Proceedings of the 2016 Irrigation Association Technical Conference, Las Vegas, Nevada, December 5-9,
Available from the Irrigation Association, Fairfax, Virginia

Irrigation Scheduling Of Field Corn Under Institutional Constraints

Dr. Freddie R. Lamm
Professor and Research Irrigation Engineer
Kansas State University
Northwest Research-Extension Center
Colby, Kansas
Voice: 785-462-6281
Fax: 785-462-2315
flamm@ksu.edu

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. These 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 voluntary 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 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 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 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.

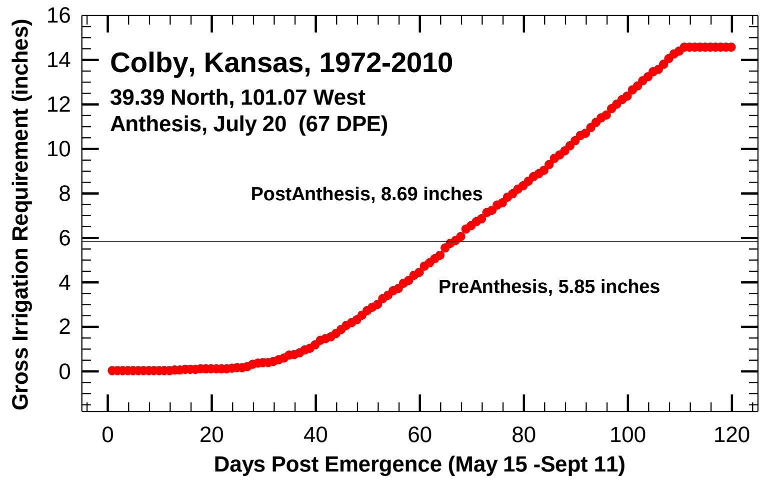

Figure 1. Seasonal gross irrigation requirements for field corn at Colby, Kansas.

A 4-year field study was conducted to examine restriction of irrigation to approximately to 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 at the KSU Northwest Research-Extension Center at Colby, Kansas. For brevity only the average datas from the four hybrids will be discussed here. 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. 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

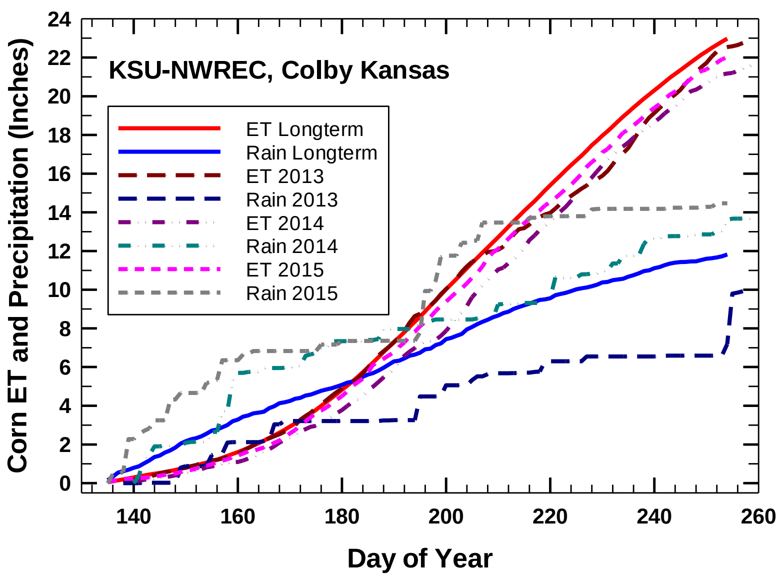

Figure 2. Cumulative calculated crop ET and precipitation during the growing season for Colby, Kansas, 2013 to 2015.

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 treatments with pre-anthesis water restrictions (Trt 2, 50% ET pre-anthesis and Trt 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 (Trt 4).

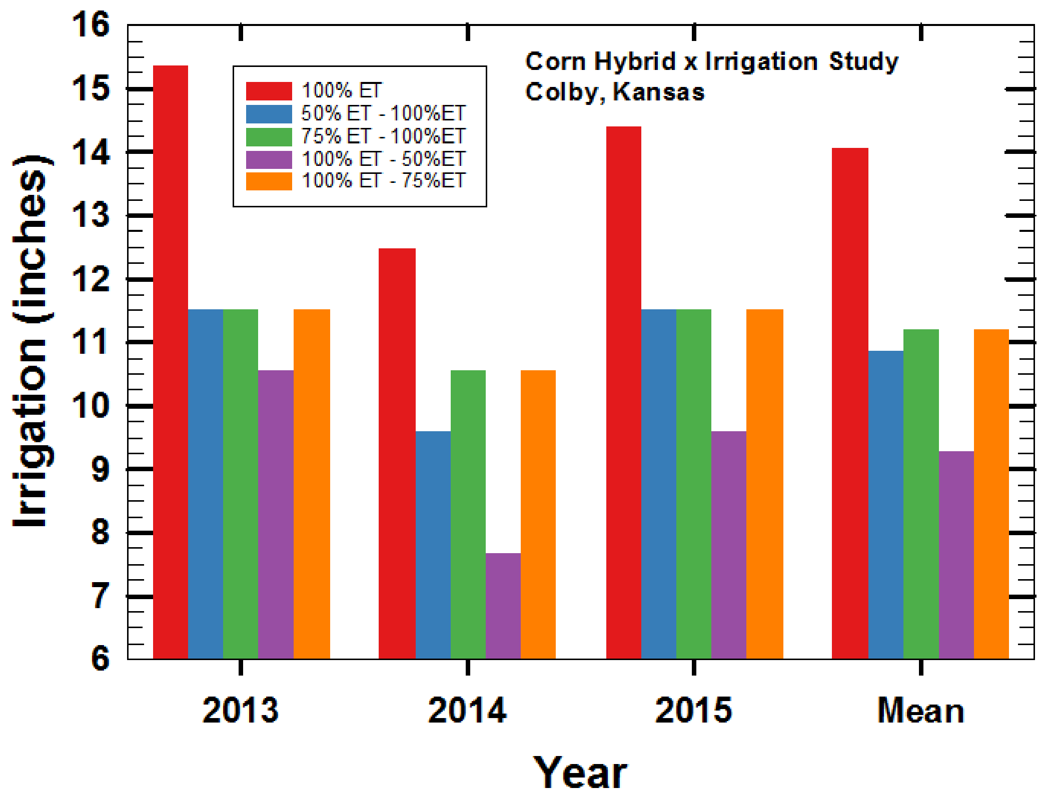

Figure 3. Irrigation amounts for the five irrigated corn treatments during the three years of the study.

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 (Trt 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 (Trt 2 and 3) than for similar post-anthesis restrictions (Trt 4 and 5). These results suggests 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.

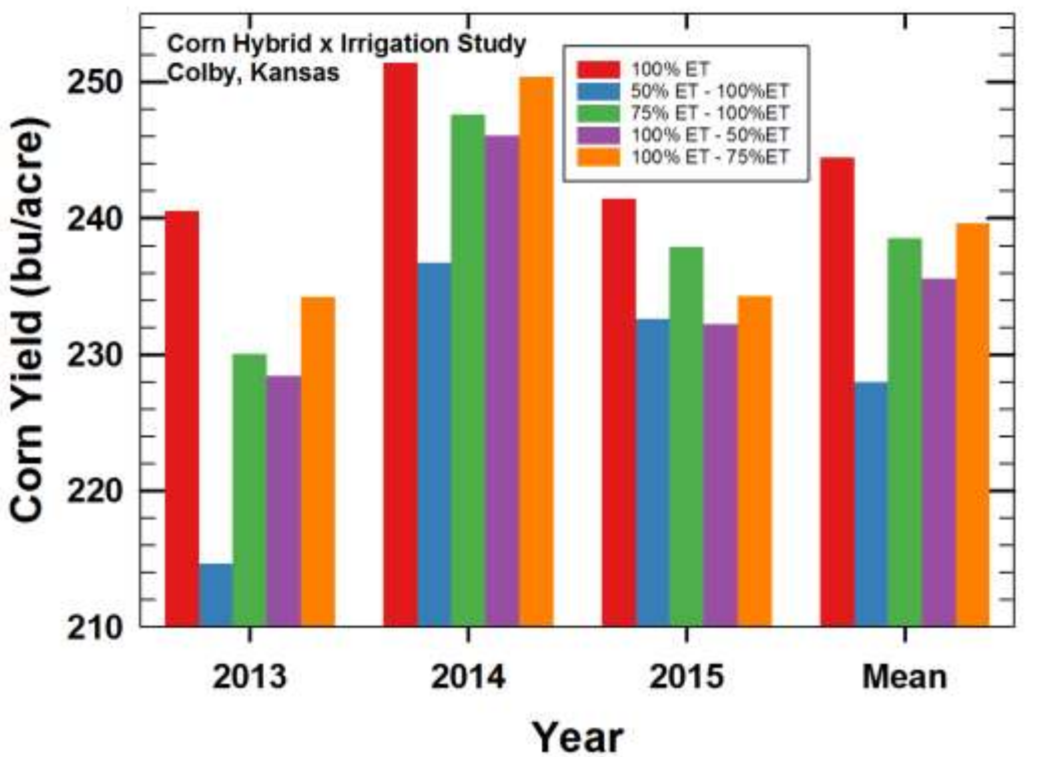

Figure 4. Corn yields for the five irrigation treatments during the three years of the study.

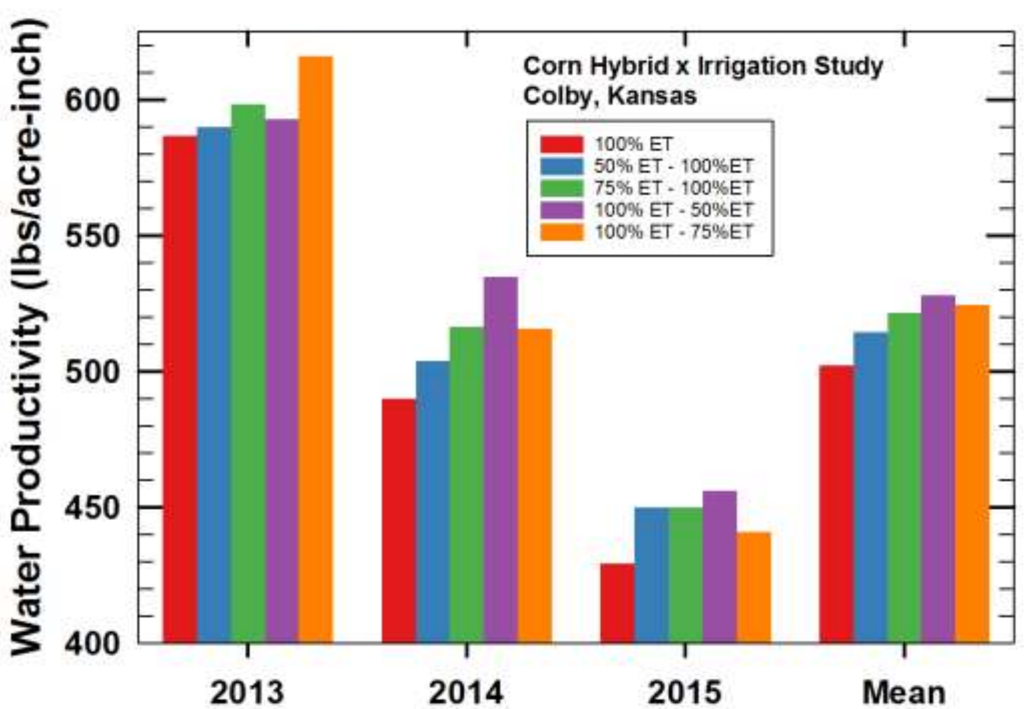

Figure 5. Water productivity for the five irrigation treatments during the three years of the study.

Table 1. Corn yield, yield component, and water use parameters in an irrigated corn study 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	B
2. 50/100% ET	11.52	215	C	32779	A	0.99	A	483	C	349	A	20.5	C	590	B
3. 75/100% ET	11.52	230	B	32634	A	0.99	A	522	B	347	A	21.6	B	598	AB
4. 100/50 % ET	10.56	228	B	32561	A	0.99	A	524	B	344	A	21.7	B	593	B
5. 100/75% ET	11.52	234	B	32561	A	1.00	A	527	AB	349	A	21.4	B	616	A
Prob > F		<0.0001		0.8328		0.3872		<0.0001		0.3976		0.0001		<0.0001	
Year 2014															
1. 100% ET	12.48	251	A	33215	A	1.00	A	566	A	339	A	28.76	A	490	C
2. 50/100% ET	9.60	237	B	33360	A	1.00	A	539	B	336	A	26.34	D	504	B
3. 75/100% ET	10.56	248	A	33251	A	1.01	A	557	A	337	A	26.89	C	516	B
4. 100/50 % ET	7.68	246	A	33069	A	1.00	A	558	A	338	A	25.82	E	535	A
5. 100/75% ET	10.56	250	A	33215	A	1.00	A	566	A	338	A	27.22	B	516	B
Prob > F		0.0010		0.6060		0.1034		0.0059		0.9002		<0.0001		<0.0001	
Year 2015															
1. 100% ET	14.40	241	A	32380	A	1.00	A	575	A	330	A	31.50	A	429	A
2. 50/100% ET	11.52	233	A	32525	A	1.00	A	563	A	323	A	28.98	A	450	B
3. 75/100% ET	11.52	238	A	32597	A	1.00	A	574	A	324	A	29.65	A	450	B
4. 100/50 % ET	9.60	232	A	32452	A	0.99	A	574	A	320	A	28.59	A	456	C
5. 100/75% ET	11.52	234	A	32670	A	0.99	A	573	A	322	A	29.78	A	441	B
Prob > F		0.0786		0.6613		0.0900		0.8987		0.6180		0.5629		<0.0001	
All Years															
1. 100% ET	14.08	244	A	32682	A	1.00	A	561	A	339	A	27.75	A	502	C
2. 50/100% ET	10.88	228	C	32888	A	1.00	A	529	B	336	A	25.26	D	515	C
3. 75/100% ET	11.20	239	B	32827	A	1.00	A	551	A	336	A	26.05	C	522	B
4. 100/50 % ET	9.28	236	B	32694	A	1.00	A	552	A	334	A	25.36	E	528	A
5. 100/75% ET	11.20	240	B	32815	A	1.00	A	556	A	336	A	26.14	B	524	A
Prob > F		<0.0001		0.5298		0.3079		<0.0001		0.4560		<0.0001		<0.0001	

Examination of Yield Components

Yield can be calculated as:

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

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 6). Full irrigation (Trt 1) had the greatest number of kernels/ear while the 50% ET pre-anthesis treatment (Trt 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 6. 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, Trt 1 and the pre-anthesis 50% ET, Trt 2 were affected the greatest.

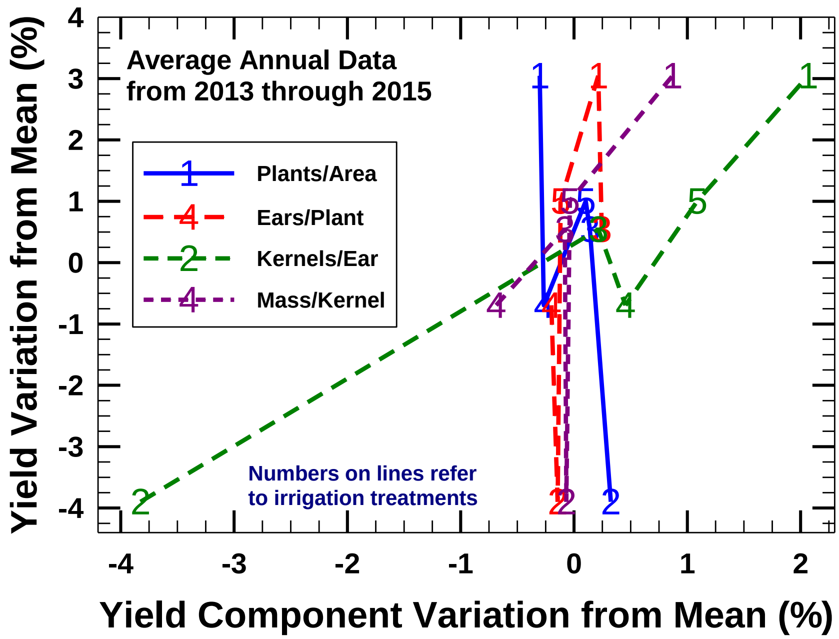

Figure 6. Yield variation as affected by variation in the yield components for the 5 different irrigation treatments.

Although Trt 4 (50% ET post-anthesis) averaged using 1.6 inches less irrigation than Trt 2 (50% ET pre-anthesis), its average corn yield was 8 bushels/acre greater (Table 1). 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 Trt 4 and 2 is that Trt 4 was able to set a kernels/ear value much closer to the mean value than Trt 2.

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.**

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.

- **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 (Trt 4) still performed better than the 50% pre-anthesis treatment (Trt 2) in 2013, the year with the greatest irrigation need.

ACKNOWLEDGEMENTS

This research was supported in part by the Ogallala Aquifer Program, a consortium between USDA Agricultural Research Service, Kansas State University, Texas AgriLife Research, Texas AgriLife Extension Service, Texas Tech University, and West Texas A&M University.

REFERENCES

Lamm, F. R. and A. A. Aboukheira. 2012. Effect of late season water stress on corn in northwest Kansas. ASABE paper no. 121337206. Available from ASABE, St. Joseph, MI. 10 pp.

Lamm, F. R. and A. A. Aboukheira. 2011. Effect of early season water stress on corn in northwest Kansas. ASABE paper no. 1111338. Available from ASABE, St. Joseph, MI. 11 pp.

Lamm, F. R. and D. H. Rogers. 2015. The importance of irrigation scheduling for marginal capacity systems growing corn. Applied Engineering in Agric. 31(2): 261-265.

Rogers, D. H. 1995. Using Evapotranspiration Reports for Center Pivot Irrigation Scheduling. KSU Coop. Extension Service, Manhattan, Kansas, Irrigation Management Series L-915. 6 pp