

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

A. Schlegel and 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 P₂O₅/bu) and grain K content reached a maximum of 0.19 lb/bu (0.23 lb K₂O/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. Nitrogen fertilization increased soil organic matter and decreased soil pH. Phosphorus fertilization tended to maintain or increase soil test P levels.

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 P₂O₅ and zero K; and with 40 lb/a P₂O₅ and 40 lb/a K₂O. 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). After harvest in 2020, all plots were soil sampled (8 probes/plot) to a depth of 6 inches, dried, and ground. Servi-Tech Laboratories analyzed the samples for soil pH, organic matter (OM), P (Bray-1 and Mehlich-3), K, zinc (Zn), manganese (Mn), and iron (Fe).

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 P₂O₅/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.

After 60 years, pH of the surface soil was decreased up to 1 unit by N fertilization (Table 3). Nitrogen fertilization increased soil OM, Mn, and Fe concentrations while decreasing P, K, and Zn concentrations. Phosphorus fertilization increased P (both Bray-1 and Mehlich-3) and Zn concentrations with little effect on other soil properties. The original soil test P level (in 1961) was about 17 ppm (Bray-1), so annual applications of 40 lb/a P₂O₅ tended to maintain or increase soil test P levels. Potassium fertilization only affected the K content of the soil.

Acknowledgment

The former International Plant Nutrition Institute and Servi-Tech Laboratories partially supported this research project.

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Persons using such products assume responsibility for their use in accordance with current label directions of the manufacturer.

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

Fertilizer			Grain yield										
N	P ₂ O ₅	K ₂ O	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 ₂ O ₅	K ₂ O	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 ₂ O ₅ -K ₂ O, 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 ₂ O ₅	K ₂ O	N	P	K	N	P	K	N	P	K	*AFNR _g	*AFPR _g	*AFKR _g
----- lb/a -----			----- % -----						----- 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 ₂ O ₅	K ₂ O	N	P	K	N	P	K	*AFNR _g	*AFPR _g	*AFKR _g	
----- lb/a -----			----- % -----			----- lb/bu -----			----- % -----			
ANOVA (P>F)												
Nitrogen			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
Quadratic			0.001	0.004	0.001	0.001	0.004	0.001	0.001	0.001	0.053	0.001
P-K			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	---	---	---
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
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	---
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
80			1.24 c	0.263 b	0.347 c	0.61 c	0.129 b	0.170 c	82 c	18	23 b	56 b
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
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
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
LSD _(0.05)			0.04	0.014	0.006	0.02	0.007	0.003	5	2	1	7
P ₂ O ₅ -K ₂ O, 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
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
LSD _(0.05)			0.03	0.010	0.004	0.01	0.005	0.002	4	1	1	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 ($P < 0.05$).

Table 3. Effect of 60 years of nitrogen (N), phosphorus (P), and potassium (K) fertilizers to irrigated grain sorghum on soil properties (0–6 inch), Tribune, KS, 2020

N	P ₂ O ₅	K ₂ O	pH	OM	Mehlich		K	Zn	Mn	Fe
					Bray 1 P	3P				
----- lb/acre -----				%	----- ppm -----					
0	0	0	7.8	1.9	5	9	600	0.62	5.8	5
0	40	0	7.7	2.0	44	59	607	0.80	6.2	7
0	40	40	7.7	2.0	35	51	687	0.74	6.2	6
40	0	0	7.7	2.0	5	11	580	0.52	6.2	6
40	40	0	7.7	2.3	36	47	620	0.74	7.4	8
40	40	40	7.6	2.2	35	42	688	0.70	7.4	9
80	0	0	7.4	2.2	5	9	588	0.50	8.4	7
80	40	0	7.5	2.3	24	31	568	0.62	8.0	9
80	40	40	7.5	2.3	28	34	684	0.68	8.2	8
120	0	0	7.3	2.1	4	8	579	0.48	8.0	7
120	40	0	7.5	2.2	13	21	580	0.62	7.2	6
120	40	40	7.5	2.3	28	34	653	0.66	8.4	8
160	0	0	6.7	2.2	8	15	546	0.52	11.2	10
160	40	0	7.1	2.3	26	31	525	0.66	10.8	10
160	40	40	7.2	2.2	14	20	622	0.52	9.8	8
200	0	0	6.6	2.3	11	14	543	0.56	16.6	14
200	40	0	6.9	2.2	26	32	545	0.58	12.2	12
200	40	40	6.8	2.4	31	34	616	0.66	13.2	12

continued

Table 3. Effect of 60 years of nitrogen (N), phosphorus (P), and potassium (K) fertilizers to irrigated grain sorghum on soil properties (0–6 inch), Tribune, KS, 2020

N	P ₂ O ₅	K ₂ O	pH	OM	Mehlich		K	Zn	Mn	Fe
					Bray 1 P	3P				
----- lb/acre -----				%	----- ppm -----					
ANOVA (P>F)										
Nitrogen			0.001	0.001	0.008	0.001	0.001	0.001	0.001	0.001
Linear			0.001	0.001	0.016	0.001	0.001	0.001	0.001	0.001
Quadratic			0.013	0.037	0.004	0.001	0.419	0.001	0.006	0.019
P-K			0.120	0.002	0.001	0.001	0.001	0.001	0.569	0.742
Zero P vs. P			0.043	0.001	0.001	0.001	0.001	0.001	0.314	0.442
P vs. P-K			0.740	0.307	0.914	0.714	0.001	0.557	0.741	0.963
N × P-K			0.556	0.202	0.030	0.001	0.721	0.002	0.626	0.537
MEANS										
Nitrogen										
0 lb/a			7.8 a	2.0 c	28 a	40 a	631 a	0.72 a	6.1 d	6 c
40			7.7 ab	2.2 b	25 ab	33 ab	629 ab	0.65 b	7.0 cd	8 bc
80			7.5 b	2.3 ab	19 bc	24 c	614 ab	0.60 c	8.2 c	8 bc
120			7.5 b	2.2 b	15 c	21 c	604 b	0.59 c	7.9 cd	7 c
160			7.0 c	2.2 ab	16 c	22 c	564 c	0.57 c	10.6 b	9 b
200			6.7 d	2.3 a	23 abc	27 bc	568 c	0.60 c	14.0 a	13 a
LSD _{0.05}			0.2	0.1	8	7	26	0.05	2.0	2
P ₂ O ₅ -K ₂ O										
0 lb/a			7.3	2.1 b	6 b	11 b	573 b	0.53 b	9.4	8
40 - 0			7.4	2.2 a	28 a	37 a	574 b	0.67 a	8.6	9
40 - 40			7.4	2.2 a	29 a	36 a	658 a	0.66 a	8.9	9
LSD _{0.05}			0.2	0.1	5	5	18	0.03	1.4	1

Zn = zinc. Mn = manganese. Fe = iron.

Different letters in the same column indicate significant differences ($P < 0.05$).