

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

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### **Summary**

Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated grain sorghum in western Kansas. In 2019, N applied alone increased yields 66 bu/a, whereas N and P applied together increased yields up to 85 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields up to 78 bu/a. Application of 160 lb/a N (with P) produced the maximum yield in 2019, which is slightly more than the 10-year average. Application of potassium (K) has had no effect on sorghum yield throughout the study period. Average grain N content reached a maximum of ~0.7 lb/bu while grain P content reached a maximum of 0.16 lb/bu (0.34 lb  $P_2O_5$ /bu) and grain K content reached a maximum of 0.19 lb/bu (0.23 lb  $K_2O$ /bu). At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 31% for N, 65% for P, and 38% for K.

### **Introduction**

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

### **Procedures**

This field study is conducted at the Tribune Unit of the Kansas State University Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 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 in 2010–2011, Pioneer 84G62 in 2012–2014, Pioneer 86G32 in 2015, Pioneer 84G62 in 2016–2017, and Pioneer 85P44 in 2018–2019) was planted in late May or early June. Irrigation is used to minimize water stress. Sprinkler irrigation has been used since 2001. The center two rows of each plot are machine harvested after physiological maturity. Grain yields are adjusted to 12.5% moisture. Grain samples were collected at harvest, dried, ground, and analyzed for N, P, and K concentrations. Grain N, P, and K content (lb/bu) and removal (lb/a) were calculated. Apparent fertilizer N recovery in the grain (AFNR<sub>g</sub>) 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<sub>g</sub>) and apparent fertilizer K recovery (AFKR<sub>g</sub>).

## Results

Grain sorghum yields in 2019 were 3% lower than the 10-year average (Table 1). Nitrogen alone increased yields 66 bu/a while P alone increased yields 6 bu/a. However, N and P applied together increased yields up to 85 bu/a. Averaged across the past 10 years, N and P applied together increased yields up to 78 bu/a. In 2019, 40 lb/a N (with P) produced about 74% of maximum yield, which is less than the 10-year average of 83%. The 10-year average for 80 lb/a N (with P) and 120 lb/a N (with P) was 93 and 94% of maximum yield, respectively. Sorghum yields were not affected by K fertilization, which has been the case throughout the study period.

The 10-year average grain N concentration (%) increased with N rates but tended to decrease when P was also applied, presumably because of higher grain yields diluting N content (Table 2). Grain N content reached a maximum of ~0.7 lb/bu. Maximum N removal (lb/a) was obtained with 160 lb N/a or greater with P. Similar to N, average P concentration increased with P application but decreased with higher N rates. Grain P content (lb/bu) of ~0.15 lb P/bu (0.34 lb P<sub>2</sub>O<sub>5</sub>/bu) was similar for all N rates when P was applied. Grain P removal was similar for all N rates of 40 lb/a or greater with P removal ranging from 19 to 22 lb/a. Average K concentration (%) and content (lb/bu) tended to decrease with increased N rates. Similar to P, K removal was similar for all N rates of 40 lb/a or greater plus K ranging from 22 to 26 lb/a. At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 31% for N, 65% for P, and 38% for K.

## Acknowledgment

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

| Fertilizer       |                               |                  | Yield            |      |      |      |      |      |      |      |      |      |      |
|------------------|-------------------------------|------------------|------------------|------|------|------|------|------|------|------|------|------|------|
| N                | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | 2010             | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Mean |
| ----- lb/a ----- |                               |                  | ----- bu/a ----- |      |      |      |      |      |      |      |      |      |      |
| 0                | 0                             | 0                | 51               | 75   | 78   | 62   | 90   | 89   | 80   | 70   | 77   | 68   | 74   |
| 0                | 40                            | 0                | 51               | 83   | 90   | 77   | 94   | 102  | 91   | 79   | 87   | 74   | 83   |
| 0                | 40                            | 40               | 55               | 88   | 93   | 72   | 96   | 97   | 91   | 80   | 83   | 67   | 82   |
| 40               | 0                             | 0                | 66               | 106  | 115  | 94   | 115  | 122  | 106  | 87   | 93   | 94   | 100  |
| 40               | 40                            | 0                | 77               | 121  | 140  | 114  | 144  | 160  | 142  | 120  | 126  | 113  | 126  |
| 40               | 40                            | 40               | 73               | 125  | 132  | 110  | 142  | 155  | 137  | 118  | 131  | 114  | 124  |
| 80               | 0                             | 0                | 73               | 117  | 132  | 102  | 120  | 133  | 120  | 104  | 103  | 109  | 111  |
| 80               | 40                            | 0                | 86               | 140  | 163  | 136  | 151  | 173  | 154  | 123  | 144  | 145  | 141  |
| 80               | 40                            | 40               | 84               | 138  | 161  | 133  | 164  | 178  | 160  | 129  | 140  | 139  | 143  |
| 120              | 0                             | 0                | 70               | 116  | 130  | 100  | 116  | 127  | 108  | 93   | 91   | 102  | 105  |
| 120              | 40                            | 0                | 88               | 145  | 172  | 137  | 162  | 177  | 164  | 121  | 128  | 139  | 143  |
| 120              | 40                            | 40               | 90               | 147  | 175  | 142  | 170  | 178  | 170  | 131  | 143  | 150  | 150  |
| 160              | 0                             | 0                | 74               | 124  | 149  | 117  | 139  | 150  | 135  | 120  | 107  | 129  | 124  |
| 160              | 40                            | 0                | 92               | 152  | 178  | 146  | 171  | 181  | 173  | 137  | 134  | 153  | 152  |
| 160              | 40                            | 40               | 88               | 151  | 174  | 143  | 176  | 179  | 161  | 131  | 139  | 142  | 148  |
| 200              | 0                             | 0                | 78               | 128  | 147  | 119  | 139  | 155  | 151  | 123  | 121  | 134  | 130  |
| 200              | 40                            | 0                | 84               | 141  | 171  | 136  | 165  | 177  | 167  | 131  | 134  | 140  | 145  |
| 200              | 40                            | 40               | 87               | 152  | 175  | 138  | 170  | 179  | 170  | 131  | 130  | 149  | 148  |

*continued*

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

| Fertilizer                                            |                               |                  | Yield            |        |        |        |        |       |       |        |        |       |       |
|-------------------------------------------------------|-------------------------------|------------------|------------------|--------|--------|--------|--------|-------|-------|--------|--------|-------|-------|
| N                                                     | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | 2010             | 2011   | 2012   | 2013   | 2014   | 2015  | 2016  | 2017   | 2018   | 2019  | Mean  |
| ----- lb/a -----                                      |                               |                  | ----- bu/a ----- |        |        |        |        |       |       |        |        |       |       |
| ANOVA (P>F)                                           |                               |                  |                  |        |        |        |        |       |       |        |        |       |       |
| Nitrogen                                              |                               |                  | 0.001            | 0.001  | 0.001  | 0.001  | 0.001  | 0.001 | 0.001 | 0.001  | 0.001  | 0.001 | 0.001 |
| Linear                                                |                               |                  | 0.001            | 0.001  | 0.001  | 0.001  | 0.001  | 0.001 | 0.001 | 0.001  | 0.001  | 0.001 | 0.001 |
| Quadratic                                             |                               |                  | 0.001            | 0.001  | 0.001  | 0.001  | 0.001  | 0.001 | 0.001 | 0.001  | 0.001  | 0.001 | 0.001 |
| P-K                                                   |                               |                  | 0.001            | 0.001  | 0.001  | 0.001  | 0.001  | 0.001 | 0.001 | 0.001  | 0.001  | 0.001 | 0.001 |
| Zero P vs. P                                          |                               |                  | 0.001            | 0.001  | 0.001  | 0.001  | 0.001  | 0.001 | 0.001 | 0.001  | 0.001  | 0.001 | 0.001 |
| P vs. P-K                                             |                               |                  | 0.892            | 0.278  | 0.826  | 0.644  | 0.117  | 0.806 | 0.943 | 0.727  | 0.549  | 0.789 | 0.726 |
| N × P-K                                               |                               |                  | 0.229            | 0.542  | 0.186  | 0.079  | 0.012  | 0.002 | 0.001 | 0.084  | 0.003  | 0.001 | 0.001 |
| MEANS                                                 |                               |                  |                  |        |        |        |        |       |       |        |        |       |       |
| Nitrogen, lb/a                                        |                               |                  |                  |        |        |        |        |       |       |        |        |       |       |
| 0                                                     |                               |                  | 52 c             | 82 d   | 87 d   | 70 d   | 94 e   | 96 d  | 87 d  | 76 d   | 82 c   | 70 d  | 80 d  |
| 40                                                    |                               |                  | 72 b             | 117 c  | 129 c  | 106 c  | 134 d  | 146 c | 129 c | 108 c  | 117 b  | 107 c | 116 c |
| 80                                                    |                               |                  | 81 a             | 132 b  | 152 b  | 124 b  | 145 c  | 161 b | 145 b | 119 b  | 129 a  | 131 b | 132 b |
| 120                                                   |                               |                  | 82 a             | 136 ab | 159 ab | 126 b  | 149 bc | 161 b | 147 b | 115 bc | 121 ab | 130 b | 133 b |
| 160                                                   |                               |                  | 84 a             | 142 a  | 167 a  | 135 a  | 162 a  | 170 a | 156 a | 129 a  | 127 a  | 142 a | 142 a |
| 200                                                   |                               |                  | 83 a             | 141 a  | 165 a  | 131 ab | 158 ab | 170 a | 163 a | 129 a  | 128 a  | 141 a | 141 a |
| LSD <sub>(0.05)</sub>                                 |                               |                  | 5                | 8      | 9      | 8      | 9      | 8     | 8     | 9      | 9      | 7     | 6     |
| P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O, lb/a |                               |                  |                  |        |        |        |        |       |       |        |        |       |       |
| 0 - 0                                                 |                               |                  | 68 b             | 111 b  | 125 b  | 99 b   | 120 b  | 129 b | 117 b | 99 b   | 99 b   | 106 b | 107 b |
| 40 - 0                                                |                               |                  | 80 a             | 130 a  | 152 a  | 124 a  | 148 a  | 162 a | 149 a | 119 a  | 126 a  | 127 a | 132 a |
| 40 - 40                                               |                               |                  | 79 a             | 133 a  | 152 a  | 123 a  | 153 a  | 161 a | 148 a | 120 a  | 128 a  | 127 a | 132 a |
| LSD <sub>(0.05)</sub>                                 |                               |                  | 4                | 6      | 6      | 5      | 6      | 5     | 6     | 6      | 6      | 5     | 4     |

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

LSD = least significant difference.

ANOVA = analysis of variance.

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

| Fertilizer       |                               |                  | Grain         |       |       |                   |       |       | Grain Removal    |    |    |                    |                    |                    |
|------------------|-------------------------------|------------------|---------------|-------|-------|-------------------|-------|-------|------------------|----|----|--------------------|--------------------|--------------------|
| N                | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | N             | P     | K     | N                 | P     | K     | N                | P  | K  | *AFNR <sub>g</sub> | *AFPR <sub>g</sub> | *AFKR <sub>g</sub> |
| ----- lb/a ----- |                               |                  | ----- % ----- |       |       | ----- lb/bu ----- |       |       | ----- lb/a ----- |    |    | ----- % -----      |                    |                    |
| 0                | 0                             | 0                | 1.04          | 0.251 | 0.354 | 0.51              | 0.123 | 0.173 | 37               | 9  | 13 | ---                | ---                | ---                |
| 0                | 40                            | 0                | 1.03          | 0.313 | 0.380 | 0.51              | 0.153 | 0.186 | 41               | 13 | 15 | ---                | 21                 | ---                |
| 0                | 40                            | 40               | 1.03          | 0.311 | 0.380 | 0.50              | 0.152 | 0.186 | 41               | 12 | 15 | ---                | 20                 | 7                  |
| 40               | 0                             | 0                | 1.15          | 0.227 | 0.341 | 0.56              | 0.111 | 0.167 | 55               | 11 | 17 | 45                 | ---                | ---                |
| 40               | 40                            | 0                | 1.11          | 0.315 | 0.368 | 0.54              | 0.155 | 0.180 | 68               | 19 | 23 | 76                 | 60                 | ---                |
| 40               | 40                            | 40               | 1.11          | 0.309 | 0.364 | 0.54              | 0.152 | 0.178 | 67               | 19 | 22 | 73                 | 56                 | 28                 |
| 80               | 0                             | 0                | 1.35          | 0.212 | 0.337 | 0.66              | 0.104 | 0.165 | 73               | 12 | 18 | 44                 | ---                | ---                |
| 80               | 40                            | 0                | 1.21          | 0.293 | 0.352 | 0.60              | 0.144 | 0.173 | 83               | 20 | 24 | 57                 | 64                 | ---                |
| 80               | 40                            | 40               | 1.19          | 0.305 | 0.356 | 0.58              | 0.149 | 0.174 | 83               | 21 | 25 | 56                 | 70                 | 37                 |
| 120              | 0                             | 0                | 1.41          | 0.196 | 0.334 | 0.69              | 0.096 | 0.164 | 72               | 10 | 17 | 29                 | ---                | ---                |
| 120              | 40                            | 0                | 1.31          | 0.279 | 0.350 | 0.64              | 0.137 | 0.172 | 91               | 19 | 25 | 45                 | 60                 | ---                |
| 120              | 40                            | 40               | 1.32          | 0.300 | 0.354 | 0.65              | 0.147 | 0.173 | 96               | 22 | 26 | 49                 | 74                 | 39                 |
| 160              | 0                             | 0                | 1.40          | 0.224 | 0.342 | 0.69              | 0.110 | 0.167 | 85               | 14 | 21 | 30                 | ---                | ---                |
| 160              | 40                            | 0                | 1.39          | 0.301 | 0.354 | 0.68              | 0.148 | 0.173 | 103              | 22 | 26 | 41                 | 76                 | ---                |
| 160              | 40                            | 40               | 1.36          | 0.276 | 0.349 | 0.67              | 0.135 | 0.171 | 98               | 20 | 25 | 38                 | 63                 | 38                 |
| 200              | 0                             | 0                | 1.41          | 0.230 | 0.346 | 0.69              | 0.113 | 0.169 | 89               | 15 | 22 | 26                 | ---                | ---                |
| 200              | 40                            | 0                | 1.39          | 0.280 | 0.355 | 0.68              | 0.137 | 0.174 | 98               | 20 | 25 | 30                 | 62                 | ---                |
| 200              | 40                            | 40               | 1.39          | 0.284 | 0.352 | 0.68              | 0.139 | 0.173 | 100              | 20 | 26 | 31                 | 65                 | 38                 |

*continued*

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

| Fertilizer                                            |                               |                  | Grain         |         |         |                   |         |         | Grain Removal    |        |       |                    |                    |                    |
|-------------------------------------------------------|-------------------------------|------------------|---------------|---------|---------|-------------------|---------|---------|------------------|--------|-------|--------------------|--------------------|--------------------|
| N                                                     | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | N             | P       | K       | N                 | P       | K       | N                | P      | K     | *AFNR <sub>g</sub> | *AFPR <sub>g</sub> | *AFKR <sub>g</sub> |
| ----- lb/a -----                                      |                               |                  | ----- % ----- |         |         | ----- lb/bu ----- |         |         | ----- lb/a ----- |        |       | ----- % -----      |                    |                    |
| ANOVA (P>F)                                           |                               |                  |               |         |         |                   |         |         |                  |        |       |                    |                    |                    |
| Nitrogen                                              |                               |                  | 0.001         | 0.001   | 0.001   | 0.001             | 0.001   | 0.001   | 0.001            | 0.001  | 0.001 | 0.001              | 0.001              | 0.001              |
| Linear                                                |                               |                  | 0.001         | 0.001   | 0.001   | 0.001             | 0.001   | 0.001   | 0.001            | 0.001  | 0.001 | 0.001              | 0.001              | 0.001              |
| Quadratic                                             |                               |                  | 0.001         | 0.007   | 0.001   | 0.001             | 0.007   | 0.001   | 0.001            | 0.001  | 0.001 | 0.050              | 0.001              | 0.001              |
| P-K                                                   |                               |                  | 0.001         | 0.001   | 0.001   | 0.001             | 0.001   | 0.001   | 0.001            | 0.001  | 0.001 | 0.001              | 0.736              | ---                |
| Zero P vs. P                                          |                               |                  | 0.001         | 0.001   | 0.001   | 0.001             | 0.001   | 0.001   | 0.001            | 0.001  | 0.001 | ---                | ---                | ---                |
| P vs. P-K                                             |                               |                  | 0.589         | 0.876   | 0.758   | 0.589             | 0.876   | 0.758   | 0.985            | 0.779  | 0.823 | ---                | ---                | ---                |
| N × P-K                                               |                               |                  | 0.060         | 0.013   | 0.082   | 0.060             | 0.013   | 0.082   | 0.120            | 0.001  | 0.001 | 0.045              | 0.041              | ---                |
| MEANS                                                 |                               |                  |               |         |         |                   |         |         |                  |        |       |                    |                    |                    |
| Nitrogen, lb/a                                        |                               |                  |               |         |         |                   |         |         |                  |        |       |                    |                    |                    |
| 0                                                     |                               |                  | 1.03 e        | 0.292 a | 0.371 a | 0.51 e            | 0.143 a | 0.182 a | 40 e             | 11 d   | 15 d  | ---                | 21 c               | 7 c                |
| 40                                                    |                               |                  | 1.12 d        | 0.284 a | 0.358 b | 0.55 d            | 0.139 a | 0.175 b | 63 d             | 16 c   | 21 c  | 65 a               | 58 b               | 28 b               |
| 80                                                    |                               |                  | 1.25 c        | 0.270 b | 0.348 c | 0.61 c            | 0.132 b | 0.171 c | 80 c             | 18 abc | 23 b  | 53 b               | 67 a               | 37 a               |
| 120                                                   |                               |                  | 1.35 b        | 0.258 b | 0.346 c | 0.66 b            | 0.127 b | 0.169 c | 86 b             | 17 bc  | 23 b  | 41 c               | 67 a               | 39 a               |
| 160                                                   |                               |                  | 1.38 ab       | 0.267 b | 0.348 c | 0.68 ab           | 0.131 b | 0.171 c | 95 a             | 19 a   | 24 a  | 36 c               | 69 a               | 38 a               |
| 200                                                   |                               |                  | 1.40 a        | 0.264 b | 0.351 c | 0.68 a            | 0.130 b | 0.172 c | 96 a             | 18 ab  | 24 a  | 29 d               | 64 ab              | 38 a               |
| LSD <sub>(0.05)</sub>                                 |                               |                  | 0.04          | 0.013   | 0.006   | 0.02              | 0.006   | 0.003   | 5                | 1      | 1     | 6                  | 8                  | 5                  |
| P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O, lb/a |                               |                  |               |         |         |                   |         |         |                  |        |       |                    |                    |                    |
| 0 - 0                                                 |                               |                  | 1.29 a        | 0.223 b | 0.342 b | 0.63 a            | 0.109 b | 0.168 b | 69 b             | 12 b   | 18 b  | 35 b               | ---                | ---                |
| 40 - 0                                                |                               |                  | 1.24 b        | 0.297 a | 0.360 a | 0.61 b            | 0.145 a | 0.176 a | 81 a             | 19 a   | 23 a  | 50 a               | 57                 | ---                |
| 40 - 40                                               |                               |                  | 1.23 b        | 0.298 a | 0.359 a | 0.60 b            | 0.146 a | 0.176 a | 81 a             | 19 a   | 23 a  | 49 a               | 58                 | ---                |
| LSD <sub>(0.05)</sub>                                 |                               |                  | 0.03          | 0.009   | 0.004   | 0.01              | 0.004   | 0.002   | 3                | 1      | 1     | 5                  | 5                  | ---                |

\*AFNR<sub>g</sub> = Apparent fertilizer N recovery (grain).AFPR<sub>g</sub> = Apparent fertilizer P recovery (grain).AFKR<sub>g</sub> = Apparent fertilizer K recovery (grain).

LSD = least significant difference.

ANOVA = analysis of variance.