LIMITED IRRIGATION OF GRAIN SORGHUM

Alan J. Schlegel
Research Agronomist
Kansas State University
Southwest Research-Extension Center
Tribune, Kansas
Phone: 620-376-4761
Email: schlegel@ksu.edu

Freddie R. Lamm
Research Irrigation Engineer
Kansas State University
Northwest Research-Extension Center
Colby, Kansas
Phone: 785-462-6281
Email: flamm@ksu.edu

Isaya Kisekka
Assistant Professor/Irrigation Engineer
University of California Davis
Depts. of Biological and Agricultural Engineering/LAWR
Davis, California
Phone: 530-379-9549
Email: ikisekka@ucdavis.edu

ABSTRACT

Grain sorghum yield under full and limited irrigation was evaluated at three locations in western Kansas (Colby, Tribune, and Garden City). The top-end yield under full irrigation was about 190 bu/ac measured at Tribune in 2015 and Colby in 2017. In 2015, there were no significant differences among irrigation treatments at any of the three locations due to the above normal rainfall. In 2016, the fully irrigated treatment (100% ET) was not significantly different from deficit irrigated treatments at Tribune and Colby. However, dryland yields were lower than irrigated grain sorghum yields at Colby and most irrigated treatments at Garden City. In 2017, there were no significant differences in yields among any treatment at any location. These results also indicate that there is potential to improve grain sorghum yields and that management that constrains irrigation to replenish only 50% ET prior to boot can enhance water productivity. There were no substantial differences in yield between irrigation management limited to 6 and 10 inches of water per season in a normal to wet years, which makes grain sorghum a suitable crop choice for limited irrigation.

INTRODUCTION

Grain sorghum is one of the major irrigated crops in Kansas. Irrigators are faced with the problem of declining well capacities due to water withdrawals from the Ogallala aquifer for irrigation exceeding mean annual recharge. In addition to limited well capacities, public policy may also impose limits on total amounts of water that can be pumped. For examples, a Local Enhanced Management Area (LEMA) policy in a portion of Groundwater Management District (GMD) 4 with a 20% reduction in pumped water and several Water Conservation Areas (WCAs) that have been implemented in GMD 3. The drought tolerance attributes of grain sorghum make it a good choice for limited irrigation. However, grain sorghum irrigated area lags those of other irrigated crops in Kansas mainly corn and soybean. One of the major challenges facing irrigated grain sorghum producers in Kansas is how to increase yields under declining well capacities or limited water supplies.

To develop limited irrigation management strategies for grain sorghum, we evaluated yield response under well-watered conditions as well as under very limited water supplies. The purpose of the study was to 1) determine the top-end grain sorghum yield potential under well-watered conditions (100%ET) at three locations in western Kansas (Colby, Garden City, and Tribune) and 2) the effect of growth stage based irrigation timing on grain sorghum yields, water productivity and yield components with water supplies limited to 6 or 10 inches total.

MATERIALS AND METHODS

The study was conducted at three locations in western Kansas including; 1) the Kansas State University, Southwest Research-Extension Center (SWREC) near Garden City, 2) SWREC, near Tribune and 3) the Northwest Research-Extension Center (NWREC), near Colby. The soil type at Tribune and Garden City is Ulysses silt loam while that at Colby is a Keith silt loam. The climate at the three locations is semi-arid with mean annual rainfall of 17, 18, and 19 inches for Tribune, Garden City, and Colby respectively. Cumulative rainfall and reference evapotranspiration during the 2015 - 2017 growing seasons at each location are shown in Figures 1-3. The experimental design was a randomized complete block design with four replications at each location.

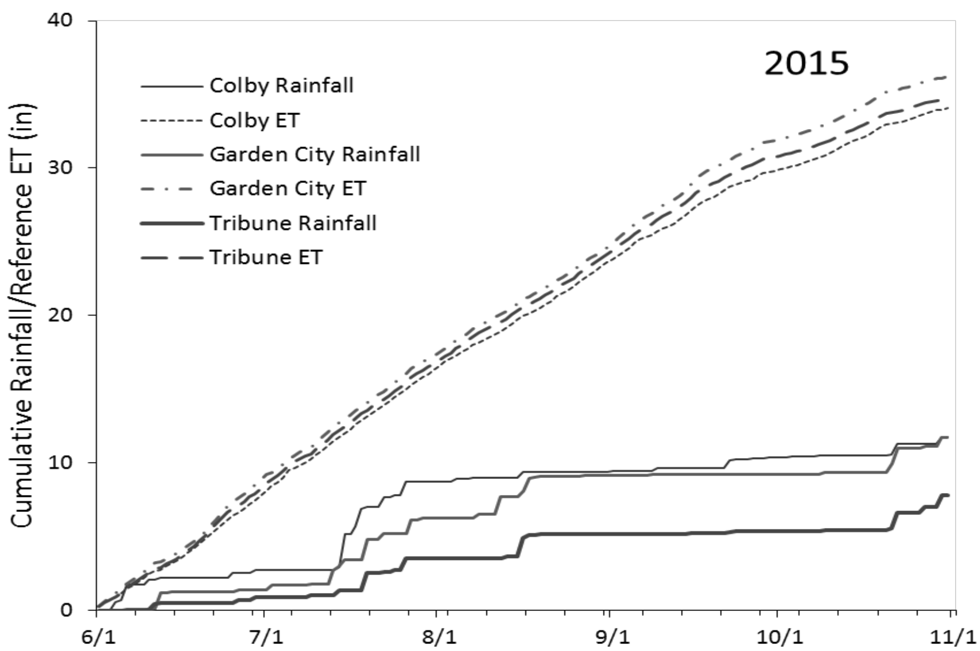

Figure 1. Cumulative rainfall and reference evapotranspiration (grass based reference ET from KSU Mesonet stations) at Colby, Garden City and Tribune, Kansas during the 2015 grain sorghum growing season. Reference ET is shown to indicate evaporative demand, but actual crop ET would be less than reference ET.

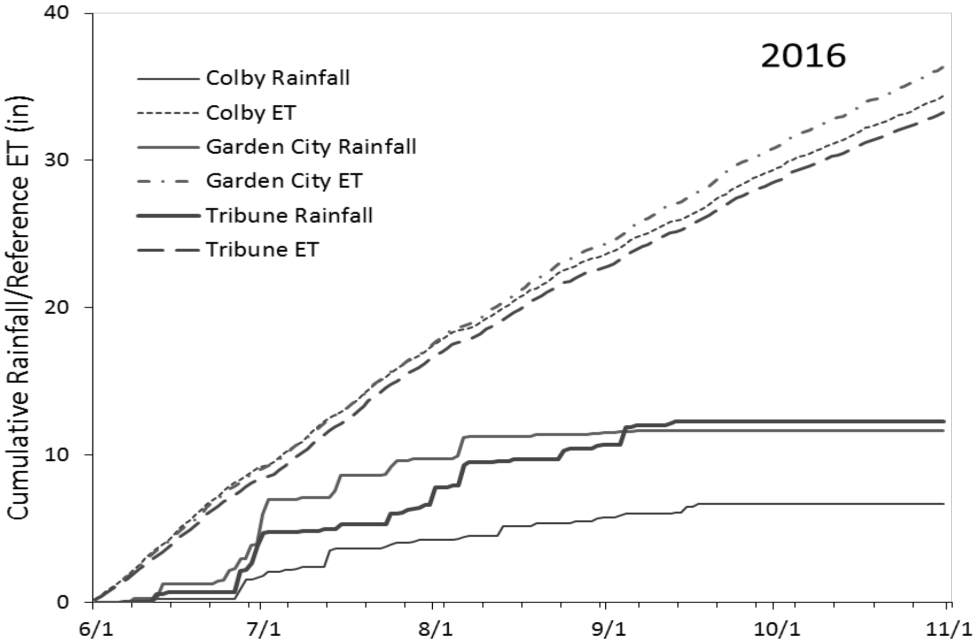

Figure 2. Cumulative rainfall and reference evapotranspiration (grass based reference ET from KSU Mesonet stations) at Colby, Garden City and Tribune, Kansas during the 2016 grain sorghum growing season. Reference ET is shown to indicate evaporative demand, but actual crop ET would be less than reference ET.

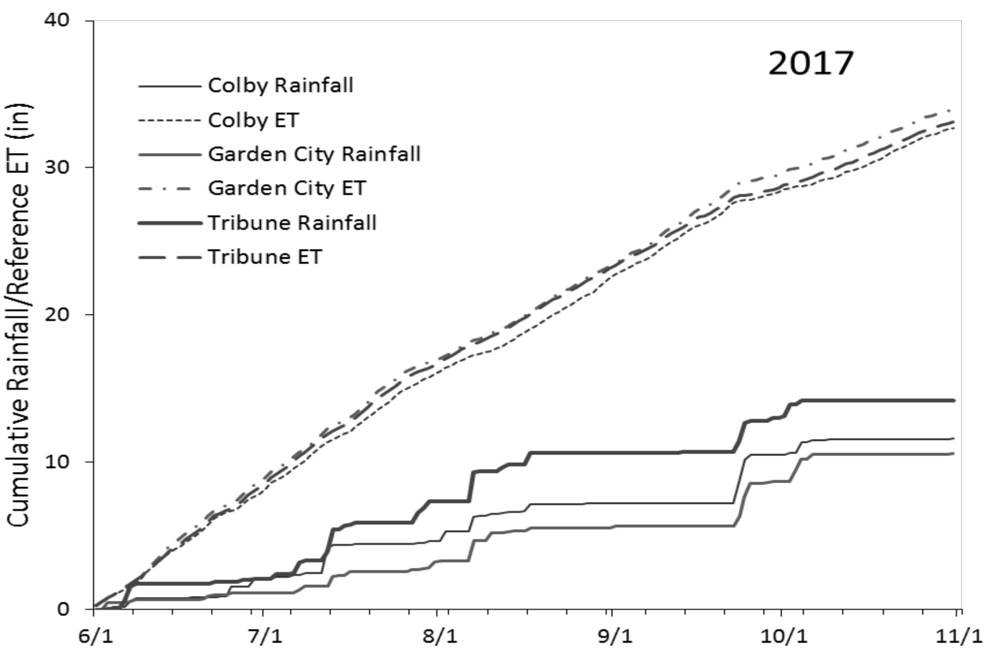

Figure 3. Cumulative rainfall and reference evapotranspiration (grass based reference ET from KSU Mesonet stations) at Colby, Garden City and Tribune, Kansas during the 2017 grain sorghum growing season. Reference ET is shown to indicate evaporative demand, but actual crop ET would be less than reference ET.

Irrigation management

At each of the three locations, the study was conducted under a lateral move sprinkler irrigation system modified to apply irrigation water in any desired treatment combination. The irrigation treatments included the following:

1. Full irrigation 100%ET
2. 50% ET prior to booting of grain sorghum and 100% ET after boot and total irrigation limited to 10 inches
3. 100% ET limited to 10 inches
4. 50% ET prior to booting of grain sorghum and 100% ET after boot and total irrigation limited to 6 inches
5. 100% ET limited to 6 inches
6. Dryland (only for Garden City and Colby sites)

All irrigation was scheduled with a weather-based water budget where calculated crop evapotranspiration (ETc) was a debit and irrigation and rainfall were deposits. The treatments were designed to replace specified fractions of ETc minus precipitation subject to any other specified timing limitation. As a case study, two limitations on total irrigation, 6 and 10 inches (Treatments 2-5) were compared to full irrigation. The fully irrigated treatment was managed as a non-water limiting crop with 100% ET minus rainfall replenishment. Soil water in the 0-8 ft soil profile was measured as a check for adequacy of the ET-based irrigation scheduling and for determination of crop water use. Soil water measurements were made using neutron scattering technique (neutron probe). Weather data was measured using automated weather stations that exist on all sites and phenological and growth stages data were recorded throughout the growing season. Grain yield was determined by harvesting a representative sample at physiological maturity. Determinations were made of all yield components; (grain yield, plant density, heads/plant, kernels/head, and kernel mass) as well as the important intermediate yield component, kernels/area.

Crop water use was calculated by summing soil water depletion (soil water at planting less soil water at harvest) plus in-season irrigation and precipitation. Crop water productivity (CWP) was calculated by dividing grain yield (lb a^{-1}) by crop water use (in).

The hybrid used at all the three locations was Pioneer 84G62 because it is full season and well adapted under both irrigated and dryland environments. Grain sorghum was planted at seeding rate of 100,000 seeds per acre on June 04, 2015, June 04, 2015 and June 02, 2015 at Tribune, Garden City, and Colby respectively. In 2016, grain sorghum was planted on June 01, 2016, May 24, 2016, and May 25 at Tribune, Garden City, and Colby, respectively. In 2017, grain sorghum was planted on June 2, May 23, May 31 at Tribune, Garden City, and Colby, respectively. Best management practices for fertilizer and weed control for high yielding grain sorghum were followed. For example, at planting 10:34:0 was applied at a rate of 10 gal/ac and at least 160 lb N/a was applied. Some of the herbicides used for weed control included Atrazine 4L (32 oz/ac), Lumax EZ (80 oz/ac), Sharpen (2 oz/ac), and Huskie (13 oz/ac). Grain sorghum was harvested on November 12, 2015, October 20, 2015 and October 20, 2015 at Tribune, Garden City and Colby respectively. In 2016 grain sorghum was harvested on October 19, October 13, and October 6 at Tribune, Garden City, and Colby respectively. In 2017, grain sorghum was harvested on Nov. 1, Oct. 30, and Oct. 25 at Tribune, Garden City, and Colby, respectively. In 2015, at Tribune the previous crop was fallow (2014), at Garden City the previous crop was corn (2014) at Colby the previous crop was sunflower

(2014). In 2016, at Tribune the previous crop was grain sorghum, at Garden City the previous crop was corn and at Colby the previous crop was sunflower. In 2017, the previous crop was grain sorghum at Tribune, canola at Garden City, and sorghum at Colby.

RESULTS AND DISCUSSION

Grain sorghum yield and yield components

There were no significant differences in grain yield between irrigation treatments at Colby, Garden City and Tribune for the 2015 grain sorghum growing season (Tables 1 to 3). This is probably due to the above normal rainfall received during the 2015 grain sorghum growing season (Figure 1). In 2015, it was shown that the top-end yield potential could exceed 190 bu/ac (Table 3). The grain yield results are within range of K-State variety trials data that have shown grain sorghum to have a potential yield of higher than 200 bu/ac. The highest grain sorghum yields were recorded at Tribune, followed by Garden City and Colby. Kernels per head, which greatly influences yield, was highest at Tribune. There were more heads per acre at Garden City and Colby compared to Tribune, but Tribune had higher yields implying the effect of kernel number per head, which was highest at Tribune, might exert a strong influence on grain yield compared to heads per acre. Kernel weight was similar between the three locations in 2015.

In 2016, yields were significantly different among treatments at Colby (Table 4) and Garden City (Table 5) but not significantly different across all irrigation treatments at Tribune (Table 6). Averaged across treatments, grain yields were 18.4%, higher in Colby in 2016 compared to 2015. Averaged across treatments, grain yields were 5.3% and 17.9% lower in Garden City and Tribune in 2016 compared to 2015. The differences could be attributed to seasonal variations in weather such as rainfall amount and distribution, environment and management. It is worth noting that the fully irrigated treatment (100% ET) was not significantly different from deficit irrigated treatments in both years at the three locations. In addition, there were no substantial differences in yield between irrigation management limited to 6 and 10 inches of water per season and between growth-stage based irrigation treatments. Dryland treatments resulted in a yield reduction of more than 25 bu/ac at Colby in 2016, which was drier than normal. At Colby in 2016, all irrigated treatments produced significantly higher yield than the dryland treatment (p-value= 0.003). At Garden City the dryland treatment resulted in yield reduction up to 21 bu/acre. Grain sorghum appears to be a suitable crop for limited irrigation with very little water needed to obtain maximum yield in a normal to wet year like 2015 and 2016.

In 2017, there were no significant differences in irrigated yields at Colby (Table 7), Garden City (Table 8), and Tribune (Table 9), although dryland yields were always less than irrigated yields. Averaged across 3 years (2015-2017) there were no significant yield differences among irrigation treatments at Colby (Table 10), Garden City (Table 11) or Tribune (Table 12). However, the dryland treatment was the lowest yielding at both Colby and Garden City. Averaged across the 3 years, kernel mass was less with the dryland treatment compared to all irrigated treatments at Colby but not at Garden City. There were no differences in average kernel mass within irrigated treatments at any location. No other yield component (head population or kernels/head) was significantly changed by irrigation at any site when averaged across years.

Crop yield response to water

Analysis of the measured crop water use data generally indicated that growth-stage based irrigation management reduced crop water use as compared to the fully irrigated treatment (100% ET) in most years and at most locations. When averaged across all the years, growth-stage based irrigation resulted in statistically significant reductions in crop water use compared to full irrigation at all three locations).

The effect of irrigation was significant for water use efficiency but was inconsistent among locations. At Garden City, average WUE was greatest with the dryland treatment with no statistical differences among treatments receiving irrigation. At Colby, average WUE was similar for 3 treatments (dryland, 50/100% ET to 6”, and 50/100% ET to 10”) with all being greater than the 100% ET (whether limited to 6, 10, or unlimited). This suggests that at this site WUE can be increased by growth-stage based irrigation. A similar trend was observed at Tribune with greater average WUE with the growth-stage based irrigation.

These results indicate no substantial difference in yield for irrigation application amounts between 6 and 10 inches and between growth-stage based irrigation treatments. This implies that in a normal year producers might only need to allocate 6 inches of irrigation to obtain maximum yield. However, in a drought year using ET-based irrigation scheduling with reductions in irrigation prior to the boot stage, irrigation might increase to an amount less than 8 to10 inches under soil conditions and climatic environment of western Kansas.

CONCLUSIONS

Grain sorghum yield under full and limited irrigation was evaluated at three locations in western Kansas (Colby, Tribune, and Garden City). The top-end yield under full irrigation was about 190 bu/ac measured at Tribune in 2015 and Colby in 2017. However, there were no significant differences among irrigation treatments at all the three locations due to the above normal rainfall received during the 2015. In 2016, the fully irrigated treatment (100% ET) was not significantly different from deficit irrigated treatments (treatments 2 to 5) at Tribune and Colby. However, dryland yields were lower than irrigated grain sorghum yields at Colby and less than most irrigated treatments at Garden City. In 2017, there were no significant differences in grain yield among irrigation treatments and this was also the case when averaged across 2015-2017. These results indicate that there is potential to improve grain sorghum yields and that management that constrains irrigation to replenish only 50% ET prior to boot can enhance water use efficiency. There were no substantial differences in yield between irrigation management limited to 6 and 10 inches of water per season in a normal to wet years, which makes grain sorghum a suitable crop choice for limited irrigation. Since irrigated grain sorghum has lower input costs than corn and is very tolerant of water stress, this makes it an ideal crop for lower capacity irrigation systems or where irrigation is constrained by governmental limits.

ACKNOWLEDGEMENTS

This research was supported in part by the Kansas Grain Sorghum Commission.

Table 1. Crop parameters as affected by irrigation timing and amount at Colby, KS, 2015.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	130	25.59 a	284 a	92	18282	1482	3043	2.1
50/100%ET[2] to 10”	157	24.13 b	363 b	88	16868	1690	3388	2.0
100%ET to 10”	145	25.91 a	312 ab	95	16709	1426	3112	2.2
50/100%ET to 6”	150	23.28 b	360 b	91	16129	1505	3102	2.1
100%ET to 6”	126	24.00 b	295 a	85	16911	1434	2746	1.9
Dryland	149	20.76 c	402 ab	91	17174	1603	3291	2.1
ANOVA (P>F) Trt.	0.221	0.001	0.008	0.788	0.127	0.836	0.398	0.788

In-season rainfall (6/03 - 10/05) was 8.12”.

In-season irrigation (6/10 - 9/21) was 1 = 10.56"; 2 = 7.68"; 3 = 9.60"; 4 = 5.76"; 5 = 5.76", 6 = 0.00".

Table 2. Crop parameters as affected by irrigation timing and amount at Garden City, KS, 2015.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	157	20.7 a	426	90	17971	1826	3835	2.1
50/100%ET[2] to 10”	157	20.1 b	436	91	16676	1640	3445	2.1
100%ET to 10”	150	20.9 a	403	88	16434	1541	3236	2.1
50/100%ET to 6”	160	19.5 ab	461	89	16393	1623	3373	2.1
100%ET to 6”	149	18.6 b	444	86	16505	1579	3156	2.0
Dryland	145	16.7 c	490	88	18120	1661	3321	2.0
ANOVA (P>F) Trt.	0.590	0.001	0.095	0.997	0.492	0.844	0.756	0.997

In-season rainfall (6/22 - 10/13) was 8.95”.

In-season irrigation (7/13 – 9/18) was 1 = 7.0"; 2 = 6.0"; 3 = 6.0"; 4 = 6.0"; 5 = 6.0", 6 = 1.0". Plus 1.75” preplant irrigation.

Table 3. Crop parameters as affected by irrigation timing and amount at Tribune, KS, 2015.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	190	25.19 a	422 b	69	16119	2497	3931	1.6
50/100%ET[2] to 10”	181	22.54 b	447 ab	72	16691	2346	3847	1.7
100%ET to 10”	186	24.78 a	419 b	71	15937	2352	3800	1.6
50/100%ET to 6”	185	21.53 b	479 a	67	16198	2508	3832	1.5
100%ET to 6”	182	21.31 b	478 a	70	16341	2383	3803	1.6
ANOVA (P>F) Trt.	0.738	0.002	0.046	0.918	0.417	0.766	0.945	0.918

In-season rainfall (6/10 - 11/06) was 9.02”.

In-season irrigation (6/10 - 11/06) was 1 = 11.74"; 2 = 7.30"; 3 = 10.21"; 4 = 5.77"; 5 = 6.02".

[1] WUE = water use efficiency

[2] 50% ET to boot then 100% ET until seasonal limit of 6 or 10 inches is reached

Table 4. Crop parameters as affected by irrigation timing and amount at Colby, KS, 2016.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	176 a	22.0 ab	447 ab	118	14596 a	1214	3295	2.7
50/100%ET[2] to 10”	178 a	20.9 ab	480 ac	121	14899 a	1231	3416	2.8
100%ET to 10”	172 a	22.6 b	426 b	112	14613 a	1261	3233	2.6
50/100%ET to 6”	178 a	20.2 c	496 c	119	15603 b	1311	3573	2.7
100%ET to 6”	176 a	21.5 ab	458 ab	115	14741 a	1264	3332	2.6
Dryland	150 b	17.2 d	490 a	118	16950 c	1209	3266	2.7
ANOVA (P>F) Trt.	0.003	0.001	0.008	0.56	0.001	0.836	0.24	0.56

In-season rainfall (6/03- 10/05) was 7.11”.

In-season irrigation (6-23- 9-09) was 1 = 11.12"; 2 = 7.68"; 3 = 10.16"; 4 = 5.76"; 5 = 6.32", 6 = 0.00".

Table 5. Crop parameters as affected by irrigation timing and amount at Garden City, KS, 2016.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	144 abc	20.7 a	346 ab	69	17089	2006	3158	1.6
50/100%ET[2] to 10”	148 ab	20.1 b	367 ab	74	17102	1923	3254	1.7
100%ET to 10”	156 a	20.9 a	379 a	74	16517	1954	3317	1.7
50/100%ET to 6”	137 b	19.5 ab	338 b	66	16776	1976	2959	1.5
100%ET to 6”	149 ab	18.6 b	355 ab	72	17457	2021	3347	1.7
Dryland	135 c	16.7 c	410 c	71	17993	1932	3100	1.6
ANOVA (P>F) Trt.	0.047	0.001	0.01	0.48	0.40	0.97	0.44	0.997

In-season rainfall (6/23 – 10/11) was 11.64”.

In-season irrigation (7/28 – 9/9) was 1 = 9.0"; 2 = 7.0"; 3 = 9.0"; 4 = 6.0"; 5 = 7.0", 6 = 0.0". Plus 0.75” preplant irrigation

Table 6. Crop parameters as affected by irrigation timing and amount at Tribune, KS, 2016.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	154	24.87 a	347 ab	108	17840	1911	3540	1.8
50/100%ET[2] to 10”	153	22.64 ab	379 b	104	17693	1961	3475	1.8
100%ET to 10”	149	24.93 a	334 a	104	18122	1933	3455	1.8
50/100%ET to 6”	153	22.63 ab	379 b	110	17799	1866	3502	1.9
100%ET to 6”	150	25.58 a	328 a	104	17710	1911	3408	1.8
ANOVA (P>F) Trt.	0.94	0.001	0.03	0.67	0.94	0.94	0.94	0.67

In-season rainfall (6/01/2016 – 10/20/2016) was 12.61”.

In-season irrigation (6/01/2016 – 10/20/2016) was 1 = 9.26"; 2 = 6.10"; 3 = 9.26"; 4 = 6.10"; 5 = 9.26".

[1] WUE = water use efficiency

[2] 50% ET to boot then 100% ET until seasonal limit of 6 or 10 inches is reached

Table 7. Crop parameters as affected by irrigation timing and amount at Colby, KS, 2017.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft²	Heads /ft²
100% ET	191	23.35 ab	459 ab	99	16499	1786	4062	2.3
50/100%ET[2] to 10"	191	21.69 c	493 a	94	16888	1921	4137	2.2
100%ET to 10"	186	24.46 a	427 b	100	16942	1761	4050	2.3
50/100%ET to 6"	187	22.57 bc	466 ab	99	17126	1830	4125	2.3
100%ET to 6"	182	22.43 bc	455 ab	100	17567	1792	4110	2.3
Dryland	175	19.90 d	491 a	95	18025	1879	4037	2.2
ANOVA (P>F) Trt.	0.080	0.001	0.049	0.672	0.109	0.729	0.985	0.672

In-season rainfall (6/09 – 10/24) was 10.82".
In-season irrigation (7/10 – 9/05) was 1 = 9.60"; 2 = 6.72"; 3 = 9.60"; 4 = 5.76"; 5 = 5.76", 6 = 0.00".

Table 8. Crop parameters as affected by irrigation timing and amount at Garden City, KS, 2017.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft²	Heads /ft²
100% ET	159	25.0 a	357 c	80	12576	1407	2579	1.9
50/100%ET[2] to 10"	160	24.1 b	372 c	84	12882	1372	2648	1.9
100%ET to 10"	165	25.0 a	370 c	86	12701	1370	2695	2.0
50/100%ET to 6"	162	21.7 d	419 ab	84	12631	1375	2634	1.9
100%ET to 6"	160	22.7 c	397 bc	82	13025	1423	2689	1.9
Dryland	149	18.5 e	454 a	81	12578	1288	2406	1.9
ANOVA (P>F) Trt.	0.276	0.001	0.001	0.697	0.828	0.726	0.259	0.697

In-season rainfall (6/8 – 10/18) was 11.54".
In-season irrigation (6/26 – 9/22) was 1 = 12.0"; 2 = 9.0"; 3 = 10.0"; 4 = 6.0"; 5 = 6.0", 6 = 0.0". No preplant irrigation

Table 9. Crop parameters as affected by irrigation timing and amount at Tribune, KS, 2017.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft²	Heads /ft²
100% ET	145	25.89 a	313 c	70	20433	2352	3799	1.6
50/100%ET[2] to 10"	151	24.66 b	344 ab	72	20555	2426	3994	1.6
100%ET to 10"	151	25.82 a	327 bc	71	20070	2376	3893	1.6
50/100%ET to 6"	152	23.79 c	358 a	72	19967	2370	3901	1.6
100%ET to 6"	138	24.27 bc	319 bc	70	21209	2347	3763	1.6
ANOVA (P>F) Trt.	0.175	0.001	0.040	0.504	0.367	0.912	0.671	0.504

In-season rainfall (6/06/2017 – 10/31/2017) was 15.13".
In-season irrigation (6/06/2017 – 10/31/2017) was 1 = 9.06"; 2 = 7.64"; 3 = 9.06"; 4 = 6.12"; 5 = 6.00".

[1] WUE = water use efficiency
[2] 50% ET to boot then 100% ET until seasonal limit of 6 or 10 inches is reached

Table 10. Average across years (2015-2017) crop parameters as affected by irrigation timing and amount at Colby, KS.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	166	23.66 a	397 b	103	16459 b	1494	3467	2.4
50/100%ET[2] to 10”	175	22.22 b	445 a	101	16218 b	1614	3647	2.3
100%ET to 10”	167	24.33 a	388 b	103	16088 b	1483	3465	2.4
50/100%ET to 6”	172	22.00 b	441 a	103	16286 b	1549	3600	2.4
100%ET to 6”	161	22.64 b	403 b	100	16406 b	1497	3396	2.3
Dryland	158	19.29 c	461 a	101	17383 a	1564	3532	2.3
ANOVA (P>F) Trt.	0.136	0.001	0.002	0.815	0.002	0.511	0.590	0.815

Table 11. Average across years (2015-2017) crop parameters as affected by irrigation timing and amount at Garden City, KS.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	153	23.23 a	374 b	80	14555	1586	2877	1.8
50/100%ET[2] to 10”	155	22.52 ab	389 b	83	14022	1485	2785	1.9
100%ET to 10”	157	23.23 a	381 b	83	13699	1471	2764	1.9
50/100%ET to 6”	153	21.53 c	404 b	79	13753	1506	2699	1.8
100%ET to 6”	153	21.97 bc	396 b	80	14105	1518	2770	1.8
Dryland	143	18.00 d	450 a	80	14628	1474	2672	1.8
ANOVA (P>F) Trt.	0.288	0.001	0.003	0.675	0.412	0.681	0.776	0.675

Table 12. Average across years (2015-2017) crop parameters as affected by irrigation timing and amount at Tribune, KS.

Treatment	Grain yield, bu/a	Water use (in)	WUE[1], lb/a-in.	Heads, 10^3/a	Seeds /lb	Kernels /head	Kernels /ft^2	Heads /ft^2
100% ET	163	25.33a	361c	73	18131	2253	3757	1.7
50/100%ET[2] to 10”	161	23.29b	389ab	74	18313	2244	3772	1.7
100%ET to 10”	162	25.31a	358c	73	18043	2220	3716	1.7
50/100%ET to 6”	163	22.91b	400a	74	17988	2248	3745	1.7
100%ET to 6”	156	23.84b	372bc	72	18420	2213	3658	1.7
ANOVA (P>F) Trt.	0.470	0.001	0.009	0.967	0.493	0.979	0.782	0.967

[1] WUE = water use efficiency

[2] 50% ET to boot then 100% ET until seasonal limit of 6 or 10 inches is reached