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SPRINKLER IRRIGATION MANAGEMENT OF MODERN CORN HYBRIDS UNDER INSTITUTIONAL CONSTRAINTS

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ABSTRACT

Two pre-anthesis (pre-silking) and two post-anthesis (post-silking) deficit sprinkler irrigation strategies for four corn hybrids where total irrigation was constrained to 11.5 inches against a fully irrigated control were compared in terms of grain yield and yield components, water use, and crop water productivity. This study was in response to a voluntary agreement of producers in a region of northwest Kansas (USA) where they agreed to reduce irrigation water application to 55 inches over a 5-year period. This study attempted to determine the best irrigation strategy for these limited applications. Results indicated full irrigation was still relatively efficient but used 30 to 36% more water. When corn prices are greater, managing at the full irrigation level and reducing irrigated land area may be more profitable. Pre-anthesis water stress was more detrimental to grain yield than similar levels of post-anthesis stress because of reductions in kernels/ear. When water is greatly restricted, a 50% reduction in irrigation post-anthesis might fare reasonably well by relying on stored soil water and precipitation for grain filling. Hybrids responded to irrigation regime similarly with kernels/ear being most affected by irrigation, but the hybrids attained their own maximum yield in different manners. The greatest yielding hybrid had the greatest kernel mass and the smallest kernels/ear while the lowest yielding hybrid had the greatest kernel number but lowest kernel mass. These overall results might not repeat on less productive soils or under harsher environmental conditions.

INTRODUCTION

In the semi-arid Central Great Plains and particularly northwest Kansas, soils are generally productive deep silt loam soils but precipitation is limited and sporadic with mean annual precipitation ranging from 16 to 20 inches across the region, which is only 60-80% of the seasonal water use for corn. Irrigation is often used to mitigate these water stress effects but at the expense of the continued decline of the Ogallala Aquifer.

In 2012, the Kansas legislature passed new water laws that allowed creation of a new water management structure known as a Locally Enhanced Management Area (LEMA). It allows stakeholder groups of various sizes to locally come together and design a management strategy to reduce overdraft of the Ogallala Aquifer in their area subject to approval by the Kansas Division of Water Resources. The first LEMA to be approved known as Sheridan High Priority Area 6 became a reality within Sheridan and Thomas Counties in northwest Kansas in 2013. The stakeholders in a 100 square mile area voluntarily agreed to reduce their average water right to 11 inches/year for the next 5-year period. This area is centered approximately 30 miles east of the KSU Northwest Research-Extension Center at Colby, Kansas. In Kansas, annual rainfall decreases approximately 1 inch for every 18 miles moving east to west and greatest annual rainfall in western Kansas is in the months of May, June, and July, so a similar appropriate restriction at Colby to the Sheridan HPA #6 LEMA might be approximately 12 inches instead of 11 inches. Corn is the major irrigated crop in the region and producers in this LEMA would prefer to continue growing corn due to the availability of good local markets that include two large cattle feeding operations as well as a nearby dairy. The LEMA reduction of water right to 11 inches represents about a 27% reduction in water from the 80% chance Net Irrigation Requirement for Sheridan County (15 inches). The producers within the LEMA have the flexibility to apply their 5-year allocation of water as they so determine, but could benefit from research that determines when water can be restricted without a large corn yield penalty.

ET-based irrigation scheduling has been promoted in the Central Great Plains for many years (Rogers, 1995). As producers move to deficit irrigation strategies, this method of scheduling can still be useful in alerting the producer to soil water conditions and can help the producer decide when to allocate their limited water supply (Lamm and Rogers, 2015). Management Allowable Depletion (MAD) values have been established as a means of helping producers know when to irrigate, but these established values recently have been questioned as too harsh for modern corn production (Lamm and Aboukheira, 2011; 2012).

Sprinkler irrigation does not allow for large amounts of water to be timed to a specific growth stage without incurring runoff, so strategies must be employed that can slowly restrict or slowly increase water available to the crop and to soil water storage for later usage. Preliminary computer simulation indicated that on average, approximately 40% of the seasonal irrigation amount is required prior to anthesis (Figure 1), so an imposed reduction of 50% during the pre-anthesis period might be acceptable most years, yet not be excessive in the drier years. However, this does not fully reflect the ability of the soil profile to be a "bank," so examining a higher irrigation regime is also warranted.

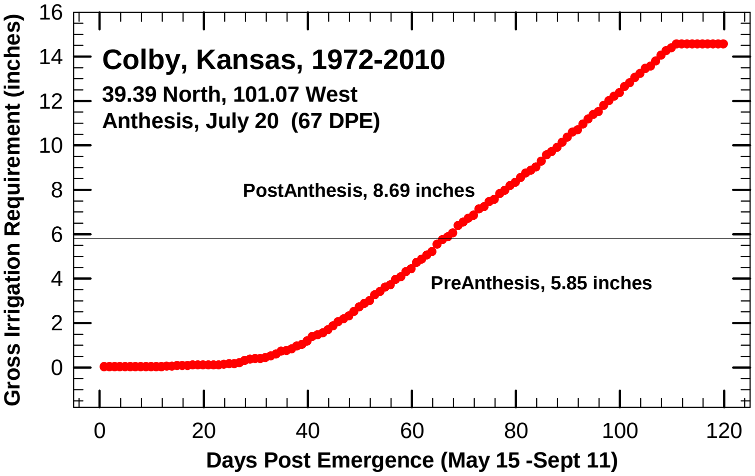

Figure 1. Seasonal gross irrigation requirements for field corn at Colby, Kansas.

A three-year field study was conducted to examine restriction of irrigation to approximately 50 or 75% of the ET-Rain value for either the pre-anthesis period or during the post-anthesis period. Since grain filling (post-anthesis) is important, intuitively, one might surmise that those strategies restricting water during the pre-anthesis stages would always be preferable, but the pre-anthesis period is also when the number of kernels/acre is being potentially set and also the soil water storage allows for "banked" water to be used later by a deep rooted crop such as corn. These deficit strategies were compared to a fully irrigated control treatment.

PROCEDURES

Four different commercial corn hybrids (two specifically marketed as drought tolerant) were compared under five different irrigation regimes in a three-year (2013-2015) field study on a deep silt loam at the KSU Northwest Research-Extension Center at Colby, Kansas.

The irrigation regimes were: 1) Full irrigation (100% ET) with no restriction on total irrigation; 2) Irrigation restricted pre-anthesis to 50% of ET, 100% of ET thereafter with 11.5 inches total restriction; 3) Irrigation restricted pre-anthesis to 75% of ET, 100% of ET thereafter with 11.5 inches total restriction; 4) Irrigation restricted post-anthesis to 50% of ET with 11.5 inches total restriction; and 5) Irrigation restricted post-anthesis to 75% of ET with 11.5 inches total restriction. Irrigation amounts of 1 inch/event were scheduled according to water budget weather-based irrigation scheduling procedures only as needed subject to the specific treatment limitations. As an example, during the pre-anthesis stage Irrigation Trt 3 would only receive 75% ET, but after anthesis would receive irrigation at 100% until such time that the total irrigation is 11.5 inches.

The four corn hybrids were Pioneer brand 35F48, P0876CHR, P1151YXR, and P1498AM1 with the latter two hybrids being marketed as drought tolerant Aquamax hybrids.

Soil water was monitored periodically (approximately 2 to 3 times/month) to a depth of 8 ft. in 1-ft. increments with neutron moderation techniques. This data was used to assess MAD values as well as to determine total water use throughout the season. Corn yield and yield components were determined through hand harvesting a representative sample at physiological maturity. Crop water productivity was calculated as grain yield/crop water use.

The 5 irrigation treatments (whole plot, 6 reps) were in a RCB design with irrigation applied using a lateral move sprinkler and the 4 corn hybrid treatments superimposed as split plots. The data were analyzed using standard PC-SAS procedures.

RESULTS AND DISCUSSION

Weather Conditions and Irrigation Requirements

Overall weather conditions for the three years were favorable for excellent corn production during the study. Calculated crop ET for 2013 through 2015 was slightly lower than long term values and seasonal precipitation was 2 to 3 inches greater than normal in 2014 and 2015 and 2 inches less than normal in 2013 (Figure 2).

Full irrigation amounts varied from 12.48 inches in 2014 to 15.36 inches in 2013 (Figure 3 and Table 1). The irrigation treatments with pre-anthesis water restrictions (Irr 2, 50% ET pre-anthesis and Irr 3, 75% ET pre-anthesis) reached their water limitation (11.5 inches) in two of the three years (2013 and 2015) as did the post-anthesis deficit irrigated treatment that was irrigated with 75% of ET during the post-anthesis period. The irrigation treatment using the least amount of water during the three years of the study was the treatment where irrigation was restricted to 50% of ET during post-anthesis period (Irr 4).

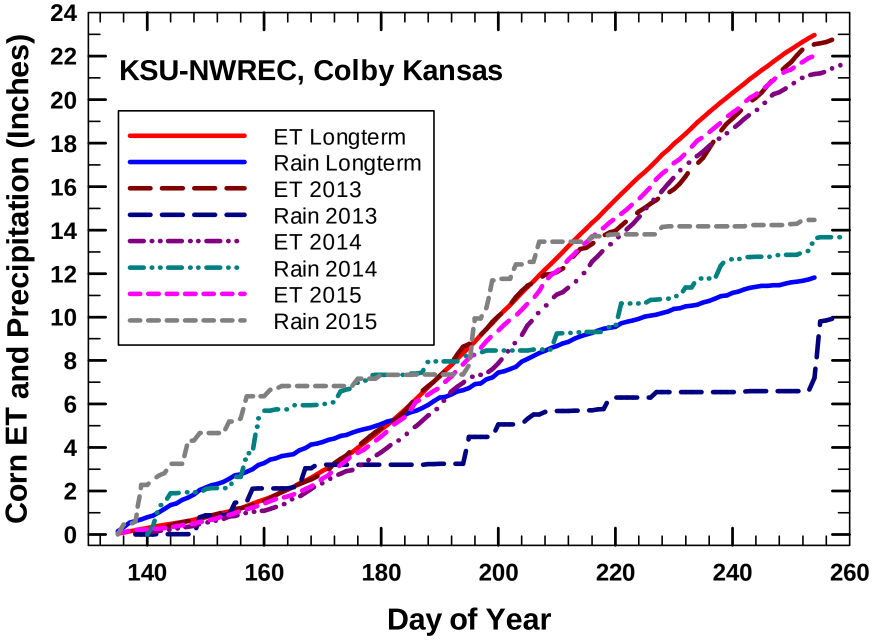

Figure 2. Cumulative calculated crop ET and precipitation during the growing season for Colby, Kansas, 2013 to 2015.

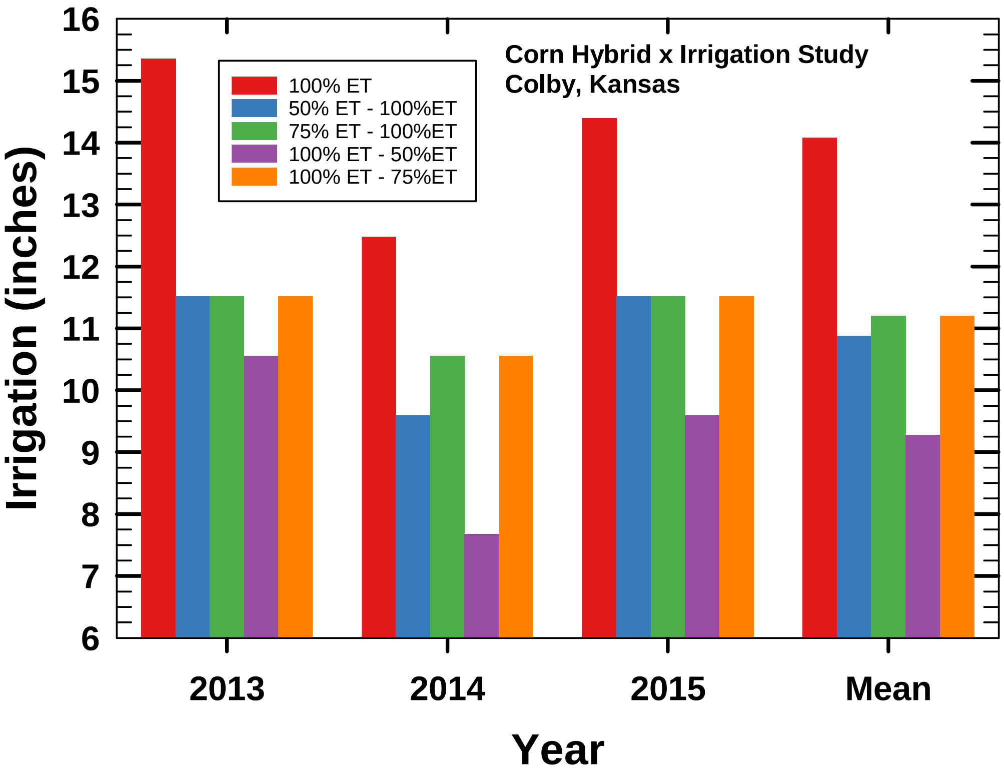

Figure 3. Irrigation amounts for the five irrigated corn treatments during the three years of the study.

Crop Yield and Water Use Parameters

Corn grain yield was greatest in 2014 and was lowest in 2013, the year with the greatest irrigation need (Figure 4 and Table 1). Fully irrigated corn grain yields ranged annually from 241 to 251 bushels/acre with the deficit-irrigated lowest yields ranging from 215 to 237 bushels/acre. Corn yield was greatest for unrestricted irrigation (Irr 1) but required 30 to 36% more irrigation, but was still very efficient with only a 2 to 4% reduction in water productivity (WP) (Figure 4 and 5 and Table 1). Lower yields occurred for pre-anthesis water restrictions (Irr 2 and 3) than for similar post-anthesis restrictions (Irr 4 and 5). These results suggest that obtaining sufficient kernel set was more important than saving irrigation for grain filling in this study. When irrigation is greatly restricted, a 50% reduction post-anthesis appears as a promising alternative, relying more heavily on stored soil water and precipitation for grain filling. In a general sense, all of the irrigation treatments (9.3 to 14 1. inches, Table 1) were relatively efficient with excellent overall average yields (228 to 244 bu/a, Table 1) with total seasonal water use (25.4 to 27.8 inches) and residual fall soil water (11.7 to 13.7 inches) which were both in a fairly narrow range of values, respectively (Figure 6).

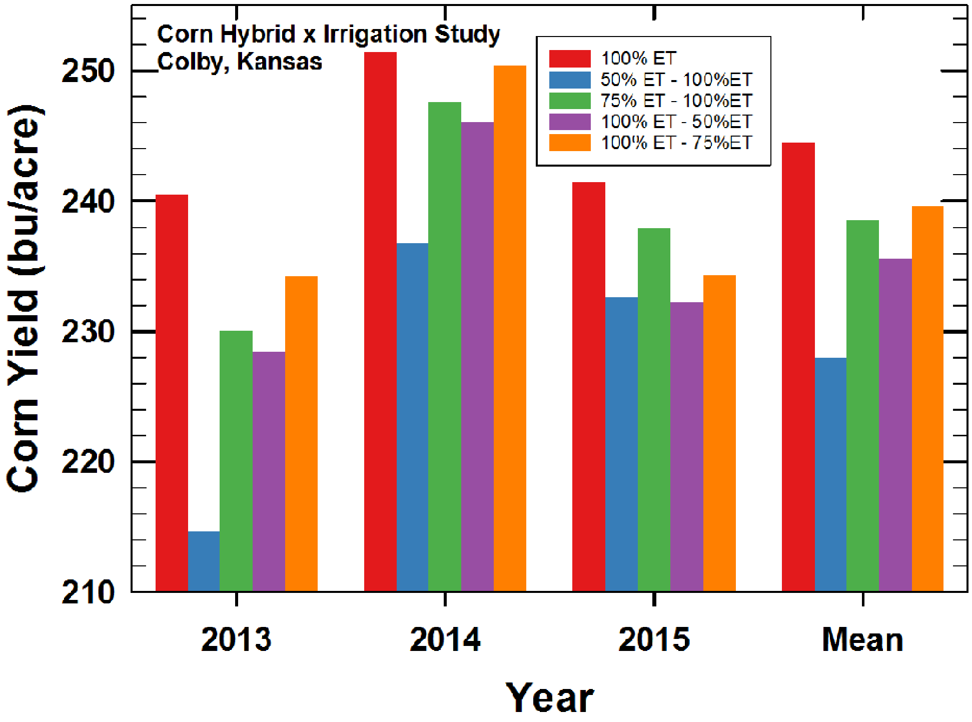

Figure 4. Corn yields for the five irrigation treatments during the three years of the study.

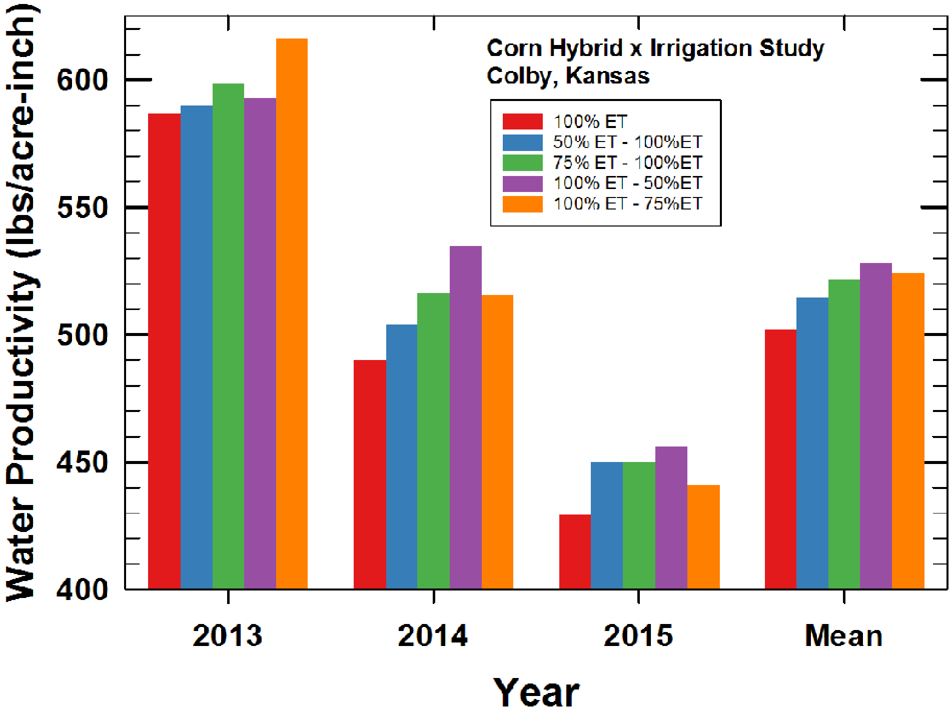

Figure 5. Water productivity for the five irrigation treatments during the three years of the study.

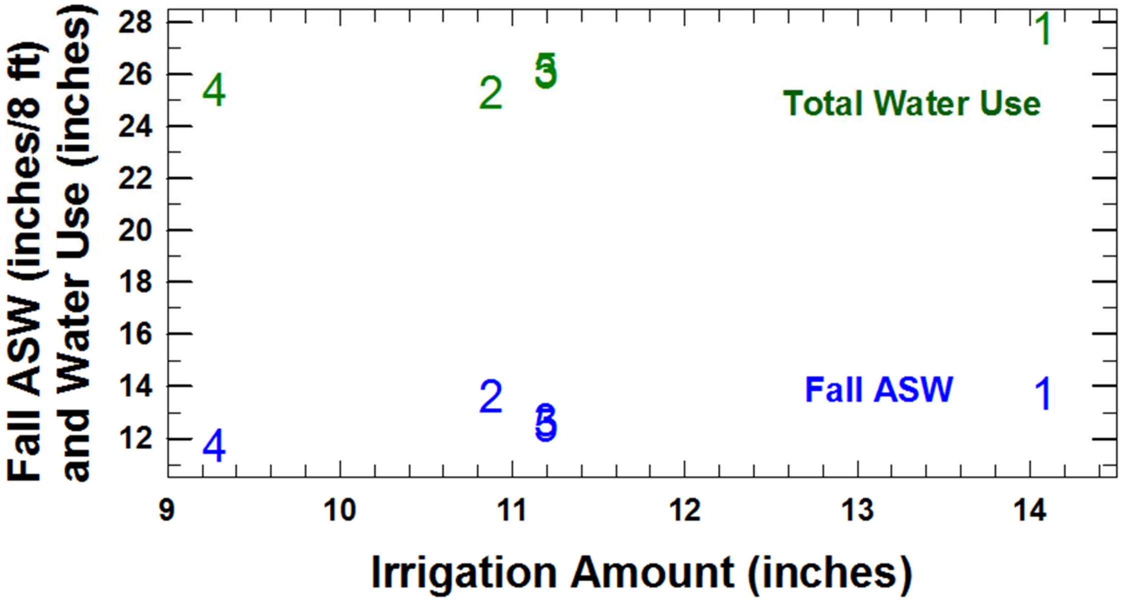

Figure 6. Fall available soil water (ASW) at harvest and seasonal water use as affected by irrigation regime (numbers on plot), KSU Northwest Research-Extension Center, Colby Kansas. Note: Irrigation Trts 3 and 5 coincidentally resulted in similar values. Overall, large differences in irrigation (≈ 5 inches) had minimal effect on residual ASW (2 inches) and total water use (2.4 inches), suggesting that all the treatments were relatively efficient.

Table 1. Corn yield, yield component, and water use parameters as affected by irrigation at Colby, Kansas, 2013-2015.

Irr Trt.	Irr. Amount	Yield, bu/a		Plant density, p/a		Ears/ plant		Kernels/ ear		Kernel mass, mg		Water use, inches		WP, lbs/acre-in	
Year 2013															
1. 100% ET	15.36	241	A	32452	A	1.00	A	542	A	349	A	23.0	A	587	A
2. 50/100% ET	11.52	215	C	32779	A	0.99	A	483	B	349	A	20.5	B	590	A
3. 75/100% ET	11.52	230	AB	32634	A	0.99	A	522	A	347	A	21.6	B	598	A
4. 100/50 % ET	10.56	228	B	32561	A	0.99	A	524	A	344	A	21.7	AB	593	A
5. 100/75% ET	11.52	234	AB	32561	A	1.00	A	527	A	349	A	21.4	B	616	A
Prob > F		0.0015		NS		NS		0.0029		NS		0.0161		NS	
Year 2014															
1. 100% ET	12.48	251	A	33215	A	1.00	A	566	A	339	A	28.8	A	490	C
2. 50/100% ET	9.60	237	B	33360	A	1.00	A	539	B	336	A	26.3	C	504	BC
3. 75/100% ET	10.56	248	A	33251	A	1.01	A	557	A	337	A	26.9	B	516	AB
4. 100/50 % ET	7.68	246	A	33069	A	1.00	A	558	A	338	A	25.8	D	535	A
5. 100/75% ET	10.56	250	A	33215	A	1.00	A	566	A	338	A	27.2	B	516	AB
Prob > F		0.0090		NS		NS		0.0140		NS		<0.0001		0.0053	
Year 2015															
1. 100% ET	14.40	241	A	32380	A	1.00	A	575	A	330	A	31.5	A	429	A
2. 50/100% ET	11.52	233	A	32525	A	1.00	A	563	A	323	A	29.0	CD	450	A
3. 75/100% ET	11.52	238	A	32597	A	1.00	A	574	A	324	A	29.7	BC	450	A
4. 100/50 % ET	9.60	232	A	32452	A	0.99	A	574	A	320	A	28.6	D	456	A
5. 100/75% ET	11.52	234	A	32670	A	0.99	A	573	A	322	A	29.8	B	441	A
Prob > F		NS		NS		NS		NS		NS		<0.0001		NS	
All Years															
1. 100% ET	14.08	244	A	32682	A	1.00	A	561	A	339	A	27.8	A	502	A
2. 50/100% ET	10.88	228	C	32888	A	1.00	A	529	B	336	A	25.3	C	515	A
3. 75/100% ET	11.20	239	B	32827	A	1.00	A	551	A	336	A	26.1	B	522	A
4. 100/50 % ET	9.28	236	B	32694	A	1.00	A	552	A	334	A	25.4	C	528	A
5. 100/75% ET	11.20	240	AB	32815	A	1.00	A	556	A	336	A	26.1	B	524	A
Prob > F		0.0001		NS		NS		0.0001		NS		<0.0001		NS	

Corn grain yield was significantly greater for hybrid P1151YXR (Table 2) with average (3-year) yield increases ranging from 4 to 9 bu/a over the other three hybrids. There were significant differences in the yield components with the highest yielding hybrid, P1151YXR 2014, having the smallest number of kernels/ear (524 vs. average of 558 kernels/ear for the other three hybrids) but having much greater kernel mass (358 vs. average of 329 mg/kernel for the other three hybrids). Water use though statistically different for the four hybrids actually varied on average less than 0.4 inches (Table 2). Water productivity was approximately 3% greater for the highest yielding hybrid, P1151YXR, and was attributable to the greater yield of this hybrid. In comparing the lowest yielding hybrid, 35F48, to the highest yielding hybrid, P1151YXR (Table 2), it can be seen that although the lowest yielding hybrid had the greatest number of kernels/ear (566 vs 524), it had the lowest kernel mass (321 vs 358 mg) and thus grain filling limited its yield. Combining the hybrid results with the irrigation results suggests that it is important to select a high yielding hybrid and then to make sure that it establishes an appropriate number of kernels/ear for its inherent characteristics. In the following section, the yield components will be examined more closely to further bolster this conclusion.

Examination of Yield Components

Yield can be calculated as:

$$\boldsymbol{Yield} = \frac{\boldsymbol{Plants}}{\boldsymbol{Area}} \times \frac{\boldsymbol{Ears}}{\boldsymbol{Plant}} \times \frac{\boldsymbol{Kernels}}{\boldsymbol{Ear}} \times \frac{\boldsymbol{Mass}}{\boldsymbol{Kernel}} \qquad \textbf{Eq. 1.}$$

The first two terms are typically determined by the cropping practices and generally are not affected by irrigation practices later in the season. Water stresses during the mid-vegetative period through about 2 weeks after anthesis can greatly reduce kernels/ear. Kernel mass, through greater grain filling, can partially compensate when insufficient kernels/ear are set, but may be limited by late season water stress or hastened senescence caused by weather conditions.

In this study, the yield component most strongly affected (as much as 6% corn yield variation) by irrigation practices was kernels/ear and was significantly affected (Pr F<0.05) in two years and also for the average of all years (Table 1 and Figure 7). Full irrigation (Irr 1) had the greatest number of kernels/ear while the 50% ET pre-anthesis treatment (Irr 2) consistently had the smallest value. These results suggest that pre-anthesis water stresses must be limited so that sufficient kernels/ear (i.e. sinks) can be set for modern corn hybrids.

Because all the yields components combine directly through multiplication to calculate yield, their effect on yield can be easily compared in Figure 7. The numbers on the lines refer to the 5 irrigation trts and the lines just connect similar data (i.e., the lines are not showing any pattern of results from one trt. to the next). A variation of 1% in any yield component would affect yield by the same 1%. It can be observed that there is much greater horizontal dispersion for kernels/ear than for all the other yield components which vary less than approximately 1%. Thus, irrigation treatment had a much greater effect on kernels/ear and the fully irrigated 100% ET, Irr 1 and the pre-anthesis 50% ET, Irr 2 were affected the greatest.

Although Irr 4 (50% ET post-anthesis) averaged using 1.6 inches less irrigation than Irr 2 (50% ET pre-anthesis), its average corn yield was 8 bu/a greater (Table 1). Irrigation treatment 4 also had the greatest water productivity of all five treatments although all water productivities were respectable. It can be seen in Figure 6 that the major difference between Irr 4 and 2 is that Irr 4 was able to set a kernels/ear value much closer to the mean value than Irr 2.

As indicated earlier there were appreciable differences in how the hybrids attained their grain yields through combination of their yield components (Figure 8). The graph indicates that the highest yielding hybrid, P1151YXR, had the least number of kernels/ear while the lowest yielding hybrid, 35F48, had the greatest kernels/ear. This ranking reversed for kernel mass with P1151YXR having the greatest kernel mass and 35F48 having the least. The other two hybrids (P0876CHR and P1498AM1) had near average values of kernels/ear and kernel mass. It can be noted that hybrid P1151YXR and P1498AM1 are both marketed as drought tolerant (Aquamax hybrids).

The effect of irrigation treatment on individual hybrid performance is shown in Figure 9. Kernels/ear was the yield component most affected by irrigation treatment for all four hybrids, with the adequate pre-anthesis irrigation (such as Irr 1, 4, and 5) being necessary to enhance kernels/ear. Although as previously discussed, kernel mass was very different for hybrids 35F48 and P1151YXR (Table 2), both hybrids individually had stable values that were relatively unaffected by irrigation treatment (Figure 9). The other two hybrids P0876CHR and P1498AM1 had slightly greater ability to flex kernel mass (Figure 9) with differences between Irr 1 and 2 having the greatest effect on kernel mass and subsequently yield (i.e, greater irrigation increased kernel mass and subsequently increased yield). It can also be seen in Figure 9 when comparing Irr 2 and 4 for all four hybrids that Irr 4 (least amount of total irrigation, 9.28 inches, Table 1) had relatively minor effect on the yield components and thus had little effect on grain yield while Irr 2 (10.88 inches) negatively affected kernels/ear and severely reduced grain yield. These differences in how the hybrids attained grain yield clearly indicate the combined importance of good irrigation management and hybrid selection.

Table 2. Corn yield, yield component, and water use parameters as affected by hybrid at Colby, Kansas, 2013-2015.

Hybrid	Yield, bu/a		Plant density, p/a		Ears/ plant		Kernels/ ear		Kernel mass, mg		Water use, inches		WP, lbs/acre-in	
Year 2013														
1. 35F48	219	C	32263	B	0.99	A	549	A	31.53	D	21.31	C	577	B
2. P0876CHR	230	B	32902	A	1.00	A	527	B	33.86	C	21.77	AB	595	B
3. P1151YXR	243	A	32902	A	1.00	A	493	D	38.31	A	21.93	AB	624	A
4. P1498AM1	226	B	32322	B	0.99	A	509	C	35.27	B	21.52	BC	592	B
Prob > F	<0.0001		0.0117		NS		<0.0001		<0.0001		0.0133		<0.0001	
Year 2014														
1. 35F48	241	B	33164	B	1.01	A	571	AB	322	C	26.96	A	502	C
2. P0876CHR	249	A	32989	B	1.00	A	581	AB	329	B	26.96	A	519	AB
3. P1151YXR	251	A	33599	A	1.00	A	513	C	369	A	26.90	A	523	A
4. P1498AM1	244	AB	33135	B	1.00	A	564	B	331	B	27.20	A	504	BC
Prob > F	0.0183		0.0016		NS		<0.0001		<0.0001		NS		0.0140	
Year 2015														
1. 35F48	240	A	32641	A	1.00	A	578	A	325	A	29.4	B	457	A
2. P0876CHR	233	A	32583	A	0.99	A	563	A	326	A	29.6	B	442	A
3. P1151YXR	234	A	32583	A	1.00	A	564	A	324	A	29.4	B	445	A
4. P1498AM1	236	A	32292	A	1.00	A	582	A	320	A	30.3	A	437	A
Prob > F	NS		NS		NS		NS		NS		<0.0001		NS	
All Years														
1. 35F48	233	C	32689	BC	1.00	A	566	A	321	C	25.9	C	512	B
2. P0876CHR	238	B	32825	AB	1.00	A	557	AB	331	B	26.1	AB	519	B
3. P1151YXR	242	A	33028	A	1.00	A	524	C	358	A	26.1	BC	531	A
4. P1498AM1	236	BC	32583	C	1.00	A	552	B	335	B	26.3	A	511	B
Prob > F	<0.0001		0.0031		NS		<0.0001		<0.0001		0.0027		<0.0001	

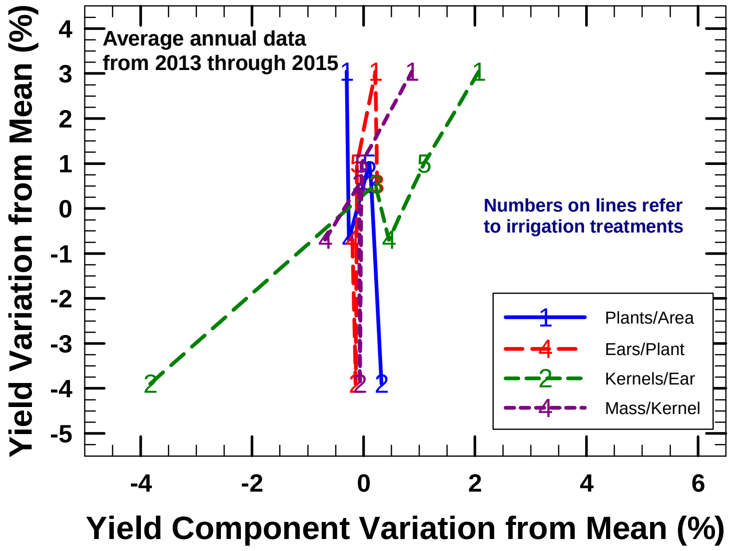

Figure 7. Yield variation as affected by variation in the yield components for the five different irrigation treatments, KSU Northwest Research-Extension Center, Colby, Kansas. *Note: Upward sloping lines to the right, such as Kernel/Ear indicate that irrigation treatment heavily affected the yield component and subsequently affected the grain yield, while vertical lines with little yield component variation from zero indicate little irrigation effect.*

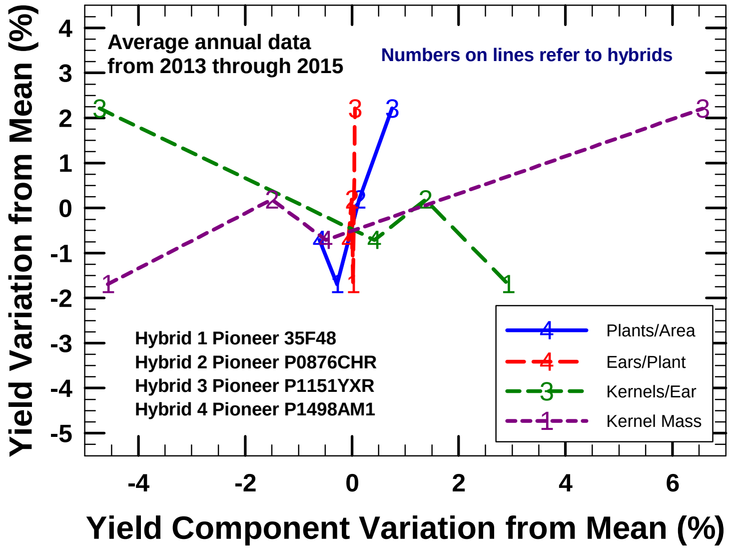

Figure 8. Yield variation as affected by variation in the yield components for the four corn hybrids, KSU Northwest Research-Extension Center, Colby, Kansas. *Note: Sloping lines, such as the Kernels/Ear and Kernel Mass indicate that the corn hybrid appreciably affected that yield component and subsequently affected the grain yield, while vertical lines of with little yield component variation from zero indicate little effect of corn hybrid.*

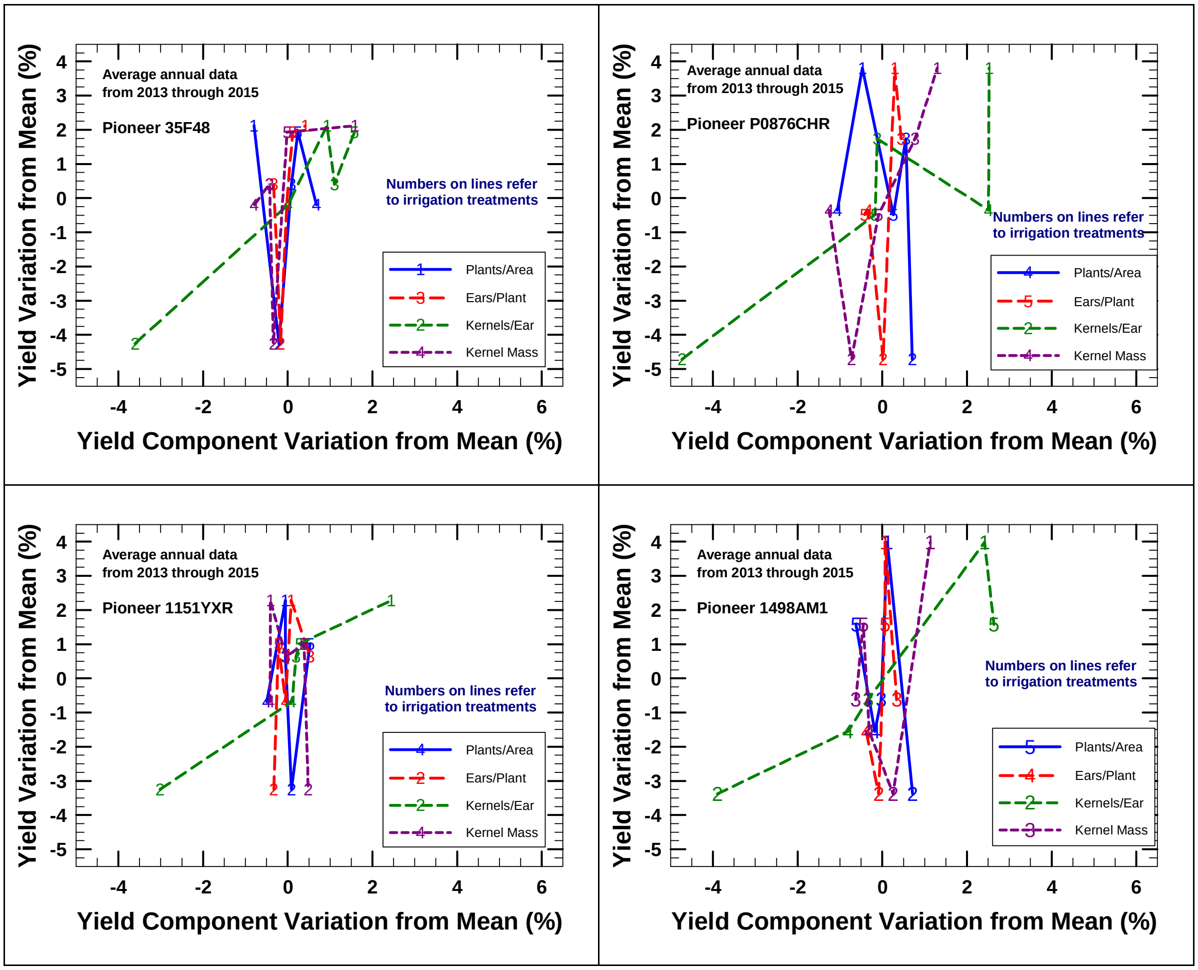

Figure 9. Yield variation for the four different hybrids as affected by variation in the yield components for the five different irrigation treatments, KSU Northwest Research-Extension Center, Colby, Kansas. *Note: Upward sloping lines to the right, such as Kernel/Ear indicate that irrigation treatment heavily affected the yield component and subsequently affected the grain yield, while vertical lines with little yield component variation from zero indicate little irrigation effect. Note: Each of the four panels relate to an individual hybrid and all plotted data refers to only that hybrid (i.e., Mean values are calculated across all irrigation treatments only for that hybrid.*

CLOSING THOUGHTS AND CONCLUSIONS

- **Full irrigation was still relatively efficient but used 30 to 36% more water.**

When irrigation is not severely restricted, corn prices are greater, and/or irrigation costs are lower, managing irrigation at this level and reducing irrigated land area may be more profitable.

- **Pre-anthesis water stress was more detrimental to grain yield than similar levels of post-anthesis water stress because of reductions in kernels/ear. Reductions in kernels/ear occurred for all four hybrids for when subjected to pre-anthesis irrigation reductions.**

This result is somewhat counter to typical older guidelines which indicated that moderate stress during the vegetative stage for corn may not be detrimental. This may be indicating that kernel set on modern hybrids is a greater factor in determining final yields.

- **When water is greatly restricted, a 50% reduction post-anthesis might fare reasonably well by relying on stored soil water and precipitation for grain filling.**

The rationale behind this comment is that it is important to establish a sufficient number of kernels/ear (i.e., sinks) that potentially can be filled if soil water and weather conditions permit.

- **Hybrid selection remains very important and modern corn hybrids exhibited different schemes of attaining yields (i.e., changes in yield components).**

As an example, the highest yielding hybrid attained greater kernel mass which was relatively stable across irrigation regimes while the lowest yielding hybrid attained the largest number of kernels/ear and had a relatively stable but much smaller kernel mass.

- **These results might not repeat on less productive soils or under harsher environmental conditions.**

On coarser soils (e.g. sandy soils), stored soil water and sporadic precipitation might not be sufficient to "carry" the crop through the post-anthesis period as well as in this study. However, it can be noted that the 50% ET post-anthesis treatment (Irr 4) still performed better than the 50% pre-anthesis treatment (Irr 2) in 2013, the year with the greatest irrigation need.

ACKNOWLEDGEMENTS

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