Kansas Agricultural Experiment Station Research Reports

Volume 3
Issue 3 *Kansas Fertilizer Research*

Article 12

6-2017

Kansas Fertilizer Research 2017

Recommended Citation

(2017) "Kansas Fertilizer Research 2017," *Kansas Agricultural Experiment Station Research Reports*: Vol. 3: Iss. 3. https://doi.org/10.4148/2378-5977.1403

KANSAS STATE UNIVERSITY

Kansas Fertilizer Research 2017

K-STATE
Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

Kansas Fertilizer Research 2017

Contents

Contributors

D.S. Abel, Graduate Student, Department of Agronomy, K-State, Manhattan

H.D. Bond, Assistant Scientist, Southwest Research-Extension Center, Tribune

R.E. Carver, Graduate Student, Department of Agronomy, K-State, Manhattan

I. Ciampitti, Assistant Professor, Crop Production and Cropping Systems, Department of Agronomy, K-State, Manhattan

R.S. Currie, Associate Professor, Weed Scientist, Southwest Research-Extension Center, Garden City

I.B. Cuvaca, Graduate Student, Department of Agronomy, K-State, Manhattan

A.J. Foster, Extension Specialist, Crops and Soils, Southwest Research-Extension Center, Garden City

J. Holman, Cropping Systems Agronomist, Southwest Research-Extension Center, Garden City

G.J. Kluitenberg, Soil and Environmental Physics, Department of Agronomy, K-State, Manhattan

M. Knapp, Service Climatologist, Weather Data Library, Department of Agronomy, K-State, Manhattan

N.O. Nelson, Associate Professor, Soil Fertility and Nutrient Management, Department of Agronomy, K-State, Manhattan

G. Newdigger, County Coordinator, Agriculture Extension Agent, 4-H Agent, Stafford County, K-State Research and Extension

A.K. Obour, Assistant Professor of Soil Science, Department of Agronomy, Agricultural Research Center, Hays

C.W. Rice, University Distinguished Professor, Soil Microbiology, Department of Agronomy, K-State, Manhattan

J. Rivera-Zayas, Graduate Student, Department of Agronomy, K-State, Manhattan

K.L. Roozeboom, Associate Professor, Cropping Systems, Department of Agronomy, K-State, Manhattan

D.A. Ruiz Diaz, Associate Professor, Soil Fertility and Nutrient Management, Department of Agronomy, K-State, Manhattan

A.J. Schlegel, Agronomist, Southwest Research-Extension Center, Tribune

D.D. Serba, Millet Breeder, Agricultural Research Center, Hays

C. Thompson, Professor, Weed Management, Department of Agronomy, K-State, Manhattan

J.R. Williams, Professor, Natural Resource and Environmental Economics, Department of Agricultural Economics, Kansas State University

T.E. Zee, Undergraduate Student, Department of Agronomy, K-State, Manhattan

Precipitation Data

Month	Manhattan	SWREC, Tribune	SEARC, Parsons	ECK Experiment Field, Ottawa
	---------- in. ----------			
2015				
August	3.62	2.48	4.76	2.69
September	3.83	0.32	2.99	2.72
October	0.74	2.48	1.57	0.37
November	5.28	2.24	8.20	4.66
December	2.73	0.08	6.43	4.22
Total 2015	43.39	21.72	53.78	43.02
Departure from normal	+8.59	+4.38	+11.69	+3.81
2016				
January	0.74	Trace	1.01	0.69
February	0.50	0.92	0.45	0.64
March	0.32	0.20	2.72	1.57
April	8.37	5.16	4.84	3.77
May	6.09	1.46	5.28	7.70
June	1.21	1.78	7.02	2.03
July	7.68	4.07	6.16	6.22
August	6.10	3.51	4.32	8.67
September	6.03	2.11	4.47	4.34

Month	NCK Experiment Field, Belleville	KRV Experiment Field	SCK Experiment Field, Hutchinson	ARC-Hays
	------------------ in. ------------------			
2015				
August	3.89	2.72	2.46	0.44
September	0.83	5.52	2.83	0.48
October	1.30	0.78	1.07	1.42
November	1.97	3.54	3.88	1.83
December	2.35	2.27	2.44	1.77
Total 2015	31.68	39.80	29.49	19.64
Departure from normal	+0.79	+4.60	-0.83	-3.85
2016				
January	0.87	0.74	0.68	0.68
February	0.55	0.53	0.50	0.70
March	0.58	1.03	0.96	0.56
April	4.93	6.37	4.44	7.46
May	9.44	5.61	7.46	3.04
June	1.12	2.73	4.62	3.44
July	4.65	5.30	5.57	2.58
August	7.25	4.96	8.43	3.78
September	2.24	10.30	5.84	2.08

SWREC = Southwest Research-Extension Center; SEARC = Southeast Agricultural Research Center; ECK = East Central Kansas; HC = Harvey County; NCK = North Central Kansas; KRV = Kansas River Valley; SCK = South Central Kansas; and ARC = Agricultural Research Center.

Nitrogen and Phosphorus Application Effects on Pearl Millet Forage Yield and Nutritive Value

D.D. Serba and A.K. Obour

Summary

There is limited information on the nitrogen (N) and phosphorus (P) fertilizer requirement of pearl millet forage in dryland systems. Determination of optimum N and P rates for pearl millet forage production in dryland environments of the Great Plains will have economic advantage for farmers and ranchers growing pearl millet for forage. A field experiment was conducted in 2016 at the Agricultural Research Center-Hays, KS, to investigate N and P fertilizer application effects on forage yield and nutritive value of pearl millet. Factorial combinations of five levels of N (0, 30, 60, 90, and 120 lb/a) and three levels of P (0, 15, and 30 lb/a) were evaluated in randomized complete block design with four replications. A forage-hybrid cultivar, TifLeaf 3, released by U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) unit at the University of Georgia (Tifton, GA) was used for the experiment. The seed was drilled in six rows at 15 lb/a in individual plot sizes of 5 ft wide × 30 ft long. The results indicate that N fertilizer application increased forage yield, crude protein content, and *in vitro* dry matter digestibility. Although increase in N rate increased the protein content and digestibility of the forage, this single season on-station experiment indicates that N rate of 30 lb/a is adequate for pearl millet forage production under rain-fed conditions. Application of P fertilizer had no effect on forage yield. However, applying 15 lb P/a did increase *in vitro* dry matter digestibility compared to the check treatment.

Introduction

Pearl millet is a drought and heat tolerant warm season cereal crop used by livestock producers as a summer forage in the United States. With the increased threatening of sorghum forage production from sugarcane aphid (*Melanaphis sacchari*) in the Great Plains, non-host pearl millet would be an alternative forage species with great drought tolerance and insect resistance characteristics. Several hybrid and open pollinated forage cultivars have been released by USDA-ARS at Tifton, GA and are available commercially to growers. A renewed effort is also being made at the Kansas State University Agricultural Research Center-Hays to develop improved cultivars of pearl millet for the drought prone areas of western Kansas.

There is limited information available on N and P fertility requirement of pearl millet forage, particularly in dryland environments in the Great Plains. Most of the farmers growing pearl millet forage in the region are applying fertilizer rates recommended for forage sorghum or practice blind application. This may affect the productivity, the economics of forage production, and/or the quality of the forage produced. This study was, therefore, conducted to determine N and P fertilizer rates and their interaction effects on pearl millet forage yield and nutritive value. The goal is to determine the economic optimum N and P rates for pearl millet forage production in dryland systems.

Procedures

The experiment was conducted at the Kansas State University Agricultural Research Center-Hays in the summer of 2016 under rain-fed conditions. Treatments were factorial combinations of five levels of N (0, 30, 60, 90, and 120 lb/a) and three levels of P (0, 15, and 30 lb/a) arranged in randomized complete blocks with four replications. The experiment was planted on June 13, 2016 and harvested at heading stage on August 26, 2016. Individual plot sizes were 5 ft wide × 30 ft long (6 rows at 10 inches spacing). The experiment was conducted using pearl millet forage hybrid, TifLeaf 3, at a seeding rate of 15 lb/a. An area of 3 ft wide (4 middle rows) was harvested from each plot at heading using a Carter small plot forage harvester (Carter Manufacturing Company, Inc. Grand Haven, MI). Fresh weights were recorded immediately and subsamples were collected, weighed and dried in forced air oven at 115°F for 5 days. The weight of the subsamples was determined and the dry matter yield was calculated based on the moisture content of the subsamples. The dried samples were ground to 1 mm particle size (mesh size 20) using Wiley Mill, Standard Model No. 3 (Thomas Wiley, Inc., Swedesboro, NJ). The forage nutritive values were determined using Near Infra-red Spectrometry (NIRS) at Ward Laboratories, Inc. (Kearney, NE). The data obtained were analyzed using Generalized Linear Model on SAS 9.4 (SAS Institute Inc., Cary, NC).

Results

Results showed that N fertilizer application had a significant effect on biomass yield, crude protein, and *in vitro* dry matter digestibility of the forage (Table 1). However, application of P fertilizer did not affect biomass yield and crude protein but had an effect on *in vitro* dry matter digestibility. The interaction effect of N and P was also significant on biomass yield and crude protein content.

Biomass Yield

Greater biomass yields were obtained at 90 and 30 lb/a N rates (Figure 1). Application of N fertilizer at 120 lb/a did not improve biomass yield. Although an increase in N rate increased the protein content and digestibility of the forage, this single season on-station experiment indicates that an N rate of 30 lb/a is adequate for pearl millet forage production under rain-fed conditions.

The application of P fertilizer had no effect on biomass yield as the control (P0) plots yielded 6590 lb/a compared to the 6384 lb/a from 15 lb/a and 6540 lb/a from 30 lb/a P rates plots. Therefore, the application of P fertilizer in pearl millet forage has no effect on forage yield.

Protein Content and Digestibility

Forage crude protein concentration increased linearly with N fertilizer application (Figure 2). Crude protein concentration ranged from 13.15% with the control to 16.78% when N was applied at 120 lb/a. The unfertilized plots (N0) had significantly lower crude protein content than the fertilized plots. Among the fertilized plots, increasing N fertilizer rates significantly increased the crude protein content of the forage. As summarized in Figure 2, 120 lb/a N significantly increased the crude protein content compared with the 30 and 60 lb/a N.

The N × P rate interaction effect was significant on crude protein content. Phosphorus fertilizer application at 30 lb/a significantly increased crude protein concentration at the 30 to 90 lb/a N rates (Figure 3). The P0 showed high effect at N at 120 lb/a probably due to the compensation effect of the high N fertilizer.

However, *in vitro* dry matter digestibility increased with an increase in N fertilizer rates (Figure 4). Mean forage digestibility was 77.1% at N0 while it was 78.3% at 120 lb/a N. This increase in digestibility with an increase in N rate is closely related to the increase in protein concentration with N fertilizer application voiding the effect of phosphorus fertilizer.

Simple scatterplot matrix analysis was also performed to depict the correlation of the three important traits: biomass yield, protein content, and forage digestibility (Figure 5). The result indicated that protein content and *in vitro* dry matter digestibility were positively and linearly correlated. However, there was not a defined relationship between biomass yield and crude protein concentration as well as biomass yield and *in vitro* dry matter digestibility. The independence of forage yield and forage nutritive values imply the difficulty of simultaneous improvement of these traits in pearl millet.

Table 1. Analysis of variance (ANOVA) for biomass yield, protein content, and *in vitro* dry matter digestibility of pearl millet forage in 2016 at Hays, KS

Source	df	Dry biomass yield	Crude protein content	*In vitro* digestibility	Phosphorus content
Replication	3	NS	NS	NS	NS
Nitrogen (N)	4	**	***	*	NS
Phosphorus (P)	2	NS	NS	*	NS
N × P	8	***	*	NS	NS
Error	42	NS	NS	NS	NS

Df = degree of freedom; *, **, *** = Significant at 0.05. 0.01, and 0.001 probability levels;
NS = Not significant at 0.05 probability level.

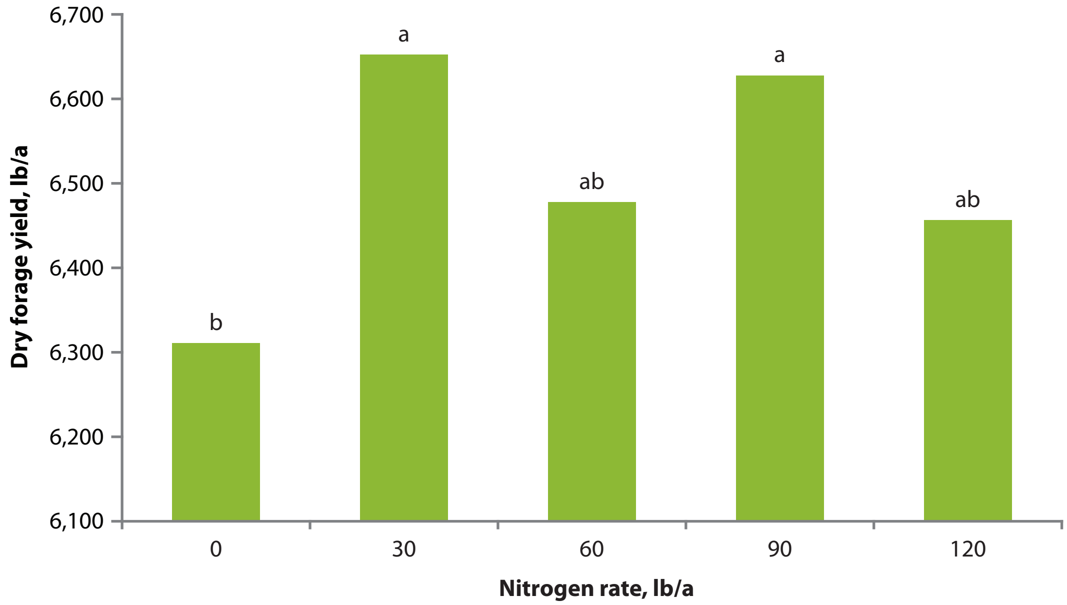

Figure 1. Dry pearl millet forage yield as affected by nitrogen fertilizer rates.

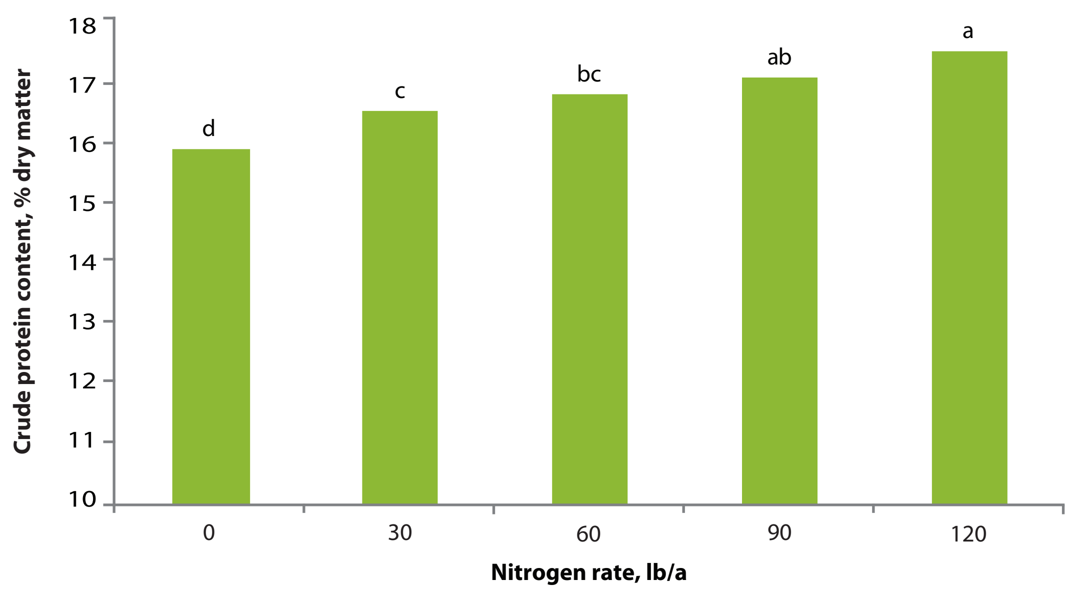

Figure 2. Mean crude protein content as affected by nitrogen fertilizer rates (bars with the same letter are not significantly different from each other).

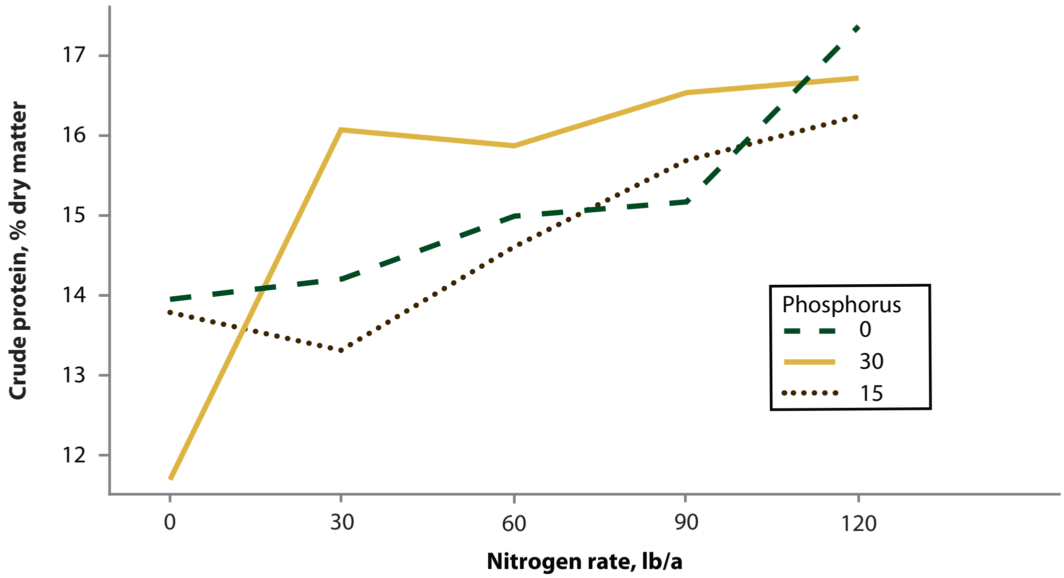

Figure 3. The nitrogen and phosphorus interaction effect on the crude protein content of pearl millet forage.

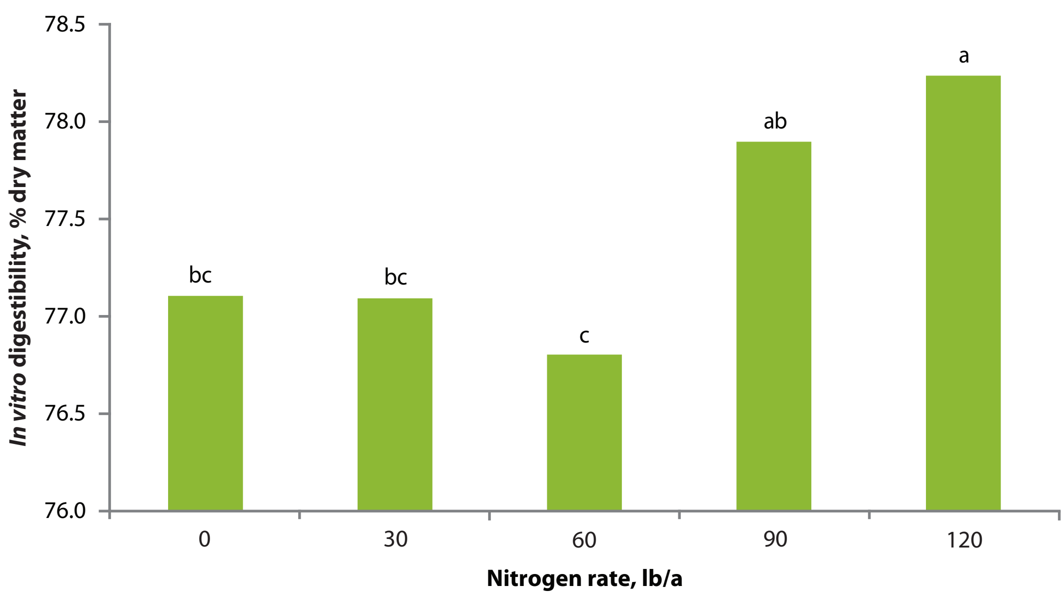

Figure 4. Effect of nitrogen fertilizer levels on *in vitro* dry matter digestibility of the forage.

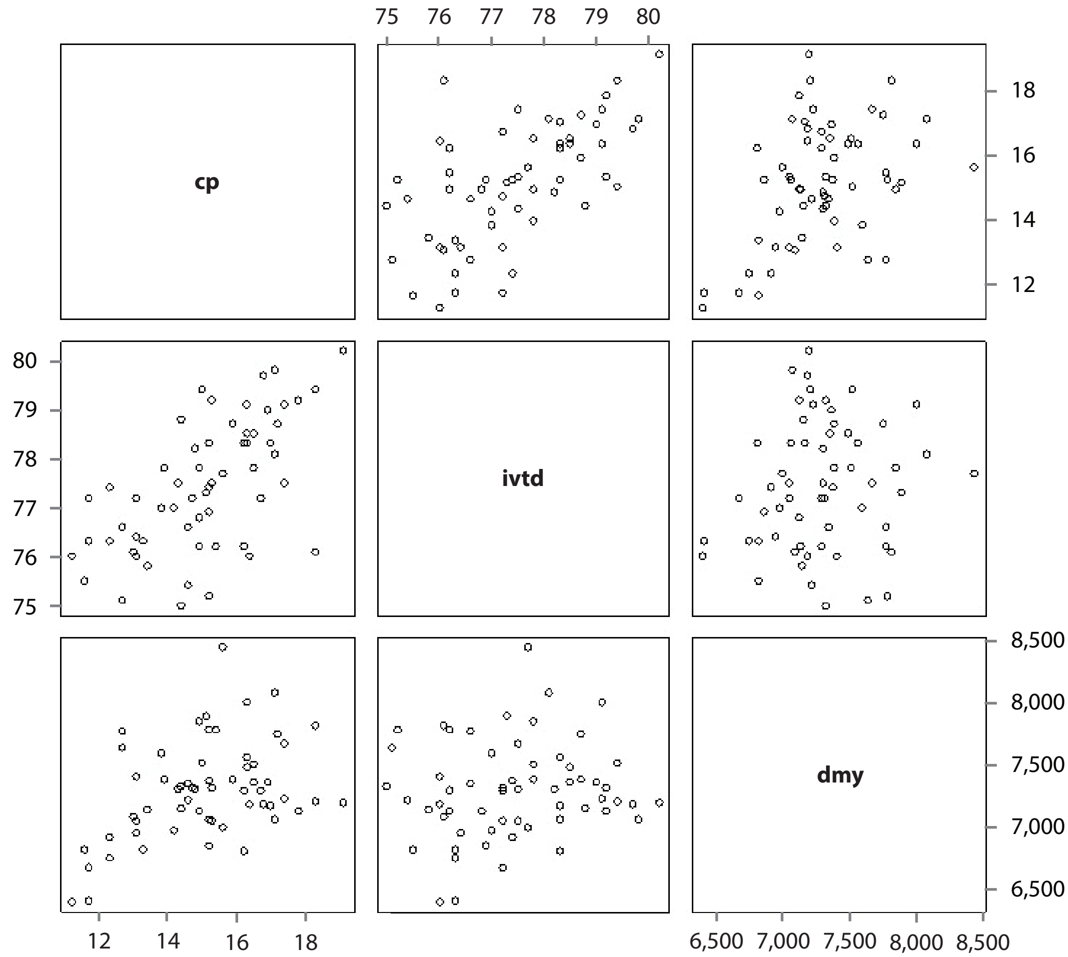

Figure 5. Correlation matrix of crude protein content (cp), *in vitro* dry matter digestibility (ivtd), and dry biomass yield (dmy) of the forage.

Agricultural Bio-Stimulant Application to Enhance Phosphorus Availability in Grain Sorghum

A.K. Obour

Summary
This study was conducted to determine the effectiveness of AgZyme and SuperHume (both products of Ag Concepts Corp) application on phosphorus (P) uptake and utilization efficiency in grain sorghum. Treatments were a control, 30 lb P_2O_5/a, 20 oz/a AgZyme, 20 oz/a AgZyme + 30 lb P_2O_5/a, 20 oz/a AgZyme + 30 lb P_2O_5/a + 6 qt/a SuperHume, which were arranged in a randomized complete block design with four replications. Preliminary results in 2016 showed grain sorghum aboveground biomass, grain moisture content, and test weight were not affected by the application of either P alone or with a bio-stimulant. Applying AgZyme alone resulted in a 9 bu/a yield increase above the control. The application of AgZyme with P did not improve grain yield compared to control. This observation was possibly due to greater initial soil P content (45 lb P/a) at the study site. However, tissue P concentration was greatest when AgZyme was applied with 30 lb P_2O_5/a. Applying AgZyme, SuperHume, and 30 lb P_2O_5/a together reduced both sorghum grain yield and tissue P concentration.

Introduction
Phosphorus fertilization is essential for crop production and is one of the most common nutrient inputs by Kansas growers. This nutrient is involved in many essential metabolic roles within the plant; deficiencies result in reduced yields, poor growth, and lost income. Soils vary in their ability to supply P to plants due to its low solubility and fixation by calcium, iron, and aluminum. Due to P fixation many growers over-apply P fertilizers, operating outside the curve of economic return. Thus improving phosphorus use efficiency is important for crop production in the region.

Agricultural plant bio-stimulants are a wide and broad class of compounds designed to promote plant growth and development, nutrient cycling, microbial activity, and soil health. Application of agricultural bio-stimulants increased the efficiency of organic fertilizers and significantly increased cotton lint yield (Khaliq et al., 2006). Calvo et al. (2013) found that applications of bio-stimulants reduced nitrous oxide emissions by 80% in soils fertilized with UAN 32. Other studies have demonstrated the effectiveness of additions of bio-stimulants on plant nutrient uptake (Shaharoona et al., 2008). This suggests that bio-stimulants have some effect on soil nutrient dynamics. However, research has shown these products to have varied results. The objective of this study was to determine the effectiveness of AgZyme and SuperHume application on P uptake and utilization efficiency in grain sorghum.

Procedures
Field experiments were conducted in the summer of 2016 at the Kansas State University Agricultural Research Center—Hays, KS to measure the effect of AgZyme applica-

tion on grain yield and P utilization in grain sorghum. The soil at the experiment site was a Harney silt loam (fine, montmorillonite, mesic Typic Agriustoll). Prior to this study, the experimental site was planted to winter camelina in the fall of 2013. The camelina crop had 40 lb N/a and 20 lb P_2O_5/a applied as broadcast urea and monoammonium phosphate, respectively. The field has been fallowed since the camelina harvest in June 2014. Soil fertility analysis conducted from soil samples collected at 0 to 6 in. depth in the summer of 2016 was not different among the pre-assigned treatment plots. Averaged across the four experimental blocks, initial soil chemical analysis was as follows: 2.1% soil organic matter, pH 6.4, 45 lb P/a, 1080 lb potassium (K)/a , and 22 lb nitrate (N)/a.

The study had five treatments (Table 1; control, 30 lb P_2O_5/a, 20 oz/a AgZyme, 20 oz/a AgZyme + 30 lb P_2O_5/a, 20 oz/a AgZyme + 30 lb P_2O_5/a + 6 qt/a SuperHume) which were arranged in a randomized complete block design with four replications. The trial was planted on June 8, 2016 at a seeding rate of 26,000 seeds/a with a John Deere four row planter. Plot sizes were 10 feet wide (in 30-inch row spacing) by 30 feet long. Nitrogen fertilizer was applied to the plots at the time of planting as a broadcast urea at 100 lb N/a. Except the control and AgZyme only treatments, the remaining treatments received 30 lb P_2O_5/a as broadcast application of monoammonium phosphate (11-52-0). The AgZyme and SuperHume products were applied in-furrow with the seed at planting at 20 oz/a and 6 qt/a, respectively and diluted with 10 gal/a water to allow for uniform application.

At maturity, entire plants in a 2.5 × 5 ft area from the outer row in each plot were cut at 2 in. above the soil surface. Fresh weights of the harvested samples were recorded, sub-samples were collected, chopped through a wood chipper and weighed (samples included both sorghum seeds and stalks). The samples were oven dried at 140°F for at least 48 hours in a forced-air oven for dry matter determination. Oven-dried samples were ground to pass through a 1-mm mesh screen in a Wiley Mill, Standard Model No. 3 (Thomas Wiley, Inc., Swedesboro, NJ). The ground samples were then analyzed for nutrient concentrations at Ward Laboratories, Inc., Kearney, NE.

Two middle rows from each plot were harvested to determine grain yield, moisture content, and test weights. Statistical analysis with the Proc GLM procedure in SAS 9.4 (SAS Institute Inc., Cary, NC) was used to examine sorghum biomass, grain yield and nutrient concentration as a function of bio-stimulant and P application using analysis of variance (ANOVA).

Results

Grain sorghum aboveground biomass, grain moisture content, and test weight were not affected by the application of either P alone or with a bio-stimulant. However, there was a significant ($P = 0.05$) treatment effect on sorghum grain yield. Applying AgZyme alone resulted in a 9 bu/a yield increase above the control treatment (Table 2). The application of AgZyme with P did not improve grain yield compared to control. This observation was possibly due to greater initial soil P levels (45 lb P/a) at the experimental site. Notwithstanding, tissue P concentration was greatest when AgZyme was applied with 30 lb P_2O_5/a (Table 3). Applying AgZyme, SuperHume, and 30 lb P_2O_5/a together reduced both sorghum grain yield and tissue P concentration (Table 3).

Overall, these preliminary findings suggest that AgZyme has an effect on soil phosphorus cycling, but also demonstrates the possible antagonistic effects between AgZyme, SuperHume, and phosphate fertilizer in grain sorghum production. Further studies are needed to confirm these observations.

Acknowledgment

This research was developed in collaboration with Jeremy Cusimano and supported by Ag Concepts Corp., Boise, ID.

References

Calvo, P., D. B. Wattes, R.N. Ames, J.W. Kloepper, and H.A. Torbert. 2013. Microbial-based inoculants impacts nitrous oxide emissions from an inoculated soil medium containing urea fertilizers. J. Environ. Qual. 42:704-712.

Khaliq, A., M.K. Abbasu, and T. Hussain. 2006. Effects of integrated use of organic and inorganic nutrient sources with effective microorganisms on seed cotton yield in Pakistan. Bioresour. Technol. 97:967-972.

Shaharoona, B., M. Naveed, M. Arshad, and Z. Zahir. 2008. Fertilizer-dependent efficiency of Pseudomonads for improving growth, yield, and nutrient use efficiency of wheat (*Triticum aestivum* L.). Appl. Microbiol. Biotechnol. 79:147-155.

Table 1. AgZyme, SuperHume, and P treatments at Kansas State University Agricultural Research Center—Hays, KS, in 2016

Treatment		AgZyme (AZ)	SuperHume (HA)	Phosphorus (P)
		oz/a	qt/a	lb/a
1	Control	0	0	0
2	P only	0	0	30
3	AZ	20	0	0
4	AZ + P	20	0	30
5	AZ + HA + P	20	6	30

Table 2. Grain sorghum total aboveground biomass, grain yield, moisture content, and test weight as affected by bio-stimulant and phosphorus (P) application in 2016 at Hays, KS

Treatment	Moisture	Test weight	Biomass	Yield
	%	lb/bu	lb/a	bu/a
Control	12	57.2	8626	81.3
P only	12	57.1	8871	76.0
AZ	11.9	56.2	8085	90.3
AZ + P	11.9	56.3	8512	80.8
AZ + HA + P	11.9	57.2	8262	69.5
LSD (0.05)	NS	NS	NS	13.0
P-value	0.73	0.51	0.99	0.05

AZ = AgZyme.
HA = SuperHume.
LSD = least significant difference.

Table 3. The concentration of nitrogen, phosphorus (P), potassium, and sulfur in grain sorghum aboveground biomass as affected by bio-stimulant and P application in 2016 at Hays, KS

Treatment	Nitrogen	Phosphorus	Potassium	Sulfur
	----------------------- % -----------------------			
Control	1.7	0.23	1.68	0.13
P only	1.6	0.21	2.04	0.12
AZ	1.7	0.24	1.54	0.12
AZ + P	1.8	0.25	1.48	0.12
AZ + HA + P	1.7	0.20	1.62	0.12
LSD (0.05)	NS	0.03	NS	NS
P-value	0.06	0.03	0.10	0.83

AZ = AgZyme.
HA = SuperHume.
LSD = least significant difference.

Long-Term Tillage and Nitrogen Fertilization Effects on Soil Surface Chemistry

A.K. Obour and J. Holman

Summary
Long-term crop management practices can affect nutrient cycling and availability to crops. This study examined the long-term effects of nitrogen (N) fertilizer application (N rates of 0, 20, 40, and 60 lb N/a) and tillage intensity (conventional tillage (CT), reduced tillage (RT), and no-tillage (NT)) on soil phosphorus (P), micronutrients, and soil acidity in a dryland winter wheat *(Triticum aestivum* L.)–sorghum *(Sorghum bicolor* L.*)*–fallow cropping system. Results showed soil organic matter (SOM), iron (Fe), and zinc (Zn) concentrations were greater under NT compared to CT or RT. Similarly, NT (32 ppm) increased P accumulation in the upper 3 in. soil depth compared to CT (21 ppm) or RT (26 ppm). Soil pH at the surface (0 to 3 in.) declined markedly with increasing N fertilizer application rate, ranging from 6.1 with the control to 5.5 when 60 lb N/a was applied. Averaged across N rates, soil pH was lower with NT (5.7) compared to CT (6.3) and RT (6.2) treatments. Iron and manganese (Mn) concentrations increased with increasing N application rates, probably due to the decrease in pH associated with N application.

Introduction
Growers in dryland environments of the Great Plains region are increasingly adopting conservation tillage practices such as no-tillage (NT). No-tillage has several benefits, including reduced soil erosion and runoff, improved soil physical properties, enhanced soil organic matter (SOM) content, and improved soil water retention. Despite these benefits, continuous NT practice results in accumulation of crop residue at the surface and leads to SOM build-up and stratification of nutrients compared to CT or RT systems. In the semi-arid environments, low precipitation and drought conditions may enhance nutrient accumulation in the upper soil layer, reduce nutrient movement to the lower soil layers, and could decrease nutrient availability for plant uptake.

Long-term studies are valuable and critical to improve our knowledge and understanding on the influence of different management practices on soil nutrient dynamics. Few studies have investigated the effects of long-term (> 20-yr) tillage and N fertilizer management on soil chemistry in semi-arid cropping systems. The objective of this study was to examine soil chemical properties after 50 years of tillage and nitrogen applications to a wheat-grain sorghum-fallow (W-S-F) cropping system in western Kansas.

Procedures
This long-term study was conducted at the Kansas State University (K-State) Agricultural Research Center-Hays, Kansas on a Harney silt loam soil (fine, montmorillonite, mesic Typic Agriustoll). The study was established in 1965 to investigate the effects of

tillage intensity on winter wheat and grain sorghum yields in a W-S-F rotation scheme. The three tillage treatments were conventional tillage (CT), reduced tillage (RT), and no-tillage (NT) arranged in randomized complete blocks with four replications. Each phase of the W-S-F crop rotation was present in each year of the study.

The experiment was modified in 1975 to add N fertilizer application rates in a split-plot arrangement. The original tillage treatments (CT, RT, and NT) were the main plots and sub-plot factor was four N application rates (0, 20, 4, and 60 lb N/a). Individual plot sizes were 67 × 100 ft for the tillage treatments, and 11 × 100 ft for the N application rate treatments. There was an 11 feet wide border between tillage treatments. Soil fertility analysis conducted at the beginning of the study in 1965 was not different among the preassigned crop rotation and tillage treatment plots. Averaged across the four experimental blocks, soil pH in the upper 0 to 3 in. of the soil was 6.3, extractable P was 62.5 ppm , and SOM was 2.1%. Similarly, soil pH measured at 3 to 6 in. depth was 6.6, while P and SOM concentrations were 40.1 ppm and 1.9%, respectively. Ammonium nitrate was the N fertilizer source from 1975 to 2002, thereafter; urea was the N fertilizer source applied to the plots. Nitrogen fertilizer was broadcasted in the fall prior to wheat planting while N application to grain sorghum plots were done in early spring before sorghum planting in June. Fertilizer was incorporated in the CT and RT tilled plots while fertilizer addition remained on the soil surface under NT. Because soil test levels for available P were medium to high over the study period and exchangeable potassium (K) is inherently high in this soil, N was the only fertilizer applied over the 50-year study period.

Seedbed preparation in the CT plots during fallow was done by disking and plowing with residue-incorporating implements (disk, and mulch treader) to about 6 in. depth. In the RT treatments, tillage was accomplished with residue-saving implements such as V-blade and sweeps to about 6 in. depth. Approximately 3 to 4 tillage operations were performed in the fallow phase prior to winter wheat planting in CT while 2 to 3 tillage operations occurred in the RT plots. One tillage operation was usually conducted in both CT and RT plots prior to sorghum planting. Only herbicides were used for weed control in the NT plots. Weed control during the growing season and fallow periods was accomplished with appropriate herbicides as needed across all tillage practices.

During the 50 years of the study, winter wheat was usually seeded in late September through October 15, and sorghum seeding was done in mid-May through the third week in June. Grain yields were determined by harvesting an area of 5 × 100 ft from each plot with a plot combine. Grain sorghum was usually harvested in October while winter wheat was harvested in July of each year of the study.

Soil samples were collected at the beginning of the study in the fall of 1965. Three soil cores (1 in. diameter) were collected randomly from each plot at 0 to 3 in. and 3 to 6 in. soil depths. These initial samples were air-dried, crushed, and sieved through a 2-mm sieve and then analyzed for soil pH, SOM, and P concentration. Soil samples were taken again in May 2015 in the fallow phase to determine changes in soil chemical properties after fifty years of tillage and N fertilization. Three soil cores (1 in. diameter) were randomly collected in each plot from 0 to 3 in. and 3 to 6 in. soil depth. The samples were composited per depth for each plot, air-dried, crushed, and sieved to pass through a 2-mm stainless steel screen. The sieved soil samples were then analyzed for pH and soil extractable nutrients at the K-State Research and Extension Soil Testing Laboratory using standard soil testing procedures.

Results

Soil pH and Organic Matter

Results showed a decrease in soil pH in all tillage treatments in the upper 6 in. of soil compared to the initial soil pH levels. Averaged across N rates and soil depth, soil pH was 5.7 with NT, which was significantly lower than pH of 6.2 with CT or 6.3 under RT (Table 2). Compared to the initial soil pH, this represents 0.8, 0.3, and 0.2 units decrease in soil pH with NT, CT, and RT, respectively. In NT systems, mineralization of SOM and nitrification of applied N fertilizer occurs on the soil surface that can result in a significant decrease in pH at the soil surface. However, tillage operations employed in CT or RT incorporate and mix fertilizer with a larger soil volume. In addition, tillage results in mixing and redistribution of soil from the subsoil that has relatively greater pH and concentrations of Ca and Mg. This process provides some buffering against pH changes under CT or RT.

Soil pH was also affected by the interaction of sampling depth × N fertilizer application rate. Application of N at 60 lb N/a significantly decreased soil pH in the top 3 in. compared to the other N rates. However, beyond this depth, pH was not different among the N application rates (Table 3). The decrease in pH may be due to nitrification of NH_4^+ to NO_3^- when ammonium-containing fertilizers (ammonium nitrate and urea in the present study) are applied. In the present study, soil pH with 20 and 40 lb N/a was similar to the control after 50-yr of the study. However, applying N at a higher rate of 60 lb/a decreased soil pH markedly relative to the control, suggesting soil acidification from N fertilization depends on the amount of N applied.

Nitrogen application had no effect ($P > 0.05$) on soil organic matter concentration. However, SOM was affected by tillage system. Averaged across N application rates and soil depth, SOM concentration with NT and RT were not different, but greater than that measured under CT (Table 2). Regardless of tillage treatment, SOM concentration increased in the upper 6 in. of the soil after 50-yr of the study. This observation may be due to increase in cropping intensity that adds more residues to the soil. The increase in SOM concentration between 1965 and 2015 ranged from 0.42% under CT, 1.2% with RT, and 1.2% with NT (Table 2). No difference in Δ SOM was observed between NT and RT. These changes correspond to 21% increase in SOM associated with CT and 58% increase in SOM concentration associated with NT and RT. The elimination or reduction in tillage operations reduced soil disturbance and SOM decomposition resulting in greater crop residue accumulation. This leads to the significant SOM accretion under NT and RT in the present study.

Extractable Macronutrients

The extractable P concentration measured in 2015 was affected by tillage × sampling depth interaction. Phosphorus concentration in the upper 3 in. of soil under NT was 32.0 ppm, greater than P concentrations under CT (20.6 ppm) or RT (26.1 ppm) measured at this depth (Figure 1). Below 3 in., P concentration was similar among the tillage treatments. This observation was expected because P is relatively immobile within the soil and tends to accumulate on the soil surface in NT systems where there are no tillage operations to incorporate crop residue and redistribute P to deeper soil layers. The differences in soil P associated with different depths were due to tillage operation and soil mixing up to 6 in. depth with CT and RT treatments. After 50 years of tillage and N fertilizer application, P concentrations measured in the upper 6 in. of the soil declined markedly regardless of tillage intensity. Averaged across tillage and N application rates, soil P concentration in the upper 3 in. in 1965 was 62.5 ppm, significantly greater than P concentration of 26.3 ppm that was measured at this same depth in 2015 (Figure 2). This represents a 58% decline in soil P concentration relative to the initial P concentration. Similarly, soil P concentration measured at 3 to 6 in. soil depth in 2015 was 83% less than that measured at the same depth in 1965 (Figure 2). This decrease in P concentration was expected because no P fertilizer were applied during the 50 years of the study. Over all, the significant P reduction from 1965 to 2015 was due to crop P uptake for the last 50 years.

Average P concentrations measured in 2015 in the upper 6 in. were 13.7 ppm for CT, 17.3 ppm for RT, and 18.6 ppm with NT. Current KSU fertilizer guidelines recommend P fertilizer application when Mehlich-3 soil test P concentration in the upper 6 in. soil depth is < 20 ppm (Leikam et al., 2003). Based on this P fertilizer guideline, P fertilizer required for a 40 bu/a winter wheat yield goal will be 25 lb P_2O_5/a for wheat produced under CT, and 15 P_2O_5/a for wheat that will be planted under RT or NT.

Extractable K, Ca, and Mg concentrations were not affected by either tillage or N application rate. The lack of tillage effects on exchangeable cations observed in the present study is probably due to inherently greater levels of basic cations in soils at the experimental site. In water-limited environments as in the case of western Kansas, limited leaching of basic cations occurs in the soil. It is therefore common to measure greater concentrations of Ca, K, and Mg in the upper surface of soils in these environments.

Micronutrients

Soil Fe and Zn concentrations differed among tillage treatments but not Mn. Averaged across N rates and sampling depth, Fe concentration ranged from 27 ppm with either CT or RT, to 40 ppm under NT. Similarly, Zn concentration was greater with NT compared to the other tillage treatments. It is likely that the observed differences in Fe and Zn concentrations among the tillage treatments were due to the lower soil pH observed under NT that increased Fe and Zn availability. The interaction of sampling depth × N application significantly affected soil Fe and Mn concentration but not Zn. Both Fe and Mn concentrations in the upper soil surface (0 to 3 in.) increased with increasing N fertilizer application rate (Table 3). Averaged across tillage treatments, Fe concentration with 60 lb N/a was 1.8-fold greater than that of the control N rate at the soil surface. Similarly, Mn concentration ranged from 24.2 ppm with the control to 40.4 ppm when 60 lb N/a was applied (Table 3). Conversely, Fe and Mn concentrations below 3 in. soil depth were not different among the N application rates. The increase in Fe and Mn concentrations with increasing N application rates is probably due to the decrease in pH associated with N application. Regression analysis showed an inverse relationship between pH and soil micronutrient concentrations (Figure 3). The correlation coefficients of the relationship between soil pH and Fe, and Mn concentrations were 0.59 and 0.71, respectively. Availability of these micronutrient cations (Fe and Mn) increased when the soil pH was slightly acidic to neutral (Figures 3a and b).

Micronutrient availability is reduced at higher soil pH because of the change in ionic form of the cations into metal oxides or hydroxides that are relatively insoluble.

Table 1. Soil pH, soil organic matter, iron, and zinc concentrations measured in 2015 as affected by tillage and soil sampling depth

Tillage system	pH	Δ pH	Soil organic matter	Δ soil organic matter	Iron	Zinc
			------------- %	-------------	----------- ppm	-----------
Conventional tillage	6.2 a†	-0.25 b	2.4 b	4.2 b	26.9 b	0.4 b
Reduced tillage	6.3 a	-0.23 b	3.1 a	1.2 a	26.6 b	0.5 ab
No-tillage	5.7 b	-0.75 a	3.1 a	1.1 a	39.9 a	0.6 a
SE‡	0.2	0.19	0.1	0.1	2.1	0.1

†Means followed by same letter (s) within a tillage system are not significantly different using the least squares means (LSMEANS) and adjusted Tukey multiple comparison procedure ($P > 0.05$). Data are averaged across four nitrogen rates, two sampling depths and four replicates ($n = 32$).
‡SE = Standard error of the mean.
Δ pH = difference between pH measured in 2015 and 1965.
Δ SOM = difference between SOM measured in 2015 and 1965.

Table 2. Soil pH, iron, and manganese concentrations measured in 2015 as affected by tillage and soil sampling depth

Nitrogen rates (lb/a)	pH	Iron	Manganese
		------------------------ ppm	------------------------
0 to 3 in.			
0	6.1 a†	23.8 c	24.2 c
20	6.0 a	28.8 c	29.9 b
40	6.0 a	37.0 b	31.6 b
60	5.5 b	43.7 a	40.4 a
SE‡	0.1	3.3	2.7
3 to 6 in.			
0	6.4 a	22.2 a	19.6 a
20	6.2 a	23.5 a	21.3 a
40	6.3 a	26.0 a	22.2 a
60	6.2 a	25.3 a	21.0 a
SE	0.1	3.3	2.7

†Means followed by same letter(s) within nitrogen rate are not significantly different using the least squares means (LSMEANS) and adjusted Tukey multiple comparison procedure ($P > 0.05$). Data are averaged across three tillage treatments and four replicates ($n = 12$).
‡SE = Standard error of the mean.

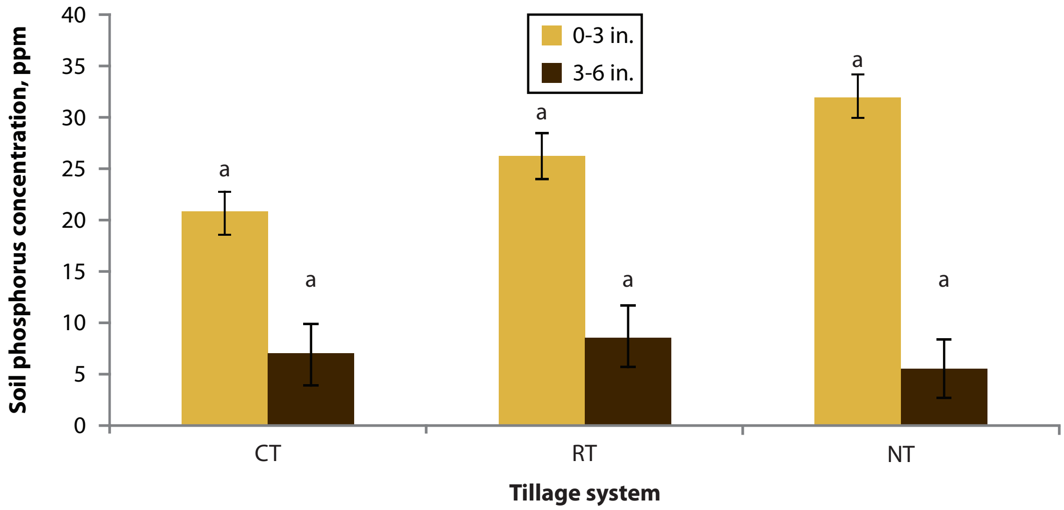

Figure 1. Soil phosphorus concentration measured in 2015 as affected by tillage practice. Error bars represent one standard error of the mean. Means followed by the same letter(s) within a soil depth are not significantly different using the least squares means (LSMEANS) and adjusted Tukey multiple comparison procedure (*P* > 0.05).
CT = conventional tillage.
RT = reduced tillage.
NT = no-tillage.

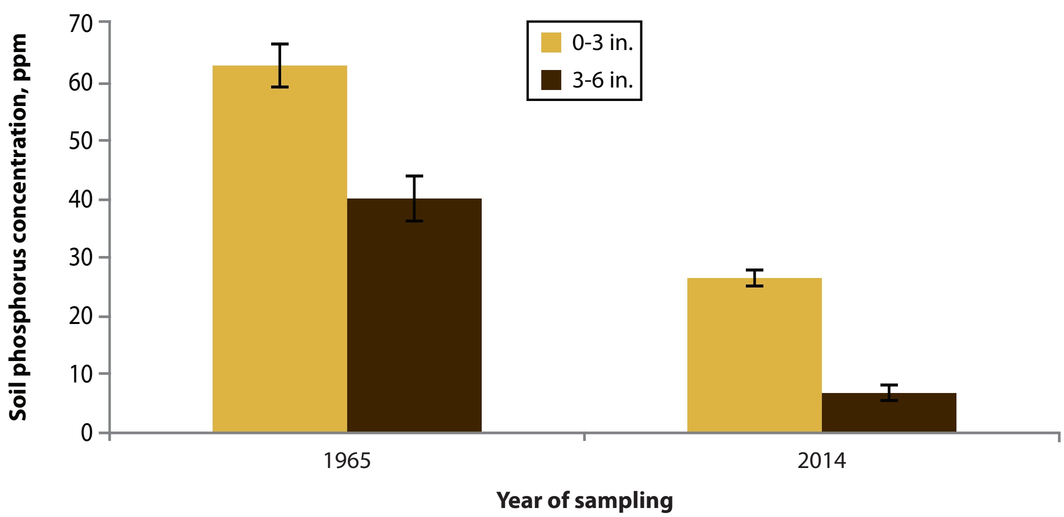

Figure 2. Changes in soil phosphorus concentration during the 50-year study period. Error bars represent one standard error of the mean. Means followed by the same letter(s) within a soil depth are not significantly different using the least squares means (LSMEANS) and adjusted Tukey multiple comparison procedure (*P* > 0.05).

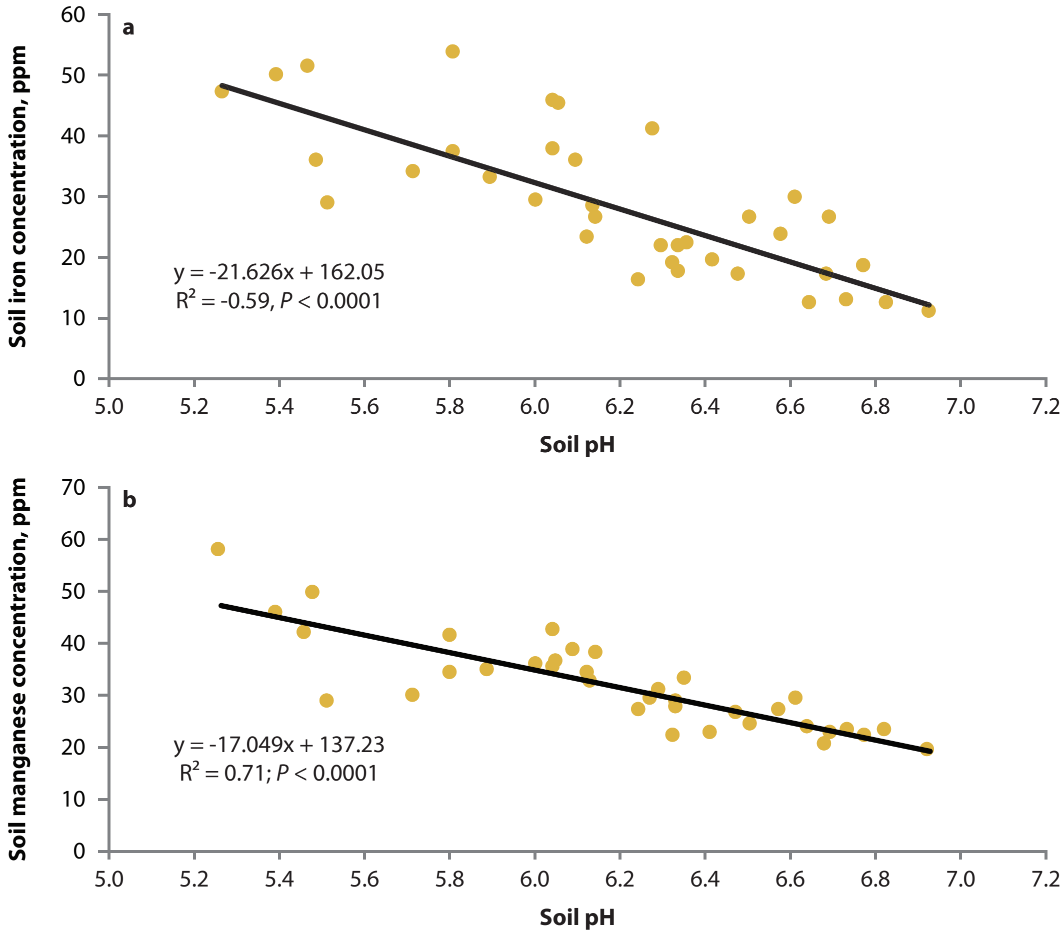

Figure 3. Relationship of soil pH with iron (a) and manganese (b) availability in the upper 3 in. of the soil measured in 2015.

Corn Grain Yield Trends from 2012 to 2016: A 26-Year Long-Term Experiment

J. Rivera-Zayas and C.W. Rice

Summary
Long-term research trials provide an understanding of long-term effects on crop production. This long-term research studied the effect of conventional tillage (CT) and no-tillage (NT) systems. Factors of this 22-year study of corn (*Zea mays L.*) production also included the application of nitrogen (N) in the forms of ammonium nitrate and manure at rates of 150 lb/N/a. Corn grain yield trends during 2012 to 2016 were affected by the interaction between N source and year ($P < 0.05$). The interaction between tillage practices and N source and the overall interaction between the last 5 years did not yield performance ($P > 0.05$). Under the studied conditions the 75 lb/N/a as N fertilizer or manure achieved high corn yields.

Introduction
During the 1960s the Green Revolution was able to increase crop yields while increasing the food supply to reach the demand capacity. Over the last decade, agricultural yields have increased but soil resources have been depleting as a result of intensive agricultural practices. At the same time the cost of N fertilizer, one of the main agricultural inputs for increasing yields, has increased. Currently, the agricultural sector faces the challenge of increasing production for meeting the demand for 9 billion people by 2050. Currently, farmers face the challenge of increasing crop yields while using more efficient practices regarding inputs and restoration of soils. The agricultural industry must identify agricultural practices for corn (*Zea mays L.*) that will achieve an increase in yields while maintaining or restoring soil and water resources on a long-term basis.

Agronomic practices such as N fertilization and soil management have a direct effect on crop yields. Studies have shown how tillage practices have a direct effect on soil physical properties and soil nutrient availability for crop growth (Young et al., 2009; Cook and Trlica, 2016). In the U.S. corn belt, the two most common soil management practices for corn production are conventional tillage (CT) and no-tillage (NT). Conservative soil management with the NT practice offers an increase in physical, chemical, and biological soil quality characteristics that leads to higher nutrient availability in soils. The benefits also represent an efficient use of inputs and lower environmental impact. Under CT practices, soil nutrient dynamics are more susceptible to losses in the environment by soil erosion, losses to the atmosphere, and leaching (Cook and Trlica, 2016; Fernández and Schaefer, 2012; Young et al., 2009).

Soil nutrient additions are usually met by mineral fertilizer or an organic source such as animal or vegetable manure. Mineral fertilizers tend to be immediately available for plant uptake, which are easily absorbed, therefore, resulting in higher crop yields. However, studies have shown how disproportionate use of mineral fertilizer may increase soil acidity and reduce soil microbial communities. Organic fertilizers, such as cattle manure (CM) may be more stable in soils, can increase soil organic content, and increase soil microbial diversity when compared to soils with the addition of mineral fertilizers (Wang et al., 2007; Li et al., 2015; Busari et al., 2016).

Previous results from the study showed minimum soil disturbance from the NT practice, nutrient stratification in soil layers from 0-15 in., and higher soil organic carbon retention (unpublished data). Overall, results from this 26-year long-term experiment support soil conservation practices as a management tool to achieve competitive yields. Corn yield trends from 2012 to 2016 validate the long-term effect of the most common agricultural practices in order to identify the most sustainable agricultural system.

Procedures

Data were based on the results of a long-term experiment established in 1990 at the North Farm of Kansas State University in Manhattan, KS (39° 12' 42"N, 96° 35' 39"W). The soil is a moderately well-drained Kennebec silt loam (fine-silty, mixed, superactive mesic Cumulic Hapludoll); main chemical properties are shown in Table 1. The local average annual precipitation is 31.5 in. and the annual mean temperature is 51.8°F.

Corn (*Zea mays L.*) was grown continuously on the site from 1990 to present. The tillage practices were CT with a chisel plow and offset disc, and NT with zero soil disturbance. The N treatments were 75 lb/N/a as ammonium nitrate (LF), 75 lb/N/a as composted cattle manure (LM), 150 lb/N/a as ammonium nitrate (HF), 150 lb/N/a as composted cattle manure (HM), and a control (CO) treatment. The CM application rates were calculated assuming that 100% of the NH_4^+-N was available immediately after applied and approximately 35% of the organic N was mineralized the first years following application. Fertilizer N application was during spring before the corn was planted and manure was broadcast applied.

The experiment was arranged in split-plot randomized blocks with four replications. The experimental design is a split-split plot with four blocks, tillage as the whole plot and N source as the split-plot. Data were analyzed with a PROC GLIMMIX with repeated measurements over time procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The model included the effects of tillage, fertilizers, and their interaction; which were considered random. Significant differences were studied with a LSMEANS with Tukey at a $P < 0.05$.

Results

The interaction between N source and year significantly affected corn grain yields ($P < 0.05$). Harvest yield from 2013 and 2016 showed the higher yields. Lower grain yields from 2016 were from the CO with 121 bu/a; followed by an average of 176 bu/a between the other treatments (Figure 1). Yields were lower for all treatments ($P < 0.05$) during 2012 with an average of 77 bu/a. The LF treatment showed significant higher yields during 2013, 2014, and 2016 with 157, 134, and 183 bu/a, respectively. There was not a significant difference ($P < 0.05$) between the LF and HF with yields during 2013 and 2016 of 158 and 176, bu/a, respectively. The LM showed higher yields during 2013, 2014, and 2016 with 157, 135, and 172 bu/a, respectively. Additionally, fertilizer treatments of LM and HM were not significant. Higher yields were recorded for HM during 2013, 2014, and 2016 with 155, 150, and 181 bu/a, respectively.

Overall, there was no difference between grain yields during 2013, 2014, and 2016 for the LF, LM, and HM treatments; this also includes the 2013 and 2016 HF treatments. Lower yields during 2012 and 2015 may be a result of weather conditions such as drought.

References

Cook, R. L., and Trlica, A. 2016. Tillage and fertilizer effects on crop yield and soil properties over 45 years in Southern Illinois. *Agronomy Journal*, *108*(1), 415–426. http://doi.org/10.2134/agronj2015.0397

Fernández, F. G., and Schaefer, D. 2012. Assessment of soil phosphorus and potassium following real time kinematic-guided broadcast and deep-band placement in strip-till and no-till. *Soil Science Society of America Journal*, *76*(3), 1090–1099. http://doi.org/10.2136/sssaj2011.0352

Li, J., J.M. Cooper, Z. Lina, Y. Lia, X. Yanga, B. Zhao (2015). "Soil microbial community structure and function are significantly affected by long-term organic and mineral fertilization regimes in the North China Plain." Applied Soil Ecology 96: 75-87.

Wang, X.B., D.X. Cai, W.B. Hoogmoed, O. Oenema, and U.D. Perdok. 2007. Developments in conservation tillage in rainfed regions of North China. Soil and Tillage Research, 93, 239–250.

Young, R. R., Wilson, B., Harden, S., Bernardi, A. 2009. Accumulation of soil carbon under zero tillage cropping and perennial vegetation on the Liverpool Plains, eastern Australia. *Australian Journal of Soil Research*, *47*(3), 273. http://doi.org/10.1071/SR08104

Table 1. Soil chemical characteristics of 0 to 2 in. soil layer of conventional tillage and no-tillage plots

Tillage	pH	Bray-P	Potassium	CEC*	Sand	Silt	Clay
		----------- ppm	----------	cmolc kg^{-1}	----------------	g kg^{-1}	---------------
CT	6.2	55	371	17.1	100	700	200
NT	5.8	55	318	18.4	120	680	200

*CEC = cation exchange capacity.

Table 2. Analysis of variance for the factors tillage, treatment, and year for a significant level of $P < 0.05$

Factor	P-value
Tillage	0.1249
Treatment	<.0001
Tillage × Treatment	0.8486
Year	<.0001
Tillage × Year	0.7241
Treatment × Year	0.0015
Tillage × Treatment × Year	0.9252

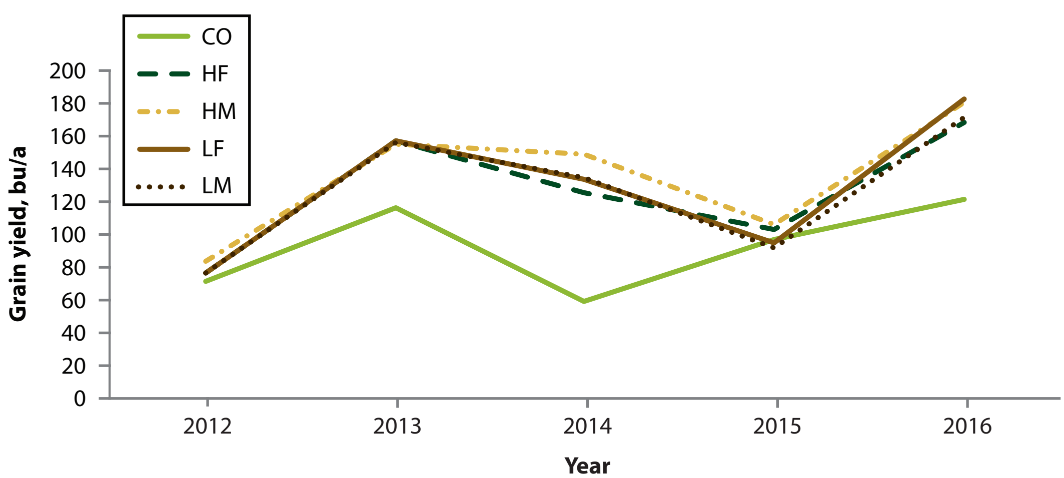

Figure 1. Effect of nutrient source over grain yield trends from 2012 to 2016 ($P < 0.05$). CO = control treatment, HF = 150 lb/N/a as ammonium nitrate, HM = 150 lb/N/a as composted manure, LF = ammonium, and LM = 75 lb/N/a as composted manure.

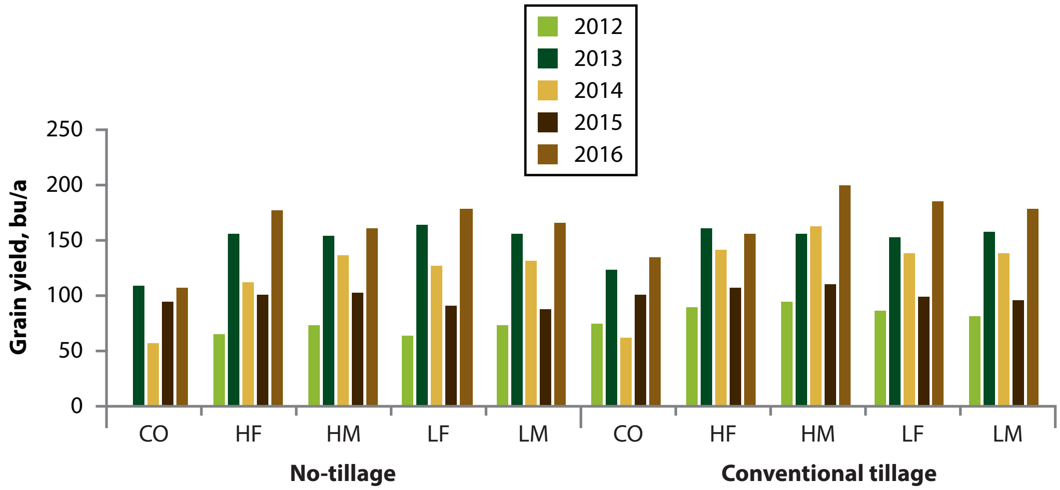

Figure 2. Grain yields trends from 2012 to 2016 as an effect of tillage practice and nutrient source (*P* > 0.05). CO = control treatment, HF = 150 lb/N/a as ammonium nitrate, HM = 150 lb/N/a as composted manure, LF = ammonium, and LM = 75 lb/N/a as composted manure.

Impact of Cover Crops and Phosphorus Fertilizer Management on Nutrient Cycling in No-Tillage Corn-Soybean Rotation

R.E. Carver, N.O. Nelson, D.S. Abel, K.L. Roozeboom, G.J. Kluitenberg, P.J. Tomlinson, and J.R. Williams

Summary
The objective of this study was to quantify the effects of cover crops and different fertilizer management techniques on the amount of nutrients being removed and recycled in the soil system. This study was conducted at Ashland Bottoms, KS, from 2014-2016. A 2 × 3 factorial design with three replicates was utilized in this study. The fertilizer management treatments included a control of 0 lb/a P_2O_5, along with fall broadcast and spring injected applications of P_2O_5 based on a build and maintain recommendation system. Results show that total uptake of K_2O and recycling of P_2O_5 and K_2O are directly influenced by cover cropping. Application of P_2O_5 fertilizer also statistically impacted the yield of soybeans during the 2016 growing season.

Introduction
This study began in 2014 to determine the effect of cover cropping and fertilizer management on phosphorus (P) loss from a no-tillage corn-soybean rotation. By studying the effects of cover cropping and fertilizer management, this study looks to protect soil and water resources all while maximizing net returns and management flexibility for the producer. As part of this study, crop yield, nutrient uptake, and nutrient removal were determined.

Procedures
This trial was conducted at the Kansas Agricultural Watershed (KAW) Field Research Facility, located at Ashland Bottoms Research Farm in Manhattan, KS, on a Smolan silty clay loam with an average slope of 6-8%. The KAW research facility consists of 18 plots varying from 1.2 to 1.6 acres in size. Six different management systems are expressed in this study. These systems include fall broadcast (FB) application of phosphorus fertilizer, spring injected (SI) phosphorus fertilizer, and no phosphorus (CN) fertilizer. All fertilizer application methods were studied both with cover crop (CC), and no cover crop (NC). Treatments for this study were arranged in a 2 × 3 factorial design and replicated three times using randomized complete block orientation.

For the 2015 growing season, a cover crop mix of winter wheat, rapeseed, and hairy vetch was planted in November 2014 on all cover crop treatments followed by corn planting in April of 2015 for the entire experiment. Cover crop was terminated by herbicide at the time of corn planting. The FB plots received 75 lb P_2O_5/a as diammonium phosphate (DAP) broadcast in January 2015 and the SI plots received 75 lb P_2O_5/a as ammonium polyphosphate (APP), applied in a 2 × 2 placement at seeding. All applications of phosphorus fertilizer were based on build and maintain recommendations. Nitrogen (N) fertilizer was injected as 28% urea ammonium nitrate at various rates to each treatment to bring the total applied nitrogen up to 130 lb N/a per treatment. Corn ears were hand harvested from two 30-ft-long rows at three sub-plot locations. Care was taken to leave the corn husk attached to the stalk. Biomass samples were collected by harvesting ten stalks from each sub-plot location.

For the 2016 growing season, a winter wheat cover crop was planted in September of 2015 and terminated with herbicide in May 2016. Soybean was planted in June of 2016. The FB plots received 55 lb P_2O_5/a as DAP broadcast in November 2015 and the SI plots received 55 lb P_2O_5/a APP, applied in a 2 × 2 placement at seeding. Fertilizer applications rates were based on build and maintain recommendations. Biomass samples were collected from 3 feet of the planted row at three sub-plot locations. Grain was harvested from two rows across the entirety of each plot using a plot combine.

Three composite soil samples were collected at 0 to 2 and 2 to 6 inches deep from each plot following grain harvest but prior to fertilizer application each year of the experiment and analyzed for pH, P, potassium (K), nitrate (NO_3-N), and organic matter. Soil analysis for 0 to 6 inches was computed as the weighted average from the 0 to 2 and 2 to 6 inch data.

Results

Cover crop and fertilizer treatments did not affect soil organic matter, soil pH, potassium, or nitrate concentrations in the soil ($P > 0.05$), therefore, these data were summarized by year (Table 1). The FB fertilizer increased the 0- to 2-inch soil test P each year (Figure 1). The SI treatment maintained or increased soil test P, while the CN decreased soil test P (Figure 1).

Analysis of cover crop nutrient uptake data revealed no statistical differences between fertilizer management practices for either year (Table 2). There was greater nutrient uptake in 2016 compared to 2015, which can be attributed to variance in growth between the two years. In 2015, cover crop growth was minimal due to cover crop being planted after soybean and being harvested prior to planting corn. There was much greater growth and therefore greater nutrient uptake during 2016.

Neither cover crop nor fertilizer management influenced corn growth, yield, or nutrient uptake in 2015 ($P > 0.05$; Table 3). The only effect of cover crop on soybean yield and nutrient uptake was decreased N content in soybean residue (Table 4). This could be caused by N uptake by the cover crop, but more data are required to be conclusive. Phosphorus fertilizer application increased soybean grain yield, total P uptake, and N, P, and K removal in the grain (Table 4). Greater N removal by P-fertilized soybean can be attributed to greater grain yield. Greater P and K removal by P-fertilized soybean is because of both greater yield and greater nutrient concentrations in the seed (data not shown).

In Table 5, the total nutrient uptake and removal for the 2015 and 2016 growing seasons are analyzed. Statistical differences were found in the total amount of K_2O uptake along with P_2O_5 and K_2O returned to the soil in the residue for the CC versus NC plots. Plots grown with CC had statistically greater uptake of all three categories which is correlated to the CC plots having greater amounts of P_2O_5 and K_2O deposited on the surface with the plant residue. Statistical differences were also observed when comparing fertilizer management interactions. The FB and SI plots had statistically greater removal of K_2O in the grain. This increased K_2O content of the grain could be a result of heathier or greater root mass caused by the application of phosphorus fertilizer.

Table 1. Soil analysis for 0 to 6 inches deep prior to the experiment (2014) and following grain harvest each year of the experiment (95% confidence intervals in parentheses)

Year	Organic matter[1]	pH[2]	Potassium[3]	NO_3-N[4]
	%		------------------- ppm	-------------------
2014	1.5 (+/- 0.1)	6.0 (+/- 0.1)	323 (+/- 12)	3.6 (+/- 0.6)
2015	1.6 (+/- 0.1)	6.7 (+/- 0.1)	328 (+/- 12)	2.5 (+/- 0.6)
2016	1.6 (+/- 0.1)	6.7 (+/- 0.1)	349 (+/- 12)	4.5 (+/- 0.6)

[1]Total C/0.75; where total carbon measured by combustion.
[2]1:1 soil:water pH; lime was applied after soil sample collection in 2014 because preliminary soil analysis indicated soil pH of 5.6 to 6.0.
[3]Ammonium acetate extractable potassium.
[4]Potassium chloride extraction.

Table 2. Two-year biomass and nutrient uptake of nitrogen, phosphorus (P_2O_5), and potassium (K_2O) of cover crops grown at KAW Field Research Facility

	2015				2016			
	Biomass	Nitrogen	P_2O_5	K_2O	Biomass	Nitrogen	P_2O_5	K_2O
	------------------------				lb/a ------------------------			
CN	248	9.6	1.5	9.9	1190	10.2	5.8	15.2
FB	216	9.0	1.4	8.6	1910	15.7	9.7	25.9
SI	192	7.4	1.0	7.5	1620	16.1	7.4	23.3
P-value	0.23	0.12	0.30	0.25	0.27	0.31	0.26	0.24

All data are expressed in lb/a.
CN = No phosphorus fertilizer.
FB = fall broadcast application of phosphorus fertilizer.
SI = spring injected phosphorus fertilizer.
P-value < 0.05 indicate significant differences between treatments.

Table 3. Effect of cover crop, fertilizer management, and cover crop by fertilizer management on nutrient uptake and yield in 2015 corn crop

	Total					Grain			Residue			
	Yield	Biomass	Nitrogen	P_2O_5	K_2O	Nitrogen	P_2O_5	K_2O	Biomass	Nitrogen	P_2O_5	K_2O
	bu/a	lb/a										
CC	160	15,800	172	76	156	113	53	32	8,250	58	23	123
NC	162	15,400	175	72	153	117	52	32	7,700	58	20	122
P-value	0.68	0.41	0.73	0.44	0.76	0.36	0.78	0.85	0.09	0.92	0.17	0.85
CN	161	15,600	174	73	154	117	52	32	7,950	57	21	123
FB	158	15,300	165	73	148	110	52	31	7,790	56	22	117
SI	164	15,900	181	77	162	118	54	33	8,180	60	21	127
P-value	0.66	0.59	0.35	0.79	0.48	0.31	0.75	0.54	0.57	0.99	0.71	0.52
CN-CC	158	15,700	166	73	158	110	52	31	8,240	58	23	129
CN-NC	165	15,400	182	72	149	125	53	32	7,660	57	20	118
FB-CC	160	15,600	164	78	147	109	53	32	8,070	55	25	115
FB-NC	156	14,900	167	69	148	111	50	30	7,510	57	19	119
SI-CC	162	16,100	186	77	163	120	54	33	8,430	60	21	124
SI-NC	166	15,800	176	76	162	117	54	33	7,920	60	22	129
P-value	0.71	0.92	0.49	0.71	0.90	0.29	0.86	0.70	0.99	0.93	0.42	0.59

All data are expressed in lb/a.
CC = cover crop.
NC = no cover crop.
P-value < 0.05 indicate significant differences between treatments.
CN = No phosphorus fertilizer.
FB = fall broadcast application of phosphorus fertilizer.
SI = spring injected phosphorus fertilizer.

Table 4. Effect of cover crop, fertilizer management, and cover crop by fertilizer management interaction on nutrient uptake and yield in 2016 soybean crop

	Total					Grain			Residue		
	Yield	Biomass	Nitrogen	P_2O_5	K_2O	Nitrogen	P_2O_5	K_2O	Nitrogen	P_2O_5	K_2O
	bu/a	----------	----------	----------	----------	lb/a	----------	----------	----------	----------	----------
CC	62.3	11,300	346	66	216	233	45	79	113	21	137
NC	61.9	11,800	385	66	219	229	44	77	156	23	142
P-value	0.83	0.29	0.06	0.94	0.78	0.63	0.44	0.49	0.02	0.66	0.69
LSD									41.27		
Control	58.3	10,700	338	56	203	216	38	70	122	18	133
FB	65.3	12,000	388	73	227	245	49	84	143	25	144
SI	62.6	11,800	371	69	222	232	46	80	140	23	142
P-value	0.04	0.08	0.13	0.02	0.10	0.04	<0.01	0.01	0.52	0.74	0.60
LSD	5.29			4.36		21.70	1.84	5.80			
CN-CC	59.3	10,300	316	56	199	220	39	73	96	17	126
CN-NC	57.2	11,200	360	56	208	213	36	68	147	20	140
FB-CC	64.3	11,800	366	73	230	244	49	84	121	25	145
FB-NC	66.4	12,200	411	73	225	246	49	83	165	25	142
SI-CC	63.2	11,700	357	69	221	235	47	80	122	22	141
SI-NC	62.0	11,900	385	70	223	228	46	80	157	24	143
P-value	0.66	0.84	0.92	0.99	0.94	0.87	0.70	0.88	0.92	0.92	0.77

CC = cover crop.
NC = no cover crop.
P-value < 0.05 indicate significant differences between treatments.
LSD = least significant difference.
CN = No phosphorus fertilizer.
FB = fall broadcast application of phosphorus fertilizer.
SI = spring injected phosphorus fertilizer.

Table 5. Effect of cover crop, fertilizer management, and cover crop by fertilizer management on total nutrient uptake and removal for 2015-2016

	Total			Grain			Residue		
	Nitrogen	P_2O_5	K_2O	Nitrogen	P_2O_5	K_2O	Nitrogen	P_2O_5	K_2O
	----------------			lb/a			----------------		
CC	547	152	407	346	98	112	193	53	290
NC	561	139	372	347	96	109	214	43	263
P-value	0.56	0.07	0.03	0.99	0.58	0.49	0.25	0.02	0.03
LSD			24.9					3.6	23.5
CN	523	134	371	334	90	102	189	43	269
FB	566	152	393	355	100	115	211	52	278
SI	573	150	405	351	101	113	211	49	284
P-value	0.19	0.07	0.16	0.24	0.09	0.04	0.49	0.22	0.51
LSD						8.8			
CN-CC	504	139	384	330	92	104	174	47	280
CN-NC	542	129	358	338	89	100	204	40	258
FB-CC	554	162	411	353	102	116	201	61	295
FB-NC	579	142	374	357	99	113	222	43	260
SI-CC	583	155	425	356	101	114	206	52	296
SI-NC	562	146	385	345	100	113	217	46	272
P-value	0.57	0.76	0.91	0.76	0.99	0.96	0.90	0.46	0.87
LSD									

CC = cover crop.
NC = no cover crop.
P-value < 0.05 indicate significant differences between treatments.
LSD = least significant difference.
CN = No phosphorus fertilizer.
FB = fall broadcast application of phosphorus fertilizer.
SI = spring injected phosphorus fertilizer.

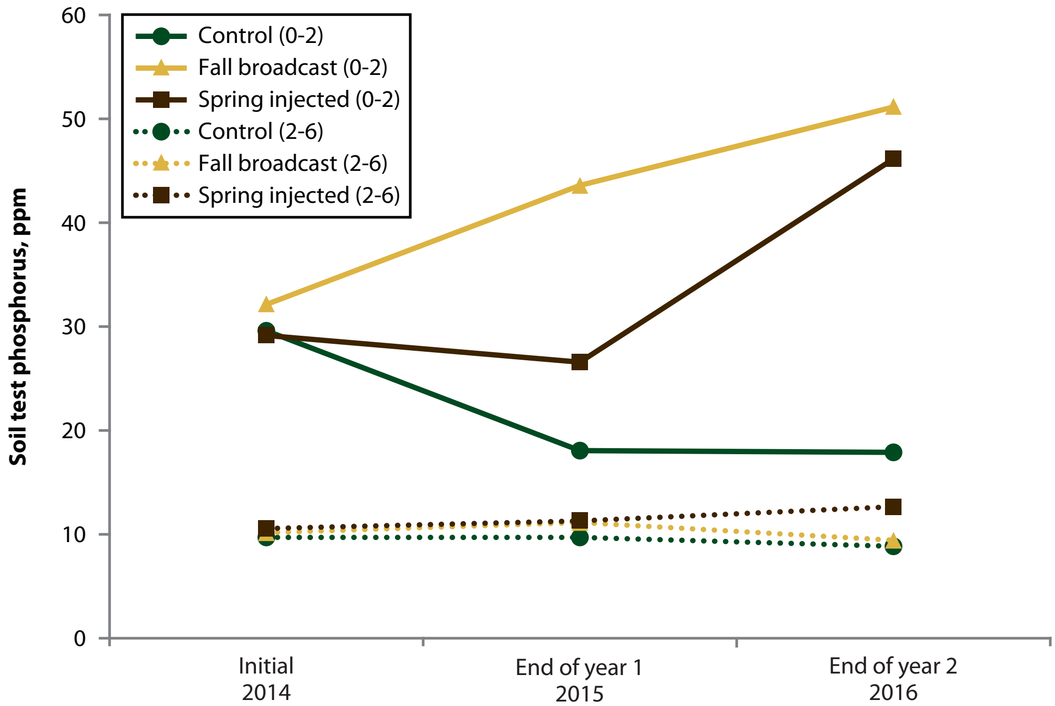

Figure 1. Fertilizer management effects on Mehlich 3 soil test P at 0- to 2-inch (solid lines) and 2- to 6-inch (dotted lines) depths. Letters indicate significant differences within year at the 0- to 2-inch depth ($P < 0.05$). There were not any significant differences at the 2- to 6-inch depth.

Biochar and Nitrogen Effects on Winter Wheat Growth

T.E. Zee, N.O. Nelson, and G. Newdigger

Summary

Biochar, a co-product of thermochemical bioenergy production, may be a valuable soil amendment, but little is known about its potential long-term effects on plant growth and soil fertility. In order to gain more information, this experiment was performed to see if the addition of biochar, in comparison to lime and fertilizer treatments, has the potential to return key nutrients back to the soil or increase crop yield. A field study to investigate the effects of biochar on plant growth was initiated in 2011 near St. John, KS. Treatments included biochar applied at 16.6 ton/a (biochar), lime and annual applications of phosphorus and potassium fertilizer (lime+P&K), and a control. Four rates of nitrogen (N) fertilizer were applied within each treatment (0, 45, 90, and 135 lb N/a). Winter wheat was planted in 2015 and harvested in 2016. The biochar treatment had greater wheat yield and better plant growth than the control but it was similar to the lime+P&K treatment. The greater yields from the biochar and the lime+P&K were likely due to increased soil pH from the lime and biochar. Biochar appears to be an effective method of supplying phosphorus (P), potassium (K), and increasing soil pH, and there was no effect on nitrogen availability.

Introduction

Thermochemical methods of bioenergy production, such as pyrolysis and gasification, can be used to convert biomass feedstocks (such as crop residues, wood chips, or other bio-based products) into advanced biofuels. These processes produce a high carbon (C) by-product, biochar, that contains many of the nutrients in the original feedstock. Land application of biochar could improve crop growth by returning P, K, and other nutrients to the soil. There is evidence that biochar can improve soil properties such as increased water holding capacity and increased soil pH. The high C in the biochar could reduce N availability through immobilization. The goal of this study is to determine the effects of biochar application on winter wheat growth and production, soil nutrient availability, and crop nitrogen response.

Procedures

A field study was conducted at the Sandyland Experiment Field near St. John, KS. The soil series is mapped as a Carwile fine sandy loam (0 to 1% slopes); initial soil analysis is listed in Table 1. The experiment was a split-block study with whole-plot treatments consisting of a control (no lime, P, or K applied), a lime+P&K treatment (lime plus annual applications of 92 lb P_2O_5/a and 193 lb K_2O/a), and a biochar treatment (single application of 16.6 ton/a). Sub-plot treatments were 0, 45, 90, and 135 lb/a N. Treatments were replicated three times.

Biochar from the gasification of wheat middlings was applied at 16.6 ton/a (dry weight) to the biochar treatments and ag-lime was applied to the lime+P&K whole-plots at 1,150 lb/a effective calcium carbonate (ECC) on April 5, 2011. Biochar properties are listed in Table 2. Biochar and lime were incorporated with two passes of an offset disk on the day of application. Forage sorghum was grown on the plots for the 2011, 2012, 2013, and 2014 growing seasons (with 0, 54, 107, and 161 lb/a N as annual N rates). On October 9, 2015, Antero hard white winter wheat was planted. The wheat was harvested on June 17, 2016. Soil samples were collected at 0 to 6, 6 to 12, and 12 to 24 in. deep from every subplot in July 2016.

Results

There was a significant treatment by N-rate interaction for soil pH (Table 3). Soil pH was greater in the biochar and lime+P&K treatments compared to the control and soil pH declined with increasing N rate (Figure 1). However, increasing N rate decreased soil pH more in the control than in other treatments. Soil test P, K, and total carbon were only affected by the whole plot treatment (Table 3), where biochar increased P, K, and carbon (C) concentrations in the soil (Figure 2).

There was a significant interaction between the whole plot treatment and nitrogen rate for both plant height and yield (Table 3). Plant height increased to a maximum at 90 lb N/a. Plant height decreased at 135 lb N/a for the control, but not for other treatments (Figure 3). Grain yield in biochar and lime+P&K treatments followed a typical nitrogen response, increasing to 90 lb N/a followed by plateau (Figure 4). However, grain yield for the control decreased at nitrogen rates above 45 lb N/a. In general, lime+P&K resulted in wheat yields similar to when biochar was applied.

The control treatment had low wheat yield at high N rates due to soil acidification. The treatment by N-rate interaction indicates that growth-limiting factors are present for the control at high N rates that are not present for the biochar and lime+P&K treatments. Biochar and lime+P&K treatments had a greater soil pH than the control. It is likely that the low pH in the control, especially at high N rates, resulted in poor wheat yields. The liming effect of the biochar and the lime application in the lime+P&K treatment increased pH and maintained a higher pH at high nitrogen rate thus maximizing yield.

Although there are treatment effects on soil P, K, and C (Figure 2), these differences do not explain the treatment by N rate interaction observed for wheat yield. Soil test P concentrations are all above the critical level of 20 parts per million (ppm). Although control soils have lower extractable K, it is still above the critical level of 130. Biochar from gasification is an effective method of increasing soil pH, P, and K; resulting in wheat yield similar to that obtained with conventional lime, P, and K fertilizers.

Table 1. Soil analysis prior to biochar application (2011)

Cation exchange capacity	pH	Total carbon	Total nitrogen	Mehlich 3 phosphorus	Extractable potassium	Extractable calcium	Extractable magnesium
meq/100 g		------------ % ------------		------------------------------ ppm ------------------------------			
5.2	5.2	0.4	0.04	34	102	326	48

Table 2. Physical and chemical analysis of biochar co-produced from gasification of wheat middlings

Property	Result	Units
Volatile matter	17.8 ±1.4	%
Ash	23.1 ±0.9	%
Cation exchange capacity	28.4 ±5.4	meq/100 g
Carbon	63.5 ±6.1	%
Hydrogen	1.04 ±0.12	%
Nitrogen	4.00 ±0.29	%
Sulfur	0.25 ±0.02	%
Phosphorus	1.23 ±0.33	%
Water extractable phosphorus	41 ±9	% of total P
Potassium	1.11 ±0.25	%
Calcium	0.19 ±0.05	%
Magnesium	0.43 ±0.15	%
Iron	240 ±63	ppm
Zinc	119 ±24	ppm
Copper	24 ±16	ppm
Manganese	144 ±41	ppm

Table 3. Results from analysis of variance (*P*-values)

Effect	Plant height	Yield	pH	Mehlich 3 phosphorus	Extractable potassium	Total carbon
Treatment (whole plot)	0.017	0.006	0.126	<0.001	<0.001	<0.001
Nitrogen rate (sub plot)	<0.001	<0.001	<0.001	0.057	0.147	0.842
Treatment by nitrogen rate	0.046	<0.001	0.030	0.242	0.610	0.997

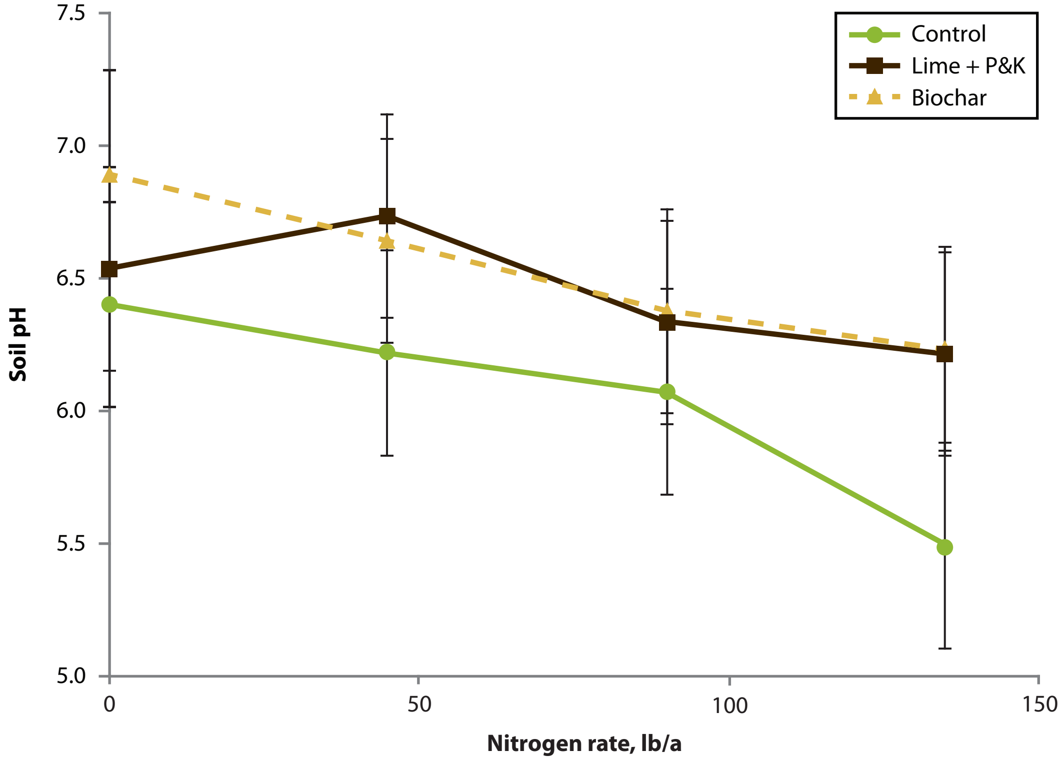

Figure 1. Soil pH response to nitrogen application for control, lime+P&K, and biochar treatments. Error bars indicate the 95% confidence interval for means.

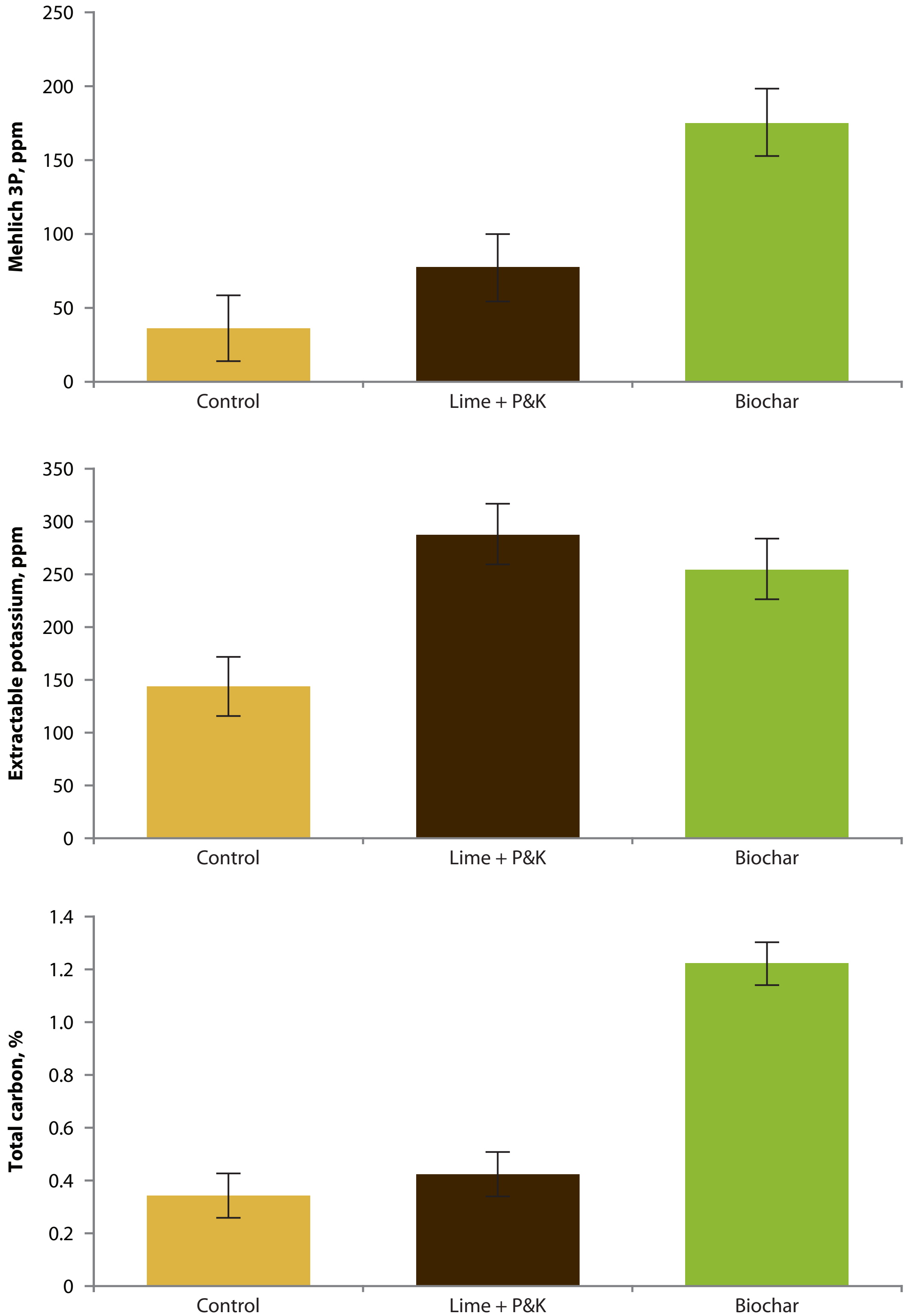

Figure 2. Mehlich 3P, extractable potassium (K), and total carbon (C) levels present in the control, lime+P&K, and biochar treatments. Error bars indicate the 95% confidence interval for means.

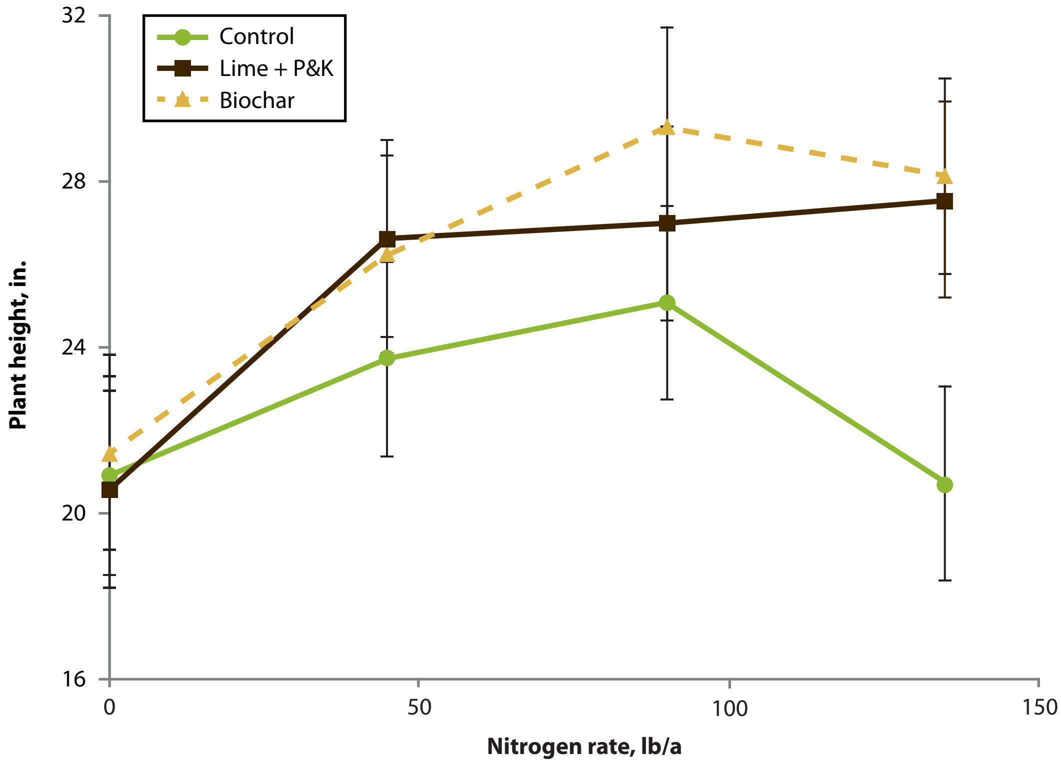

Figure 3. Wheat height response to nitrogen application for control, lime+P&K, and biochar treatments at Feekes growth stage 5. Error bars indicate the 95% confidence interval for means.

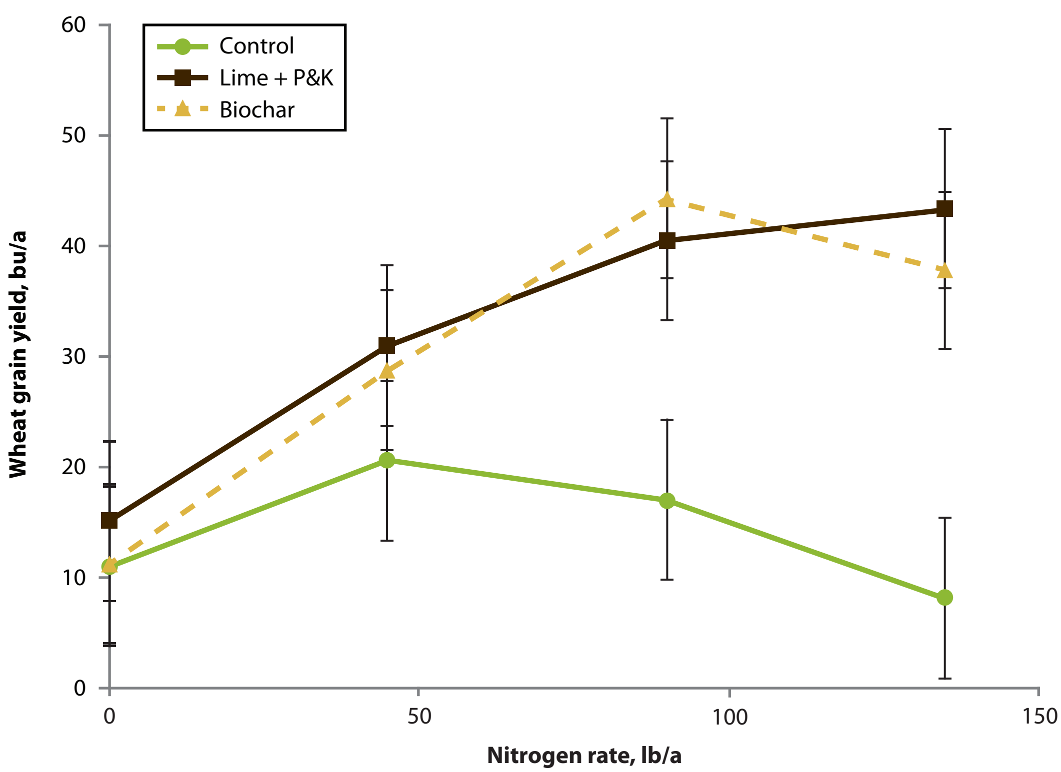

Figure 4. Wheat grain yield to nitrogen application for control, lime+P&K, and biochar treatments. Error bars indicate the 95% confidence interval for means.

Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Grain Sorghum

A.J. Schlegel and H.D. Bond

Summary

Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated grain sorghum in western Kansas. In 2016, N applied alone increased yields 71 bu/a, whereas N and P applied together increased yields up to 93 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields up to 77 bu/a. Application of 80 lb/a N (with P) was sufficient to produce 89% of maximum yield in 2016 which is slightly less than the 10-yr average. Application of potassium (K) has had no effect on sorghum yield throughout the study period. Average grain N content reached a maximum of ~0.7 lb/bu while grain P content reached a maximum of 0.15 lb/bu (0.34 lb P_2O_5/bu) and grain K content reached a maximum of 0.19 lb/bu (0.23 lb K_2O/bu). At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 33% for N, 69% for P, and 40% for K.

Introduction

This study was initiated in 1961 to determine responses of continuous grain sorghum grown under flood irrigation to N, P, and K fertilization. The study is conducted on a Ulysses silt loam soil with an inherently high K content. The irrigation system was changed from flood to sprinkler in 2001.

Procedures

This field study is conducted at the Tribune unit of the Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a N without P and K; with 40 lb/a P_2O_5 and zero K; and with 40 lb/a P_2O_5 and 40 lb/a K_2O. All fertilizers are broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. Sorghum (Pioneer 8505 in 2007, Pioneer 85G46 in 2008–2011, Pioneer 84G62 in 2012-2014, Pioneer 86G32 in 2015, and Pioneer 84G62 in 2016) was planted in late May or early June. Irrigation is used to minimize water stress. Sprinkler irrigation has been used since 2001. The center two rows of each plot are machine harvested after physiological maturity. Grain yields are adjusted to 12.5% moisture. Grain samples were collected at harvest, dried, ground and analyzed for N, P, and K concentrations. Grain N, P, and K content (lb/bu) and removal (lb/a) were calculated. Apparent fertilizer N recovery in the grain ($AFNR_g$) was calculated as N uptake in treatments receiving N fertilizer minus N uptake in the unfertilized control divided by N rate. The same approach was used to calculate apparent fertilizer P recovery in the grain ($AFPR_g$) and apparent fertilizer K recovery ($AFKR_g$).

Results

Grain sorghum yields in 2016 were 10% greater than the 10-year average (Table 1). Nitrogen alone increased yields 71 bu/a while P alone increased yields 11 bu/a. However, N and P applied together increased yields up to 93 bu/a. Averaged across the past 10 years, N and P applied together increased yields up to 77 bu/a. In 2016, 40 lb/a N (with P) produced about 82% of maximum yield, which is slightly less than the 10-year average of 84%. The 10-year average for 80 lb/a N (with P) and 120 lb/a N (with P) was 93 and 96% of maximum yield, respectively. Sorghum yields were not affected by K fertilization, which has been the case throughout the study period.

The 10-year average grain N concentration (%) increased with N rates but tended to decrease when P was also applied, presumably because of higher grain yields diluting N content (Table 2). Grain N content reached a maximum of ~0.7 lb/bu. Maximum N removal (lb/a) was obtained with 160 lb N/a or greater with P. Similar to N, average P concentration increased with P application but decreased with higher N rates. Grain P content (lb/bu) of ~0.15 lb P/bu (0.34 lb P_2O_5/bu) was similar for all N rates when P was applied. Grain P removal was similar for all N rates of 40 lb/a or greater with P removal ranging from 19 to 23 lb/a. Average K concentration (%) and content (lb/bu) tended to decrease with increased N rates. Similar to P, K removal was similar for all N rates of 40 lb/a or greater plus K ranging from 23 to 27 lb/a. At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 33% for N, 69% for P, and 40% for K.

Table 1. Nitrogen, phosphorus, and potassium fertilizers on irrigated grain sorghum yields, Tribune, KS, 2007-2016

Fertilizer			Grain sorghum yield										
N	P_2O_5	K_2O	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
------------ lb/a ------------			---------- bu/a ----------										
0	0	0	80	66	64	51	75	78	62	90	89	80	74
0	40	0	97	60	70	51	83	90	77	94	102	91	82
0	40	40	94	65	76	55	88	93	72	96	97	91	83
40	0	0	123	92	84	66	106	115	94	115	122	106	102
40	40	0	146	111	118	77	121	140	114	144	160	142	127
40	40	40	145	105	109	73	125	132	110	142	155	137	123
80	0	0	138	114	115	73	117	132	102	120	133	120	116
80	40	0	159	128	136	86	140	163	136	151	173	154	143
80	40	40	166	126	108	84	138	161	133	164	178	160	142
120	0	0	138	106	113	70	116	130	100	116	127	108	112
120	40	0	164	131	130	88	145	172	137	162	177	164	147
120	40	40	165	136	136	90	147	175	142	170	178	170	151
160	0	0	146	105	108	74	124	149	117	139	150	135	125
160	40	0	170	138	128	92	152	178	146	171	181	173	153
160	40	40	167	133	140	88	151	174	143	176	179	161	151
200	0	0	154	120	110	78	128	147	119	139	155	151	130
200	40	0	168	137	139	84	141	171	136	165	177	167	149
200	40	40	170	135	129	87	152	175	138	170	179	170	151

continued

Table 1. Nitrogen, phosphorus, and potassium fertilizers on irrigated grain sorghum yields, Tribune, KS, 2007-2016

Fertilizer			Grain sorghum yield										
N	P_2O_5	K_2O	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
------------ lb/a ------------			---------------- bu/a ----------------										
ANOVA (P>F)													
Nitrogen			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
P-K			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zero P vs. P			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
P vs. P-K			0.992	0.745	0.324	0.892	0.278	0.826	0.644	0.117	0.806	0.943	0.974
N × P-K			0.965	0.005	0.053	0.229	0.542	0.186	0.079	0.012	0.002	0.001	0.012
MEANS													
Nitrogen, lb/a													
0			91d	64d	70c	52c	82d	87d	70d	94e	96d	87d	79d
40			138c	103c	104b	72b	117c	129c	106c	134d	146c	129c	118c
80			155b	123b	120a	81a	132b	152b	124b	145c	161b	145b	134b
120			156ab	124ab	126a	82a	136ab	159ab	126b	149bc	161b	147b	137b
160			161ab	125ab	125a	84a	142a	167a	135a	162a	170a	156a	143a
200			164a	131a	126a	83a	141a	165a	131ab	158ab	170a	163a	143a
$LSD_{(0.05)}$			9	7	11	5	8	9	8	9	8	8	6
P_2O_5-K_2O, lb/a													
0 - 0			130b	101b	99b	68b	111b	125b	99b	120b	129b	117b	110b
40 - 0			151a	117a	120a	80a	130a	152a	124a	148a	162a	149a	133a
40 - 40			151a	117a	116a	79a	133a	152a	123a	153a	161a	148a	133a
$LSD_{(0.05)}$			6	5	7	4	6	6	5	6	5	6	4

N = nitrogen.
P = phosphorus.
K = potassium.
ANOVA = analysis of variance.
LSD = least significant difference.

Table 2. Nitrogen, phosphorus, and potassium fertilizers on grain N, P, and K content of irrigated grain sorghum, Tribune, KS, 2007-2016

Fertilizer			Grain						Grain removal					
N	P_2O_5	K_2O	N	P	K	N	P	K	N	P	K	*$AFNR_g$	*$AFPR_g$	*$AFKR_g$
------------ lb/a ------------			----------------- % -----------------			--------------- lb/bu ---------------			------------ lb/acre ------------			----------------- % -----------------		
0	0	0	1.04	0.267	0.370	0.51	0.131	0.181	37	9	13	---	---	---
0	40	0	1.02	0.314	0.389	0.50	0.154	0.191	41	13	16	---	18	---
0	40	40	1.02	0.312	0.386	0.50	0.153	0.189	41	13	16	---	18	7
40	0	0	1.14	0.239	0.344	0.56	0.117	0.169	57	12	17	49	---	---
40	40	0	1.11	0.318	0.377	0.54	0.156	0.185	69	20	24	79	59	---
40	40	40	1.11	0.311	0.373	0.54	0.152	0.183	67	19	23	73	53	28
80	0	0	1.35	0.226	0.339	0.66	0.111	0.166	76	13	19	49	---	---
80	40	0	1.23	0.299	0.360	0.60	0.146	0.176	85	21	25	60	65	---
80	40	40	1.20	0.311	0.367	0.59	0.153	0.180	83	22	25	57	69	37
120	0	0	1.40	0.213	0.335	0.69	0.104	0.164	77	12	18	33	---	---
120	40	0	1.33	0.287	0.354	0.65	0.141	0.174	95	21	26	48	63	---
120	40	40	1.33	0.309	0.360	0.65	0.151	0.176	98	23	27	50	76	40
160	0	0	1.43	0.233	0.345	0.70	0.114	0.169	87	14	21	31	---	---
160	40	0	1.39	0.309	0.362	0.68	0.151	0.177	104	23	27	42	78	---
160	40	40	1.36	0.288	0.355	0.66	0.141	0.174	100	21	26	39	67	39
200	0	0	1.43	0.239	0.348	0.70	0.117	0.171	91	15	22	27	---	---
200	40	0	1.39	0.288	0.361	0.68	0.141	0.177	101	21	26	32	66	---
200	40	40	1.40	0.294	0.361	0.69	0.144	0.177	103	22	27	33	69	40

continued

Table 2. Nitrogen, phosphorus, and potassium fertilizers on grain N, P, and K content of irrigated grain sorghum, Tribune, KS, 2007-2016

Fertilizer	Grain						Grain removal					
N P_2O_5 K_2O	N	P	K	N	P	K	N	P	K	*$AFNR_g$	*$AFPR_g$	*$AFKR_g$
------------ lb/a ------------	----------------- % -----------------			--------------- lb/bu ---------------			------------ lb/acre ------------			----------------- % -----------------		
ANOVA (P>F)												
Nitrogen	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.001	0.001	0.054	0.001	0.001
P-K	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.790	---
Zero P vs. P	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	---	---	---
P vs. P-K	0.435	0.707	0.963	0.435	0.707	0.963	0.672	0.822	0.991	---	---	---
N × P-K	0.407	0.014	0.083	0.407	0.014	0.083	0.101	0.001	0.007	0.001	---	---
MEANS												
Nitrogen, lb/a												
0	1.03e	0.298a	0.382a	0.50e	0.146a	0.187a	40e	12c	15d	---	18c	7c
40	1.12d	0.289ab	0.365b	0.55d	0.142ab	0.179b	64d	17b	21c	67a	56b	28b
80	1.26c	0.279bc	0.355cd	0.62c	0.137bc	0.174cd	82c	18a	23b	55b	67a	37a
120	1.35b	0.269c	0.350d	0.66b	0.132c	0.171d	90b	18a	24b	44c	69a	40a
160	1.39ab	0.277bc	0.354cd	0.68ab	0.136bc	0.174cd	97a	19a	25a	37d	72a	39a
200	1.41a	0.274c	0.357c	0.69a	0.134c	0.175c	98a	19a	25a	30e	67a	40a
$LSD_{(0.05)}$	0.04	0.012	0.006	0.02	0.006	0.003	4	1	1	6	8	4
P_2O_5-K_2O, lb/a												
0 - 0	1.30a	0.236b	0.347b	0.64a	0.116b	0.170b	71b	13b	19b	38b	---	---
40 - 0	1.25b	0.303a	0.367a	0.61b	0.148a	0.180a	82a	20a	24a	52a	58	---
40 - 40	1.24b	0.304a	0.367a	0.61b	0.149a	0.180a	82a	20a	24a	51a	59	---
$LSD_{(0.05)}$	0.03	0.009	0.004	0.01	0.004	0.002	3	1	1	4	5	---

*$AFNR_g$, $AFPR_g$, and $AFKR_g$= Apparent Fertilizer N Recovery (grain), Apparent Fertilizer P Recovery (grain), and Apparent Fertilizer K Recovery (grain).
N = nitrogen.
P = phosphorus.
K = potassium.
ANOVA = analysis of variance.
LSD = least significant difference.

Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Corn

A.J. Schlegel and H.D. Bond

Summary
Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated corn in western Kansas. In 2016, N applied alone increased yields 85 bu/a, whereas P applied alone increased yields only 12 bu/a. Nitrogen and P applied together increased yields up to 164 bu/a. This is 20 bu/a greater than the 10-year average, where N and P fertilization increased corn yields up to 144 bu/a. Application of 120 lb/a N (with highest P rate) produced about 94% of maximum yield in 2016, which is similar to the 10-year average. Application of 80 instead of 40 lb P_2O_5/a increased average yields 6 bu/a. Average grain N content reached a maximum of 0.6 lb/bu while grain P content reached a maximum of 0.15 lb/bu (0.34 lb P_2O_5/bu). At the highest N and P rate, $AFNR_g$ was 44% and $AFPR_g$ was 62%.

Introduction
This study was initiated in 1961 to determine responses of continuous corn and grain sorghum grown under flood irrigation to N, P, and potassium (K) fertilization. The study is conducted on a Ulysses silt loam soil with an inherently high K content. No yield benefit to corn from K fertilization was observed in 30 years, and soil K levels remained high, so the K treatment was discontinued in 1992 and replaced with a higher P rate.

Procedures
This field study is conducted at the Tribune unit of the Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a without P and K; with 40 lb/a P_2O_5 and zero K; and with 40 lb/a P_2O_5 and 40 lb/a K_2O. The treatments were changed in 1992; the K variable was replaced by a higher rate of P (80 lb/a P_2O_5). All fertilizers were broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. The corn hybrids [Pioneer 33B54 (2007), Pioneer 34B99 (2008), DeKalb 61-69 (2009), Pioneer 1173H (2010), Pioneer 1151XR (2011), Pioneer 0832 (2012-2013), Pioneer 1186AM (2014), Pioneer 35F48 AM1 (2015), and Pioneer 1197 (2016)] were planted at about 32,000 seeds/a in late April or early May. Hail damaged the 2008 and 2010 crops. The corn is irrigated to minimize water stress. Sprinkler irrigation has been used since 2001. The center two rows of each plot are machine harvested after physiological maturity. Grain yields are adjusted to 15.5% moisture. Grain samples were collected at harvest, dried, ground and analyzed for N and P concentrations. Grain N and P content (lb/bu) and removal (lb/a) were calculated. Apparent fertilizer N recovery in the grain ($AFNR_g$) was calculated as N uptake in treatments receiving N fertilizer less N uptake in the unfertilized control divided by N rate. The same approach was used to calculate apparent fertilizer P recovery in the grain ($AFPR_g$).

Results

Corn yields in 2016 were 10% greater than the 10-year average (Table 1). Nitrogen alone increased yields 85 bu/a, whereas P alone increased yields only 12 bu/a. However, N and P applied together increased corn yields up to 164 bu/a. Maximum yield was obtained with 160 lb/a N with 80 lb/a P_2O_5. Corn yields in 2016 (averaged across all N rates) were 6 bu/a greater with 80 than with 40 lb/a P_2O_5.

The 10-year average grain N concentration (%) increased with N rates but tended to decrease when P was also applied, presumably because of higher grain yields diluting N content (Table 2). Grain N content reached a maximum of 0.6 lb/bu. Maximum N removal (lb/a) was greatest at the highest yield levels, which were attained with 200 lb N and 80 lb P_2O_5/a. At the highest N and P rate, $AFNR_g$ was 44% and $AFPR_g$ was 62%. Similar to N, average P concentration increased with increased P rates but decreased with higher N rates. Grain P content (lb/bu) of about 0.15 lb P/bu (0.34 lb P_2O_5/bu) was greater at the highest P rate with low N rates. Grain P removal averaged 30 lb P/a at the highest yields.

Table 1. Nitrogen (N) and phosphorus (P) fertilization on irrigated corn yields, Tribune, KS, 2007-2016

Fertilizer		Yield										
N	P_2O_5	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
------ lb/a ------		---------- bu/a ----------										
0	0	49	36	85	20	92	86	70	86	92	74	69
0	40	50	57	110	21	111	85	80	95	103	78	79
0	80	51	52	106	28	105	94	91	98	104	86	81
40	0	77	62	108	23	114	109	97	106	113	105	91
40	40	112	105	148	67	195	138	125	153	164	145	135
40	80	116	104	159	61	194	135	126	149	162	135	134
80	0	107	78	123	34	136	128	112	117	131	118	108
80	40	163	129	179	85	212	197	170	187	195	196	171
80	80	167	139	181	90	220	194	149	179	193	193	171
120	0	106	65	117	28	119	134	114	115	124	109	103
120	40	194	136	202	90	222	213	204	213	212	212	190
120	80	213	151	215	105	225	211	194	216	216	223	197
160	0	132	84	139	49	157	158	122	128	144	142	125
160	40	220	150	210	95	229	227	199	211	215	226	198
160	80	227	146	223	95	226	239	217	233	216	238	206
200	0	159	99	155	65	179	170	139	144	162	159	143
200	40	224	152	207	97	218	225	198	204	214	216	196
200	80	232	157	236	104	231	260	220	238	221	235	213

continued

Table 1. Nitrogen (N) and phosphorus (P) fertilization on irrigated corn yields, Tribune, KS, 2007-2016

Fertilizer		Yield										
N	P_2O_5	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
------ lb/a ------		---------- bu/a ----------										
ANOVA (P>F)												
Nitrogen		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Phosphorus		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N × P		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
MEANS												
Nitrogen, lb/a												
0		50f	48e	100e	23e	103d	88f	80e	93e	100e	79e	76e
40		102e	91d	138d	50d	167c	127e	116d	136d	146d	129d	120d
80		146d	115c	161c	70c	189b	173d	143c	161c	173c	169c	150c
120		171c	118c	178b	74bc	189b	186c	171b	181b	184b	182b	163b
160		193b	127b	191a	80ab	204a	208b	179ab	190ab	192ab	202a	177a
200		205a	136a	199a	89a	209a	218a	186a	196a	199a	203a	184a
$LSD_{(0.05)}$		11	9	12	9	13	10	10	10	9	10	8
P_2O_5, lb/a												
0		105b	71b	121c	36b	133b	131c	109b	116c	128b	118b	107c
40		160a	122a	176b	76a	198a	181b	163a	177b	184a	179a	162b
80		168a	125a	187a	81a	200a	189a	166a	186a	185a	185a	167a
$LSD_{(0.05)}$		8	6	9	7	9	7	7	7	6	7	5

*Note: Hail events on 7/23/10 and 5/28/15.

Table 2. Nitrogen (N) and phosphorus (P) fertilization on grain N and P content of irrigated corn, Tribune, KS, 2007-2016

Fertilizer		Grain				Grain removal			
N	P_2O_5	N	P	N	P	N	P	*$AFNR_g$	*$AFPR_g$
--------- lb/a ---------		---------- % ----------		-------- lb/bu --------		------- lb/acre -------		---------- % ----------	
0	0	0.99	0.230	0.47	0.109	31	7	---	---
0	40	0.95	0.312	0.45	0.147	35	12	---	24
0	80	0.96	0.321	0.45	0.152	36	12	---	14
40	0	1.15	0.182	0.55	0.086	49	8	45	---
40	40	0.97	0.301	0.46	0.143	61	19	75	67
40	80	0.98	0.323	0.46	0.153	61	21	75	37
80	0	1.26	0.177	0.60	0.084	64	9	40	---
80	40	1.05	0.257	0.50	0.122	84	21	66	74
80	80	1.03	0.310	0.49	0.147	82	25	63	49
120	0	1.25	0.170	0.59	0.081	61	8	24	---
120	40	1.14	0.226	0.54	0.107	102	20	58	71
120	80	1.10	0.297	0.52	0.140	102	28	59	57
160	0	1.25	0.176	0.59	0.083	73	10	26	---
160	40	1.18	0.242	0.56	0.114	110	22	49	84
160	80	1.17	0.281	0.56	0.133	114	27	51	55
200	0	1.24	0.186	0.59	0.088	83	12	26	---
200	40	1.20	0.239	0.57	0.113	110	22	39	82
200	80	1.19	0.295	0.56	0.140	119	30	44	62

continued

Table 2. Nitrogen (N) and phosphorus (P) fertilization on grain N and P content of irrigated corn, Tribune, KS, 2007-2016

Fertilizer		Grain				Grain removal			
N	P_2O_5	N	P	N	P	N	P	*$AFNR_g$	*$AFPR_g$
--------- lb/a ---------		---------- % ----------		-------- lb/bu --------		------- lb/acre -------		---------- % ----------	
ANOVA (P>F)									
Nitrogen		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	---	0.001
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	---	0.001
Phosphorus		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	---
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	0.001	---
N × P		0.001	0.001	0.001	0.001	0.001	0.001	0.036	0.126
MEANS									
Nitrogen, lb/a									
0		0.97e	0.288a	0.46e	0.136a	34f	10e	---	19d
40		1.04d	0.269b	0.49d	0.127b	57e	16d	65a	52c
80		1.11c	0.248c	0.53c	0.117c	77d	18c	56b	62b
120		1.16b	0.231d	0.55b	0.109d	88c	19c	47c	64ab
160		1.20a	0.233d	0.57a	0.110d	99b	20b	42d	70ab
200		1.21a	0.240cd	0.57a	0.114cd	104a	21a	36e	72a
$LSD_{(0.05)}$		0.02	0.011	0.01	0.005	4	1	5	8
P_2O_5, lb/a									
0		1.19a	0.187c	0.56a	0.088c	60b	9c	32b	---
40		1.08b	0.263b	0.51b	0.124b	84a	19b	57a	67a
80		1.07b	0.304a	0.51b	0.144a	86a	24a	58a	46b
$LSD_{(0.05)}$		0.01	0.008	0.01	0.004	3	1	4	5

*$AFNR_g$ and $AFPR_g$ = Apparent Fertilizer N Recovery (grain) and Apparent Fertilizer P Recovery (grain).

Interaction of Seeding and Nitrogen Rate on Grain Sorghum Yield in Southwest Kansas

A.J. Foster, A.J. Schlegel, J. Holman, I. Ciampitti, C. Thompson, and D. Ruiz Diaz

Summary

This study compared drilled planted sorghum at four seeding rates to planted sorghum at three different nitrogen (N) fertility levels at two locations in southwest Kansas (Garden City and Tribune). At the Garden City location, no difference was observed in yield among the drilled seeded sorghum populations greater than 27,000 seeds/a compared to the standard planted sorghum (sorghum planted at 27,000 seeds/a with a planter at 30 in.-row spacing). At Tribune, there was no difference in yield between the drilled sorghum and the standard planted sorghum (sorghum planted at 40,000 seeds/a with a planter at 30 in.-row spacing) regardless of seeding rate. Nitrogen fertilizer did not interact with seeding rate or affect yield independently at either location. The use of normalized difference vegetation index (NDVI) to assess canopy coverage suggested that planted sorghum and drilled sorghum at population greater than 40,000 seeds/a may achieve canopy coverage at a faster rate. In general, nitrogen rate and seeding rates did not affect sorghum yield. However, we did observe that drilled planted sorghum was more at risk of irregular stand emergence and required a higher seeding rate to achieve canopy closure at a rate similar to that of planted sorghum.

Introduction

Drilled sorghum is normally done at super-high population at row spacing between 7.5 and 10 inches, compared to rows planted at spacing between 15 and 30 inches. Thompson (1983), growing super-thick sorghum at the Hays Research Station from 1974-1977, found that sorghum planted in narrow rows (12-18 in.) often produced higher yields than when planted in wide rows (24-40 in.). Norwood (1982) in Garden City repeated Thompson's work and also came to the conclusion that yield of high population narrow row sorghum could exceed that of low population wide row when subsoil moisture and precipitation were adequate. The conclusion from the work of Thompson and Norwood was that subsoil moisture and precipitation were big drivers for the high population, narrow-row sorghum to equal or exceed the yield of the low population wide row. Since then, most researchers have found yield response to plant population to be variable depending on environment. Overall, the general consensus is that under conditions of adequate moisture, yield of high population sorghum can continue to increase, but can decrease under dry conditions. Today moisture still remains the key for successful dryland sorghum production in southwest Kansas. Thus, the very familiar saying, "moisture and fertility are joined at the hip." Thompson's and Norwood's work did not evaluate narrow row at population under 25,000 seeds/a and at spacing below 10 in. We hypothesized that drilled sorghum at lower population could make better use of water resources and produce similar yields to drilled sorghum at higher population, and planted sorghum at the same population. Thus, the objective of this study is to evaluate drilled sorghum at different populations ranging from 20,000 to 80,000 seeds/a at row spacing of 10 in. or less at different nitrogen rates. Furthermore, most farmers in southwest Kansas own both a drill and a planter. Thus, it is not just an agronomic issue, but it is also about getting better value from a single piece of equipment in an already economically challenging wheat-sorghum-fallow production system.

Procedures

Experiments with small plots were conducted under dryland conditions at two locations in western Kansas (Southwest Research-Center in Garden City and Tribune) to determine interaction of seeding rate and nitrogen rate under narrow row sorghum in southwest Kansas.

Planting Dates and Plot Layout

Sorghum variety Dekalb 3707 was planted at both locations on June 2, 2016 in Garden City and June 7, 2016 in Tribune.

A randomized complete block design with a 5 × 3 factorial treatment arrangement with four replications was used at both locations. At Garden City, the five factors included four drilled seeding rates (27,000 (lowest amount recommended with the air seeder no-tillage planter) and 40,000, 54,000, and 68,000 seeds/a) and sorghum planted at 27,000 seeds/a with a planter at 30-in. row spacing. At Tribune, the five factors included four drilled seeding rates (20,000, 40,000, 60,000, and 80,000 seeds/a) and sorghum planted at 40,000 seeds/a with a planter at 30 in.-row spacing. The three factors included three nitrogen rates (0, 50, and 100 lb/a) at Tribune; (50, 75, and 100 lb/a) at Garden City.

At both locations, potassium (K) and phosphorus (P) were applied based on the soil test recommendations provided by the Kansas State University Soil and Plant Testing Laboratory. At Garden City, the drilled treatments were planted with a John Deere 1910 air seeder no-tillage drill and the planted with a John Deere 7300 planter. In Tribune, drilled treatments were planted with a John Deere 1590 no-tillage drill and the planted with a John Deere 1700 planter.

Herbicide management at Garden City was the application of Glyphosate at 1.25 qt/a + Harness at 2.5 pt/a + Starane Ultra at 0.75 pt/a applied pre-plant on June 1, 2016. At Tribune, Atrazine at 1 lb/a + Dicamba at 1 pt/a was applied early on March 10, 2016, followed by Degree Extra at 3 qt/a + Sharpen at 2 oz /a + Glyphosate at 0.75 lb a.e./a applied pre-emergence on June 8, 2016.

Data Collection and Analysis

Reducing plant density in narrow row planted sorghum could result in large areas of exposed soil. This exposed soil is subjected to wind and water erosion and weed infestation during the growing season and after harvest. However, the sorghum plant has an extreme capability to compensate and utilize space by tillering. Normalized difference vegetation index (NDVI) measurements were collected during the growing season as a means of assessing exposed soil among the different plant population treatments. NDVI was measured using the GreenSeeker® hand-held device (NTech Industries Inc, Stillwater, OK). Measurement was collected from an approximately 80 ft^2 (2 ft GreenSeeker viewing area × 40 ft plot length) area at Garden City and a 100 ft^2 (2 ft GreenSeeker viewing area × 50 ft plot length) area in Tribune from each treatment plot.

The Garden City location was harvested using a 7.5 ft wide head plot combine and Tribune was harvested with a 5 ft wide head. Crop weights were adjusted to 13% moisture.

Data were analyzed using PROC GLM with SAS 9.4 (SAS Institute, Inc., Cary, NC) and a model statement appropriate for a factorial design. Treatment means were separated by Fisher's projected least significant difference test.

Results

Garden City

The emergence of drilled sorghum was more irregular compared to the standard planted (Figure 1). Emergence of the drilled sorghum was over a 3-15 day period compared to 3-5 days of the planted sorghum. This may have contributed to the large variation in yield observed among the treatments (least significant difference (LSD) = 24 bu/a). The 2016 results found no difference in yield among the three nitrogen rates (Figure 2), and drilled sorghum populations greater than 40,000 seeds/a and the standard planted sorghum (Figure 3). Grain yield of the standard planted sorghum was 31 bu/a greater than the drilled sorghum at 27,000 seeds/a. These results are in agreement with our initial hypothesis that drilled sorghum at lower population would not result in a yield penalty.

Tribune

The 2016 results found no difference in grain yield among the N rates (Figure 4) and for drilled sorghum at different populations and the standard planted sorghum (Figure 5). Similar to Garden City, the results are in agreement with our hypothesis that narrow sorghum could be planted at lower seeding rates without a yield penalty.

Assessing Canopy Coverage/Canopy Closure

Normalized difference vegetation index (NDVI) measured during the growing season was used to monitor the rate of change in green area among the different treatments throughout the growing season. The rate of change in green area was used to reflect the rate of canopy coverage over the plot area. Figure 6 shows that planted sorghum at 27,000 reached maximum green coverage or canopy closure at a faster rate compared to the drilled sorghum at the different populations at Garden City. At Tribune, the planted sorghum reached maximum green coverage at a similar rate to the higher drilled rates of 80,000 and 60,000 (Figure 6). Normalized difference vegetative index measurements starting at 23-29 days after planting showed lower readings for the lower drilled seeding rates throughout the growing season (Table 1). These results indicate that narrow row planted at lower seeding rates (20,000 – 40,000 seeds/a) reached canopy closure at a much slower rate. Based on field observation, the slower rate of canopy closure of the drilled sorghum at Garden City could be attributed to non-uniform emergence that lasted over 10-15 days. This result indicates the importance of achieving a uniform emergence on the rate of canopy closure.

References

Norwood, C. A. 1982. High population, narrow row dryland sorghum for southwest Kansas. Keeping up with research, 62. Kansas Agricultural Experiment Station. http://krex.k-state.edu/dspace/handle/2097/16547

Thompson, C. 1983. Super-thick sorghum management. Kansas Agricultural Experiment Station Report of Progress, 437, 24.

Table 1. Normalized difference vegetation index (NDVI) measurements collected at different times after planting at five seeding rates across two locations in southwest Kansas

	Garden City			
	Days after planting			
Seeding rate	29	36	47	54
Seeds/a				
STAND_27[1]	0.428	0.768	0.823	0.848
67,500	0.392	0.631	0.793	0.839
54,000	0.324	0.549	0.753	0.819
40,500	0.288	0.424	0.650	0.792
27,000	0.288	0.417	0.642	0.748
LSD[3]	0.077	0.110	0.100	0.063
CV[4]	26	15.6	6.4	3.6

	Tribune				
	Days after planting				
Seeding rate	23	32	38	45	65
Seeds/a					
STAND_40[2]	0.214	0.347	0.537	0.749	0.787
80,000	0.223	0.411	0.634	0.796	0.803
60,000	0.210	0.338	0.560	0.756	0.795
40,000	0.209	0.285	0.520	0.689	0.771
20,000	0.209	0.248	0.426	0.664	0.759
LSD	0.02	0.064	0.12	0.076	0.024
CV	6.3	15.9	12.04	7.16	2

[1]Sorghum planted with a planter on 30 in.-row spacing at seeding rate of 27,000 seeds/a.
[2]Sorghum planted with a planter on 30 in.-row spacing at seeding rate of 40,000 seeds/a.
[3]LSD = least significant difference.
[4]CV = coefficient of variation.

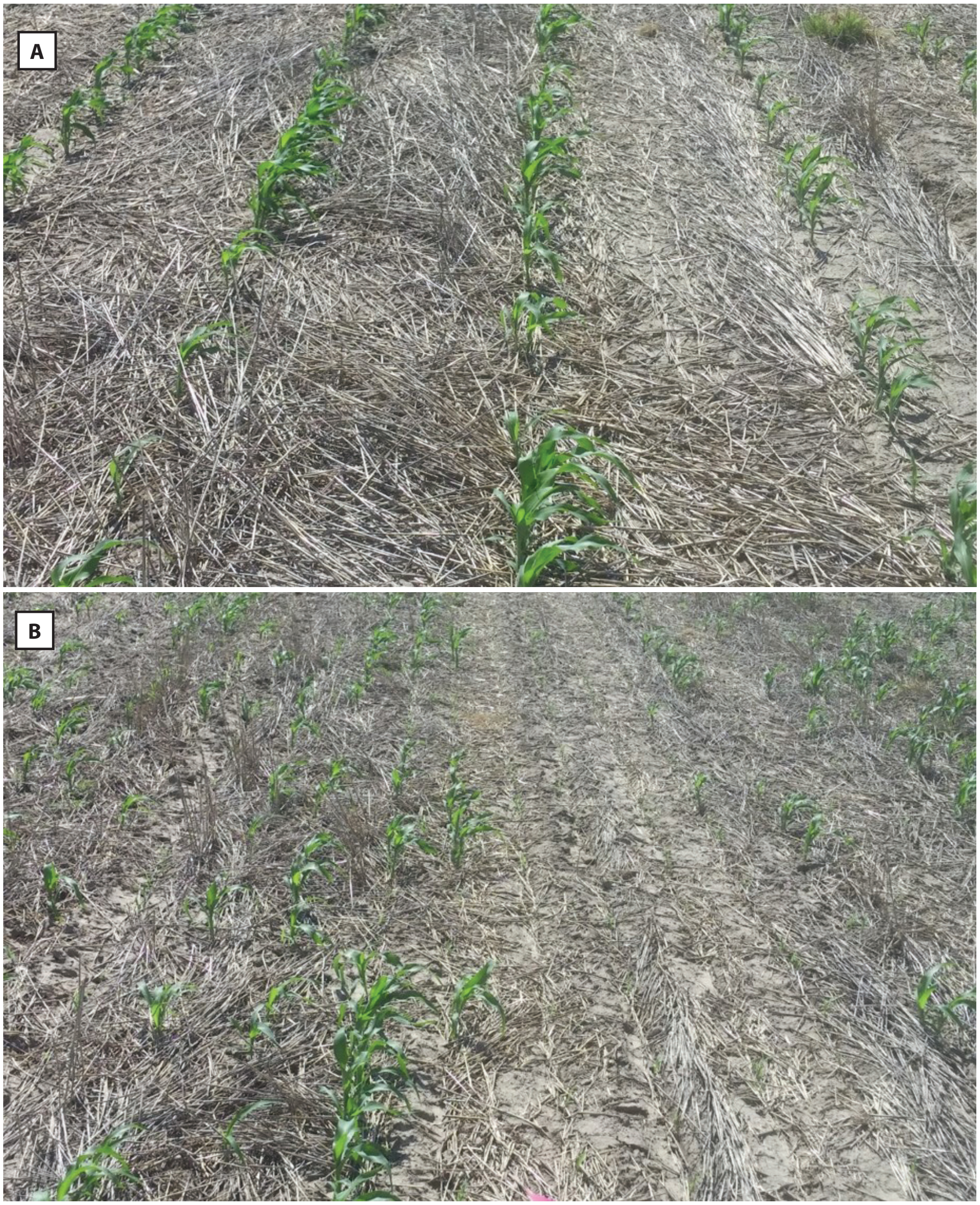

Figure 1. Emergence of drilled and planted sorghum. A) Sorghum planted using a standard 30 in. planter. B) Sorghum planted using a no-tillage air seeder drill.

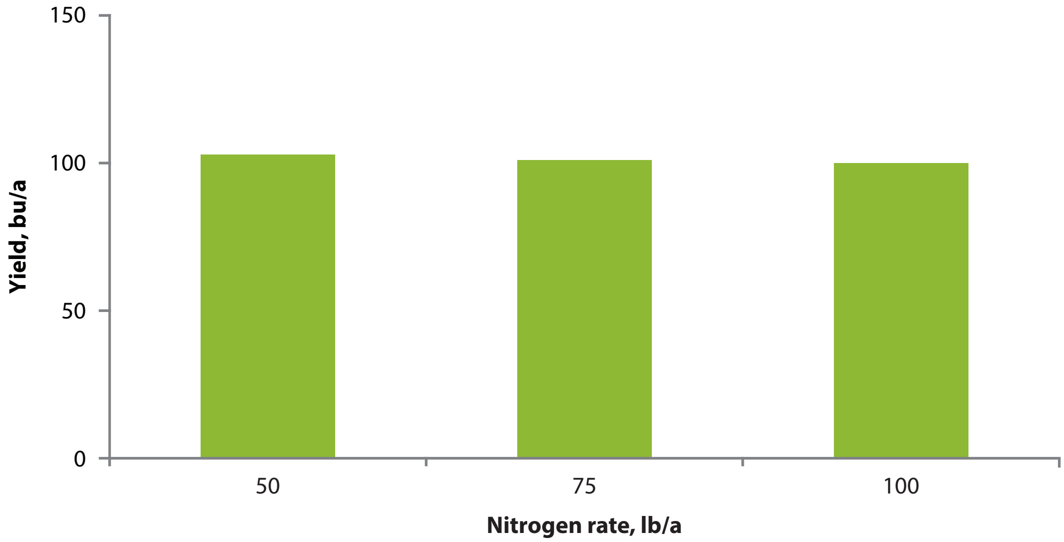

Figure 2. Grain sorghum yield affected by nitrogen rate under four drilled seeding rates and the standard planting rate in Garden City, KS (least significant difference = 6).

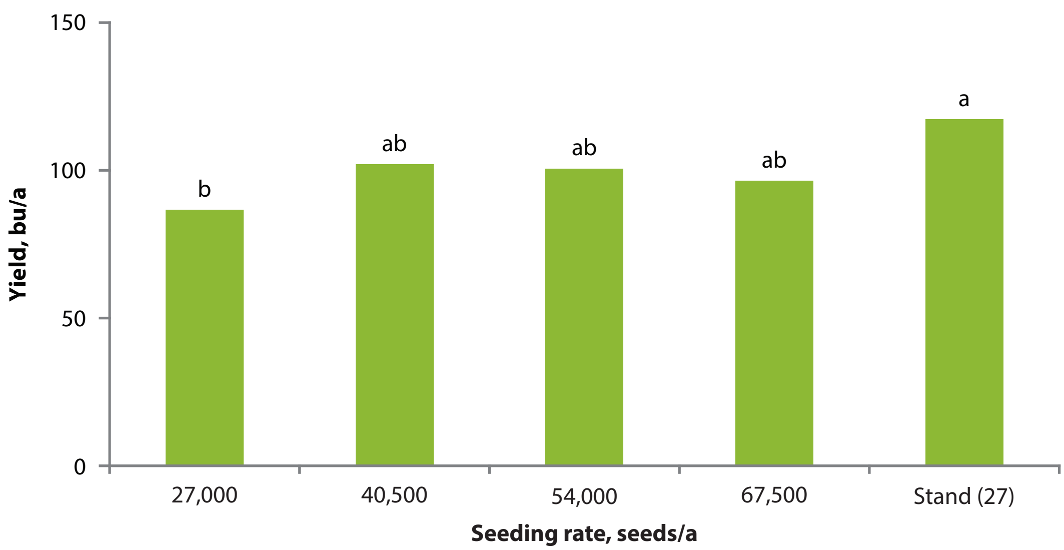

Figure 3. Grain sorghum yield affected by four drilled seeding rates and the standard planting rate at three different nitrogen rates in Garden City, KS.
[ab]Means followed by same letter are not significantly different (least significant difference = 24).

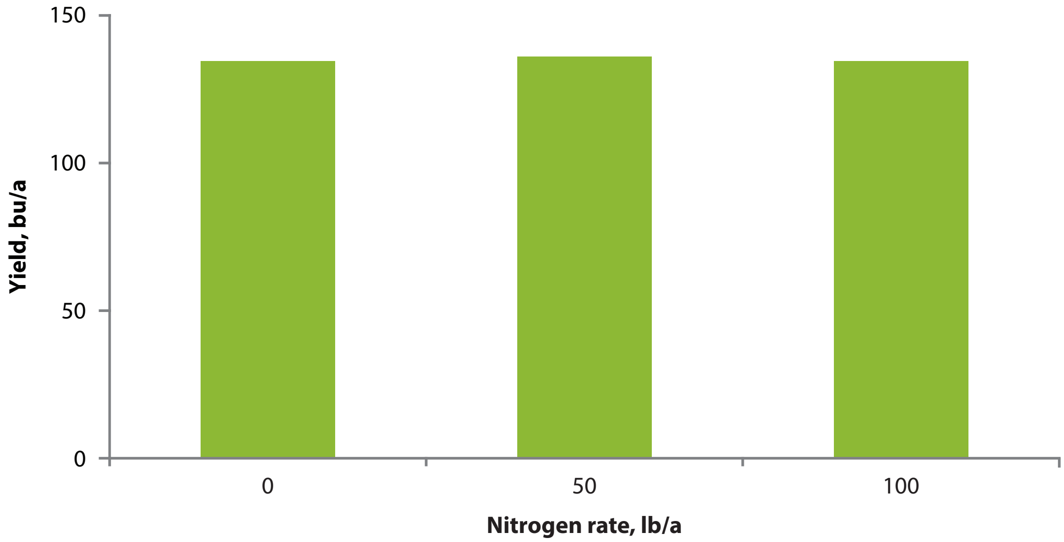

Figure 4. Grain sorghum yield affected by N rate under four drilled seeding rates and the standard planting rate in Tribune, KS (least significant difference = 4).

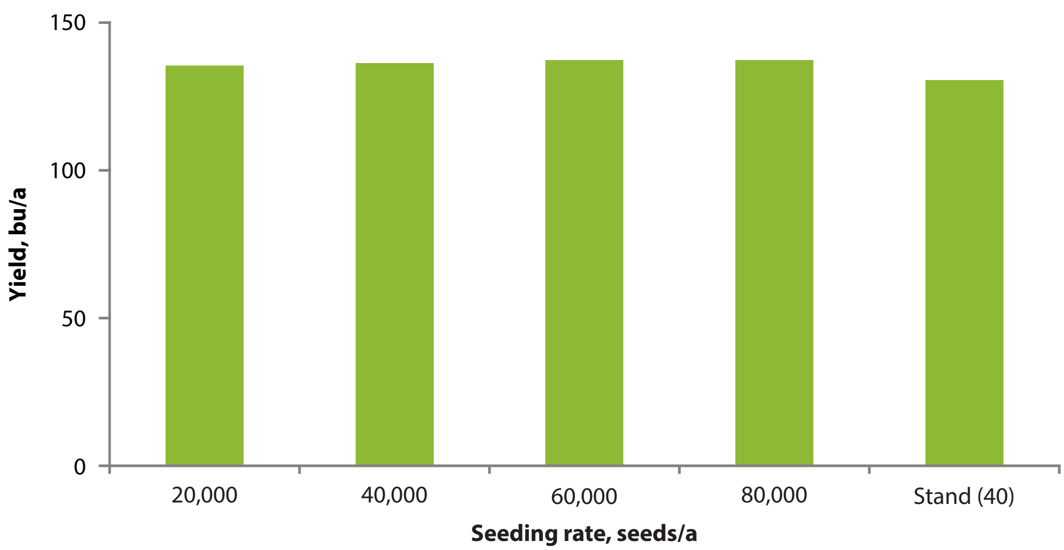

Figure 5. Grain sorghum yield affected by four drilled seeding rates and the standard planting rate averaged across three different N rates at Tribune, KS (least significant difference = 7).

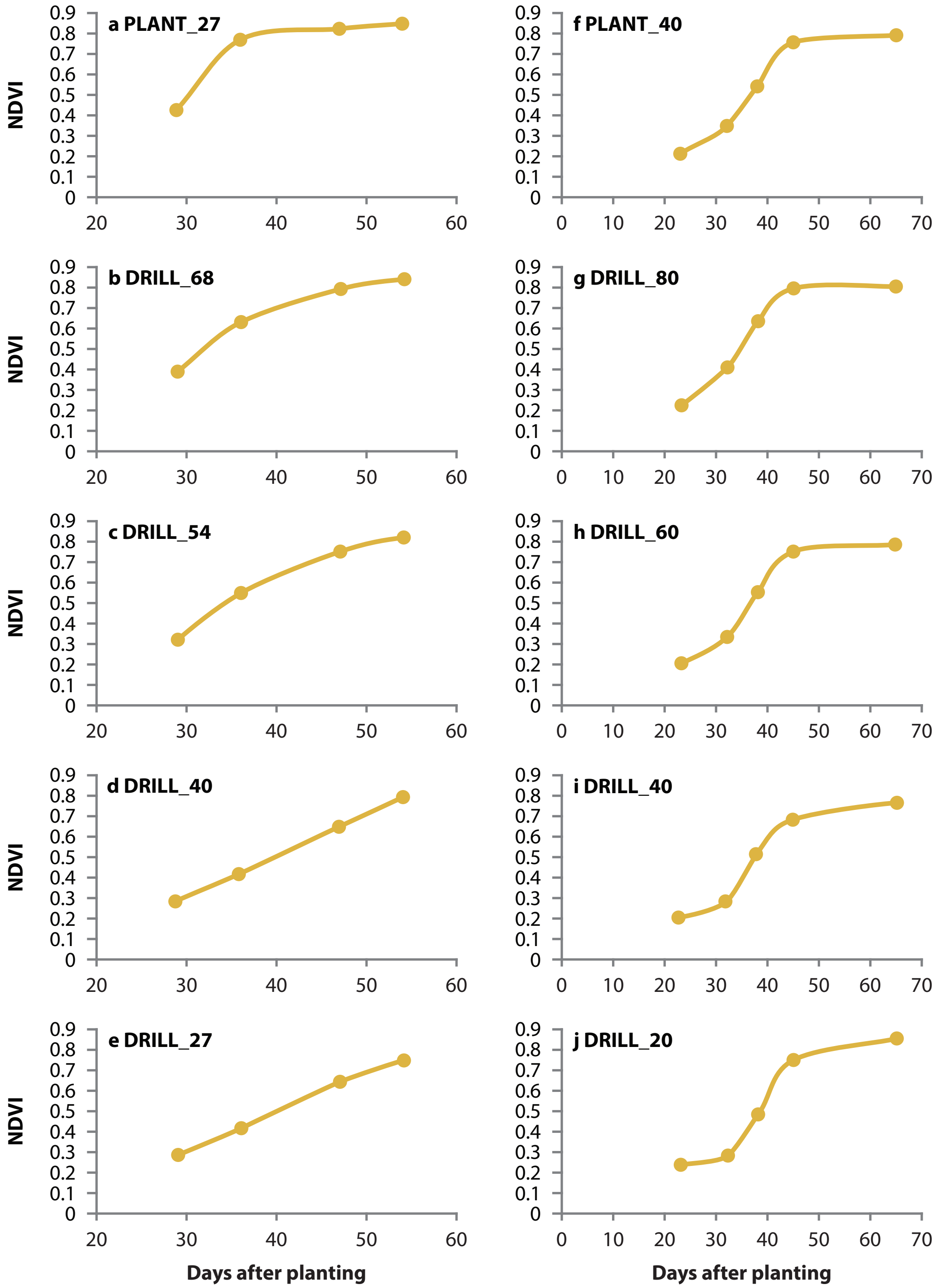

Figure 5. Normalized difference vegetation index and days after planting in relation to drilled vs. planted sorghum for both Garden City and Tribune locations used for determining the rate of canopy closure. Garden City: (a) planted sorghum at 27,000 seeds/a, (b) drilled at 67,500 seeds/a, (c) drilled at 54,000 seeds/a, (d) drilled at 40,500 seeds/a, and (e) drilled at 27,000 seeds/a. Tribune: (f) planted sorghum at 40,000 seeds/a, (g) drilled at 80,000 seeds/a, (h) drilled at 60,000 seeds/a, (i) drilled at 40,000 seeds/a, and (j) drilled at 20,000 seeds/a.

Palmer Amaranth (*Amaranthus palmeri*) Suppression with Half Rates of Dicamba and Atrazine with Increasing Sorghum (*Sorghum bicolor*) Density and Nitrogen Rate

I.B. Cuvaca, R.S. Currie, and A.J. Foster

Summary
Palmer amaranth (PA) competition can result in severe yield loss in grain sorghum. Increasing sorghum density and nutrient supply could promote early/rapid canopy closure and therefore reduce the amount of light that could otherwise penetrate the canopy and promote PA growth in sorghum. A study was conducted at the Southwest Research-Extension Center near Garden City, KS, to determine if PA could be suppressed with dicamba and atrazine applied as PRE at half rates combined with increasing sorghum density (60,000, 90,000, and 120,000 seeds/a), and nitrogen rate (0, 100, 200 lb/a). Preliminary results indicate that increasing plant density and nitrogen rate did not suppress PA growth. The increase in plant density and nitrogen (N) rate had no affect on reducing PA height, number, and biomass in plots without in-season control (hoeing). In-season control of Palmer amaranth significantly ($P < 0.01$) increased grain yield, sorghum height and number of heads, and was required to maximize yield. These results suggest that increasing plant density within the row does not reduce light penetration into sorghum canopy to suppress PA growth. Therefore, narrow-row planting will be added to the treatment structure to further determine the effect of plant density on suppressing PA in irrigated sorghum production.

Introduction
Sorghum is an important crop in Kansas. Similar to corn, sorghum is very sensitive to biological stress, especially weeds. Several studies have shown that sorghum cropping systems can suffer substantial yield loss when infested with Palmer amaranth.

This 2- to 3-year study aims to investigate the ability of integrated weed management approaches that combine cultural and chemical measures to control Palmer amaranth while maintaining or improving grain yield of sorghum. Particular research emphasis is aimed to understand the effect(s) of increasing planting density by increasing seeding rate and fertilizer rate with ultra-low herbicide applications on Palmer amaranth control and grain yield in irrigated sorghum cropping systems.

Successful completion of this project will provide a basis for a more comprehensive understanding and management of Palmer amaranth using integrated approaches as alternatives to chemical measures in irrigated sorghum cropping systems.

Procedures

Experimental Site

In 2016, field experiments were conducted at the Southwest Research-Extension Center, near Garden City, KS. The soil at the site was predominantly Richfield silt loam (fine, montmorillonitic, mesic Aridic Argiustoll).

Experimental Design

Three planting densities (60,000, 90,000, and 120,000 seeds per acre), three fertilizer rates (0, 100, and 200 pounds per acre N), and two in-season weed control levels (hoeing; weed vs. weed free) were evaluated for their ability to suppress Palmer amaranth while maintaining grain yield of sorghum using a completely randomized block design with split-split plot arrangement and four replicates. Planting density, fertilizer rate, and in-season weed control were treated as main plot, sub-plot, and sub-sub plot factors, respectively.

Plot Establishment and Management

Experimental plots were established using a John Deere MaxEmerge planter in a field with natural infestation of Palmer amaranth. Due to limited space each sub-sub plot was planted to four 22.5-ft-long rows of sorghum. The field was disked and field cultivated to assure a weed-free seedbed at planting while at the same time creating an optimum environment for both sorghum and Palmer amaranth emergence and establishment. Sorghum, "DK 3707," was planted on June 20, 2016, in rows 30 in. apart and with 8 oz of dicamba tank mixed with 1 pint atrazine + .25% v/v Induce (surfactant) was sprayed across all plots at the spike stage or after sorghum has sprouted but prior to sorghum emergence to avoid potential injury from the herbicide. No other weed species but Palmer amaranth was allowed to grow within the plots to avoid unwanted sources of variation. Further, hand-pulling and hoeing was done as necessary in plots assigned for in-season weed control. Irrigation was supplied to meet 120% of crop evapotranspiration. Sorghum was harvested at physiological maturity and yields were adjusted to 13% grain moisture.

Data Collection

Yield and other parameters, including sorghum height and headcount, Palmer amaranth number, height, and biomass were estimated from the two central rows. Other data that were measured include the normalized difference vegetation index (NDVI), which is indicative of the abundance of photosynthetically active vegetation. NDVI was measured using a hand-held Green Seeker model 505 (Trimble Navigation, Sunnyvale, CA) which is an active sensor (i.e. unaffected by time of day or night, nor cloud cover as it emits its own light), equipped with a COMPAQ iPAQ pocket PC and specific software that collects and stores NDVI data. Leaf area index (LAI) was measured using AccuPAR model LP-80 Ceptomenter (Decagon Devices, Inc., Pullman, WA) which is a portable linear array of photosynthetically active radiation sensors that together with an external sensor accurately measures LAI at any location within a plant canopy in real time without destroying the crop regardless of the ambient light conditions.

Data Analysis

Data were analyzed using SAS 9.3 (SAS Institute, Inc., Cary, NC) and Sigmaplot 12.0 software.

Results

Preliminary results indicate that increasing planting density and nitrogen rate did not suppress Palmer amaranth growth, number, and biomass (Table 1 and Figure 1), but in-season weed control (hoeing) of Palmer amaranth did increase sorghum height, number of heads, and grain yield (Table 1 and Figure 2). Increasing planting density within the row did not reduce light penetration (data not shown) into sorghum canopy enough to suppress Palmer amaranth growth. In regards to these results, narrow-row planting will be added to the treatment structure in 2017 to further determine the effect of planting density on suppressing Palmer amaranth in irrigated sorghum.

Table 1. Summary statistics; *P*-values and least significant difference (LSD) at α = .001

	Source of variation		
	P-values (LSD)		
Parameter	Planting density	Nitrogen rate	In-season weed control
Sorghum headcount	<0.001(12.306)*	0.382(12.306)	<0.001(10.048)*
Sorghum height	0.098(5.019)	0.412(5.019)	<0.001(4.098)*
Sorghum grain yield	0.886(17.088)	0.868(17.088)	<0.001(13.953)*
Palmer amaranth fresh biomass	0.217(1215.4)	0.932(1215.4)	---
Palmer amaranth dry biomass	0.232(513.29)	0.816(513.29)	---
Palmer amaranth fresh-dry biomass	0.225(726.07)	0.983(726.07)	---
Palmer amaranth height	0.569(51.065)	0.263(51.065)	---
Palmer amaranth per yd row	0.185(10.463)	0.981(10.463)	---

*Significant at .1% probability level.

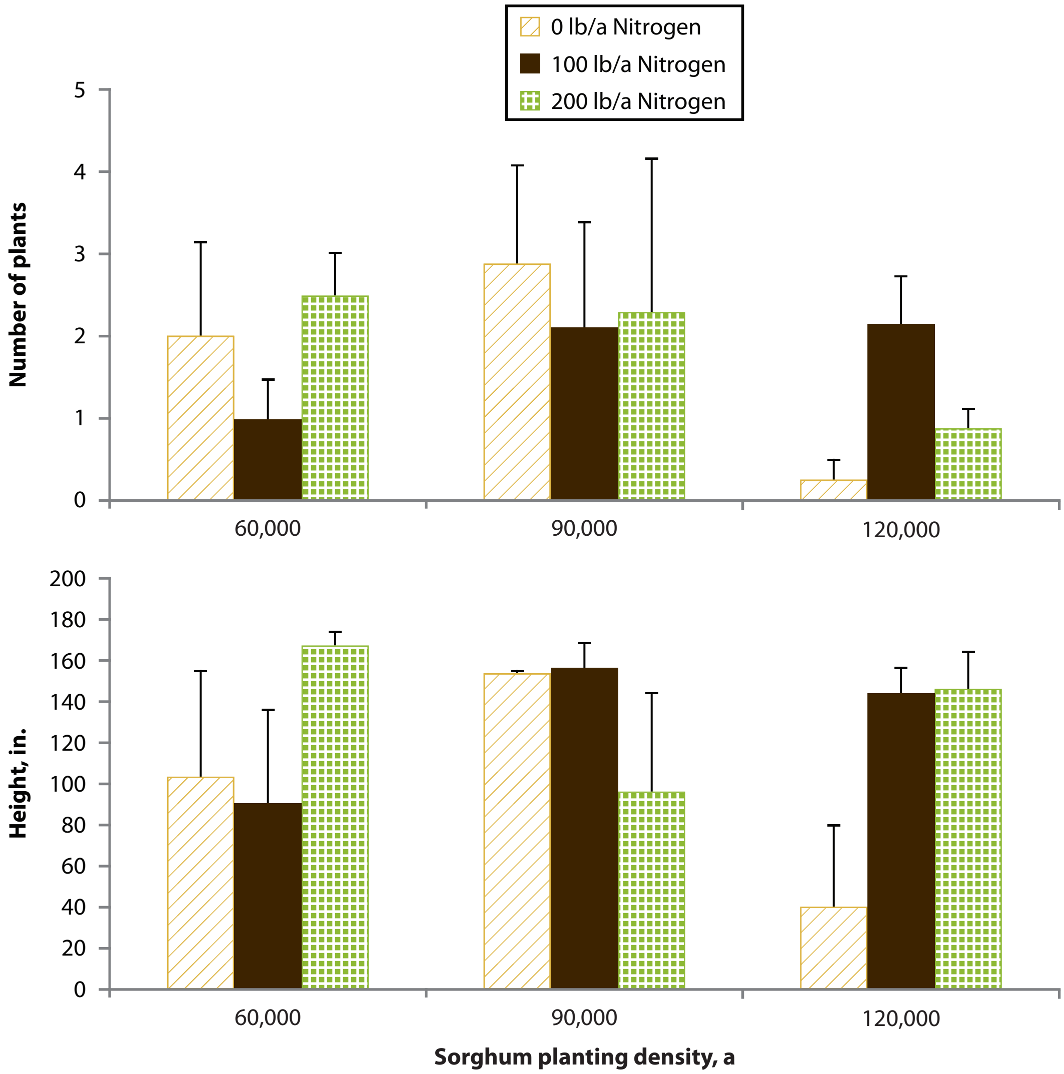

Figure 1. Palmer amaranth number (A) and height (B) by sorghum planting density and nitrogen rate.

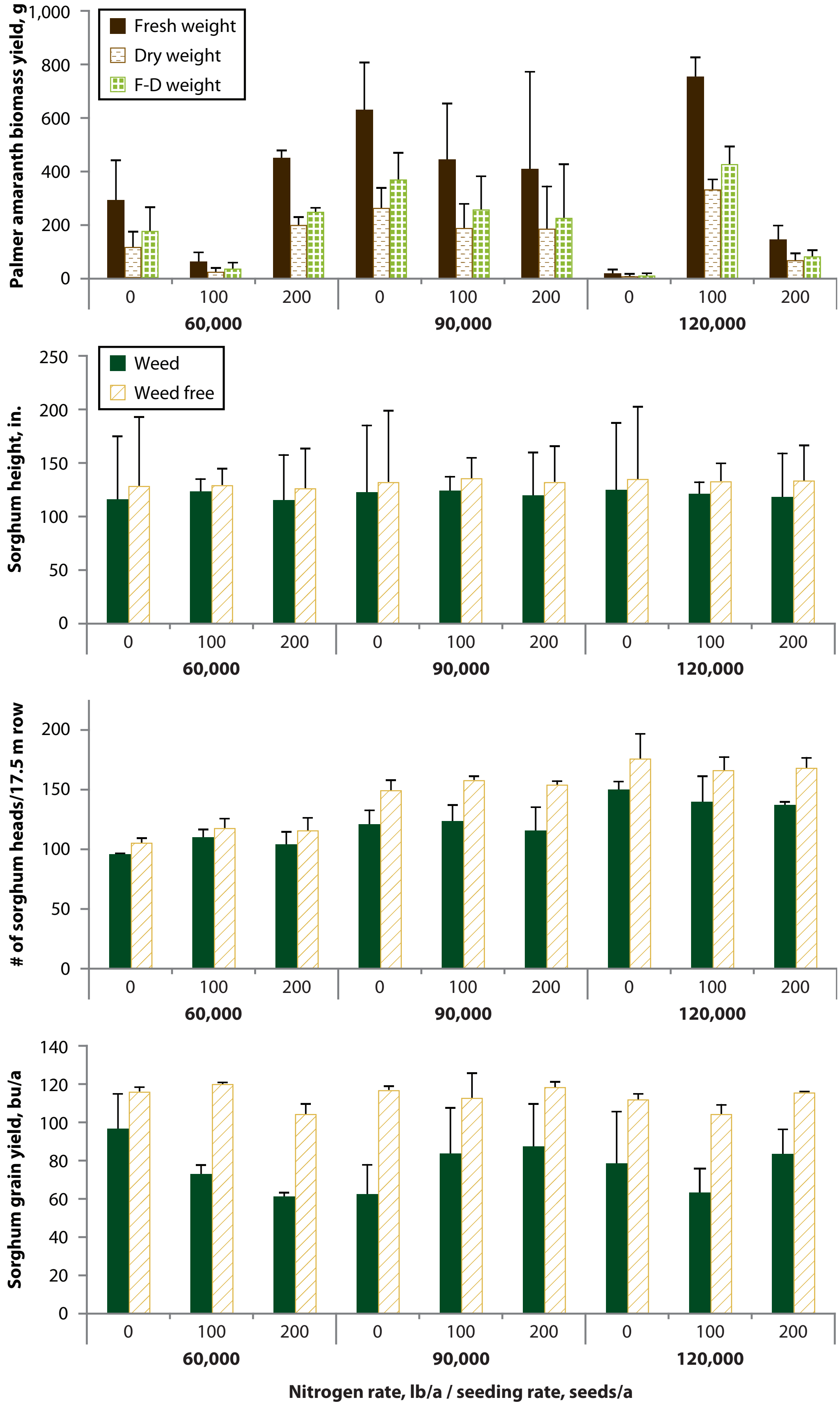

Figure 2. (A) Palmer amaranth biomass, (B) sorghum height, (C) headcount, and (D) grain yield by sorghum planting density and nitrogen rate.

Kansas Fertilizer Research 2017

Chemical Disclaimer

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Experiments with pesticides on nonlabeled crops or target species do not imply endorsement or recommendation of nonlabeled use of pesticides by Kansas State University. All pesticides must be used consistent with current label directions. Current information on weed control in Kansas is available in *2017 Chemical Weed Control for Field Crops, Pastures, Rangeland, and Noncropland*, Report of Progress 1132, available from the Distribution Center, Umberger Hall, Kansas State University, or at: ***https://www.bookstore.ksre.ksu.edu/*** (type Chemical Weed Control in search box).

Publications from Kansas State University are available at: ***www.ksre.ksu.edu***

KANSAS STATE UNIVERSITY AGRICULTURAL EXPERIMENT STATION AND COOPERATIVE EXTENSION SERVICE

K-State Research and Extension is an equal opportunity provider and employer.

June 2017