas, managing like the top 30% of producers in these regions increases grain yield and decreases the yield gap. A further increase in management intensity is not necessary to increase yield. Variety impacted both regions, affecting yield either by increasing yield or interacting with the management intensity.

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

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ABSTRACT

Forage Sorghum (Sorghum-Sudan grass) is a forage crop harvested in the form of silage or dry-hay and is intended to distribute to livestock as feed. The research objective for this study is to observe how nitrogen timing plays a role in crop total biomass yield. Observations and data were collected during the 2021 growing season, with a total of two harvests allowed due to weather conditions in the area. This trial was conducted at two locations: Lake Carl Blackwell near Stillwater, Oklahoma and Cimarron Valley Research Station in Perkins, Oklahoma. This research study was established with eight nitrogen (N) treatments replicated three times. The N treatments were an application of urea-ammonium nitrate (UAN) applied to seven of the eight total treatments at pre-plant, with one un-fertilized check. A top-dress application of urea-ammonium nitrate (UAN) is performed on three of the seven pre-plant treatments after the first harvest. Treatments range from 50 lbs ac^{-1} to 200 lbs ac^{-1} of total nitrogen applied. Silage was the harvest method used to collect biomass from each treatment and all forage harvests were performed at the first observation of heading stage. After analysis, data results show nitrogen has a positive effect on biomass production, with some split applications of pre-plant and top-dress producing more overall biomass compared to pre-plant only applications.

INTRODUCTION

Forage sorghum can produce multiple biomass harvests in a single growing season, the biomass can then be used to supplement livestock feed. Forage sorghum production acres in Oklahoma have been steadily increasing since 2018 (NASS, 2022).In Oklahoma, 16,000 acres of forage sorghum harvested in 2020, increasing to 23,000 acres harvested during the 2021 growing season (NASS, 2022). . When used correctly, nitrogen timing can be beneficial to forage sorghum biomass production, such as by increasing biomass production. However, due to the increasing price of nitrogen, the need to understand how nitrogen timing can effect production is essential. The objective of this study is to evaluate the impact of nitrogen application rate and timing on the biomass production of forage sorghum.

MATERIALS AND METHODS

The study was established during the 2021 growing season in north central Oklahoma to evaluate how N timing influences forage production across multiple biomass collections. This research study was conducted in a randomized complete block design with 8 total treatments, replicated three times (Table 1.). The forage sorghum was planted at 45,000 seeds ac^{-1} on a 7.5 inch row spacing. Urea ammonium nitrate (28-0-0) was applied at pre-plant and top-dress with SJ3 streamer nozzles. The data collected includes: pre-plant soil samples, NDVI readings, and wet biomass yields. There was a total of two biomass harvests, which were conducted at the first sign of the heading stage, and the crop was harvested 6 inches from the ground surface. The top-dress application was applied four days after the first biomass harvest.

Treatment	Preplant Nitrogen (lbs N ac^{-1})	Topdress Nitrogen (lbs N ac^{-1})	Total Nitrogen (lbs N ac^{-1})
1	**0**	**0**	**0**
2	**50**	**0**	**50**
3	**100**	**0**	**100**
4	**150**	**0**	**150**
5	**200**	**0**	**200**
6	**50**	**50**	**100**
7	**75**	**75**	**150**
8	**100**	**100**	**200**

Table 1. Treatment Structure of the Nitrogen use Effect on Forage Sorghum research study.

RESULTS AND DISCUSSION

The forage sorghum study located at the Cimarron Valley Research station in Perkins, Oklahoma was planted on April 26th, 2021. The first biomass collection was taken on July 23rd, 2021, and the second biomass collection was taken on September 22nd, 2021. The data collected from this research study observed the increase in production with both pre-plant and top-dress applications. For the Perkins first harvest, N application above the check statistically maximized yield at $\alpha=0.05$ (Figure 1). The second harvest timing suggested value in split N applications over traditional pre-plant applications. Harvest 2 yields were greatest with split applications of N. Among pre-plant only application, only the 200-0 lbs ac^{-1} rate was statistically greater than the check at 13.5 tons for the 200-0 lbs ac^{-1} pre-plant rate over approximately 5 tons per acre for the 0-0 N check.

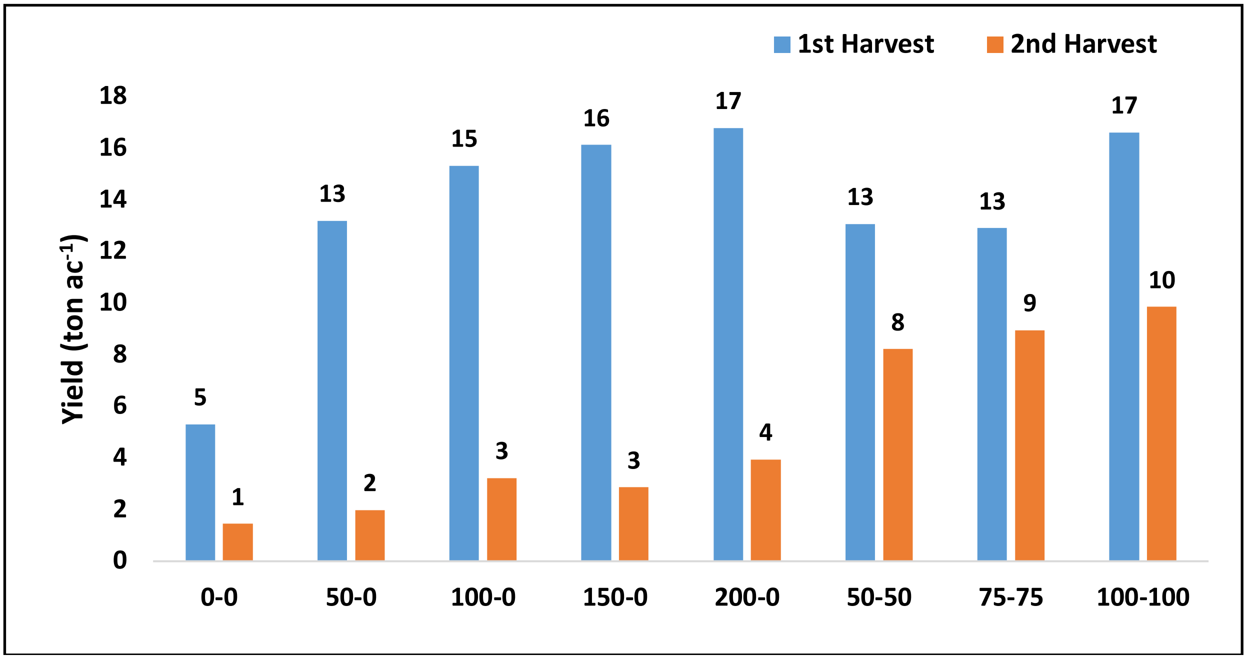

Figure 1. Mean wet biomass yields observed from the Nitrogen use Effect on Forage Sorghum research study conducted at the Cimarron Valley Research Station in Perkins, Oklahoma.

The forage sorghum study located at the Lake Carl Blackwell research farm near Stillwater, Oklahoma was planted on April, 26th 2021. The first biomass collection was taken on July 22nd 2021, and the second biomass collection was taken on September 23rd 2021. The observations from this study show that nitrogen application influenced biomass yield (Figure 2). In this analysis yield was significantly impacted by nitrogen application at both locations. At lake Carl Blackwell in 2021 N application was significant α=0.05. When analyzed by harvest time a pre-plant application at 200 lbs ac^{-1} of N maximized yield at 15.7 tons of biomass per acre. However, the 200-0 lbs ac^{-1} rate did not statistically differ from any pre plant application greater than 75 lbs N ac^{-1}. In the second harvest plots receiving only pre-plant applications were significantly decreased when N was applied at less than 200 lbs ac^{-1} compared with similar split applications.

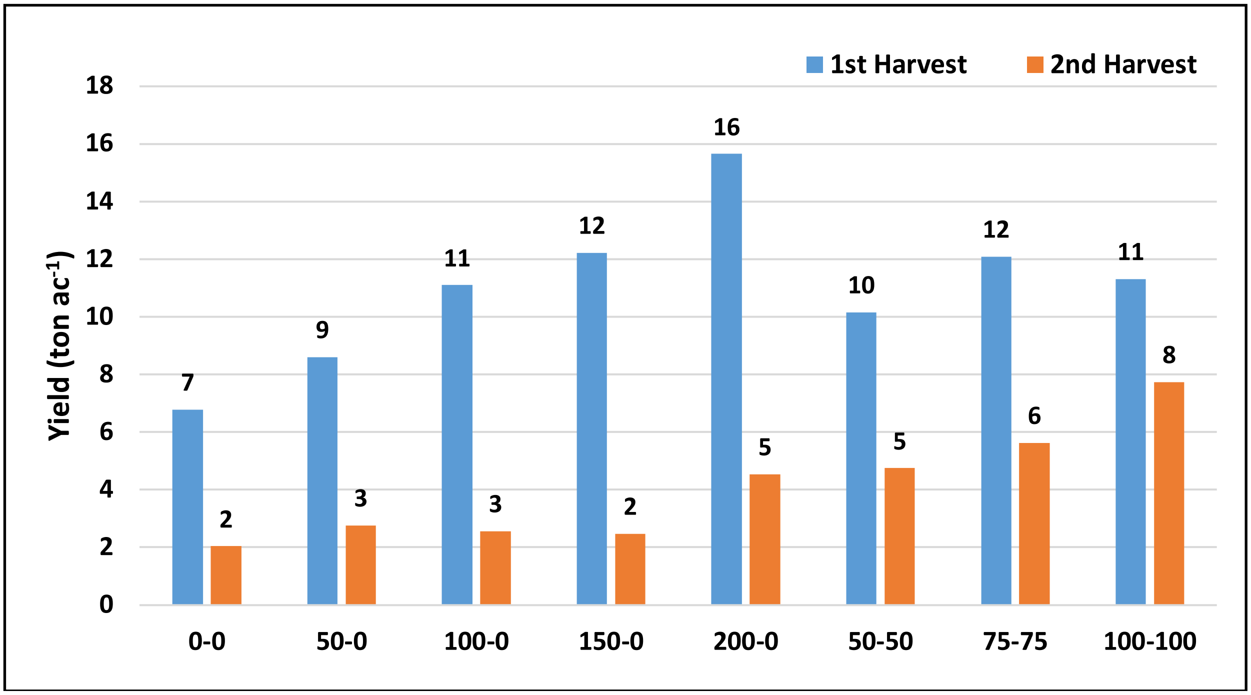

Figure 2. Mean wet biomass yields observed from the Nitrogen use Effect on Forage Sorghum research study conducted at the Lake Carl Blackwell research farm near Stillwater, Oklahoma.

Analysis of the total production of biomass harvested throughout the growing season, at each location show yields were significantly impacted by the influence of nitrogen α=0.05 (Figure 3). At the Lake Carl Blackwell location the application of 200 lbs N ac^{-1}, regardless of timing, was the only nitrogen rate that reported a significant increase of the 0 N check and 50 lbs N ac^{-1} pre-plant rates by 10 and 8 tons ac^{-1}, respectively. The split application of 75 lbs N ac^{-1} at pre-plant and 75 lbs N ac^{-1} at top-dress also yield a 9 ton ac^{-1} increase over the 0 N check. At the Perkins location all N treatments reported yield increases significantly greater than the 0 N check (7 tons ac^{-1}). The split application of 100 lbs N ac^{-1} pre-plant and 100 lbs ac^{-1} at top-dress yielded the highest numerically with 26 tons ac^{-1} which was greater than the 150, 100, and 50 lb pre-plant rates by at least 7 tons ac^{-1}.

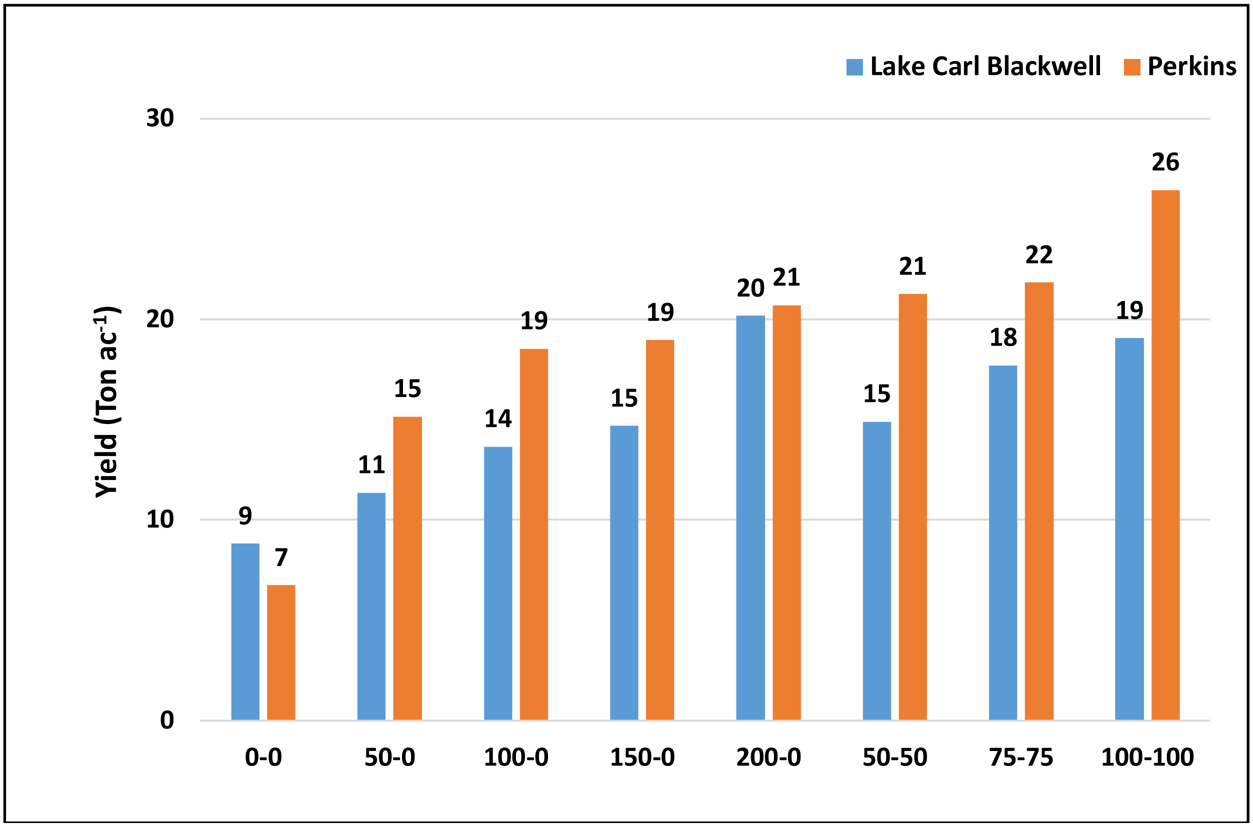

Figure 3. Total harvest mean wet biomass production by treatment at both locations, the Cimarron Valley research station in Perkins, Oklahoma, and the Lake Carl Blackwell research farm near Stillwater, Oklahoma.

SUMMARY

The evaluation of nitrogen rate and timing on forage sorghum conducted in north central Oklahoma during 2021 conclude positive impacts of nitrogen in forage sorghum. Both pre-plant and top-dress applications are significant to biomass yields. Both locations in this study reported greatest increases of biomass yield when N was applied at a 200 lbs ac^{-1}, regardless if applied all at pre-plant or as a split application of 100 lbs ac^{-1} at pre-plant and again at top-dress. Due to the increasing nitrogen price, using a split application method can be economically beneficial to producers in the great plain's region. By utilizing a split application a producer could mitigate losses of applied nitrogen that could potentially occur with a pre-plant application.

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MICROPLASTICS: POLYMER COATED FERTILIZERS IN URBAN LANDSCAPES

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ABSTRACT

The introduction and use of polymer coated fertilizers in urban landscapes has proven beneficial in supplying nutrients with less loss to the environment. However, these have recently come under scrutiny due to concerns with microplastics in the environment. The objectives of this study were to determine the microplastics concentrations in runoff water in urban landscapes. The full factorial study design consisted of two fertilizer sources (Uncoated Dry and Coated Dry), compared to an unfertilized control, in all combinations of three landscape types (Sod, Mulched Beds, or Xeriscapes). Two runoff events were simulated during the season and microplastics concentrations determined. There were significant differences between each landscape type, with Mulched Beds and Xeriscape having 255% and 340%, respectively, more sediment loss than the Sod. As expected, there were no microplastics in the treatments receiving uncoated fertilizer and the control. For the coated fertilizer treatments, there were significant differences between each landscape type. The Sod prevented microplastics in the runoff, but 0.17% and 0.01% of the applied polymer coatings were found in the runoff water for the Mulched Beds and Xeriscape, respectively. It is apparent that there is potential for microplastics to enter the runoff water, but a sod cover can greatly reduce sediment and potentially eliminate microplastics movement compared to mulched beds and xeriscape systems.

INTRODUCTION

Whether in large commercial agricultural settings or with smaller home gardens/yards, providing for plant nutrition and soil fertility is vital for a sustainable soil-plant system (Hopkins, 2020). In general, the law of the conservation of mass requires replenishment of nutrients that are removed. The development and use of fertilizers as part of the “Green Revolution” has greatly improved the availability of food, fuel, and fiber globally, but it has come with problems of nutrient pollution and natural resource depletion.

Agriculture is the leading cause of water quality problems in developed nations, with nitrogen and phosphorus enrichment resulting in eutrophication (Hopkins, 2020). Although agriculture covers vast tracts of land, increasing urban sprawl is also significant in its contribution. Although the urban footprint is relatively smaller, homeowners are less motivated to be conservative in their use of fertilizers and irrigation water (which can move these nutrients to surface waters) and these areas are frequently congregated in close proximity to surface water. These landscapes vary in their use and application, including sod covered surfaces, mulched beds, xeriscapes, etc. It is important to find ways to fertilize the urban landscape efficiently.

Significant efforts have been made to synergistically allow for efficient fertilization while minimizing negative impacts on water and other natural resources. One of the best discoveries in enhancing fertilizer efficiency is polymer coated fertilizers. This technology has resulted in decreased nutrient losses to the environment, while allowing reduced application rates without negatively impacting plant growth. However, recent concerns have cast scrutiny on this source due to potentially negative impacts of microplastics in aquatic environments, as well as possible concerns for these in terrestrial ecosystems (Alimi et al., 2018).

The objective of the study is to measure microplastics in the runoff water from three landscape systems with polymer coated fertilizers compared to traditional, uncoated fertilizers.

MATERIALS AND METHODS

A field study was conducted in 2021 at Brigham Young University (BYU; 40°16'1.40"N 111°39'28.59"W) in Provo UT to measure microplastics loss in three urban landscape systems: (Sod, Mulched Bed, and Xeriscape). The study was conducted on a disturbed, calcareous sandy loam soil with various landscape plants. Best management practices were generally followed in growing the plants. Irrigation was supplied to keep adequate soil moisture while avoiding runoff.

The full factorial study design consisted of two fertilizer sources (uncoated or polymer coated) with the three landscape systems with four replications. Fertilized plots received 220-80-80-169(S)-3(Zn)-4(Fe)-3(Mn)-0.6(Cu)-1.4(B) in lb./ac. The macronutrients were applied as: 1) Uncoated = urea, monoammonium phosphate, and potassium sulfate or 2) Coated = Environmentally Smart Nitrogen (ESN) (Nutrien, Saskatoon, Saskatchewan, Canada) and Osmocote 14-14-14 (ICL, Dublin, Ohio, USA). The micronutrients were applied as an elemental sulfur impregnated dry material (Tiger Industries, Houston, Texas).

Plots were built to mimic urban landscapes with each plot 3.3 ft wide and 6.6 ft long. Plants placed in these plots consisted of Kentucky bluegrass (*Poa pratensis* L.) in the sod plots; Ornamental grasses (Bronze Veil Hair Grass (*Deschampsia cespitosa 'Bronzechleier'*), Strawberries and Cream (*Phalaris arundinacea*), Fountain Grass (*Pennisetum alopecuroides Hameln*), and Northern Sea Oats (*Chasmanthium latifoium*) and Ice Plant (*Delosperma*) and Creeping Jenny (*Lysimachia nummularia*) groundcover plants were used in the Xeriscape. In the mulched beds, Oregon Grape shrubs (*Creeping Mahonia, Mahonia repens*) were used with the ground covered with Scotts Brown mulch (The Scotts Company LLC. Maryville, Ohio).

Plots were built to be gently sloping (~1%) towards one end where a 9 by 13 inch aluminum pan with a lid with holes drilled through the tops was buried at the soil surface to allow runoff water collection. Runoff water was collected on July 22 with a simulated large precipitation event until the pan had approximately ~16-32 ounces of water and sediment. The water and sediment were immediately transferred to 32 ounce glass jars and sealed and refrigerated (samples were stored in the dark to avoid microplastics degradation).

The sediment was filtered out (FisherBrand P5 paper, porosity medium, filter rate slow) and measured gravimetrically after drying. A drop of concentrated sodium hypochlorite was added to the remaining water and then a subsample stored for nutrient and non-visible microplastics analysis (data not complete).

Visible microplastics coatings were removed manually from the filtered sediment. The coatings were punctured and placed in a vial with deionized water in order to release any fertilizer left in the coatings. After 24 hours, the coatings were removed and rinsed and then dried at room temperature of at least 24 hours. Microplastics concentrations were determined gravimetrically.

Statistical analysis was performed by ANOVA with mean separation by the Tukey Kramer method using SAS software.

RESULTS AND DISCUSSION

There were significant differences for sediment loss for landscape type, with Xeriscape (80 lb ac^{-1}) > Mulched Beds (60 lb ac^{-1}) > Sod (23 lb ac^{-1}) (Fig. 1). There were no differences between fertilizer sources.

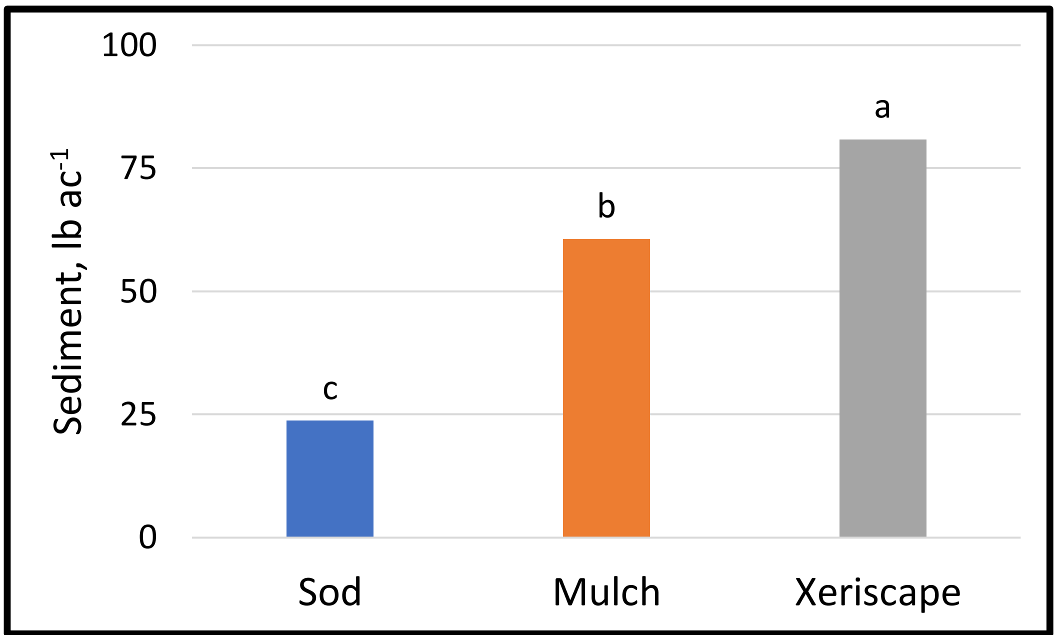

Fig. 1. Orthogonal comparison for sediment loss for three urban landscape systems. All treatments were significantly different than each other (P = 0.05).

As expected, there were no microplastics in the uncoated treatments (Fig. 2). Similarly, there were no microplastics found in the runoff water with sod, even when it was fertilized with coated materials (Fig. 2). However, there were microplastics found in the runoff water for Xeriscape and Mulched Beds, with Xeriscape having significantly greater (12 times) than Mulched Beds with 0.030 and 0.0025 lb ac^{-1}, respectively (Fig. 2).

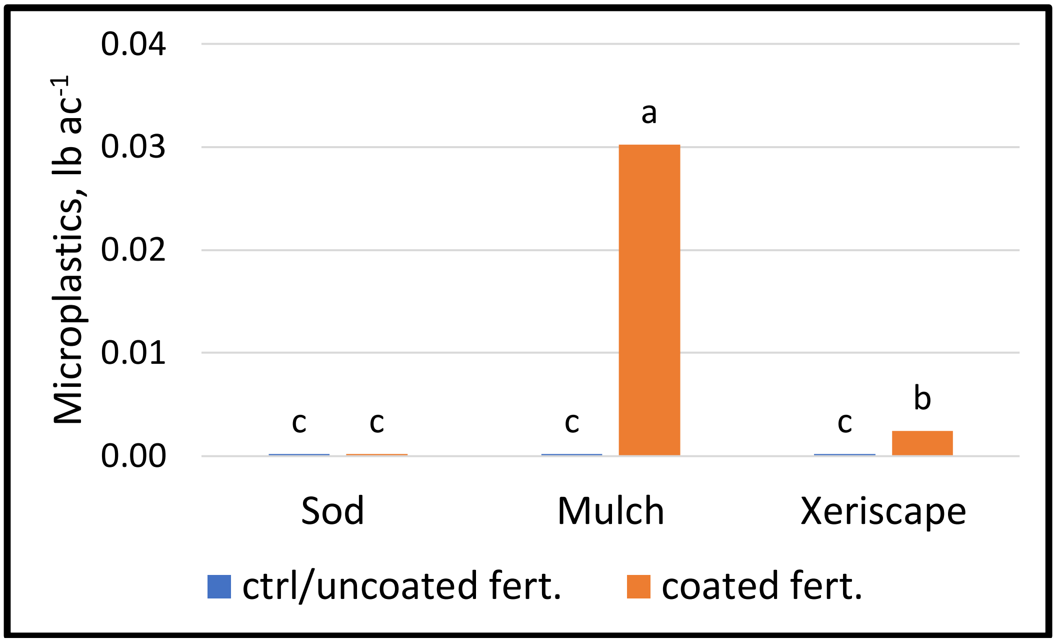

Fig. 2. Microplastics in runoff water for three urban landscape systems with polymer coated urea (PCU) compared to uncoated control. Bars sharing the same letters on top are statistically identical to one another (P<0.001).

The data provided by this study up to this point shows the presence of microplastics in the runoff water from two commonly used urban landscape types. The argument between which type the public should practice in their own landscape ventures is up for debate. There are pros and cons that are connected to each type. From an environmental standpoint and avoiding the contaminations microplastics pose, the Sod type of landscapes is the best choice as it experienced no microplastics in the runoff with very little sediment loss. The downside to using Sod is the extensive use of water, nutrients, and other inputs. However, sod helps sequester carbon from the atmosphere, provides a playable surface, and, as this study shows, greatly reduces soil erosion when the ground is covered in plants. In general, covering the ground in plants is a good management practice. We acknowledge that our results may change as the plants in the Mulched Beds and the Xeriscape become more established and spread to cover a larger portion of the landscape.

Concerning the mulched beds, it is a very moderate rate of care, having to maintain the mulch and care of the soil. However, mulched beds experienced the highest amount of microplastics contained in the runoff in this study. Which can negatively affect the environment, leading to eutrophication and the decrease of water quality.

Comparatively, the xeriscape experienced a significant amount of microplastic runoff as well as a very large amount of sediment. The sediment which was recorded as runoff shows the possible affect it may have if there is runoff and the fertilizer pieces are included in it.

The discussion derived from this study revolves around if the polymer coated fertilizers are present in the runoff water of common urban landscapes and to summarize the study to this point would be to say there are most definitely microplastics in the runoff water of urban landscapes. Further testing and analysis will be done, however, up to this point, there is enough evidence to suggest the presence of microplastics in the runoff and enough to assume the side effects will be present in the coming years. Possibly leading to eutrophication and microplastics contamination in surface waters.

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IN-SEASON NITROGEN APPLICATION METHOD INFLUENCE ON GRAIN SORGHUM PERFORMANCE

R.L. Sharry and D.B. Arnall

ABSTRACT

Grain sorghum production in the United States is concentrated in the Great Plains. This region is prone too harsh environments that may provide opportunities for extensive N losses when relying on pre-plant N application alone. This problem may be alleviated through moving N application later in the growing season to optimize N availability when plant N uptake is most required to prevent yield loss. However, fertilizer application equipment availability may be limited for many producers in the region that utilize wheat as their primary crop. This study compares multiple N application methods influence on visual injury symptomology, crop recovery and subsequent potential for yield loss. The study made use of urea (46-0-0) and UAN (28-0-0) across 3 locations in central Oklahoma. 9 fertilized treatments and one zero N in-season check tested the influence of N source, nozzle type, nozzle height and nozzle spacing on grain sorghum performance. A pre-plant N application of approximately 60 lb ac-1 was applied to all treatments followed by 60 lb ac-1 applied in season according to treatment method. The information provided by this experiment will empower grain sorghum producers to make informed decisions about their N application within the bounds of restraints such as equipment availability and source options to maximize profit opportunities.

INTRODUCTION

Grain Sorghum production continues to be an important component of many crop rotations on the great plains. However, production decisions such as N application timing continue to be restrained by equipment availability for many producers who focus on small grains production. Research into N application timing of several crops including grain sorghum exhibit several possible benefits to in-season N application over a traditional pre-plant application. This study looks to compare in-season N application methods in grain sorghum to provide sound agronomic information on potential yield response to sub-optimal N application methods.

MATERIALS AND METHODS

This experiment was located at 3 sites in central Oklahoma, Chickasha, Perkins, and Lake Carl Blackwell. The experiment consisted of 10 in-season N application treatments replicated 4 times. Plots were approximately 20’ long and 4 rows wide. Sorghum was planted on 30” row spacings. Treatment application methods are denoted in figures 1-3 using abbreviations; BC= broadcast, FF= flat fan nozzle, SJ3= Teejet SJ3 streamer, and T-Bar= Chafer Streamer Bar. All plots were applied N pre-plant using UAN (28-0-0). In-season applications were also made at a rate of 60 lbs. N ac^{-1}. Data analysis was completed using SAS 9.4.

RESULTS AND DISCUSSION

Nitrogen application significantly increased yield at 2 of 3 locations (Perkins and Lake Carl Blackwell). At the Perkins location (Figure 1) all differences between fertilized treatments were insignificant excluding the T-bar treatment. Similar results were observed at the Lake Carl Blackwell (Figure 2) with the T-bar application treatment yielding significantly lower than the other fertilized treatments. The Chickasha location did not respond to additional N application above the check. However, the T-bar treatment yielded significantly less than all other treatments including the check. The results observed across these three locations suggest that in-season applications made with sub-optimal equipment can provide similar performance. This excludes the T-Bar application which decreased yield across all locations. This is believed to be attributable to the large amount of damage to leaf material relative to the other treatments tested.

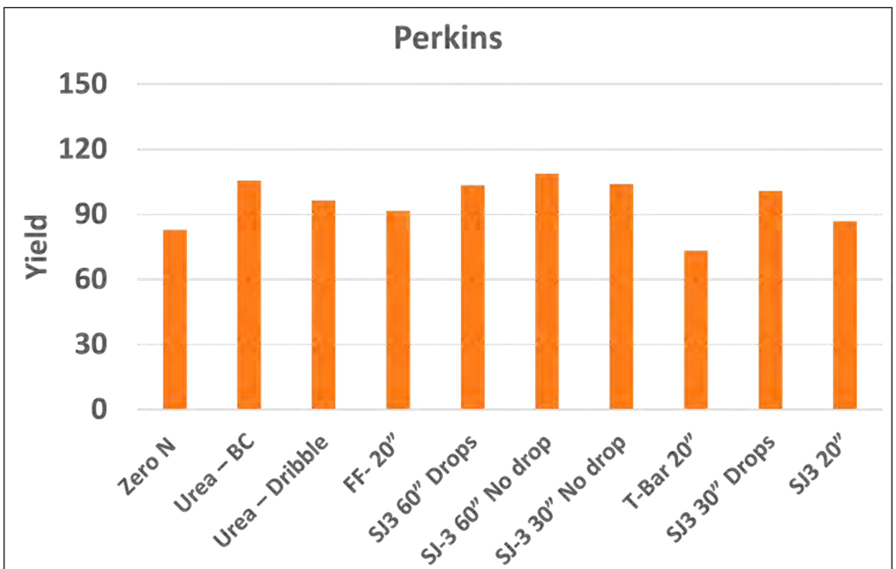

Figure 1. Grain yield (bu ac^{-1}) of a grain sorghum N application method study located at Perkins, OK in the 2021 growing season.

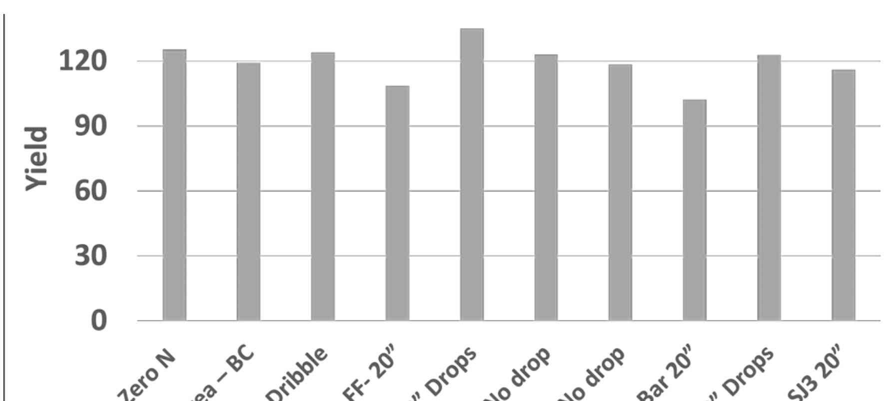

Figure 2. Grain yield (bu ac^{-1}) of a grain sorghum N application method study located at Chickasha, OK in the 2021 growing season.

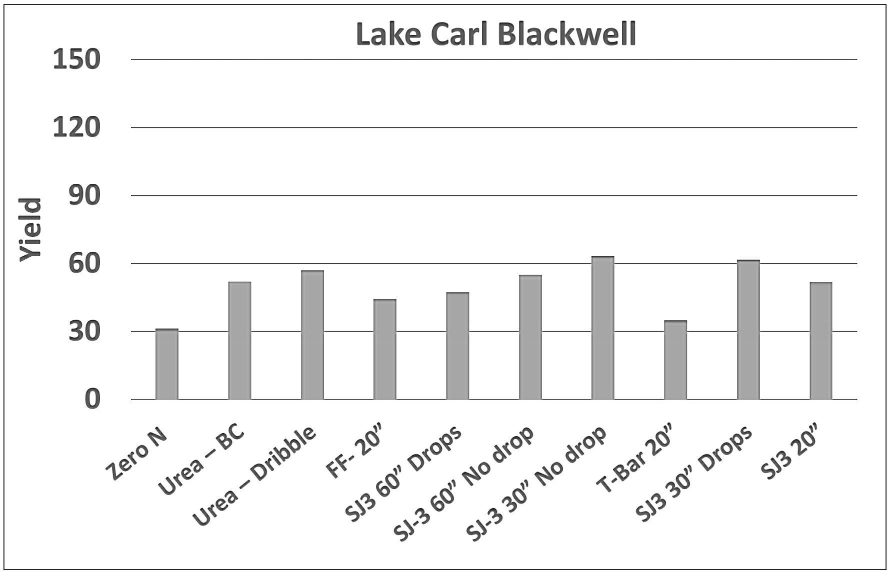

Figure 3 Grain yield (bu ac^{-1}) of a grain sorghum N application method study located at Lake Carl Blackwell near Stillwater, OK in the 2021 growing season.

SUMMARY

Nitrogen management in grain sorghum is an important component of many systems of the Great Plains. When considering the equipment limitations of many producers of the region, in-season applications with many of the technologies tested in this study may be a feasible alternative to purchasing new equipment/technologies. This study suggests that grain yield performance of grain sorghum is unlikely to be hindered when using most application methods. However, producers should be aware that excessive damage to grain sorghum leaf material such as that observed under the T-bar treatment can not only impair yield relative to other application methods but create a negative response to N application. Excessively stressful or beneficial environments may further influence performance of these application methods, as such this study will be continued to increase observations under different environmental conditions.

EFFECT OF MANURE APPLICATIONS COMPARED TO COMMERCIAL FERTILIZER FOR TOTAL NITROGEN IN DRYLAND WINTER WHEAT (TRITICUM AESTIVUM L.)

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ABSTRACT

The Magruder plots are one of the staples in research agriculture not only in Oklahoma but across the country. The historic data gathered from the Magruder Plots allows for the analysis of long term data sets in excess of 124 years of data. The Magruder treatment structure allows for the comparison of the added benefits of manure applications as compared to inorganic sources of fertilizers. Manure applications were made once every four years as a total nitrogen source compared to annual applications of commercial based Nitrogen (N), Phosphorous (P) and Potassium (K) fertilizers as well as lime (Ca) on winter wheat. Response to N, P, K, yield and organic matter have been measured in the Magruder plots since 1931, yield and organic matter response has been tracked since the implementation of the plots in 1892. Having access to 124 years of yield history has showed that moving to bi or tri annual applications will increase the efficiency of N utilization from mineralization in dryland winter wheat. Oklahoma State University suggest that first year mineralization occurring at a rate of 50 to 70% is highly over estimated according to the results of the study, although the OSU expected future mineralization rate of 10-20% is more accurate. The data suggest that growers could make tri-annual applications of the 269 kg N ha^{-1}rate to stabilize yield in their system. Utilizing a tri-annual application will allow growers to maximize N mineralization as well as N from the inorganic form when producing winter wheat. Further analysis of nitrogen mineralization rates in beef feedlot manure should considered by Oklahoma State University moving forward. Soil test should be conducted regularly to ensure phosphorous levels are maintained below critical threshold for losses

INTRODUCTION

Farmers use manure as a long-term investment in arable land because it decomposes slowly and provides nutrients to crops for many years. Manure is a vital source of organic matter as well as a source of many nutrients for crop cultivation. Increased soil organic matter improves soil structure or tilth, improves drainage in fine-textured clay soils, offers a source of slow-release nutrients, minimizes wind and water erosion, and stimulates the growth of earthworms and other beneficial soil organisms (Rosen and Bierman, 2017).

Winter wheat (*Triticum aestivum* L.) is a major crop in the state of Oklahoma even prior to its statehood in 1907 with approximately 1.78 million hectares planted per year (NASS, 2020). Wheat has always played a significant role in Oklahoma's agricultural economy, with harvested grains providing $474 million in income in 2019. Weather patterns for producing crops in Oklahoma are anything but consistent, with year-to-year changes in environmental circumstances, as well as dropping grain prices, leaving growers looking for new ways to enhance yield while lowering operational costs. Winter wheat growers are seeking for strategies to reduce production costs without making drastic modifications to their production practices that might reduce yields in this era of high production costs and low commodity prices. Producers are questioning the effectiveness and advantages of fertilizer sources such as dung due to their availability. Researchers at Oklahoma State University are looking at solutions for a more effective approach to use manures due to increased demand.

The Magruder experiment (also known as Magruder plots) is one of the country's oldest experiments. It was founded in 1892 by A.C. Magruder to examine the productivity of native prairie soils without fertilizer. It began with a control treatment and was later divided after 6 years to apply manure in half of the experiment. It was modified again to include ten different treatments in 1930. Since 1947, there are six treatments available: manure, control, P, NP, NPK, and NPKL, with manure applied every four years, chemical fertilizers applied annually, and lime applied only when the pH went below 5.5.

The objective of this study is to evaluate the effect of manure application on grain yield and nitrogen contribution. To accomplish the objectives of this study, we used only manure, control, and NPKL treatments.

MATERIAL AND METHOD

For this study, historical data from a long-term continuous winter wheat experiment (Magruder plots) were analyzed. These plots have been managed under conventional tillage since 1892 at the Agronomy Experiment Station in Stillwater, Oklahoma (36°, 7'11.1" N, 97° 5'18.9" W). Magruder plots are situated on Kirkland silt loam (fine, mixed, thermic Udertic Paleustolls), with an average annual rainfall of 33 inches and a mean annual temperature of 15.5 degrees Celsius.

There are currently six non-replicated plots, including an unfertilized plot (control), manure, P, NP, NPK, and NPK-Lime (lime applied when soil pH 5.5). For this study, only three treatments were used. There was no robust use of statistical methods in agricultural experiments at the time of the establishment of this long-term experiment. As a result, replications were omitted from the experimental plan. Manure treatment began in 1899, and inorganic fertilizer was introduced in 1929. Prior to 1968, manure was used to deliver 134 kg N ha^{-1}. Following that, manure plots received 269 kg N ha^{-1} of cattle manure every four years beginning in 1968. While inorganic fertilizers are applied before planting on an annual basis. We only used manure, control, and NPK-lime treatments in this study (Table 1). Between 1930 and 1967, nitrogen was applied as sodium nitrate at 37 kg N ha^{-1}, ammonium nitrate at 67 kg N ha^{-1} from 1968 to 2014, and urea at 67 kg N ha^{-1} since 2005. Between 1931 and 1967, phosphate was applied as ordinary superphosphate (osp) (20 percent P) at a rate of 15 kg P ha^{-1}, and in 1968, it was changed to triple superphosphate (46 percent P2O5). Since 1931, potassium has been used as a muriate of potash at a rate of 29 kg K2O ha^{-1}. Lime was given to the NPK-lime plot just twice over the life of the Magruder Plots (1929 and 1954) when the pH fell below 5.5. Each plot is 30.5 m long and 5.3 m wide, with a 1.2 m alley between them.

All plots were kept in accordance with the recommendations of the Oklahoma State University Extension Service. Using a Massey Ferguson 8XP plot harvester, the center of each plot (about 5 m) was harvested for grain yield each year of the study period, and wheat straw was uniformly redistributed within each plot each year. For the study period, simple statistics with a mean yield were produced. SAS 9.4 was used for the analysis of variance, with an alpha of 0.05.

Table 1. Treatment structure

	1932-1967			1968- Present		
	N	P	K	N	P	K
		Kg ha-1			Kg ha-1	
Manure	134 Kg N/ac, every 4th year			269 Kg N/ac, every 4th year		
Check	0	0	0	0	0	0
NPKL *	37	15	30	67	15	30

*, pH <5.5, 3T/ac
N source- Sodium Nitrate (16-0-0) (1932-1967); Ammonium Nitrate (34-0-0) (1946-2003); Urea (46-0-0) (2004-Present)
P- Ordinary superphosphate (0-20-0-12) (1932-1967); Triple superphosphate (0-46-0) (1968- Present)
K- Muriate of Potash (0-0-60) (1932-Present)

RESULTS AND DISCUSSION

Effect of Manure Application on Grain Yield

The data is grouped according to the amount of Nitrogen applied. Average grain yields for the check, manure, and NPKL treated plots are presented in Table 2 (1932-1967 period) and Table 3 (1968-2015 period).

During the period 1932-1967, manure applied plots averaged 1.38, 1.55, 1.50, and 1.65 Mg ha^{-1} one, two, three, and four years after application (YAA), respectively, while unfertilized check averaged 1.00, 0.87, 1.01, and 1.04 Mg ha^{-1}. However, the manure treatment yielded 0.13 Mg ha^{-1} (8%) less than the NPKL treatment, even though no significant difference was identified between the two treatments in this study.

After 1968, manure application rate was raised to 269 kg N ha^{-1} to satisfy the needs of high yielding dwarf wheat varieties. Over the study period of 1968-2015, grain yield in the unfertilized plot ranged from 1.04 to 1.28 Mg ha^{-1}, while that for the manure and NPKL treatments ranged from 1.84 to 2.49 and 2.21 to 2.62 Mg ha^{-1}, respectively. There was a significant difference ($p = < 0.0001$) in grain yield between the unfertilized check and fertilized treatments, but no differences were observed between the manure and the NPKL applied plots expect 4th year after manure application. This shows that applying manure instead of inorganic fertilizers could result in a similar yield. Ghosh et al., 2004 and Tayebeh et al., 2010 discovered similar results. However, the quality and kind of organic fertilizer used are critical to achieve comparable yields to chemical fertilizers

(Tayebeh et al., 2010). Farmers should consider using animal manure because fertilizer prices have nearly doubled since last year. Furthermore, soil organic carbon has decreased significantly in the Magruder plots since 1893, with the manure plot showing the least reduction when compared to the others. This suggests that manure helps in the improvement of soil health.

Table 2. Mean, minimum, and maximum wheat grain yield values for manure, NPKL, and unfertilized (check) plots at Stillwater, OK. 1932-1967.

	1 YAA			2 YAA			3 YAA			4 YAA		
Treatment	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
						Mg ha^{-1}						
Manure	1.38	0.81	2.03	1.55	0.43	2.70	1.50	0.69	2.52	1.65	0.22	2.99
NPKL	1.77	1.03	2.27	1.57	0.57	2.59	1.48	0.73	2.56	1.77	0.44	2.96
Check	1.00	0.40	1.32	0.87	0.06	1.73	1.01	0.17	2.00	1.04	0.29	1.89

Table 3. Mean, minimum, and maximum wheat grain yield values for manure, NPKL, and unfertilized (check) plots at Stillwater, OK. 1968-2015.

	1 YAA			2 YAA			3 YAA			4 YAA		
Treatment	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
							Mg ha^{-1}					
Manure	2.49 a	1.08	4.07	2.17 ab	0.17	3.45	2.09 ab	1.22	3.07	1.84 bc	0.20	3.31
NPKL	2.62 a	1.69	4.39	2.48 a	0.36	4.19	2.35 ab	1.63	2.90	2.21 a	0.46	4.10
Check	1.28 c	0.90	1.82	1.04 d	0.33	1.42	1.18 c	0.63	1.90	1.06 d	0.12	1.82

Relative Yield

It is defined as the ratio of the yields between two treatments. Crop yield is affected by number of environment factors, so to remove the environment factor relative yield is a good option to examine effect of manure on wheat grain yield. Looking at the yield ratios of the manure-applied plots versus the unfertilized control, the addition of manure at 134 and 269 kg N ha-1 enhanced wheat production by 44 to 142 percent and 77 to 100 percent, respectively (Table 4). In both periods, the relative yield of wheat was highest at two years after planting. The high relative yield in the second year following treatment may be related to the rate and dynamics of feedlot manure mineralization. It is possible that the first year following application saw an initial immobilization with slow net mineralization, followed by increased mineralization in the second year, resulting in maximum wheat yield, and then a steady drop in the third and fourth years. Yield ratio between the manure applied plots and the NPKL treatments were below one, regardless of the study period except at three YAA with manure applied at 134 kg N ha^{-1} (Table 4). A relative yield value less than one shows that the NPKL plots outperformed the manure plots. However, the values (0.80 to 0.99) found in both times were close to one, implying that manure applied plot yields were comparable to NPKL treatments.

Table 4. Relative yield of winter wheat applied with cattle feedlot manure at 134 and 269 kg ha^{-1} in relation to the unfertilized check and the NPKL applied treatment

Year after manure application	Unfertilized Check		NPKL Treatment	
	134 kg ha^{-1}	269 kg ha^{-1}	134 kg ha^{-1}	269 kg ha^{-1}
1	1.44	1.95	0.80	0.94
2	2.42	2.01	0.99	0.90
3	1.99	1.77	1.09	0.87
4	1.73	1.83	0.90	0.85

Total Nitrogen Contributed by Manure

The results showed that manure applied at 134 kg N ha^{-1} contributed roughly 77 kg ha^{-1} of N across the four-year cycle, equating to a nitrogen usage efficiency (NUE) of 64%. On a yearly basis, N contribution was 15.06, 26.19, 19.38, and 24.23 kg N ha^{-1} one, two, three, and four years after application, respectively. Manure applied at a rate of 269 kg N ha^{-1} contributed about 140 kg N ha^{-1}, or to 58 percent NUE. N contribution per year was 48.11, 44.74, 34.56, and 29.05 kg N ha^{-1} for one, two, three, and four YAA, respectively. According to Kansas State University (KSU), the current estimate for the first-year manure treatment is 25%, half (12%) the following year, and even less (approximately 6%) the third growing season. In Oklahoma, the estimated range of N availability in feedlot manure is 50-70 percent in the first year and 10-20 percent in the subsequent years (Zhang, 2017). However, according to the study's findings (269 kg N ha-1 rate), feedlot manure N availability is 18, 17, 13, and 11 percent for one, two, three, and four YAA (Table 5). Overall, the mineralization rate at one YAA was 25-30% for five of the twelve years, 20% or higher for six of the twelve years (50 percent of the observations), and 15% or higher for nine of the twelve years (75 percent of the observations). At two YAA, minimum mineralization was always less than 20%. Nitrogen availability of feedlot manure for the first year of application is essentially lower compared to the current estimates. In the second year, N availability was comparable to the estimates of Oklahoma and KSU. According to the results from this data Kansas State Nitrogen availability for the first two years of application is essentially lower compared to the current estimates. Knowledge of availability of nitrogen is important because it influences the timing of manure application. Furthermore, inaccurate prediction of N availability may lead to the excess or under application of required nutrients for optimum growth and yield. The data suggest that growers could make tri-annual applications of the 269 kg N ha^{-1} rate to stabilize yield in their system. Utilizing a tri-annual application will allow growers to maximize N mineralization as well as N from the inorganic form when producing winter wheat. Further analysis of nitrogen mineralization rates in beef feedlot manure should considered by Oklahoma State University moving forward.

Table 5. Nitrogen contribution and availability of applied cattle feedlot manure to wheat in a four-year cycle at 134 (1932-1967) and 269 kg N ha^{-1} (1968-2015).

Years after application	134 kg ha^{-1}		269 kg ha^{-1}	
	N contribution	N availability	N contribution	N availability
	kg ha-1	%	kg ha-1	%
1	15.06	11	48.11	18
2	27.19	20	44.74	17
3	19.38	14	34.56	13
4	24.23	18	29.05	11
Total	85.86		156.46	
NUE	64		58	

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EFFECT OF POTASSIUM TIMING AND SOURCE ON COTTON LINT QUALITY AND YIELD

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ABSTRACT

The importance of potassium (K) is numerously documented as it's essential for photosynthesis, stomatal regulation, enzyme activation and chlorophyll development. While a majority of cotton production occurs in the southwest portion of Oklahoma, producers from south to northwest are implementing rotations of cotton and wheat. In the western portion of the state soil pH becomes increasingly alkaline [whereas areas in wheat production are predominantly acidic]. Although K becomes more available in alkaline soils not all of K is plant available and could be tied up amongst soil textures of various pore sizes. In acidic conditions commonly found in areas of wheat production K becomes insoluble and unavailable for plant uptake. With the combination of acidic conditions and the intricate role of potassium, it's apparent previous methods of supplying K should be observed and enhanced if necessary. In addition, K levels have proven to fluctuate with soil temperatures, a phenomenon also observed among soil textures. Various types of fertilizer products containing K are available to producers, of which the sources and additives may impact their availability to a cotton crop.

INTRODUCTION

The importance of potassium (K) is numerously documented, as it contributes to photosynthesis, stomatal regulation, enzyme activation, and chlorophyll development (Reddy *et al.*, 2000). Traditional practice of Oklahoma producers is to apply the entire K requirement as a preplant application, which could be found ineffective due to the complexity of K interactions within the soil solution, making proper management challenging.

In the soil solution potassium can be described in terms of mineral, exchangeable, and non-exchangeable, the concentration of K is affected by equilibrium reactions, meaning only a portion of K is available for crop uptake. Mineral and exchangeable K forms are readily available for plant uptake, while non-exchangeable K is fixed between clay minerals making it unavailable to plants. The release of non-exchangeable K occurs when the levels of mineral and exchangeable K are decreased by crop removal or K loss through leaching (Mouhamad *et al.*, 2016). This fluctuation in available K through interaction of clay minerals or effects of equilibrium reactions demonstrates the necessity for refined K recommendations.

In consideration of the complexity of K fertilization and economic return, it is possible the sole preplant application may not always be sufficient as significant demand occurs during reproductive stages, as set bolls become sinks for K. Within the plant K is essential for its role in fiber development. During fiber development K is utilized to regulate turgor pressure to promote fiber elongation if deficient turgor pressure decreases causing shorter fibers and poor lint quality (Oosterhuis, 2002).

MATERIALS AND METHODS

This study was conducted during the 2018, 2019 and 2020 growing seasons at the Cimarron Valley Research Station near Perkins, OK. In 2018 two granular sources of potassium were utilized, muriate of potash (0-0-50) and aspire (0-0-58-.5) which consisted of trace amounts of boron. For the 2019 and 2020 growing seasons an additional source in the form of foliar fertilizer (0-0-29) was incorporated. Applications occurred during two timings (preplant and pinhead square), with rates of 30, 60 lbs ac^{-1} and a split application of 30/30 lbs ac^{-1}, and 1 gal ac^{-1} for foliar applications. Granular fertilizer was spread by hand while foliar application occurred using a backpack CO_2 sprayer. Cotton lint was collected using a John Deere 482 stripper, and samples were cleaned using a Mitchell field cleaner and ginned using an Eagle 10 saw cotton gin. Lint quality analysis was conducted by Texas Tech University Fiber & Biopolymer Research Institute. This experiment utilized a RCBD with four replications, with five treatments in 2018, and 10 treatments in 2019 and 2020.

RESULTS AND DISSCUSSION

This study was conducted during the 2018, 2019, and 2020 growing seasons at the Cimarron Valley Research Station near Perkins, OK., of those three years yield was not found to be significantly different among treatment application rates, products, or timings. Not included in the results section is the fiber quality data, fiber quality was collected during the 2020 growing season and indicated no significant differences in response to potassium fertilization. Further research is necessary to determine adequate timing, rate, and product effectiveness.

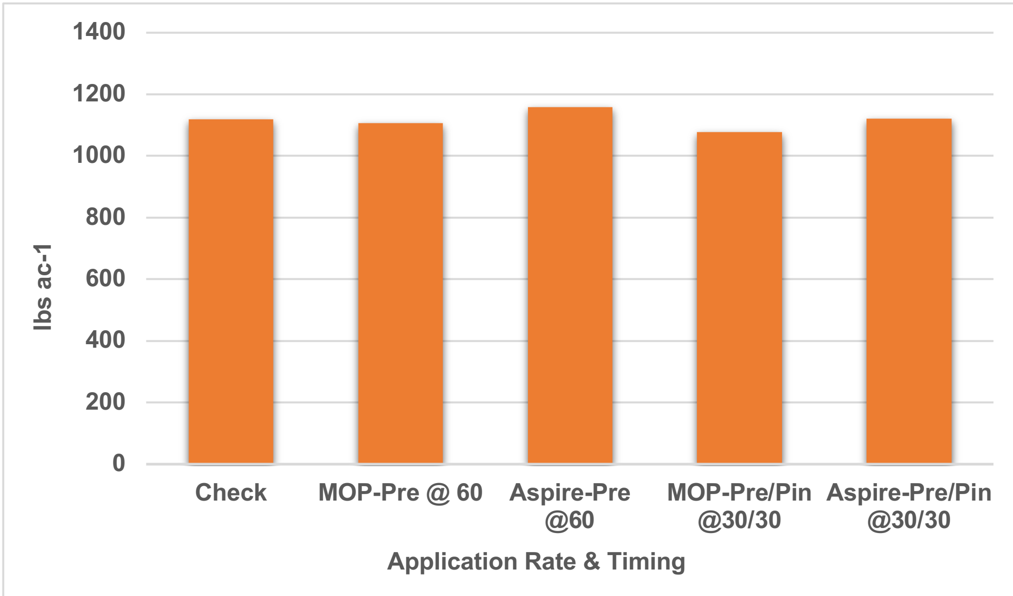

Figure 1. Shows 2018 lint yield data for the perkins location across all treatments. The unfertilized check is included to indicate the lack of reponse to timing and rate of potassium fertilization. Pre indicates the timing of application while the @ denotes the rate of ferilizer used.

TRT	Product	Timing	Rate
1	CHECK	-	-
2	MOP	Pre	30
3	Asprie	Pre	30
4	MOP	Pre	40
5	Aspire	Pre	60
6	MOP	Pre-Pin	30/30
7	Aspire	Pre-Pin	30/30
8	Foliar	Pin	1 gal ac-1
9	MOP/Fol	Pre-Pin	30-1 gal ac-1
10	MOP/Fol	Pre-Pin	60-1 gal ac-1

Table 1. Contains treatment infromation including product, timing, and rate of application to be used with figures 2 and 3 for the 2019 and 2020 lint yield.

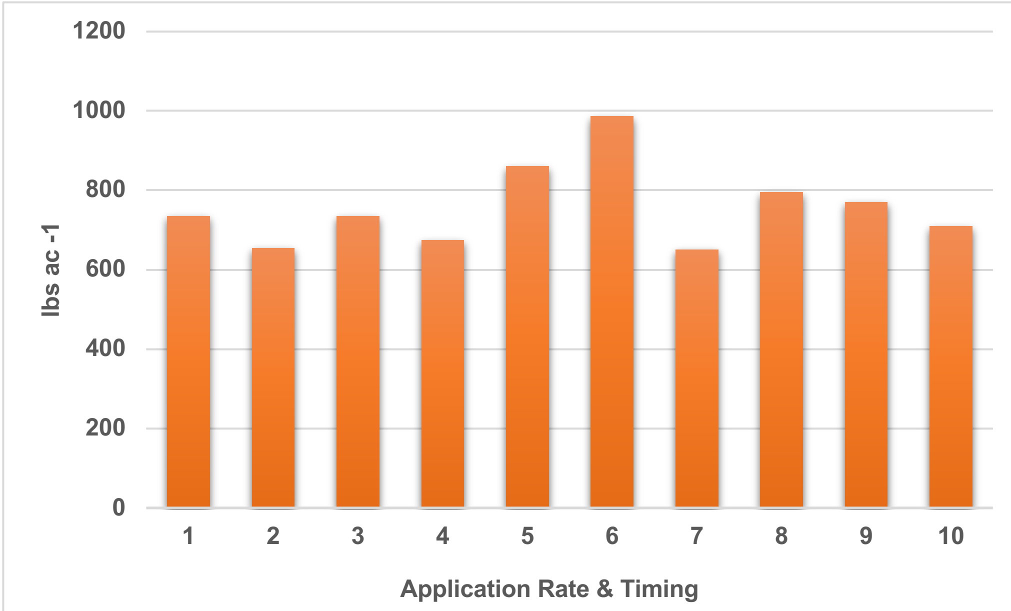

Figure 2. shows 2019 lint yield data for the perkins location across all treatments. The unfertilized check is included to indicate the lack of reponse to timing and rate of potassium fertilization. Numbers denote treatments, the use of table 1 is required to determine the product, rate, and timing.

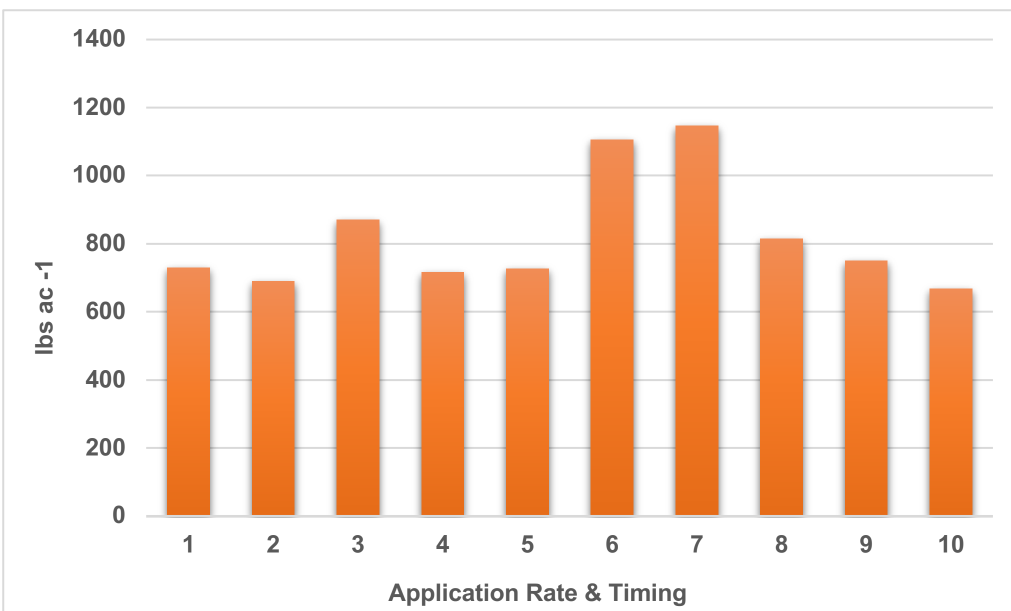

Figure 3. shows 2020 lint yield data for the perkins location across all treatments. The unfertilized check is included to indicate the lack of reponse to timing and rate of potassium fertilization. Numbers denote treatments, the use of table 1 is required to determine the product, rate, and timing.

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STACKING NUTRIENT 4Rs ON POTATO AND WHEAT

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ABSTRACT

The 4Rs of nutrient management are research-based guidelines with the aim to improve the sustainability of major cropping systems and the environment without compromising crop yield and quality. The objective for this project is to evaluate individual and stacked 4R management practices and how they intersect. A field trial near Grace, Idaho was conducted on potato (*Solanum tuberosum* L.) in 2020 and hard white spring wheat (*Triticum aestivum* L.) in 2021. Nitrogen (N) fertilizer treatments included all combinations of two sources (uncoated vs polymer coated urea (PCU)), two rates (100 or 75%), two timings (emergence or split applied), and two placements (broadcast or band + broadcast) compared to an untreated control. Overall, potato was responsive to N, but the wheat was not (which is common when following potato). Despite large numerical increases for all treatments compared to the unfertilized control (50-129 cwt ac^{-1}), only the source (PCU) treatment was significantly different (144 cwt ac^{-1}). It is also noteworthy that the reduced rate of urea performed identically to the full rate of urea. Although this is a limited amount of data, it reinforces the 4R principles and suggests that stacking some methods may not be necessary. For example, a timing component did not provide further increase when an enhanced efficiency source was used. Future trials are planned to continue this investigation.

INTRODUCTION

Crops cannot take up all plant available N at once (Gayler et al., 2002). Therefore applying a full rate of nitrogen (N) fertilizer all before the plant emerges is problematic (Hopkins et al., 2020). The N in fertilizer can quickly become unavailable to plants through the processes of volatilization, denitrification, and leaching (Hopkins et al., 2020). Therefore, N fertilization is not completely efficient.

Implementing the 4Rs of nutrient management potentially increases yields, crop quality, and/or profits while reducing environmental risk (Hopkins et. al, 2020). The 4Rs include applying the “right” rate of fertilizer using the “right” source at the “right” timing and placement (Flis, 2020). A plethora of scientific studies have developed and vetted these practices that have been shown to work in field conditions with growers. However, there are only limited studies where two or more of the 4Rs are included at the same time and none that we know of where all four have been tested in concert with each other.

For example, the Grower’s Standard Practice (GSP) for potato involves split application of N fertilizer with 25-50% typically applied preplant and/or at cultivation with the remainder injected in the irrigation water, based on petiole nitrate-N analysis, periodically during the growing season. Many studies have resulted in understanding the correct rate. Other studies have evaluated Enhanced Efficiency Fertilizers (EEF), such as polymer coated urea (PCU). Some studies show that less fertilizer needs to be applied when using a PCU due to the increased Nitrogen Use Efficiency (NUE). The improved efficiency of PCU also potentially reduces the need to split apply fertilizer, which may save time and equipment and fuel costs. Although there are limited studies evaluating these practices with PCU, there is not sufficient data examining if the timing and rates need to be adjusted.

The 4Rs are also effective at mitigating nitrogen losses to the environment. Applying a reduced rate of fertilizer automatically decreases the amount of N that could be lost to the environment. PCU has also proven effective at reducing N lost to the atmosphere through volatilization and to groundwater through leaching (Hopkins et al., 2020). As more farmers begin to implement the 4Rs of nutrient management, we expect to see less N pollution in the environment from agricultural sources.

The objective for this project is to evaluate individual and stacked 4R management practices for potato and wheat and how they intersect, including all combinations of two sources (uncoated vs polymer coated urea (PCU)), two rates (100 or 75%), two timings (emergence or split applied), and two placements (broadcast or band + broadcast) compared to an untreated control.

MATERIALS AND METHODS

Irrigated Russet Burbank potato (*Solanum tuberosum* L.) and Dayn hard white spring wheat trials were conducted in 2020 and 2021, respectively, in a field near Grace, Idaho, USA on calcareous sandy loam soil. Treatments (Table 1 for potato and Table 2 for wheat) were arranged in a randomized complete block, full factorial design with six replications. For wheat, each of the 4Rs are evaluated in combination with the other practices, but for potato the timing and placement treatments are combined as this better represents what growers actually do.

Table 1: 2020 experimental treatments (potato). Highlighted fields indicate implementation of 4R factors.

Trt #	Treatment	Source (applied at emergence)	N at emergence, kg/ha	N in-season, kg/ha	total N, kg/ha	Rate	Timing/Placement (pre-emerge is PCU or urea; in-season is urea only)
1	Negative Control	n/a	0	0	0	n/a	n/a
2	Positive Control	urea	247	0	247	full	Pre-Emergence
3	Source (S)	PCU	247	0	247	full	Pre-Emergence
4	Rate (R)	urea	207	0	207	reduced	Pre-Emergence
5	Timing (T)	urea	207	40	247	full	Split
6	SxR	PCU	207	0	207	reduced	Pre-Emergence
7	SxT	PCU	207	40	247	full	Split
8	RxT	urea	168	40	207	reduced	Split

9	SxRxT	PCU	168	40	207	reduced	Split

Table 2: 2021 experimental treatments (wheat). Highlighted fields indicate implementation of 4R factors.					
Trt #	**Treatment**	**Source**	**Rate**	**Time**	**Place**
1	Negative control	n/a	0% YG	n/a	n/a
2	Low	Urea	50% YG	Pre-plant (PP)	BRCST
3	Average (positive ctrl)	Urea	100% YG	PP	BRCST
4	Rate (R)	Urea	75% YG	PP	BRCST
5	Source (S)	PCU	100% YG	PP	BRCST
6	Timing (T) - this is GSP	Urea/UAN	100% YG	PP+Flag leaf (FL)	BRCST+F
7	Placement (P)	Urea	100% YG	PP+Band at planting (AP)	BRCST+BA
2-way interactions					
8	RS	PCU	75% YG	PP	BRCST
9	RT	Urea/UAN	75% YG	PP+FL	BRCST+F
10	RP	Urea	75% YG	PP+AP	BRCST+BA
11	ST	PCU/UAN	100% YG	PP+FL	BRCST+F
12	SP	PCU	100% YG	PP+AP	BRCST+BA
13	TP	Urea/UAN	100% YG	PP+AP+FL	BRCST+BA+F
3-way interactions					
14	RST	PCU/UAN	75% YG	PP+FL	BRCST+F
15	RSP	PCU	75% YG	PP+AP	BRCST+BA
16	RTP	Urea/UAN	75% YG	PP+AP+FL	BRCST+BA+F
17	STP	PCU/UAN	100% YG	PP+AP+FL	BRCST+BA+F
4-way interactions					
18	RSTP	PCU/UAN	75% YG	PP+AP+FL	BRCST+BA+F

Handheld Normalized Difference Vegetative Index (NDVI) were measured (four dates for potato and three for wheat) in-season (GreenSeeker, Trimble Agriculture, Westminster, CO). Composite potato petiole and wheat flag leaf samples were collected and analyzed for nitrate (NO_3^--N) or total N, respectively. Total yield was measured at harvest, along with various quality measurements. Statistical analysis was performed by ANOVA with mean separation using the Tukey Kramer method using SAS software.

RESULTS AND DISCUSSION

Potato was responsive to N, as indicated by an orthogonal yield increase for fertilized treatments over the unfertilized, negative control (P = 0.421). Although the numerical increases in yield were large in magnitude (50-129 cwt ac^{-1}), only the source (PCU) treatment was significantly different at 144 cwt/ac more total yield than the unfertilized control (Fig. 1).

For US No. 1 tuber percentage (data not shown), only the source x timing (ST) treatment was significantly greater at 95% than the unfertilized control at 80%. It was also significantly greater than the rate x timing (RT) treatment also with 80% US No. 1 tubers. All other treatments performed similar to the ST treatment, ranging from 83-93%.

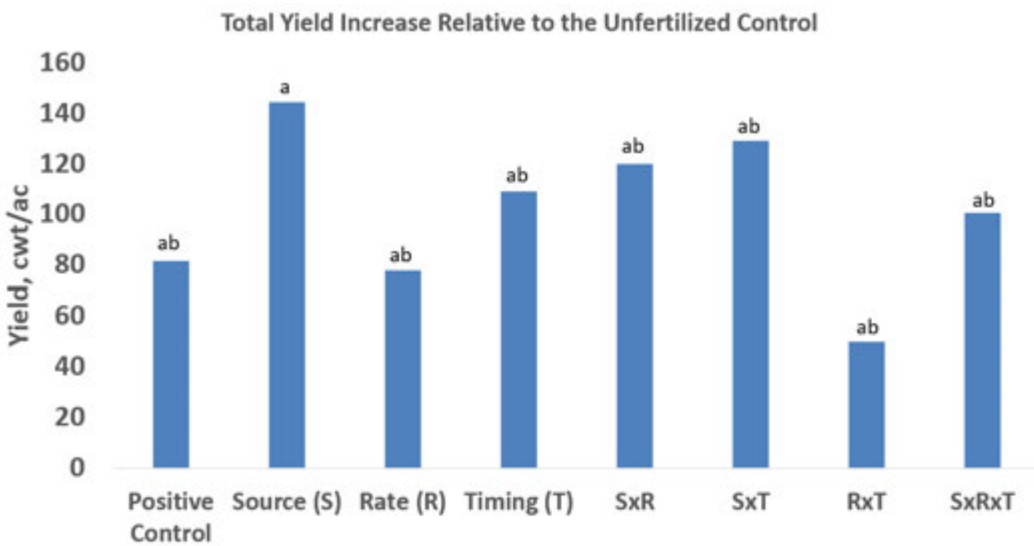

Figure 1. Potato yield increase relative to unfertilized control (its statistical indicator is a "b"). Bars sharing the same letter are not statistically different from one another.

Total yield measurements followed a trend similar to the one seen in petiole nitrate results. For all sampling dates, the petiole NO_3^--N for the unfertilized control was significantly lower than all fertilized treatments (Fig. 2). Almost all other treatments were statistically similar throughout the growing season. However, the positive control was statistically higher than all other treatments.

For NDVI, the negative control performed statistically similar to all fertilized treatments on the first sampling date, but was statistically lower for the remaining sampling dates (Fig. 3). The NDVI values for all fertilized treatments stayed mostly the same for the first three sampling dates. On the fourth sampling date, values differed among the treatments and reached statistical significance. Each treatment with PCU as the fertilizer source performed better than the urea fertilizer treatments, except for the rate treatment on the last sampling date.

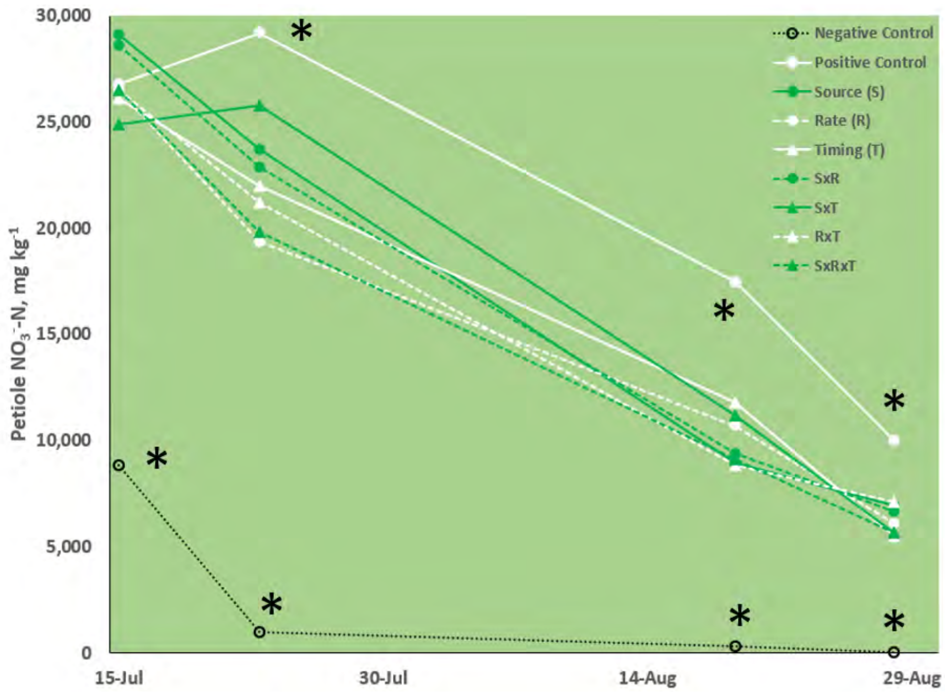

Figure 2. Potato petiole nitrate-N. Asterisks indicate values significantly different than the Grower's Standard Practice (GSP).

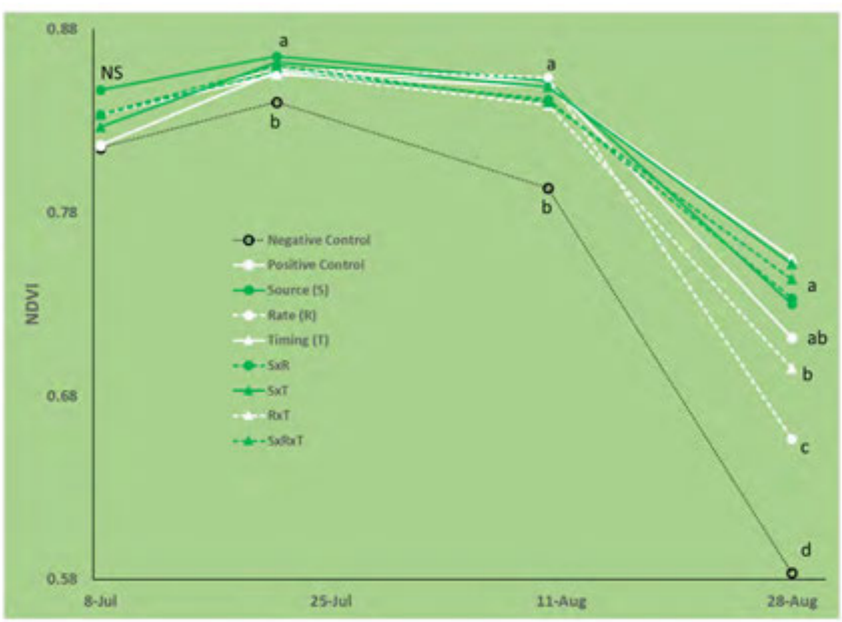

Figure 3. Potato Normalized Difference Vegetative Index (NDVI). Values or groups of values close to one another sharing the same letter are not statistically different from one another. (P = 0.05)

There were no significant differences between any of our treatments for any measurement for wheat. This includes our negative control, which received no N fertilizer at any time in 2021. This is likely because this was a wheat crop following a potato crop. Potato production often results in high residual N in the soil after harvest. (Hopkins et al., 2020). With a root zone deeper than potato, the wheat crop was likely able to access the residual N from previous years. Additionally, in contrast to growing after another grain crop, the crop residue following a potato crop has a low C:N ratio and has a relatively high amount of readily available N. Therefore, it is logical that it takes less N to grow a crop following potato than most other crops. Thus, the wheat was able to be healthy, despite receiving no N fertilizer additions in our negative control plots. This result reinforces the historical success of the 4Rs. Our study shows that farmers can reduce fertilizer rates in certain scenarios and still yield an acceptable crop.

Implications

Our results suggest that implementing the 4Rs of nutrient management can effectively grow healthy potato plants. Each treatment, except for the negative control, resulted in acceptable levels of petiole nitrate and NDVI values. Thus, the 4Rs can serve as reliable guidelines in making management decisions.

The in-season data confirms other findings that PCU is a viable N source for Russet Burbank potato. Each treatment with PCU as the fertilizer source performed as well or better than the GSP. For NDVI, each PCU treatment performed statistically better than the GSP treatment. The relatively higher petiole nitrate and NDVI values are a result of the slow-release technology of PCU.

The polymer coating around PCU fertilizer granules allows moisture from the soil to enter the granule and dissolve the nitrogen. That nitrogen solution then diffuses out of the polymer coating at a rate controlled by the temperature of the surrounding soil (Hopkins et al., 2020). This mechanism allows for the gradual release of N to the plant throughout the growing season. Thus, rather than receiving more N than the plant can use all at once, plants fertilized with PCU are fed with N in smaller amounts over time.

In conclusion, our results indicate that healthy potato plants can be grown by applying the 4R nutrient management principles. Implementing these practices will help farmers save money and time, use natural resources more efficiently, and reduce the impact of fertilizers on the environment.

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CAN SOIL HEALTH METRICS IMPROVE SOIL FERTILITY RECOMMENDATIONS IN MISSOURI CORN PRODUCTION?

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ABSTRACT

It is speculated that integrating soil health (SH) with soil fertility (SF) testing would improve fertilizer recommendations. However, impacts of SH properties, specifically soil biological properties, on fertilizer demand are not quantified. The objective of this research was to explore corn (Zea mays L.) yield response to phosphorus (P) and potassium (K) fertilization as influenced by established SF analysis and common SH metrics. From 2018 to 2020, 532 fertilizer response plots (1592 ft2) were implemented in 84 producer fields across central Missouri. Response plot treatments were 1) an unfertilized control, 2) 100 lbs ac-1 of K2O, and 3) 100 lbs ac-1 of P2O5. Each treatment received the same producer-specific nitrogen (N) rates, with an additional 40 lbs N acre-1 applied near V6 corn growth stage to prevent N deficiencies. Random forest analysis was used to model yield response to P and K fertilization and to investigate the influence of SH and SF analysis on model performance. Two-thirds of established monitoring sites were below established P and K soil-test critical concentrations—with 32% and 36% of the low fertility plots responding to P and K fertilizer application, respectively. The most consistent P and K yield improvements occurred in established “Very Low” and “Low” fertility ratings with yield improvement at 52% and 56% of the sites respectively. However, integrating SH and SF for predicting yield response was only minimally helpful, resulting in R2 values of 15% and 7% for the P and K treatments, respectively. The low R2 values are likely due to the variability in P and K availability and crop demand introduced by the diversity of cropping systems, management practices, and soils of the research sites. Assessment of variable importance in the models indicated that the established University of Missouri recommended SF tests best predicted grain yield responsiveness to P and K fertilization. The addition of SH metrics provided minimal additional predictive power. Although improved SH may offer multiple environmental or agronomic benefits, this study indicates that across central and northern Missouri soils, established physiochemical SF analysis remains the most effective tool to guide P and K fertilizer decisions in corn production.

INTRODUCTION

Modern-day fertilization contributions 40-60% of current corn grain yield in the United States but offsite transport of fertilizer nutrients leads to regional, local, and worldwide environmental issues (Stewart et al., 2005). The bedrock of fertilizer recommendations is soil fertility (SF) testing. Soil fertility testing uses established correlation datasets between soil nutrient concentrations and relative yield response to identify whether estimated soil nutrient supply suffices for crop demand (McGrath et al., 2014). For crop phosphorus (P) and potassium (K) nutrient needs, these relationships also identify nutrient concentration thresholds where additional fertilizer will not improve yield (Fryer et al., 2019). This, in-turn, serves to recommend where not to fertilize, and prevents potential nutrient runoff from cropped fields (McGrath et al., 2014). However, recent research has highlighted possible improvements in fertilizer recommendations associated with soil-test P (STP) and soil-test K (STK), with reported accuracies as low as 40% (Fryer et al., 2019). Investigating inadequacies and improving these recommendations are crucial in maintaining profitability and averting ongoing environmental pollution.

The University of Missouri P and K recommendations rely upon physiochemical soil extractions and yield response relationships developed decades ago (Bray, 1945). These relationships were developed in cropping systems with regular and deep tillage, limited crop rotations, and fallow periods. In contrast, modern conservation practices include diversification of crop rotations, incorporating cover crops, and minimizing tillage. These conservation practices improve physical, chemical, and biological soil properties, creating an environment different from when SF recommendations were developed. Despite these changes in common management practices, SF analysis and evaluations have largely remained unchanged. Monitoring these improvements led to the development of 'soil health' (SH) and the focus on improved soil biological properties. However, it remains uncertain whether enhancements in nutrient cycling and availability from improved soil biological properties affect SF recommendations. Current SF assessments of nutrient status are physiochemical and do not measure soil biological properties and do not directly measure the impact from soil improvements through conservation systems on labile soil nutrients. Because of this void, some have recommended expanding SF assessments to include soil biological assessments. However, these asserted benefits remain conceptual, with little empirical evidence (Bünemann et al., 2018).

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

MATERIALS AND METHODS

Research was implemented in mid-Missouri across 84 commercial fields in diverse management practices over three seasons (2018-2020). To evaluate response to P and K fertilization across these diverse environmental conditions, multiple fertilizer response trials (i.e., 'monitoring sites') were established on these fields. Each monitoring site was a 1593 ft^2 and included four 398 ft^2 non-replicated single-rate fertilizer treatments with a total of 446 total monitoring sites. Monitoring sites followed a standardized plot plan with the following treatments: 1) unfertilized control, 2) 100 lbs $acre^{-1}$ of K_2O using KCl (0-0-60), and 3) 100 lbs $acre^{-1}$ of P_2O_5 using triple superphosphate (0-46-0). Fertilizer treatments were applied before or at planting while cooperating farmers selected hybrids, weed control, tillage, N fertilization, planting dates and other practices based on their standard management practices. An additional 40 lbs N $acre^{-1}$ were applied near V6 corn growth stage to prevent N deficiencies. Planting dates varied by climate and soil properties and ranged between April 5 toJune 10.

Prior to fertilization (March-April), SH and SF samples were collected for each monitoring site. Soil samples were collected from eight randomly sampled 0-15 cm depth cores. Soil fertility samples were air-dried and submitted for analysis to Ward Laboratories (Ward Laboratories, Kearney, NE). Soil fertility analysis included organic matter (OM), Bray-1 P, ammonium acetate K extraction, sulfate sulfur, cation exchange capacity (CEC), pH, and particle size. Soil biological tests for SH metrics were completed in the USDA-ARS Soil Quality Lab on the University of Missouri Columbia Campus and included: soil organic carbon (SOC), total nitrogen, permanganate oxidizable carbon (POXC), 4-day soil respiration, autoclaved citrate extractable protein (ACE Protein), acid phosphatase activity, aryl-sulfatase activity, and β-glucosidase activity. Soil health samples were broken into two horizons 0 to 5 and 5 to 15 cm, stored in a cooler at 1.6° C, and later processed by passing through a 1 cm screen, air-drying, and dry sieving through a 2 mm screen. For POXC and SOC, soils were ground to a powder prior to analysis. Grain yield was hand harvested at maturity and weights were adjusted to 15.5% moisture from 118 ft^2 from each treatment. Yield response was calculated as the control treatment divided by the respective fertilizer treatment (P and K) at that monitoring site. Statistical approaches used relative yield as the response variable, with the suite of SF and SH metrics as explanatory variables. Relative yield was fit with quadratic plateau models to evaluate current SF recommendations with soil test K and soil test P. Random forest algorithms with variable importance plots were used to evaluate whether integrating SF and soil biological tests improve predictions of relative yield.

RESULTS AND DISCUSSION

University of Missouri Soil Fertility Recommendations

At monitoring sites below the recommended soil test P and K levels, there was an average 10% yield increase for P fertilization and 11% yield increase for K fertilization. Fertilizer application of P and K improved yield at 46 and 36% of total monitoring sites respectively. The greatest rate of responses to fertilization occurred in the “Low” and “Very Low” fertility ratings with yield response at 52 and 32% of monitoring sites for P fertilization respectively (Figure 1). Despite being below recommended STP critical concentration, monitoring sites with “Medium” STP responded with similar rates as sites above the critical concentration (High, Very High, and Extremely High). Similar trends were observed in the K treatments, with the greatest rate of response to K fertilization occurring in the “Low” fertility rating (Figure 1). The “Medium” and “High” fertility ratings contained similar response to fertilization. The response rate in the “High” fertility rating was greater than expected considering the soil test K concentration was above recommended concentrations.

Variability in fertilization above the critical concentration of STP and STK are well documented. Distributions of relative yield in the University of Missouri correlation datasets range 80-120% at high soil STP and STK values (Fisher, 1974). Stronger relationships than those observed in this dataset have been observed, but these strong relationships often include few sites typically under similar management practices.

Despite controlling these factors, significant variability can remain with critical soil test concentrations differing between 6-10 ppm between research sites (Dodd and Mallarino, 2005). These differences in P critical concentrations, in part, are due to better drainage properties which created a soil environment which promote root acquisition of available P from an overall improved growing environment (Dodd and Mallarino, 2005). The data reported in this dataset reflect over 20+ soil types with unique properties and management practices. Distinctive critical concentrations between soil types would introduce significant variability in yield response to fertilization near established critical levels and could explain the variability in yield response to fertilization for both P and K.

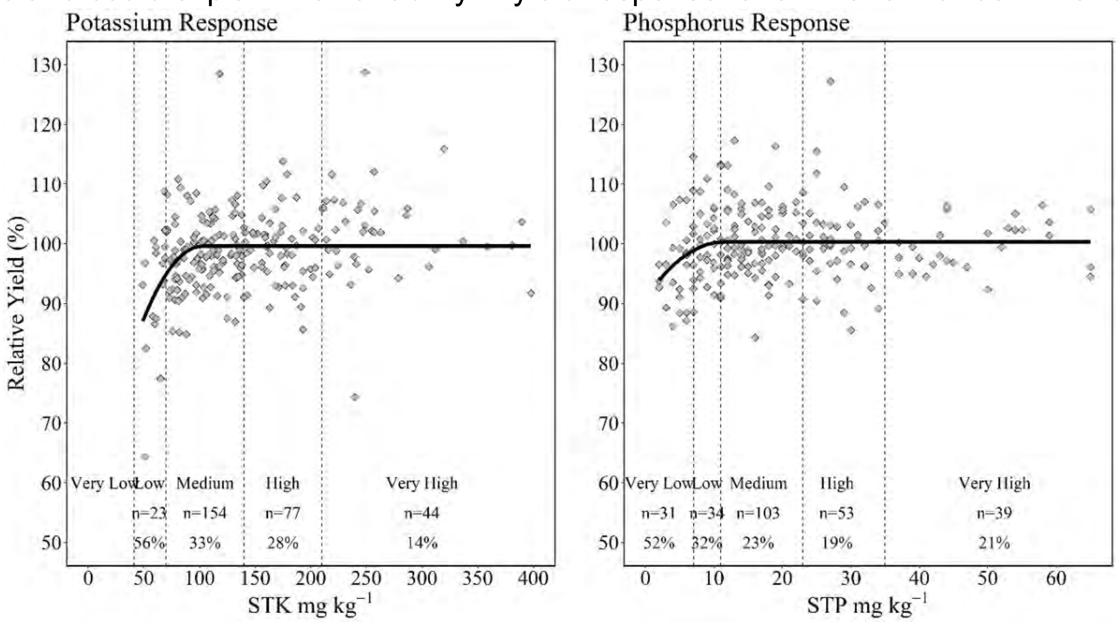

Figure 1: Relationships between soil test phosphorus (STP) and soil test potassium (STK) and relative yield of corn across all experimental years and overlaid with best-fit quadratic plateau linear functions. Vertical dashed lines represent University of Missouri SF ratings, which reflect the probability of yield improving from fertilizer application. Under each rating label is the number of observations and percent of observations with ≥ 5% yield increases shown.

Integrating Soil Health and Soil Fertility Metrics

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

Relative yield response to P or K fertilization was the explanatory variable used to evaluate the integration of SH into established SF analysis. Integration of SH metrics marginally improved model performance relative to current SF soil tests (Table 1). The addition of SH metrics marginally improved the out-of-bag error R^2 values for the calibration dataset for both P and K fertilization (Table 3). However, no substantial improvement in RMSE from the calibration to the validation datasets indicates the supplementary factors did not improve model accuracy. These results differ from conclusions observed with N fertilization in which soil biological tests have improved traditional SF metrics (McDaniel et al., 2020). These differences likely evolve from differences in P and K crop demand, crop sensitivity to fertilization, and differences in nutrient cycling. Biological processes govern the cycling and availability of N, while chemical and physical processes drive P and K availability to crops. The SH metrics included in this study were biological analyses and reflect nutrient cycles that are microbiologically driven. Chemical and physical processes dominate P and K nutrient transformations and availability; therefore, introducing biological analysis may not directly translate to improvements in evaluating P and K crop availability.

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

Model Inputs and Dependent Variable		**Calibration**		**Validation**
	mtry	R^2	***RMSE***	***RMSE***
Relative Yield to Potassium Fertilization				
Soil Fertility	1	86%	7%	6.7%
Soil Fertility + Soil Health Metrics (Integrated)	2	92%	7%	6.4%
Relative Yield to Phosphorus Fertilization				
Soil Fertility	1	89%	6%	6.5%
Soil Fertility + Soil Health Metrics (Integrated)	2	94%	6%	3.0%

Variable importance analysis of relative yield response to P and K fertilization was used to evaluate the importance of each explanatory variable (Figure 2). Bray-1 and CEC were identified as the top indicators of yield response to P fertilization for both the SF and integrated random forest models. The Bray-1 soil extraction is currently the only soil metric used for the University of Missouri P recommendations. These data suggest CEC could reflect factors that govern yield response to P fertilization that are not currently realized in the Bray-1 test. Similar observations were made in Iowa where differences in yield response to P fertilization between field sites were attributed to drainage properties and an overall soil environment, in addition to the Bray-1 soil test (Dodd and Mallarino,, 2005). Cation exchange capacity is related to several soil properties, including soil texture and soil OM. However, percent clay was also included in the SF model and considered relatively unimportant. Therefore, CEC likely reflects additional soil properties beyond soil texture, such as OM, to explain its relatively high importance in predicting yield response to P fertilization. For both the SF and integrated random forest models, the ammonium acetate K extraction was considered the most important variable in predicting yield response to K fertilization, with CEC also considered an important factor. This follows the current University of Missouri recommendation system that integrates these two variables. The inclusion of soil test K as the top variable for both variable importance methods confirms the relative power of this measurement in identifying soils responsive to K fertilization. However, further refinement of the current University of Missouri recommendations is required, when considering the relatively inconsistent response to P and K fertilization across central Missouri soils and cropping systems (Figure 1).

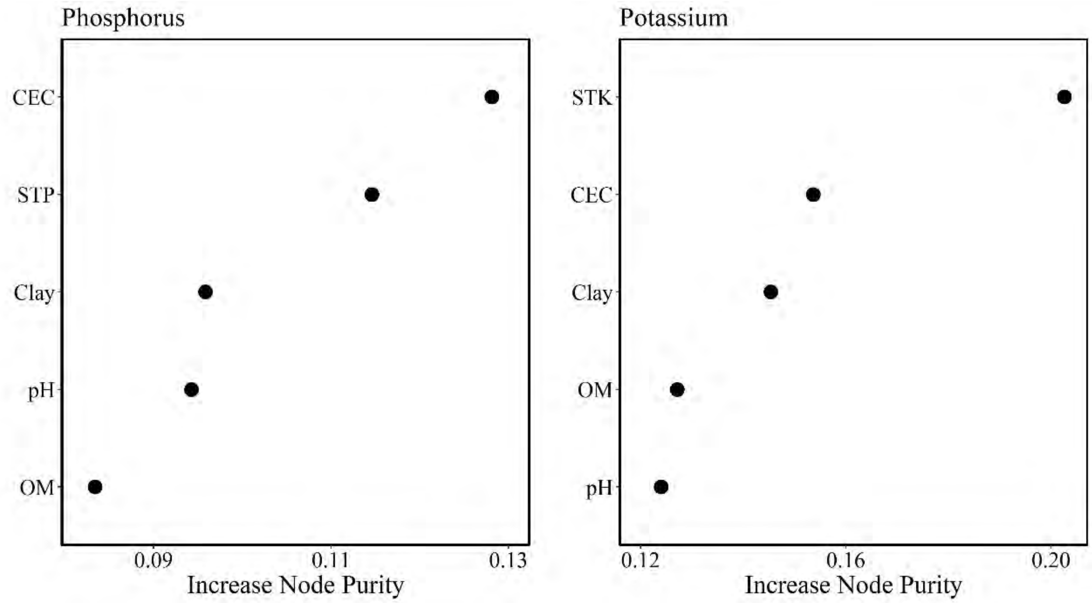

Figure 2: Variable importance plots for established random forest models that included soil fertility tests. Increase in node purity reflects a reduction in residual sum of squares at each split when summed over all splits and trees for each variable. The greater the number, the greater the relative importance in predicting yield response to P and K fertilization.

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EVALUATION OF STARTER NITROGEN FERTILIZER RATES FOR GRAIN SORGHUM PRODUCTION IN THE SOUTHERN GREAT PLAINS

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ABSTRACT

With the continuous increase in fertilizer prices, it's become more evident that management practices need improved to ensure nutrient use efficiency (NUE). This study was conducted to observe the effects of placement and rate of starter nitrogen (N) on sorghum plant growth, and final grain yield. Two sources of N were utilized, liquid UAN (28-0-0), and granular urea (46-0-0) in combination with three rates of N 8, 16, 24 lbs N ac^{-1}, and four-application methods in-furrow, surface dribble, surface, and 2x2 side-dress. It has been documented that at lower rates of N placement could negatively affect crop emergence, while results from this study suggest no correlation.

INTRODUCTION

The unpredictability of Oklahoma's climate Grain sorghum is one of the few crops adapted to such harsh environments, making it the fifth most planted crop in that state covering approximately 305,000 acres planted in 2020. Majority sorghum acres are used for grain production producing approximately 10.35 million bushels, while 195,000 tons of silage are produced (NASS, 2020). Non-uniform stands and uneven early season growth have been shown to significantly reduce grain sorghum yields (Conley et al., 2005).To overcome these issues, the use of starter fertilizer in conjunction with grain sorghum has increased. Starter fertilizer application involve the placement of fertilizer in close proximity to the seed at or near planting (Lofton et al., 2019). Here is where you could briefly discuss the negative effects of starter N placement

MATTERIALS AND METHODS

This experiment was conducted across two locations, Lake Carl Blackwell (LCB) and EFAW (in Stillwater, OK) during the 2020 and 2021 growing season. . The LCB location is irrigated using a T&L linear irrigation system and EFAW is a dry land environment. This study utilizes a Randomized Complete Block Design (RCBD) with 13 treatments replicated 3 times. The planter used is a John Deere Max Emerge 2 vacuum 4-row planter with 30 inch row spacing. The planter has Yetter row cleaners; the seed firmer is a Keeton 2 tube universal seed firmer and Schefert 2x2 and dribble band attachment. The nitrogen source used is UAN-28. The UAN application is driven by CO_2 and controlled by electronic solenoids. Insect boxes were converted to handle dry fertilizer via a 1 inch hose that placed the urea behind the seed firmer and in front of the closing wheels, which exposed some urea to the seed furrow. The Dribble Surface methods were done by planting the plot then picking the planter up off the ground. While the planter is picked up reverse to the start of the plot, keep the planter raised about 6-10 inches off the ground engage the UAN dribble surface option and drive forward at the specified rate to get the correct amount of nitrogen placed. All other fertilization methods are done as planting while planting the plot. Stand counts were done by counting every emerged sorghum plant in the middle two rows in every treatment plot. Treatments are in table 1 also included is nitrogen rate, source and method of application. All statistical analysis was preformed using SAS 9.4.

Treatment	N Rate (lbs N^{-1})	Source	Method
1	0	----	----
2	8	UAN	With Seed
3	16	UAN	With Seed
4	24	UAN	With Seed
5	8	UAN	Dribble Surface
6	16	UAN	Dribble Surface
7	24	UAN	Dribble Surface
8	8	UREA	Dry Surface
9	16	UREA	Dry Surface
10	24	UREA	Dry Surface
11	8	UAN	2x2
12	16	UAN	2x2
13	24	UAN	2x2

Table 1*. List of treatments from* evaluation of *starter nitrogen rates and placement study in grain sorghum in central Oklahoma*

RESULTS AND DISCUSSION

For the growing season of 2020 there was no stand count data was collected. In 2021, stand counts were collected at both locations, the EFAW location averaged one plant foot^{-1} and the LCB location averaged two plants ft^{-1}. At the designated planting population of 35,284 plants ac^{-1}, there is an expected four plants ft^{-1}. The check plots for EFAW averaged one plant foot^{-1} and the checks from LCB averaged two plants foot^{-1}. In 2021 at both locations, stand count had no significant impact on grain sorghum yield. There was also no significant impact of application method, nitrogen rate, or an interaction of method and nitrogen rate at any site year. There was also no significant impact of method, rate and site year on the yield of grain sorghum. There are a few potential reasons on why there was nothing reported statistically. One reason is that the nitrogen rates were not at a level to cause significant salt damage that would limit emergence. The nitrogen application rates were not high enough to produce a significant difference in yield. There is the possibility that the closing wheels on the planter did not close the furrow for good soil seed contact for proper germination, which resulted in universal stand counts below expectation.

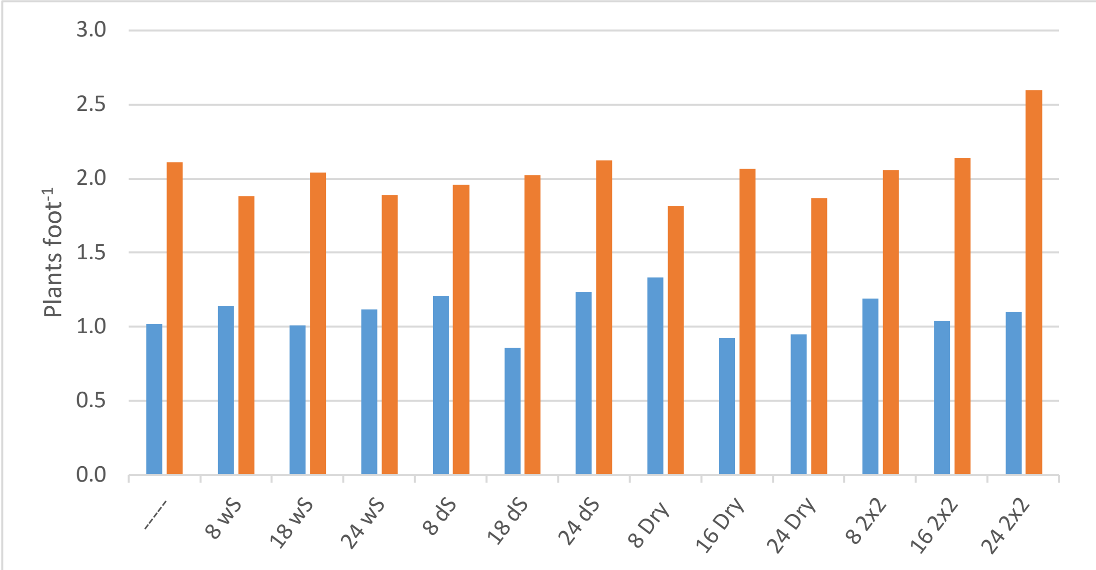

Figure 1. *2021 stand counts from evaluation of starter nitrogen rates and placement study EFAW (blue bar) and Lake Carl Blackwell (orange bar). Data only collected from only counting middle two rows of each plot.*

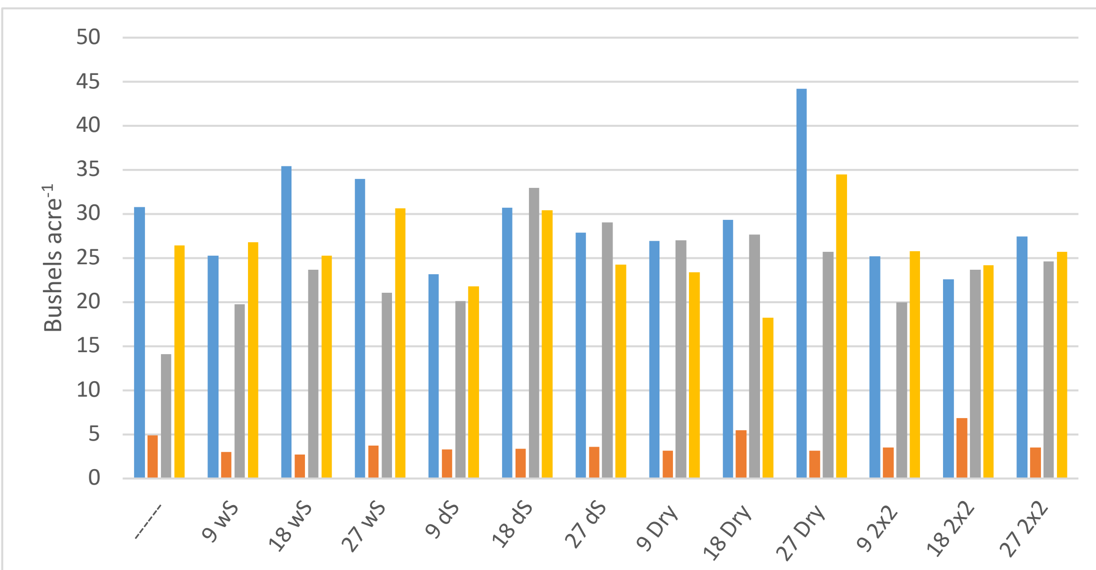

Figure 2. *2020 and 2021 grain sorghum yield from evaluation of starter nitrogen rates and placement study from Lake Carl Blackwell 20 (blue bar), EFAW 20 (orange bar), EFAW 21 (gray bar), and Lake Carl Blackwell 21 (yellow bar), wS (with seed), dS (dry surface), dry (dry surface)*

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