RESPONSE OF CORN TO DEFICIT IRRIGATION AND CROP ROTATIONS

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Introduction

Dwindling water supplies for irrigation are prompting alternative management choices by irrigators. Deficit irrigation, where less water is applied than full crop demand, may be a viable approach. Application of deficit irrigation management to corn was examined in this research. A field study was designed to test crop management that (1) took advantage of delayed irrigation during crop vegetative growth, (2) reduced irrigation when water applications were unable to supply the full potential of crop yields, and (3) used no-till practices to reduce soil water evaporation and achieve other soil and water conservation benefits. Multi-year crop performance results were needed to determine the yield risks for adopting deficit irrigation practices. The specific objectives of this study were to: (1) find relationships of irrigation and crop yield, (2) determine crop evapotranspiration (ETc), (3) measure soil water gains non-growing season and soil water use during the growing season, (4) predict the probabilities for achieving grain yields.

METHODS

Crop rotation research with full irrigation, deficit irrigation, and dryland management was conducted at the West Central Research and Extension Center of the University of Nebraska-Lincoln at North Platte, Nebraska located at 41.1° N, 100.8° W and 2800 feet above sea level (Schneekloth et al. 1991; Hergert et al., 1993). The semiarid climate in North Platte is characterized by frequent and rapid changes in weather conditions throughout the year. The average annual precipitation is approximately 19 inches, which is 36% of annual reference ET (ETr) using alfalfa as the reference crop (Kincaid and Heermann, 1984). The soil texture was predominantly Cozad silt loam (fluventic Haplustoll) with pH of 7.5. Plant-available soil water holding capacity was 0.17 ft^3 ft^{-3} for volumetric soil water contents from 32% for field capacity to 15% for permanent wilting. The land slope was less than 1%.

The crop rotations were continuous corn (CC) and wheat-corn-soybean (WCS). Both rotations were managed with no-till practices and non-limiting fertility and pest management. Corn was planted directly into the previous crop's residue with a no-till planter equipped to apply starter fertilizer. The rest of the nitrogen was applied near the four to six leaf growth stage. Pre-emergence and post-emergence herbicides were applied as needed.

Irrigation to meet full crop ET (ETc) was scheduled from measurements of soil water deficits in each crop rotation treatment. An annual water allocation was restricted to 6 inches for the deficit irrigation treatments unless there was sufficient soil water to achieve full ETc. Deficit irrigation was scheduled to favor applications during critical growth stages for crop development. For corn, irrigation was reduced or withheld during the vegetative period and concentrated on reproduction and grain fill.

Soil water was measured weekly to a depth of 6 ft. in 1 ft. increments with the neutron attenuation method (Evett and Steiner, 1995). Precipitation, net irrigation, and changes in soil water from one measurement to the next were used to calculate weekly ETc. Drainage was assumed to be minimal within the one-week sampling interval of soil water and was not included in the soil water balance. Water runoff and run-on to the plots were observed to be zero. ETr, referenced to alfalfa, was estimated with a Penman combination model, which used maximum and minimum daily air temperatures, relative humidity, solar radiation, and daily wind run as inputs.

RESULTS AND DISCUSSION

PRECIPITATION & IRRIGATION

Cropping season precipitation (table 1) was the sum of all precipitation that occurred from October in the year preceding corn planting through September of the growing season. Cropping season precipitation as a percentage of long-term average annual precipitation provided a characterization of wetter or drier years. The criterion for wetter and drier years was ±95% of the average cropping season precipitation, which divided the years into two equal groups. Years 1985, 1989, 1990, 1991, 1994, 1997, and 1998 were considered drier than the long-term average. Years 1986, 1987, 1988, 1992, 1993, 1995, and 1996 were considered wetter. Precipitation during the growing season also was a factor for crop yields. Drier years had less than 12 inches of rain during May through September, while the precipitation in the wetter years for the same time period was 12 to 24 inches. Another indicator of crop performance was rainfall for April, May, and June because this water accumulated closest to crop water needs was more effective than earlier precipitation. For example, 1995 was classified as wetter overall; however, adequate early growing season rainfall was followed by very dry months of July and August, which coincided with periods of high ET demand.

Table 1. Cropping season precipitation (inches) for Oct. 1-Sep. 30.

Drier Years	1985	1989	1990	1991	1994	1997	1998
Precipitation	17.7	13.8	10.8	14.9	16.7	11.2	17.3
% of Avg.	89	69	54	74	84	56	86
Wetter Years	1986	1987	1988	1992	1993	1995	1996
Precipitation	21.2	20.8	25.7	21.1	20.6	19.4	25.0
% of Avg.	106	104	129	105	103	97	125

Average annual irrigation (table 2) was less than anticipated. The first water applications on the deficit irrigation plots often were later than those on the full irrigation plots. Timely precipitation events during June were more effective for the deficit irrigation when irrigation was delayed.

Table 2. Average annual irrigation (in) applied to corn at North Platte, Nebraska, during 1985-1999.

	-Deficit Irrigation--		--Full Irrigation--	
	CC	WCS	CC	WCS
Irrigation	4.7	4.6	10.1	9.9
% of Full	47	47	---	---
Annual Precip.	18.5	18.5	18.5	18.5
c. Precip. + Irr.	23.2	23.1	28.6	28.4

Cropping season precipitation plus irrigation for the full and deficit irrigation treatments correlated with ETr (data not shown). Irrigation plus precipitation was from 23.2 to 28.4 inches during the fourteen years of record, which was 80% to 125% of the mean. Atmospheric demand for evaporation was predicted by ETr, which ranged from 0.16 to 0.30 inch day^{-1} and from 61% to 121% of the mean.

GRAIN YIELD

Average corn grain yields were 70% to 127% of the mean for 1985-1999 (tables 3). More or less, corn production followed the pattern of wetter and drier years, except for 1995, which had the least precipitation in July and August. Corn yields were statistically different among water treatments and increased with additional irrigation. Corn yields from the WCS rotation were significantly more (10 bu ac^{-1}) than CC during 1985-1999, which could be attributed to more off-season gains in stored soil water and in-season use of stored soil water in the WCS rotation..

Table 3. Results for corn in the continuous corn (CC) and wheat-corn-soybean (WCS) rotations at North Platte, Nebraska, during 1986-1998.

	Yield[b]	IWUE[c]	CS[d] Precip	Net Irr.	SW Gain[e]	SW Use[f]	ETc/day[g]	ETr/day[g]	
	bu/ac	bu/ac-in	in	in	in	in	in/day	in/day	Etc/ETr
(a) Irrigation as an independent variable over years and rotations									
Dryland	116 c	--	16.6	0.0	8.1 a	7.6 a	0.19 c	0.25	0.77
Deficit	158 b	8.9 a	16.6	4.7	6.0 b	5.7 b	0.22 b	0.25	0.88
Full	175 a	5.9 b	16.6	9.8	4.4 c	3.2 c	0.27 a	0.25	1.06
$LSD_{0.05}$	6	1.1	--	--	0.8	0.7	0.01	--	0.04
(b) Rotation as an independent variable over years and water treatments									
CC	137 b	---	16.6	7.2	4.5 b	4.9 b	0.22 b	0.25	0.88
WCS	147 a	---	16.6	7.2	7.8 a	6.1 a	0.23 a	0.25	0.93
$LSD_{0.05}$	5	---	--	--	0.7	0.6	0.01	--	0.03

[a] Means followed by the same letters in the same column and independent variable are not significantly different.
[c] IWUE = irrigation water use efficiency (irrigated yield - dryland yield)/(irrigation amount).
[d] Cropping season precipitation from Oct. 1 of previous year to Sept. 30 of current year.
[e] Off-season soil water accumulation from previous fall through the current spring.
[f] Growing season stored soil water use.
[g] ETc and ETr = crop and reference ET during soil water measurement period.

More soil water was accumulated and consumed in the WCS rotation because more time was available to accumulate soil water after winter wheat harvest than after the corn harvest

Irrigation water use efficiency (IWUE = [irrigated yield - dryland yield] / [irrigation amount]) was calculated for the deficit and full irrigation treatments. IWUE was consistently more for deficit irrigation than full irrigation because the first increment of irrigation was used more efficiently than additional irrigation. Full irrigation had more possibility for more soil water evaporation from more frequent surface wetting.

Soil Water

Growing season use of soil water (tables 3) tended to correlate with off-season gains in soil water. Available soil water holding capacity in the deep silt loam soil at the research site contributed to the ability to store water. Gains and use of soil water increased with less irrigation because roots grew deeper, creating more soil water storage volume to hold off-season precipitation. Dryland corn extracted water from as much as 7 feet deep into the soil, while fully irrigated corn extracted most of its water from the top 3 feet of soil (data not shown). When the CC and WCS rotations were compared, soil water gain and use were significantly different from each other. More time was available for soil water accumulation in the WCS rotation because corn followed winter wheat rather than corn in the CC rotation. Stored soil water use was 15%, 27%, and 52% of ETc for full irrigation, deficit irrigation, and dryland, respectively. Less stored soil water contributed to ETc as more irrigation was added. Stored soil water was 27% to 32% of ETc across the three crop rotations.

ETc and ETc/ETr (tables 3) increased significantly for each water treatment from dryland to full irrigation. However, ETc and ETc/ETr remained nearly constant across crop rotations. Additional irrigation was used to increase ETc, and more off-season soil water accumulation from dryland management also contributed to more ETc.

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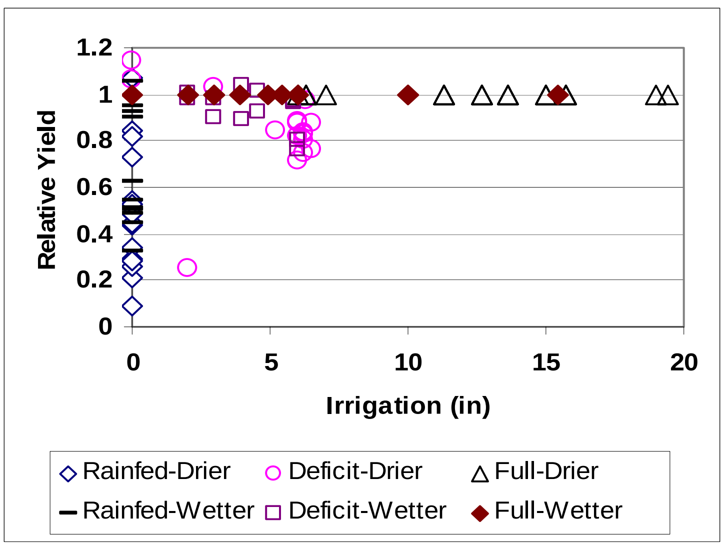

Figure 1. Crop yields as a fraction of fully irrigated yields for the drier years of 1985, '89, '90, '91, '94, '97, and '98 and the wetter years of 1986, '87, '88, '92, '93, '95, and '99.

RELATIVE GRAIN YIELD

Deficit irrigation and dryland corn yields were scaled as a fraction of fully irrigated yields from the same year (fig. 1). Data from all crop rotations were used in this analysis. The range of relative yields from dryland management (*y*-axis of fig. 1) was 0.10 to 1.15 in the drier years and 0.20 to 1.05 in the wetter years, which indicated somewhat more variation in yields from the drier years. The deficit irrigation applications generally were more during the drier years than the wetter years. Deficit irrigation increased relative yields compared with dryland yields and decreased the risk for yield results because added irrigation reduced the range of relative yields to 0.2 to 1.2 for the wetter years and 0.75 to 1.15 for the drier years. The range of full irrigation applications demonstrated that irrigation scheduling was necessary to capitalize on water conservation during the wetter years and match ETc during drier years.

YIELD PROBABILITY

Corn yields were ranked from maximum to minimum by water treatments for all years and crop rotations. The ranked data were divided into seven groups of probability values by years (fig. 2). Annual rainfall was 640, 610, 560, 510, 460, 430, and 410 mm for the 14%, 28%, 42%, 56%, 70%, 84%, and 98% probability levels, respectively (NOAA, 2007). Corn yields for each grouping of vertical bars would be expected to exceed that amount *X* years out of 100 years. For the least probability or wettest years (14 out of 100 years), all water treatments had similar yields. As probability increased from wet to dry years, irrigated corn yields decreased, but the dryland yields decreased more dramatically.

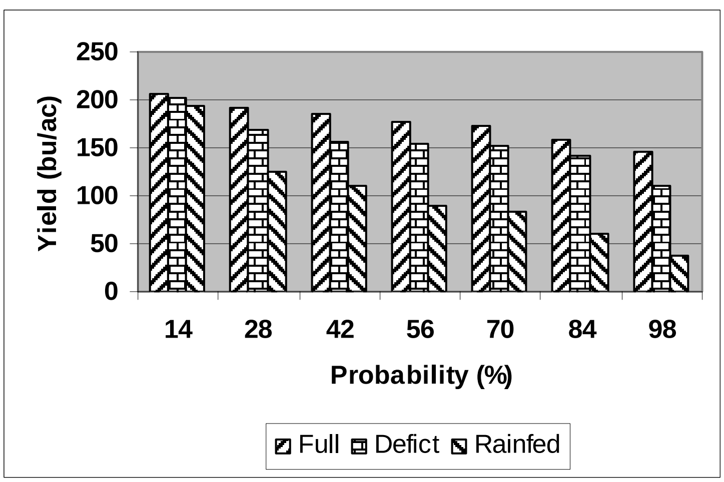

Figure 2. Percentage of time that crop yields exceed a given amount. Results based on yield history for the years 1985-1999.

SUMMARY

Corn was grown in a no-till cropping system using best management practices to apply water to deficit and full irrigation treatments. Deficit irrigation was initiated late in the vegetative growth stage or early in the reproductive stage, while full irrigation was applied to meet ETc during the growing season. The deficit irrigation treatment received no more than 6 inches of water, which was timed to favor supplying water during the reproductive and grain fill growth stages. Continuous corn (CC), and wheat-corn-soybean (WCS) crop rotations were grown in the dryland, deficit irrigation, and full irrigation treatments. Corn yields were statistically different among dryland, deficit irrigation, and full irrigation treatments and increased with added irrigation. Corn yields were statistically more in the WCS rotation than the CC rotation across water treatments. ETc was significantly different among water treatments, increasing with additional irrigation, but there was a small crop rotation effect on ETc. Irrigation water use efficiency (IWUE), defined as the additional crop yield over dryland production divided by irrigation, was significantly more from deficit irrigation than full irrigation.

From soil water parameter measurements, corn in the WCS was able to use more stored soil water than the CC rotation, which led to less dependence on irrigation. The dryland treatment accumulated significantly more soil water during the non-growing season than the deficit or fully irrigated treatments because the dryland corn was forced to extract more soil water deeper into the soil profile, leaving more room for water storage.

Dryland yields, as a fraction of fully irrigated yields (relative yield), varied more than deficit irrigation yields, which decreased the income risk for deficit irrigation compared with dryland. Over the years of the study, a wide range in water applications to the full irrigation treatment demonstrated the need to schedule irrigations to match crop water needs; otherwise, over and under irrigation could occur. When crop yields from all years and rotations were ranked from maximum to minimum values within each water treatment, yield results were predicted on the basis of probabilities. During the wettest years with low probability of occurrence, dryland, deficit irrigation, and full irrigation yields were nearly the same. As probabilities to achieve yields increased, indicating drier and drier years, dryland yields were 25% of fully irrigated yields, and deficit irrigation yields were 75% of fully irrigated yields at 98% probability of occurrence.

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