Kansas Fertilizer Research 2020

D. A. Ruiz Diaz
Kansas State University, ruizdiaz@ksu.edu

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Abstract

A summary of research conducted in 2018-2020 on fertilizer use and management practices for crops in Kansas. Published in 2020 from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service https://www.ag.k-state.edu/.

Keywords

fertilizer, tillage, nitrogen, phosphorus, irrigation, sorghum, wheat, sulfur, corn, soybean

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2020 Fertilizer Report Contributors

Philip Barnes, Emeritus Research Engineer, Dept. of Biological and Agricultural Engineering, Manhattan

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

Carlos A. Bonini Pires, Graduate Student, Dept. of Agronomy, Manhattan

Diego A. Charbonnier, Graduate Research Assistant, Dept. of Agronomy, Manhattan

Marta .J.A. Coelho, Postdoctoral Research Associate, Dept. of Agronomy, Manhattan

Will Davis, Graduate Student, Dept. of Agronomy, Manhattan

Jaymelynn K. Farney, Associate Professor, Beef Systems Specialist, Southeast Research-Extension Center, Parsons

Mary Guttieri, Adjunct Assistant Professor, Plant Research Geneticist, Dept. of Agronomy, Manhattan

John D. Holman, Professor, Cropping Systems Agronomist, Southwest Research-Extension Center, Garden City

Tyler E. Husa, Graduate Research Assistant, Dept. of Agronomy, Manhattan

Brent R. Jaenisch, Graduate Student, Dept. of Agronomy, Manhattan

Mary Knapp, Service Climatologist, Dept. of Agronomy, Manhattan

James S. Lin, Graduate Student, Dept. of Agronomy, Manhattan

Romulo P. Lollato, Assistant Professor, Wheat and Forages Extensions Specialist, Dept. of Agronomy, Manhattan

Kavan E. Mark, Assistant Scientist, Dept. of Agronomy, Manhattan

Joe L. Moyer, Professor Emeritus, Forage Research, Southeast Research-Extension Center, Parsons

Nathan O. Nelson, Professor, Soil Fertility and Nutrient Management, Dept. of Agronomy, Manhattan

Augustine K. Obour, Assistant Professor, Soil Scientist, Agriculture Research Center, Hays

Gary Pierzynski, Professor, Dept. of Agronomy, Manhattan

Charles W. Rice, Distinguished Professor, Soil Microbiology, Dept. of Agronomy, Manhattan

Kraig L. Roozeboom, Professor, Cropping Systems, Dept. of Agronomy, Manhattan

Dorivar A. Ruiz Diaz, Professor, Soil Fertility and Nutrient Management, Dept. of Agronomy, Manhattan

E. Bryan Rutter, Graduate Research Assistant, Dept. of Agronomy, Manhattan

Alan J. Schlegel, Professor, Soil Management, Southwest Research-Extension Center, Tribune

Dan W. Sweeney, Professor, Soil and Water Management, Southeast Research-Extension Center, Parsons

Chris Weber, Graduate Research Assistant, Dept. of Agronomy, Manhattan

Tara Wilson, Graduate Student, Dept. of Agronomy, Manhattan

2018–2019 Precipitation Data

Month	Manhattan	SWREC Tribune	SEREC Parsons	ECK Exp. Field Ottawa	Ashland Bottoms
			--- in. ---		
2018					
August	7.47	3.11	8.76	8.13	6.65
September	7.29	1.52	3.35	3.13	5.02
October	6.30	3.42	5.01	10.52	5.88
November	1.36	0.39	1.76	1.32	0.75
December	2.95	0.95	2.98	2.56	2.48
Total 2018	37.88	19.64	41.94	39.80	32.27
Departure from normal	+3.08	+1.74	-1.03	-0.50	-0.28
2019					
January	0.73	0.96	2.27	3.22	1.23
February	1.71	1.16	1.53	1.85	1.29
March	2.51	2.00	3.00	3.19	2.44
April	1.68	0.20	2.78	4.39	2.20
May	14.12	3.73	19.27	15.31	12.10
June	7.11	2.60	7.23	7.66	5.71
July	4.33	3.84	3.21	1.65	2.30
August	10.19	2.29	14.59	18.29	8.60
September	4.88	1.15	8.00	4.15	2.35

continued

Month	NCK Exp. Field Belleville	KRV Exp. Field	SCK Exp. Field Hutchinson	ARC-Hays	Girard
	--- in. ---				
2018					
August	4.20	3.67	3.14	5.33	9.98
September	5.09	1.87	4.43	3.84	1.06
October	5.72	7.03	9.18	6.73	5.36
November	1.37	0.81	0.81	0.82	1.65
December	3.41	3.29	2.62	2.29	2.88
Total 2018	36.71	27.78	39.78	37.55	41.22
Departure from normal	+6.11	-7.86	+9.17	+14.10	-4.50
2019					
January	0.66	1.12	0.70	0.88	1.57
February	1.19	1.12	1.21	0.77	2.59
March	2.23	2.77	1.77	1.10	4.19
April	0.85	3.88	1.54	0.80	2.62
May	8.91	11.28	10.62	8.06	19.47
June	5.95	4.53	3.95	1.90	9.24
July	4.48	4.77	0.47	0.95	5.11
August	7.73	9.20	6.36	10.64	8.74
September	2.65	2.53	0.31	1.69	9.21

SWREC = Southwest Research-Extension Center; SEREC = Southeast Research-Extension Center; ECK = East Central Kansas; NCK = North Central Kansas; KRV = Kansas River Valley; SCK = South Central Kansas; ARC = Agricultural Research Center.

Nitrogen Fertilizer Timing and Phosphorus and Potassium Fertilization Rates for Established Endophyte-Free Tall Fescue

D.W. Sweeney, J.K. Farney, and J.L. Moyer

Summary

A tall fescue production study was conducted at two locations, beginning in the fall of 2016 and the fall of 2017. At both sites, phosphorus (P) fertilization rate only affected the spring harvest, with few differences in yield. Applying nitrogen (N) in late fall or late winter resulted in greater spring yields than applying N in spring or not applying N. However, at Site 1 in 2017 fall harvest yields were greater from the spring N application, but this response was less at Site 2 in 2018. In both years, applying N increased tall fescue yield, but at Site 2 the yield differences from N timings were greater.

Introduction

Tall fescue is the major cool-season grass in southeastern Kansas. Perennial grass crops, as with annual row crops, rely on proper fertilization for optimum production; however, meadows and pastures are often under-fertilized and produce low quantities of low-quality forage. The objective of this study was to determine the effect of N fertilizer timing and P and potassium (K) fertilization rates on tall fescue yields.

Experimental Procedures

The experiment was conducted on two adjacent sites of established endophyte-free tall fescue in the fall of 2016 (Site 1) and 2017 (Site 2) at the Parsons Unit of the Kansas State University Southeast Research and Extension Center. The soil at both sites was a Parsons silt loam. The experimental design was a split-plot arrangement of a randomized complete block. The six whole plots received combinations of P_2O_5 and K_2O fertilizer rates allowing for two separate analyses: 1) four rates of P_2O_5 consisting of 0, 25, and 50 lb/a each year and a fourth treatment of 100 lb/a only applied at the beginning of the study; and 2) a 2 × 2 factorial combination of two rates of P_2O_5 (0 and 50 lb/a) and two levels of K_2O (0 and 40 lb/a). Subplots were four application timings of N fertilization consisting of none, late fall, late winter, and spring (E2 growth stage). Phosphorus and K fertilizers were broadcast applied in the fall as 0-46-0 (triple superphosphate) and 0-0-60 (potassium chloride). Nitrogen, as 46-0-0 (urea) solid at 120 lb N/a, was broadcast applied to appropriate plots on December 6, 2016, March 8, 2017, and April 19, 2017 at Site 1. Nitrogen was applied on December 1, 2017, March 2, 2018, and April 27, 2018 at Site 2. First-year harvest dates from each site were as follows: 1) spring yield was measured at R4 (half bloom) on May 15, 2017, at Site 1 and on May 17, 2018, at Site 2; 2) fall harvest was taken on September 13, 2017, at Site 1 and on September 12, 2018, at Site 2.

Results and Discussion

In the first year of the study at Site 1, spring harvest yield of tall fescue in 2017 was increased with 25 lb P_2O_5/a, but yield did not increase with greater P rates (Table 1).

Fall harvest was unaffected by P rate so that the total annual production mirrored the response measured in the spring harvest. Spring harvest yield was greatest when N was applied either in late fall or late winter. Even though applying N fertilizer at the E2 growth stage in spring resulted in greater yield than with no N, delaying N application resulted in more than a 50% reduction in spring yield compared with the more traditional timings of either late fall or late winter. However, at the fall harvest tall fescue yield was greater from spring N applications compared with no N or N applied in either late fall or late winter. Thus, average annual total tall fescue yields were more than doubled by applying N. However, the differences in total yield from different N application timings were small with only late fall N application resulting in a 0.3 ton/a greater yield than applying N in the spring.

Dry conditions in 2018 resulted in low, first-year tall fescue yields at Site 2 (Table 2). Tall fescue yield was greater with 50 or 100 lb P_2O_5/a than with no P, but the average differences were less than 0.2 ton/a. Phosphorus fertilization rates had no effect on the fall or total harvest yields. Spring tall fescue yield was greatest with late fall fertilization. However, as for the first year at Site 1 (Table 1), both late fall and late winter N fertilization in the first year at Site 2 resulted in greater spring yield than with no N or N applied at the E2 growth stage in spring (Table 2). In contrast to results from Site 1 (Table 1), spring N application did not result in greater fall yield than with no N and only yielded 0.19 to 0.24 ton/a more than with late fall or late winter fertilization (Table 2). At Site 2, the first-year tall fescue yield rank as affected by N fertilizer timing was late fall>late winter>spring>no N.

Table 1. First-year yield of established tall fescue in the spring (R4-half bloom) and fall 2017 as affected by P₂O₅ fertilization rates and nitrogen (N) application timing at Site 1

Treatment	Spring harvest	Fall harvest	Total harvest (R4 + Fall)
P_2O_5 (lb/a)	------------------------- ton/a, 12% moisture -------------------------		
0	0.69	1.32	2.01
25	1.11	1.41	2.53
50	1.08	1.35	2.43
100[1]	1.19	1.23	2.42
LSD (0.10)	0.18	NS	0.34
N application timing			
None	0.20	1.03	1.23
Late fall	1.68	1.16	2.84
Late winter	1.57	1.22	2.78
Spring	0.63	1.91	2.54
LSD (0.05)	0.14	0.21	0.29

[1]The 100 lb P_2O_5/a rate was only applied at the beginning of the study (Fall 2016).

Table 2. First-year yield of established tall fescue in the spring (R4-half bloom) and fall 2018 as affected by P₂O₅ fertilization rates and nitrogen (N) application timing at Site 2

Treatment	Spring harvest	Fall harvest	Total harvest (R4 + Fall)
P_2O_5 (lb/a)	----------------- ton/a, 12% moisture ----------------		
0	0.80	0.72	1.53
25	0.87	0.76	1.64
50	0.90	0.72	1.62
100[1]	0.97	0.84	1.81
LSD (0.10)	0.10	NS	NS
N application timing			
None	0.17	0.88	1.06
Late fall	1.31	0.67	2.17
Late winter	1.19	0.62	1.92
Spring	0.53	0.86	1.45
LSD (0.05)	0.09	0.13	0.13 [1]

The 100 lb P_2O_5/a rate was only applied at the beginning of the study (Fall 2017).

Tillage and Nitrogen Placement Effects on Yields in a Short-Season Corn/Wheat/Double-Crop Soybean Rotation

D.W. Sweeney and D. Ruiz-Diaz

Summary

In 2018, adding nitrogen (N) greatly improved average wheat yields with about a 10% increase with knife compared to broadcast application methods. Even though tillage did not affect wheat yields, soybean yield was about 10% greater with no-till.

Introduction

Many crop rotation systems are used in southeastern Kansas. This experiment is designed to determine the long-term effect of selected tillage and N fertilizer placement options on yields of short-season corn, wheat, and double-crop soybean in rotation.

Experimental Procedures

A split-plot design with four replications was initiated in 1983 with tillage system as the whole plot and N treatment as the subplot. In 2005, the rotation was changed to begin a short-season corn/wheat/double-crop soybean sequence. Use of three tillage systems (conventional, reduced, and no-till) continued in the same whole plots as the previous 22 years. The conventional system consisted of chiseling, disking, and field cultivation. Chiseling occurred in the fall preceding corn or wheat crops. The reduced-tillage system consisted of disking and field cultivation prior to planting. Glyphosate was applied to the no-till areas prior to planting. The four N treatments for the crop were: no-N (control) and N fertilizer placement as broadcast, dribble (surface band), and knife (subsurface band at 4 inches deep) UAN (28% N) solution. The N rate for the corn crop grown in odd-numbered years was 125 lb/a. The N rate of 120 lb/a for wheat was split as 60 lb/a applied pre-plant as broadcast, dribble, or knifed UAN. All plots except for the no-N controls were top-dressed in the spring with broadcast UAN at 60 lb/a N.

Results and Discussion

In 2018, tillage system did not affect wheat yield (Table 1). Overall, fertilizing with N quadrupled wheat yield. Preplant N application by knifing resulted in 10% greater wheat yield than with broadcast, with dribble application resulting in intermediate yields. The average yield of soybean planted doublecrop after wheat harvest was nearly 50 bu/a in 2018 and no-till was about 10% greater than with tillage. There was no residual effect on soybean yields from N applied by different pre-plant methods to the previous wheat crop.

Table 1. Effect of tillage and fall nitrogen (N) fertilization on yield of wheat and following double-crop soybean in 2018

Treatment	Wheat yield	Double-crop soybean yield
	---------------------------- bu/a -----------------------------	
Tillage		
Conventional	31.2	46.5
Reduced	29.7	46.4
No-till	31.9	50.9
LSD (0.05)	NS	3.8
N Fertilization		
No-N control	9.0	48.0
Broadcast UAN†	38.2	48.5
Dribble UAN	40.4	48.9
Knife UAN	42.2	46.4
LSD (0.05)	3.0	NS

†UAN: urea-ammonium nitration solution, 28% N.

Pre-Plant Nitrogen Rate and Application Method and Side-Dress Nitrogen Rate Effects on Corn Grown No-Till on a Claypan Soil

D.W. Sweeney and D. Ruiz-Diaz

Summary

Corn yield in 2018 was increased by about 5 bu/a with knife application of pre-plant nitrogen (N) fertilizer compared with broadcast application. Fertilizing with increasing rates of N applied pre-plant, at side-dress, or both had little effect on yield or yield components of corn in 2018.

Introduction

Environmental conditions vary widely in the spring in southeastern Kansas. As a result, much of the N applied prior to corn planting may be lost before the time of maximum plant N uptake. Pre-plant N application method, pre-plant N rate, and side-dress N rate selection to provide N during rapid growth periods may improve N use efficiency while reducing potential losses to the environment. The objective of this study was to determine the effect of timing of pre-plant and side-dress N fertilization options on corn grown on a claypan soil.

Experimental Procedures

The experiment was established in spring 2018 on a Parsons silt loam soil at the Parsons Unit of the Kansas State University Southeast Research and Extension Center that had been in continuous no-till for more than 10 years. The experiment was a factorial arrangement of a randomized complete block design with four blocks (replications). The two factors were pre-plant N fertilizer placement of broadcast and knife (subsurface band at 4 inches deep) and pre-plant/side-dress N rates of 0-0, 0-150, 100-0, 100-50, 100-100, 150-0, 150-50, 150-100, and 200-0 lb/a. Side-dress applications were broadcast at the V10 growth stage using 7-stream pattern fertilizer nozzles. The N source for all treatments was liquid urea-ammonium nitrate (UAN; 28% N) fertilizer. Pre-plant N fertilizer was applied on March 12, 2018, and side-dress N was applied at V10 on June 4, 2018, to appropriate plots. Corn was planted on April 10 and harvested on August 28, 2018.

Results and Discussion

Even though individual yield components were not significantly affected by pre-plant N application method, general trends resulted in more than 5 bu/a greater corn yields when N was knife applied rather than broadcast prior to planting (Table 1). In general, applying N at any rate and time resulted in approximately 50% greater corn yield in 2018 than the 75.6 bu/a in the no-N control. However, there were few differences in yield among the eight treatments receiving N fertilizer. For example, general increases in total N applied, as well as applying no N until the V10 growth stage (0-150 lb/a

pre-plant/side-dress N rate), had little effect on yield in 2018. Stand was not affected by pre-plant/side-dress N rates, but fertilizing with N increased kernel weight, the number of ears/plant, and the number of kernels/ear compared with corn grown in the no-N control.

Table 1. Pre-plant application method and pre-plant/side-dress nitrogen (N) rates effects on yield and yield components of corn planted no-till on a claypan soil in 2018

Treatment	Yield	Stand	Kernel weight	Ears/plant	Kernels/ear
	bu/a	plants/a	mg		
Pre-plant N method					
Broadcast	101.1	16600	253	1.07	622
Knife[1]	115.6	17200	249	1.10	634
LSD (0.10)	4.4	NS	NS	NS	NS
Pre-plant/side-dress[2]					
N rates (lb/a)					
0-0 (No-N control)	75.6	16700	227	1.00	521
0-150	113.2	16000	263	1.05	675
100-0	110.8	16600	249	1.11	625
100-50	116.8	17500	259	1.06	637
100-100	115.3	17300	256	1.13	638
150-0	114.5	16600	251	1.12	643
150-50	114.3	16800	257	1.14	641
150-100	121.2	16600	254	1.13	665
200-0	111.3	17800	243	1.06	609
LSD (0.05)	9.5	NS	15	0.11	70

[1]Knife: subsurface band at 4 inch depth.
[2]Side-dress applications were made at the V10 growth stage.

Response of Soybean Grown on a Claypan Soil in Southeastern Kansas to the Residual of Different Plant Nutrient Sources and Tillage[1]

D.W. Sweeney, P. Barnes,[2] and G. Pierzynski[3]

Summary

The residual from previous high-rate turkey litter applications, which were based on nitrogen (N) requirements of the previous grain sorghum crop, increased 2018 soybean yield more than that obtained from the residual of phosphorus (P)-based turkey litter applications (low rate), commercial fertilizer, or the control. Even though early soybean growth was sporadically affected by residual treatments, the dry matter production at the R6 growth stage tended to be where the N-based litter was applied.

Introduction

Increased fertilizer prices in recent years–especially noticeable when the cost of phosphorus spiked in 2008–have led U.S. producers to consider other alternatives, including manure sources. The use of poultry litter as an alternative to fertilizer is of particular interest in southeastern Kansas because large amounts of poultry litter are imported from nearby confined animal feeding operations in Arkansas, Oklahoma, and Missouri. Annual application of turkey litter can affect the current crop, but information is lacking concerning any residual effects from several continuous years of poultry litter applications on a following crop. This is especially true for tilled soil compared with no-till because production of most annual cereal crops on the claypan soils of the region is often negatively affected by no-till planting. The objective of this study was to determine if the residual from fertilizer and poultry litter applications under tilled or no-till systems affects soybean yield and growth.

Experimental Procedures

A water quality experiment was conducted near Girard, KS, on the Greenbush Educational facility's grounds from spring 2011 through spring 2014. Fertilizer and turkey litter based on rates of 120 lb N/a and 50 lb P_2O_5/a were applied prior to planting grain sorghum each spring. Individual plot size was 1 acre. The five treatments, replicated twice, were:

1. Control: no N or P fertilizer or turkey litter – no tillage;
2. Fertilizer only: commercial N and P fertilizer – chisel-disk tillage;
3. Turkey litter, N-based: no extra N or P fertilizer – no tillage;
4. Turkey litter, N-based: no extra N or P fertilizer – chisel-disk tillage; and
5. Turkey litter, P-based: supplemented with fertilizer N – chisel-disk tillage.

Starting in 2014 after the previously-mentioned study, soybean was planted with no further application of turkey litter or fertilizer. Prior to planting soybean, tillage operations were done in appropriate plots as in previous years. A sub-area of 20 × 20 ft near the center of each 1-acre plot was designated for crop yield and growth measurements. Samples were taken for dry matter production at V3-V4 (approximately 3 weeks after planting), R2, R4, and R6 growth stages. Yield was determined from the center 4 rows (10 × 20 ft) of the sub-area designated for plant measurements in each plot.

Results and Discussion

In 2018, the residual effects of turkey litter and fertilizer amendments affected soybean yield, stand, pods/plant, and dry matter production (Table 1). The two treatments which had previously received a high application rate of turkey litter based on N requirements, regardless of tillage system, resulted in greater yields than from plots that had received low rates of turkey litter (P-based), commercial fertilizer, or no fertilizer N or P. The number of pods/plant were greater where N-based turkey litter had been applied in no-till than where fertilizer, a low rate of turkey litter, or no fertilizer or litter had been applied. In addition, stand was slightly improved where fertilizer or the high rates of turkey litter had been applied. The effect of residual treatments on soybean dry matter production was sporadic. However, by R6, dry matter production was greater where turkey litter had previously been applied on an N-basis (high rate) than on a P-basis (low rate), with dry matter from the fertilizer treatment being intermediate.

Table 1. Residual effect of turkey litter and fertilizer amendments on soybean yield, yield components, and dry matter production during 2018

Residual amendment[1]	Yield	Stand (×1000)	Seed weight	Pods/ plant	Seeds/ pod	Dry matter			
						V3	R2	R4	R6
	bu/a	plants/a	mg			---------------- lb/a ----------------			
Control	25.5	96	143	33	2.0	60	790	2410	3530
Fert-C	41.3	102	150	3743	2.2	100	1440	2900	5150
TL-N	59.8	100	138	5160	2.2	100	1300	2830	6440
TL-N-C	63.0	103	146	4353	2.2	110	2370	4200	6530
TL-P-C	33.9	96	157	3134	2.0	80	1190	2570	3870
LSD (0.05)	15.6	4	NS	13	NS	NS	760	NS	1600

[1]Control, no turkey litter or N and P fertilizer with no tillage; TL-N, N-based turkey litter application with no tillage; TL-N-C, N-based turkey litter application incorporated with conventional tillage; TL-P-C, P-based turkey litter application and supplemental N application incorporated with conventional tillage; and Fert-C, commercial fertilizer incorporated with conventional tillage.

Long-Term Nitrogen, Phosphorus, and Potassium 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 2019, N applied alone increased yields by 66 bu/a, whereas N and P applied together increased yields up to 85 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields up to 78 bu/a. Application of 160 lb/a N (with P) produced the maximum yield in 2019, which is slightly more than the 10-year 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 0.16 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 31% for N, 65% for P, and 38% 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 Kansas State University Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 were 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. Grain sorghum (Pioneer 85G46 in 2010-2011, Pioneer 84G62 in 2012–2014, Pioneer 86G32 in 2015, Pioneer 84G62 in 2016–2017, and Pioneer 85P44 in 2018–2019) 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 2019 were 3% lower than the 10-year average (Table 1). Nitrogen alone increased yields by 66 bu/a while P alone increased yields 6 bu/a. However, N and P applied together increased yields up to 85 bu/a. Averaged across the past 10 years, N and P applied together increased yields up to 78 bu/a. In 2019, 40 lb/a N (with P) produced about 74% of maximum yield, which is less than the 10-year average of 83%. The 10-year average for 80 lb/a N (with P) and 120 lb/a N (with P) was 93 and 94% 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 22 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 22 to 26 lb/a. At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 31% for N, 65% for P, and 38% for K.

Acknowledgment

Table 1. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2010–2019

Fertilizer			Yield										
N	P_2O_5	K_2O	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean
------------ lb/a ------------			--- bu/a ---										
0	0	0	51	75	78	62	90	89	80	70	77	68	74
0	40	0	51	83	90	77	94	102	91	79	87	74	83
0	40	40	55	88	93	72	96	97	91	80	83	67	82
40	0	0	66	106	115	94	115	122	106	87	93	94	100
40	40	0	77	121	140	114	144	160	142	120	126	113	126
40	40	40	73	125	132	110	142	155	137	118	131	114	124
80	0	0	73	117	132	102	120	133	120	104	103	109	111
80	40	0	86	140	163	136	151	173	154	123	144	145	141
80	40	40	84	138	161	133	164	178	160	129	140	139	143
120	0	0	70	116	130	100	116	127	108	93	91	102	105
120	40	0	88	145	172	137	162	177	164	121	128	139	143
120	40	40	90	147	175	142	170	178	170	131	143	150	150
160	0	0	74	124	149	117	139	150	135	120	107	129	124
160	40	0	92	152	178	146	171	181	173	137	134	153	152
160	40	40	88	151	174	143	176	179	161	131	139	142	148
200	0	0	78	128	147	119	139	155	151	123	121	134	130
200	40	0	84	141	171	136	165	177	167	131	134	140	145
200	40	40	87	152	175	138	170	179	170	131	130	149	148

Table 1. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2010–2019

Fertilizer			Yield											
N	P_2O_5	K_2O	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	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			0.892	0.278	0.826	0.644	0.117	0.806	0.943	0.727	0.549	0.789	0.726
N × P-K			0.229	0.542	0.186	0.079	0.012	0.002	0.001	0.084	0.003	0.001	0.001
MEANS													
Nitrogen, lb/a													
0			52 c	82 d	87 d	70 d	94 e	96 d	87 d	76 d	82 c	70 d	80 d
40			72 b	117 c	129 c	106 c	134 d	146 c	129 c	108 c	117 b	107 c	116 c
80			81 a	132 b	152 b	124 b	145 c	161 b	145 b	119 b	129 a	131 b	132 b
120			82 a	136 ab	159 ab	126 b	149 bc	161 b	147 b	115 bc	121 ab	130 b	133 b
160			84 a	142 a	167 a	135 a	162 a	170 a	156 a	129 a	127 a	142 a	142 a
200			83 a	141 a	165 a	131 ab	158 ab	170 a	163 a	129 a	128 a	141 a	141 a
LSD$_{(0.05)}$			5	8	9	8	9	8	8	9	9	7	6
P_2O_5-K_2O, lb/a													
0 - 0			68 b	111 b	125 b	99 b	120 b	129 b	117 b	99 b	99 b	106 b	107 b
40 - 0			80 a	130 a	152 a	124 a	148 a	162 a	149 a	119 a	126 a	127 a	132 a
40 - 40			79 a	133 a	152 a	123 a	153 a	161 a	148 a	120 a	128 a	127 a	132 a
LSD$_{(0.05)}$			4	6	6	5	6	5	6	6	6	5	4

**Note: Hail events on 7/23/2010, 5/28/2015, 8/18/2017, and 9/20/2019.
ANOVA = analysis of variance. LSD = least significant difference.

Table 2. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on grain nutrient content and removal by irrigated grain sorghum, Tribune, KS, 2010–2019

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/a -------------			----------------- % -----------------		
0	0	0	1.04	0.251	0.354	0.51	0.123	0.173	37	9	13	---	---	---
0	40	0	1.03	0.313	0.380	0.51	0.153	0.186	41	13	15	---	21	---
0	40	40	1.03	0.311	0.380	0.50	0.152	0.186	41	12	15	---	20	7
40	0	0	1.15	0.227	0.341	0.56	0.111	0.167	55	11	17	45	---	---
40	40	0	1.11	0.315	0.368	0.54	0.155	0.180	68	19	23	76	60	---
40	40	40	1.11	0.309	0.364	0.54	0.152	0.178	67	19	22	73	56	28
80	0	0	1.35	0.212	0.337	0.66	0.104	0.165	73	12	18	44	---	---
80	40	0	1.21	0.293	0.352	0.60	0.144	0.173	83	20	24	57	64	---
80	40	40	1.19	0.305	0.356	0.58	0.149	0.174	83	21	25	56	70	37
120	0	0	1.41	0.196	0.334	0.69	0.096	0.164	72	10	17	29	---	---
120	40	0	1.31	0.279	0.350	0.64	0.137	0.172	91	19	25	45	60	---
120	40	40	1.32	0.300	0.354	0.65	0.147	0.173	96	22	26	49	74	39
160	0	0	1.40	0.224	0.342	0.69	0.110	0.167	85	14	21	30	---	---
160	40	0	1.39	0.301	0.354	0.68	0.148	0.173	103	22	26	41	76	---
160	40	40	1.36	0.276	0.349	0.67	0.135	0.171	98	20	25	38	63	38
200	0	0	1.41	0.230	0.346	0.69	0.113	0.169	89	15	22	26	---	---
200	40	0	1.39	0.280	0.355	0.68	0.137	0.174	98	20	25	30	62	---
200	40	40	1.39	0.284	0.352	0.68	0.139	0.173	100	20	26	31	65	38

continued

Table 2. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on grain nutrient content and removal by irrigated grain sorghum, Tribune, KS, 2010–2019

Fertilizer			Grain						Grain removal					
N	P₂O₅	K₂O	N	P	K	N	P	K	N	P	K	*AFNR_g	*AFPR_g	*AFKR_g
-------------- lb/a --------------			--------------- % ---------------			------------- lb/bu -------------			------------- lb/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	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	0.007	0.001	0.001	0.007	0.001	0.001	0.001	0.001	0.050	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	0.736	---
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			0.589	0.876	0.758	0.589	0.876	0.758	0.985	0.779	0.823	---	---	---
N × P-K			0.060	0.013	0.082	0.060	0.013	0.082	0.120	0.001	0.001	0.045	0.041	---
MEANS														
Nitrogen, lb/a														
0			1.03 e	0.292 a	0.371 a	0.51 e	0.143 a	0.182 a	40 e	11 d	15 d	---	21 c	7 c
40			1.12 d	0.284 a	0.358 b	0.55 d	0.139 a	0.175 b	63 d	16 c	21 c	65 a	58 b	28 b
80			1.25 c	0.270 b	0.348 c	0.61 c	0.132 b	0.171 c	80 c	18 abc	23 b	53 b	67 a	37 a
120			1.35 b	0.258 b	0.346 c	0.66 b	0.127 b	0.169 c	86 b	17 bc	23 b	41 c	67 a	39 a
160			1.38 ab	0.267 b	0.348 c	0.68 ab	0.131 b	0.171 c	95 a	19 a	24 a	36 c	69 a	38 a
200			1.40 a	0.264 b	0.351 c	0.68 a	0.130 b	0.172 c	96 a	18 ab	24 a	29 d	64 ab	38 a
LSD(0.05)			0.04	0.013	0.006	0.02	0.006	0.003	5	1	1	6	8	5
P₂O₅-K₂O, lb/a														
0 - 0			1.29 a	0.223 b	0.342 b	0.63 a	0.109 b	0.168 b	69 b	12 b	18 b	35 b	---	---
40 - 0			1.24 b	0.297 a	0.360 a	0.61 b	0.145 a	0.176 a	81 a	19 a	23 a	50 a	57	---
40 - 40			1.23 b	0.298 a	0.359 a	0.60 b	0.146 a	0.176 a	81 a	19 a	23 a	49 a	58	---
LSD(0.05)			0.03	0.009	0.004	0.01	0.004	0.002	3	1	1	5	5	---

*AFNR_g, AFPR_g, and AFKR_g= Apparent fertilizer N recovery (grain), apparent fertilizer P recovery (grain), and apparent fertilizer K recovery (grain).
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 2019, N applied alone increased yields by 71 bu/a, whereas P applied alone increased yields by 10 bu/a. Nitrogen and P applied together increased yields up to 131 bu/a, which is 10 bu/a less than the 10-year average of 141 bu/a. Application of 120 lb/a N (with highest P rate) produced 97% of maximum yield in 2019, which is slightly greater than the 10-year average. Application of 80 instead of 40 lb P_2O_5/a increased average yields by 4 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, apparent fertilizer nitrogen recovery in the grain ($AFNR_g$) was 41% and apparent fertilizer phosphorus recovery in the grain ($AFPR_g$) was 60%.

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 Kansas State University Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 were 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 1173H (2010), Pioneer 1151XR (2011), Pioneer 0832 (2012–2013), Pioneer 1186AM (2014), Pioneer 35F48 AM1 (2015), Pioneer 1197 (2016), Pioneer 0801 (2017–2018), and Pioneer 0339 (2019)] were planted at about 32,000 seeds/a in late April or early May. Hail damaged the 2010, 2015, 2017, and 2019 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 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 ($AFPR_g$). Grasshoppers were treated by aerial application of insecticide.

Results

Corn yields in 2019 were only 2% higher than the 10-year average (Table 1). Nitrogen alone increased yields 71 bu/a, whereas P alone increased yields 7–10 bu/a. However, N and P applied together increased corn yields up to 131 bu/a. Maximum yield was obtained with 200 lb/a N with 80 lb/a P_2O_5. Corn yields in 2019 (averaged across all N rates) were 4 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. Nitrogen removal (lb/a) was greater at the higher yield levels. Maximum N removal (116 lb/a), was attained with 200 lb N and 80 lb P_2O_5/a. At the highest N and P rate, $AFNR_g$ was 41% and $AFPR_g$ was 60%. 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 29 lb P/a at the highest yields.

Acknowledgment

Table 1. Nitrogen (N) and phosphorus (P) fertilization on irrigated corn yields, Tribune, KS, 2010–2019

Fertilizer		Yield										
N	P$_2$O$_5$	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean
------ lb/a ------		-- bu/a --										
0	0	20	92	86	70	86	92	74	44	82	76	72
0	40	21	111	85	80	95	103	78	47	93	86	80
0	80	28	105	94	91	98	104	86	52	99	83	84
40	0	23	114	109	97	106	113	105	60	110	93	93
40	40	67	195	138	125	153	164	145	92	160	156	139
40	80	61	194	135	126	149	162	135	90	159	154	137
80	0	34	136	128	112	117	131	118	70	117	117	108
80	40	85	212	197	170	187	195	196	132	212	183	177
80	80	90	220	194	149	179	193	193	129	207	189	174
120	0	28	119	134	114	115	124	109	62	102	95	100
120	40	90	222	213	204	213	212	212	142	218	193	192
120	80	105	225	211	194	216	216	223	162	243	201	200
160	0	49	157	158	122	128	144	142	84	139	133	125
160	40	95	229	227	199	211	215	226	154	230	196	198
160	80	95	226	239	217	233	216	238	165	251	191	207
200	0	65	179	170	139	144	162	159	114	158	147	144
200	40	97	218	225	198	204	214	216	148	231	186	194
200	80	104	231	260	220	238	221	235	174	243	207	213

continued

Table 1. Nitrogen (N) and phosphorus (P) fertilization on irrigated corn yields, Tribune, KS, 2010–2019

Fertilizer		Yield										
N	P_2O_5	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	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		23 e	103 d	88 f	80 e	93 e	100 e	79 e	48 e	91 d	82 d	79 e
40		50 d	167 c	127 e	116 d	136 d	146 d	129 d	81 d	143 c	135 c	123 d
80		70 c	189 b	173 d	143 c	161 c	173 c	169 c	110 c	179 b	163 b	153 c
120		74 bc	189 b	186 c	171 b	181 b	184 b	182 b	122 b	188 b	163 b	164 b
160		80 ab	204 a	208 b	179 ab	190 ab	192 ab	202 a	134 a	207 a	173 ab	177 a
200		89 a	209 a	218 a	186 a	196 a	199 a	203 a	145 a	211 a	180 a	184 a
LSD$_{(0.05)}$		9	13	10	10	10	9	10	11	13	13	8
P_2O_5, lb/a												
0		36 b	133 b	131 c	109 b	116 c	128 b	118 b	72 c	118 c	110 b	107 b
40		76 a	198 a	181 b	163 a	177 b	184 a	179 a	119 b	191 b	167 a	163 a
80		81 a	200 a	189 a	166 a	186 a	185 a	185 a	129 a	200 a	171 a	169 a
LSD$_{(0.05)}$		7	9	7	7	7	6	7	8	9	9	6

*Note: Hail events on 7/23/2010, 5/28/2015, 8/18/2017, and 9/20/2019.

ANOVA = analysis of variance. LSD = least significant difference.

Table 2. Nitrogen (N) and phosphorus (P) fertilization on grain N and P content of irrigated corn, Tribune, KS, 2010–2019

Fertilizer		Grain				Grain removal			
N	P_2O_5	N	P	N	P	N	P	*AFNR$_g$	*AFPR$_g$
--------- lb/a ---------		---------- % ----------		-------- lb/bu --------		-------- lb/a --------		---------- % ----------	
0	0	0.99	0.228	0.47	0.108	33	8	---	---
0	40	0.94	0.306	0.45	0.145	35	12	---	22
0	80	0.94	0.318	0.45	0.151	36	13	---	14
40	0	1.17	0.183	0.55	0.087	51	8	44	---
40	40	0.96	0.297	0.46	0.141	62	20	74	67
40	80	0.97	0.317	0.46	0.150	61	21	72	36
80	0	1.26	0.178	0.60	0.084	63	9	38	---
80	40	1.04	0.249	0.49	0.118	86	21	66	72
80	80	1.01	0.305	0.48	0.145	82	25	62	49
120	0	1.28	0.172	0.60	0.081	60	8	23	---
120	40	1.12	0.226	0.53	0.107	101	20	57	71
120	80	1.08	0.293	0.51	0.139	101	28	57	56
160	0	1.26	0.176	0.59	0.083	74	10	26	---
160	40	1.16	0.241	0.55	0.114	108	22	47	83
160	80	1.14	0.275	0.54	0.130	111	27	49	53
200	0	1.22	0.189	0.58	0.090	82	13	25	---
200	40	1.17	0.234	0.55	0.111	106	21	37	77
200	80	1.15	0.288	0.55	0.136	116	29	41	60

Table 2. Nitrogen (N) and phosphorus (P) fertilization on grain N and P content of irrigated corn, Tribune, KS, 2010–2019

Fertilizer		Grain				Grain removal			
N	P_2O_5	N	P	N	P	N	P	*$AFNR_g$	*$AFPR_g$
--------- lb/a ---------		---------- % ----------		-------- lb/bu --------		--------- lb/a ---------		---------- % ----------	
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	0.022	0.090
MEANS									
Nitrogen, lb/a									
0		0.96 e	0.284 a	0.45 e	0.134 a	35 e	11 e	---	18 c
40		1.03 d	0.266 b	0.49 d	0.126 b	58 d	16 d	64 a	52 b
80		1.10 c	0.244 c	0.52 c	0.116 c	77 c	18 c	55 b	61 a
120		1.16 b	0.230 d	0.55 b	0.109 d	87 b	19 bc	45 c	63 a
160		1.19 a	0.231 d	0.56 a	0.109 d	98 a	20 ab	41 d	68 a
200		1.18 ab	0.237 cd	0.56 ab	0.112 cd	101 a	21 a	34 e	68 a
LSD$_{(0.05)}$		0.02	0.011	0.01	0.005	4	1	5	9
P_2O_5, lb/a									
0		1.19 a	0.188 c	0.57 a	0.089 c	60 b	9 c	31 b	---
40		1.07 b	0.259 b	0.50 b	0.122 b	83 a	19 b	56 a	65 a
80		1.05 b	0.299 a	0.50 b	0.142 a	85 a	24 a	56 a	45 b
LSD$_{(0.05)}$		0.02	0.008	0.01	0.004	3	1	4	5

*$AFNR_g$ = Apparent fertilizer N recovery (grain). $AFPR_g$ = Apparent fertilizer P recovery (grain).
ANOVA = analysis of variance. LSD = least significant difference.

Long-Term Effect of Tillage Practices and Nitrogen Fertilization on Corn Yield

C. Bonini Pires, M.M. Sarto, J.S. Lin, W. Davis, and C.W. Rice

Summary

The objective of this study was to investigate the effect of different tillage systems and nitrogen (N) fertilizers on corn yield. Higher corn yields (207 bu/a and 203 bu/a) were found under no-tillage + high (150 lb N/a) manure application, and tillage + super high manure (750 lb N/a), respectively. The trend observed for the different nitrogen fertilizers between tillage systems was the same. However, a greater corn yield was observed under no-till in comparison to tilled conditions for both high fertilizer and high manure. No-till improves soil water infiltration, aggregation, nutrient cycling, and may increase crop yield. On other hand, soil erosion, runoff, and a depreciated plant stand may have been the reasons for lower yields under tillage for some of the treatments. Overall, the addition of organic fertilizer associated with no-till was a better practice for increasing corn yield compared to the use of mineral fertilizer associated with or without tillage.

Introduction

Long-term experiments are essential to understand how corn yield is affected by different agricultural practices and to make management decisions associated with cropping system performance (Richter et al., 2007). Such experiments are critical for corn producers because replacing chisel plow with no-till (NT) practices is a cultural change driven by multiple factors including markets, weather cycles, agribusiness, and scientific advances (Coughenour and Chamala, 2000). Economically, NT is attractive because individual tillage events are eliminated, thus reducing machinery fuel, energy, and maintenance costs (Lal et al., 2007). No-till can also affect crop productivity (Daigh et al., 2018) and improve several soil properties, such as soil organic carbon (Nicoloso et al., 2018), soil aggregation (Fabrizzi et al., 2009), bulk density (Blanco-Canqui et al., 2009), and soil microbial community (Smith et al., 2016), thus improving soil health. Organic waste and organic fertilizer, such as cattle manure, may replenish and maintain soil nutrient equilibrium, thus increasing nutrient status and perhaps crop yield. The objective of this study was to investigate the effect of different long-term tillage systems and different nitrogen (N) fertilizers on corn yield.

Procedures

This study was based on a long-term (31 years) experiment established in 1990 at the Kansas State University Department of Agronomy North Farm in Manhattan, KS (39° 12′ 42"N, 96° 35′ 39"W). The local mean annual precipitation and potential evapotranspiration were 31.5 and 51.2 inches, respectively, with a mean annual temperature of 11.4°C. The soil was a moderately well-drained Kennebec silt loam (fine-silty, mixed, superactive mesic Cumulic Hapludoll). Prior to the establishment of the experiment, the area was used for small grain production (wheat, oats, and other C3 crops) under intensive tillage for at least 60 years. The experiment was initiated in 1990 when corn (*Zea mays* L.) was first introduced at this site. The tillage systems

were fall chisel plow with pre-plant spring offset disk (chisel tillage: T) and no-till (NT) by planting directly through the crop residues with minimal soil disturbance. The chisel plow and disking operations were performed to a depth of 6 and 4 inches, respectively. The fertilization treatments were different N fertilizers applied just before planting: 1) 750 lb N/a of available N as organic fertilizer, super high manure (SHM); 2) 150 lb N/a of available N as mineral fertilizer (urea, HF); 3) 150 lb N/a of organic N fertilizer (HM); 4) 75 lb N/a of available N as mineral fertilizer (urea, LF); 5) 75 lb N/a of organic N fertilizer (LM); and 6) a control without N (C). Mineral fertilizer was broadcast-applied and left on the surface for NT, and incorporated at 2–4 inches for T. The organic fertilizer was composted organic waste collected at the North Farm's composting facility and consisted of a mixture of food waste, hay waste, and cattle manure. The organic fertilizer was analyzed for total N, organic N, NH_4^+ and NO_3^- and the application rate was calculated assuming that 30% of organic N and 100% of mineral N was available during the crop growing season. The corn (hybrid DKC-35RIB, VT2PRIB) was planted at a seeding rate of 28,000 seeds/a, using 30 inches row spacing, on May 17, 2019. To evaluate corn yield, corn ears from the middle 2 rows at 30-ft length of each plot were hand-harvested on October 18, 2019. The corn grain was adjusted to 15.5% moisture for yield calculation.

The treatments were arranged as a split-plot in randomized complete block design with four replications. Tillage treatments (NT and conventional tillage) were considered the main plot and the N fertilizers were considered the subplot. The effect of tillage, fertilizer, and their respective interaction (fixed effects) on corn yield (response variable) were analyzed by ANOVA with a mixed model. Random effects corresponded to the block (replication) and tillage within block. A pairwise comparison was used to determine significant differences among treatments for all the fixed effects presenting a significance equal or lower than 0.05 using the Fisher's least significant difference (LSD) (R Core Team, 2017).

Results

A significant two-way interaction ($P = 0.009$) was found for tillage × fertilizer. Higher corn yield was found under NT-HM (207 bu/a) and T-SHM (203 bu/a), respectively (Figure 2). The trend observed for the N fertilizers between tillage systems was the same. However, greater corn yield was observed under no-till compared to tilled conditions for both high fertilizer and high manure. Plant stand was not evaluated in this study; however, fewer plants were observed in some of the T plots after several precipitation events (Figure 3a and 3b). Thus, corn yield under T treatments may have been affected by the lower number of final plants in the plots (Figures 3c and 3c). According to Mikha and Rice (2004), NT improves soil properties, such as soil organic matter, aggregate stability, and water holding capacity, which help maintain land productivity compared to intensively tilled soils. Moreover, NT increases water infiltration and reduces soil erosion, runoff, and raindrop impact on the soil surface due to physical protection from the crop residue. Crop residue maintains soil moisture and reduces soil temperature during warm periods, providing a more stable environment for plant and root growth. No differences were found when comparing C, SHM, LF, and LM within tillage systems.

Compost (HM) produced 17% more grain than HF, 190 bu/a and 157 bu/a, respectively. The same was found for LM and HM, where LM produced 30% more than LF, 170 bu/a and 120 bu/a, respectively. It is well known that besides N, organic amendments also provide organic carbon, phosphorus, potassium, and micronutrients, such as zinc, boron, and manganese to the plant. Moreover, an increase in soil organic matter increases micronutrient uptake (Dhaliwal et al., 2019). Overall, the addition of organic fertilizer associated with no-till was a better practice for increasing corn yield compared to the use of mineral fertilizer associated with or without tillage.

References

Blanco-Canqui, H., Stone, L.R., Schlegel, A.J., Lyon, D.J., Vigil, M.F., Mikha, M.M., Stahlman, P.W., Rice, C.W., 2009. No-till Induced Increase in Organic Carbon Reduces Maximum Bulk Density of Soils. Soil Sci. Soc. Am. J. 73, 1871. https://doi.org/10.2136/sssaj2008.0353.

Coughenour, C.M., Chamala, S., 2000. Conservation Tillage and Cropping Innovation: Constructing the New Culture of Agriculture. Iowa State University Press, Ames, IA.

Daigh, A.L.M., Dick, W.A., Helmers, M.J., Lal, R., Lauer, J.G., Nafziger, E., Pederson, C.H., Strock, J., Villamil, M., Mukherjee, A., Cruse, R., 2018. Yields and yield stability of no-till and chisel-plow fields in the Midwestern US Corn Belt. F. Crop. Res. 218, 243–253. https://doi.org/10.1016/j.fcr.2017.04.002.

Dhaliwal, S.S., Naresh, R.K., Mandal, A., Singh, R., Dhaliwal, M.K., 2019. Dynamics and transformations of micronutrients in agricultural soils as influenced by organic matter build-up: A review. Environ. Sustain. Indic. 1–2, 100007. https://doi.org/10.1016/J.INDIC.2019.100007.

Fabrizzi, K.P., Rice, C.W., Amado, T.J.C., Fiorin, J., Barbagelata, P., Melchiori, R., 2009. Protection of soil organic C and N in temperate and tropical soils: Effect of native and agroecosystems. Biogeochemistry 92, 129–143. https://doi.org/10.1007/s10533-008-9261-0.

Lal, R., Reicosky, D.C., Hanson, J.D., 2007. Evolution of the plow over 10,000 years and the rationale for no-till farming. Soil Tillage Res. https://doi.org/10.1016/j.still.2006.11.004.

Mikha, M.M., Rice, C.W., 2004. Tillage and Manure Effects on Soil and Aggregate-Associated Carbon and Nitrogen. Soil Sci. Soc. Am. J. 68, 809. https://doi.org/10.2136/sssaj2004.0809.

Nicoloso, R.S., Rice, C.W., Amado, T.J.C., Costa, C.N., Akley, E.K., 2018. Carbon saturation and translocation in a no-till soil under organic amendments. Agric. Ecosyst. Environ. 264, 73–84. https://doi.org/10.1016/j.agee.2018.05.016.

R Core Team, 2017. R Development Core Team. R A Lang. Environ. Stat. Comput.

Richter, D. deB., Hofmockel, M., Callaham, M.A., Powlson, D.S., Smith, P., 2007. Long-Term Soil Experiments: Keys to Managing Earth's Rapidly Changing Ecosystems. Soil Sci. Soc. Am. J. 71, 266–279. https://doi.org/10.2136/sssaj2006.0181.

Smith, C.R., Blair, P.L., Boyd, C., Cody, B., Hazel, A., Hedrick, A., Kathuria, H., Khurana, P., Kramer, B., Muterspaw, K., Peck, C., Sells, E., Skinner, J., Tegeler, C., Wolfe, Z., 2016. Microbial community responses to soil tillage and crop rotation in a corn/soybean agroecosystem. Ecol. Evol. 6, 8075–8084. https://doi.org/10.1002/ece3.2553.
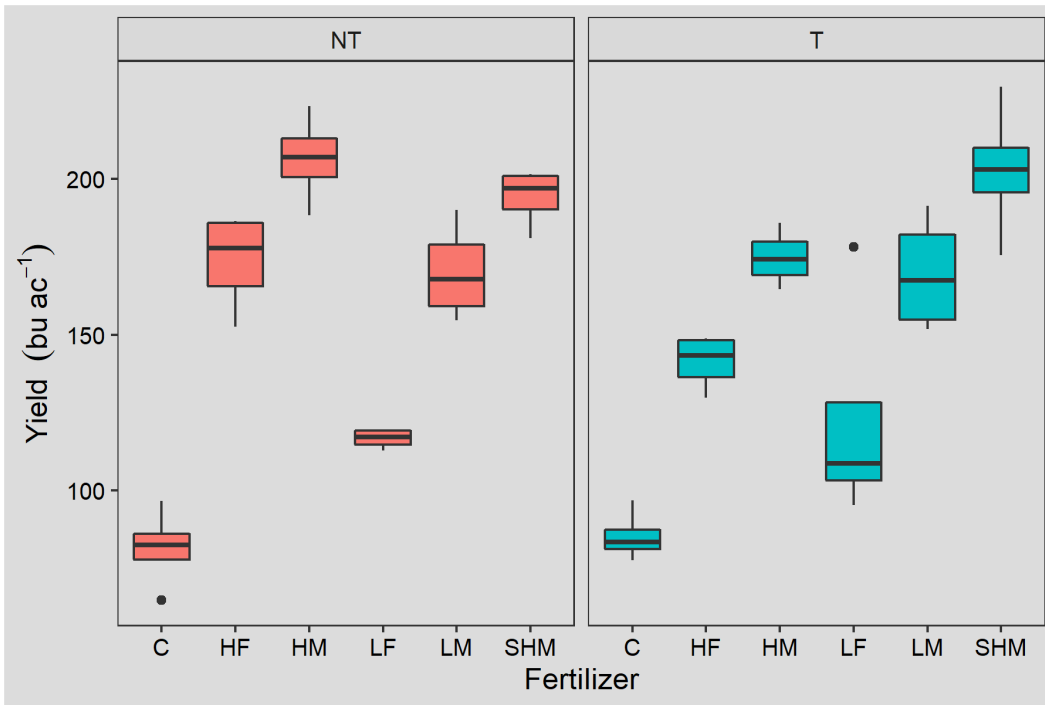
Figure 1. Graphical summary of the dataset. Dots represent outliers. NT: no-tillage; T: tillage; HM: high manure; HF: high fertilizer; LM: low manure; LF: low fertilizer; SHM: super high manure; C: control.
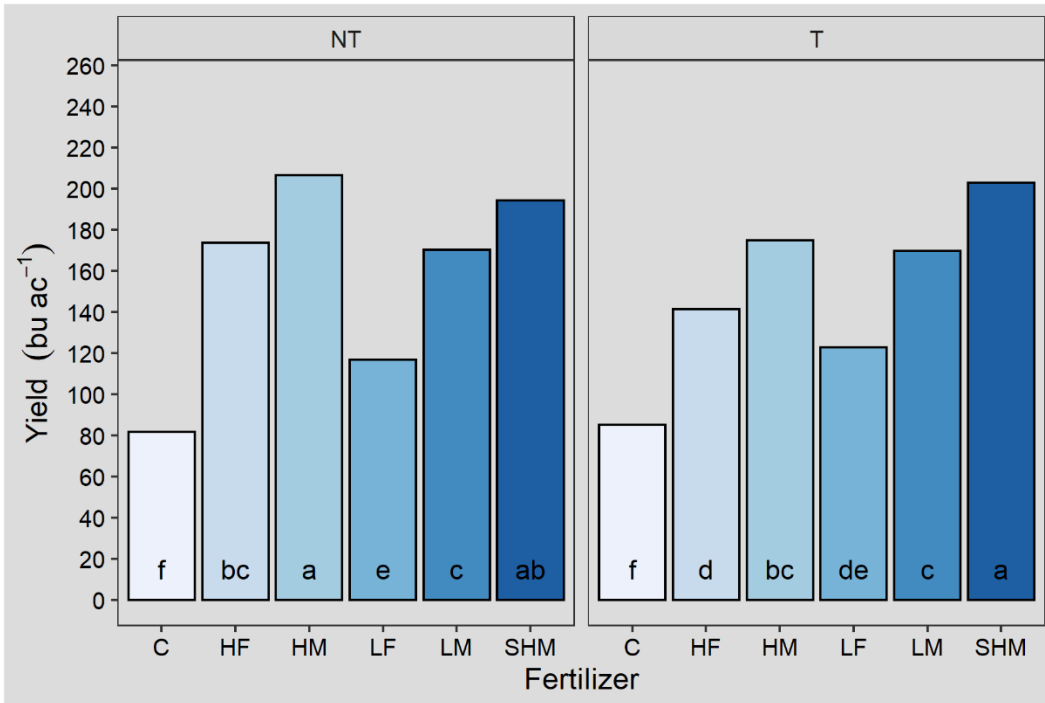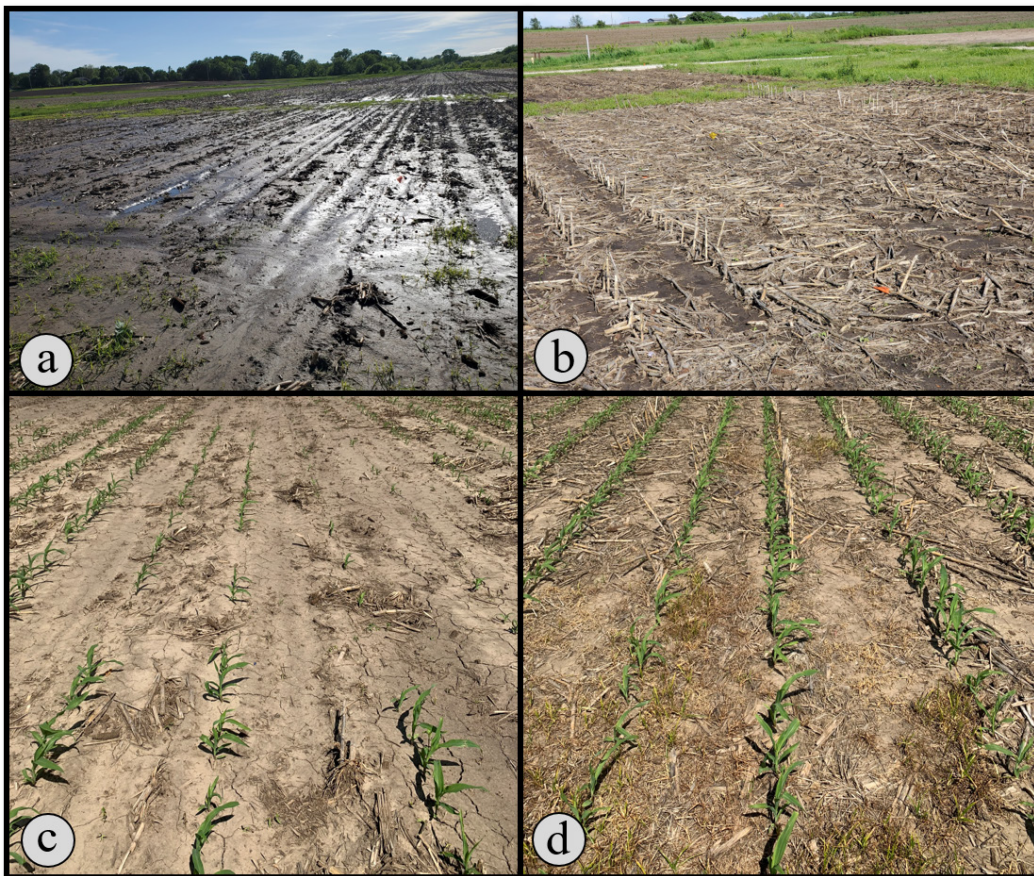

Figure 2. Corn yield differences by tillage system and fertilizer. Different letters indicate statistical differences ($P < 0.05$). NT: no-tillage; T: tillage; HM: high manure; HF: high fertilizer; LM: low manure; LF: low fertilizer; SHM: super high manure; C: control.

Figure 3. View of selected plots from the different treatments. (a) The tilled plot one week after planting (May 24, 2019); (b) no-tilled plot one week after planting (May 24, 2019); (c) tilled plot on June 12, 2019; (d) no-tilled plot on June 12, 2019.
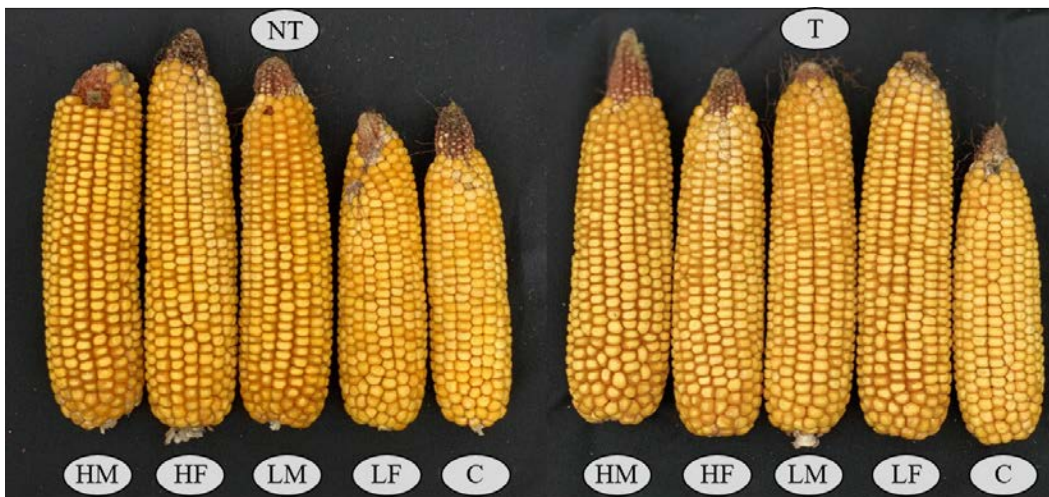
Figure 4. View of the corn ears from the different treatments. NT: no-tillage; T: tillage; HM: high manure; HF: high fertilizer; LM: low manure; LF: low fertilizer; C: control.

Wheat Grain Yield and Protein Concentration Response to Nitrogen and Sulfur Rates

B.R. Jaenisch, T. Wilson, N. Nelson, M. Guttieri, and R.P. Lollato

Summary

Winter wheat is often double-cropped after soybeans in no-tillage systems. The soybean crop removes large quantities of sulfur (S), which might cause S deficiency for the following wheat crop. Our objective was to evaluate the responses of three wheat varieties to three nitrogen (N) and four S fertilizer rates representing a range of N:S ratios. The experiment was conducted near Ashland Bottoms and Hutchinson, KS. Treatments were arranged as a complete factorial structure with a split-split-plot design. Variety was the whole-plot, N was the sub-plot, and S was the sub-sub plot. Nitrogen rates were 50, 100, and 150% of the university recommendations for a 60 bushel per acre yield, and S rates were 0, 10, 20, and 40 pounds of S per acre. Wheat varieties evaluated were Zenda, SY Monument, and LCS Mint. Increasing the N rate increased grain yield at both locations. Sulfur increased grain yield at Ashland Bottoms but not at Hutchinson. Nitrogen by S interaction occurred for protein concentration at both locations. At Hutchinson, N rates of 50, 100, and 150% N resulted in grain yield of 62, 73, and 78 bu/a. For the 50% and 100% N rate, protein concentration was 10.8% and 11.3%; however, the 150% N rate with 20 or 40 lb S/a increased protein concentration to 11.8% as compared to 11.5% observed in the 0 or 10 lb S/a treatments. At Ashland Bottoms, N rates of 50, 100, and 150% resulted in grain yield of 56, 69, and 74 bu/a across S treatments. For the 0 pounds of S per acre treatment, though, these N rates resulted in grain yields of 36, 42, and 40 bu/a. The 150% N rate with 20 and 40 lb S/a increased grain yield by 5 bu/a as compared to the 10 lb S/a treatment. At the 50% N rate, protein concentration was 9.7% with an application of S as compared to 10.3% for the 0 lb S/a, which is due to a dilution effect from the increased grain yield. As S application increased, protein concentration decreased at the 100% N rate. However, at the 150% N rate, protein concentrations were 12.2, 11.5, 11.8, and 11.9% for the 0, 10, 20, and 40 lb S/a, respectively. Our results suggest that a balanced fertilization of N and S are essential for improving yield and protein concentration in no-till systems following soybeans, and that initial S in the profile and soil organic matter (OM) play a crucial role in determining the crop's response to the added fertilizers.

Introduction

Sulfur plays many roles within the plant, including the synthesis of amino acids, formation of disulfide linkages, glucoside oils, and chlorophyll (Taiz and Zierger, 2010). Sulfur is supplied to plants through rainfall, mineralization of the soil's OM and crop residue, or as part of organic or mineral fertilizers. The Clean Air Act was successful in decreasing the emission of SO_2 to the atmosphere within the continental USA, which in turn, reduced atmospheric S deposition from about 13 to about 3.5 pounds of sulfur per acre per year (Sullivan et al., 2018). While this is a success story in reducing environmental pollution, rainfall has historically been an important supplier of S to growing crops. The reduction in S deposition in the rainfall, coupled with increased crop removal and other factors (e.g., decreased use of manure as a fertilizer and decreased S content of traditional fertilizers) has increased S deficiency in many wheat-growing regions (Kaiser et al., 2019). Particularly in Kansas, where winter wheat planted after soybeans has become the preferred crop rotation in recent years for many producers (Lollato et al., 2019a), the issue seems to be severe as a 60 bushel per acre grain soybean crop removes approximately 25 pounds of S in the grain and stover (Lamond, 1997). The high removal of S by soybeans, coupled with lower organic matter mineralization in the spring and reduced S deposition in the rainfall, resulted in increasingly common symptoms of S deficiency in the wheat crop. While the S requirements of wheat are generally low [i.e., an 80 bushel per acre crop needs about 22 pounds of S to complete its cycle, (Lamond, 1997)], recent evidence suggests that depending on the S content of the soil, wheat can be S-limited at these yield levels when mineral fertilizer is not supplied (Jaenisch et al., 2019).

Because co-limitation and stoichiometry between N and S can explain the crop responses to both fertilizers (Carciochi et al., 2020), it is important to study S effects on the wheat crop within the context of N fertility. Proper N fertilization ensures a high tiller number and grain yield in wheat (Lollato et al., 2019b), which is generally sink-limited, and kernel per foot acts as coarse regulator of grain yield (Lollato and Edwards, 2015). Potential kernel per foot is determined by Feekes 6 in the winter wheat growing season, and N deficiency at this time will result in decreased yield potential. Thus, matching N application with this critical growth stage is important for maximizing kernels per foot (de Oliveira Silva et al., 2020a). Likewise, N concentration within the plant changes throughout the growing season according to biomass levels; thus, N dilution curves help determine N deficiencies in crops (de Oliveira Silva et al., 2020b). Research is needed to determine the optimal N concentration and N:S ratios in plant tissue to maximize grain yield and quality in Kansas. Thus, our objectives were to evaluate the effects of S and N fertility and their interactions with winter wheat variety on grain yield and grain protein concentration.

Procedures

The experiment was established at the South-Central Experiment Field in Hutchinson (fine-loamy, Ost loam) and the Agronomy Farm in Ashland Bottoms, KS. Both locations were managed under rainfed conditions and were chosen as no-till wheat is commonly sown into soybean stubble. A three-way factorial experiment was arranged in a split-split-plot design with four replications. The varieties SY Monument, LCS Mint, and Zenda, selected for their differences in N use efficiency, were the whole plot. Three N rates (i.e., 50, 100, and 150% of the N needed for a 60 bushel per acre yield

goal considering the soil N profile analyses for each location) were the sub-plot and were applied using urea ammonium nitrate (UAN, 28-0-0). The N rates for 50, 100, and 150% of the yield goal were 66, 127, and 189 lb N/a and 52, 102, and 153 lb N/a for Ashland and Hutchinson, respectively. Four S rates were the sub-sub-plot, in which S was applied as ammonium thiosulfate (12-0-0-26S) at 0, 10, 20, and 40 lb S/a. A pressurized CO_2 back sprayer with a three-nozzle spray boom applied both the N and S. The specific streamer nozzles (SJ3-02-VP - SJ3-05-VP) varied due to the change in N and S rates. The N and S were applied in combination for specific treatments and application occurred at Feekes 4. The UAN rates were adjusted to balance the N application for treatments receiving ammonium thiosulfate.

Wheat was sown no-till into soybean stubble directly after harvest with a Great Plains 506 no-till drill (7 rows spaced at 7.5 inches) with plot dimensions of 4.375-ft wide × 30-ft long at all locations. Seed was treated with 5 oz Sativa IMF Max across the whole study so neither fungicide nor insecticide were a limiting factor. Likewise, the three varieties were sown at 1.5 million seeds/a due to the later sowing date. Soil samples were collected at sowing at each location for soil nutrient analysis at two depths i.e., 0–6 in. and 6–24 in. (Table 1). A total of 15 cores were pulled per depth and combined to represent a composite sample at each location. Weeds were controlled to ensure they were not limiting factors by a pre- and post-emergence herbicide application. Insect pressure was not experienced in 2018–2019.

Results
Weather
The 2018–2019 winter wheat growing season had a cold and wet winter, a cold and wet early spring, and a cool and wet late spring/early summer. The wet and cool temperatures kept the wheat crop dormant until late April. Likewise, the cool spring and increased rainfall reduced spring tillering but incorporated the applied fertilizer. Grain harvest occurred very late due to the cool and wet weather. These conditions resulted in above-average grain yields at both Ashland Bottoms and Hutchinson.

Initial Soil Profile
Initial soil test results varied greatly for Ashland Bottoms and Hutchinson (Table 1). The soil at Ashland Bottoms had lower organic matter content and sulfate-S as compared to Hutchinson. A significant amount of sulfate-S comes from OM mineralization and this mineralization can be sufficient enough to avoid yield losses from S deficiencies. Based on the soil test results, Ashland Bottoms and Hutchinson had a supply of 10 and 17 lb of S/a, respectively. Thus, while Ashland Bottoms was severely deficient in S; Hutchinson had sufficient S depending on the yield level of the crop.

Wheat Grain Yield
Across locations, increasing N rates increased wheat grain yield (Figure 1). At Hutchinson, N rate was the only significant effect and N rates of 50, 100, 150% N resulted in grain yield of 62, 73, and 78 bu/a, respectively (Figure 1). Grain yield did not respond to S application at Hutchinson. At Ashland Bottoms, there was a significant N by S interaction—the absence of S resulted in grain yields of about 40 bushels per acre, regardless of N rate. However, when S fertilizer was applied, grain yield increased to the 60–85 bushels per acre range and became responsive to N. Interestingly, when 10 pounds of S

per acre was provided, wheat grain yield increased from 50 to 100% N, and plateaued afterwards. Nonetheless, providing 20 or 40 pounds of S per acre allowed grain yields to respond linearly to increases in N rates to as much as 150% N. At this rate, 20 and 40 pounds of S per acre increased grain yield by 5 bu/a as compared to the 10 pounds of S per acre.

Grain Protein Concentration

There was a significant N by S interaction on grain protein concentration, as well as a significant variety effect, at both locations. First, there was an overarching trend of increased protein concentrations with increased N rates at both locations. At Ashland Bottoms, the significant interaction resulted from the tendency to stabilize protein concentrations for N rates beyond 100% for the 0 and 10 pounds of S per acre treatments, while 20 and 40 pounds of S per acre allowed protein concentrations to continue to increase with increases in N rate. Specifically, at the 50% N rate, protein concentration was 9.7% with an application of S (regardless of S rate) as compared to 10.3% for the 0 lb of S. As sulfur application increased, protein concentration decreased at the 100% N rate. However, at the 150% N rate, protein concentration was 12.2, 11.5, 11.8, and 11.9% for the 0, 10, 20, and 40 pounds of S per acre. Zenda had a protein concentration of 11.4%, which was greater than SY Monument and LCS Mint. At Hutchinson, the trends were not as clear as at Ashland Bottoms, but likewise, protein concentrations increased with N rates, and the 20 and 40 pounds of S per acre resulted in the highest protein concentrations at high N rates. Specifically, at the 50% and 100% N rate, protein concentration was 10.8% and 11.3%, respectively. However, the 150% N rate with 20 or 40 lb S/a increased protein concentration to 11.8% as compared to 11.5% for the 0 or 10 lb S/a. Following the same trend as that measured at Ashland Bottoms, Zenda had protein concentration of 11.8%, which was greater than SY Monument and LCS Mint.

Preliminary Conclusions

Due to limitations of sites and years, it is difficult to make strong conclusions out of a single year of data. However, the significant N by S rate interactions for both grain yield and protein concentration suggest that a balanced nutrition is needed for both nutrients to produce high yields. One trend that surfaced was that increasing N increased grain yield and protein concentration, suggesting that N rates can be further increased to maximize yield (depending on yield potential). Increasing the S rate to 20 lb per acre maximized wheat yield at Ashland Bottoms; however, no grain yield response to S rate was measured at Hutchinson. Thus, these results suggest that soil profile S plays an important role in maximizing wheat yield, as the soil at Ashland Bottoms was at deficient levels as compared to the soil at Hutchinson. We will evaluate the plants' tissue nutrient concentration for co-limitations and stoichiometry to further decipher this interaction of N by S within wheat plants.

Acknowledgements

References

Carciochi, W.D., Sadras, V.O., Pagani, A. and Ciampitti, I.A., 2020. Co-limitation and stoichiometry capture the interacting effects of nitrogen and sulfur on maize yield and nutrient use efficiency. European Journal of Agronomy, 113, p.125973.

de Oliveira Silva, A., Ciampitti, I.A., Slafer, G.A. and Lollato, R.P., 2020a. Nitrogen utilization efficiency in wheat: A global perspective. European Journal of Agronomy, 114, p.126008.

de Oliveira Silva, A., Slafer, G.A., Fritz, A.K. and Lollato, R.P., 2020b. Physiological basis of genotypic response to management in dryland wheat. Frontiers in Plant Science, 10, p.1644.

Jaenisch, B.R., de Oliveira Silva, A., DeWolf, E., Ruiz-Diaz, D.A. and Lollato, R.P., 2019. Plant population and fungicide economically reduced winter wheat yield gap in Kansas. Agronomy Journal, 111(2), pp.650-665.

Kaiser, D.E., Sutradhar, A.K. and Wiersma, J.J., 2019. Do Hard Red Spring Wheat Varieties Vary in Their Response to Sulfur? Agronomy Journal, 111(5), pp.2422-2434.

Lamond, R.E. 1997. Sulphur in Kansas: Plant, soil, and fertilizer considerations. Kansas State Univ. MF-2264, Kansas State Univ. Agri. Exp. Stat. and Coop. Ext. Serv., Manhattan.

Leikam, D., R. Lamond, and D. Mengel. 2003. Soil test interpretations and fertilizer recommendations. Kansas State Univ. MF-2586, Kansas State Univ. Agri. Exp. Stat. and Coop. Ext. Serv., Manhattan.

Lollato, R.P. and Edwards, J.T., 2015. Maximum attainable wheat yield and resource-use efficiency in the southern Great Plains. Crop Science, 55(6), pp.2863-2876.

Lollato, R.P., Ruiz Diaz, D.A., DeWolf, E., Knapp, M., Peterson, D.E. and Fritz, A.K., 2019a. Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. Crop Science, 59(1), pp.333-350.

Lollato, R.P., Figueiredo, B.M., Dhillon, J.S., Arnall, D.B. and Raun, W.R., 2019b. Wheat grain yield and grain-nitrogen relationships as affected by N, P, and K fertilization: A synthesis of long-term experiments. Field Crops Research, 236, pp.42-57.

Sullivan, T.J., Driscoll, C.T., Beier, C.M., Burtraw, D., Fernandez, I.J., Galloway, J.N., Gay, D.A., Goodale, C.L., Likens, G.E., Lovett, G.M. and Watmough, S.A., 2018. Air pollution success stories in the United States: The value of long-term observations. Environmental science & policy, 84, pp.69-73.

Taiz, L., and E. Zieger. 2010. Chapter 5 - Mineral nutrition. p. 782. In: Plant Physiology. 5th ed. Sinauer Associates, Inc., Sunderland, MA.

Table 1. Initial soil fertility levels at Ashland Bottoms and Hutchinson, KS, for the 2018–2019 growing season

Location	Depth	pH	P	K	Ca	Mg	Na	NH$_4$-N	NO$_3$-N	Cl$^-$	SO$_4$-S	OM	CEC
	inches	ppm										%	Meq 100 g^{-1}
Ashland Bottoms	0–6	6.2	45	179	1129	138	9	2.6	3.3	4.1	2.5	1.5	10
	6–24	6.6	27	116	1284	144	8	2.6	1.3	3.1	1	1.5	8
Hutchinson	0–6	5.3	50	228	1018	185	8	3.3	9.7	3.7	3.5	1.8	17
	6–24	6.4	11	151	1920	330	17	3	3.2	4.6	2	1.8	16

Fertility levels include soil pH, buffer pH, Mehlich-3 extractable phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), ammonium- (NH$_4$-N) and nitrate-nitrogen (NO$_3$-N), chloride (Cl), sulfate-sulfur (SO$_4$-S), organic matter (OM), and cation exchange capacity (CEC). Sampling depths were 0–6 in. and 6–24 in.

Table 2. Treatment description of three winter wheat varieties (Sy Monument, LCS Mint, and Zenda), three nitrogen rates based on a yield goal of 60 bu/a (50, 100, and 150%), and four sulfur rates (0, 10, 20, and 40 lb S/a) at Ashland Bottoms and Hutchinson, KS, in 2019

Winter wheat varieties	Nitrogen rate based on a yield goal of 60 bu/a	Sulfur rate
SY Monument	50%	0 lb S/a
LCS Mint	100%	10 lb S/a
Zenda	150%	20 lb S/a
		40 lb S/a
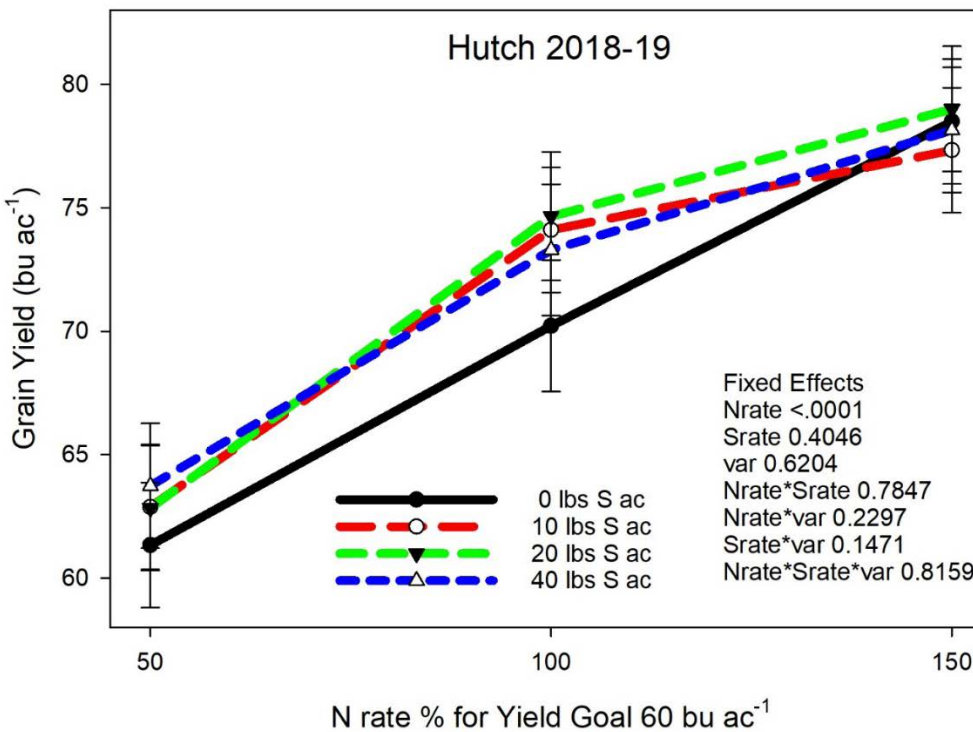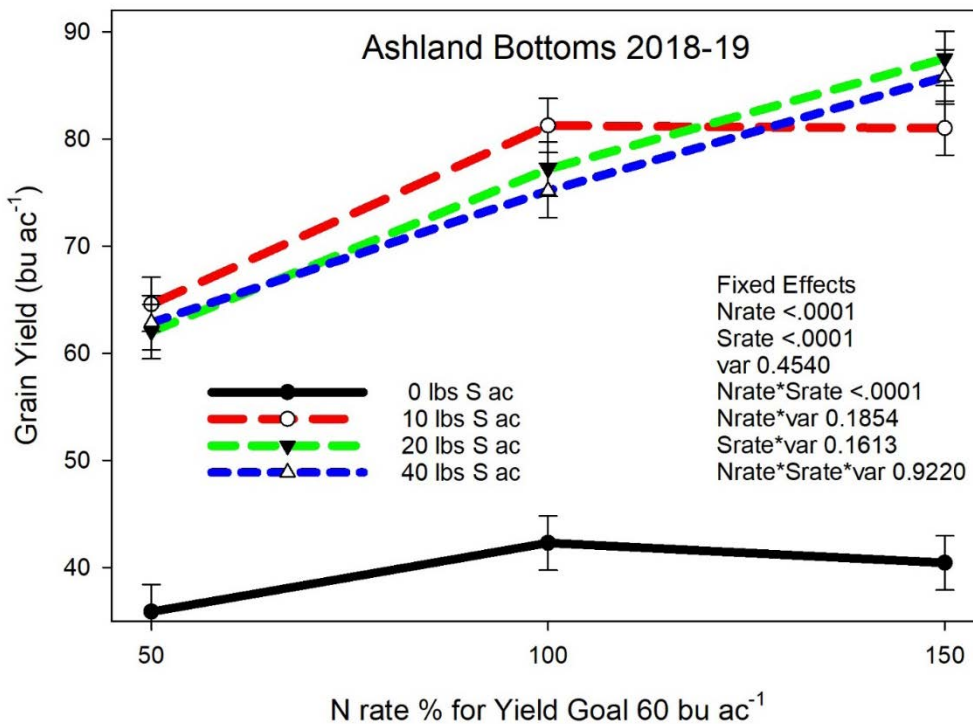
Figure 1. Average wheat grain yield (bu/a) response to three nitrogen (N) (50, 100, and 150 %) and four sulfur (S) (0, 10, 20, and 40 lb S/a) rates across all winter wheat varieties for Ashland Bottoms and Hutchinson, KS, during the 2018–2019 growing season.
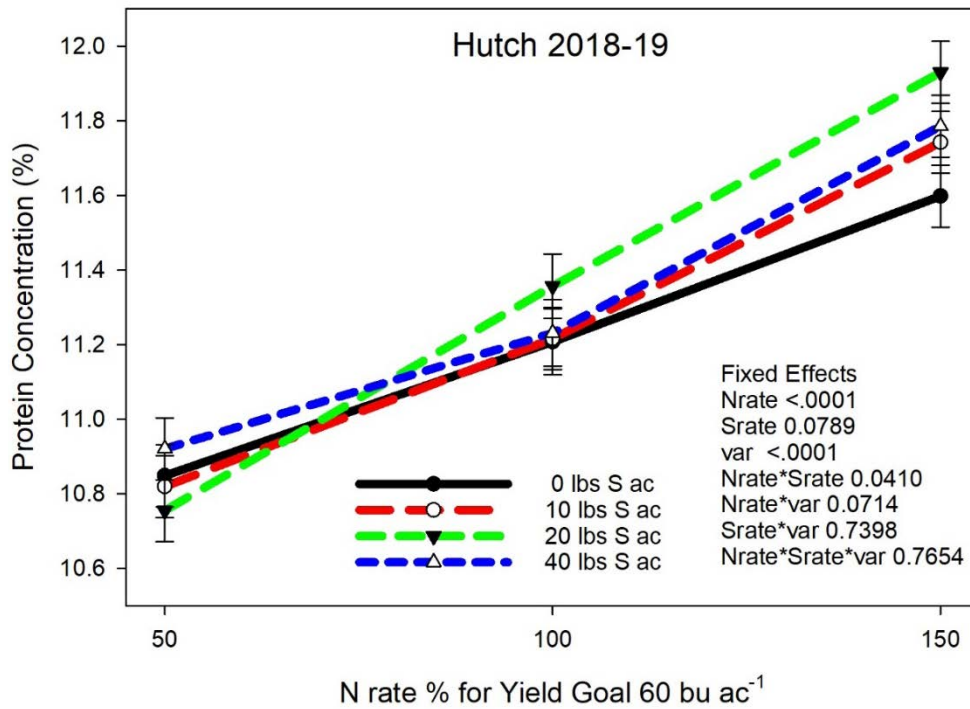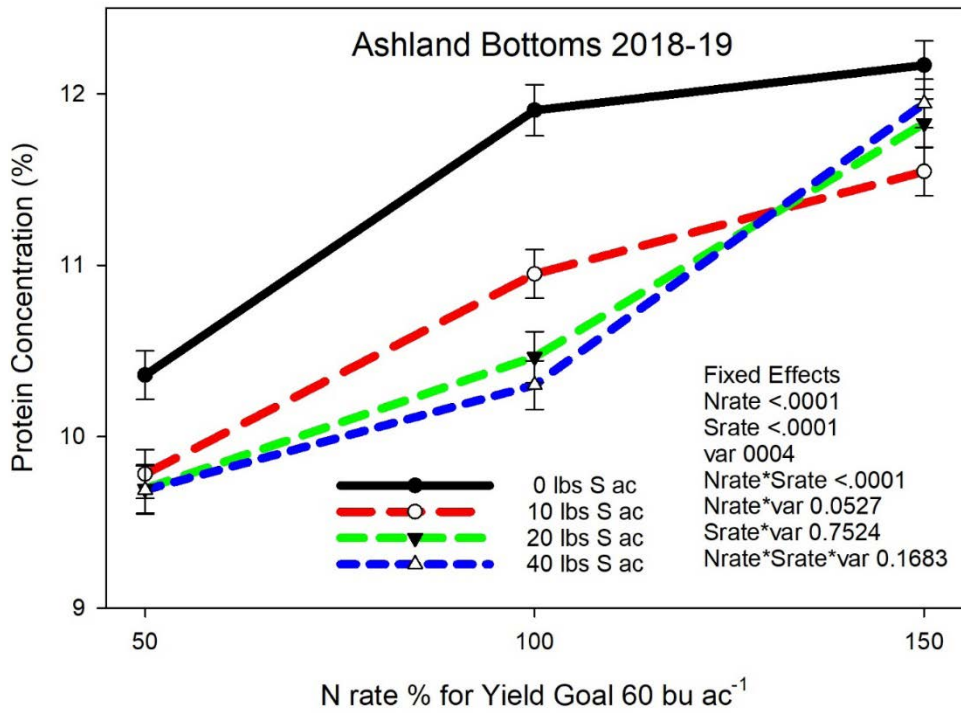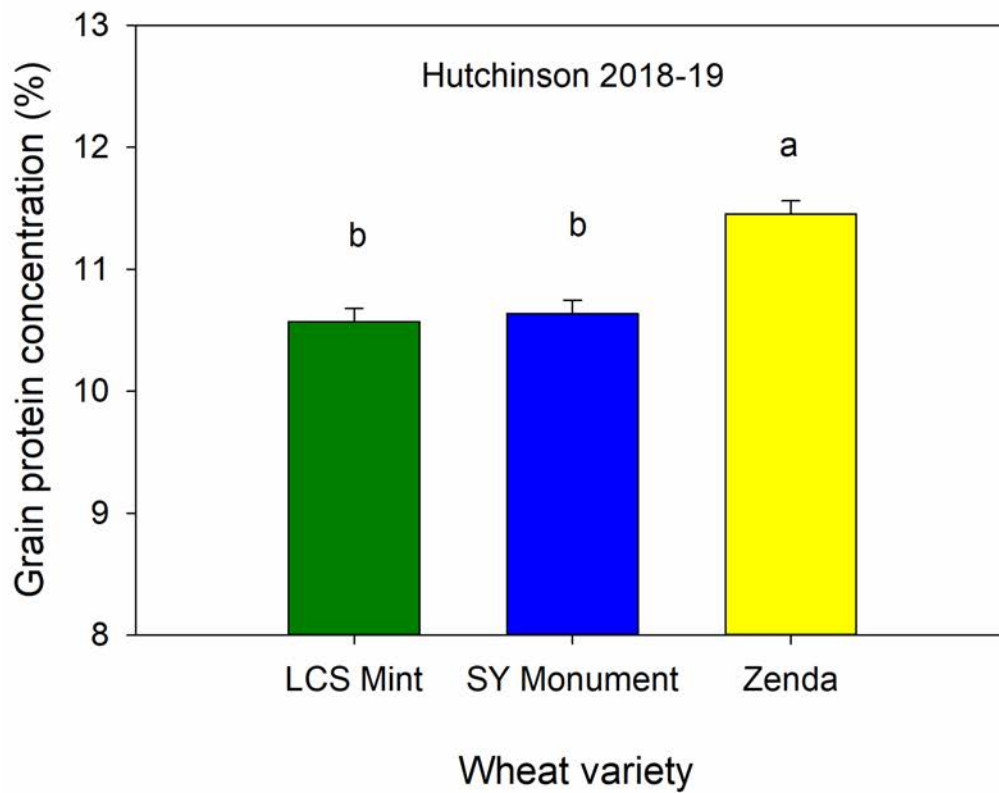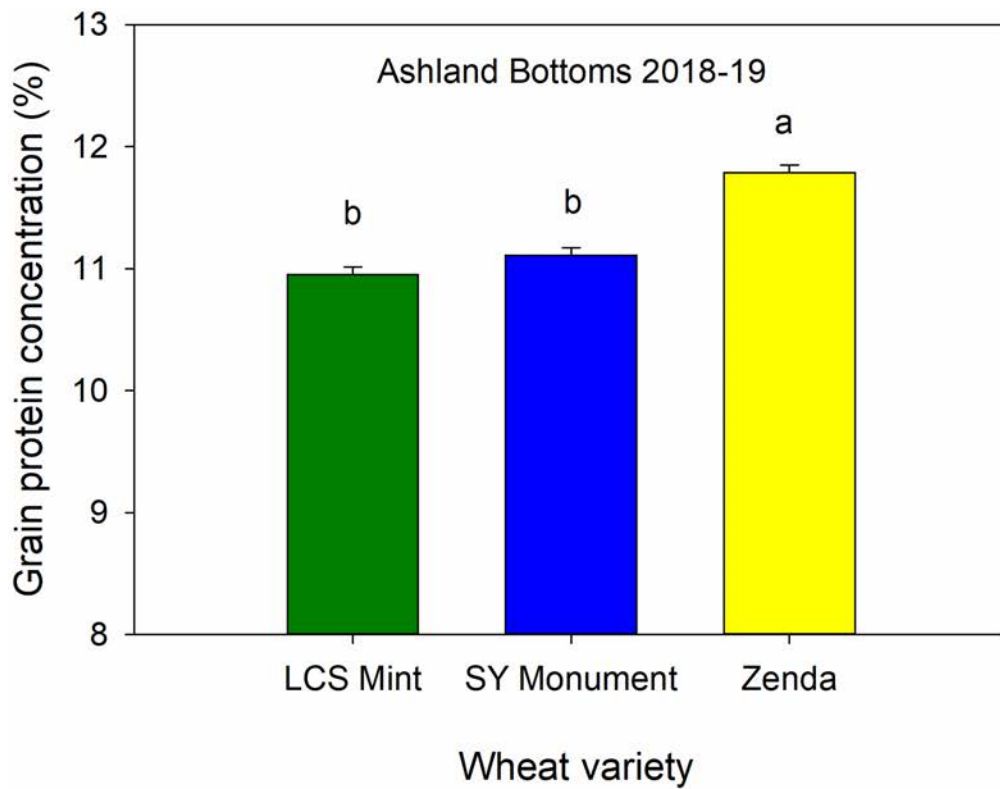
Figure 2. Average wheat grain protein concentration (%) response to three nitrogen (N) (50, 100, and 150 %) and four sulfur (S) (0, 10, 20, and 40 lb S/a) rates across all winter wheat varieties for Ashland Bottoms and Hutchinson during the 2018–2019 growing season.

Figure 3. Average wheat grain protein concentration (%) as affected by three winter wheat varieties (LCS Mint, SY Monument, and Zenda) across three nitrogen (N) (50, 100, 150 %) and four sulfur (S) (0, 10, 20, 40 lb S/a) rates for the trials conducted at Ashland Bottoms and Hutchinson during the 2018–2019 growing season. At both locations, Zenda had statistically greater protein concentration than LCS Mint and SY Monument.

Wheat Grain Yield and Grain Protein Concentration Response to Nitrogen Rate During the 2018–2019 Growing Season in Kansas

R.P. Lollato, K. Mark, and B.R. Jaenisch

Summary

The objective of this project was to evaluate winter wheat grain yield and grain protein concentration responses to nitrogen (N) rate in the state of Kansas during the 2018–2019 growing season. Experiments evaluating the response of the wheat variety Zenda to four nitrogen rates (0, 50, 100, and 150 lb N/a) were established at four locations. In-season measurements included flag leaf N concentration, grain yield, yield components, and grain protein concentration. Flag leaf N concentration ranged from 2.4 to 4.1% across all environments and treatments, and increases in N rates increased flag leaf N concentration linearly. Grain yield ranged from 36.3 to 94.4 bu/a and increased with increases in N rate usually following quadratic relationships at all locations except for Belleville, where no response was observed, likely due to the high organic matter levels. Grain protein concentration ranged from 11 to 15% across all locations and treatments and increases in N rates increased grain protein concentration following a usually linear relationship; however, the quadratic yield response to N rate, coupled to the linear protein response to N rate, indicated that greater N rates might be needed to maximize protein as compared to maximizing yields. Both relative grain yield and relative grain protein concentration variables calculated relative to the maximum in each respective environment, were related to flag leaf N concentration in a linear-plateau way, suggesting that flag leaf N concentration could be used as a diagnostic tool for crop N status.

Introduction

Nitrogen is a critical component of different amino acids and proteins needed to complete a plant's life cycle; thus, it is an essential element to crops (Taiz and Zieger, 2010). About 80% of total wheat N uptake occurs by anthesis (Waldren and Flowerday, 1979). Total N uptake at maturity depends on yield level and ranges from near zero to about 360 lb N/a (de Oliveira Silva et al., 2020a). Different aspects of N management (i.e., rate and timing) are among the leading causes behind the large yield gap in Kansas (de Oliveira Silva et al., 2020b; Lollato et al., 2019a), which is estimated at about 50% (Lollato et al., 2017). The exception to this rule is when the system is already saturated by N. In these cases, no response to N rate usually occurs and other factors, such as fungicide and seeding rate, become prevalent (Jaenisch et al., 2019). A recent comprehensive synthesis of long-term experiments conducted in the region suggested that wheat grain yield and grain protein concentration responses to N rate depended on yield environment (Lollato et al., 2019b). In other words, while there were limited yield responses to increases in N rate at low yield environments, yield followed a quadratic response to N rate in medium, high, and very high yield environments, with an agronomic optimum N rate increasing with increases in yield environment. Higher

yield environments resulted in lower protein concentrations, as expected (Lollato and Edwards, 2015), and protein concentration increased linearly with increases in N rate.

Due to the importance of N management to wheat yield and protein, the objectives of this project were to assess winter wheat grain yield, grain protein concentration, flag leaf nitrogen concentration, and yield components as affected by different nitrogen rates in the state of Kansas during the 2018–2019 growing season.

Procedures

Field experiments were conducted during the 2018–2019 winter wheat growing season in different locations across Kansas: Ashland Bottoms, Belleville, Great Bend, Hutchinson, and Manhattan. At all locations, plots were comprised of seven 7.5 in.-spaced rows wide and 30-ft long, for a total plot area of approximately 131 ft^2. A total of four treatments resulting from four N rates were evaluated in each location. The fertility treatments evaluated consisted of 0, 50, 100, and 150 lb N/acre applied as urea during the fall. Planting, harvest, and product application dates are provided in Table 1. The same wheat variety (Zenda) was evaluated at all locations. Harvest occurred using a Massey Ferguson XP8 small-plot, self-propelled combine. Plot ends were trimmed at harvest time to avoid border effect, and the portion harvested for grain was approximately 100 ft^2 at both locations, comprising the central portion of the plots.

Measurements and Statistical Analyses

A total of 15 individual soil cores (0 to 24-in. depth) were collected from each location and divided into 0–6 in. and 6–24 in. increments for initial fertility analysis. The individual cores were mixed to form one composite sample, which was later analyzed for base fertility levels (Table 2).

Measurements included flag leaf N concentration taken at heading (approximately 40 flag leaves were collected per plot); a 0.19 m^2 biomass sample retrieved at harvest maturity from which we measured yield components (aboveground biomass, harvest index, head number per area, kernels per head, kernels per area, and 1000-kernel weight); and grain yield, grain test weight, and grain protein concentration. Nitrogen removal in the grain was calculated using a 5.7 conversion factor from protein to nitrogen in the wheat grain, and multiplying grain N by grain yield.

Statistical analysis of the data collected in this experiment was performed using PROC GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC). Replication was treated as a random effect in the analysis for individual locations, while location and replication nested within location were random effects in the analysis across locations.

Results

Weather Conditions

The 2018–2019 winter wheat growing season in Kansas was characterized by below average temperatures and above average precipitation (Table 3). The fall had anywhere from 9.3 to 13.9 inches of precipitation in the studied locations, sometimes resulting in poor stand establishment across the state. Due to this excessive fall precipitation and its consequent waterlogging, the Great Bend location was abandoned. The studied locations received anywhere from 16.3 to 24.9 inches of precipitation during the spring (April until July) which, coupled with below average temperatures, extended the growing season and delayed harvest until early to mid-July.

Overall Treatment Significance on the Measured Variables

Table 4 shows the results from the analysis of variance for each location individually, as well as for the combined analysis across locations. At the 0.1 probability level, nitrogen rate was a significant effect for most of the measured parameters at Ashland Bottoms, followed by Manhattan, Hutchinson, and finally the least responsive location to N rate was Belleville. The combined analysis showed a significant N rate effect on all but three measured parameters (Table 4).

Grain Yield and Yield Components

Across all treatments and locations, grain yield ranged from 36.3 to 94.4 bu/a. The lowest yielding location was Ashland Bottoms (average yield: 47 bu/a) and the highest yielding location was Belleville (average yield: 88 bu/a). At all locations except for Belleville, grain yield increased with increases in N rate (Table 5), usually following quadratic relationships (increasing until about 100 lb N per acre and plateauing at greater N rates) although in some instances, the relationship was linear. The lack of a significant N rate effect at the Belleville location could result from high levels of organic matter in this location, releasing organic nitrogen during the cycle of the crop (Table 2).

The ANOVA results for the yield components are shown in Table 6. Overall, the yield components most often impacted by N rate were shoot biomass and 1000-kernel weight, although in some locations there were also significant effects on heads per area and kernels per area. Biomass ranged from 5116 to 14,262 lb/a, and usually increased with increased N rates (Table 6). Harvest index ranged from 0.39 to 0.46 and was not impacted by the treatments evaluated. Heads per square foot ranged from 44 to 83 and increased with increasing N rates in the combined analysis (although the individual site-year analysis failed to detect significant treatment effects). At a few sites, increasing N rate reduced 1000 kernel weight, which is probably explained by more kernels being produced due to more N, and thus, additional smaller/secondary kernels originated. Increases in N rate generally increased kernels per area.

Flag Leaf N Concentration, Grain Protein Concentration, and Grain Test Weight

Flag leaf N concentration ranged from 2.4 to 4.1% across all environments and treatments, and it was significantly affected by N rate at Ashland Bottoms, Belleville, Manhattan, and in the combined analysis (Table 7). Usually, increasing N rates increased flag leaf N concentration (c.a., 2.9% in the zero-N control versus 3.28% in the 150 lb N/a). Across all sources of variation, a linear plateau model explained the rela-

tionship between relative grain yield (calculated in each location relative to the maximum yield in that respective location) and flag leaf N concentration with an overall robustness of $r^2 = 0.26$. This model suggested that relative yield increased from ~0.5 at flag leaf N of 2.4%, to 0.84 at flag leaf N of 2.97%, and plateaued afterwards for flag leaf N concentration as high as 4.1% (Figure 1).

Grain protein concentration ranged from 11 to 15% across all locations and treatments. Nitrogen rate had a significant effect on grain protein concentration at all locations, including the combined analysis (Table 7). Increasing N rates increased grain protein concentration usually in a linear way (Ashland Bottoms, Manhattan, and combined analysis), but sometimes the relationship tended to reach a plateau or quadratic relationship in which there was no increase in protein concentration beyond a given N rate (Belleville and Hutchinson). Similarly to relative grain yield, relative grain protein concentration (calculated by location relative to the maximum respective to each location) was related to flag leaf N concentration ($r^2 = 0.23$) and followed a linear-plateau shape (Figure 1). Relative grain protein concentration increased from about 0.75 at flag leaf N concentration of 2.4%, to 0.94 at flag leaf N concentration of 2.95%. Further increases in flag leaf N concentration did not increase relative grain protein content.

Grain test weight ranged from 57.3 to 64.2 pounds per bushel across all treatments and locations. There were significant N rate effects on test weight in Hutchinson and Manhattan, as well as in the combined analysis. At these locations, test weight tended to decrease with increases in N rate, likely because greater N rates originated more tillers and these secondary tillers usually are later and result in lighter kernels (although this was not measured in the current study).

Preliminary Conclusions
Winter wheat response to N rate is dependent on environmental conditions, including not only the weather experienced in the season (and thus the potential yield of the season), but also the amount of inorganic nitrogen made available through the soil. In this research, most of the yield response to N rate was quadratic, suggesting that the 100 lb N/a rate was sufficient to maximize yields at the yield environments here studied (though small site-to-site variations were reported). Protein tended to follow a more linear response, perhaps suggesting that more N is needed to maximize protein as compared to yield. The linear-plateau relationship developed between relative grain yield or relative grain protein as affected by flag leaf N concentration provides preliminary evidence for using flag leaf N as an in-season diagnostic tool for crop N status.

References

de Oliveira Silva, A., Ciampitti, I.A., Slafer, G.A. and Lollato, R.P., 2020a. Nitrogen utilization efficiency in wheat: A global perspective. European Journal of Agronomy, 114, p.126008.

de Oliveira Silva, A., Slafer, G.A., Fritz, A.K. and Lollato, R.P., 2020b. Physiological basis of genotypic response to management in dryland wheat. Frontiers in Plant Science, 10, p.1644.

Jaenisch, B.R., de Oliveira Silva, A., De Wolf, E., Ruiz-Diaz, D.A. and Lollato, R.P., 2019. Plant population and fungicide economically reduced winter wheat yield gap in Kansas. Agronomy Journal, 111(2), pp.650-665.

Lollato, R.P. and Edwards, J.T., 2015. Maximum attainable wheat yield and resource-use efficiency in the southern Great Plains. Crop Science, 55(6), pp.2863-2876.

Lollato, R.P., Edwards, J.T. and Ochsner, T.E., 2017. Meteorological limits to winter wheat productivity in the US southern Great Plains. Field Crops Research, 203, pp.212-226.

Lollato, R.P., Ruiz Diaz, D.A., De Wolf, E., Knapp, M., Peterson, D.E. and Fritz, A.K., 2019a. Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. Crop Science, 59(1), pp.333-350.

Lollato, R.P., Figueiredo, B.M., Dhillon, J.S., Arnall, D.B. and Raun, W.R., 2019b. Wheat grain yield and grain-nitrogen relationships as affected by N, P, and K fertilization: A synthesis of long-term experiments. Field Crops Research, 236, pp.42-57.

Taiz, L., and E. Zieger. 2010. Chapter 5 - Mineral nutrition. p. 782. In: Plant Physiology. 5th ed. Sinauer Associates, Inc., Sunderland, MA.

Waldren, R.P. and Flowerday, A.D., 1979. Growth Stages and Distribution of Dry Matter, N, P, and K in Winter Wheat 1. Agronomy Journal, 71(3), pp.391-397.

Table 1. Dates of field activities for the nitrogen rate trials conducted in 2018–2019

Activity	Stage	Ashland Bottoms	Belleville	Great Bend	Hutchinson	Manhattan
Planting	---	11/1/2018	10/3/2018	10/2/2018	10/22/2018	10/23/2018
Nitrogen application	Feekes 1	1/9/2019	11/7/2019	11/20/2019	11/14/2019	12/10/2019
Herbicide	Feekes 4	3/22/2019	4/2/2019	3/27/2019	3/18/2019	3/22/2019
Flag leaf sampling	Feekes 10	5/15/2019	5/17/2019	---	5/6/2019	5/15/2019
Fungicide	Feekes 10.5	5/31/2019	5/16/2019	---	5/15/2019	5/20/2019
Harvest index	Maturity	7/1/2019	7/15/2019	---	6/26/2019	7/1/2019

The Great Bend location was abandoned due to excessive fall precipitation causing waterlogging and sub-optimal stand establishment.

Table 2. Soil fertility analysis for all experimental locations where the nitrogen rate trials were established during the 2018–2019 growing season

Sample Name	Depth	Ca	Cu	Mg	Mn	Na	OM	P-M	CEC meq/100 g	pH	NO$_3$-N	NH$_4$-N	K	Zn	Fe	S	Cl
	in.	--------------------- ppm -------------------					%	ppm			-------------------------------- ppm ------------------------------						
Ashland Bottoms	0–6	3329	1.8	550	15.1	21	3.0	8.4	22.1	6.5	3.0	6.5	304	0.6	47.1	2.6	8.2
	6–24	3604	2.0	760	10.7	36	2.2	3.7	25.3	6.7	1.7	7.9	309	0.2	33.3	2.2	6.6
Belleville	0–6	2056	2.1	296	43.1	17	3.1	52.4	27.98	5.4	0.4	3.0	437	0.8	114.2	3.4	7.7
	6–24	4022	2.2	555	15.5	58	2.4	7.8	25.96	6.6	4.0	5.0	381	0.3	52.3	3.0	8.9
Hutchinson	0–6	4746	1.1	163	7.0	35	2.9	27.2	26.05	8.0	9.7	3.2	315	0.3	19.9	3.3	8.0
	6–24	5202	0.8	162	4.3	128	2.2	4.0	28.41	8.1	3.2	4.5	194	0.1	14.4	12.5	12.3
Manhattan	0–6	2977	2.4	357	30.4	17	3.5	22.3	26.27	6.2	3.2	7.3	162	0.9	92.1	2.5	7.5
	6–24	4477	2.7	411	16.3	26	2.8	8.9	26.48	7.0	2.6	5.9	217	0.5	50.9	3.5	9.1

Information was collected for the 0 to 6-in. depth, and 6 to 24-in. depth.
Fertility level include soil pH, buffer pH, Mehlich-3 extractable phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), ammonium-(NH$_4$-N) and nitrate-nitrogen (NO$_3$-N), chloride (Cl), sulfate-sulfur (SO$_4$-S), organic matter (OM), and cation exchange capacity (CEC). Sampling depths were 0–6 in. and 6–24 in.

Table 3. Average maximum (Tmax) and minimum (Tmin) temperatures, precipitation, and grass evapotranspiration (ETo) during the fall (October 1–December 31), winter (January 1–March 31), and spring (April 1–July 15)

Location	Season	Tmax	Tmin	Precipitation	ETo
		-------------- °F --------------		-------------- in. --------------	
Ashland Bottoms	Fall	52.4	30.5	9.1	5.1
	Winter	41.3	23.2	5.0	5.2
	Spring	77.2	55.0	22.3	20.4
Belleville	Fall	49.6	28.4	8.9	5.3
	Winter	37.9	21.3	2.2	4.6
	Spring	75.0	51.7	17.9	18.8
Hutchinson	Fall	52.3	30.8	13.9	6.2
	Winter	44.6	24.6	3.3	6.1
	Spring	78.0	54.4	19.0	19.5
Manhattan	Fall	53.2	31.6	9.3	5.3
	Winter	42.2	24.0	5.0	5.0
	Spring	77.8	55.6	24.9	19.0

Table 4. Significance of nitrogen (N) rate on different measured variables at all Kansas locations where the trial was conducted, as well as the analysis combined across sites, during the 2018–2019 growing season

Variable	Ashland Bottoms	Belleville	Hutchinson	Manhattan	Combined
	--- $P < F$ ---				
Test weight	0.29	0.99	**0.06**	**0.03**	**0.02**
Yield	**<0.01**	0.32	**0.05**	**<0.01**	**<0.01**
Protein	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
N removal	**<0.01**	0.12	**0.01**	**<0.01**	**<0.01**
Flag leaf N	**0.01**	**<0.01**	0.13	**<0.01**	**<0.01**
Yield components					
Biomass	**0.06**	0.97	0.83	0.46	**0.03**
HI	0.41	0.27	0.71	0.88	0.36
Heads/m^2	0.12	0.74	0.11	**0.07**	**<0.01**
1000-KW	**0.01**	0.7	0.49	0.96	0.31
Kernels/m^2	**0.04**	0.78	0.7	0.49	**0.01**
Kernels/head	**0.04**	0.48	0.42	**0.06**	0.83

Bold numbers show significant effects at $P < 0.1$.
HI = harvest index. KW = kernel weight.

Table 5. Wheat grain yield as affected by nitrogen (N) rate at four experiments conducted in Kansas during the winter wheat season of 2018–2019

N rate	Ashland Bottoms	Belleville	Hutchinson	Manhattan	Combined
lb of N/a	--- bu/a ---				
0	36.3 d	82.5	69.5 bc	50.1 c	59.6 d
50	46.8 c	89.5	73.4 abc	64.6 b	68.6 c
100	52.4 a	85.8	76.1 ab	74.6 a	72.2 abc
150	52.8 a	94.4	78.1 a	76.9 a	75.6 ab

Means followed by the same letter indicate no statistical difference at the 0.05 probability level.

Table 6. Wheat yield components as affected by nitrogen rate at four experiments conducted in Kansas during the winter wheat season of 2018–2019

Location	Nitrogen rate	Biomass	Harvest index	Heads/ft²	1000 KW	Kernels/ft²	Kernels/ head
	lb N/a	lb/a					
Ashland Bottoms	0	5116 c	0.46	44	28.9 a	828 c	19.0 bc
	50	6743 bc	0.46	52	28.7 ab	1122 ab	22.0 a
	100	7492 a	0.46	59	28.2 bc	1254 a	20.5 ab
	150	7616 a	0.45	59	27.6 c	1300 a	21.5 a
Belleville	0	13927 ab	0.45	75	30.8 a	2078	27.5
	50	14168 a	0.44	82	30.0 ab	2180	27.0
	100	14262 a	0.44	77	30.2 ab	2205	29.0
	150	13901 ab	0.46	79	29.8 b	2246	28.5
Hutchinson	0	7777	0.39	53	32.8 b	972	18.5
	50	7924	0.4	51	33.0 ab	999	20.0
	100	8325	0.39	55	33.7 a	1026	18.5
	150	8094	0.41	58	32.1 b	1061	18.0
Manhattan	0	9159	0.43	62	31.6	1295	21.0
	50	9983	0.42	72	31.3	1421	19.5
	100	10977	0.42	80	31.4	1578	19.5
	150	10705	0.43	83	31.7	1512	18.0
Combined	0	8994 d	0.43	58 c	31.0	1293 c	21.5
	50	9702 cd	0.43	63 bc	30.8	1430 ab	22.0
	100	10264 a	0.43	67 ab	30.9	1516 a	22.0
	150	10077 b	0.44	69 a	30.3	1529 a	21.5

KW = kernel weight (g).

Table 7. Winter wheat flag leaf nitrogen (N) concentration (%), grain protein concentration (%), and grain test weight (lb/bu) as affected by nitrogen rate at four experiments conducted in Kansas during the winter wheat season of 2018–2019

Location	N rate	Flag leaf N	Protein	Test weight
	lb N/a	------------------ % ------------------		lb/bu
Ashland Bottoms	0	2.59 b	12.4 c	64.2
	50	2.73 ab	12.4 cd	63.9
	100	2.83 a	13.5 ab	63.3
	150	2.85 a	14.3 a	63.0
Belleville	0	3.62 c	14.2 c	58.8
	50	3.83 b	14.6 ab	59.3
	100	4.06 a	14.6 ab	59.0
	150	4.02 a	15.0 a	59.8
Hutchinson	0	2.78	13.7 c	60.7 a
	50	2.77	13.8 bc	61.1 a
	100	2.86	14.0 a	60.5 ab
	150	2.96	13.8 bc	58.4 bc
Manhattan	0	2.70 c	11.1 d	63.1 a
	50	3.05 b	11.3 dc	62.3 abc
	100	3.30 a	12.0 ab	61.9 abc
	150	3.29 a	12.4 a	61.3 c
Combined	0	2.92 c	12.8 c	61.7 a
	50	3.09 b	13.0 c	61.7 a
	100	3.26 a	13.5 ab	61.2 abc
	150	3.28 a	13.9 a	60.6 bc
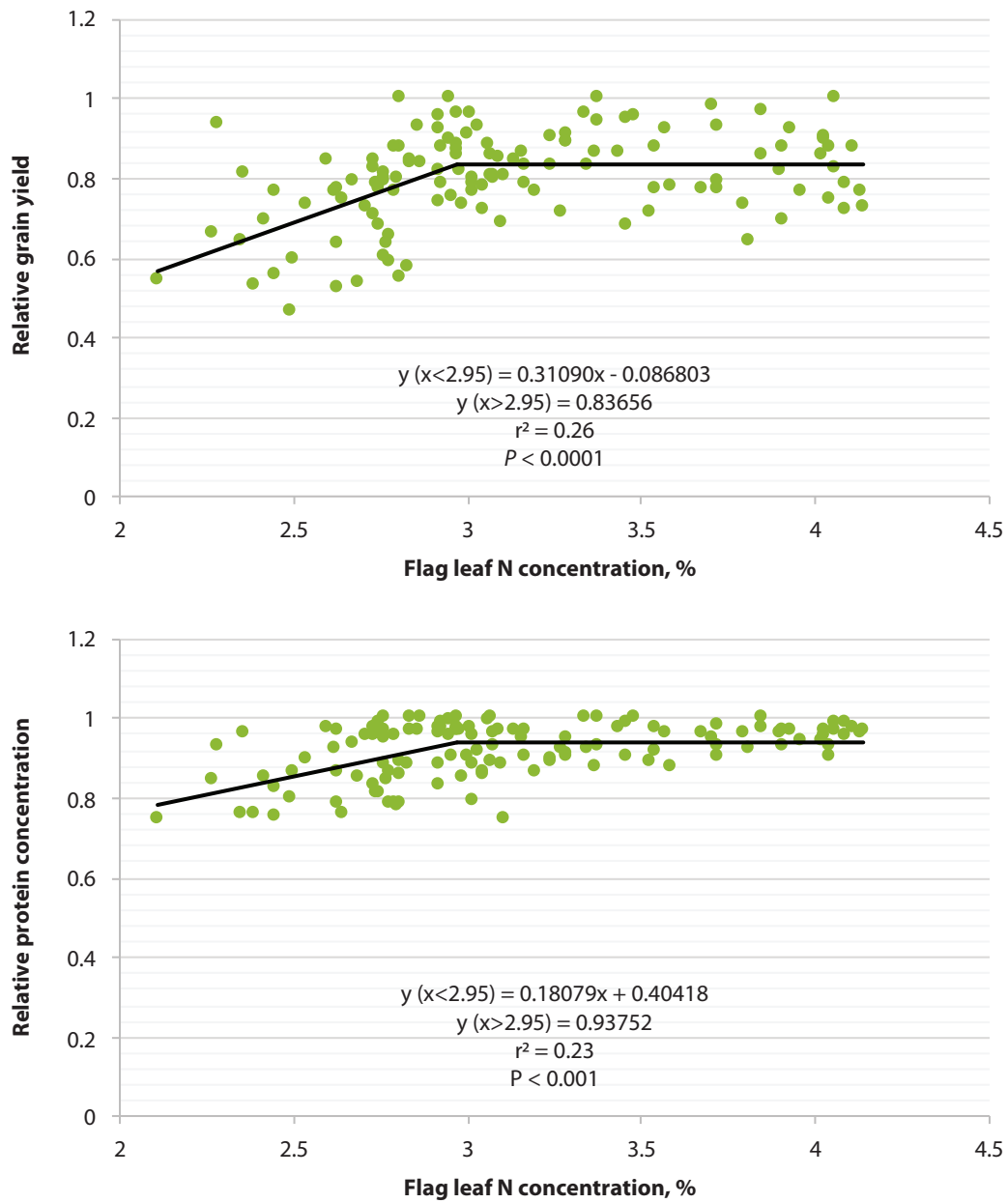
Figure 1. Relative grain yield (upper panel) and relative grain protein concentration (lower panel) as affected by flag leaf nitrogen (N) concentration across all environments and treatments.

Pivot Bio Proven Inoculant as a Source of Nitrogen in Corn

W. Davis, C. Bonini Pires, D. Ruiz Diaz, K.L. Roozeboom, and C.W. Rice

Summary

Nitrogen (N) fertilizer represents a significant annual cost for farmers. Additionally, N losses pose environmental concerns and represent loss of resources. Proven, an N fixing bacterial inoculant for corn developed by Pivot Bio (Berkeley, CA) is expected to fix between 20 and 30 lb N/a over a growing season. The use of bacterial inoculants to fix N for corn reduces the risk of N loss through leaching and volatilization by reducing the amount of inorganic fertilizers required to maximize yield. To evaluate the efficacy of Proven, a field trial was established in Manhattan, KS, on a Kennebec silt loam that had been under continuous no-till corn production for 5 years. The experiment was arranged in a split-plot design with four replications. The main treatment was N fertilizer rate at 0, 50, 100, and 150 lb N/a applied as urea directly before planting. The subplot factor was with and without Proven. Soil samples were taken before planting (0–36 in.), at V6 (0–12 in.), R1 (0–12 in.), and harvest (0–36 in.) for inorganic N. Plant measurements included vigor at V4 and V8-V10; NDVI at V5-V8; SPAD readings at R1-R3; and green leaf counts during grain fill. Whole plant biomass and N content were determined at R6. At harvest, grain moisture, test weight, and yield were measured. Nitrogen rate significantly affected grain yield and plant N uptake. The effect of Proven was not significant nor was the interaction between N rate and Proven.

Introduction

Historically, N fixing microbes have had little to no role in agronomy outside of those in symbiotic association with legumes. The ability to use N fixing microbes as a source of N in crops provides great benefits, including decreased N losses and increased available N later in the growing season without additional synthetic fertilizers. Pivot Bio has recently released Proven, a bacterial inoculant intended to fix N in corn. Proven is applied in-furrow at seeding and forms a mutualistic relationship with the corn, growing on its roots and consuming plant exudates while fixing atmospheric N, even in the presence of high soil N. This N fixed by Proven is then available for plant uptake. Pivot Bio claims that Proven can be used as a source of approximately 20–30 lb N/a over a growing season. The objective of this study was to determine the contribution of Proven as an N source for corn. The hypothesis was that Proven would contribute 20–30 lb N/a for corn production.

Procedures

A replicated split-plot design experiment was established at the Kansas State University Department of Agronomy North Farm in the spring of 2019. The local mean annual precipitation and potential evapotranspiration were 31.5 and 51.2 in., respectively, with a mean annual temperature of 52.52°F. The soil at the experimental site is classified as Kennebec silt loam (fine-silty, Hapludoll). The main treatment was N rate at 0, 50, 100, and 150 lb N/a applied by hand as urea immediately before planting, and the subplot factor was the presence or absence of Proven. The experiment had four replicates.

Each plot was composed of four 47-ft rows with 30-inch row spacing seeded at 28,000 plants/a.

Extensive soil sampling characterized nutrient status before, during, and after the growing season. Soil samples were collected and homogenized within each plot before planting (0–36 in), at V6 (0–12 in.), R1 (0–12), and after harvest (0–36). Inorganic soil N content was determined for each sampling by KCl extraction. Additionally, subsamples from each plot from the baseline soil sampling were tested for P, K, and pH analysis (0–12 in.). Based on these P, K, and pH results, an application of 30 lb/a of P was applied to the entire experiment in the form of triple superphosphate.

Corn growth and N uptake were documented in several ways. Stand counts were taken at R6 for the center two rows of each plot to determine the plant population in plants/a. Whole plant samples were also taken at R6 by cutting five representative plants from each of the center two rows of each plot at ground level. The plant biomass for each plot was separated from the ears and weighed separately. Subsamples of the biomass were coarse ground and dried. After drying and grinding using a 2-mm sieve, carbon and nitrogen analysis was performed. The biomass N and mass were used to calculate total biomass N content/plant, which with the stand counts was used to determine biomass N content/a.

Harvest took place when grain moisture content was less than 20%. Ears were collected by hand from each of the center two rows of a representative 10-ft area, totaling 20 ft of yield row. Ears were shelled with a stationary sheller, and the mass of the collected grain from each plot was used to estimate grain yield. A subsample of the grain was submitted to the Kansas State University Soil Testing Lab for carbon and nitrogen analysis. Grain N, along with the grain mass were used to calculate total grain N uptake/plant. The total grain N and total biomass N for each plot were summed to determine total N uptake/plant. The plant population was then multiplied by the total N uptake/plant to determine the total plant N uptake in lb/a.

Once total plant N uptake (lb/a) was determined for each plot, the amount of mineralized N (lb/a) was determined by summing the harvest soil N and total plant N and subtracting the preplant soil N. The difference in N uptake between plots with Proven and plots without Proven was calculated by subtracting the total plant N without Proven from the total N uptake with Proven. Plant N uptake with and without Proven was characterized by plotting N uptake vs. fertilizer N rate. Analysis of Variance (ANOVA) was conducted on all data using Sisvar with an alpha of 0.05 to assess the effects of N rate, Proven, and their interaction.

Results

There was no statistically significant effect of Proven ($P = 0.1965$) or a Proven by N rate interaction ($P = 0.6209$) on grain yield (Figure 1). However, increasing the rate of N fertilizer significantly increased grain yield ($P = 0.0001$) from 0 to 100 lb N/a with no additional increase at 150 lb N/a.

The rate of N fertilizer significantly affected total plant N uptake ($P = 0.0000$). The effect of Proven on total plant N uptake was not significant ($P = 0.3093$) nor was the

interaction of Proven and N rate (P = 0.9916). However, total plant N uptake tended to be higher with Proven at all N rates (Figure 2).

Soil N mineralization without Proven produced 68 lb N/a, those treated with Proven produced 84 lb N/a, although this difference was not significant (P = 0.3358). Although there was a tendency for a positive effect of Proven on N mineralization, it was not significant.

Preliminary Conclusions
Although there was some evidence that Proven resulted in greater N mineralization, yield, and plant N uptake, the effects were not significant. These preliminary results suggest that Proven may be acting as an N source, but the amount of N provided by Proven may not be significant, or may not be enough to produce a significant increase in yield and total plant N in the conditions present in this experiment. It is important to emphasize that these results and conclusions are based on one site and one year, so generalizations that can be made about Proven based on these results are limited.

Acknowledgments

Nitrogen rate vs. grain yield
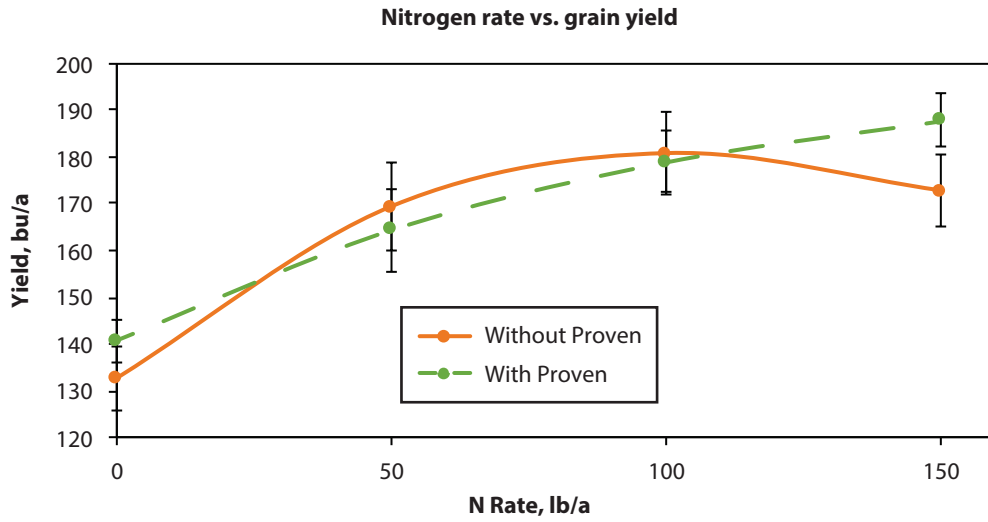
Figure 1. Grain yield and nitrogen (N) applied with and without Proven.

Nitrogen rate vs. total plant N
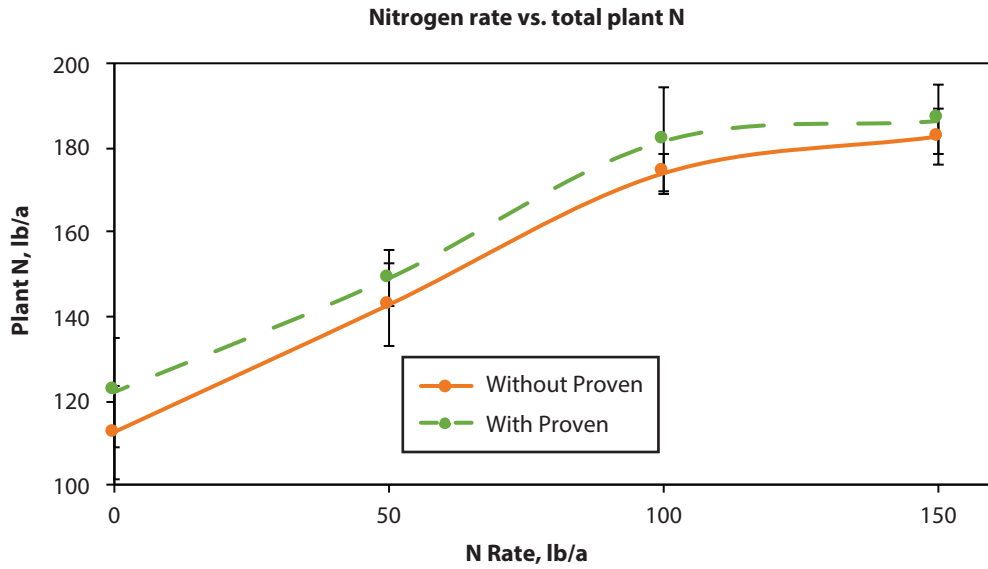
Figure 2. Total nitrogen (N) uptake with and without Proven.

Occasional Tillage and Nitrogen Application Effects on Winter Wheat and Grain Sorghum Yield

A.K. Obour, J.D. Holman, and A.J. Schlegel

Summary

Occasional tillage ahead of winter wheat planting could alleviate herbicide-resistant weeds, redistribute soil acidification, and improve seedbed at wheat planting. The objective of this study was to determine occasional tillage and nitrogen (N) fertilizer application effects on winter wheat, and grain sorghum yields and soil quality in a wheat-sorghum-fallow cropping system. Treatments were three tillage practices: 1) continuous no-tillage (NT); 2) continuous reduced-tillage (RT); and 3) single tillage operation every 3 years (June-July) ahead of winter wheat planting [occasional tillage (OT)]. The sub-plot treatments were assigned to four N fertilizer rates (0, 40, 80, and 120 lb/a of N). Results showed tillage had no effect on winter wheat grain yield. Averaged across the 2 study years, wheat yields were 29.4 bu/a with NT, 31.0 bu/a with RT, or 31.6 bu/a with OT. Applying N fertilizer increased wheat yield, ranging from 20 bu/a with no N fertilizer to 38.7 bu/a when N fertilizer was applied at 120 lb/a of N. However, tillage ($P = 0.04$) and year × N rate interaction ($P = 0.003$) had significant effect on grain sorghum yield. Average grain sorghum yield with RT (73.6 bu/a) was less than NT (79.4) or OT (75.4 bu/a). Averaged across tillage and years, sorghum grain yield was 60.3 bu/a with no N fertilizer and 86.8 bu/a when N was applied at 120 lb/a of N. In most years, sorghum and winter wheat grain yields obtained with 80 lb/a of N were not different from those with 120 lb/a of N, suggesting 80 lb/a of N may be adequate for both crops.

Introduction

Adoption of NT practices during fallow by many producers in the central Great Plains (CGP) has increased the quantity of residues retained on the soil surface, and soil moisture storage. This has allowed for cropping intensification in dryland systems in the CGP from winter wheat-fallow to winter wheat-summer crop-fallow or a more intensified cropping system with no fallow depending on soil water availability. The benefits of NT include reduction in soil erosion, increased soil organic matter accumulation, improved soil structure, and increased soil water storage.

Despite these benefits, stratification of soil nutrients, organic matter, and pH tend to develop near the soil surface in long-term continuous NT systems. In addition, the lack of effective herbicides for perennial grass weeds such as three-awn grass (*Aristida purpurea* Nutt.) and tumble windmill grass (*Chloris verticillata* Nutt.) control, and the emergence of glyphosate-resistant weeds pose challenges in NT crop production. In addition, in drier years, the upper layer (0–2 inches) of soils in NT tends to be "hard" and presents a challenge to placing seed in subsoil moisture at the time of wheat planting. This may cause poor plant establishment and reduce winter wheat yields. Occasional tillage of NT soils may be necessary to alleviate herbicide-resistant weed issues, redistribute soil acidity, and improve seedbed at wheat planting. The objective of this

study was to determine occasional tillage and nitrogen (N) fertilizer application effects on winter wheat, and grain sorghum yields and soil quality in a wheat-sorghum-fallow cropping system.

Procedures

Field experiments were initiated in spring 2017 at the Kansas State University Agricultural Research Center near Hays, KS, to address the previously mentioned objectives. Study design is a split-split-plot with three replications in a randomized complete block design. Main plots were three crop phases of a wheat-sorghum-fallow, sub-plot treatments were three tillage practices: 1) continuous NT; 2) continuous RT; and 3) single tillage operation every 3 years (June-July) ahead of winter wheat planting (OT). The sub-sub-plots were assigned to four N fertilizer application rates (0, 40, 80, and 120 lb/a of N). The reduced tillage treatments had two to three tillage operations during fallow ahead of wheat planting and one tillage operation prior to sorghum planting. All tillage operations were done with a sweep-plow to a depth of 3 to 4 inches. Each phase of the crop rotation, tillage, and N fertilizer treatment was implemented in each year of the study. Winter wheat and sorghum grain yields were determined by harvesting a 5- × 80-ft area from the center of each plot using a small plot combine. Statistical analysis with the PROC MIXED procedure in SAS version 9.4 (SAS Inst., Cary, NC) was used to examine winter wheat and grain sorghum yields as a function of tillage and N fertilizer application.

Results

Winter Wheat Grain Yield

Winter wheat grain yield was not affected ($P = 0.54$) by tillage in this study (Figure 1a). Averaged across N rates and years, wheat grain yield was 29.4 bu/a with NT, 31.6 bu/a with OT, and 31.0 bu/a with RT. Winter wheat grain yield response to N fertilizer application varied by year (Figure 1b). In 2018, there were no significant wheat yield increases when N fertilizer was applied beyond 80 lb/a of N. Nonetheless, 120 lb/a N was required for maximum wheat yield in 2019. Across years grain yield increased linearly with N fertilizer application, ranging from 20.5 bu/a with no N fertilizer to 38.7 bu/a when N fertilizer was applied at 120 lb/a of N. However, wheat grain yield was not different when N was applied at 80 lb/a of N or 120 lb/a of N in 2018 (Figure 1b).

Tillage had a significant ($P = 0.04$) effect on sorghum grain yield over this 3-year study. Averaged across N rates and years, sorghum grain yields with NT (79.4 bu/a) or OT (75.4 bu/a) were not different. However, RT operations reduced sorghum grain yield compared to the other tillage treatments (Figure 2). Year × N rate interaction had a significant effect on sorghum grain yield (Figure 3). Application of N fertilizer increased sorghum yields in 2017, but grain yields produced with 40 lb/a of N were similar to those achieved with greater N rates. In the 2018 growing season, applying N fertilizer resulted in a linear increase in sorghum grain yield. Similarly, N fertilizer application did increase sorghum grain yield but significant yield increases occurred beyond 80 lb/a of N. The differences in N response between 2017, 2018, and 2019 growing seasons were because of the differences in precipitation amount in the 3 years that affected amount of available soil water for sorghum production. Across the 3 years and tillage treatments, applying N fertilizer increased grain yield from 60.3 bu/a with the check

treatment (no N applied) to 86.8 bu/a with 120 lb/a of N. However, grain yield with 80 lb/a of N in 2 of the 3 years of the study were not different from that obtained with the highest N rate of 120 lb/a of N.
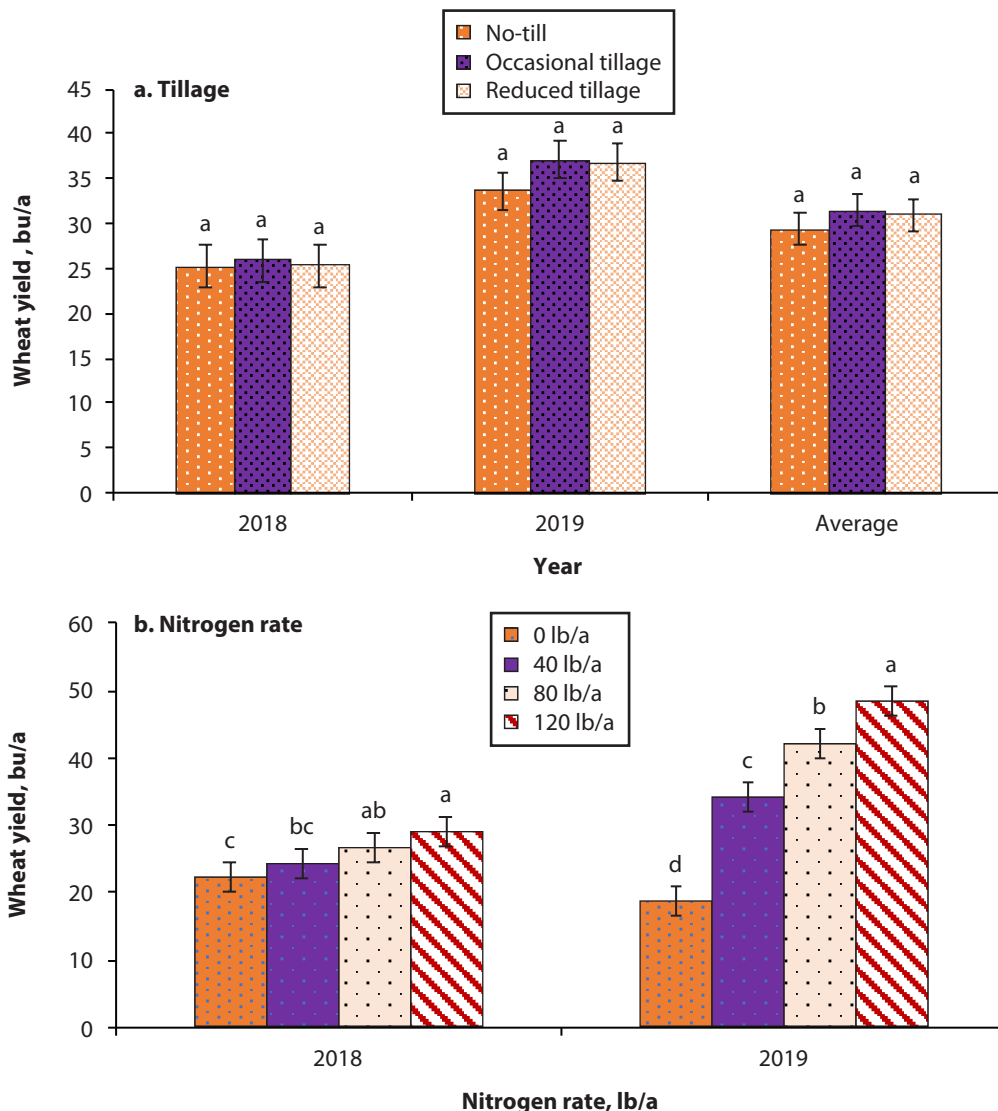

Figure 1. Winter wheat grain yield as affected by tillage (a) and nitrogen (N) fertilizer application rate (b) in 2018 and 2019 growing seasons at Hays, KS. Data for tillage effects are averaged across four N rates and three replications (n = 12), and data for N rate effects are averaged across three tillage treatments and three replications (n = 9). Means followed by same lowercase letter(s) are not significantly different (*P* > 0.05).
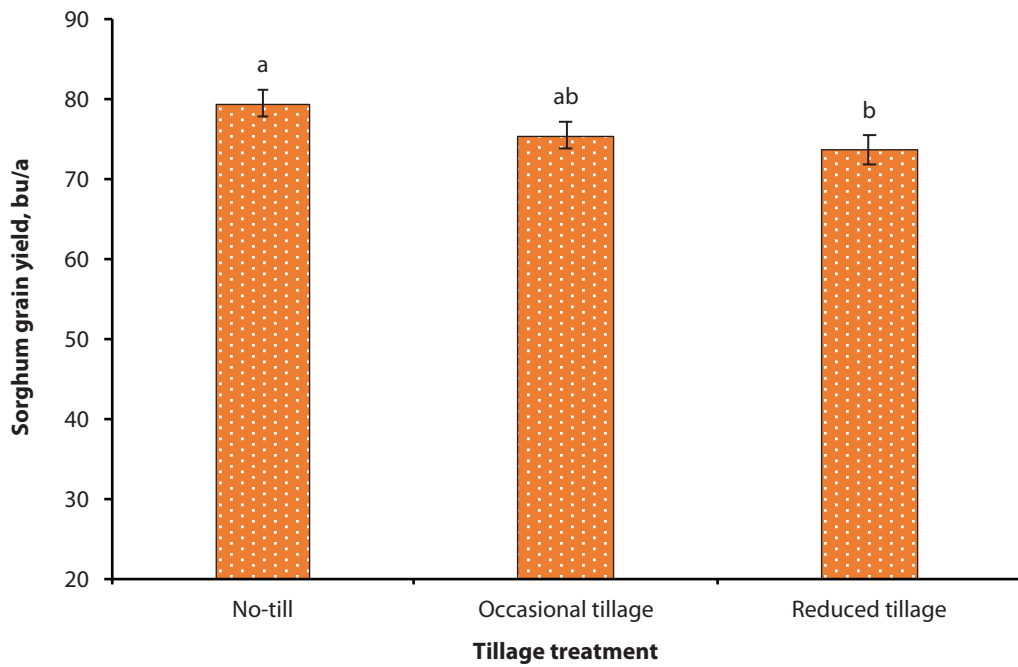
Figure 2. Grain sorghum grain yield as affected by tillage system in three (2017–2019) growing seasons at Hays, KS. Data are averaged across four nitrogen treatments, three years and three replications (n = 36). Means followed by same lowercase letter(s) within a year are not significantly different (*P* > 0.05).
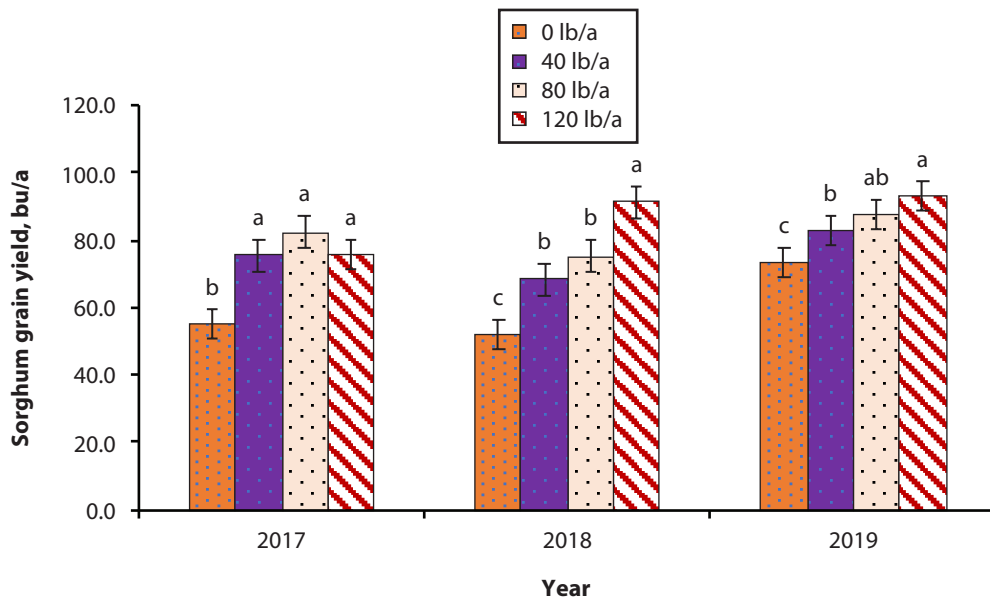
Figure 3. Grain sorghum grain yield as affected by nitrogen fertilizer application rates in three (2017–2019) growing seasons at Hays, KS. Data are averaged across three tillage treatments and three replications (n = 9). Means followed by same lowercase letter(s) within a year are not significantly different (*P* > 0.05).

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

M.J.A. Coelho and D.A. Ruiz Diaz

Summary

Phosphorus (P) fertilizer placement can affect the long-term dynamics and forms of P, and the overall soil P pools. These changes can vary by soil type, and affect P uptake and use efficiency by crops. The objective of this study was to evaluate the changes in the labile P fractions in three Kansas soil types under P fertilizer placements (broadcast versus deep band) after ten years of crop rotation. Three field studies were conducted at Scandia, Ottawa, and Manhattan. Three treatments were evaluated: 1) a control with no P fertilizer application and two fertilizer treatments (80 lb P_2O_5/a); 2) surface broadcast; and 3) deep band at approximately 4–6 in. depth. All treatments received strip-tillage. After ten years, soil samples were collected from the row, and between the row at two sampling depths (0–3 and 3–6 inches) and soil P pools (inorganic and organic P labile) were measured. Significant changes in soil labile P pools for treatments compared to control were observed due to the long-term effect of P fertilizer placement. The broadcast P fertilizer placement increased the total labile (Pt_{LP}) and inorganic labile P (Pi_{LP}) in the soil surface (0–3 in.) and deep band in the subsoil (3–6 in.) at all sites studied. However, the highest amount of organic labile P (Po_{LP}) was observed for the control broadcast treatments in the subsoil (3–6 in.) at the Scandia site. The total labile P was affected by maximum P adsorption capacity (MPAC) and P fertilizer placement.

Introduction

Fixation of plant nutrients by soils is a major concern for economical use efficiency of fertilizer. Phosphorus (P) from fertilizer can become "fixed" in some soils due to conversions into compounds of limited bioavailability for plant uptake (Coelho et al., 2019; Preston et al., 2019). Phosphorus in the soil exists in inorganic (Pi) as well as organic (Po) forms of comparable solubility, and the soil fixation of all these forms depends upon many factors (organic matter content, pH, clay types, soil maximum P adsorption capacity, and fertilizer placement). Thus, efficient P management in crop production is needed to minimize depletion of soil P reserves, environmental issues due to the waste from the higher rates, and production costs. Fertilizer P placement can affect crop P utilization in the short-term during the growing season. However, the long-term interactions of placement and plant root uptake in different soils can also affect the forms of P and the overall soil P pools, especially the residual labile P concentration at various soil depths and soil-plant interactions (Adee et al., 2016). The objective of this study was to evaluate the changes in the labile P fractions in three Kansas soils under different P fertilizer placements (broadcast versus deep band) after ten years of crop rotation.

Procedures

Field experiments were conducted at the Kansas State University research and extension centers located in Scandia, Ottawa, and Manhattan. Initial soil samples were

collected in April 2006 before initiating the study by collecting a representative sample from the 0–3 and 3–6 inch layers for the characterization of soil properties of the experimental areas (Table 1). A strip-tillage operation was performed before planting corn, while soybean was planted into the corn residue with no prior tillage. Strip-tillage was used for all plots, including the control, which received no P fertilizer application. Deep-band P fertilizer application was completed with the strip-tillage operation at 30-in. row spacing and made in the same row location for ten years. Corn and soybean were planted in the center of the strip in the same row each year. The phosphorus fertilizer source for the broadcast treatment was triple superphosphate (0-45-0). The P fertilizer source for deep banding was ammonium polyphosphate (10-34-0). Treatments included a control with no P application and two treatments of 80 lb of P_2O_5/a as a broadcast or deep band. After the last crop harvest for each experiment in 2015, soil samples were collected from 0–3 and 3–6 inches depths from the row. Soil P fractions were determined by the sequential P fractionation method (Condron et al., 1985). All statistical analyses were completed in SAS Studio (version 9.3; SAS, Institute, Inc, Cary, NC). The GLIMMIX procedure was used for the analysis of variance (ANOVA).

Results

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

Inorganic Phosphorus Pool

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

Organic Phosphorus Pool

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

Total Labile P Pool

In general, the Pt_{LP} showed the same tendency as Pi with higher amount in the soil surface (0–3 in.) for the broadcast and in the 3–6 in. soil layer for deep band (Figure 1,

G, H, and I). In addition, preliminary results of this study suggested that the Pt_{LP} in the soil profile (0–6 in.) showed different tendencies across locations (Figure 2) and was affected by maximum P adsorption capacity (MPAC). The broadcast treatment showed a higher amount of Pt_{LP} (118 ppm) than deep band (112 ppm) and control (84 ppm) treatments at Scandia site with low MPAC (288 ppm). However, at the Ottawa location with medium MPAD (348 ppm) the higher amount of Pt_{LP} was observed for deep band (126 ppm) than broadcast (119 ppm) and control (86 ppm) treatments. In addition, at the Manhattan site with the higher MPAC (424 ppm) of this study the broadcast and deep band treatments showed the same or greater than the amount of Pt_{LP} (174 ppm) for the control treatment (84 ppm). The maximum P adsorption capacity of these soils plus the P placement may have affected these results. With lower MPAC the continuum application of P as broadcasted in a reduced tillage may have contributed to reducing large P sorption reactions and contributed to increasing labile P concentrations near the soil surface (Coelho et al., 2019; Hansel et al., 2017). In addition, the soil with a medium amount of P fixing components, when P fertilizer is deep banded in the row with lower soil volume and minimum disturbance of the soil, can contribute to reducing the high P sorption reactions, and that may have contributed to increasing the labile P levels. However, in the soil with higher P sorption reactions the effect of P fertilizer placement as broadcast and deep band on TotP are the same in soil profile after 10 years of crop rotations, or maybe the ten years of P application were not enough to saturate the adsorption P sites of the soil.

References

Adee E., Hansel F.D., Ruiz Diaz D.A., Janssen K. 2016. Corn Response as Affected by Planting Distance from the Center of Strip-Till Fertilized Rows. Front. Plant Sci. 7:1232. doi: 10.3389/fpls.2016.01232.

Coelho, M.J.A., D.A. Ruiz Diaz, G.M. Hettiarachchi, F.D. Hansel, and P.S. Pavinato. 2019. Soil phosphorus fractions and legacy in a corn-soybean rotation on Mollisols in Kansas, USA. Geoderma Regional. 18:228. https://doi.org/10.1016/j.geodrs.2019.e00228.

Condron, L.M., Goh, K.M., Newman, R.H., 1985. Nature and distribution of soil phosphorus as revealed by a sequential extraction method followed by 31P nuclear magnetic resonance analysis. Eur. J. Soil Sci. 36:199-207.

Fageria, N.K., 2001. Nutrient management for improving upland rice productivity and sustainability. Commun. Soil Sci. Plant Anal. 32:2603-2629.

Hansel, F.D., Ruiz Diaz, D.A., Amado, T.J.C. and Rosso, L.H.M. (2017), Deep Banding Increases Phosphorus Removal by Soybean Grown under No-Tillage Production Systems. Agronomy Journal, 109: 1091-1098. doi:10.2134/agronj2016.09.0533.

Rheinheimer D.S., Anghinoni I., Conte E., Kaminski J., Gatiboni L.C. 2003. Phosphorus desorption evaluated by successive extractions in soil samples from no-tillage and conventional tillage systems. Rural Sci. 33:1053-1059.

Preston, C., Ruiz Diaz, D. and Mengel, D. (2019), Corn Response to Long-Term Phosphorus Fertilizer Application Rate and Placement with Strip-Tillage. Agronomy Journal, 111: 841-850. doi:10.2134/agronj2017.07.0422.

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

Site	pH	TON	TOC	K	Ca	Mg	Na	CEC	Clay	Silt	Sand	MPAC
		-------- % --------		-------------- ppm --------------				cmol$_c$ kg^{-1}	----------- % -----------			ppm
0–3 in.												0–6 in.
Scandia	6.5	0.18	0.20	586	2159	371	31	17	21	59	20	288
Ottawa	5.5	0.18	0.20	311	2003	347	12	24	32	50	18	348
Manhattan	5.7	0.21	0.23	131	2124	377	15	22	26	60	14	424
3–6 in.												
Scandia	6.5	0.16	0.14	452	2443	426	45	21	29	55	16	
Ottawa	5.5	0.12	0.13	192	2309	407	14	26	36	48	16	
Manhattan	5.2	0.19	0.18	109	2275	344	27	27	32	58	10	

TON = total organic nitrogen. TOC = total organic carbon. K = potassium. Ca = calcium. Mg = magnesium. Na = sodium. CEC = cation exchange capacity. MPAC = maximum phosphorus adsorption capacity.
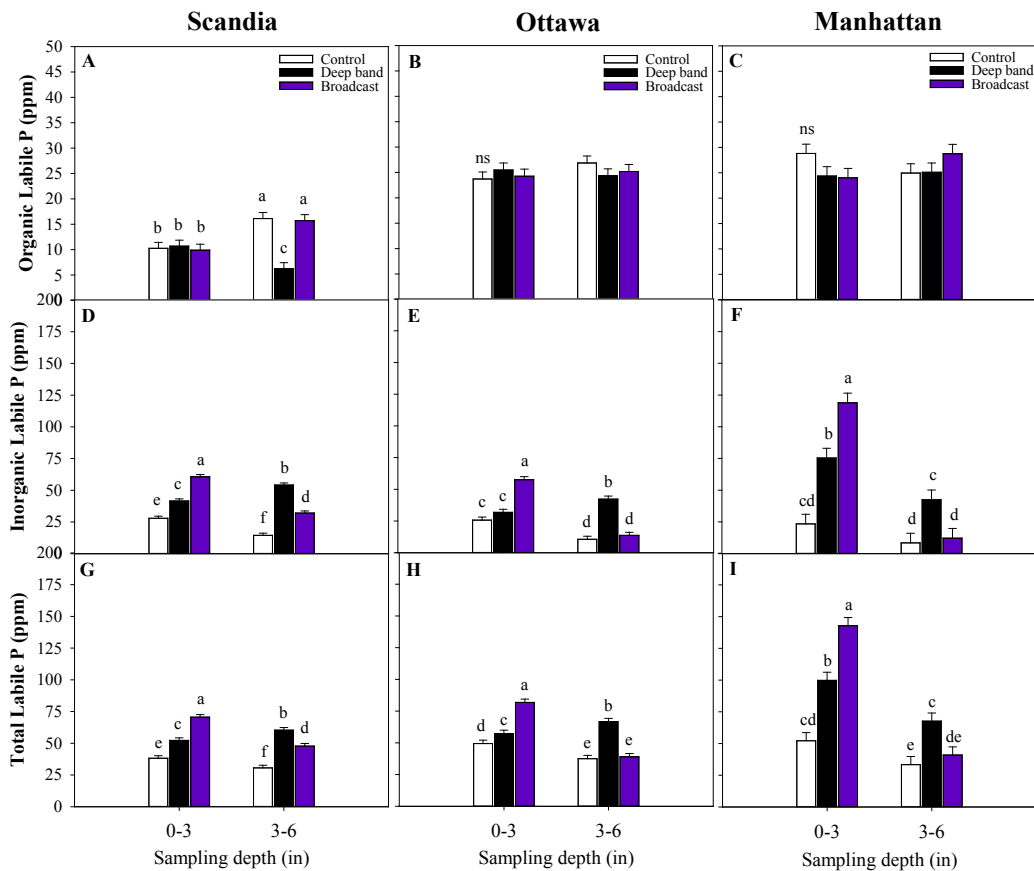
Figure 1. Labile phosphorus (P) pool: organic - Po$_{LP}$ (A, B, C); inorganic - Pi$_{LP}$ (D, E, F); and total - Pt$_{LP}$ (G, H, I) for two soil sampling depths for three locations: Scandia, Ottawa, and Manhattan, respectively, as affected by P fertilizer treatments (deep-band, broadcast, and control) after 10 years of a corn-soybean rotation for Scandia and Ottawa and, corn-soybean-wheat rotation for Manhattan. Error bars indicate the standard error of the mean and mean values followed by the same letter are not statistically different ($P > 0.05$). ns = not significant.
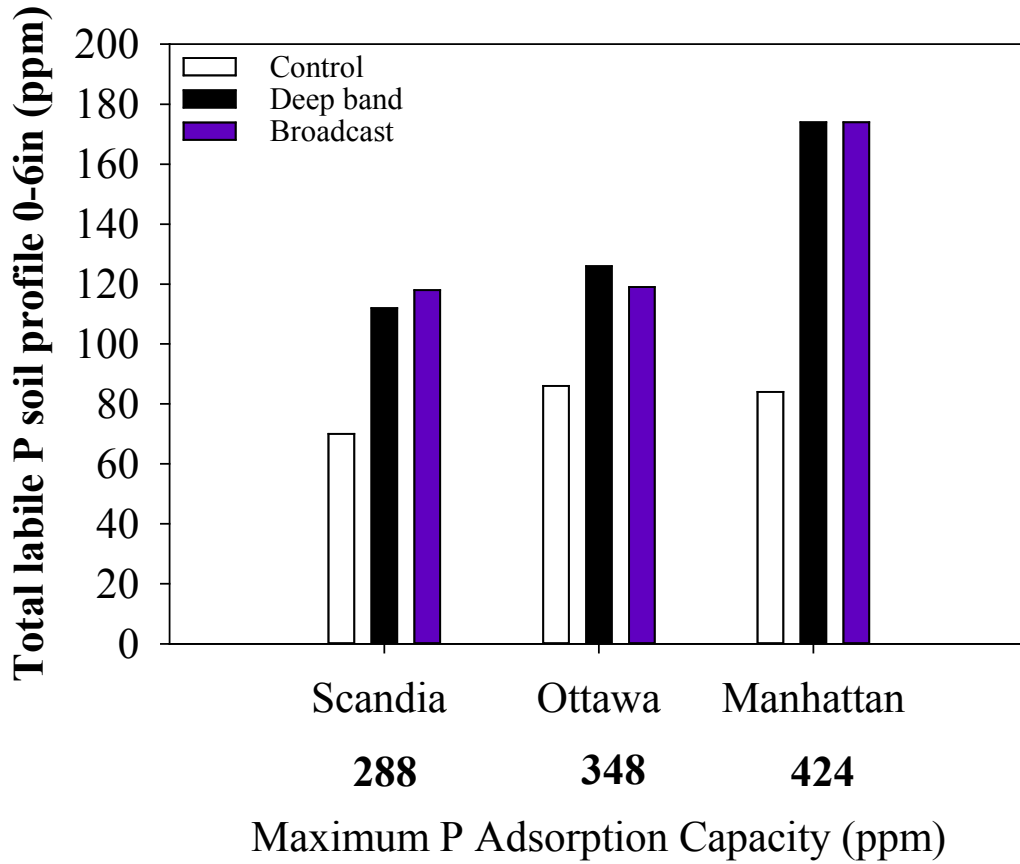
Figure 2. Total labile phosphorus (P) in the soil profile (0–6 inches) as affected by P fertilizer treatments (deep-band, broadcast, and control) after 10 years of crop rotation and maximum P adsorption capacity for three locations: Scandia, Ottawa, and Manhattan.

Fertilizer Source and Rate Affect Sulfur Uptake and Yield Response in Corn

T.E. Husa and D.A. Ruiz Diaz

Summary

With sulfur deficiencies being found throughout Kansas, the evaluation of sulfur fertilization and plant uptake are vital to optimize corn production. The objective of this study was to evaluate the effect of application rates of sulfur on yield and uptake in corn. Nutrient concentrations in corn biomass and grain were evaluated at the Kansas River Valley Experiment Field at Rossville, KS, in 2019. Five treatments were evaluated, including a control with no sulfur and no nitrogen (N), and four fertilizer treatments with 180 lb of nitrogen and four rates of sulfur fertilizer (0, 30, 50, and 200 lb S/a). The nitrogen source was urea and balanced for all treatments at 180 lb N/a. The sulfur-containing fertilizer applications were at the time of planting corn. Whole corn plant biomass and grain samples were taken at physiological maturity and analyzed for nitrogen and sulfur concentrations. Results for the study show that sulfur application rates have a significant yield response in corn, likely contributing to increased uptake of nitrogen. Moreover, high yielding environments increased total plant sulfur uptake and removal.

Introduction

Until recent years, sulfur is a nutrient that had often been overlooked. Increasing crop removals was due to higher yields, decreased atmospheric deposition, and a greater amount of crop residues have increased the likelihood of sulfur deficiency (Camberato and Casteel, 2017). Sulfur application is economically feasible in soils that have a severe sulfur deficiency, but not all fields respond to sulfur applications (Sawyer et al., 2011). Moreover, nitrogen application rates play a significant role in the response to sulfur application rates (Steinke et al., 2015). This study used Kansas State University's recommended rate for nitrogen for the Kansas River Valley Experiment Field and applied four different rates of sulfur.

Procedures

The Rossville field study was completed in September of 2019, initial soil samples were collected at the 0–6 in. soil layer and analyzed for various soil parameters (Table 1). The experiment was a randomized block design with four replications. Five treatments were evaluated, including a control (No N/ No S) and four rates of sulfur fertilizer (0, 30, 50, and 200 lb S/a), which will be called control, low, medium, and high, respectively. The fifth treatment solely utilized urea and served as the sulfur control treatment (Table 2). Sulfur sources include urea calcium sulfate (27% and 33%), and ammonium sulfate. The nitrogen source for the S control was urea following Kansas State University's recommended nitrogen rate (180 lb N/a). Whole plant biomass and grain samples were collected at physiological maturity in the corn crop. Whole plant biomass samples were gathered, weighed, and dried at 140°F and then reweighed to attain dry matter content. Corn was harvested, and the yield was calculated and corrected to 15.5% moisture. After corn harvest, soil samples were collected from 0–24 in. depth. All the soil samples

were dried at 106°F, and sulfur was measured by a monocalcium phosphate extraction. All statistical analyses were completed in SAS (v. 9.4 (SAS Inst. Inc., Cary, NC)) using the generalized linear mixed model (GLIMMIX) procedure for analysis of variance (ANOVA).

Results

Preliminary results for this study showed significant differences between sulfur fertilization rates for both nitrogen and sulfur plant total uptake (Figures 1 and 2). Whole plant sulfur uptake significantly increased when sulfur was applied. Increasing the rate of sulfur showed no significant difference between sulfur rates (Figure 1), suggesting a rate of 30 lb was sufficient for the corn crop. Increases in nitrogen uptake were seen when sulfur was applied (Figure 2). A substantial increase in nitrogen uptake is likely linked to keeping the balance of nitrogen to sulfur within the plant. Nitrogen uptake is indicative of increased yield and sulfur uptake, suggesting that higher-yielding environments will also have elevated levels of sulfur removal (Figure 3). Soil sulfate levels in the 0–24 in. soil profile post-harvest were only significantly different at the high sulfur rate (Figure 4). This is likely due to excess S applied related to corn total need. Preliminary results show that the highest sulfur application rate significantly increased yield compared to the urea-only application (Figure 5). This suggests sulfur applied at the lowest rate may have not been sufficient for maximum yield. An increase in nitrogen provided significantly more yield gain over the control when compared to sulfur.

References

Camberato, J., and Casteel, S., 2017. Purdue University Department of Agronomy Soil Fertility Update Sulfur deficiency, pp. 1-6.

Sawyer, J. E., Lang, B. J., and Barker, D. W. 2011. Sulfur Fertilization Response in Iowa Corn Production. Agronomy Publications. 62. https://lib.dr.iastate.edu/agron_pubs/62.

Table 1. Soil test parameters for 0–6 in. pre-plant samples

P	K	Zn	Ca	Mg	Na	Fe	Mn
--ppm--							
31	148	1.7	1194	123	11	21	8

pH	Sikora	OM	Sand	Silt	Clay	CEC Sum.	EC
-----------pH-----------			--------------------%--------------------			Meq/100 g	mS/cm
6.5	7.3	1.5	55	37	9	7	0.42

P = phosphorus. K = potassium. Zn = zinc. Ca = calcium. Mg = magnesium. Na = sodium. Fe = iron. Mn = manganese. OM = organic matter. CEC = cation exchange capacity. EC = electrical conductivity.

Table 2. Nitrogen and sulfur rates for each treatment

Treatment	Source	Nitrogen rate	Sulfur rate
		lb N/a	lb S/a
1	Ammonium sulfate	180	200
2	Urea + calcium sulfate	180	50
3	Urea + calcium sulfate	180	30
4	Urea	180	0
5	Control	0	0
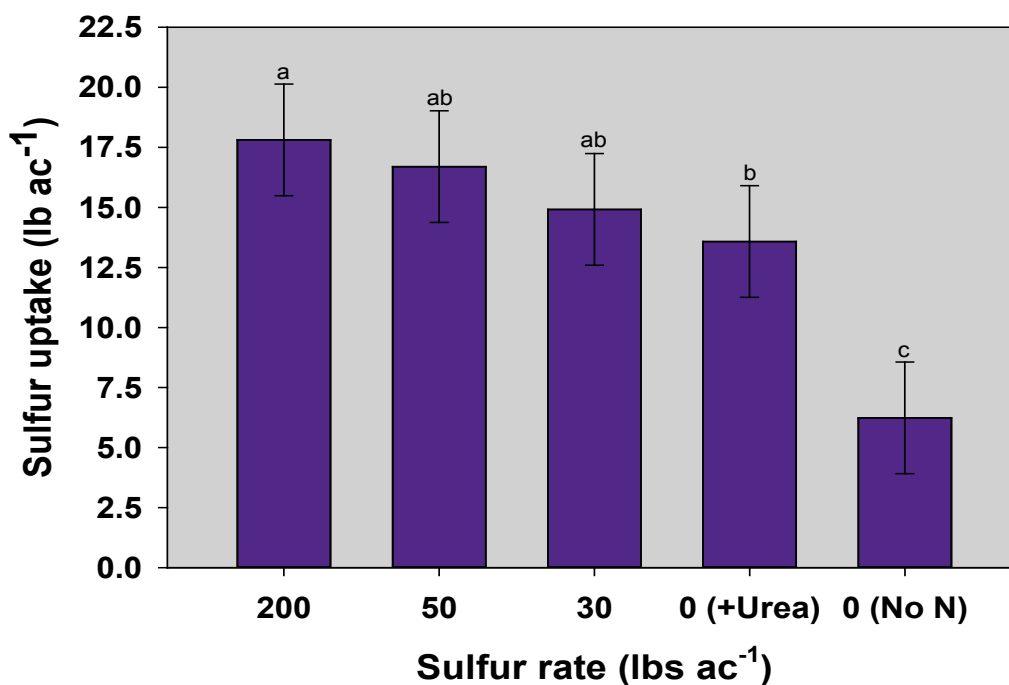
Figure 1. Whole plant sulfur uptake response at different levels of sulfur application in corn. Letters represent significant differences between treatments at $P < 0.05$.
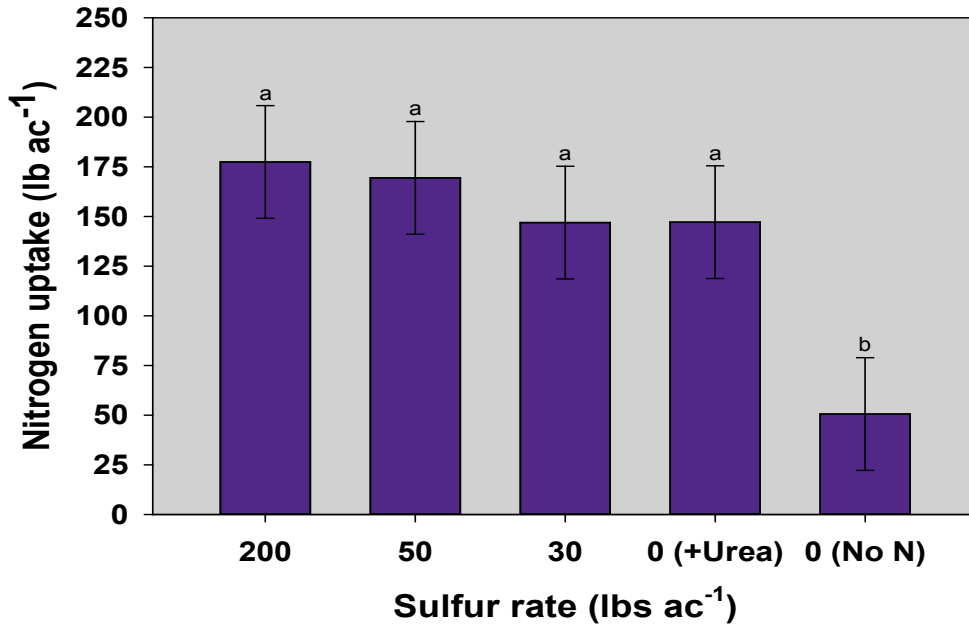
Figure 2. Whole plant nitrogen uptake response at different levels of sulfur application in corn. Letters represent significant differences between treatments at *P* < 0.05.
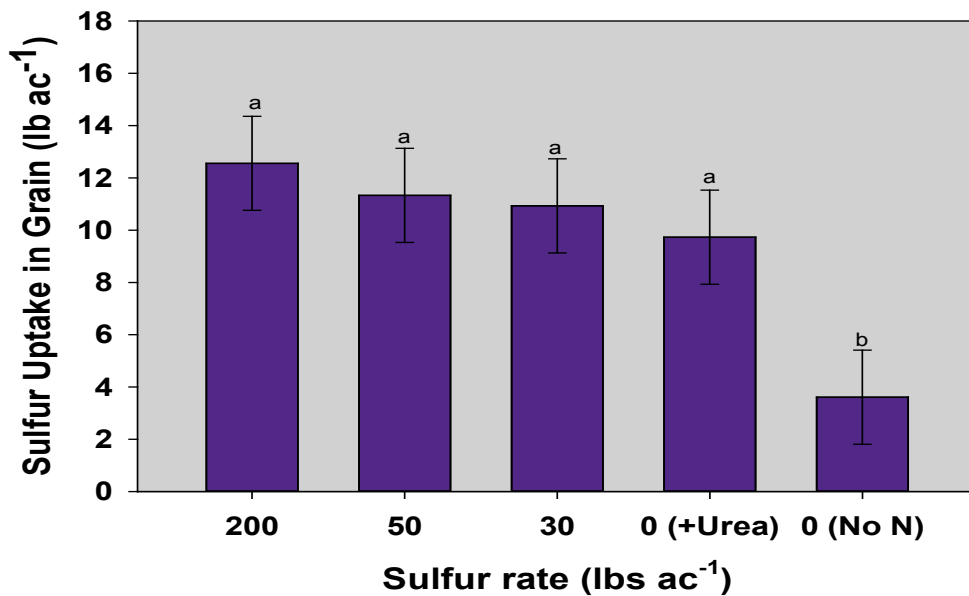
Figure 3. Sulfur removal in grain at physiological maturity in corn. Letters represent significant differences between treatments at *P* < 0.05.
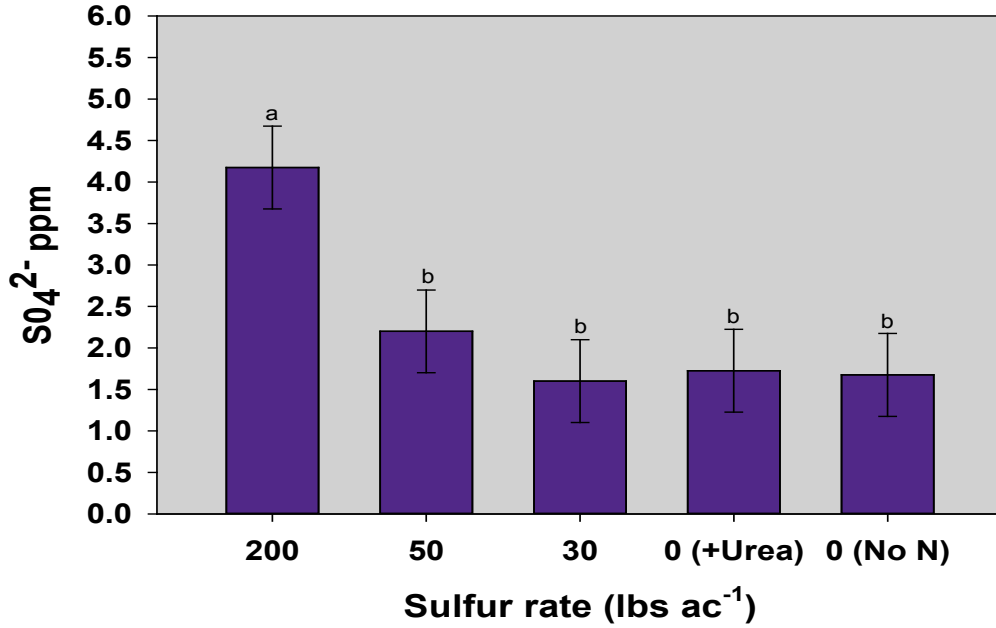
Figure 4. Corn post-harvest sulfate levels in the 0–24 in. soil profile samples. Letters represent significant differences between treatments at *P* < 0.05.
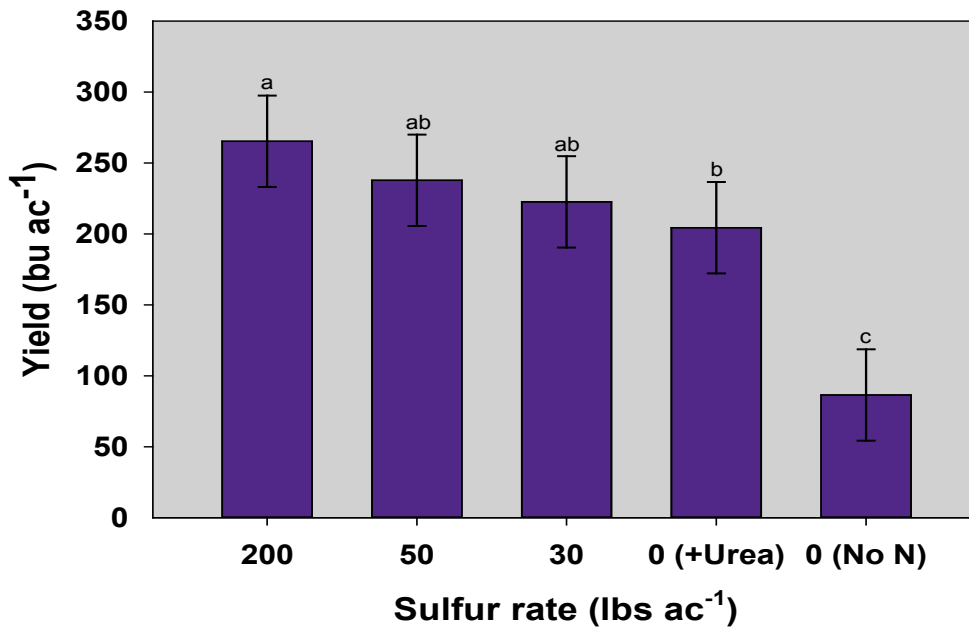

Figure 5. Corn yield response as affected by different rates of sulfur application. Letters represent significant differences between treatments at *P* < 0.05.

Relationships between the Haney H3A and Conventional Soil Tests for Phosphorus and Potassium in Kansas Soils

E.B. Rutter and D.A. Ruiz Diaz

Summary

The Haney H3A soil test procedure has gained popularity in recent years for soil health evaluation and has been used in some circles to adjust fertilizer management practices. However, data relating this test to current soil tests, relative crop yield, or total nutrient uptake are nonexistent in Kansas soils. The objective of this study is to evaluate the correlation between H3A soil test phosphorus (P) and potassium (K) with soil tests currently used in Kansas (e.g. Mehlich-3). Soils from a nitrogen response study were extracted using both Mehlich-3 and H3A (version 4) soil test procedures. Mehlich-3 and Haney extractable P and K were positively correlated (r = 0.90 and 0.91, respectively) in data combined from all sites. Linear regression models fit to the combined data indicate that Mehlich-3 extracts approximately 25% more P and 250% more K. The Root Mean Square Error (RMSE) of these models (15.4 ppm P and 83.4 ppm K) indicate that existing calibration based on Mehlich-3 values are likely not suitable for use with H3A-4.

Introduction

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

The Haney H3A extracting solution is intended to simulate the chemistry of actively growing roots more closely (Haney et al., 2006). The H3A extracting solution is comprised of a dilute mixture of organic acids, but has undergone numerous iterations since its initial development (Haney et al., 2017). The current iteration, version 4, is comprised of malic, citric, and oxalic acids, and has a weakly buffered pH of approximately 3.75 (Haney et al., 2017). The primary objectives of this study were to investigate relationships between M3 and H3A soil test P and K in selected Kansas soils.

Procedures

Field studies were initiated at multiple sites across the state of Kansas during the 2017, 2018, and 2019 corn growing seasons, 14 site-years in total (Table 1). Treatments consisted of nitrogen (N), P, and K fertilizer combinations applied at rates ranging from 0 to 200 lb N/a, 0 or 80 lb P_2O_5/a, and 0 or 100 lb K_2O/a. Soil samples were collected from each plot using a hand probe to a depth of six inches prior to treatment application. Soil measurements include soil pH, OM, M3 and H3A-4 extractable P, K, Ca, Mg, Al, Cu, Fe, Mn, and Zn.

Relationships between Mehlich-3 and H3A-4 extractable nutrients were evaluated using linear regression models. Data analyses were performed in R version 3.6 (R Core Team, 2019) and evaluated at the 95% confidence level.

Results

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

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

References

Haney, R. L., E. B. Haney, L.R. Hossner, J.G. Arnold. (2006). "Development of a New Soil Extractant for Simultaneous Phosphorus, Ammonium, and Nitrate Analysis." Communications in Soil Science and Plant Analysis 37(11-12): 1511-1523.

Haney, R. L., E. B. Haney, D.R. Smith, and M.J. White. (2017). "Removal of Lithium Citrate from H3A for Determination of Plant Available P." Open Journal of Soil Science 07(11): 301-314.

Table 1. General site descriptions, and soil chemical and textural parameters for 14 experimental sites included in the study

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

All sites were located across Kansas. Soil parameters were measured from composite soil samples representing the site. Phosphorus (P) and potassium (K) were determined using Mehlich-3 soil test.
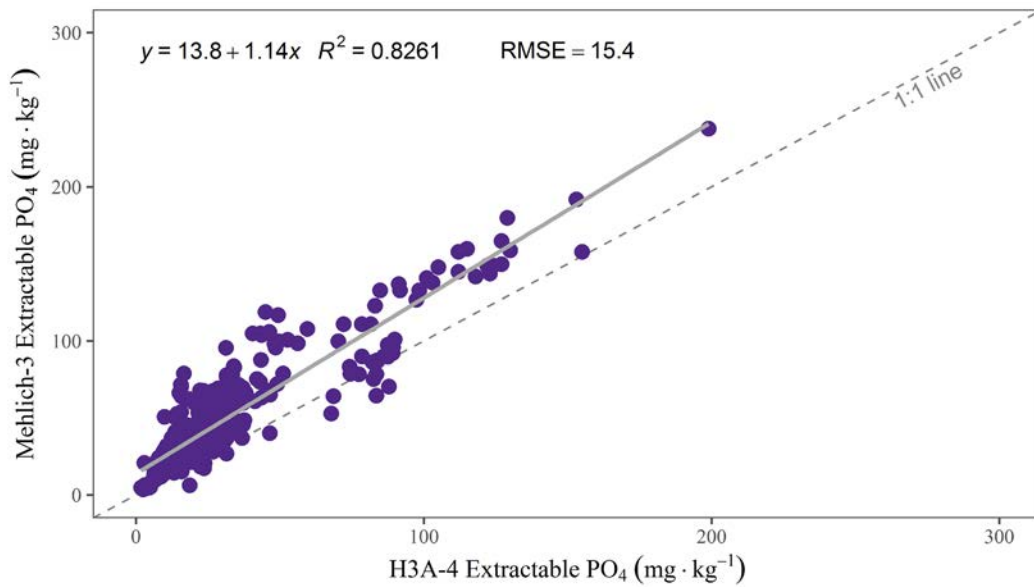
Figure 1. Mehlich-3 (horizontal axis) and H3A-4 (vertical axis) extractable phosphorus (P) from soils collected from plots at each site. The combined data show a positive linear relationship between the two soil test methods for P, with M3 extracting approximately 30% more P than H3A-4.
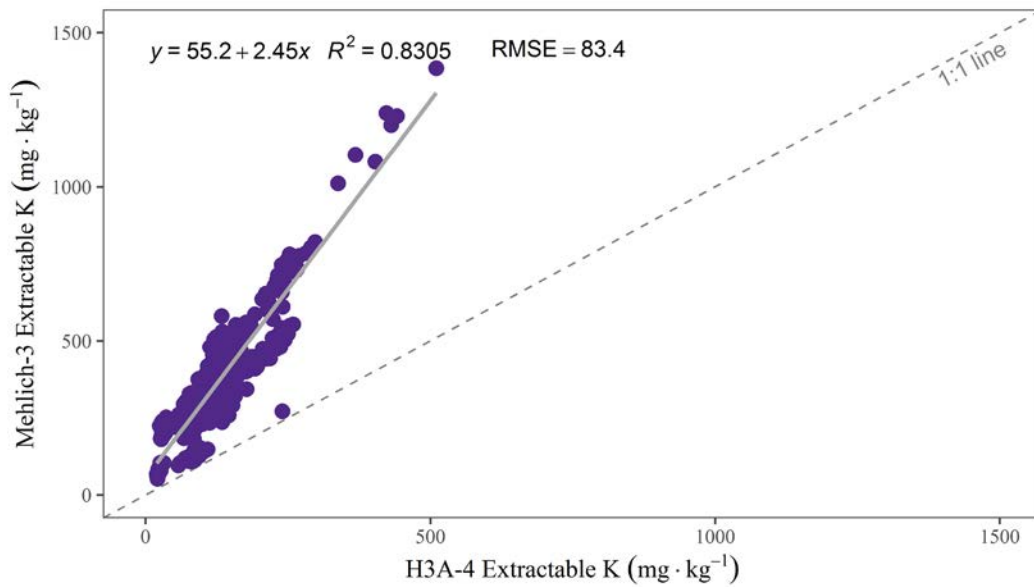

Figure 2. Mehlich-3 (horizontal axis) and H3A-4 (vertical axis) extractable potassium (K) measured from soil samples representing the 0–6 in. (15 cm) soil layers. M3 K and H3A-4 K exhibit a positive linear relationship in these combined data, with M3 extracting approximately three times more K than H3A-4.

Cation Exchange Resins as Indicator of In-Season Potassium Supply for Soybean in Kansas

D.A. Charbonnier, M.J.A. Coelho, and D.A. Ruiz Diaz

Summary

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

Introduction

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

Procedures

Field experiments were conducted at two locations in eastern Kansas during 2019 (Table 1). Sites were located at Ashland Bottoms (Manhattan, KS) and Ottawa, KS, under a conventional tillage system. Treatments included a control (check) with no K application and one with an application of 150 lb K_2O/a (high K rate). Both treatments had an application of 80 lb P_2O_5/a. The fertilizer applications were a surface broadcast at pre-plant using triple superphosphate (TSP) and potassium chloride (KCl) as a P and K sources, respectively. For this study, we used a commercial CER PRS as an indicator of the in-season K supply to soybean. This product consists of an exchange resin membrane held in a plastic frame that is inserted into the soil to measure *in situ* ion supply. The Ottawa location had six burial periods and Ashland had seven. Burial length consisted of 7 days with a time between burials of 15 days. A total of 4 probes were distributed within the plot to obtain a composite sample. The CERs were inserted vertically into the soil (facing plant row), between 2–4 inches soil depth at a distance of 3 inches from the soybean row. For every new burial period, the CERs were buried 5 inches apart from the previous period (parallel to the row) to avoid sampling the same portion of soil. Aboveground plant samples were collected at V4, R2, R4, and R6 stages in order to measure plant K uptake. Soil samples were taken at the beginning and end of each burial period to calculate soil moisture content (air-dried at 104°F). Statistical analysis (ANOVA) was performed using the GLIMMIX procedure in SAS v. 9.4 (Cary Inst. Inc., Cary, NC).

Results

Plant K uptake measured at reproductive stages (R2, R4, and R6) was increased by K fertilization in both locations (Figure 1). Location 2 had significantly higher plant K uptake measured at R2, R4, and R6 stages when 150 lb K_2O/a was applied (Figure 2). At the R6 stage, fertilized plots had 50% more K uptake and 40% more K adsorption (cumulative) by CER compared to the control. This observation suggests the potential use of CER as an indicator of K supply to soybean in field conditions. In both locations, CER were able to adsorb more K (measured as cumulative adsorption) at high K rate. The amount of K that was adsorbed by the CER was influenced by soil moisture content, particularly at location 1 (Figure 3). A similar trend was observed between these two variables. Plots without K fertilization were less affected, and minor fluctuations were measured compared to those with high K rate. However, data from location 2 did not show a clear pattern (Figure 4). Preliminary results from this study suggest that CER can be used as an indicator of K supply, particularly in low K soils.

References

Cooperband, L. R. and Logan, T. J. 1994. Measuring in situ changes in labile soil phosphorus with anion-exchange membranes. Soil Science Society of America Journal, 58: 105-114. doi:10.2136/sssaj1994.03615995005800010015x.

Qian, P., Schoenau, J. J., and Huang, W. Z. 1996. Use of ion exchange membranes in routine soil testing. Communications in Soil Science and Plant Analysis, 23:15-16, 1791-1804. doi:10.1080/00103629209368704.

Qian, P. and Schoenau, J. J. 2002. Practical applications of ion exchange resins in agricultural and environmental soil research. Canadian Journal of Soil Science, 82 (1): 9-21. https://doi.org/10.4141/S00-091.

Table 1. Selected soil properties for 0–6 inch samples

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

OM = organic matter. P-M = Mehlich-3 P. K-M = Mehlich-3 K. K = potassium. Ca = calcium. Mg = magnesium. Na = sodium. CEC = cation exchange capacity.
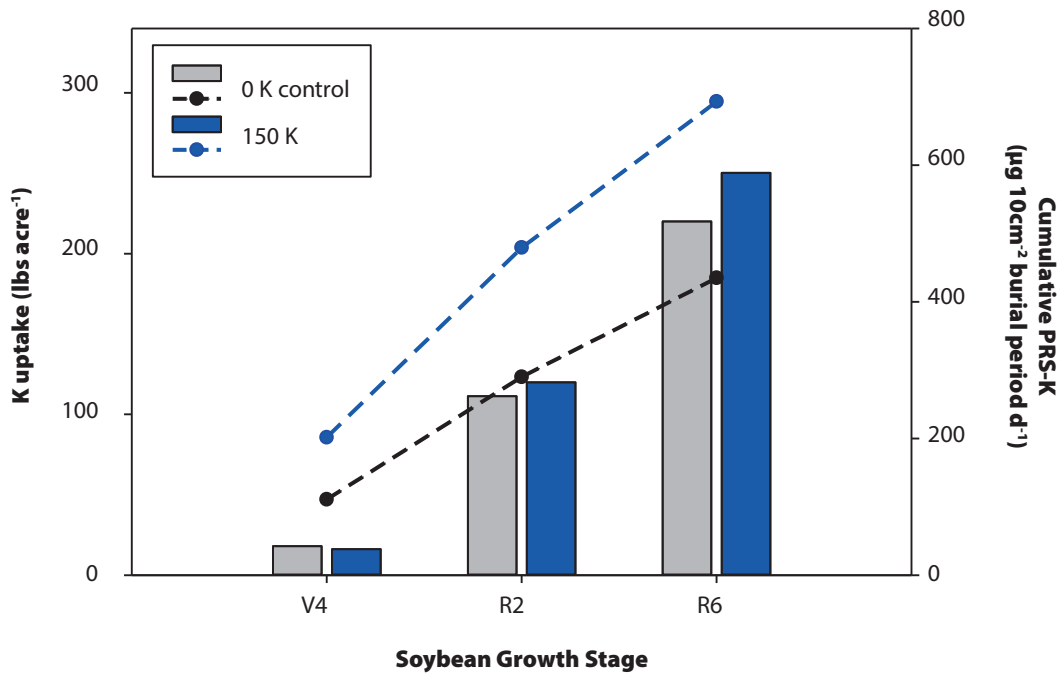
Figure 1. Soybean plant potassium (K) uptake (bars) and cumulative PRS K adsorption as affected by two levels of K application at Location 1 (Riley County).
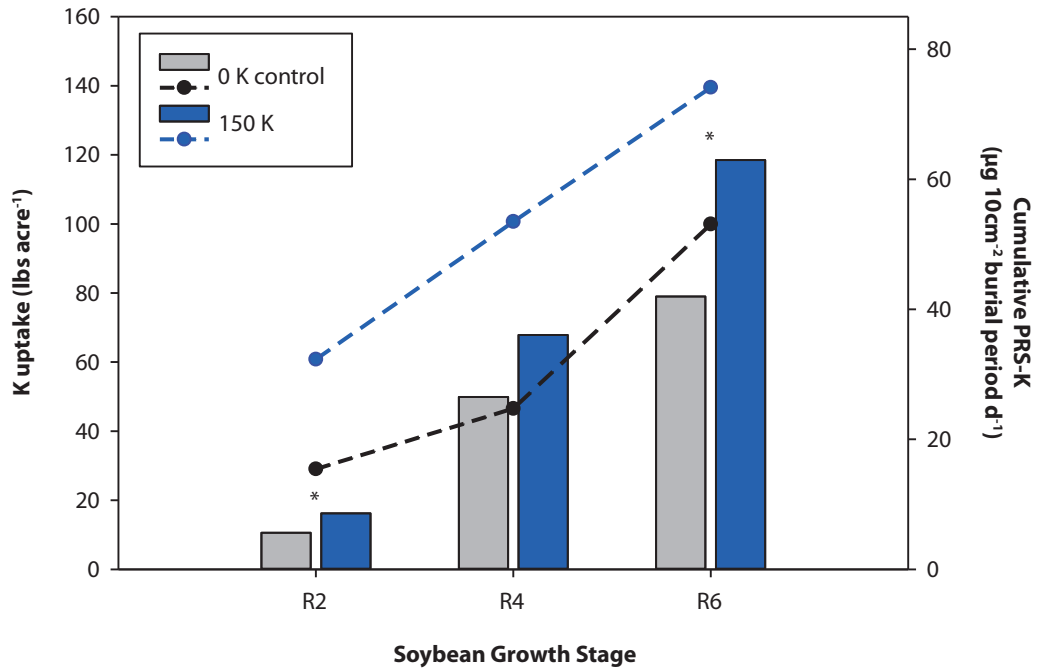
Figure 2. Soybean plant potassium (K) uptake (bars) and cumulative Plant Root Simulator (PRS, Western Ag Innovations, Saskatchewan, Canada) K adsorption as affected by two levels of K application at Location 2 (Franklin County). Pairwise comparisons of K fertilizer application rate within each stage are indicated by "*" when statistically significant at the $P < 0.05$.
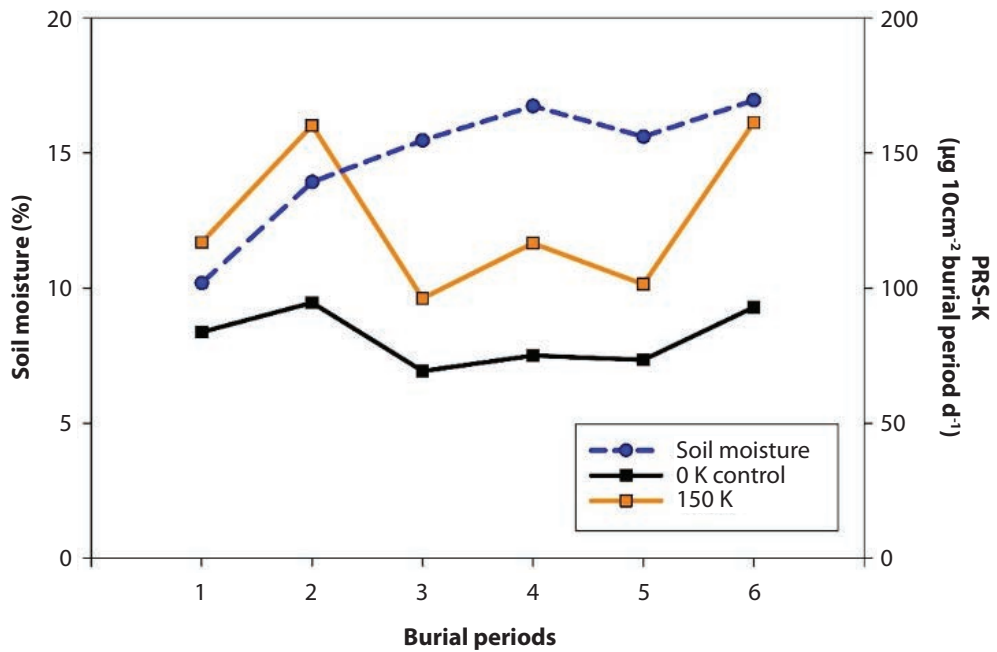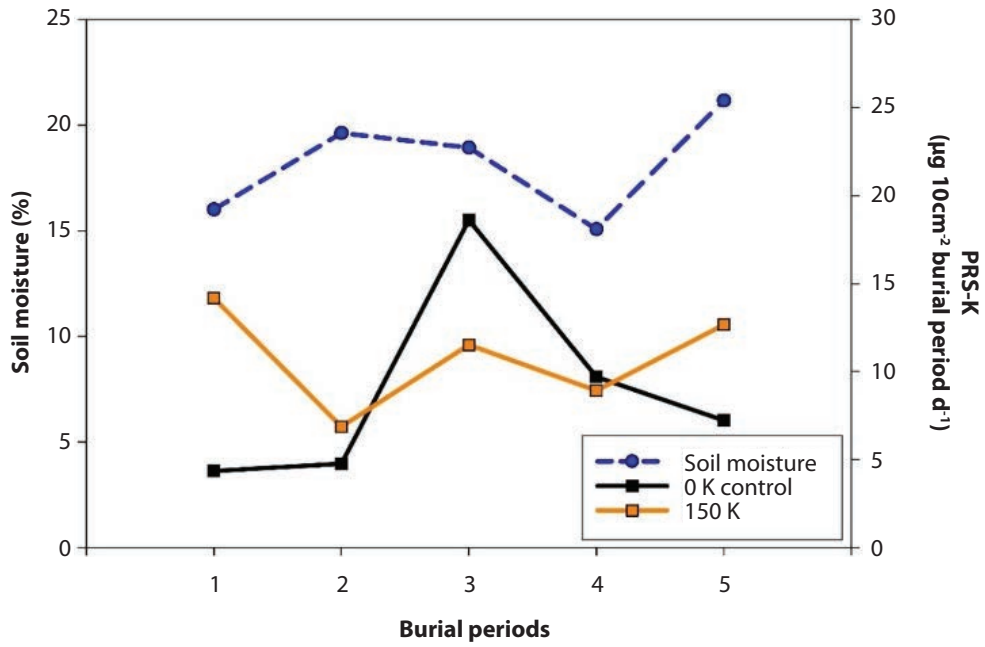

Figure 3. Plant Root Simulator (PRS, Western Ag Innovations, Saskatchewan, Canada) potassium (K) adsorption as affected by two levels of K application compared to soil moisture content at Location 1 (Riley County).

Figure 4. Plant Root Simulator (PRS, Western Ag Innovations, Saskatchewan, Canada) potassium (K) adsorption as affected by two levels of K application compared to soil moisture content at Location 2 (Franklin County).

Response to Mixing Wheat Seed with Fertilizer in the Drill at Planting

C. Weber and D.A. Ruiz Diaz

Summary

Mixing dry phosphorus (P) fertilizer with winter wheat seed is common in Kansas to provide a starter fertilizer benefit to the crop. This study was designed to evaluate the effects of dry P sources, rates, and times fertilizer mixed with wheat seed, effects on early growth and overall productivity and yield of the crop. Two winter wheat studies were conducted in the 2018–2019 wheat growing season at Manhattan (site 1) and Topeka (site 2) Kansas. The previous crop for site 1 was soybean and corn at site 2. The winter wheat was no-till drilled at 70 lb/a and mixed with either diammonium phosphate (DAP) (18-46-0) or Micro-Essentials SZ "MESZ" (12-40-0-10S-1Zn) rates of 30, 60, and 120 lb P_2O_5/a. Mixing times in which wheat seed was in contact with the fertilizer were 0, 12, 28, and 40 days. The winter wheat was drilled in October and November and top-dressed with 100 lb N/a using UAN 28% at green-up in the spring. The overall trends observed in these preliminary results suggest that either P fertilizer source can be stored for a prolonged period of time with no negative impact, and producers can avoid the economic expenses of replacing the seed-fertilizer blend.

Introduction

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

Procedures

The study was conducted at two locations during the 2018–2019 wheat growing season at Manhattan (site 1) and Topeka (site 2) in northeast Kansas near Kansas State University (Table 1). The previous crop for site 1 was soybean and site 2 was corn. The winter wheat variety Everest was mixed with DAP (18-46-0) and Micro-Essentials SZ - MESZ (12-40-0-10S-1Zn) fertilizers. The blend of seed and fertilizer was stored in open plastic buckets for 0, 12, 28, and 40 days before drilling. Rates included 0, 30, 60, and 120 lb P_2O_5/a with 70 lb wheat seed/a (a complete combination of P rates and times for two P fertilizer sources). No nitrogen (N) was applied in the fall except

for the N present in DAP and MESZ fertilizers. At green-up, 100 lb N/a was applied to all plots to ensure N was not a limiting factor. Normalized difference vegetation index (NDVI) measurements were taken at jointing (Feekes 6) stage with a Holland RapidSCAN CS-45 active sensor ran 35–40 inches above the crop canopy. Averages of NDVI readings were then recorded for each treatment. Biomass samples were collected at jointing (Feekes 6) and were taken from 2.5 feet of row times two rows in the back-side of the plots. Additional biomass samples were taken at soft dough (Feekes 11.2) in the same manner as the jointing biomass samples. Grain harvest was completed with a plot combine, and subsamples were taken from each treatment. All biomass samples and grain were analyzed for P concentrations using the salicylic-sulfuric acid digestion method (Miller and Keeney, 1982). All statistical analyses were completed using SAS Studio (version 9.4; SAS, Institute, Inc, Cary, NC). Analysis of variance (ANOVA) using the GLIMMIX procedure was conducted.

Results

Early Growth

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

Grain Yield and Phosphorus Removal

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

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

period of time with no negative impact, and producers can avoid the economic expenses of replacing the seed-fertilizer blend.

References

Bremner, J.M., and Mulvaney, C.S. 1982. Total nitrogen and total phosphorus on soil and plant tissue are analyzed by the salicylic-sulfuric acid digestion. Salicylic acid thiosulfate modification of the Kjeldhal method to include nitrate and nitrite. p. 621. *In* Miller, R.H. Miller, and Keeney, D.R., (eds.) Methods of Soil Analysis. Part 2. Am. Soc. Agron., Inc., Madison, WI.

Gieseking, J.E., Snider, H.J., and Getz, C.A. 1935. Destruction of organic matter in plant material by the use of nitric and perchloric acids. Ind. and Eng. Chem., Anal. Ed., V.7, p185-186.

Ruiz Diaz, D. and Weber, C. 2019. In-furrow starter fertilizers for wheat. Issue 763. Kansas State Univ. Ext., Manhattan.

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

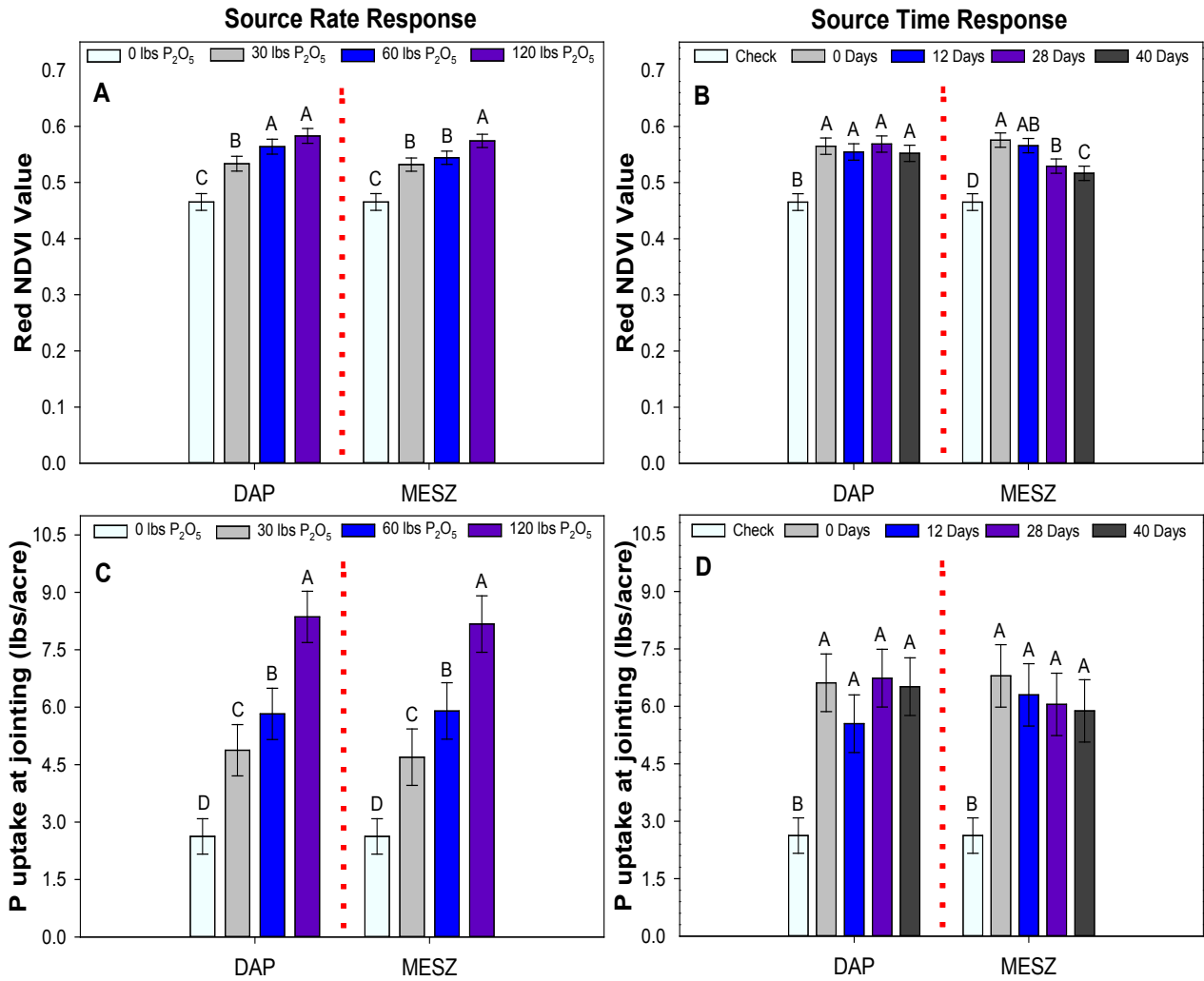| Location	County	Soil type	Soil texture	Planting date	0–6 inch samples		
					pH	P	OM
						ppm	%
1	Riley	Smolan	Silt Loam	11/19/2019	5.75	17	3.2
2	Shawnee	Eudora	Silt Loam	10/19/2019	6.99	18	1.6

P = phosphorus. OM = organic matter.

Figure 1. Normalized difference vegetation index (NDVI) measurements taken at the jointing (Feekes 6) stage with comparison made between fertilizer source rates mixed with seed (A), and comparison made between fertilizer mixing duration with seed (B). Phosphorus (P) uptake, lb/a, at the jointing (Feekes 6) stage with comparison made between fertilizer source rates mixed with seed (C), and comparison made between fertilizers mixing duration with seed (D). DAP = diammonium phosphate. MESZ = Micro essentials fertilizer.
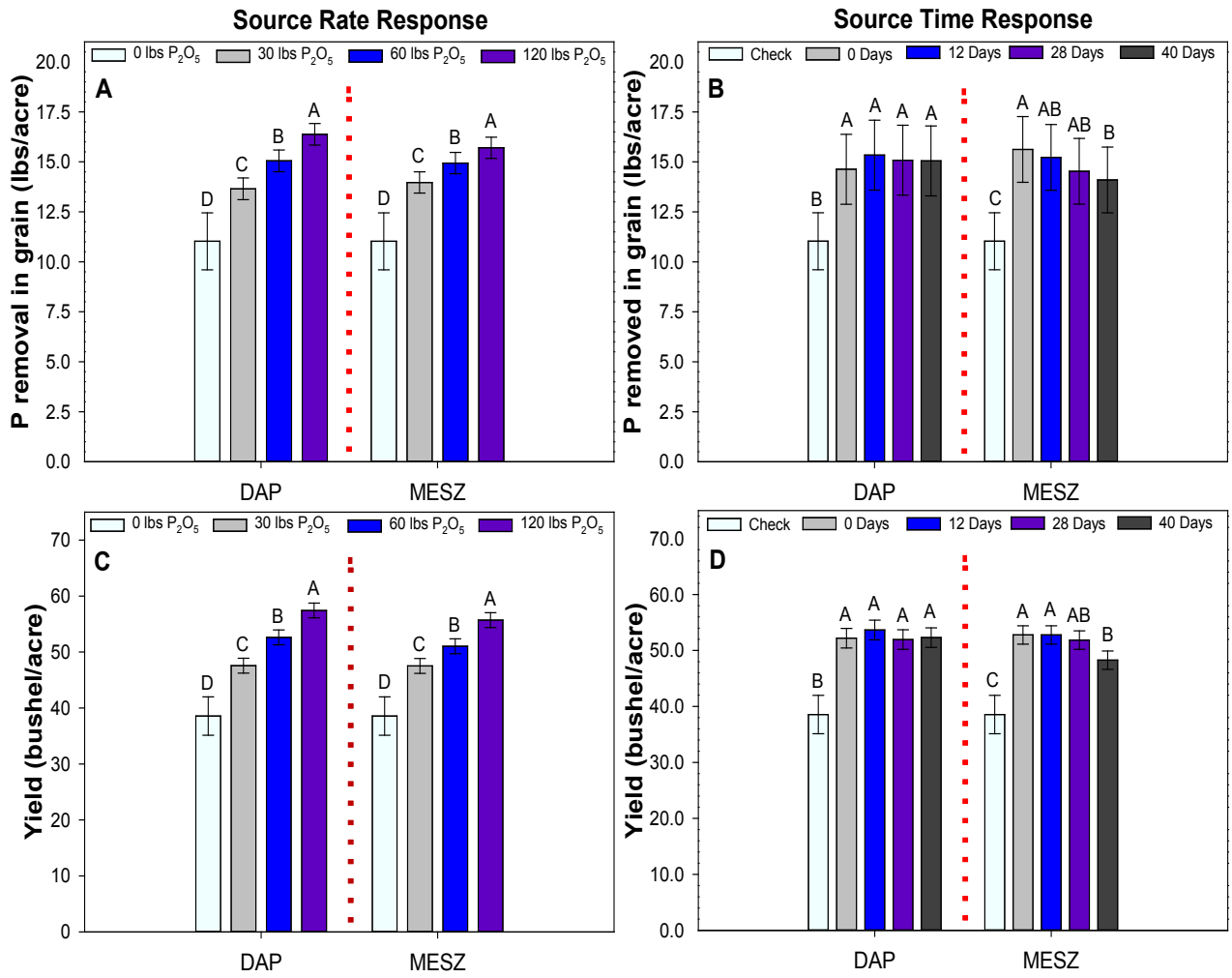
Figure 2. Phosphorus (P) removed in grain lb/a at grain harvest with comparison made between fertilizer source rates mixed with seed (A) and comparison made between fertilizer mixing duration with seed (B). Grain yield in bu/a with comparison made between fertilizer source rates mixed with seed (C), and comparison made between fertilizers mixing duration with seed (D). DAP = diammonium phosphate. MESZ = Micro essentials fertilizer.

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