KANSAS STATE UNIVERSITY

KANSAS FERTILIZER RESEARCH 2021

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Research and Extension

KANSAS STATE UNIVERSITY AGRICULTURAL EXPERIMENT STATION AND COOPERATIVE EXTENSION SERVICE

KANSAS FERTILIZER RESEARCH 2021

Contents

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Precipitation Data

Month	Manhattan	SWREC Tribune	SEREC Parsons	Girard
	------------------------------ in. ------------------------------			
2019				
August	10.19	2.29	14.59	8.74
September	4.58	1.15	8.00	9.21
October	3.43	0.60	4.48	5.15
November	0.74	0.34	1.71	1.79
December	1.60	0.72	1.57	2.56
Total 2019	52.73	19.59	69.64	72.24
Departure from normal	17.93	1.69	14.59	26.52
2020				
January	1.18	0.41	3.64	3.80
February	0.69	1.36	3.54	3.31
March	2.74	1.58	3.07	6.24
April	2.23	0.06	3.42	4.09
May	6.42	1.02	12.66	9.38
June	3.10	2.01	1.08	0.66
July	7.79	4.29	4.38	3.33
August	2.30	2.66	1.44	3.00
September	2.20	0.66	3.97	3.88

continued

Month	Ashland Bottoms	KRV, Rossville	Scandia	Osage County, Overbrook
	----------------- in. -----------------			
2019				
August	8.60	9.00	4.67	10.03
September	2.35	1.94	1.76	4.71
October	2.73	2.55	2.67	1.37
November	0.61	0.98	0.25	0.44
December	1.06	1.85	2.25	1.33
Total 2019	42.62	43.12	30.86	50.06
Departure from normal	10.07	5.91	2.04	10.57
2020				
January	1.82	1.39	1.11	1.29
February	0.78	0.95	0.04	1.36
March	2.32	2.55	0.99	3.10
April	2.40	2.93	0.38	2.35
May	7.45	4.19	2.81	4.95
June	5.04	4.35	4.02	4.31
July	10.13	8.61	7.84	4.56
August	1.76	0.98	0.64	1.49
September	2.60	2.67	1.39	1.52

SWREC = Southwest Research-Extension Center. SEREC = Southeast Research-Extension Center. KRV = Kansas River Valley.

Long-Term Nitrogen, Phosphorus, and Potassium Fertilization of Irrigated Grain Sorghum

A. 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 2020, N applied alone increased yields 60 bu/a, whereas N and P applied together increased yields up to 83 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields up to 82 bu/a. The application of 160 lb/a N (with P) produced the maximum yield in 2020, which is slightly less than the 10-year average (2011–2020). The application of potassium (K) has had no effect on sorghum yield throughout the study period. The 10-year average grain N content reached a maximum of ~0.7 lb/bu while grain P content reached a maximum of ~0.15 lb/bu (0.34 lb P_2O_5/bu) and grain K content reached a maximum of ~0.19 lb/bu (0.23 lb K_2O/bu). At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 33% for N, 69% for P, and 40% for K.

Introduction

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

Procedures

This field study is conducted at the Tribune Unit of the Kansas State University Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a N without P and K; with 40 lb/a P_2O_5 and zero K; and with 40 lb/a P_2O_5 and 40 lb/a K_2O. All fertilizers are broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. Grain sorghum (Pioneer 85G46, 2011; Pioneer 84G62, 2012–2014; Pioneer 86G32, 2015; Pioneer 84G62, 2016–2017; Pioneer 85P44, 2018–2019; and Pioneer 86P33, 2020) was planted in late May or early June. Hail damaged the 2015, 2017, 2019, and 2020 crops. 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 2020 were ~5% lower than the 10-year average (Table 1). Nitrogen alone increased yields 60 bu/a, while P alone increased yields 9 bu/a. However, N and P applied together increased yields up to 83 bu/a. Averaged across the past 10 years, N and P applied together increased yields up to 82 bu/a. In 2020, 40 lb/a N (with P) produced about 75% of maximum yield, which is less than the 10-year average of 82%. 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 23 lb/a. Average K concentration (%) and content (lb/bu) tended to decrease with increased N rates. Similar to P, K removal was similar for all N rates of 40 lb/a or greater plus K ranging from 23 to 27 lb/a. At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 33% for N, 69% for P, and 40% for K.

Acknowledgment

The International Plant Nutrition Institute partially supported this research project.

Table 1. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2011–2020

Fertilizer			Grain yield										
N	P_2O_5	K_2O	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
------------ lb/a ------------			---------- bu/a ----------										
0	0	0	75	78	62	90	89	80	70	77	68	71	76
0	40	0	83	90	77	94	102	91	79	87	74	80	86
0	40	40	88	93	72	96	97	91	80	83	67	75	84
40	0	0	106	115	94	115	122	106	87	93	94	93	103
40	40	0	121	140	114	144	160	142	120	126	113	115	130
40	40	40	125	132	110	142	155	137	118	131	114	124	129
80	0	0	117	132	102	120	133	120	104	103	109	101	114
80	40	0	140	163	136	151	173	154	123	144	145	142	147
80	40	40	138	161	133	164	178	160	129	140	139	147	149
120	0	0	116	130	100	116	127	108	93	91	102	97	108
120	40	0	145	172	137	162	177	164	121	128	139	141	149
120	40	40	147	175	142	170	178	170	131	143	150	147	155
160	0	0	124	149	117	139	150	135	120	107	129	125	130
160	40	0	152	178	146	171	181	173	137	134	153	154	158
160	40	40	151	174	143	176	179	161	131	139	142	142	154
200	0	0	128	147	119	139	155	151	123	121	134	131	135
200	40	0	141	171	136	165	177	167	131	134	140	147	151
200	40	40	152	175	138	170	179	170	131	130	149	151	154

continued

Table 1. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2011–2020

Fertilizer			Grain yield										
N	**P_2O_5**	**K_2O**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**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			0.278	0.826	0.644	0.117	0.806	0.943	0.727	0.549	0.789	0.731	0.700
N × P-K			0.542	0.186	0.079	0.012	0.002	0.001	0.084	0.003	0.001	0.001	0.001
MEANS													
Nitrogen, lb/a													
0			82 d	87 d	70 d	94 e	96 d	87 d	76 d	82 c	70 d	75 d	82 d
40			117 c	129 c	106 c	134 d	146 c	129 c	108 c	117 b	107 c	111 c	120 c
80			132 b	152 b	124 b	145 c	161 b	145 b	119 b	129 a	131 b	130 b	137 b
120			136 ab	159 ab	126 b	149 bc	161 b	147 b	115 bc	121 ab	130 b	128 b	137 b
160			142 a	167 a	135 a	162 a	170 a	156 a	129 a	127 a	142 a	140 a	147 a
200			141 a	165 a	131 ab	158 ab	170 a	163 a	129 a	128 a	141 a	143 a	147 a
$LSD_{(0.05)}$			8	9	8	9	8	8	9	9	7	8	6
P_2O_5-K_2O, lb/a													
0 - 0			111 b	125 b	99 b	120 b	129 b	117 b	99 b	99 b	106 b	103 b	111 b
40 - 0			130 a	152 a	124 a	148 a	162 a	149 a	119 a	126 a	127 a	130 a	137 a
40 - 40			133 a	152 a	123 a	153 a	161 a	148 a	120 a	128 a	127 a	131 a	138 a
$LSD_{(0.05)}$			6	6	5	6	5	6	6	6	5	6	5

Different letters in the same column indicate significant differences ($P < 0.05$).
Hail events occurred on 8/18/2017, 9/20/2019, and 8/10/2020.

Table 2. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on grain nutrient content and removal by irrigated grain sorghum, Tribune, KS, 2011–2020

Fertilizer			Grain						Grain Removal			Grain		
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	1.00	0.244	0.354	0.49	0.119	0.174	38	9	13	---	---	---
0	40	0	1.00	0.311	0.382	0.49	0.152	0.187	42	13	16	---	23	---
0	40	40	1.00	0.310	0.382	0.49	0.152	0.187	41	13	16	---	21	8
40	0	0	1.13	0.217	0.340	0.55	0.106	0.167	56	11	17	47	---	---
40	40	0	1.10	0.314	0.366	0.54	0.154	0.179	70	20	23	80	63	---
40	40	40	1.09	0.308	0.364	0.53	0.151	0.178	69	19	23	78	60	30
80	0	0	1.35	0.202	0.337	0.66	0.099	0.165	75	12	19	46	---	---
80	40	0	1.20	0.288	0.351	0.59	0.141	0.172	86	21	25	61	67	---
80	40	40	1.17	0.300	0.354	0.58	0.147	0.173	86	22	26	60	74	38
120	0	0	1.40	0.186	0.334	0.69	0.091	0.164	74	10	18	30	---	---
120	40	0	1.29	0.272	0.349	0.63	0.133	0.171	94	20	25	47	62	---
120	40	40	1.31	0.295	0.351	0.64	0.144	0.172	100	22	27	52	77	41
160	0	0	1.39	0.216	0.342	0.68	0.106	0.167	88	14	22	32	---	---
160	40	0	1.39	0.297	0.354	0.68	0.146	0.173	107	23	27	43	80	---
160	40	40	1.34	0.267	0.346	0.66	0.131	0.170	101	20	26	40	64	39
200	0	0	1.40	0.222	0.345	0.69	0.109	0.169	92	15	23	27	---	---
200	40	0	1.38	0.274	0.353	0.68	0.134	0.173	102	20	26	32	65	---
200	40	40	1.38	0.278	0.351	0.67	0.136	0.172	104	21	26	33	69	40

continued

Table 2. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on grain nutrient content and removal by irrigated grain sorghum, Tribune, KS, 2011–2020

Fertilizer			Grain						Grain Removal			Grain		
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 - - - - -			- - - - - - - - - % - - - - - - - -		
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	0.004	0.001	0.001	0.004	0.001	0.001	0.001	0.001	0.053	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	0.774	---
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			0.412	0.958	0.597	0.412	0.958	0.597	0.934	0.812	0.865	---	---	---
N × P-K			0.010	0.009	0.019	0.010	0.009	0.019	0.104	0.001	0.001	0.048	0.028	---
MEANS														
Nitrogen, lb/a														
0			1.00 e	0.288 a	0.373 a	0.49 e	0.141 a	0.183 a	40 e	12 d	15 d	---	22 c	8 c
40			1.10 d	0.280 a	0.357 b	0.54 d	0.137 a	0.175 b	65 d	17 c	21 c	68 a	61 b	30 b
80			1.24 c	0.263 b	0.347 c	0.61 c	0.129 b	0.170 c	82 c	18 abc	23 b	56 b	71 a	38 a
120			1.34 b	0.251 b	0.345 c	0.65 b	0.123 b	0.169 c	89 b	17 bc	23 b	43 c	69 ab	41 a
160			1.37 ab	0.260 b	0.347 c	0.67 ab	0.127 b	0.170 c	99 a	19 a	25 a	38 c	72 a	39 a
200			1.39 a	0.258 b	0.350 c	0.68 a	0.126 b	0.171 c	99 a	19 ab	25 a	31 d	67 ab	40 a
$LSD_{(0.05)}$			0.04	0.014	0.006	0.02	0.007	0.003	5	2	1	7	9	5
P_2O_5-K_2O, lb/a														
0 - 0			1.28 a	0.215 b	0.342 b	0.63 a	0.105 b	0.168 b	71 b	12 b	18 b	37 b	---	---
40 - 0			1.23 b	0.293 a	0.359 a	0.60 b	0.143 a	0.176 a	84 a	20 a	24 a	53 a	60	---
40 - 40			1.22 b	0.293 a	0.358 a	0.60 b	0.144 a	0.175 a	83 a	20 a	24 a	52 a	61	---
$LSD_{(0.05)}$			0.03	0.010	0.004	0.01	0.005	0.002	4	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).
Different letters in the same column indicate significant differences ($P < 0.05$).

Comparison of Mehlich-3 and Ammonium Acetate Extractable Calcium and Magnesium in Kansas Soils

E.B. Rutter, D.A. Ruiz Diaz, and L. Hargrave

Summary
The use of the Mehlich-3 (M3) soil test procedure to assess the plant availability of numerous macro and micronutrients has become common at soil testing labs across the US. Mehlich-3 is used for soil tests for phosphorus (P) and potassium (K) in Kansas; however, data for other base cations for existing methods are scarce for Kansas soils. The objective of this study was to investigate the relationship between M3 and ammonium acetate (AA) extractable calcium (Ca) and magnesium (Mg). Regression analyses indicate a near 1:1 linear relationship between M3-Mg and AA-Mg across a wide range of soil pH and soil organic matter (SOM) contents. The relationship between M3-Ca and AA-Ca was relatively constant for acidic to neutral pH soils. However, M3 extracted substantially more Ca in higher pH soils. Regression analysis indicates that M3-Ca and AA-Ca diverge exponentially at a soil pH of 7.3 and higher. Given the current interpretation of AA-Ca as a measure of exchangeable Ca, these results suggest that M3 may extract Ca from non-exchangeable soil-Ca pools in soils with above neutral pH levels. Based on these results, M3 should not be used to assess the plant availability of soil-Ca or estimate cation exchange capacity (CEC) in soils with a pH above 7.3, as the values are likely to be overestimated.

Introduction
The Mehlich-3 soil test procedure has become part of the routine soil analysis workflow at soil testing labs across the US. This procedure allows for the simultaneous measurement of numerous essential plant nutrients from a single extraction, which reduces lab operating costs and the cost of soil testing for farmers and homeowners. However, the interpretation of these measurements requires knowledge of their relationship to nutrient uptake by plants, as well as correlation to existing soil testing methods. The interpretation of M3 extractable calcium (Ca) has been questioned, as the solubility of soil-Ca is strongly influenced by pH and the M3 extracting solution is both acidic and strongly buffered. Data relating M3 extractable Ca to conventional soil tests (ammonium acetate) for Ca are scarce, particularly for high pH soils in Kansas (Liesch et al. 2011 and 2012). A study was performed at the Kansas State University Soil Testing Laboratory to evaluate the relationship between M3 and AA extractable Ca from Kansas soils.

Procedures
Soil samples were selected randomly from those submitted to the lab by Kansas farmers and homeowners over a six-month period during the 2020 calendar year (a total of 308 soil samples for this study). They covered a wide range of pH, organic matter, Ca, and Mg contents (Table 1). These samples were dried in a forced-air oven at 104°F and ground to pass a 2-mm sieve using a flail-type grinder. Samples were dried, ground, and

stored at 21°C until analysis. A summary of general soil characteristics can be found in Table 1.

The extraction procedures employed during this study are described in the Recommended Soil Testing Procedures for the North Central Region handbook (Denning et al., 2011). The concentrations of Ca and Mg were measured using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Soil pH was measured from 1:1 soil-water suspensions using a dual probe robotic pH meter equipped with glass electrodes. Buffer pH was determined using the Sikora buffer method. Soil organic matter (SOM) content was determined using the loss on ignition method.

Results and Discussion

The concentrations measured from M3 and AA extracts were positively correlated for both Ca ($r = 0.88$) and Mg ($r = 0.98$). On average, M3 extracted approximately 12.65% more Ca than AA, and 10.2% more Mg than the AA extraction. Linear models fit the Mg soil test data well, with a nearly 1:1 linear relationship between M3- and AA-Mg (Figure 1). However, linear models fits the Ca soil test data poorly. The trends in the Ca data showed the M3 extraction procedure clearly extracts more Ca than AA in higher pH soils (Figure 1). Nonlinear regression models were used to further explore this effect. The difference between M3 and AA extractable Ca (Ca) was calculated for each soil sample. The resultant model fit the data reasonably well and suggests a soil pH breakpoint of approximately 7.3 (Figure 2). This indicates that the difference between M3-Ca and AA-Ca is relatively constant below a pH of approximately 7.3. However, as the soil pH of the sample increases to 7.3 and higher, the difference between M3 and AA extractable Ca grows exponentially. Large and variable differences between M3 and AA extractable Ca are problematic in that they prevent the use of a simple equation or conversion factor to approximate from one to the other. These results also indicate that M3 can extract appreciable amounts of Ca from non-exchangeable pools of soil-Ca, especially in higher pH calcareous soils.

Neutral ammonium acetate is the recommended extraction procedure for Ca in Kansas and the North Central US region (Denning et al., 2011), and is commonly interpreted as being "exchangeable" soil-Ca (Ciesielski et al., 1997). These exchangeable Ca values may be used to assess the plant availability of soil-Ca, and to estimate cation exchange capacity (CEC) of the soil. While Kansas soils are naturally high in Ca and deficiencies are rare, the nonlinear relationship between M3-Ca and AA-Ca makes converting one to another quite difficult, and necessitates the development of separate calibration curves for M3 in order to evaluate the likelihood of any potential crop response to Ca. Furthermore, the results of this study suggest that replacing traditional Ca measurements with M3 Ca would likely result in overestimation of exchangeable Ca and CEC calculations. The CEC by summation is used by farmers and consultants to adjust fertility and pest management practices, and the use of M3 as a soil test for Ca may result in inaccurate fertilizer, herbicide, and pesticide application rates, especially in calcareous soils.

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Table 1. General soil information and summary statistics for soil samples (n = 308) included in the study

Statistic	Soil pH	SOM	Calcium	Magnesium	CEC
		%	ppm	ppm	meq 100 g^{-1}
Range	4.4 - 8.2	0.8 - 10	165 - 6430	31 - 1417	9.3 - 39
Median	6.7	3.0	2518	291	19.7

SOM = soil organic matter. CEC = cation exchange capacity.

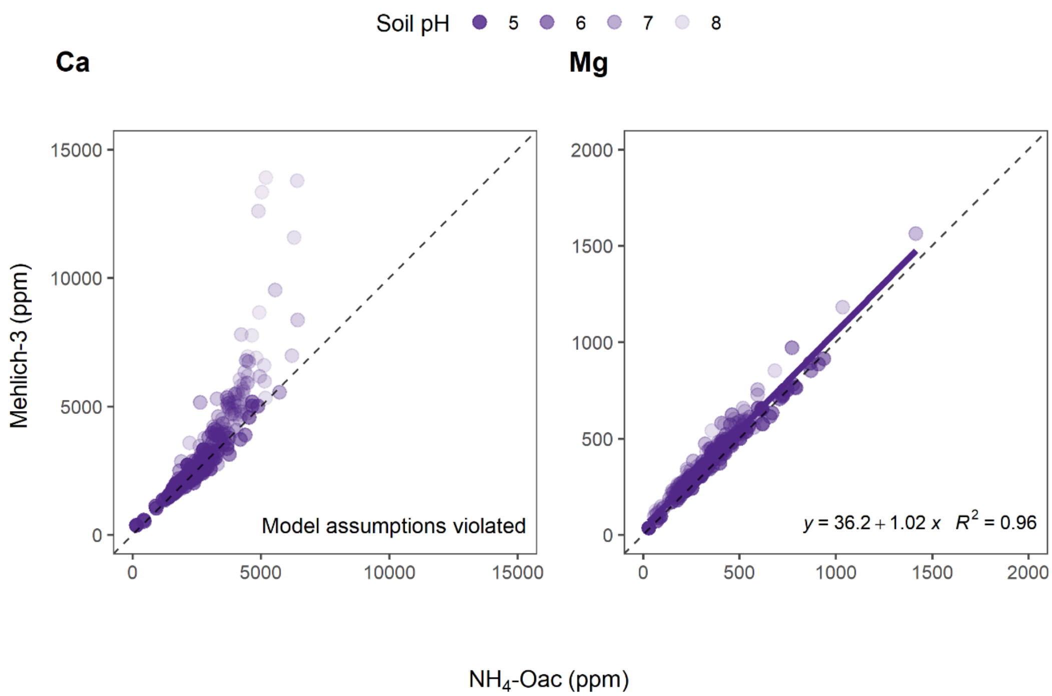

Figure 1. Mehlich-3 and ammonium acetate (AA) extractable calcium (Ca) and magnesium (Mg) from 308 soil samples from across Kansas. Regression analysis indicated a nearly 1:1 linear relationship between Mehlich-3 and AA extractable Mg. However, a linear regression was appropriate for the Ca data. Soil pH information is also displayed, where lighter shades indicate higher soil pH values. The 1:1 ratio is indicated by a dashed line for visual reference.

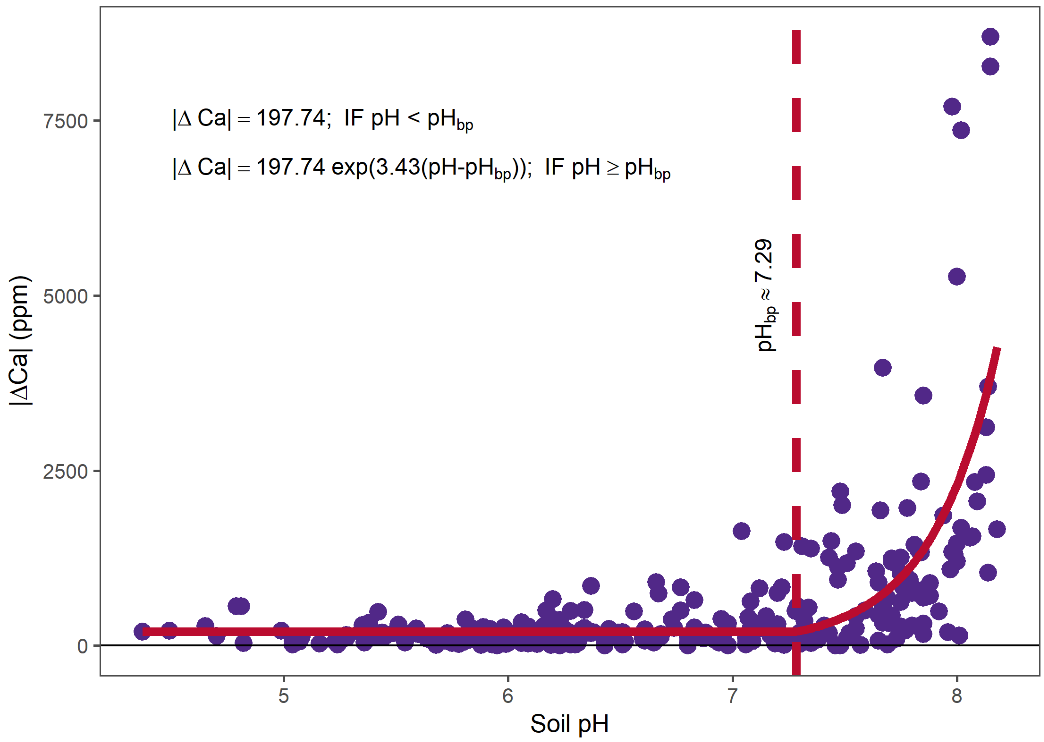

Figure 2. The difference between Mehlich-3 and ammonium acetate (AA) extractable calcium (Ca) versus soil pH using nonlinear regression. Results indicate that the difference between M3-Ca and AA-Ca (Ca) increases exponentially at approximately 7.29 soil pH. The Ca values were calculated by subtracting AA-Ca from M3-Ca.

Corn Yield Response to Sulfur Applied with Nitrogen Fertilizer

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

Summary
The objective of this study was to evaluate the effect of nitrogen (N) with added sulfur (S) fertilizer on corn yield. The treatments included 1) a control with no sulfur and no nitrogen; 2) urea ammonium nitrate (UAN) (180 lb N/a; 0 lb S/a); and 3) UAN plus ammonium thiosulfate (ATS) (180 lb N/a; 15 lb S/a). Both the UAN and UAN+ATS were balanced to 180 lb N/a. These three treatments were evaluated at two locations in 2019 and three locations in 2020. Preliminary results show that yield trended upward with the application of nitrogen plus sulfur fertilization over N alone, and the potential response to S was affected by soil characteristics and S supply from irrigation water.

Introduction
Nitrogen and sulfur are two essential nutrients for corn, and understanding the dynamics between these two nutrients is essential for optimizing corn production. Over the past decade, there has been much emphasis placed on sulfur deficiency. This is largely due to decreased atmospheric deposition and increased crop removal due to higher yields (Camberato and Casteel, 2017). With these deficiencies facilitating sulfur amendments to the soil, there is further interest in understanding how nitrogen and sulfur affect yield. The objective of this study was to evaluate corn yield with the application of nitrogen, with added sulfur.

Procedures
Field experiments were completed at two research locations in 2019 and three locations in 2020. Initial soil samples were taken prior to fertilization and were collected at the 0- to 6-in. and 0- to 24-in. and evaluated for various soil parameters (Table 1). Three treatments were evaluated, including 1) a control (No N/ No S); 2) urea ammonium nitrate (180 lb N/a; 0 lb S/a); 3) and urea ammonium nitrate plus ammonium thiosulfate (180 lb N/a;15 lb S/a). Both the UAN and UAN+ATS were balanced to a nitrogen rate of 180 lb N/a. The location near Rossville was irrigated with about 4.0 in. in 2019 and 2020; the Scandia location also received about 4.0 in. of irrigation water. Based on water analysis, these locations received about 5- to 10-lb of S with the irrigation water. The Belleville and Ashland locations were rainfed. Harvest grain weight, test weight, and moisture were used to calculate yield that was moisture-corrected to 15.5%. All statistical analyses were completed in SAS (SAS Institute, 2013) using the generalized linear mixed model (GLIMMIX) procedure.

Results
Initial results show the average corn yield increased significantly with UAN and UAN+ATS compared to the control treatment at all 5 locations and average across locations (Figure 1). The Ashland location in 2020 showed significant increases in yield with the UAN treatment and from the UAN+ATS treatment (Figure 1). The other locations didn't show a significant increase with sulfur application. This indicates that

even though the application of sulfur is needed in many fields, corn may not always be responsive to S applications in all fields.

The non-responsive locations to the additional S with ATS generally have higher soil organic matter (OM), fine-textured soil, as well as higher cation exchange capacity (CEC) values (Table 1). Also, S supplied with the irrigation water was likely a key factor for locations that could be considered potentially responsive to S (low CEC, coarse-textured soil, and low OM) (e.g., Rossville). These results showed that irrigation water and soil characteristics can both contribute to S response in corn.

References

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Table 1. Location information and preliminary soil test results

		Profile (0–24 in.)				Surface (0–6 in.)			
Location	**Year**	**NO_3**	**NH_4**	**S**	**CEC**	**OM**	**Sand**	**Silt**	**Clay**
		----------- ppm -----------			Meq $100g^{-1}$	------------------ % ------------------			
Rossville*	2019	7.1	2.1	1.3	7.0	1.5	55	36	9
Scandia*	2019	5.9	4.0	6.2	17.2	3.4	15	65	20
Ashland	2020	10	3.1	2.3	7.8	1.4	68	24	8
Belleville	2020	11	7.3	4.3	24.5	2.8	14	62	24
Rossville*	2020	7.3	3.4	1.4	12.3	1.5	40	50	10

* Irrigated locations. Analysis of irrigation water showed some level of S supply.
CEC = cation exchange capacity. OM = organic matter.

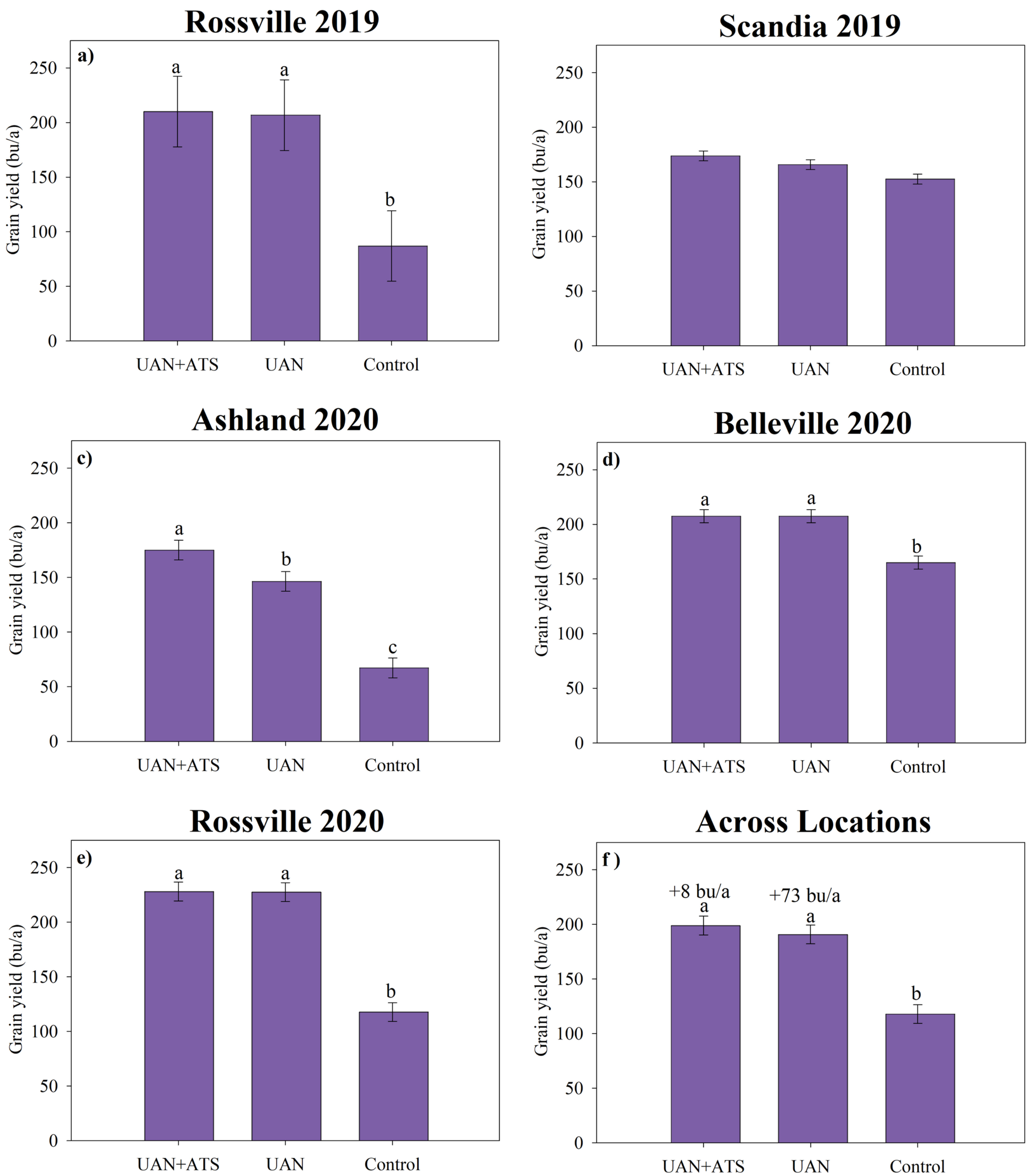

Figure 1. Grain yield for all five locations and average across locations in Kansas. Error bars indicate standard error of the mean and mean values followed by the same letter are statistically different ($P < 0.05$). Treatments: 1) a control with no sulfur and no nitrogen; 2) urea ammonium nitrate (UAN) (180 lb N/a; 0 lb S/a); and 3) UAN plus ammonium thiosulfate (ATS) (180 lb N/a; 15 lb S/a).

Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Corn

A. Schlegel and H.D. Bond

Summary
Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize the production of irrigated corn in western Kansas. In 2020, N applied alone increased yields by 85 bu/a, whereas P applied alone increased yields by 10 bu/a. Nitrogen and P applied together increased yields up to 136 bu/a, which is 11 bu/a less than the 10-year average (2011–2020) of 147 bu/a. The application of 120 lb N/a (with highest P rate) produced 98% of maximum yield in 2020, which is greater than the 10-year average. The application of 80 instead of 40 lb P_2O_5/a increased average yields 1 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 43%, and apparent fertilizer phosphorus recovery in the grain ($AFPR_g$) was 63%.

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 are N rates of 0, 40, 80, 120, 160, and 200 lb/a without P and K; with 40 lb/a P_2O_5 and zero K; and with 40 lb/a P_2O_5 and 40 lb/a K_2O. The treatments were changed in 1992; the K variable was replaced by a higher rate of P (80 lb/a P_2O_5). All fertilizers were broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. The corn hybrids (Pioneer 1151XR, 2011; Pioneer 0832, 2012–2013; Pioneer 1186AM, 2014; Pioneer 35F48 AM1, 2015; Pioneer 1197, 2016; Pioneer 0801, 2017–2018; Pioneer 0339, 2019; and Mycogen 10Z29, 2020) were planted at about 32,000 seeds/a in late April or early May. Hail damaged the 2015, 2017, 2019, and 2020 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 ($AFPR_g$).

Results

Corn yields in 2020 were similar to the 10-year average (Table 1). Nitrogen alone increased yields 85 bu/a, whereas P alone increased yields 10 bu/a. However, N and P applied together increased corn yields up to 136 bu/a. Maximum yield was obtained with 200 lb/a N with 80 lb/a P_2O_5. Corn yields in 2020 (averaged across all N rates) were 1 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 (121 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 43% and $AFPR_g$ was 63%. Similar to N, the 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 31 lb P/a at the highest yields.

Acknowledgment

The International Plant Nutrition Institute partially supported this research project.

Table 1. Nitrogen (N) and phosphorus (P) fertilization on irrigated corn yields, Tribune, KS, 2011–2020

Fertilizer		Yield										
N	P_2O_5	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
----- lb/a -----		bu/a										
0	0	92	86	70	86	92	74	44	82	76	79	78
0	40	111	85	80	95	103	78	47	93	86	88	87
0	80	105	94	91	98	104	86	52	99	83	89	90
40	0	114	109	97	106	113	105	60	110	93	98	100
40	40	195	138	125	153	164	145	92	160	156	168	150
40	80	194	135	126	149	162	135	90	159	154	153	146
80	0	136	128	112	117	131	118	70	117	117	121	117
80	40	212	197	170	187	195	196	132	212	183	191	187
80	80	220	194	149	179	193	193	129	207	189	191	184
120	0	119	134	114	115	124	109	62	102	95	100	107
120	40	222	213	204	213	212	212	142	218	193	205	204
120	80	225	211	194	216	216	223	162	243	201	210	210
160	0	157	158	122	128	144	142	84	139	133	129	133
160	40	229	227	199	211	215	226	154	230	196	206	209
160	80	226	239	217	233	216	238	165	251	191	208	218
200	0	179	170	139	144	162	159	114	158	147	164	154
200	40	218	225	198	204	214	216	148	231	186	205	205
200	80	231	260	220	238	221	235	174	243	207	215	225

continued

Table 1. Nitrogen (N) and phosphorus (P) fertilization on irrigated corn yields, Tribune, KS, 2011–2020

Fertilizer		Yield										
N	P_2O_5	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	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		103 d	88 f	80 e	93 e	100 e	79 e	48 e	91 d	82 d	85 e	85 e
40		167 c	127 e	116 d	136 d	146 d	129 d	81 d	143 c	135 c	140 d	132 d
80		189 b	173 d	143 c	161 c	173 c	169 c	110 c	179 b	163 b	168 c	163 c
120		189 b	186 c	171 b	181 b	184 b	182 b	122 b	188 b	163 b	172 bc	174 b
160		204 a	208 b	179 ab	190 ab	192 ab	202 a	134 a	207 a	173 ab	181 b	187 a
200		209 a	218 a	186 a	196 a	199 a	203 a	145 a	211 a	180 a	195 a	194 a
$LSD_{(0.05)}$		13	10	10	10	9	10	11	13	13	13	8
P_2O_5, lb/a												
0		133 b	131 c	109 b	116 c	128 b	118 b	72 c	118 c	110 b	115 b	115 b
40		198 a	181 b	163 a	177 b	184 a	179 a	119 b	191 b	167 a	177 a	173 a
80		200 a	189 a	166 a	186 a	185 a	185 a	129 a	200 a	171 a	178 a	179 a
$LSD_{(0.05)}$		9	7	7	7	6	7	8	9	9	9	6

Different letters in the same column indicate significant differences ($P < 0.05$).
Hail events occurred on 8/18/2017, 9/20/2019, and 8/10/2020.

Table 2. Nitrogen (N) and phosphorus (P) fertilization on grain N and P content of irrigated corn, Tribune, KS, 2011–2020

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	0.96	0.231	0.46	0.109	36	9	---	---
0	40	0.91	0.312	0.43	0.148	37	13	---	24
0	80	0.91	0.324	0.43	0.153	39	14	---	15
40	0	1.15	0.187	0.55	0.088	54	9	47	---
40	40	0.93	0.300	0.44	0.142	66	21	77	71
40	80	0.94	0.319	0.44	0.151	65	22	74	38
80	0	1.25	0.182	0.59	0.086	68	10	41	---
80	40	1.02	0.250	0.48	0.118	90	22	69	76
80	80	0.99	0.307	0.47	0.145	86	27	64	51
120	0	1.28	0.175	0.60	0.083	64	9	24	---
120	40	1.10	0.228	0.52	0.108	106	22	59	75
120	80	1.06	0.293	0.50	0.139	106	29	59	58
160	0	1.25	0.180	0.59	0.085	78	11	27	---
160	40	1.15	0.241	0.54	0.114	114	24	49	86
160	80	1.13	0.273	0.53	0.129	116	28	51	55
200	0	1.21	0.190	0.57	0.090	87	14	26	---
200	40	1.14	0.232	0.54	0.110	110	23	38	79
200	80	1.14	0.290	0.54	0.137	121	31	43	63

continued

Table 2. Nitrogen (N) and phosphorus (P) fertilization on grain N and P content of irrigated corn, Tribune, KS, 2011–2020

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	0.047	0.056
MEANS									
Nitrogen, lb/a									
0		0.93 d	0.289 a	0.44 d	0.137 a	37 e	12 e	---	20 c
40		1.01 c	0.269 b	0.48 c	0.127 b	62 d	17 d	66 a	55 b
80		1.09 b	0.246 c	0.51 b	0.117 c	82 c	20 c	58 b	64 a
120		1.15 a	0.232 d	0.54 a	0.110 d	92 b	20 bc	47 c	67 a
160		1.17 a	0.231 d	0.56 a	0.109 d	103 a	21 ab	42 c	71 a
200		1.16 a	0.237 cd	0.55 a	0.112 cd	106 a	22 a	35 d	71 a
$LSD_{(0.05)}$		0.03	0.011	0.01	0.005	4	1	5	9
P_2O_5, lb/a									
0		1.18 a	0.191 c	0.56 a	0.090 c	65 b	10 c	33 b	---
40		1.04 b	0.260 b	0.49 b	0.123 b	87 a	21 b	58 a	69 a
80		1.03 b	0.301 a	0.49 b	0.143 a	89 a	25 a	58 a	47 b
$LSD_{(0.05)}$		0.02	0.008	0.01	0.004	3	1	4	5

*$AFNR_g$ and $AFPR_g$ = Apparent Fertilizer N Recovery (grain) and Apparent Fertilizer P Recovery (grain).
Different letters in the same column indicate significant differences (P < 0.05).

Evaluation of Long-Term Phosphorus Fertilizer Placement Effect on Soil Phosphorus and Crop Yield

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

Summary
Phosphorus (P) accumulation in soil with long-term P fertilizer placements can result in a potentially large available reserve of this nutrient for subsequent crop production. This study investigated the effect of phosphorus fertilizer management (placement: broadcast versus deep band) after ten years on soil P, and yield response of crop rotation. Field studies were conducted for a period of ten years in Manhattan, KS. Three treatments were evaluated: 1) 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- to 6-in. depth. All treatments received strip-tillage. After ten years, soil samples were collected from the row at two sampling depths (0–3 and 3–6 in.), and the soil P and grain yield of 2015 were evaluated. The accumulation of large amounts of soil P was directly affected by P fertilizer placement. The broadcast P fertilizer placement increased the soil P by the resin method in the topsoil (0–3 in.) and deep band in the subsoil (3–6 in.). Broadcast and deep band placements had the same effect on grain yield of corn and soybean, however, the deep band showed an average lower grain yield for wheat than broadcast.

Introduction
Long-term experiments are essential to understand a large amount of residual P in the soil, with larger differences between P fertilizer placements in labile forms (Coelho et al., 2019), and how crop yield can be affected by different agricultural practices of P management under crop rotation (Adee et al., 2016; Hansel et al., 2017). Phosphorus can be analyzed by soil tests after inorganic, predominately soluble P fertilizers are used; the P Resin soil test can be compared to Mehlich-3 and Bray 1 tests. The objective of this study was to investigate the effect of phosphorus fertilizer management (placement: broadcast versus deep band) after ten years on available P and yield response of corn, soybean, and wheat in rotation.

Procedures
A ten-year field experiment (2006–2015) with corn, soybean, and wheat rotation was conducted at Agronomy North Farm Research and Extension site located in Manhattan, KS. 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 area (Table 1). 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 in a randomized complete block experimental design with three replications. A strip-tillage operation was performed before planting corn, while soybean was planted into corn residue and wheat was planted into soybean residue, both with no prior tillage. Strip-tillage was used for all plots, including the control. Deep band P fertilizer application was completed with the strip-tillage operation at

30-inch row spacing and in the same row for ten years. Corn and soybean were planted in the center of the strip in the same row each year, and wheat was drilled on 7.5-inch spacing. 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). All P fertilizer application was made before corn. After the last crops were harvested in 2015, soil samples were collected from 0–3 and 3–6 inches depths from the row.

Soil P was determined by the anion exchange resin (P Resin) method. Grain yield was evaluated for the 2015 harvest season. All statistical analyses were completed in SAS v. 9.4 (SAS Inst. Inc., Cary, NC) with a 0.05 probability level.

Results

Figure 1 shows the results of the Resin extractable P, corresponding to P available in the soil solution. Using a reference critical value of 20 ppm, the broadcast and deep band in the soil surface (0–3 in.) and deep band in subsoil (3–6 in.) showed values above 20 ppm. These results agree with the results obtained by Coelho et al. (2019) for soils in Scandia, KS. Surface broadcast P application shows an accumulation of P in the upper 3 inches, with little movement to the 3- to 6-inch layer.

The P fertilizer placement did not affect the grain yield for corn and soybean, with no differences between broadcast, deep band, and control treatment in 2015 (Figure 2). However, the control treatment showed a lower yield compared to broadcast and deep band treatment for wheat. Although it was not statistically different, the deep band P placement showed an average lower yield for wheat. The P fertilizer application with the deep band was spaced every 30 inches, and it is likely that this is affected wheat root access to P; row spacing for wheat was 7.5 inches.

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Table 1. Initial soil parameters for Agronomy North Farm Research and Extension site in Manhattan, KS

Depth	pH	TON	TOC	K	Ca	Mg	Na	CEC	Clay	Silt	Sand
in.		------ % ------		--------------- ppm ---------------				$cmol_c\ kg^{-1}$	----------- % -----------		
0-3	5.7	0.21	0.23	131	2124	377	15	22	26	60	14
3-6	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.

Maximum phosphorus adsorption capacity (MPAC) at the 0- to 6-in. sampling was 424 ppm.

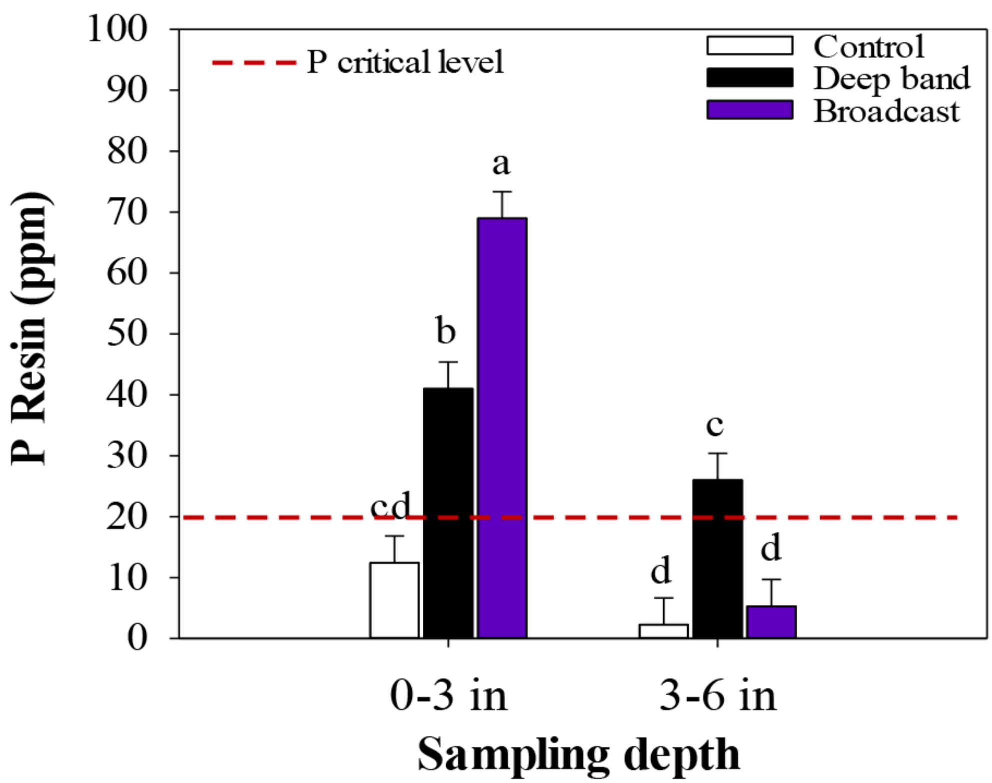

Figure 1. Phosphorus Resin: inorganic P readily diffusing into solution for two soil sampling depths in Manhattan, as affected by P fertilizer treatments (deep-band, broadcast, and control) after ten years of a corn-soybean-wheat rotation. Mean values followed by the same letter are not statistically different (*P* > 0.05).

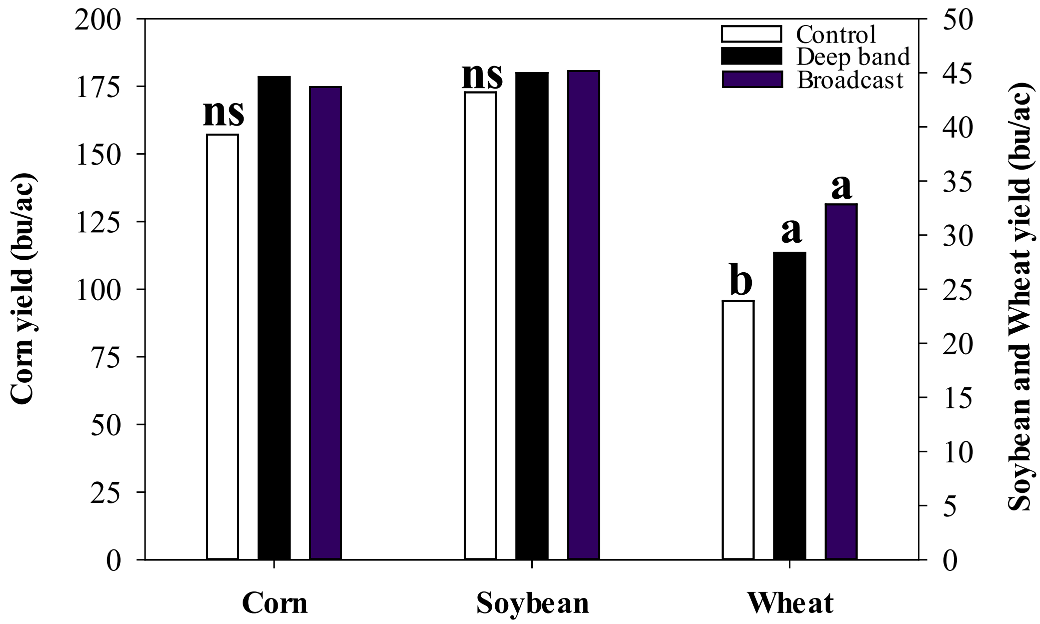

Figure 2. Grain yield for corn, soybean, and wheat at the Manhattan experimental field, as affected by P fertilizer treatments (deep-band, broadcast, and control) after ten years of a corn-soybean-wheat rotation. Mean values followed by the same letter are not statistically different ($P > 0.05$). ns = not significant. Data from the 2015 season.

Macronutrient Fertility on an Irrigated Corn/Soybean in Rotation

E.A. Adee

Summary

Effects of nitrogen (N), phosphorus (P), and potassium (K) fertilization on a corn/soybean cropping sequence were evaluated from 2013 to 2020 (corn planted in odd years) from a study initiated in 1983. Corn yield was near optimum at 160 lb/a N. Phosphorus and K fertilization alone increased corn yield 31 and 7 bu/a, respectively; and soybean yields 22 and 1.7 bu/a, respectively. As N fertilization increased, the response to P increased corn yield from 13 to 40 bu/a. The best return on fertilizer investment was when the N and P needs were met for both crops.

Introduction

A study was initiated in 1972 at the Topeka Unit of the Kansas River Valley Experiment Field to evaluate the effects of N, P, and K on furrow-irrigated soybean. In 1983, the study was changed to a corn/soybean rotation with corn planted and fertilizer treatments applied in odd years. Study objectives were to evaluate the effects of N, P, and K applications to a corn crop on grain yield of corn, yield of the following soybean crop, and soil test values.

Procedures

The initial soil test in March 1972 on this silt loam soil was 47 lb/a available P and 312 lb/a exchangeable K in the top 6 in. of the soil profile. All fertilizer treatments were applied pre-plant before corn planting and incorporated. Nitrogen rates included a factorial arrangement of 0, 120, and 160 lb/a of N (with single treatments of 80 and 240 lb/a N). Three rates of P were 0, 30, and 60 lb/a of P_2O_5, and K treatments were 0 and 150 lb/a of KCl.

The planting date average was April 22 for corn and May 14 for soybean for the last four rotations, with herbicides applied pre-plant and postemergence each year. Plots were sprinkler irrigated with a linear move irrigation system. A plot combine was used for harvesting grain yields from the middle two rows of 15 (6 rows) × 30-ft plots.

The soil P ppm has decreased from the initial sampling when the study began as a corn/soybean rotation in 1983, with a study average of 55 ppm to 16 ppm in 2018. Soil K ppm has dropped from 320 to 242 K ppm, which is not as drastic as the P levels. For this reason, yield data from both crops for the last four rotation sequences are presented here to give a picture of the current yield level. Additionally, the seed planted in the last four crop rotations better represent the yield potential of current hybrids and varieties.

The income from fertilizer was calculated for each treatment in a crop rotation. Average yields of corn and soybeans were multiplied by the current grain price (January 2021) at $5.00 for corn and $13.60 for soybeans. Fertilizer cost was calculated using the following prices, N at $0.42/lb, P_2O_5 at $0.44/lb, KCl at $0.32/lb. The fertilizer cost of each treatment was subtracted from the gross income of a rotation of corn and soybeans since the fertilizer was applied only before corn. Then the gross of the check plot with no fertilizer was subtracted from each treatment in each replication for each year. This resulted in the income returned over fertilizer cost for comparison of fertilizer treatments.

Results

The average yield response of corn and soybean yields from 2013–2019 and 2014–2020, respectively, to the fertilizer treatments applied prior to corn planting are shown in Table 1. There were differences between the treatments for both crops. The factorial analysis at the bottom of the table explains the crops' response to each nutrient.

All three macronutrients increased corn yield, with corn responding most to N and P (Table 1). Yield responses of corn to N rates are shown in Figure 1, where the P and K rates were 30 and 150 lb/a, respectively, for all N rates. Nitrogen rate had the greatest influence on corn yield, as shown in Figure 1, especially to the first 80 lb of N. The yield response curve began to flatten as the N rate increased above 80 lb. The optimum economic N rate would probably be approximately 160 lb, which could vary depending on the price of corn and the cost of N.

Similarly, the first 30 lb of P_2O_5 resulted in the greatest yield increase (23 bu/a) for corn and continued to increase (8 bu/a) with an additional 30 lb of P_2O_5 (Table 1). The addition of 150 lb of KCl did increase the corn yield 6 bu/a, though probably not enough to be cost effective.

Soybean yields showed most response to the P left over after the corn, with a 13 bu/a increase for the first 30 lb of P_2O_5, with an additional increase of 9 bu/a at the 60-lb rate. A previous report from this study (Adee et al., 2016) showed that the severity of Sudden Death Syndrome (SDS) and subsequent yield loss in soybeans were related to lower soil P values. Long-term grain removal will reduce soil P levels, especially when fertilizer P levels do not meet maintenance levels. The severity of SDS and soybean yield response were very similar in 2016 and 2018. A variety more tolerant to SDS that was treated with ILeVO seed treatment greatly reduced the foliar symptoms of SDS in 2020. There was no significant yield benefit to the soybeans from additional N and K applied to the corn.

There was a significant return on fertilizer investment for N and P fertilizer and for the treatments that provided a more balanced fertility. The 150 lb of KCl (K) did not pay for itself, though a lower rate may have been more profitable. The highest income was with treatments of 120-60-0, 120-60-150, 160-60-0, and 160-60-150 of N-P-K (Table 1).

There was a significant interaction between N and P for both crops (Table 2). Basically, as corn yields increase with the increased N rate, more P is removed from the soil, as shown by the soil test data. As a result, both crops showed an increased yield response to P as the N rate increased, and an increased income over both years of the corn/soybean rotation (Table 1).

Conclusions

As was well documented for years, these data from a long-term study show that N is the most critical fertilizer for corn. The curve representing corn's yield response to N still shows that the optimum N rate is approximately 160 lb N/a. Phosphorus follows closely behind as a critical fertilizer for both crops. The best return for fertilizer investment is a balanced program that meets the needs of both crops in the rotation, and over the long term helps maintain or build fertility levels as needed.

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Table 1. Effects of nitrogen (N), phosphorus (P), and potassium (K) applications on corn yields in a corn/soybean cropping sequence, Kansas River Valley Experiment Field, Topeka Unit

Fertilizer[1]			Corn yield		Soybean yield		2-year Income return over fertilizer cost[4]	
N	P_2O_5[2]	K_2O	2013–2019		2014–2020			
------------- lb/a -------------			------------------ bu/a ------------------				$/a	
0	0	0	96.0	g[3]	37.7	f	0.00	j
0	0	150	99.8	g	38.1	ef	-66.49	j
0	30	0	122.2	f	53.6	c	326.43	efgh
0	30	150	98.1	g	55.7	bc	137.58	i
0	60	0	109.8	gf	62.8	a	363.57	efg
0	60	150	112.0	gf	65.5	a	314.72	efgh
120	0	0	157.2	e	43.8	ed	323.7	efgh
120	0	150	164.7	de	44.2	c	241.02	ghi
120	30	0	174.3	d	50.6	c	445.65	de
120	30	150	197.4	c	56.4	bc	544.02	cd
120	60	0	195.7	c	63.1	a	694.91	a
120	60	150	206.4	bc	64.1	a	667.26	ab
160	0	0	171.7	de	41.6	ed	302.72	fgh
160	0	150	169.5	de	43.5	ed	220.57	h
160	30	0	199.0	bc	55.7	bc	604.44	abc
160	30	150	205.8	bc	53.1	c	507.02	cd
160	60	0	200.5	bc	60.8	ab	654.02	ab
160	60	150	223.2	a	64.5	a	721.82	a
80	30	150	173.2	de	54.2	c	425.75	def
200	30	150	214.4	ab	55.4	bc	546.99	bcd
Prob>F			<0.0001		<0.0001		<0.0001	

continued

Table 1. Effects of nitrogen (N), phosphorus (P), and potassium (K) applications on corn yields in a corn/soybean cropping sequence, Kansas River Valley Experiment Field, Topeka Unit

Fertilizer[1]			Corn yield	Soybean yield	2-year Income return over
N	P_2O_5[2]	K_2O	2013–2019	2014–2020	fertilizer cost [4]
-------------- lb/a --------------			------------------- bu/a -------------------		$/a
Nitrogen means					
0			106.3	52.2	179.30 b
120			182.6	53.7	486.09 a
160			195.0	53.2	501.77 a
Prob>F			<0.0001	0.38	<0.0001
Phosphorus means					
	0		143.2	41.4	170.25 c
	30		166.2	54.2	427.52 b
	60		174.6	63.5	569.38 a
Prob>F			<0.0001	<0.0001	<0.0001
Potassium means					
		0	158.5	52.2	412.83
		150	164.1	53.9	365.28
Prob>F			0.045	0.059	0.029

[1] Fertilizer applied to corn in odd years from 1983 to 2019.
[2] Phosphorus treatments not applied in 1997. Starter fertilizer of 10 gal/a of 10-34-0 was applied to all treatments in 1997 and 1998 (corn and soybean). Nitrogen and K treatments were applied to corn in 1997.
[3] Numbers followed by different letters are different at $P = 0.05$.
[4] 2-year income calculated using corn at $5.00, soybeans at $13.60, N at $0.42/lb, P_2O_5 at $0.44/lb, and KCl at $0.32/lb.

Table 2. Interaction of nitrogen (N) and phosphorus (P) fertilizer applied before corn in a corn-soybean rotation on soil phosphorus, corn and soybean yield at the Kansas River Valley Experiment Field, Topeka[1]

Nutrient		2018 soil test	Yield average	
			2013–2019	2014–2020
N	P	P, ppm	Corn	Soybean
---------------- lb/a ----------------		0–6 in. depth	-------------------- bu/a --------------------	
0	0	7.0	97.9 e[2]	37.7 d
0	30	16.7	110.1 d	54.7 b
0	60	42.9	110.9 d	64.2 a
120	0	4.2	161.0 c	44.0 c
120	30	13.2	185.9 b	53.5 b
120	60	32.8	201.0 a	63.6 a
160	0	3.9	170.6 c	42.5 c
160	30	8.4	202.4 a	54.4 b
160	60	24.3	211.8 a	62.6 a
Pr>F			0.005	0.03

[1] Fertilizer applied to corn in odd years from 1983 to 2019.
[2] Numbers followed by different letters are different at $P = 0.05$.

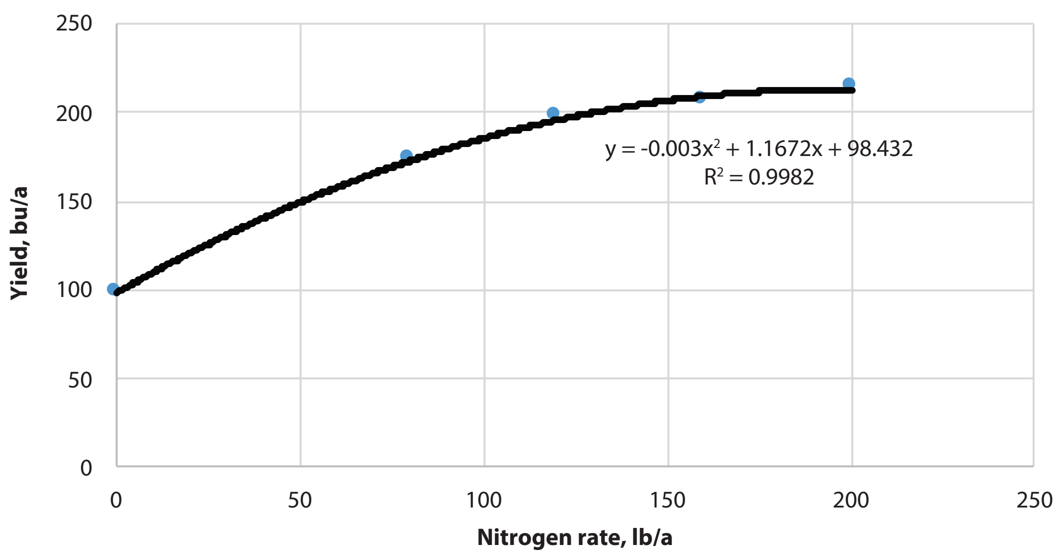

Figure 1. Average corn yield response from 2013 to 2019 to nitrogen rates applied with 30 and 150 lb of P_2O_5 and KCl, respectively, prior to the corn crop in long-term macronutrient fertility study at the Kansas River Valley Experiment Field, Topeka.

Timing, Source, and Placement of Nitrogen Fertilizer Increases Wheat Yield and Protein Content in High Yielding Environments

L.M. Simão, D.A. Ruiz Diaz, and R.P. Lollato

Summary
The efficiency of nitrogen (N) fertilizer management depends on rate, timing, placement, and source, but the benefits of an integrated program have not been clearly quantified, to our knowledge. This study aimed to investigate the effects of integrated N management on winter wheat grain yield, grain protein content, grain test weight, and biomass in Kansas. The study consisted of two N management treatments: Normal (single N application as UAN using broadcast nozzles with the absence of urea inhibitors); and Progressive (split N application into two timings using streamer bars with urease inhibitors). Both treatments had similar results in all variables measured at Hutchinson, which was the lowest yielding location. In Ashland Bottoms, the number of heads/ft^2 and total aboveground biomass did not differ significantly between the treatments. However, grain yield, grain test weight, and protein content were significantly greater in the progressive N management. These results demonstrate the enhanced N use efficiency (NUE) of progressive N management in higher-yielding environments by better N allocation in the plant. This research demonstrates that it is possible to increase both grain protein content and grain yield in high rainfall areas without extra amounts of N fertilizer.

Introduction
Nitrogen is an essential element for crops, and genetic advances have enhanced a plants' ability to take up higher amounts of N (de Oliveira Silva, 2020a), which resulted in crop intensification with greater N fertilizer inputs in the system (de Oliveira Silva, 2020b). However, nearly 50–70% of the N applied in the soil is lost (Hodge et al., 2000). Poor N management partially causes large yield gaps in winter wheat in Kansas (Patrignani et al., 2014). Closing yield gaps is essential for food security and requires crop intensification to more efficiently use resources (e.g. water, fertilizer, energy, and land) due to the finite source from nature (Fischer et al., 2012). To maximize yields, a higher amount of the N already applied must be available for plants. In general, NUE is defined by the increment of crop yield per unit of N fertilizer added. Enhancing N uptake efficiency by the plant is the key to high NUE in cropping systems.

A few strategies are used to optimize N uptake by the plant without adding extra fertilizer, such as the method of fertilizer placement (e.g. broadcasting, injection, or streamer bars), splitting of N application, and including N inhibitors with N fertilizer (Fisher et al., 1993). Studies have shown that wheat grain yield and protein as affected by N application timing depends on the yield environment (Lollato et al., 2019b, Lollato et al., 2020), which is highly site-specific. This way, finding the optimal N application timing to enhance yields and grain protein content is a continuous process. Also, few studies have shown the effects of an integrated N management plan in response to the increase in NUE in crops. Thus, this study aimed to investigate whether an intensified N management strategy (i.e., improved timing, source, and placement) would affect grain yield, grain protein content, grain test weight, and biomass of winter wheat in Kansas.

Material and Methods

Field Set-Up

The study was carried out during the 2019–2020 winter wheat growing season at the Agronomy Farm in Ashland Bottoms, KS (fine-silty, mixed, mesic Cumulic Haplustoll) and at the South-Central Experiment Field in Hutchinson (fine-loamy, mixed, thermic Typic Argiustolls), both under rainfed conditions. Zenda winter wheat variety was planted at 90 lb/a in no-tilled soybean stubble in both locations. Wheat was drilled at 7.5-in. spaced rows using a 9-row Great Plains 506 no-till drill. Plots were 40-ft wide and 50-ft long, thus a total plot area of 2,000 ft^2. In 2019, sowing dates in Ashland Bottoms and Hutchinson were October 24 and 28, respectively. Diammonium phosphate (DAP 18-46-0) starter fertilizer was used in the plots at 50 lb/a in both locations.

Weeds, diseases, and pests were kept under control so they were not limiting factors in this research. In Ashland Bottoms and Hutchinson, harvest occurred on July 7 and June 17, respectively, using a Massey Ferguson XP8 small-plot, self-propelled combine. The central portion of the plot was harvested for grain, approximately 300 ft^2 of area.

Experimental Design and Statistical Analysis

The field experiment was set up as a randomized complete block design, with four replications. Treatments consisted of two N management treatments: Normal and Progressive (Table 1). Treatments differed in application timing, placement, and presence or absence of N inhibitors. In both N management treatments, 80 lb/a of N was applied. Normal N management consisted of one single application of N in March (Feekes 4), as broadcasting UAN with flat fan nozzles and no urease inhibitor. Progressive N management consisted of N applied in two timings (40 lb/a in each): March (Feekes 4) and early April (Feekes 7), using streamer bar applicator and urease inhibitors. Statistical analysis was performed using the PROC GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC). Replication was treated as a random effect, and locations were analyzed separately due to high variation in yield environments between the two areas.

Measurements

The soil was sampled in each plot (0 to 6 in. depth) for initial fertility, and results from soil analysis were averaged across blocks (Table 2). Whole plant biomass samples were taken in a representative 2.2-ft^2 area of the plot at wheat maturity, from which aboveground biomass and number of heads per area were measured. Lastly, grain yield, grain test weight, and grain protein content were also evaluated.

Results

Weather Conditions

Precipitation was historically above average in Ashland Bottoms (34.3 in., Figure 1) and on average in Hutchinson (14 in., Figure 2) during the winter wheat growing season. Temperatures during the experiment year did not vary considerably from the 30-year average temperature except in October, which had colder temperatures in both locations (Figures 1 and 2). In Ashland Bottoms, above-average precipitation during spring and summer resulted in a longer growing season, delay in harvesting until mid-July, and above-average yields (average yield: 64.5 bu/a).

Grain Yield

In Ashland Bottoms, where precipitation exceeded the normal average, progressive N management had a significantly greater yield than the normal N management (66 versus 63 bu/a, respectively, Table 2). This is likely due to reduced N losses in the soil by splitting the amount of N applied and use of N inhibitors, especially in the wetter environment that could result in higher N losses. Also, streamer bar applicators are more likely to minimize volatilization and N immobilization and avoid leaf burn. Broadcast application can lead to interception of spray droplets in the previous crop residue, and also can cause leaf burn for being applied directly in the crop canopy (Bly and Woodard, 2003).

The lowest yielding location was Hutchinson (average yield: 39 bu/a), likely due to the lower precipitation. In this location, yields were not significantly different between both N management treatments (Table 3). Also, low rainfall environments are less prone to N losses in the soil, so splitting N application and including N inhibitors did not significantly improve NUE.

Overall Nitrogen Management on Other Variables

The number of heads/ft^2 and total aboveground biomass did not differ significantly between the treatments in both locations (Tables 2 and 3). Grain test weight and protein content were significantly higher in the progressive N management treatment (Table 2) at Ashland Bottoms. Similar amounts of biomass and number of heads produced, along with higher grain test weight and protein content, shows the enhanced NUE of progressive N management in higher-yielding environments. In Hutchinson, no differences were seen between treatments on grain test weight and protein content, implying that water can be a limiting factor on N allocation in the plant, and hence NUE.

Preliminary Conclusions

Integrated N management (i.e. the progressive treatment) provided evidence that NUE can be enhanced without adding extra fertilizer in a high-yielding environment. The results from this research showed that the plants could better allocate N in the grain and increase protein content without trading-off biomass production, number of heads, and consequently grain yield. This research also shows that it is possible to increase both grain yield and grain protein content in environments with historically higher precipitation, which usually decreases grain protein content—lastly, winter wheat's response to nitrogen management is highly dependent on environment.

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Table 1. Description of nitrogen management treatments (i.e. application timing, N inhibitor additive, and placement method) in winter wheat at Feekes 4 and Feekes 7 stages of plant development at Ashland Bottoms and Hutchinson, KS, in 2020

	Feekes 4		Feekes 7		
N management	Nitrogen[a]	Additive[b]	Nitrogen	Additive	Placement
Normal	80 lb/a	---	---	---	Broadcast
Progressive	40 lb/a	Nitrogen inhibitors	40 lb/a	Nitrogen inhibitors	Streamer bar

[a]Source: Urea ammonium nitrate (UAN 28-0-0).
[b]Nitrification inhibitor (Centuro, Koch Agronomic Services Co., Wichita, KS 67220) at 5 gallons per ton of fertilizer (UAN); and urease + nitrification inhibitor (Agrotain Plus SC, Koch Agronomic Services Co., Wichita, KS 67220) at 3 gallons per ton of fertilizer (UAN).

Table 2. Initial soil fertility analysis at Ashland Bottoms and Hutchinson, KS, during the 2019–2020 winter wheat growing season

Location	pH	P-M	K
		---------------------- ppm ----------------------	
Ashland Bottoms	6.6	14.3	317
Hutchinson	5.5	60.2	413

Soil fertility levels were based on the first 0- to 6-in. depth and included soil pH, Mehlich-3 extractable phosphorus (P), and potassium (K).

Table 3. Effect of nitrogen (N) management[a] on winter wheat grain yield, grain protein content, test weight, aboveground biomass, and number of heads/ft² at Ashland Bottoms, KS, during the 2019–2020 growing season

N management	Heads/ft²	Biomass	Test weight	Protein	Yield
		lb/a	lb/bu	%	bu/a
Normal	87 a†	11624 a	57 b	11.7 b	63 b
Progressive	82 a	11426 a	58 a	12.4 a	66 a

† Means within each column followed by the same letter are not significantly different at $\alpha = 0.05$ level using least-squares means.
[a] N management: Normal (single N application using broadcasting applicator with the absence of N inhibitors); and Progressive (split N application into two timings using streamer bars with the presence of N inhibitors).

Table 4. Effect of nitrogen (N) management[a] on winter wheat grain yield, grain protein content, test weight, aboveground biomass, and number of heads/ft² at Hutchinson, KS, during the 2019–2020 growing season

N management	Heads/ft²	Biomass	Test weight	Protein	Yield
		lb/a	lb/bu	%	bu/a
Normal	50 †	6852	59	11.2	38
Progressive	48	6824	59	11.6	40

† There were no statistical differences at $\alpha = 0.05$ level using least-squares means.
[a] N management: Normal (single N application using broadcasting applicator with the absence of N inhibitors); and Progressive (split N application into two timings using streamer bars with the presence of N inhibitors).

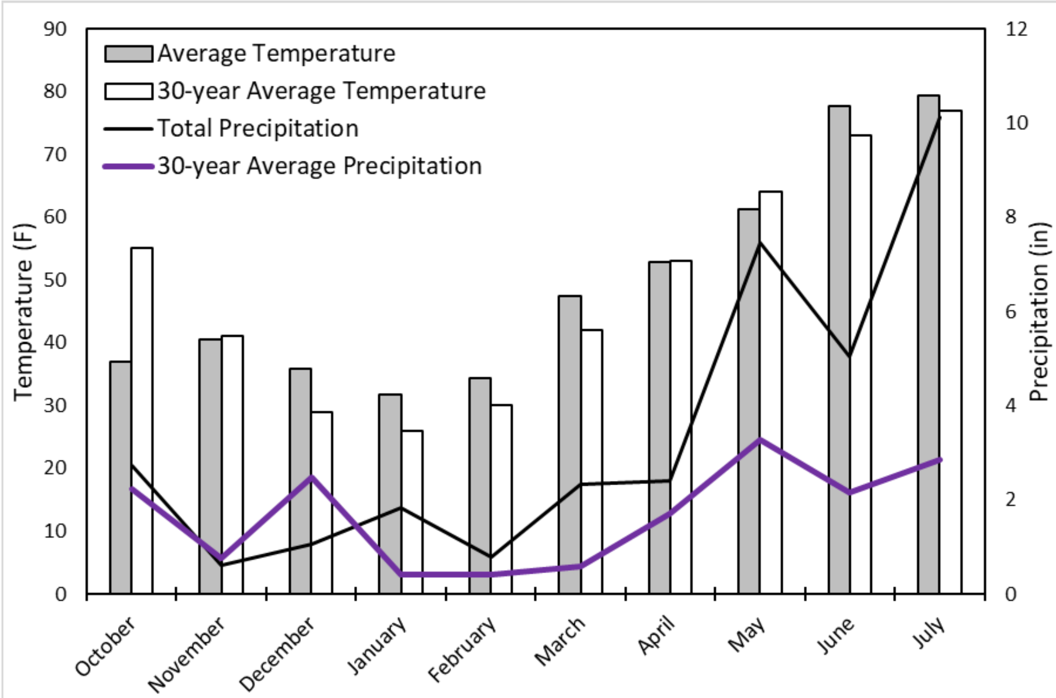

Figure 1. Monthly temperature means and total precipitation throughout 2019–2020 winter wheat growing season, and 30-year historic monthly average temperature and precipitation in Ashland Bottoms, KS.

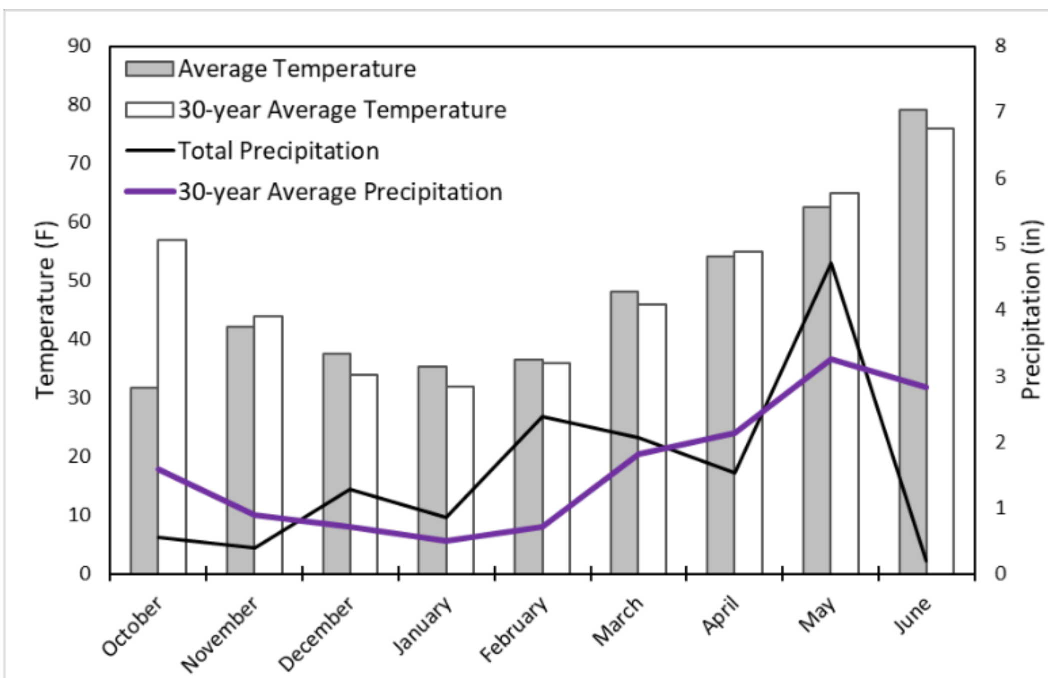

Figure 2. Monthly temperature means and total precipitation throughout 2019–2020 winter wheat growing season, and 30-year historic monthly average temperature and precipitation in Hutchinson, KS.

Do Different Wheat Varieties Respond Differently to Nitrogen Rates in Terms of Grain Yield and Grain Protein Concentration in Kansas?

N. Giordano and R.P. Lollato

Abstract

Nitrogen management in wheat can result in positive impacts on grain yield and grain protein concentration (GPC) if addressed correctly. The aim of this study was to compare whether different varieties responded differently in terms of grain yield and GPC to management of nitrogen (N) rate across different environments. Factorial field experiments were carried out in a split-plot design in four different Kansas locations to evaluate the combination of four N rates (whole plot, 0, 40, 80, and 120 lb N/a) and fourteen different commercially available winter wheat varieties (sub-plots). Grain yield and GPC were measured at harvest maturity. The grain yield average across all treatments at all locations was 50.3 bushels per acre, ranging from 33.6 to 84.9 bu/a depending on treatment and location. Mean GPC across all site-treatment combinations was 11.3%. There were significant interactions between environment and variety, and between environment and N rate for both grain yield and GPC, but not variety by N rate interaction. Different varieties provided to the highest yield and protein groups depending on location. Yield response to N was location-specific due to different amounts of soil NO_3-N in the profile. In general, the highest GPC were obtained with the highest N rates in all locations except for one study site where 80 lb N/a sufficed. Results suggest that variety performance and optimum N rate that maximizes yield changed within the different environments, but the same N rate regime should be adopted across varieties.

Introduction

Nitrogen plays an important role in plant physiology, as part of essential structural and metabolic proteins that are essential for plant growth and development. This macronutrient is often considered one of the most scarce resources that limit plant growth (de Oliveira Silva et al., 2020a; Hawkesford, 2014). Therefore, numerous attempts have been made to identify potential genetic and management traits to improve N efficiency in wheat crops (de Oliveira Silva et al., 2020b).

The mid-season N rate can determine grain yield and grain protein concentration in environments where N availability is limiting (Lollato et al., 2019a, 2021). Nitrogen fertilization is a common practice in wheat crops in the state of Kansas (Lollato et al., 2019b) and has the potential to improve profitability and reduce environmental impacts if addressed correctly. Sustainable improvements in wheat yield are often accompanied by deteriorating wheat grain quality through protein dilution (Lollato and Edwards, 2015). Grain protein concentration is an essential parameter of milling quality (Blandino et al., 2015) that can determine the end-use market of the wheat produced (Lollato et al., 2020). Genotype selection is one of the leading aspects that determine the existing yield gaps (Lollato et al., 2019b), but little is known about the response to N of current genotypes grown in Kansas. Because variety selection sets the genetic potential as well as the protein concentration of a given field, our objective was to highlight the relevance of N rate and wheat variety selection, as well as their potential interaction, in determining grain yields and grain protein concentration across several Kansas locations.

Methods

One experiment was conducted in four different locations in the state of Kansas: Ashland Bottoms (Belvue silt loam); Great Bend (Taver loam); Hutchinson (Ost loam); and Sumner County (Nalim loam). The compared treatments represented a complete factorial combination of fourteen wheat varieties and four N rates with four replicates established in a split-plot design. Nitrogen fertilizer rates (0, 40, 80, and 120 lb/a) were applied as granulated urea (46-0-0) broadcasted at Feekes 3 growing stage in early spring. Trials were sown within the first two weeks of October at 1.2 million seeds per acre. Diammonium phosphate (18-46-0) was applied at 50 lb/a in-furrow at sowing. A total of 20 lb S/a was applied to the entire experiment on the same day of N treatment application to avoid the well-known interactions within N produced by S deficiency (Jaenisch et al., 2019, 2020). Standard weed, insect, and disease management practices were carried out following the recommendations given by nearby farmers. Plots were harvested using a Massey Ferguson 8XP small plot, self-propelled combine.

Soil samples were collected to determine texture and chemical properties in the 0–6 and 6–24 inch soil layers. Soil NO_3-N measurements at sowing in the 0–24 inch profile were 26, 24, 172, and 110 lb N/a at Ashland Bottoms, Conway Springs, Hutchinson, and Great Bend.

Grain weight and moisture were measured at harvest maturity. Grain protein concentration (GPC) was determined by NIR spectroscopy. A single moisture basis of 13% was used for adjusting grain yield and GPC. Data analysis was performed using InfoStat statistical software. Mean comparisons were performed using the Fischer test of least significant differences.

Results

Grain Yield

Grain yield averaged 50.3 bu/a for all site-treatment combinations. The highest yielding location was Hutchinson with an overall mean of 71.6 bu/a. Both N rate and variety effects were location-dependent, evidenced by the significant interaction between variety and location, and between N rate and location. This indicates that there was variability in variety performance as well as in the crop's response to N rate in each studied location, but that all varieties responded similarly to N rate (no significant variety × N rate interaction) (Table 3). The varieties WB-Grainfield, WB4269, SY Monument, Bentley, and Larry, were in the top-yielding group in Ashland Bottoms, achieving an average yield of 50.2 bu/a (Table 1), this represent an 11% yield gain. In Great Bend, varieties WB-Grainfield, WB4269, Bentley, and Larry out-yielded significantly ($P < 0.0001$) the other varieties with an average yield increase of 8% (46.8 bu/a versus 43.5 bu/a yield across all varieties) (Table 1). In Hutchinson, the variety

WB4269 was the only one that yielded 19% more than the compared group, representing 13.3 bu/a more than the location mean (Table 1). There were no significant differences within varieties at the Sumner County study site (Table 1). The ANOVA showed that grain yield also responded differently to N rate depending on location (Table 3). For instance, in Hutchinson, there was no effect of N rate on grain yield, likely due to the high N in the profile at sowing (data not shown). At the other locations, grain yield maximized (i.e., showed no further gains with increases in N rate) at 80, 40, and 120 lb of N/a for Ashland Bottoms, Great Bend, and Sumner County (Table 2).

Grain Protein Concentration

Overall across locations, varieties, and N rates, grain protein concentration ranged from 7.4 to 14.8%. Similar to yield, the effects of both N rate and variety on grain protein concentration depended on location as significant interactions were found (Table 3). In Ashland Bottoms, the varieties with the highest grain protein concentration were WB4458, DoubleStop CL Plus, Green Hammer, and LCS Chrome with a GPC average of 12.0% (Table 1). At Great Bend, the variety Green Hammer tested 14.8%, the highest significant GPC value across varieties; and Tatanka the lowest GPC, tested 11.5% (Table 1). In Hutchinson the highest testing varieties were Bob Dole, WB4303, WB4458, DoubleStop CL Plus, Green Hammer, and LCS Chrome, averaging 13.3% (Table 1). The highest testing values obtained in Sumner County were represented by varieties WB4458 (10.2%), DoubleStop CL Plus (9.7%), and Green Hammer (10.0%) (Table 1). Grain protein concentration was also affected by the interaction of nitrogen rate and location (Table 3). In general, the highest grain protein concentration values were obtained with the highest N rates in all locations, except for Great Bend where GPC testing did not significantly differ in between N rates of 80 (13.3%) and 120 lb N/a (13.7%) (Table 2). The lowest GPC testings corresponded with the control (zero N applied) in all situations with the exception of Ashland Bottoms where GPC tested for zero and 40 lb of N/a treatments were not statistically different (Table 2).

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Table 1. Wheat grain yield and grain protein concentration as affected by variety in four sites across Kansas, during the 2019–2020 growing season

	Grain yield (bu/a)				Grain protein concentration (%)			
Variety	**Ashland Bottoms**	**Great Bend**	**Hutchinson**	**Sumner County**	**Ashland Bottoms**	**Great Bend**	**Hutchinson**	**Sumner County**
WB-Grainfield	**54.1**	**44.8**	72.4	**44.2**	10.0	12.6	11.9	7.8
WB4269	**51.5**	**48.5**	**84.9**	**42.6**	10.6	12.2	11.7	8.6
SY Monument	**48.9**	44.5	75.2	**44.6**	10.6	12.3	12.2	8.2
Bentley	**48.5**	**45.5**	75.8	**43.6**	10.8	12.5	12.3	8.2
Larry	**47.9**	44.3	71.8	**41.5**	10.6	13.0	12.0	8.1
Tatanka	46.5	**48.4**	71.0	**43.6**	9.6	11.5	11.3	7.4
Bob Dole	45.0	44.2	65.2	**41.6**	11.1	12.7	**13.0**	8.7
WB4303	44.0	43.1	67.9	**42.3**	11.0	13.3	**13.0**	8.5
WB4458	43.0	40.4	65.7	33.6	**12.0**	13.8	**13.2**	**10.2**
DoubleStop CL Plus	42.4	40.6	74.3	**39.2**	**12.3**	13.7	**13.5**	**9.7**
Green Hammer	41.4	36.9	68.3	**37.0**	**12.2**	**14.8**	**13.7**	**10.0**
LCS Chrome	41.2	41.9	68.6	**40.7**	**11.6**	13.7	**13.4**	9.2
Zenda	40.7	42.7	70.2	**37.9**	11.1	12.5	11.2	9.2
Everest	39.6	43.4	70.6	36.4	11.3	12.8	12.1	9.2
Location mean	45.3	43.5	71.6	40.6	11.0	12.9	12.5	8.8
LSD (0.05)	7.4	3.8	4.5	8.0	0.8	0.7	0.8	0.9
CV	23.3	12.6	9.0	28.3	9.9	8.0	9.6	14.1
P-value	**	**	**	0.2	**	**	**	**

Values in bold pertain to the top group within location for yield or protein.

** indicates significant differences at the 0.05 probability level (*p*-value < 0.05).

Table 2. Wheat grain yield and grain protein concentration as affected by nitrogen (N) rate in four sites across Kansas, during the 2019–2020 growing season

Location	N rate	Grain yield		Grain protein concentration	
	lb/a	bu/a		%	
Ashland Bottoms	0	30.8	a	10.3	a
	40	44.4	b	10.2	a
	80	52.1	c	11.3	b
	120	54.0	c	12.4	c
LSD (0.05)		2.4		0.4	
CV		14.0		8.6	
P-value		**		**	
Great Bend	0	39.9	a	12.0	a
	40	45.2	b	12.8	b
	80	44.8	b	13.3	c
	120	44.2	b	13.7	c
LSD (0.05)		2.1		0.4	
CV		13.2		8.9	
P-value		**		**	
Hutchinson	0	73.7	b	11.7	a
	40	71.6	ab	12.3	b
	80	70.1	b	12.6	b
	120	70.9	ab	13.2	c
LSD (0.05)		2.9		0.5	
CV		11.0		10.4	
P-value		0.1		**	
Sumner County	0	24.5	a	7.5	a
	40	39.1	b	8.1	b
	80	46.6	c	9.2	c
	120	52.4	d	10.5	d
LSD (0.05)		1.9		0.3	
CV		12.4		10.0	
P-value		**		**	

**Indicates significant differences at the 0.05 probability level (*P*-value < 0.05).

Different letters represent statistical differences at LSD = 0.05.

Table 3. Significance of site, nitrogen (N) rate, variety and their interactions on grain protein concentration and grain yield for trial conducted during the 2019–2020 growing season

Effect	Degrees of freedom	Grain yield	Grain protein concentration
Site (S)	3	<0.0001	<0.0001
N rate (N)	3	<0.0001	<0.0001
Variety (V)	13	<0.0001	<0.0001
S × N	9	<0.0001	<0.0001
S × V	39	<0.0001	<0.0001
N × V	39	0.9471	0.6478
S × N × V	117	0.9948	0.6763

Wheat Variety Yield Response to Nitrogen and Sulfur Rates During the 2019–2020 Growing Season

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

Abstract

Early spring visual sulfur (S) deficiency symptoms are increasingly a concern for Kansas wheat growers, but the extent of yield limitation due to S deficiencies and its interaction with nitrogen (N) supply is not well quantified in this environment. Our objective was to evaluate the responses of three wheat varieties to the interaction of N and S rates. The experiment was conducted in four Kansas locations during the 2019–2020 winter wheat growing season: Ashland Bottoms, Argonia, Belleville, and Hutchinson. These locations were selected to provide a range in soil textures and organic matter content, as these variables might impact the crop's response to the S rate. All results are discussed, but only those for Ashland Bottoms and Belleville, the most contrasting sites in terms of yield potential and soil organic matter content, are shown. 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 Kansas State University Soil Testing Lab 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 N rates improved grain yield at all locations. The yield increase depended on the S rate at Ashland Bottoms (i.e., treatments not receiving S were non-responsive to N) but not at the remaining locations. Wheat varieties differed in grain yield at all locations regardless of N rate except for Argonia, where Zenda increased yields linearly with increases in N rate, whereas the remaining varieties showed a linear-plateau response. Increases in N rate also increased protein concentration at all locations, and this increase depended on S rate at three locations. Varieties differed in protein concentration at all locations, and this difference depended on the N rate in Argonia. Our results suggest that winter wheat response to the interaction between N and S fertilizer rates is location-specific, with greater chances of response in soils with sandier texture and lower organic matter contents.

Introduction

Sulfur is mostly supplied to plants through rainfall, mineralization of the soil's organic matter and crop residue, or as part of fertilizers. The Clean Air Act has reduced atmospheric S deposition from about 13 to approximately 3.5 pounds of sulfur per acre per year (Sullivan et al., 2018). This reduction, coupled with increased crop removal, 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 (Lollato et al., 2019a), the issue seems to be severe. The high removal of S by soybeans (Lamond, 1997) 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 wheat. While the S requirements of wheat are generally no more than ~22 pounds of S in an 80 bu/a crop (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., 2019a; 2020).

Because N and S can interact to explain wheat yield and protein responses (Salvagiotti et al., 2009), it is important to study S effects within the context of N fertility. Proper N fertilization ensures a high tiller number and grain yield in wheat (Lollato et al., 2019a; 2021), which is generally sink-limited, and kernels per foot acts as a coarse regulator of grain yield (Jaenisch et al., 2019b, Lollato and Edwards, 2015). Potential kernels/ft is determined by jointing, 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/ft (de Oliveira Silva et al., 2020a). Likewise, N concentration within the plant changes throughout the growing season according to biomass levels (Lollato et al., 2021); 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. 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.

Materials and Methods

The experiment was established near Ashland Bottoms (Belvue silt loam, 1.8% organic matter), Argonia (Nalim loam, 1.6% organic matter), Belleville (Crete silt loam, 3.5% organic matter), and Hutchinson (Ost loam, 2.8% organic matter). Only data from Ashland Bottoms and Belleville, the most contrasting locations, are shown in this report.

A three-way factorial experiment was arranged in a split-split-plot design with four replicates. The varieties SY Monument, LCS Mint, and Zenda were the whole plot, three N rates (i.e., 50, 100, and 150% of the N needed for a 60 bu/a yield goal) were the sub-plot [applied as urea ammonium nitrate (UAN, 28-0-0)], and four S rates (0, 10, 20, and 40 lb S/a) applied as ammonium thiosulfate (12-0-0-26S) were the sub-sub-plot. A pressurized CO_2 backpack sprayer with a three-nozzle spray boom was used to apply the treatments, which occurred at Feekes 4.

Wheat was sown under no-till conditions into soybean stubble, which represents one of the predominant rotations in central Kansas (Lollato et al., 2019b). Plots were sown using a Great Plains 606 no-till drill (7 rows spaced at 7.5 inches) with plot dimensions of 4.4-ft wide × 30 ft long. Seed was treated with 5 oz Sativa IMF Max. The three varieties were sown at 1.5 million seeds per acre to compensate for later sowing dates (Bastos et al., 2020). Composite soil samples (15 cores) were collected at sowing for soil nutrient analysis at two depths i.e., 0–6 in. and 6–24 in. (Table 1). Weeds and diseases were controlled, and insect pressure was not experienced.

Results

Weather Conditions

Growing season precipitation ranged from 12.5 inches in Belleville to 24.2 inches in Ashland Bottoms, while the atmospheric water demand (i.e., reference grass evapotranspiration) ranged from 30.3 to 35.9 inches (Table 2). The corresponding balance between water supply (precipitation) and water demand (reference evapotranspiration) ranged from 0.40 to 0.80. The growing conditions at Ashland Bottoms were the most favorable for high yields, as the crop was exposed to heat stress near the time of grain filling in the other three locations due to late sowing dates, typical for systems in which wheat follows soybeans.

Wheat Grain Yield

At all locations, increases in N rate increased grain yield, but this yield increase depended on S rate in Ashland Bottoms (Figure 1) and on variety in Argonia (data not shown). In Ashland Bottoms, an increase in N rate from 50% to 150% resulted in no yield gain in the zero S treatment. Once S was provided; regardless of the rate, grain yield increased until the N rate reached 100% and then plateaued afterwards. In Argonia, all varieties had the same yield at the lowest N rate, but responded differently to increases in N rate, with LCS Mint yielding more than SY Monument, which yielded more than Zenda at the two highest N rates. In Belleville (Figure 2) and Hutchinson, (data not shown), grain yield increased linearly with increases in N rate. The performance of the different varieties also depended on location, with LCS Mint resulting in the greatest yield in Belleville (Figure 2); SY Monument resulting in the greatest yield in Hutchinson (data not shown); and both SY Monument and LCS Mint having the greatest yield in Ashland Bottoms (Figure 1).

Grain Protein Concentration

Grain protein concentration was affected by the interaction of N and S rates in Ashland Bottoms (Figure 1), Hutchinson, and Argonia (data not shown), and by N rate in Belleville (Figure 2). Likewise, wheat variety significantly impacted grain protein concentration in Ashland Bottoms (Figure 1), Belleville (Figure 2), and Hutchinson (data not shown), with a significant interaction between variety and N rate in Argonia (data not shown). In Ashland Bottoms, the zero S rate resulted in the highest protein concentration (Figure 1), likely due to the strong dilution from yield increases when S was applied. For treatments receiving S, increases in N rate also increased protein concentration. In Belleville, increases in N rate resulted in increased grain protein concentration (Figure 2). At both locations, Zenda had the highest protein concentration as compared to LCS Mint and SY Monument (Figures 1 and 2), which was also true in Argonia and Hutchinson (data not shown).

Preliminary Conclusions

The significant N × S rate interactions for both grain yield and protein concentration at Ashland Bottoms (low organic matter site) suggested that under these S-limited conditions, there were no benefits from increases in N rate unless S was also provided, highlighting the interaction between both nutrients. However, we also showed that in conditions under which S is not limiting (Belleville, higher organic matter site), there was virtually no benefit from applying S to the crop. The varieties LCS Mint and SY Monument consistently outperformed Zenda in terms of yield, and these results were inversed in terms of protein. The site-specific nature of the results from this research reinforce the benefits of soil sampling for informed decisions about N and S management for wheat in Kansas.

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Table 1. Soil chemical and physical properties at the four study locations during the 2019–2020 winter wheat growing season

		Ashland Bottoms		Argonia		Belleville		Hutchinson	
Analysis	**Unit**	**0–6 in.**	**6–24 in.**	**0–6 in.**	**6–24 in.**	**0–6 in.**	**6–24 in.**	**0–6 in.**	**6–24 in.**
CEC	meq/100 g	13.05	10.22	19.92	18.99	22.88	26.59	24.18	25.99
OM	%	1.8	1.4	1.6	1.6	3.5	2.9	2.8	2.2
pH		5.9	6.8	5.1	5.4	5.5	5.9	5.4	6.2
NO_3-N	ppm	6.4	3.3	2.9	3.5	9.9	6.5	7.8	5.8
NH_4-N	ppm	3.8	2.5	1.4	2.4	5.5	2.4	4.1	4.9
P	ppm	45.8	21.5	62	48.2	73.4	48.4	88.6	45.5
K	ppm	262.9	181	157.1	139.9	602.6	615.9	425.5	368.9
Ca	ppm	1,279	1,675	891	1,152	1,876	2,741	1,959	2,779
Mg	ppm	141.1	161	265.7	337	236.8	367.7	348.3	505.7
S	ppm	0.6	1.2	2	2	2.3	2.2	4.2	4.9
Mn	ppm	11.4	6.3	28.3	21.7	31.5	21.5	25	17.1
Na	ppm	9.3	10.4	16.4	30	12.8	24.2	8.8	14.5
Cu	ppm	0.6	0.5	0.8	0.8	1.7	2.1	1.2	1
Zn	ppm	0.8	0.4	0.4	0.4	1.7	1.2	0.5	0.3
Fe	ppm	50.1	29.9	70.1	65	134.1	103.6	87	58.5
Cl	ppm	3	2.6	4.6	6.7	6.1	9.2	3.9	4
Sand	%	34	26	48		14		28	26
Silt	%	54	60	30		64		44	40
Clay	%	12	14	22		22		28	34

CEC = cation exchange capacity. OM = organic matter.

Table 2. Average maximum (Tmax) and minimum (Tmin) temperatures, and cumulative precipitation, grass reference evapotranspiration (ETo) and the ratio of water supply (WS) to water demand (WD) during the growing season at the four study locations during 2019–2020

Location	**Tmax**	**Tmin**	**Precip.**	**ETo**	**WS:WD**
	--------------- °F	---------------	------------- inches	-------------	
Ashland Bottoms	59.3	37.0	24.2	30.3	0.80
Belleville	57.7	33.7	12.5	31.0	0.40
Conway Springs	61.9	39.4	16.4	35.9	0.46
Hutchinson	59.4	34.6	13.6	30.8	0.44

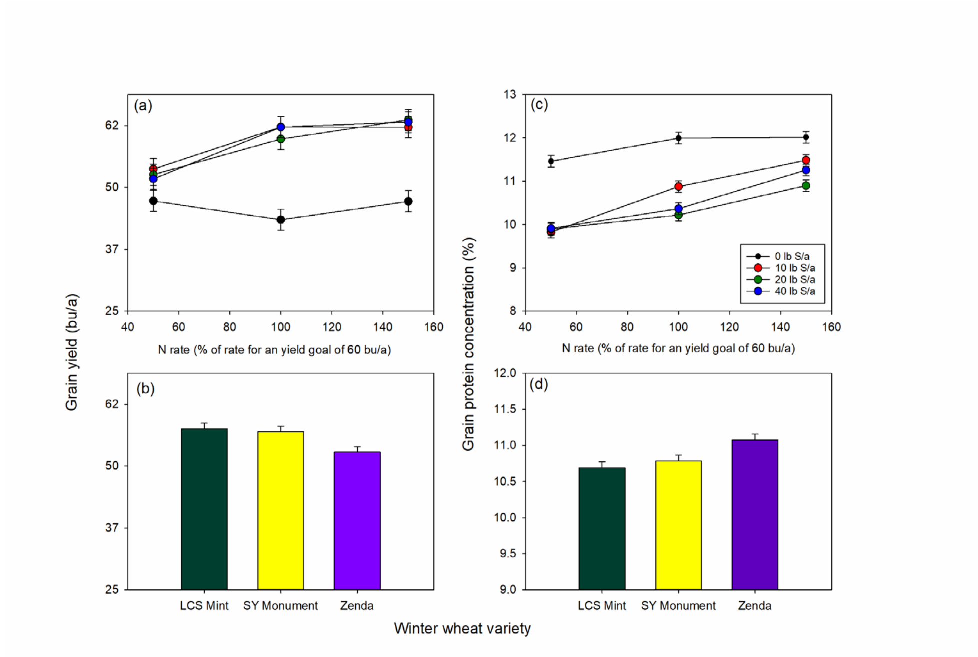

Figure 1. Winter wheat grain yield (a and b) and grain protein concentration (c and d) as affected by the interaction of nitrogen and sulfur rates (a and c) and by variety (b and d) in Ashland Bottoms, KS, during the 2019–2020 winter wheat growing season.

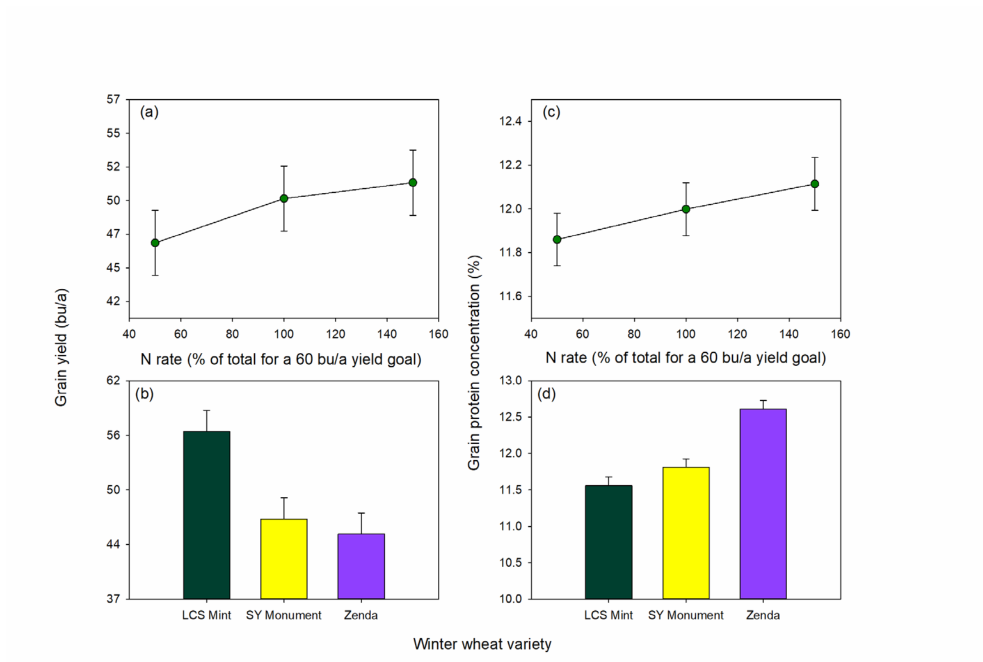

Figure 2. Winter wheat grain yield (a and b) and grain protein concentration (c and d) as affected by nitrogen (a and c) and by variety (b and d) in Belleville, KS, during the 2019–2020 winter wheat growing season.

Evaluation of Corn Response to In-Season Potassium Fertilization Using Dry Fertilizer

D.A. Charbonnier and D.A. Ruiz Diaz

Summary

In-season application of potassium (K) fertilizer may offer an alternative to remediate deficiencies developed during the growing season. The objective of this study was to determine corn response to topdress K application under deficient K soil conditions. Treatments included a control and 50 lb K_2O/a in-season broadcasted at the V8 growth stage. The fertilizer source was potassium chloride (KCl). Measurements collected were plant biomass and tissue nutrient concentration at reproductive stage (R6), and grain yield. Potassium fertilization increased yield at the location evaluated in this study. The in-season fertilized treatment produced higher yield compared to the control ($P < 0.09$). The late K fertilization had higher K concentration and uptake in the plant at R6 ($P < 0.06$) with the same plant biomass as the control treatment. Also, broadcasting KCl at V8 resulted in a higher K/Mg ratio late in the season (R6). Preliminary results of this study suggest that in-season applications using dry K fertilizers could be used when pre-plant fertilization was not done. Nevertheless, for a dry growing season, corn response might be limited.

Introduction

Potassium (K) deficiency on corn (*Zea mays*) could be detected in the early stages when soil K levels are low. In-season application of K fertilizer may offer an alternative to remediate deficiencies developed during the growing season. Currently, there is limited information on how crops respond to post-emergence applications using dry K fertilizers. Previous study by Slaton and Roberts (2020) reported similar soybean yield by applying equal rates of potassium chloride (KCl) in-season compared to pre-plant. Despite reporting similar grain yields regardless of fertilization timing, recommendations include a pre-plant application and more K fertilizer applied in-season if an economic benefit is expected. Additionally, in-season K fertilization via foliar applications may affect corn by stimulating chlorophyll synthesis. A single spraying on corn using KNO_3-solution around tasseling day increased grain yield along with a higher N, P, K, Ca, and magnesium (Mg) absorption (Suwanarit and Sestapukdee, 1989). The objective of this study was to determine corn response to topdress K application timing using dry K fertilizer under deficient soil conditions.

Procedures

The experiment was conducted in a field under conventional tillage located in Osage County, KS, in 2020. Particular areas of the field with low soil test potassium (STK) levels (Table 1) were selected to evaluate late response to K fertilization. The experiment was a randomized complete block design with two treatments and four blocks. Treatments included a control (0 lb K_2O/a), and 50 lb K_2O/a in-season broadcasted at the V8 growth stage. The fertilizer source was potassium chloride (KCl). Aboveground plant samples were collected at the R6 stage in order to measure total plant K uptake. The samples were dried at 140°F, ground to pass through a 2 mm screen, weighed, and digested by nitric-perchloric acid digestion. Total K concentration was determined by inductively coupled plasma (ICP) spectrometry. Soil samples were taken at V8 growth stage (one per plot), air-dried at 104°F, and ground to pass through a 2 mm screen. All samples were analyzed for soil pH (soil:water; 1:1), organic matter (OM) (loss on ignition method), extractable P and K (Mehlich-3), exchangeable cations (1 M NH_4OAc pH 7.0, flame atomic absorption), including the field-moist analysis for K, and cation exchange capacity (CEC) (displacement method). Grain was harvested from the center rows (20-ft length). Yield was corrected at 15.5% moisture. Statistical analysis (ANOVA) was performed using the GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC).

Results

Potassium fertilization applied in-season increased grain yield in this study by approximately 12 bu/a ($P < 0.09$) (Figure 1). This location had soil K levels that were below the critical level of 130 ppm (Table 1), and yield response to K fertilization was expected (Leikam, et al. 2003). Similar results were reported by Amanullah et al. (2015) with dry K application at V9. The K deficiency symptoms at the beginning of the experiment suggested that the soil could not provide enough K required by corn plants (Figure 2). The late K fertilization had significantly higher plant K uptake at R6 growth stage compared to control ($P < 0.04$ and $P < 0.06$, respectively) (Figure 1). Also, broadcasting KCl at V8 resulted in a higher plant K/Mg ratio late in the season (Figure 3). Preliminary results of this study suggest that in-season applications using dry K fertilizers could be used when pre-plant fertilization was not done. Nevertheless, for a dry growing season, corn response might be limited, and the full response to K can be achieved only with pre-plant applications. In-season K applications should be considered only as a rescue option.

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Table 1. Selected soil properties for 0- to 6-in. samples

pH	OM	Sand	Silt	Clay	CEC	Soil P	Soil K dry	Soil K field moist
	----------	%	----------		meq/100 g	--------	ppm	--------
7.5	2.36	14	62	24	15.0	24.8	82.1	32.1

OM = organic matter. CEC = cation exchange capacity. P = phosphorus. K = potassium.

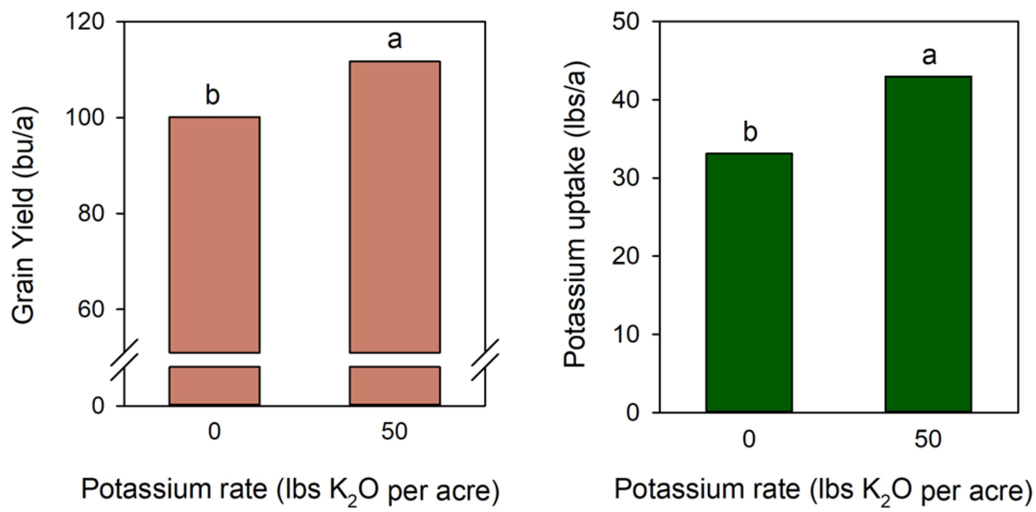

Figure 1. In-season potassium (K) application (using KCl) at the V8 stage and corn grain yield response. And corn K uptake at the R6 growth. Means followed by the same letter are not significantly different at $P < 0.05$**.**

Figure 2. Potassium deficiency symptoms at the beginning of the experiment (July 10, 2020).

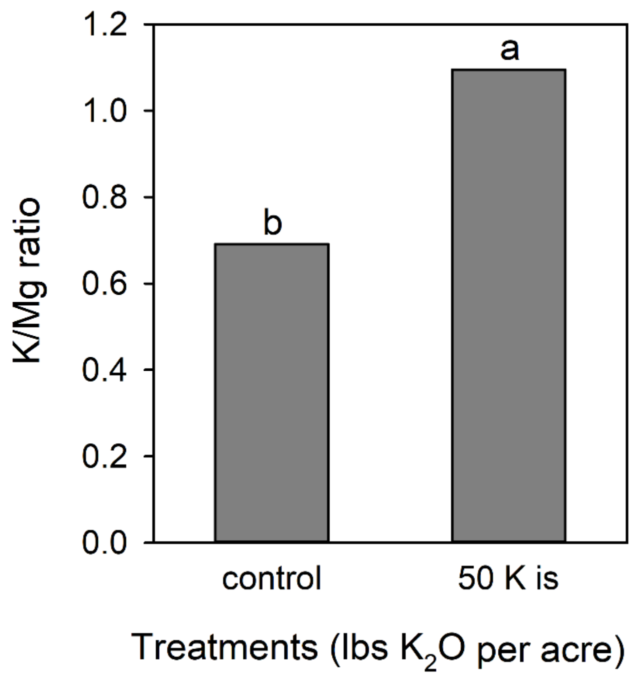

Figure 3. Plant potassium/magnesium (K/Mg) ratio at R6 growth stage as affected by treatment. Means followed by the same letter are not significantly different at $P < 0.01$.

Timing of Side-Dress Applications of Nitrogen for Corn in Conventional and No-Till Systems

D.W. Sweeney and D. Ruiz-Diaz[1]

Summary

Corn yield and yield components were affected by tillage and nitrogen (N) side-dress application options in 2019. Average corn yields were 15% greater with conventional tillage than with no-till. Yields were improved by either splitting N rate between pre-plant and side-dress at the V10 growth stage or adding additional side-dress N as compared with applying 150 lb/a pre-plant.

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. Side-dress or split applications 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 side-dress N fertilization compared with pre-plant N applications for corn grown on a claypan soil.

Experimental Procedures

The experiment was established in spring 2015 on a Parsons silt loam soil at the Parsons Unit of the Kansas State University Southeast Agricultural Research Center. The experiment was a split-plot arrangement of a randomized complete block design with four blocks (replications). Whole plot tillage treatments were conventional tillage (chisel, disk, and field cultivate) and no tillage. Sub-plot nitrogen treatments were six pre-plant/side-dress N application combinations that include:

1. A no-N control;
2. 150 lb N/a applied pre-plant;
3. 100 lb N/a applied pre-plant with 50 lb N/a applied at the V6 (six-leaf) growth stage;
4. 100 lb N/a applied pre-plant with 50 lb N/a applied at the V10 (ten-leaf) growth stage;
5. 150 lb N/a applied pre-plant with 50 lb N/a applied at the V6 growth stage; and
6. 150 lb N/a applied pre-plant with 50 lb N/a applied at the V10 growth stage.

The N source for all treatments was liquid urea-ammonium nitrate (28% N) fertilizer. Pre-plant N fertilizer was applied on March 13, 2019, side-dress N at V6 on June 3, 2019, and side-dress N at V10 on June 13, 2019, to appropriate plots. All N was broadcast applied with 7-stream pattern fertilizer nozzles. Corn was planted on April 11 and harvested on September 5, 2019.

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Results and Discussion

In 2019, average corn yielded 22 bu/a more with conventional tillage than with no-tillage, partially due to having a 9% greater established stand (Table 1). Adding N fertilizer more than tripled yields obtained in the no-N control. Splitting the N fertilizer to apply 100 lb N/a preplant followed by 50 lb N/a at the V10 growth stage improved yields by 15 bu/a more than all N applied pre-plant. Adding 50 lb N/a extra at the V6 or V10 growth stages to a 150 lb N/a preplant application did not improve yields more than that obtained with 150 lb N/a applied split pre-plant and side-dress at V10. These effects of N application timing on corn yield in 2019 appeared to be related to the combined responses in kernel weight, ears/plant, and kernels/ear.

Acknowledgment

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Table 1. Tillage and nitrogen (N) side-dress application effects on yield and yield components of corn in 2019

Treatment	Yield	Stand	Kernel weight	Ears/plant	Kernels/ear
	bu/a	plants/a	mg		
Tillage					
Conventional[1]	167	22,300	271	0.95	709
No-till	145	20,400	258	0.97	689
LSD (0.10)	15	800	NS	NS	NS
N timing[2]					
No-N control	54	21,900	205	0.84	371
150 PP	164	21,600	260	0.99	752
100 PP/50 V6	166	21,600	273	0.99	724
100 PP/50 V10	179	22,200	273	0.98	768
150 PP/50 V6	187	21,000	287	0.99	801
150 PP/50 V10	186	21,000	289	1.00	778
LSD (0.05)	9	NS	15	0.05	52

[1]Conventional tillage: chisel, disk, and field cultivate.
[2]Nitrogen treatments:
Control = no N fertilizer.
150 PP = 150 lb N/a applied pre-plant with no side-dress N.
100 PP/50 V6 = 100 lb N/a applied pre-plant with 50 lb N/a side-dress applied at V6 (six-leaf) growth stage.
100 PP/50 V10 = 100 lb N/a applied pre-plant with 50 lb N/a side-dress applied at V10 (ten-leaf) growth stage.
150 PP/50 V6 = 150 lb N/a applied pre-plant with 50 lb N/a side-dress applied at V6 growth stage.
150 PP/50 V10 = 150 lb N/a applied pre-plant with 50 lb N/a side-dress applied at V10 growth stage.

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

D.W. Sweeney and D. Ruiz-Diaz[1]

Summary

Average corn yield in 2019 was increased by 14 bu/a with knife application of pre-plant nitrogen (N) fertilizer compared with broadcast application. Applying N more than doubled yield of corn grown without N. In general, applying side-dress N increased yields compared to yields obtained with only pre-plant applications.

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 selections create opportunities to provide N during rapid growth periods and 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 no-till 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 dropped to less than a foot above the soil surface. The N source for all treatments was liquid urea-ammonium nitrate (UAN; 28% N) fertilizer. Pre-plant N fertilizer was applied on March 19, 2019, and side-dress N was applied at V10 on June 20, 2019, to appropriate plots. Corn was planted on April 11 and harvested on September 4, 2019.

Results and Discussion

Knife application of the N applied pre-plant resulted in 14 bu/a greater yields than when the pre-plant N was broadcast applied (Table 1). This was partially because of approximately 7% greater number of ears per plant with knifing than with broadcasting. The other yield components were not affected by pre-plant application method ($P = 0.05$). Applying N at any rate and time more than doubled corn yield in 2019

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compared to the 84 bu/a yield with the no-N control. In general, applying side-dress N increased yields compared to yields obtained with only pre-plant applications; however, the increase from side-dress appeared greater when the pre-plant N was 100 lb N/a than when the pre-plant N was 150 lb N/a. Increasing total N rate to greater than 100 lb N/a resulted in increased yield regardless of individual rates of pre-plant/side-dress N applications, with few differences in combinations where total N was 150 lb/a or greater. 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.

Acknowledgment

This work is supported by the U.S. Department of Agriculture National Institute of Food and Agriculture, Hatch project KS00-0104-HA.

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 2019

Treatment	Yield	Stand	Kernel weight	Ears/plant	Kernels/ear
	bu/a	plants/a	mg		
Pre-plant N method					
Broadcast	176	21,700	257	1.17	675
Knife[1]	190	21,400	261	1.25	691
LSD (0.10)	6	NS	NS	0.05	NS
Pre-plant/side-dress[2] N rates (lb/a)					
0-0 (No-N control)	84	21,000	220	0.91	510
0-150	188	21,300	277	1.11	730
100-0	174	21,900	262	1.15	674
100-50	197	22,200	262	1.20	721
100-100	201	21,100	271	1.34	677
150-0	195	21,800	264	1.26	692
150-50	205	21,700	272	1.29	691
150-100	208	21,800	240	1.33	772
200-0	194	21,200	266	1.29	681
LSD (0.05)	13	NS	20	0.10	67

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

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

Tall fescue production was measured during the second year of a study with locations started in fall of 2016 and fall of 2017. In the second year at both sites, phosphorus (P) fertilization rate did not affect harvest yields. Applying nitrogen (N) in late fall or late winter resulted in greater spring yields than applying N in spring or not applying N. However, fall harvest yields at Site 1 in 2018 were greater without N, but were greater with spring N application at Site 2 in 2019. In both site-years, the second-year tall fescue total yield rank as affected by N fertilizer timing was late fall=late winter>spring>no N, even though overall yields were greater in 2019 at Site 2.

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 beginning 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 1, 2017, March 2, 2018, and April 27, 2018, at Site 1. Nitrogen was applied on December 4, 2018, March 18, 2019, and April 25, 2019, at Site 2. Second-year harvest dates from each site were as follows: (1) spring yield was measured at R4 (half bloom) on May 17, 2018, at Site 1 and on May 17, 2019, at Site 2; (2) fall harvest was taken on September 12, 2018, at Site 1 and on September 10, 2019, at Site 2.

Results and Discussion

Dry conditions in 2018 resulted in low, second-year tall fescue yields at Site 1 (Table 1). In the second year of the study at Site 1, spring harvest, fall harvest, or total yield of tall fescue was unaffected by P fertilization. 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 compared with no N, delaying N application resulted in more than a 40% 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 less with N application than without. Average annual total tall fescue yield was increased by applying N. Late fall and late winter application resulted in similar total yields which were 35% to 67% greater than with spring (E2) fertilization or no N, respectively.

Second-year tall fescue spring harvest, fall harvest, or total yields in 2019 at Site 2 were unaffected by P fertilization (Table 2). Spring tall fescue yield was similar with late fall and late winter N fertilization. However, as for the second 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 result in greater fall yield than with no N or N applied in late fall or late winter (Table 2). At Site 2, as with Site 1 (Table 1), the second-year tall fescue total yield rank as affected by N fertilizer timing was late fall=late winter>spring>no N (Table 2).

Acknowledgment

This work is supported by the U.S. Department of Agriculture National Institute of Food and Agriculture, Hatch project KS00-0104-HA.

Table 1. Second-year yield of established tall fescue in the spring (R4-half bloom) and fall 2018 as affected by P_2O_5 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	0.82	1.02	1.83
25	1.03	0.99	2.02
50	1.06	1.01	2.07
100[1]	1.08	1.00	2.08
LSD (0.05)	NS	NS	NS
N application timing			
None	0.31	1.13	1.44
Late fall	1.43	0.96	2.39
Late winter	1.45	0.95	2.41
Spring	0.80	0.96	1.76
LSD (0.05)	0.17	0.15	0.20

[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 2019 as affected by P_2O_5 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	1.84	1.41	3.25
25	1.92	1.34	3.26
50	2.12	1.35	3.47
100[1]	2.00	1.28	3.28
LSD (0.05)	NS	NS	NS
N application timing			
None	0.62	1.17	1.79
Late fall	2.96	1.20	4.16
Late winter	2.81	1.31	4.12
Spring	1.49	1.70	3.19
LSD (0.05)	0.19	0.16	0.28

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

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

D.W. Sweeney, P. Barnes,[1] and G. Pierzynski[2]

Summary

The residual from previous high-rate turkey litter applications, which were based on nitrogen (N) requirements of the previous grain sorghum crop, increased 2019 soybean yield more than that obtained from the residual of phosphorus (P)-based turkey litter applications (low rate) or the control. Even though early soybean growth was unaffected by residual treatments, the dry matter production at the R6 growth stage was greater with N-based litter application than with P-based applications or the control.

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

Previous to this study, a water quality experiment was conducted near Girard, KS, on the Greenbush Educational facility's grounds from spring 2011 through spring 2014. Those treatments, listed below, were fertilizer and turkey litter applications based on 120 lb N/a and 50 lb P_2O_5/a rates 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. Fert-C: commercial N and P fertilizer only—chisel-disk tillage;
3. TL-N: N-based turkey litter, no extra N or P fertilizer—no tillage;
4. TL-N-C: N-based turkey litter, no extra N or P fertilizer—chisel-disk tillage; and
5. TL-P-C: P-based turkey litter, supplemented with fertilizer N—chisel-disk tillage.

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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. Soybean was planted on June 7, 2019, and harvested on October 28, 2019. Whole plant samples were taken on June 28 (V4), July 24 (R2), August 19 (R4), and September 23 (R6), 2019.

Results and Discussion

In 2019, the residual from previous high rate turkey litter applications, which were based on N requirements of the previous grain sorghum crops grown from 2011 through 2013, increased 2019 soybean yield compared to that obtained from the residual of P-based turkey litter applications (low rate) or the control (Table 1). The soybean yields with the Fert-C treatment were less than TL-N, but were not statistically different than TL-N-C. The number of pods/plant were greater where N-based turkey litter had been applied in no-till than where a low rate of turkey litter or no fertilizer or litter had been applied. The effect of residual treatments on soybean dry matter production was non-significant through most of the growing season. 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) or the no-N/no-P control, with dry matter from the Fert-C treatment being intermediate.

Acknowledgment

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Table 1. Residual effect of turkey litter and fertilizer amendments on soybean yield, yield components, and dry matter production during 2019

Residual amendment[1]	Yield	Stand (×1000)	Seed weight	Pods/ plant	Seeds/ pod	Dry matter V3	Dry matter R2	Dry matter R4	Dry matter R6
	bu/a	plants/a	mg			lb/a	lb/a	lb/a	lb/a
Control	31.3	87.0	151	50	2.2	100	970	2280	5460
Fert-C	46.7	89.1	143	77	2.2	70	710	2780	8090
TL-N	59.3	88.9	155	76	2.1	90	1030	4610	9120
TL-N-C	56.9	86.6	152	91	2.1	80	690	3340	9440
TL-P-C	41.1	86.5	151	62	2.1	100	860	3280	5500
LSD (0.10)	10.3	NS	NS	21	NS	NS	NS	NS	2650

[1]Control = no turkey litter or N and P fertilizer with no tillage.
Fert-C = commercial fertilizer incorporated with conventional 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.

Evaluation of Soil Parameters After Long-Term Subsurface Drip Irrigation Under Minimum Tillage System

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

Summary
The objective of this study was to evaluate soil parameters after the long-term use of sub-surface drip irrigation under no-till, with the use of high pH irrigation water. Results from this study showed that stratification of soil pH and soil test phosphorus (P) was more prominent when compared to other soil parameters. However, the stratification of pH and soil test P is likely the combined effect of surface fertilizer application and sub-surface irrigation water. The stratification of other parameters, such as soil calcium (Ca) and sodium (Na) and electrical conductivity (EC), was less clear. Soil test potassium (K) showed some level of stratification, with higher levels deeper in the soil profile; this is likely due to some K application through the irrigation water, but also the finer textured soil.

Introduction
Sub-surface drip irrigation (SDI) systems can contribute to a significant increase in water use efficiency and crop productivity. Drip tapes are placed permanently and can be located at different depths depending on installation guidelines and management. Older systems were generally placed at more than 10 inches below the surface. After multiple years, and depending on the characteristics of the irrigation water, some soil parameters, distribution of cations, and pH may be affected. The objective of this study was to evaluate soil parameters after the long-term use of SDI (>20 years) under no-till, with the use of high pH irrigation water.

Procedures
Soil samples were collected from a Crete silt loam located in a field near Moundridge (McPherson County, KS) that has been under no-till management and sub-surface drip irrigation for more than 20 years. Samples were collected in fall 2019 using a hand probe and pre-drilled wooden templates with holes spaced 3 inches apart. Three small trenches were dug to locate the length and direction of the SDI drip tape, which was buried approximately 14.5 inches below the soil surface. The sampling templates were laid on the ground, perpendicular to the drip tape, and staked into place to prevent movement during sampling. Soil cores were then collected from the 3-, 6-, and 9-inch horizontal increments on both sides of the drip tape. These soil cores were then separated in 3-inch depth increments, centered around the drip tape, and corresponded to 0-, 3-, and 6-inch depths above and below the tape (tape = 0-inch depth) to generate a grid with the profile distribution of nutrients (Hansel et al., 2017). Soil from each core shallower than 7 inches was saved and mixed together as a composite sample to assess the surface fertility of the sampled area. This process was repeated at each template spaced approximately 30 feet apart. A sample of the irrigation water was also collected from the groundwater well on the same day soil samples were collected.

Soil pH, nutrient analysis, and salinity tests were performed on each soil sample. Soil pH was measured using a 1:1 soil-water suspension and robotic dual-probe pH meter. Phosphorus (P) concentrations were determined from Mehlich-3 extracts. Calcium, potassium, and sodium were measured using ICP-AES from both saturated paste extracts. Soil electrical conductivity was also measured from the saturated paste extracts. Water analyses include pH, EC, Ca, magnesium (Mg), K, Na, NO_3, sulfur (S), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn).

Results

The irrigation water at this location was alkaline (pH = 7.5) with measurable levels of cations (Ca, K, Mg, and Na), in addition to NO_3 and S (Figure 1). These characteristics would typically require regular maintenance of the SDI system to avoid the accumulation of carbonates over time.

Soil sampling from this study showed that pH, soil test P, and soil test K were highly stratified in these soils (Figures 2 and 3). Soil pH and soil test K generally increased with depth from the soil surface. Soil test P was also highly stratified in these soils and was approximately ten times higher near the surface than at the bottom of the profile. These results are likely due to the history of surface P fertilizer application and reduced tillage system with no soil mixing in this field, and are similar to previous studies in Kansas (Adee et al., 2016; Arruda et al., 2019; Preston et al. 2019). The increase in soil pH near the SDI drip tape was likely contributed by the high pH irrigation water, but also the surface application of fertilizers, which contributed with acidity near the surface. The higher soil K level deeper in the profile may be due to the combination of K supply through the irrigation water (Figure 1), but also the higher clay content and cation exchange capacity at this layer.

Soil salinity parameters (EC, Ca, Na) were generally low, and no clear relationship between soil depth or horizontal distance from the SDI drip tape was observed (Figures 4 and 5). Given the age of the irrigation system and the characteristics of the irrigation water, the management practices employed in this field (such as regular acid treatments of the irrigation system) appear to manage introduced cations adequately.

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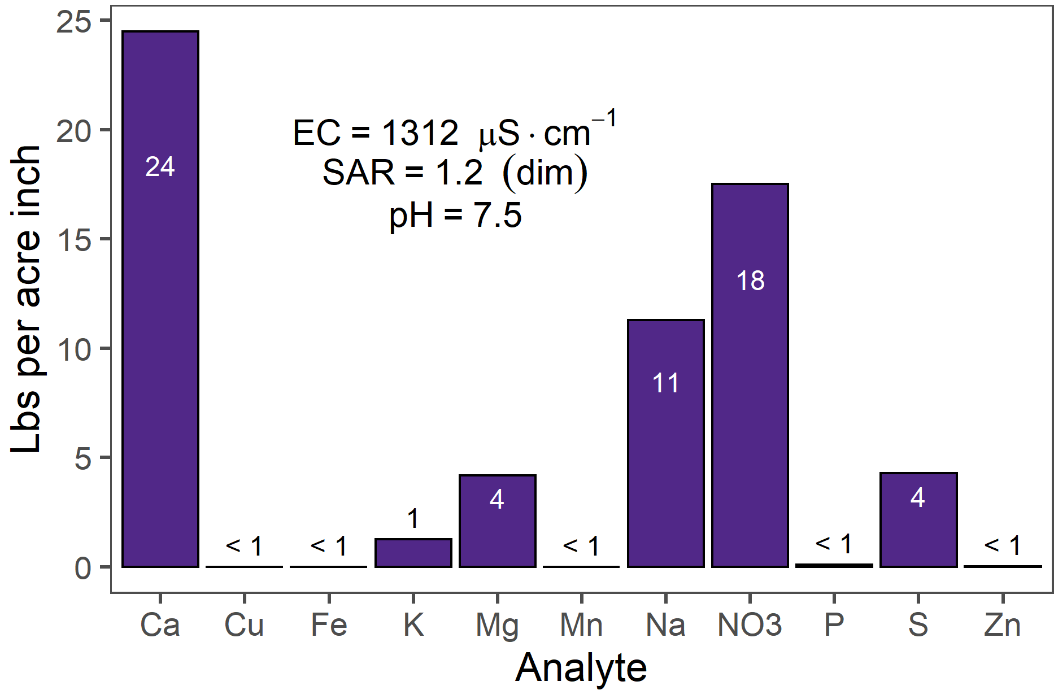

Figure 1. Nutrient analysis of the irrigation water. All nutrients are expressed in pounds of nutrient per acre inch of irrigation water applied. EC = electrical conductivity. Calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorus (P), sulfur (S), zinc (Zn). SAR = sodium adsorption ratio.

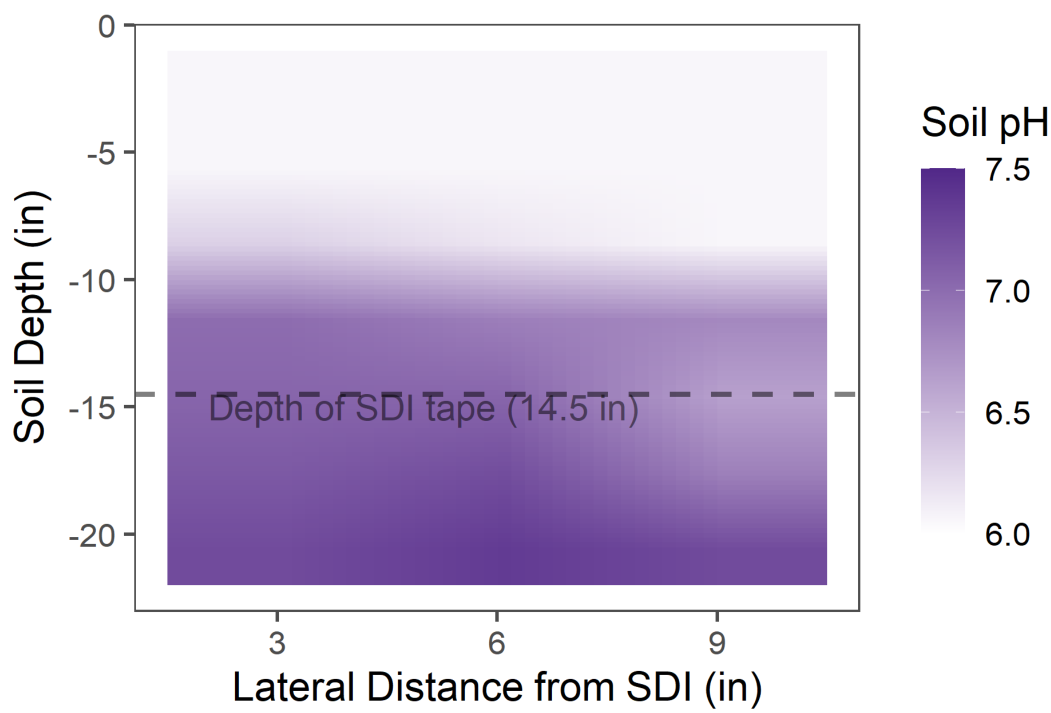

Figure 2. Soil pH as a function of soil depth and lateral distance from the sub-surface drip irrigation (SDI) drip tape. The tape was buried approximately 14 inches below the soil surface. The darker color indicates higher pH. The soil in the surface layer was approximately 6.0 pH.

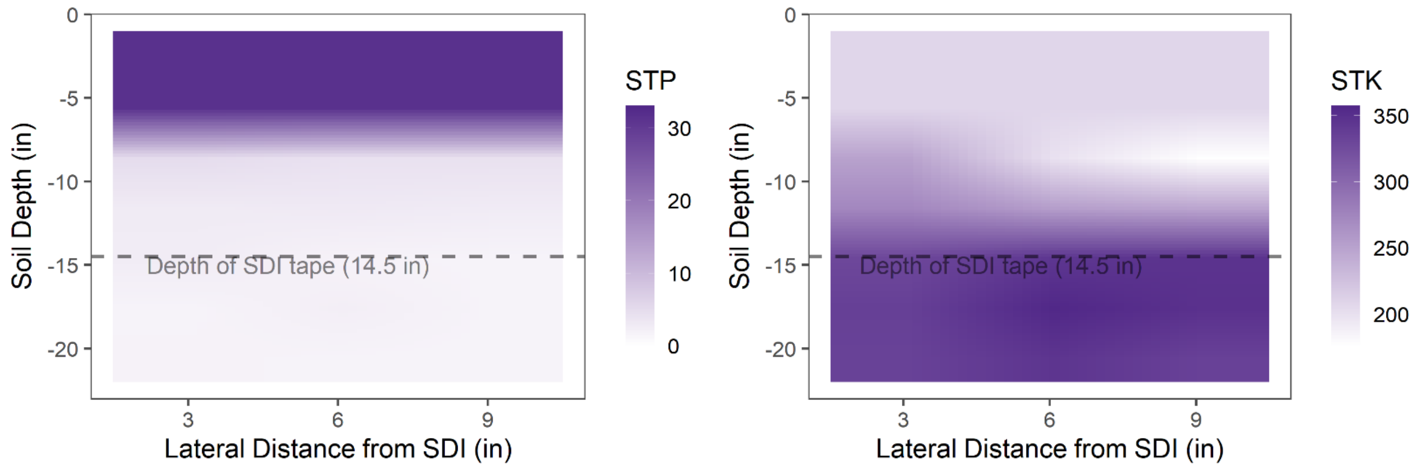

Figure 3. Soil test phosphorus (P) and potassium (K) as a function of soil depth and lateral distance from the sub-surface drip irrigation (SDI) tape. The irrigation tape was buried approximately 14 inches below the soil surface. Phosphorus is expressed as ppm and the darker color indicates higher soil test P. Soil test P (STP) in the surface layer (0–7 inches) was approximately 32 ppm. Soil test K (STK) in the surface layer was 208 ppm.

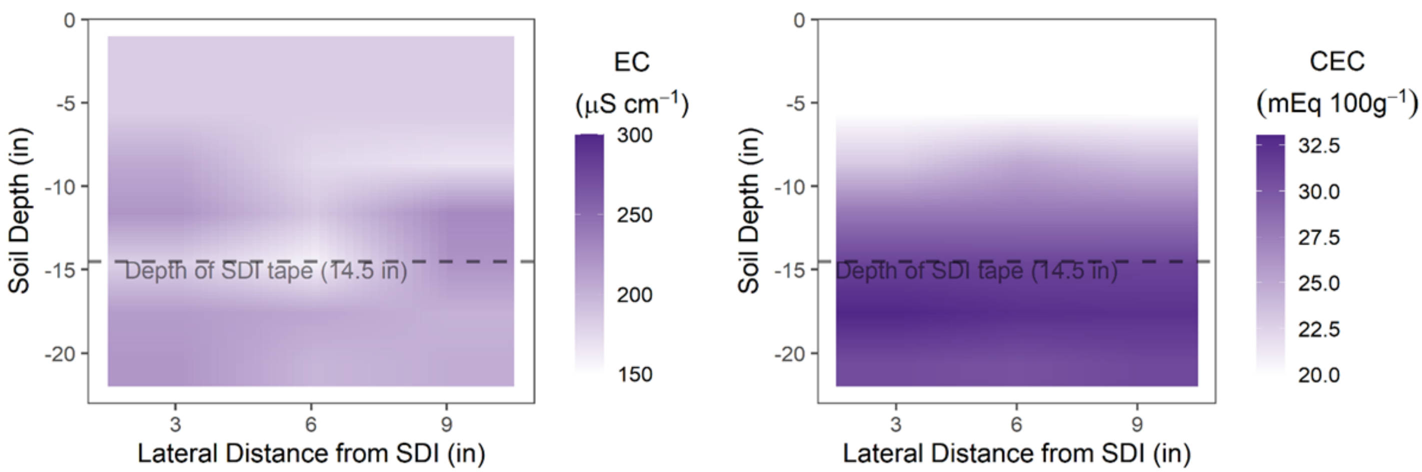

Figure 4. Soil electrical conductivity (EC) and cation exchange capacity (CEC) as a function of soil depth and lateral distance from the irrigation tape. The sub-surface drip irrigation (SDI) tape was buried approximately 14 inches below the soil surface. Electrical conductivity is expressed as µS cm^{-1} and the darker color indicates higher EC. Cation exchange capacity was estimated as a function of water required to saturate the sample.

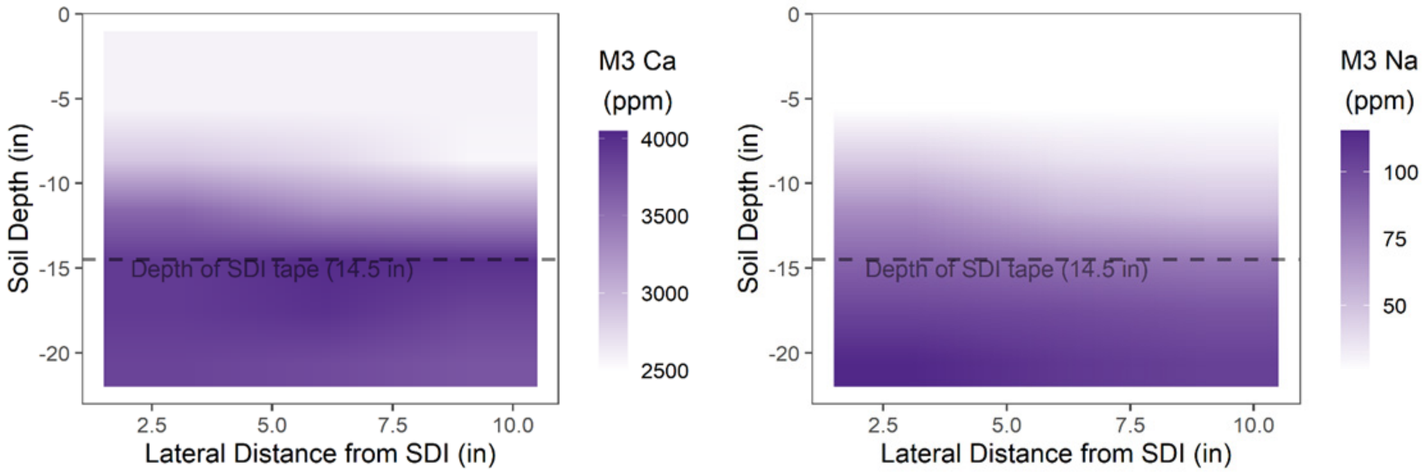

Figure 5. Soil test calcium (Ca) and sodium (Na) as a function of soil depth and lateral distance from the sub-surface drip irrigation (SDI) tape. The irrigation tape was buried approximately 14 inches below the soil surface. Calcium and Na were measured using the Mehlich-3 (M3) soil test procedures and are expressed as soil ppm.

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