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CORN YIELD RESPONSE TO DIFFERENT IRRIGATION REGIMES

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SUMMARY:

Yields were more strongly related to measured water use divided by calculated water needs (WUSE/CAET) than to water use or irrigation. The WUSE/CAET appears to describe the relative amount of water stress. Seed weight was the most strongly related to water use of all the yield components. There was considerable yield compensation occuring throughout the season.

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ABSTRACT

Corn yields were related more strongly to measured water use divided by calculated water needs (WUSE/CAET) than to water use or irrigation. The WUSE/CAET appears to describe the relative amount of stress associated with a particular irrigation treatment.

Yield component analysis showed seed weight was the most strongly related to water use of all the yield components. There was considerable yield compensation occuring throughout the season. Increased seed weight sometimes compensated for poor ear or seed set.

Using calculated ET in a water budget for irrigation scheduling gives acceptable results. ET based scheduling shows promise in limited irrigation also.

INTRODUCTION

Diminishing water supplies and increasing pumping costs have increased the need for efficient use and conservation of water and energy. Production costs have risen sharply and many farmers are facing a steadily decreasing profit margin. It is well documented that irrigation scheduling saves water and energy but many methods have met little farmer acceptance. Some of the methods are complicated and others are too time consuming.

The Kansas State University Northwest Area Extension Office has been reporting daily evapotranspiration (ET) for corn, grain sorghum and soybeans for farmers to use in a water budget for irrigation scheduling. The method is simple and similar to balancing a checkbook.

In 1982 the KSU Colby Branch Experiment Station and the KSU Northwest Area Extension Office entered into a joint project with the Northwest Kansas Groundwater Management District #4. One of the objectives of the study was to compare corn yield response to different ET-based irrigation regimes.

PROCEDURE

The project was conducted from 1982-1984 on the Colby Branch Experiment Station at Colby, Kansas, on a deep, well drained, loessial Keith silt loam. This medium-textured soil, typical of many western Kansas soils, is described in more detail by Bidwell et al. (1980). The 1.5 m (5-ft.) soil profile will hold approximately 250 mm (10 inches) of available water at field capacity. This corresponds to a volumetric soil moisture content of approximately 0.30 and a profile bulk density of approximately 1.3 gm/cm^3.

The climate can be described as semi-arid, with an average annual precipitation of 473 mm (18.6 in) and approximate annual lake evaporation of 1400 mm (55 in).

Corn was grown in a level basin 183 m (600 ft.) by 30 m (100 ft.) with the plots arranged in a complete randomized block design with 6 irrigation treatments and 3 replications. The plots, approximately 30 m (100 ft.) by 5 m (15 ft.), were moldboard plowed and/or double disked in the fall. In the spring the plots were doubled disked and firmed before planting. The corn was fertilized preplant incorporated with ammonia nitrate at a rate of 213 kg/ha, (190 lbs/a) of actual nitrogen. The corn (Pioneer 3183) was planted respectively on May 4, 1982, April 26, 1983 and May 14, 1984 with a target population of approximately 54300 plants/ha (22000 plants/a).

Each replication was instrumented with a neutron access tube to a depth of 1.5 m (5-ft.) for soil moisture determinations. Soil moisture was measured on an approximately weekly basis in 0.3 m (1-ft.) increments.

Potential ET (PET) was calculated using a modified Penman approach as used by the USBR with climatic data obtained at the Experiment Station. The actual ET (AET) was determined by multiplying PET by a crop coefficient (Kco). Crop coefficients were generated by equations developed by Kincaid and Heerman, (1974) based on work by Jensen (1969) and Jensen et al. (1970, 1971). The procedure for selecting crop coefficients was to assume 70 days from emergence to full canopy for corn with physiological maturity at 130 days.

Irrigation regimes from very heavy irrigation to very limited were devised by multiplying the daily AET value by a factor. The treatments were

1. 1.4 * ET
2. 1.2 * ET
3. 1.0 * ET
4. 0.8 * ET
5. 0.6 * ET
6. 0.4 * ET

with 1.4 ET representing very heavy irrigation, 1.0 ET representing normal irrigation, and 0.4 ET representing very limited irrigation.

Each plot (replication) was separated by small borders so that each could be irrigated separately. Irrigation was metered on each replication through gated pipe. To schedule irrigation, an initialization point (IP) for soil moisture depletion was selected, field capacity having a IP of zero. The summation of all ET since the last irrigation was then subtracted from the IP. The summation of all precipitation since the last irrigation was added to the IP. Values of IP greater than field capacity were truncated back to field capacity. Irrigation was initiated when IP reached a range of -7.6 to -12.7 cm (-3 to -5 in.) depletion. This floating depletion range was used strictly to help manage the period between irrigations. This allowed dates for the irrigation treatments to be shifted slightly to accomodate irrigation needs of other studies. In all cases, the irrigation amount was equal to the amount required to bring IP to zero again.

Twenty row-feet from the center of each plot was hand harvested for yield component analysis on October 5, 1982, September 23, 1983, and September 21, 1984 respectively.

RESULTS AND DISCUSSION

Crop Years 1982-1984

The years were very different in terms of climatic factors (Table 1). Seasonal precipitation varied from a high of 487 mm (19.14 in) in 1982 to a low of 228 mm (8.9 in) in 1983. Though 1982 had seasonal (May-September) rainfall above the 70 year average annual precipitation at Colby, it was unevenly distributed. There was even a drought period beginning July 15, running through August 30, 1982, when a freak rainstorm dumped 7.9 mm (3.10 inches). During 1982 there was one day during the season with temperatures over 37.7 C (100 F) occuring on July 22. In 1983, there was a lengthy period of high temperatures and low rainfall during July and August. Temperatures reached or exceeded 37.7 C (100 F) eight times during this period. During 1984 a lengthy dry period occurred from the middle of June through the middle of August. There were 4 days with 37.7 C (100 F) temperatures or greater in 1984.

Calculated ET during the 125 day period from May 15 to September 16 varied from a high of 705 mm (27.77 in) in 1983 to a low of 472 mm (18.59 in) in 1982. The high temperatures and low humidities during the peak water use periods July and August in 1983 and 1984 resulted in high calculated water use. Calculated water use for 1983 and 1984 were the highest on record for the six years 1979 to 1984 for which records are available.

Water Use and Irrigation

Irrigation dates and amounts are shown in Table 2. Using a 75 mm (3 inch) depletion level before irrigation is initiated resulted in no irrigation needs before the second week in July in this study. This is somewhat different than the normal practice of farmers, who generally irrigate their furrow irrigated corn immediately after the last corrugation in late June. This is to alleviate the stress caused by root pruning during the corrugation process. In this study we made no attempt to alleviate this stress until calculated depletions reached the preset level.

Water use of the various treatments is shown in Table 3. As might be expected the measured water use was much higher for the heavier irrigated plots. The measured water use was the sum of soil moisture depletion, and all irrigation and rainfall. Therefore any excess irrigation or rainfall would still be included in the measured water use, even if it's ultimate fate was deep percolation. It is probable that a sizable portion of the higher water use of the heavier irrigated treatments was water unavailable for plant use.

The measured water use (WUSE) for a particular treatment divided by the calculated water use (CAET) for 1.0 ET can be used as a term to describe the relative amount of stress incurred by a particular treatment. WUSE/CAET values greater than unity express the potential for maximum yield, where little stress occurs, even though there may be considerable water losses due to percolation. This expression is a simplification as it ignores the fact that excess rainfall may not be timely and may unduely raise WUSE. Indeed, in 1982, all the rainfall in May and June may not have translated into decreased water stress throughout the entire season. However the WUSE/CAET term may explain some of the yearly variation in corn yields.

The mean calculated ET rate (AET) for the three years of the study is shown in Figure 1. This figure was constructed using a moving average (n=5) of AET for each day since emergence. Even with using the moving average there are considerable amounts of peaks and valleys in the AET rate. Peak AET rates for the three year study were in the 7 mm/day (0.30 in/day) range. However rates between the years varied widely as can be inferred by the slopes of the cumulative AET in Figure 2.

Yield Component Analysis

Corn yields and yield components are shown in Table 3 and 4. In 1982 there was no significant differences (0.05 confidence level) in yields between the various treatments. There was a trend toward lower yields when irrigation was reduced below 1.0 ET. However, with the good seasonal precipitation and low ET, even the limited irrigation treatments yielded well. In 1983 and 1984, there were significant differences in yield due to irrigation regime. In 1983, the normal irrigation treatment (1.0 ET) gave lower yields than the heavy irrigation treatment. However the irrigation requirements of the heavy treatments are not practical with the design of typical irrigation systems in western Kansas. In two out of the three years, the normal irrigation treatment gave yields as good as the heavier irrigation treatments. The average irrigation amount of 378 mm (14.9 inches) for the normal treatment compares favorably with the SCS Kansas Irrigation Guide requirements which state a need for 391 mm (15.4 inches) of water to satisfy the needs of corn in Thomas County, Kansas for 80% of the years.

The overall 3 year average yields were highly related to the 3 year average water use and also to the 3 year average irrigation levels for the various treatments as shown in Figure 3. However, the correlations between yield and water use, and yield and irrigation for all treatments, replications and years are not very good (Figure 4 and 5). The responses are much flatter due to yearly differences in water needs. Whereas 76 mm (3 in) of irrigation resulted in a yield of 10463 kg/ha (166.7 bu/a) in 1982, there was a 574 mm (22.6 in) irrigation requirement in 1983 to produce a similar yield of 10620 kg/ha (169.2 bu/a). The yield was much more related to WUSE/CAET, the relative measure of stress discussed in the preceding section. An exponential function was found to fit the data well, being of the type

$$Y = YMAX * (1 - (e^{(-A*(WUSE/CAET))})) \qquad 1$$

where Y is the actual yield, and where YMAX, the maximum attainable yield, and A the exponential decay coefficient can be found by iterative techniques to minimize the sum of squares of the deviations in predicted and measured yields. A comparison of the different regression equations and associated statistics is given in Table 5.

Over the three years of this study highest water use efficiencie were obtained with the limited 0.4 ET irrigation treatment and the lowest water use efficiencies were obtained with the heavy 1.4 ET irrigation treatment.

The yield of corn can be expressed as

$$Y = P * E * S * W \qquad 2$$

where Y is the actual yield, P is the plant population, E is the number of ears/plant, S is the number of seeds/ear, and W is the weight of an individual seed. Recognizing this fact, we can examine how the different components are affected by irrigation level (Table 6). The plant population was nearly the same for all treatments and the differences that arise are mainly due to planting variations. The potential ears/plant and seeds/ear is set early in the plant's life. The number of seed producing ears and the number of seeds/harvested ear, as expressed in Table 6, can be reduced by stress during pollination. This is probably why there were significant differences in ears/plant in 1983 and seeds/ear in 1984. As with many biological systems, there is considerable compensation occuring throughout the season. An unfavorable condition for ear or seed set can to an extent be compensated by higher seed weight, if climatic conditions improve later in the season. Likewise, early favorable climatic conditions produce good ear and seed set may be coupled with unfavorable climatic conditions later in the season and result in reduced seed weight. Regression of the various yield components with water use showed seed weight to be most strongly related. As was the case with yield, seed weight was more strongly related with WUSE/CAET than with water use (Figure 7). The other components plants/ha, ears/plant and seeds/ear were weakly related. This is probably because much of the potential is set early in the season, when water stress was not as severe. Even though they are weakly related, ears/plant and seeds/ear tended to decrease with irrigation amount. The individual factors in Equation 2 can be multiplied together to give products expressed on a unit area basis, for example plants/ha multiplied by ears/plant gives ears/ha. In this respect, weak relationships following the same trend, when multiplied together, give stronger trends. These ideas are expressed in Figure 8 showing the relative values of these intermediate products as affected by irrigation treatment. The effect of decreased ears/plant and seeds/ear does indeed have a pronounced affect on yield.

CONCLUSIONS

Corn yields increased with increasing irrigation. In two of three years highest yields were obtained at or near the normal (1.0 ET) irrigation level. Overall yields correlated well with irrigation and total water use. However due to the difference in years, regression of individual yields and irrigation or water use gave poor correlations. Yields correlated relatively well with measured water use divided by calculated water needs (WUSE/CAET). The WUSE/CAET appears to be a term to describe the relative amount of stress experienced by corn on this well drained soil.

Yield component analysis showed seed weight to be the most strongly influenced by irrigation treatment, decreasing with decreased water use. The other yield components, ears/plant and seeds/ear also were influenced tending to decrease with decreased water use. There was a considerable amount of compensation occurring on throughout the season. It appears that compensation through increased seed weight can partially offset some of the problems caused by poor ear or seed set.

Scheduling irrigation with calculated ET water budget appears to be a reliable method. It also appears to show promise in scheduling limited irrigation.

ACKNOWLEDGEMENTS

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Table 1. Summary of Climatic Data from an Irrigation Scheduling Study
KSU Colby Branch Experiment Station. 1982-1984

Month	Average Temperature, C				Precipitation, mm				Cumulative AET, mm			
	1982	1983	1984	MEAN	1982	1983	1984	MEAN	1982	1983	1984	MEAN
MAY	14.4	12.2	15.0	13.9	135	93	72	100	14	16	25	18
JUNE	17.8	18.9	21.1	19.3	144	45	60	83	52	83	105	80
JULY	24.4	25.6	25.0	25.0	79	60	16	52	163	257	240	220
AUG	23.9	26.7	24.4	25.0	84	13	73	57	183	255	223	220
SEPT	18.3	20.0	16.7	18.3	45	15	10	24	61	95	83	80
Season	19.8	20.7	20.4	20.3	487	228	232	316	472	705	676	618

Table 2. Irrigation Dates and Amounts, mm.
KSU Colby Branch Experiment Station. 1982-1984.

Date	Days since Emergence	ET Factor					
		0.4	0.6	0.8	1.0	1.2	1.4
				1982 Data			
7/26	73	-	-	-	88	115	142
8/09	87	-	83	122	77	94	111
8/20	98	77	-	-	-	72	85
8/30	108	-	-	88	111	-	-
TOTAL		77	83	210	277	281	338
				1983 DATA			
7/08	55	-	-	76	98	122	149
7/20	67	-	88	-	71	92	113
8/03	81	64	-	126	100	125	149
8/12	90	-	103	-	66	79	93
8/18	96	-	-	102	-	74	87
8/26	104	71	64	-	127	81	95
TOTAL		135	254	304	463	574	686
				1984 DATA			
7/09	48	-	-	-	91	112	133
7/18	57	-	80	113	-	-	81
7/26	65	-	-	-	120	146	91
8/01	71	80	-	78	-	-	-
8/08	78	-	-	-	-	82	100
8/13	83	-	87	-	98	-	-
8/20	90	-	-	93	-	110	129
8/31	101	-	-	-	90	88	103
TOTAL		80	166	285	399	539	637

Table 3. Summary of yields and water use data from an irrigation scheduling study. KSU Colby Branch Experiment Station. 1982-1984

ET FACTOR	Irrigation, mm.				Water Use, mm.				Yield, Kg/Ha				WUE, Kg/Ha-mm			
	1982	1983	1984	MEAN	1982	1983	1984	MEAN	1982	1983	1984	MEAN	1982	1983	1984	MEAN
1.4	330	686	638	554	765	919	879	853	11938	11361	10853	11386	15.6	12.4	12.3	13.3
1.2	282	574	538	465	721	833	800	785	11926	10620	10752	11097	16.5	12.7	13.4	14.1
1.0	277	462	399	378	701	709	704	704	12045	8775	10790	10539	17.2	12.4	15.3	15.0
0.8	211	305	284	267	691	607	577	625	10401	8574	10765	9911	15.1	14.1	18.7	15.9
0.6	84	254	168	168	597	533	483	538	10827	8204	7105	8712	18.1	15.4	14.7	16.2
0.4	76	135	79	97	589	457	417	488	10463	6999	7312	8260	17.8	15.3	17.6	16.9
LSD $_{.05}$=					61	43	43		NS	1607	1450		NS	NS	2.3	

Table 4. Summary of Yield Component Data for Corn from an Irrigation Scheduling Study KSU Colby Branch Experiment Station. 1982-1984

ET FACTOR	PLANTS/HA (1000)				EARS/PLANT				SEEDS/EAR				SEEDWT., g/100 seeds				YIELD, Kg/Ha			
	1982	1983	1984	MEAN	1982	1983	1984	MEAN	1982	1983	1984	MEAN	1982	1983	1984	MEAN	1982	1983	1984	MEAN
1.4	55.8	51.6	66.0	57.8	1.01	1.11	1.01	1.04	655	674	605	645	32.3	29.4	27.0	29.6	11938	11361	10853	11386
1.2	52.4	53.9	63.3	56.6	1.08	1.04	0.98	1.03	640	666	624	643	32.9	28.7	28.0	29.9	11926	10620	10752	11097
1.0	53.1	56.1	65.2	58.1	1.03	0.80	0.99	0.94	696	740	612	683	31.7	27.5	27.3	28.8	12045	8775	10790	10539
0.8	57.3	56.1	65.2	59.6	0.96	0.85	0.97	0.93	613	626	611	617	30.6	29.1	27.9	29.2	10401	8574	10765	9911
0.6	50.2	58.8	65.2	58.1	1.01	0.81	0.97	0.93	682	686	525	631	31.2	25.6	21.5	26.1	10827	8204	7105	8712
0.4	56.6	51.1	65.2	57.6	0.99	0.82	0.96	0.92	572	607	499	559	32.7	27.6	23.6	28.0	10463	6999	7312	8260
LSD $_{.05}$=	3.9	NS	NS		NS	0.22	NS		62	NS	79		1.4	NS	2.1		NS	1607	1450	

Table 5. Regression Equations and Statistics for Relationships between Yield and Water Use Factors. Yield expressed in Kg/Ha and Water Use and Irrigation expressed in mm.

3 Year Average, Yield vs. Water Use $Y= -2087 + (28.059 * WUSE) - (0.014363 * WUSE^2)$	n=6	SE=105	R^2=0.999
3 Year Average, Yield vs. Irrigation $Y= 7033 + (12.576 * I) - (0.2143128 * I^2)$	n=6	SE=147	R^2=0.840
All Data Points, Yield vs. Water Use $Y= -7084 + (44.533 * WUSE) - (0.027151 * WUSE^2)$	n=54	SE=927	R^2=0.531
All Data Points, Yield vs. Irrigation $Y= 8825 + (3.607 * I)$	n=54	SE= 1707	R^2=0.139
All Data Points, Yield vs. WUSE/CAET $Y= 13809 * (1 - (e^{(-1.263 * (WUSE / CAET))}),$	n=54	SE=840	R^2=0.670

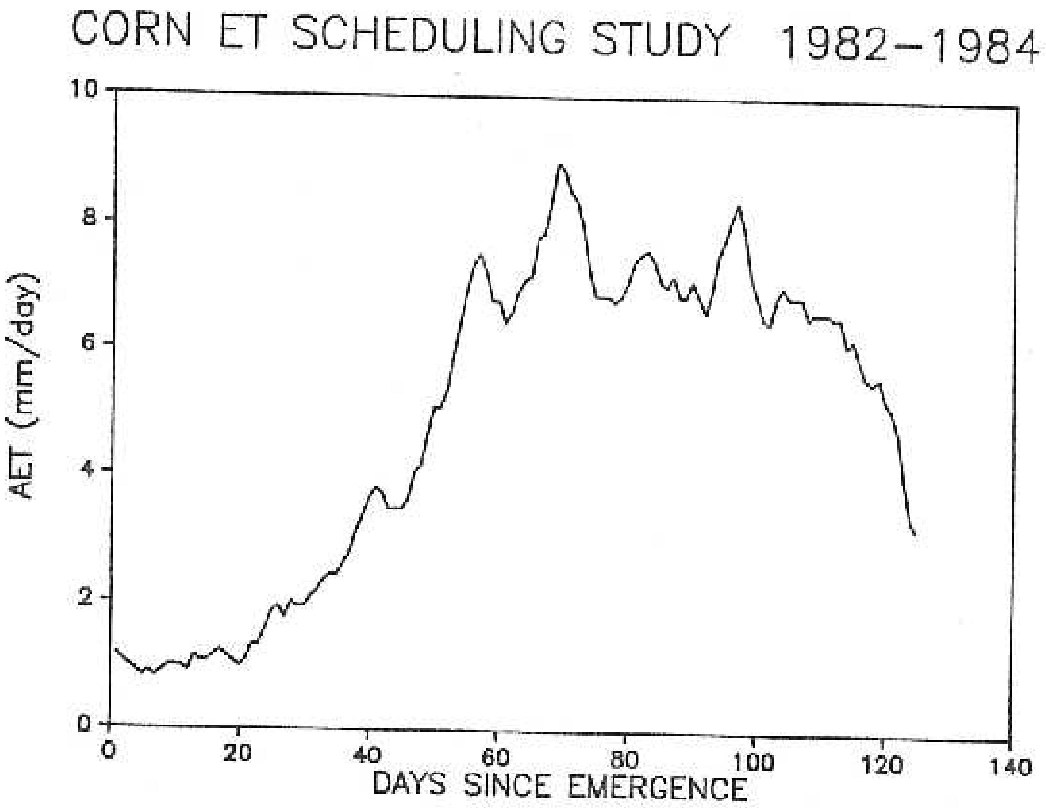

Figure 1. Average evapotranspiration rate for corn (1982-1984) for each day since emergence using a daily moving average (n=5). AET was calculated with a modified Penman approach.

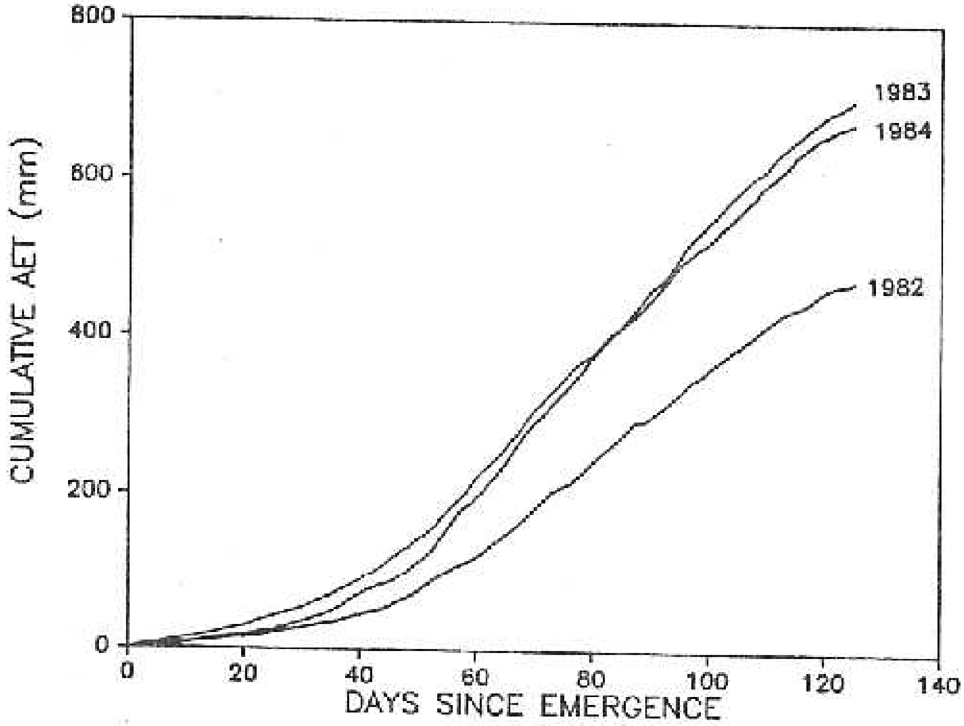

Figure 2. Cumulative evapotranspiration (AET) for corn as related to days since emergence for Colby, Kansas. AET was calculated with a modified Penman approach.

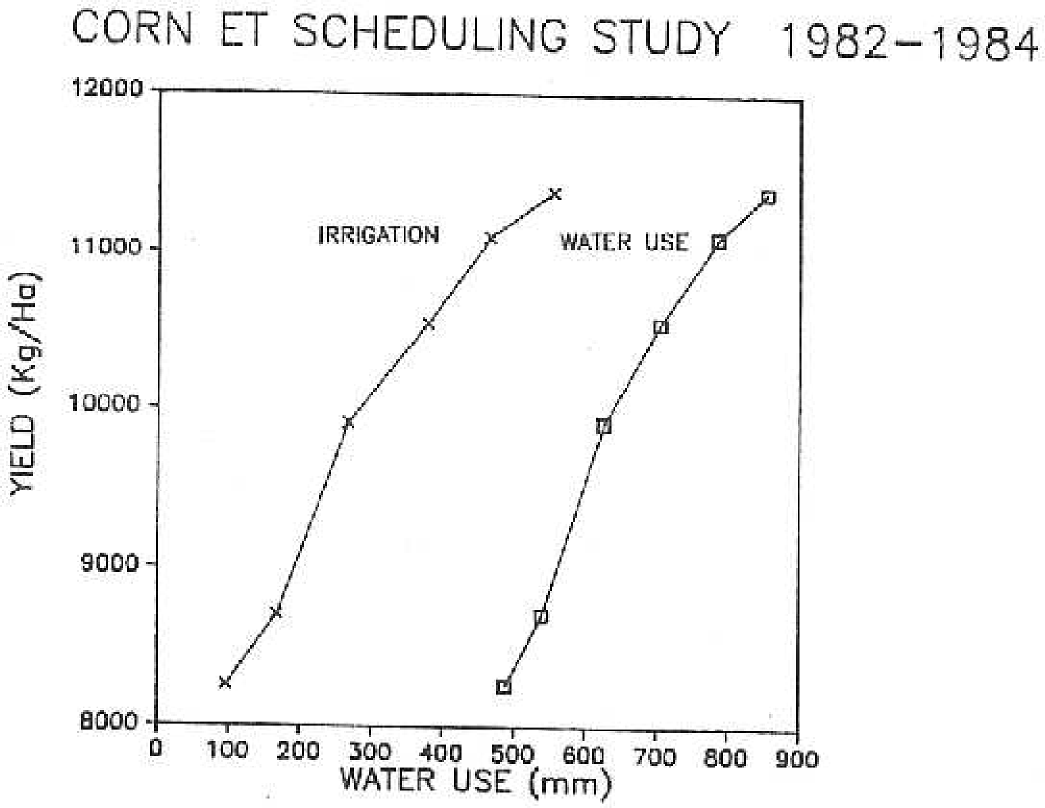

Figure 3. Average yield response (1982-1984) of corn to irrigation and total measured water use.

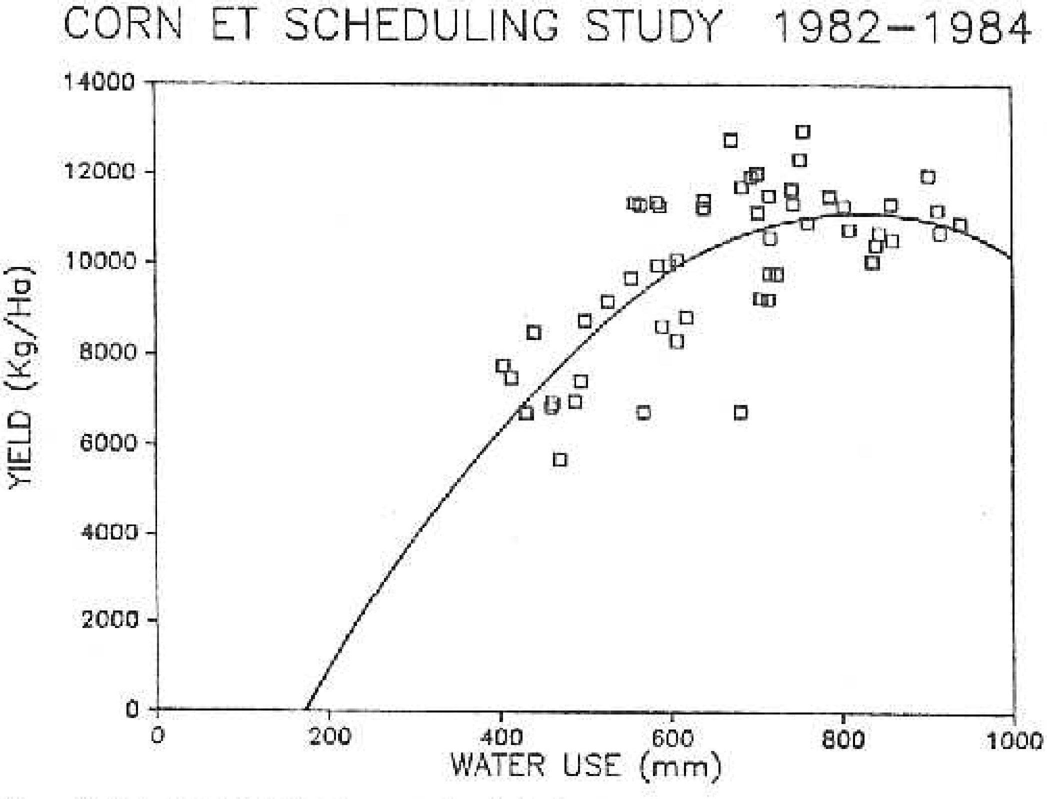

Figure 4. Yield response of corn to total measured water use in a irrigation scheduling study, Colby, Kansas, 1982-1984.

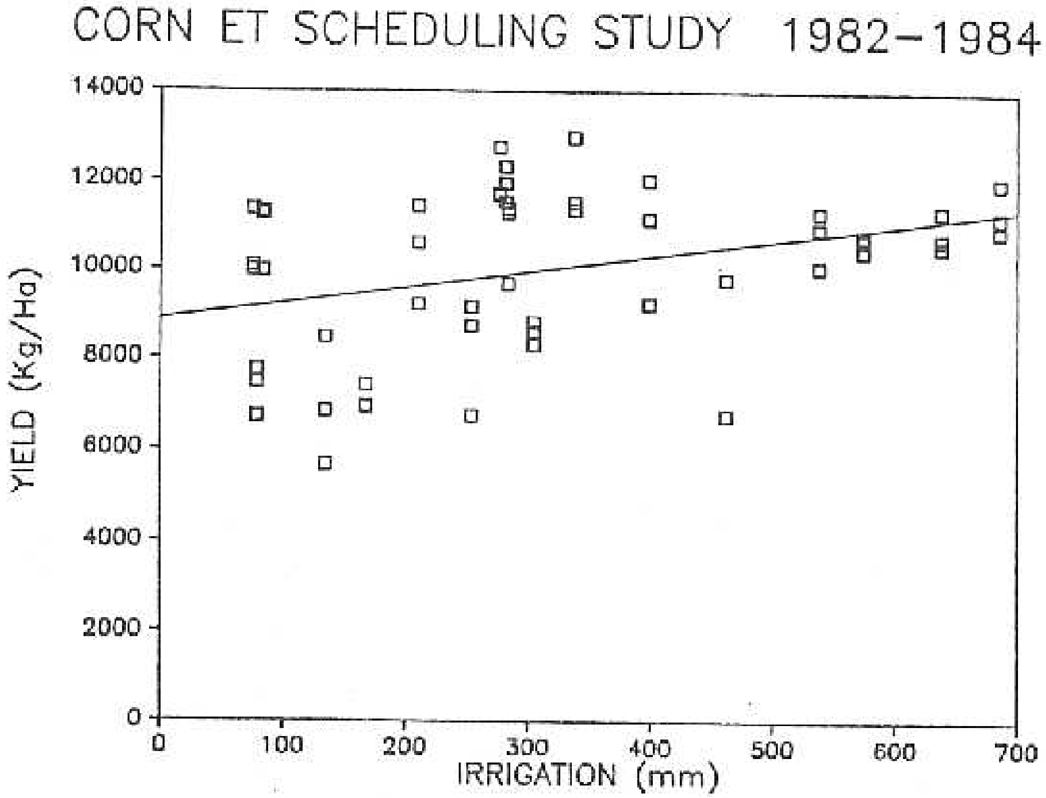

Figure 5. The weak relationship between corn yield and irrigation amount in a irrigation scheduling study, Colby, Kansas, 1982-1984.

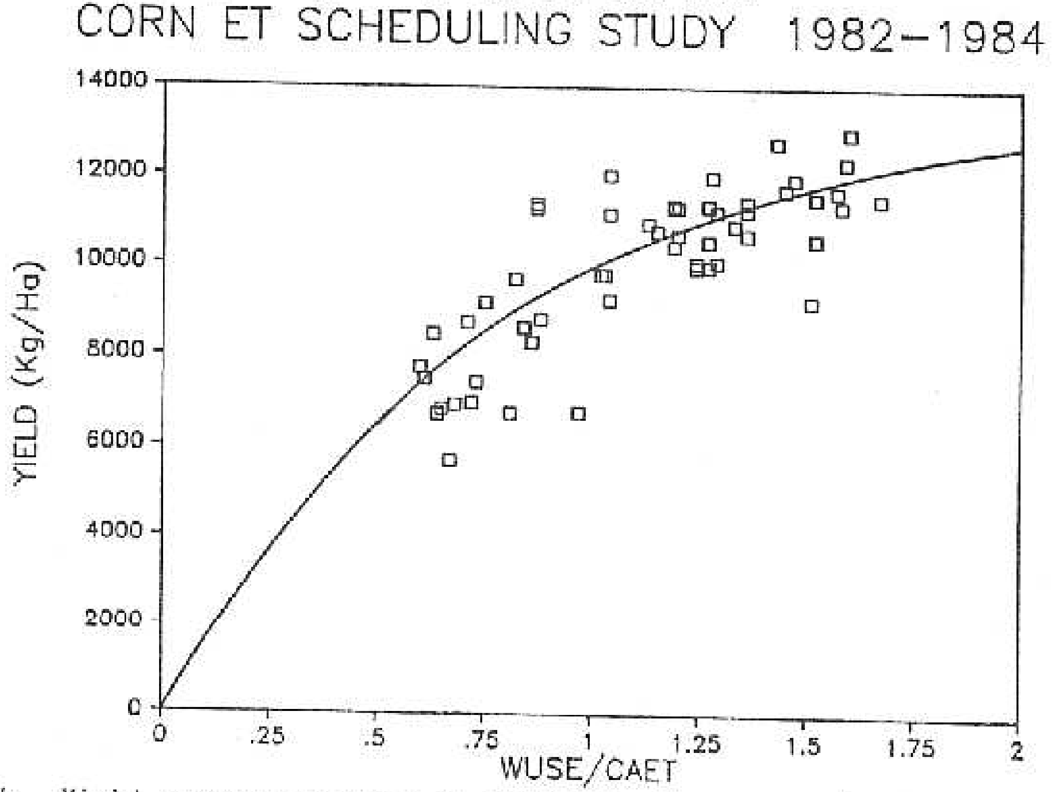

Figure 6. Yield response of corn as related to the measured water use divided by the calculated water need (WUSE/CAET) in a irrigation scheduling study, Colby, Kansas, 1982-1984.

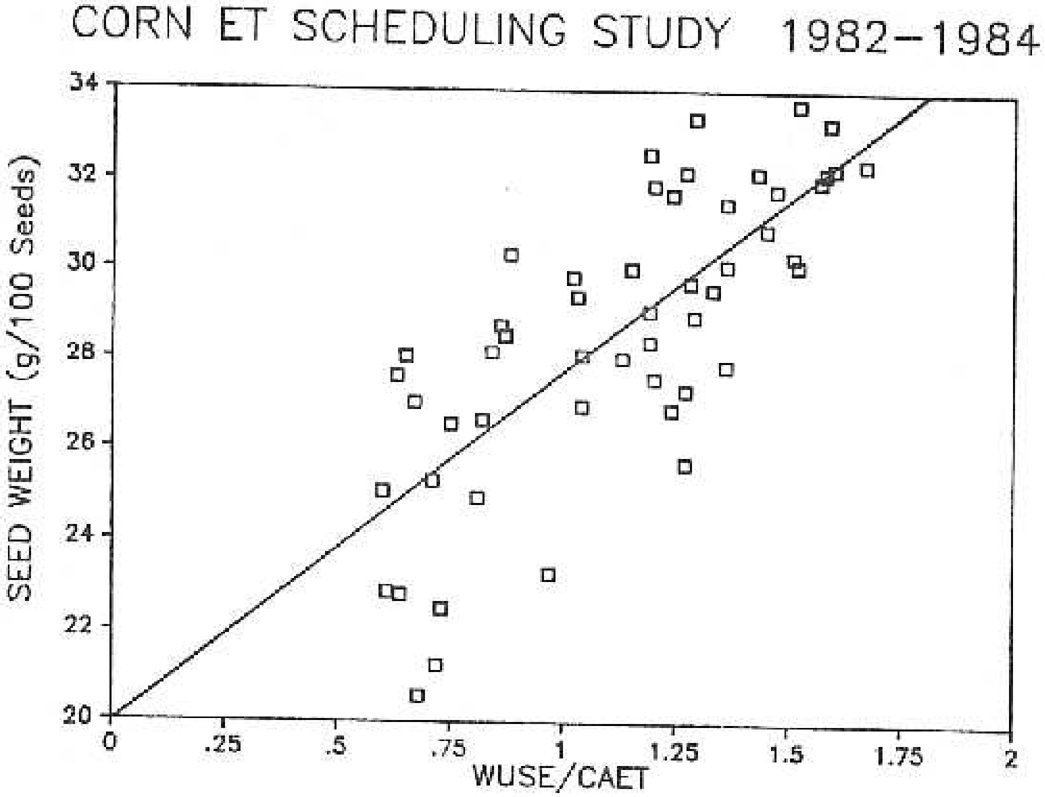

Figure 7. Relationship between corn seed weight and measured water use divided by calculated water needs in a irrigation scheduling study, Colby, Kansas, 1982-1984.

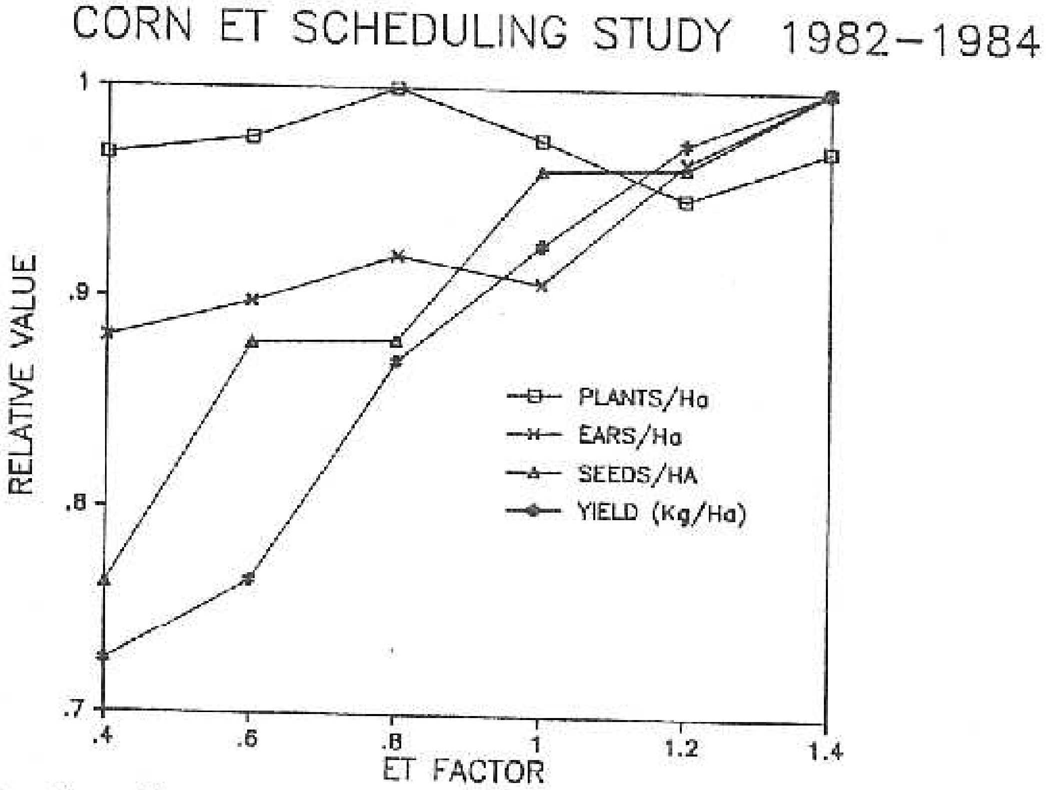

Figure 8. The effect of the irrigation regime (ET Factor) on the relative value of the various yield components expressed on a unit area basis. Data from an irrigation scheduling study, Colby, Kansas, 1982-1984.