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

A. Schlegel  
*Kansas State University, schlegel@ksu.edu*

D. Bond  
*Kansas State University, dbond@ksu.edu*

Follow this and additional works at: https://newprairiepress.org/kaesrr

**Part of the Agronomy and Crop Sciences Commons**

**Recommended Citation**

Schlegel, A. and Bond, D. (2021) "Irrigated Grain Sorghum Response to Long-Term Nitrogen, Phosphorus, and Potassium Fertilization," *Kansas Agricultural Experiment Station Research Reports*: Vol. 7: Iss. 7.  
https://doi.org/10.4148/2378-5977.8109

This report is brought to you for free and open access by New Prairie Press. It has been accepted for inclusion in Kansas Agricultural Experiment Station Research Reports by an authorized administrator of New Prairie Press. Copyright 2021 the Author(s). Contents of this publication may be freely reproduced for educational purposes. All other rights reserved. 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. K-State Research and Extension is an equal opportunity provider and employer.
Irrigated Grain Sorghum Response to Long-Term Nitrogen, Phosphorus, and Potassium Fertilization

Cover Page Footnote
The former International Plant Nutrition Institute and Servi-Tech Laboratories partially supported this research project.
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 P\(_2\)O\(_5\)/bu) and grain K content reached a maximum of 0.19 lb/bu (0.23 lb K\(_2\)O/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 P\(_2\)O\(_5\) and zero K; and with 40 lb/a P\(_2\)O\(_5\) and 40 lb/a K\(_2\)O. 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) 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) and apparent fertilizer K recovery (AFKR). 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 P\textsubscript{2}O\textsubscript{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.

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 P\textsubscript{2}O\textsubscript{5} 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 O K   | lb/a        | bu/a        |
|------------|-------------|-------------|
| 0 0 0 0    | 75 78 62 90 | 89 80 70 77 |
| 0 40 0     | 83 90 77 94 | 102 91 79 87 |
| 0 40 40    | 88 93 72 96 | 97 91 80 83 |
| 40 0 0     | 106 115 94 115 | 122 106 87 93 |
| 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 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Mean |
|------------|-------------|------|------|------|------|------|------|------|------|------|------|------|
| N | P | O | K | lb/a | bu/a | lb/a | bu/a | lb/a | bu/a | lb/a | bu/a | 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 | 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 | 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 | 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 | 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 | 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 | 0.700 | 0.700 | 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 | 0.001 | 0.001 | 0.001 |

**MEANS**

| Nitrogen, lb/a | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Mean |
|----------------|------|------|------|------|------|------|------|------|------|------|------|
| 0 | 82 d | 87 d | 70 d | 94 c | 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 | 134 d | 146 c | 129 c | 117 b | 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<sub>(0.05)</sub> | 8 | 9 | 8 | 9 | 8 | 8 | 9 | 7 | 8 | 6 | 5 |

| P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, lb/a | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Mean |
|----------------|------|------|------|------|------|------|------|------|------|------|------|
| 0 - 0 | 111 b | 125 b | 99 b | 120 b | 129 b | 117 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<sub>(0.05)</sub> | 6 | 6 | 5 | 6 | 5 | 6 | 6 | 5 | 6 | 5 | 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     | K             | N     | P   | K     | AFNR | AFPR | AFKR |
| ---        | ---   | ---           | ---   | --- | ---   | ---   | ---   | ---   |
| 0          | 0     | 0             | 1.00  | 0.244 | 0.354 | 0.49 | 0.119 | 0.174 |
| 0          | 40    | 0             | 1.00  | 0.311 | 0.382 | 0.49 | 0.152 | 0.187 |
| 0          | 40    | 40            | 1.00  | 0.310 | 0.382 | 0.49 | 0.152 | 0.187 |
| 40         | 0     | 0             | 1.13  | 0.217 | 0.340 | 0.55 | 0.106 | 0.167 |
| 40         | 40    | 0             | 1.10  | 0.314 | 0.366 | 0.54 | 0.154 | 0.179 |
| 40         | 40    | 40            | 1.09  | 0.308 | 0.364 | 0.53 | 0.151 | 0.178 |
| 80         | 0     | 0             | 1.35  | 0.202 | 0.337 | 0.66 | 0.099 | 0.165 |
| 80         | 40    | 0             | 1.20  | 0.288 | 0.351 | 0.59 | 0.141 | 0.172 |
| 80         | 40    | 40            | 1.17  | 0.300 | 0.354 | 0.58 | 0.147 | 0.173 |
| 120        | 0     | 0             | 1.40  | 0.186 | 0.334 | 0.69 | 0.091 | 0.164 |
| 120        | 40    | 0             | 1.29  | 0.272 | 0.349 | 0.63 | 0.133 | 0.171 |
| 120        | 40    | 40            | 1.31  | 0.295 | 0.351 | 0.64 | 0.144 | 0.172 |
| 160        | 0     | 0             | 1.39  | 0.216 | 0.342 | 0.68 | 0.106 | 0.167 |
| 160        | 40    | 0             | 1.39  | 0.297 | 0.354 | 0.68 | 0.146 | 0.173 |
| 160        | 40    | 40            | 1.34  | 0.267 | 0.346 | 0.66 | 0.131 | 0.170 |
| 200        | 0     | 0             | 1.40  | 0.222 | 0.345 | 0.69 | 0.109 | 0.169 |
| 200        | 40    | 0             | 1.38  | 0.274 | 0.353 | 0.68 | 0.134 | 0.173 |
| 200        | 40    | 40            | 1.38  | 0.278 | 0.351 | 0.67 | 0.136 | 0.172 |

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 | K | N | P | K | *AFNR | *AFPR | *AFKR |
|            | - - - - lb/a - - - - | - - - - % - - - - | - - - - lb/bu - - - - | - - - - % - - - - |

ANOVA (P>F)

Nitrogen
- 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 vs. P 0.412 0.958 0.597 0.412 0.958 0.597 0.934 0.812 0.865 --- --- ---
- Zero P vs. P 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 c 0.288 a 0.373 a 0.49 c 0.141 a 0.183 a 40 c 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 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

P₂O₅,K₂O, 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, *AFPR, and *AFKR = 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  | P₂O₅ | K₂O | pH  | OM | Bray 1 P | 3P | K  | Zn | Mn | Fe |
|----|------|-----|-----|----|---------|----|----|----|----|----|
| 0  | 0    | 0   | 7.8 | 1.9| 9       | 600| 0.62| 5.8| 5  |
| 0  | 40   | 0   | 7.7 | 2.0| 35      | 59 | 0.80| 6.2| 7  |
| 0  | 40   | 40  | 7.7 | 2.0| 51      | 687| 0.74| 6.2| 6  |
| 40 | 0    | 0   | 7.7 | 2.0| 11      | 580| 0.52| 6.2| 6  |
| 40 | 40   | 0   | 7.7 | 2.3| 47      | 620| 0.74| 7.4| 8  |
| 40 | 40   | 40  | 7.6 | 2.2| 42      | 688| 0.70| 7.4| 9  |
| 80 | 0    | 0   | 7.4 | 2.2| 9       | 588| 0.50| 8.4| 7  |
| 80 | 40   | 0   | 7.5 | 2.3| 31      | 568| 0.62| 8.0| 9  |
| 80 | 40   | 40  | 7.5 | 2.3| 34      | 684| 0.68| 8.2| 9  |
| 120| 0    | 0   | 7.3 | 2.1| 8       | 579| 0.48| 8.0| 7  |
| 120| 40   | 0   | 7.5 | 2.2| 21      | 580| 0.62| 7.2| 6  |
| 120| 40   | 40  | 7.5 | 2.3| 34      | 653| 0.66| 8.4| 8  |
| 160| 0    | 0   | 6.7 | 2.2| 15      | 546| 0.52| 11.2|10 |
| 160| 40   | 0   | 7.1 | 2.3| 31      | 525| 0.66| 10.8|10 |
| 160| 40   | 40  | 7.2 | 2.2| 20      | 622| 0.52| 9.8 | 8  |
| 200| 0    | 0   | 6.6 | 2.3| 14      | 543| 0.56| 16.6|14 |
| 200| 40   | 0   | 6.9 | 2.2| 32      | 545| 0.58| 12.2|12 |
| 200| 40   | 40  | 6.8 | 2.4| 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 | Bray 1 P | Bray 3P | K | Zn | Mn | Fe |
|----------|---|------------|--------|----|----|----------|---------|---|----|----|----|
| ANOVA (P>F) |   |            |        |    |    |          |         |   |    |    |    |
| Nitrogen | 0.001 | 0.001 | 0.008 | 0.001 | 0.001 | 0.001 | 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 | 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 | 0.001 | 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 | P$_2$O$_5$-K$_2$O |
|----------|----------|-------------------|
| 0 lb/a   | 7.8 a    | 7.3               |
| 40       | 7.7 ab   | 7.4               |
| 80       | 7.5 b    | 7.0 c             |
| 120      | 7.5 b    | 7.0 c             |
| 160      | 7.0 c    | 6.7 d             |
| 200      | 6.7 d    | 6.7 d             |
| LSD$_{0.05}$ | 0.2      | 0.2               |

Zn = zinc. Mn = manganese. Fe = iron.
Different letters in the same column indicate significant differences ($P < 0.05$).