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CORN PRODUCTION WITH LIMITED WATER SUPPLIES

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INTRODUCTION

Crop yield response to irrigation has been measured since the early years of irrigated agriculture research (Wagner, 1921). Field research on this topic has continued because irrigation systems, management techniques, and crop genetics have improved. Field research from the Great Plains research indicates that as irrigation applications to corn decrease, yields do not decrease at the same rate. Yield response to irrigation can be location specific and can vary by years due to differences in precipitation and stored soil water. Economic studies can use average yield responses over years to find overall trends but year to year variations in yields are needed for risk analysis. Testing and validation of crop production models need robust data sets that may include reference evapotranspiration (ETr), soil water measurements, crop grain yields, dry matter accumulation, harvest index, growth stage dates, maximum leaf area index, plant population, and crop residue coverage of the soil surface. These parameters were measured in this study to find the response of corn to a range of irrigation application amounts. The corn was grown in a no-till environment with best management practices for weed and insect control. Crop productivity (yield/ETc), yield/irrigation ratio, soil water accumulation during the non-growing season, and soil water use during the growing season were also derived from field data. Therefore, the objectives of this study were to: (1) build a robust data set of parameters for testing crop models over a range of irrigation; (2) find the relationships of grain and dry matter yields to ETc and irrigation; and (3) carry out the study over multiple years to find year to year variability in yield responses.

METHODS

The cropping systems project was located at the Kansas State University, Southwest Research-Extension Center near Garden City, Kansas. The soil type was a Ulysses silt loam (fine-silty, mixed, mesic Aridic Haplustoll) with pH of 8.1 and organic matter content of 1.5%. The soil had an available water capacity of 1.92 in/ft between field capacity (volumetric water of content of 33%) and permanent wilting (volumetric water content of 17%). Long-term average climatic data for Garden City are: annual precipitation, 18.7 inches; mean temperature, 54^{o}C; open-pan evaporation (April-September), 71 inches; and frost-free period, 170 days. Corn was grown in a five year rotation of corn-corn-wheat-sorghum-sunflower. Two consecutive years of corn were planted, the first after sunflower and the next after corn. All crops were planted in 2004 and the irrigation treatments were imposed so all crops were in rotation in 2005 and the initial soil water content included the effects of the irrigation variable from the previous 2004 crop. High through low water treatments were maintained on the same individual plots during all years and crops. Each crop was present every year in five cropping blocks, which were replicated over years. Irrigation treatments were randomized and replicated four times within each of the crop blocks in a randomized complete block design. The irrigation plots were 45 feet wide and 18 feet long.

Cultural practices, including hybrids, no-till planting techniques, fertilizer applications, and weed control, were the same across irrigation treatments. Cultural practices followed the requirements of no-till management and fertilizer and weed management were carried out so they would not limit crop production. Seeded plant populations increased across the six irrigation treatments with increasing levels of irrigation (19,500; 22,000; 24,500; 27,000; and 32,000 plants/ac) based on past research to be appropriate for the yield expectations of each irrigation treatment.

Grain yield was measured by hand harvesting two adjacent rows 10 feet long. Biomass was harvested from one row 10 feet long. Leaf area was measured by removing five plants from the field and passing the leaves through an optical scanner (Li-COR Portable leaf area meter). Crop residue coverage from the previous crop was measured shortly after planting using the line-transect method described by Dickey et al., (1986). Growth stages were recorded from field observations during the season.

A commercial four-span (135 ft span width) model 8000 Valley (Valmont Corporation) linear move sprinkler system was modified to deliver water in any combination of irrigation treatments simultaneously to each of the four replications (Klocke et al., 2003). Application depth for every irrigation event was 1 inch. Six irrigation treatments, replicated four times received from 13 inches (treatment 1) to 3 inches (treatment 6) of water during the growing season (table 1). If rainfall was sufficient to fill the soil profile to field capacity in treatment 1, water was not applied. To achieve the irrigation frequency variable, plots were irrigated or skipped during each pass of the irrigation system to achieve the target frequency (table 1). Each plot received no more than 2 inches of water per week to simulate the common commercial system capacity of 0.22 in/day.

Table 1. Average irrigation frequency and irrigation amounts for 2005-2009.

Irrigation Treatment	Irrigation Frequency	Total Irrigation
	(days)	(in)
1	4.8	13.3
2	6.3	10.5
3	7.0	9.2
4	8.8	6.8
5	12.0	5.2
6	15.2	3.2

Volumetric soil water content was measured bi-weekly to a depth of 8 feet in 6 inch increments with neutron attenuation techniques (Evett and Steiner, 1995). Drainage was calculated with a Wilcox-type equation (Miller and Aarstad, 1972) and runoff was observed to be negligible. The change in soil water from the start to the end of the sampling period, rainfall, net irrigation, and estimates of drainage were used in a water balance to calculate crop evapotranspiration (ETc). ETc was calculated for the days between plant emergence and the first soil water measurement with the Kansas Water Budget (KSWB) (Klocke et al., 2010). Reference ET (ETr) was calculated with an alfalfa-referenced Modified Penman model (Kincaid and Heermann, 1984), using weather factors including maximum and minimum air temperature, relative humidity, solar radiation, and wind run from an automatic weather station near the study site.

RESULTS

Above average ETr occurred during the 2005 and 2006 cropping seasons (previous October through current September) as well as the 2005-2006, 2007-2008, and 2008-2009 non-growing seasons (previous October through current April). Above average ETr occurred during the 2005 and 2006 growing seasons (current May through September). During the remaining periods, near average or below average ETr was recorded (table 2).

Cropping season precipitation was above average during the 2006-2007 and 2008-2009 periods and below average during the 2007-2008 periods (table 2). The other two years had nearly average cropping season precipitation and nearly the same precipitation during the growing and non-growing seasons. This year to year variation in precipitation patterns is common in the region.

Table 2. Reference ET (ETr) and precipitation with above average amounts underlined.

	ETr				Precipitation			
Year	Annual	Oct-Apr[a] In.	May-Sep[b] In.	Oct-Sep[c] In.	Annual In.	Oct-Apr[a] In.	May-Sep[b] In.	Oct-Sep[c] In.
2005	64.5	19.2	42.4	61.6	18.1	5.3	12.1	17.4
2006	69.8	29.5	42.2	71.7	22.8	5.6	13.0	18.5
2007	56.3	17.0	37.4	54.4	17.6	13.2	10.1	23.3
2008	58.4	23.1	36.5	59.5	17.3	4.4	9.5	13.9
2009	53.6	23.9	32.4	56.2	21.7	10.7	12.5	23.2
Avg	60.5	22.5	38.1	60.7	19.5	7.8	11.4	19.3

[a] Non-growing season from previous October through current April
[b] Growing season from the current May through September
[c] Cropping season from the previous October through the current September

Surface residue coverage from the previous crop varied among years and irrigation treatments (table 3). Residue coverage decreased significantly as irrigation amounts decreased, which showed the combined effects of the previous crop and residue decay during the non-growing season.

Year to year differences in leaf area index (table 3) were caused by hail events that occurred every year of the study, except 2007. Leaf area index was a good indicator of the hail's impact on the crop (Currie and Klocke, 2008). Significant leaf stripping was caused by hail events that occurred on July 4, 2005; July 11, 2006; June 20, 2008; and July 18, 2009 prior to tassel emergence. There was a hail event on June 19, 2007, but it was very minor and caused little to no leaf damage as indicated by leaf area measurements. Since effects of hail events and other possible crop stressors varied among years, relative grain yields were calculate for each year, where the relative yields were a ratio of the respective irrigation treatment yields and the yield of treatment 1.

The effects of irrigation treatments averaged over crop sequence and years showed a correlation of irrigation with grain yields, corn dry matter, and relative grain yields. Irrigation amount did not affect dry matter per plant which shows the influence of plant population on yield results.

Differences in year to year crop evapotranspiration (ETc) were not affected by the level of hail injury as much as they were by other crop production factors (table 4). ETc and grain yield decreased significantly as irrigation decreased. Productivity, the ratio of yield and ETc, was the same for the three highest levels of irrigation, but productivity declined as irrigation decreased.

Table 3. Crop yields and characteristics.

	Grain Yield	Relative Grain Yield	Total Dry Matter	Leaf Area Index	Residue Coverage
	bu/ac		tons/ac		%
(a) Year as an independent variable over irrigation treatments					
2005	133 c	0.87 a	11.6 c	N/A	46.9 c
2006	128 c	0.76 b	12.7 cb	3.22 b	52.6 a
2007	190 a	0.84 a	17.3 a	4.08 a	49 bc
2008	90 d	0.65 c	8.1 d	2.47 c	48 bc
2009	155 b	0.81 ab	13.4 B	3.26 b	50.6 ab
LSD0.05	9	0.062	1.2	0.285	3.2
(b) Irrigation treatment as an independent variable over year					
1	178 a	1 a	16.0 a	4.11 a	51.3 ab
2	167 a	0.94 ab	13.4 bc	N/A	52.6 a
3	157 b	0.88 b	14.0 b	N/A	51.2 ab
4	130 c	0.73 c	12.1 c	3.17 b	49.8 ab
5	112 d	0.63 d	10.2 d	N/A	48.5 b
6	91 e	0.5 e	9.8 d	2.49 c	43.2 c
LSD0.05	10	0.07	1.3		3.6

Table 4. Evapotranspiration, productivity, and grain yield/irrigation.

	Etc	Etr	Etc/Etr	Productivity[1]	Yield/Irr
	in	in		bu/ac-in	bu/ac-in
(a) Year as an independent variable over irrigation treatments					
2005	23.3 a	36.9	0.63 c	8.4 c	27.4 b
2006	22.0 bc	36.6	0.6 d	7.8 c	18.6 c
2007	22.1 bc	37.4	0.66 b	11.7 a	40.8 a
2008	17.5 d	30.1	0.58 e	6.8 d	15.0 d
2009	21.7 c	28.1	0.77 a	9.8 b	42.6 a
LSD0.05	0.4		0.012	0.6	2.6
(b) Irrigation treatment as an independent variable over years					
1	24.8 a	32.6	0.76 a	9.9 a	19.9 e
2	23.0 b	32.4	0.71 b	10.0 a	23.8 d
3	22.4 c	33.0	0.68 c	9.6 a	26.1 d
4	20.4 d	32.9	0.62 d	8.8 b	29.5 c
5	19.3 e	32.7	0.59 e	8.0 c	33.1 b
6	17.9 f	33.1	0.54 f	6.9 d	41.0 a
LSD0.05	0.4		0.013	0.7	2.8

[1] Grain yield/ETc

Increases in corn grain and dry matter yields had strong linear relationships to ETc (figure 1). The relationship of dry matter yields to ETc was more variable than grain yields, perhaps due in part to variation in the hail damage over the years. This linear regression of relative grain yield and ETc was much stronger than ETc and grain yield (figure 2). The slopes of Y-ETc for individual years may have been slightly different, but Y-ETc is usually considered to be an average over multiple years as the crop responds to the individual year's environment. Gomez and Gomez (1984) suggested that the treatment means averaged over replications are more appropriate for regressions of independent and dependent variables. When averaged over replications within years and replications among years, the relationship is well defined by the equation:

$$\text{Relative Yield} = 0.009\,(\text{ETc}) - 1.17 \quad \text{with } R^2 = 0.94 \qquad (1)$$

where ETc in inches; Relative Yield as a fraction of full irrigation

A quadratic regression was used for the relative grain yield-irrigation data for all irrigation treatments for all years (figure 3).

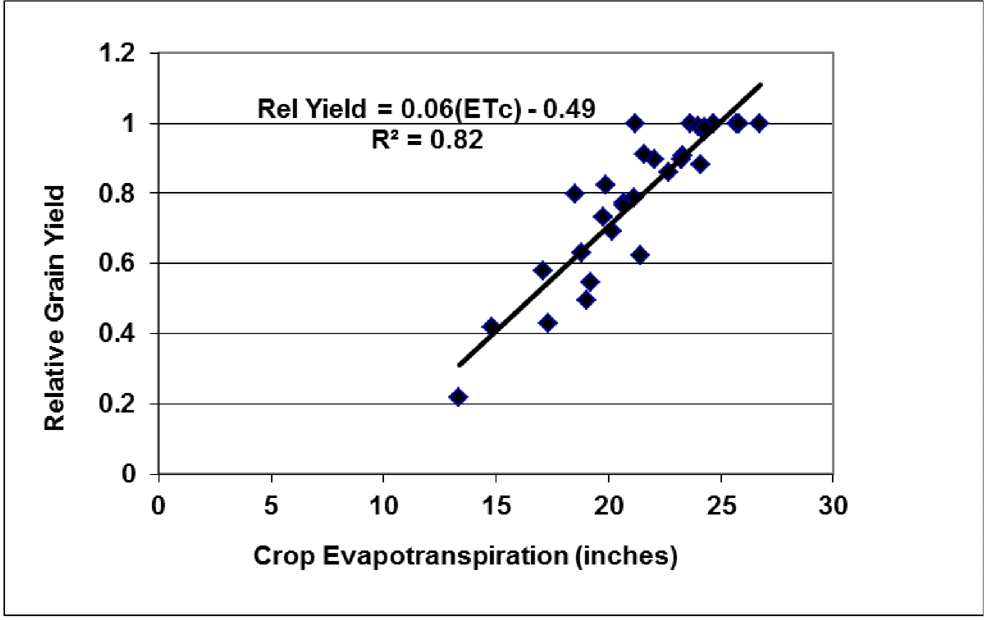

Figure 1. Relationship of relative grain yield with crop evapotranspiration (ETc).

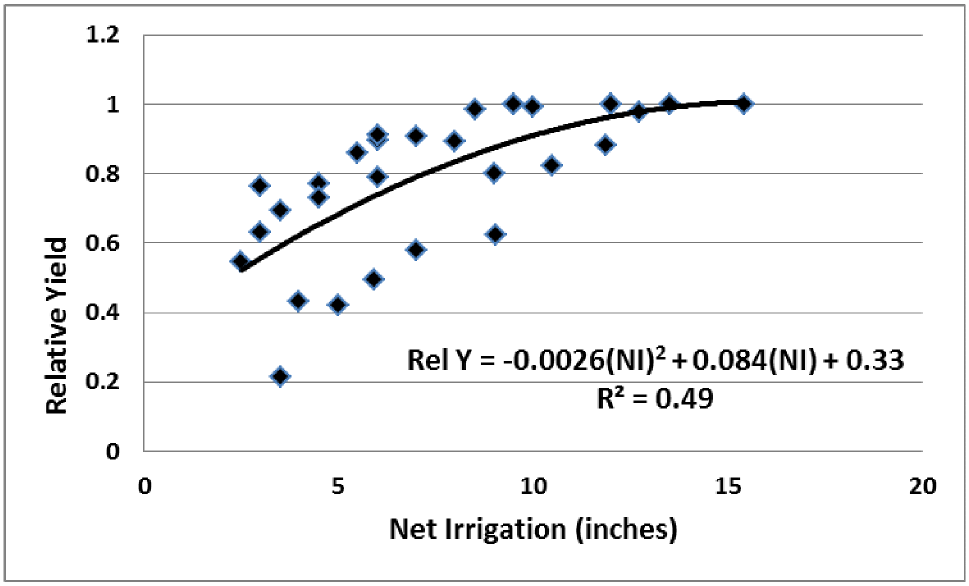

Figure 2. Relative grain yield response to irrigation.

Yield responses to irrigation among years can be distinguished from one another, where a particular year's data fall above or below the regression equation to reflect year to year differences in the environment, particularly differences in rainfall. When replications within years and replications among years were averaged for each irrigation treatment, the relationship was even more clearly defined by the equation:

$$\text{Relative Yield} = -0.0033(NI)^2 + 0.107(NI) + 0.196 \text{ with } R^2 = 0.99 \qquad (2)$$

where NI is Net Irrigation in inches; Relative Yield as a fraction of full irrigation

Since the same irrigation treatment was in the same plot location throughout all crops and years, soil water content at the end of the previous growing season influenced the next year's starting soil water content. Soil water content measured at the end of the previous growing season decreased as irrigation decreased (table 5). Soil water measurements by soil depth (data not shown) showed that the crop extracted more water from deeper in the profile in the lower irrigation treatments than in the wetter treatments. The deep silt loam soil allowed roots to extend to depths of 6 to 6.5 feet. Soil water accumulation during the non-growing season prior to planting corn was consistent among the deficit irrigation treatments (2 through 6), but the highest level of irrigation stored approximately 0.8 inch less water. Fallow efficiency, the ratio of accumulated soil water and non-grown season precipitation, showed that 60% of the precipitation was lost through soil water evaporation or drainage. Use of more stored soil water during the growing season prevented its loss during the following non-growing season and contributed to increases in water used for ETc. The crops preceding corn were also able to extract more water from deeper in the profile. The corn following corn used slightly more soil water than corn following sunflower. How effectively the crop can utilize stored soil water is one factor contributing to the diminishing return in yield from increased levels of irrigation.

Table 5. Soil water gains during the previous non-growing season and soil water use during the current growing season.

	Beg SW	End SW	SW Gain	Fallow Efficiency	SW Use	Drainage
	in	in	in		in	in
(a) Year as an independent variable over irrigation treatments						
2005	25.3 a	19.0 bc	4.0 c	0.39 b	6.3 a	0.02 bc
2006	19.9 d	19.1 b	2.0 d	0.29 c	0.7 d	0.00 c
2007	25.9 a	20.7 a	7.0 a	0.55 a	5.2 b	0.07 a
2008	20.5 c	18.5 c	1.4 d	0.21 d	2.0 c	0.01 c
2009	24.3 b	19.0 bc	5.1 b	0.51 a	5.3 b	0.04 b
LSD0.05	0.6	0.6	0.6	0.065	0.4	0.02
(b) Irrigation treatment as an independent variable over year			0.0			
1	24.8 a	22.2 a	3.1 b	0.3 b	2.6 d	0.08 a
2	24.2 ab	20.9 b	4.0 a	0.41 a	3.3 c	0.03 b
3	23.8 b	19.9 c	4.1 a	0.41 a	3.9 b	0.03 bc
4	22.7 c	18.6 d	4.3 a	0.43 a	4.1 b	0.01 bc
5	21.9 d	17.3 e	3.9 a	0.39 a	4.6 a	0.00 c
6	21.6 d	16.7 e	3.9 a	0.39 a	4.8 a	0.01 bc
LSD0.05	0.7	0.6	0.6	0.07	0.4	0.02

[1] Total soil water in 8 foot soil profile

[2] Soil water gain/non-growing season precipitation

SUMMARY

A field study of fully irrigated to deficit irrigated corn was conducted during 2005-2009 in southwest Kansas. Corn was grown in a 5-year rotation of corn-corn-wheat-grain sorghum-sunflower and 5 years of data were collected. Irrigation treatments were delineated by the irrigation frequency from 5 to 17 days with the constraint that the wettest irrigation treatment (scheduled on the basis of soil water depletion) could receive no more than two irrigation events per week, and each event delivered 1 inch of water. Grain and dry matter yields from year to year averaged over irrigation treatments and crop sequence were highly correlated to maximum leaf area index, which possibly reflected the severity of hail events that occurred 4 out of five years of the study. However, dry matter accumulation per plant did not vary across irrigation treatments. Surface residue coverage measured from the previous year's crop was 61% for corn following corn. ETc, calculated as the residual in a bi-weekly soil water balance decreased as irrigation decreased. Productivity, the ratio of yield and ETc (also known as water use efficiency) decreased as irrigation decreased and was the same for the two crop sequences. The ratio of yield to irrigation increased as irrigation decreased.

Deficit irrigation treatments were able to utilize more non-growing season precipitation because the previous crop extracted more soil water from deeper in the profile than the fully irrigated treatment leaving more room to store the subsequent precipitation. The deficit irrigated treatments also extracted more soil water during the growing season.

Although regressions of grain and dry matter yields with ETc produced reasonable linear models, regression of grain yields as a fraction of full yields (relative yields) produced better models with less variability. A curvilinear model of relative yield with irrigation had the greatest predictive value, particularly as year to year variability declined with increasing levels of irrigation. Over the five years of the study, variability in yields consistently increased as irrigation decreased, illustrating greater income risk for the producer as irrigation decreased. The yield response to irrigation, over multiple years provides essential information to build economic studies of cropping alternatives, deficit irrigation management, and income risk.

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