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WATER PRODUCTIVITY OF CORN AND DRY BEAN ROTATION ON VERY FINE SANDY LOAM SOIL IN WESTERN NEBRASKA

W. E. Spurgeon, C. D. Yonts

ABSTRACT. *Subsurface drip irrigation (SDI) was used to irrigate corn and dry beans in a crop rotation study for four years from 2005 to 2008 to evaluate the accumulative effect of irrigation amount on yield and irrigation water use efficiency (I_{WUE}). This study was conducted on a very fine sandy loam soil using a short season corn hybrid typical for the area. Four irrigation treatments based on providing a fraction of the estimated crop evapotranspiration (ET_c) were evaluated. The treatments were designed to replace a certain percentage of ET_c and were denoted as I_{125}, I_{100}, I_{75}, and I_{50} where the subscript indicates the percentage of ET replacement. The ET_c was accumulated, subtracting rain and irrigation amounts, to estimate soil water depletion. Irrigations were made at the various percentages when estimated depletion exceeded the I_{100} irrigation amount. The average corn yield response to applied irrigation water was 10.5 kg ha^{-1} mm^{-1} (excluding the I_{125} treatment). Corn yield was generally statistically different between the I_{125} and I_{100} treatments and each of the I_{75} and I_{50} treatments in dry years. Average dry bean yield response to irrigation was 1.5 kg ha^{-1} mm^{-1}. Dry bean yield was not statistically different. I_{WUE} was calculated by subtracting a representative dryland yield from the measured yield and then dividing by the amount of irrigation water applied. Average I_{WUE} for corn ranged from 17.8 kg ha^{-1} mm^{-1} for I_{125} to 31.1 kg ha^{-1} mm^{-1} for I_{50} and was not statistically different among all treatments overall due to a year interaction. Corn I_{WUE} values were generally statistically different between I_{50} and I_{125} in most years. Values for corn I_{WUE} were similar for I_{100} and I_{75} treatments. Average I_{WUE} for dry beans ranged from 4.55 kg ha^{-1} mm^{-1} for I_{125} to 9.15 kg ha^{-1} mm^{-1} for I_{50}. Bean I_{WUE} values for the I_{50} irrigation treatment were generally greater than the others, especially in dry years. Maximum corn yield occurred with 300 mm of irrigation water in a wet year and approximately 375 mm in dry years. For this study, dry bean yield was highly variable, partly due to treatments being over-watered when based on ET_c estimates developed for sprinkler irrigation. Bean yield showed little increase for irrigation amounts greater than 300 mm. Further research is needed examining smaller levels of irrigation, including dryland treatments, as well as different timing treatments based on actual soil water and crop stage of growth.*

Keywords. *Corn, Dry beans, Irrigation water use efficiency, Microirrigation, Subsurface drip irrigation.*

Subsurface drip irrigation (SDI) has been researched and adopted by growers in the Central High Plains over the past 20 years (Lamm et al., 2009). Much of the research has addressed the performance of 1.52 m dripline spacing for 0.76 m spaced rows for corn on silt loam.

The Nebraska Panhandle has some unique challenges that differ from the Central High plains. The growing season is limited and growers typically plant 100-day corn varieties, which limits yield as compared to full-season varieties. Much of the irrigated area has relatively steep row slopes, sometimes greater than 1%. A row slope of 1% often results in an optimum design by balancing friction loss with elevation head gain. This allows longer dripline length, maintains acceptable distribution uniformity and reduces pipe costs.

Much of the Nebraska Panhandle area consists of sandy soils. There is some concern about water erosion with SDI on sandy soils, especially with the limited crop residue from dry beans. However, by using SDI, growers would be able to leave more residue on the surface compared to traditional furrow practices, thus reducing erosion caused by water or wind (Dickey et al., 1985; Woodruff et al., 1966). Several studies also show that soil surface residue increases soil intake rates (Evans et al., 1982) and (Gilley et al., 1986). Although these benefits result from increased surface residue farming techniques, there could be an increased risk of increased rodent population that may cause problems with thin-walled driplines.

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Research data is limited concerning dry bean production under SDI. However, research on SDI-irrigated faba beans for a cover crop in California showed that production was greater for driplines placed nearer to the ground surface (0.30 and 0.45 m compared to 0.60 m). The soil was a Panoche clay loam and production was measured using plant dry weights rather than seed yield (Bryla et al., 2003).

Irrigation water was reduced 16% using alternate middle row driplines (partial root zone drying) compared to irrigations using driplines between every crop row without reductions in green bean yield or biomass reduction in a study performed in Turkey (Gencoglan et al., 2006). The SDI system consisted of driplines between every crop row 0.15 m deep on 0.70 m line spacing on a sandy-clay soil. Treatments consisted of irrigating using every dripline and every other dripline. The driplines used were rotated with the alternate middle row dripline treatment allowing the dry row to alternate.

The effect of water stress on black beans was studied on a silt loam soil in Akron, Colorado (Nielsen and Nelson, 1998). Black bean yields were most sensitive to water stress during the reproductive growth stage while plant height and leaf area were most sensitive to water stress during the vegetative growth stage. A daily deficit sprinkler irrigated dry bean study was conducted in Washington on a loam and a sand to loamy sand soil. Results indicated that total water used (accounting for soil water depletion) was reduced 16% using daily irrigations at 50% of ET compared to 100% of ET on the loam soil without reducing yield. It was not feasible to reduce daily irrigations below estimated ET without yield loss on the coarse-textured soil (Miller and Burke, 1983).

Research conducted on a deep silt loam soil in western Kansas showed little effect of dripline depth between 0.20 and 0.61 m on corn yield (Lamm and Trooien, 2005). Emitter spacing ranging from 0.3 to 1.2 m was evaluated in a 3-year study in Kansas on a deep silt loam soil (Arbat et al., 2009). The larger emitter flow rates for the longer emitter spacing apparently resulted in more water movement along the dripline, which resulted in acceptable distribution along the dripline. There were no significant differences among corn yield or water productivity (grain yield divided by total crop water use).

Lamm's research of SDI for corn found that the yield response per unit of irrigation water applied is approximately 13 kg ha^{-1} mm^{-1} in the Central U.S. Great Plains for the range of 50% to 100% of ET (Lamm et al., 1995). Similarly, van Donk et al. (2009) reported the yield response to range from 12 to 15 kg ha^{-1} mm^{-1}, although this was only for one year of data.

The objectives of this study were to evaluate the accumulative long-term yield response to reduced irrigation treatments on corn and dry bean crops using SDI, irrigating every other row (1.12 m) for 0.56 m crop row spacing.

PROCEDURE

SITE DESCRIPTION

Subsurface drip irrigation plots were installed in 2004 at the Panhandle Research and Extension Center near Mitchell, Nebraska (41° 56' N lat, 103° 42' W long., 1098 m elevation). Soil type was a Tripp very fine sandy loam with an available water holding capacity of 0.15 m/m. Row spacing for regionally grown crops such as dry beans and sugar beets is often narrower (0.56 m) than for traditional corn production (0.76 m). Therefore, the narrow spacing of 0.56 m was used for this study. The SDI lines were installed at a 1.12 m spacing to accommodate 0.56 m crop rows. Dripline for this study was installed 0.28 m below the surface. The 0.28 m dripline depth should be deep enough for possible future studies with sugar beets and shallow enough for the limited rooting depth of dry beans. This would also potentially provide an opportunity to bring water to the surface for early season germination. Emitter spacing for this study was 0.6 m to promote larger emitter flow rates and minimize the risk of clogging which should be acceptable because the soil is a very fine sandy loam. All crop rows were oriented North-South and were centered between driplines so that one dripline served two crop rows. Plots were 6.7 m wide (12 rows and 6 driplines) and 129 m long with an overall average study area row slope of 1.3%. Row slope ranged from 2.0% to 1.5% across the North block but was a uniform 0.8% across the South block.

EXPERIMENTAL DESIGN

Treatments consisted of four irrigation amounts, replicated three times for each crop, in a randomized complete block design. There were two blocks, consisting of 12 plots per block, a block for each crop during a given year. The crops were rotated between the two main blocks each year. Each plot consisted of 12 crop rows on 0.56 m row spacing. Irrigation treatments were not randomized each year so an accumulated effect of reduced water levels could be evaluated. Irrigation treatments were based on crop evapotranspiration (ET_c) values obtained from the University of Nebraska (UNL) High Plains Regional Climate Center automatic weather data network. The weather station is approximately 20 m south of the study area boundary. No attempt was made to adjust the ET_c values for the anticipated reduced evaporation using SDI. Irrigations were calculated to replace accumulated water use for the full irrigation treatment. The other three treatments were scaled accordingly. Subscripts of the irrigation treatment levels represent the percentage of the full crop ET. Irrigation treatments were I_{125}, I_{100}, I_{75}, and I_{50}.

Tables 1 and 2 summarize the agronomic data, first irrigation and last irrigation dates for corn and dry beans, respectively. Corn irrigation treatments were applied when cumulative ET_c (as calculated by the automatic weather network) for fully irrigated corn (I_{100}), exceeded 25 mm, after subtracting precipitation. Dry bean irrigation treatments were conducted in a similar manner. On all plots, the excess irrigation treatments were started on one day and finished the next; excess irrigation (I_{125}) treatments

Table 1. Corn agronomic and irrigation data for 2005-2008.

Variable	2005	2006	2007	2008
Fertilizer, N	157 kg ha^{-1}	213 kg ha^{-1}	157 kg ha^{-1}	157 kg ha^{-1}
Corn hybrid	DeKalb 4295	DeKalb 4295	DeKalb 4295	DeKalb 4291
Planting date	23 May	20 May	11 May	21 May
Harvest date	18 Oct.	17 Oct.	29 Oct.	13 Nov.
First irrigation	19 July	6 July	27 June	2 July
Last irrigation	6 Sept.	29 Aug.	6 Sept.	21 Aug.

Table 2. Dry bean agronomic and irrigation data for 2005-2008.

Variable	2005	2006	2007	2008
Fertilizer, N	157 kg ha^{-1}	79 kg ha^{-1}	79 kg ha^{-1}	79 kg ha^{-1}
Bean variety	Beryl G.N.	Beryl G.N.	Beryl G.N.	Beryl G.N.
Planting date	10 June	7 June	2 June	12 June
Harvest date	16 Sept.	7 Sept.	13 Sept.	10 Sept.
First irrigation	19 July	6 July	10 July	2 July
Last irrigation	24 Aug.	24 Aug.	23 Aug.	15 Aug.

ran 25% longer and the deficit irrigation treatments (I_{75} and I_{50}) ran proportionally shorter. All irrigation treatments within a crop block were irrigated within a 24-h period. Therefore, the first and last irrigation dates were recorded as the start day and were the same for all irrigation treatments within the specific crop. Final irrigation amount percentages varied from the desired values due to inaccuracies and errors in the actual amount applied. Actual final percentages for corn are: 123%, 100%, 79%, and 54% and dry beans were: 122%, 100%, 80%, and 48%.

This study was designed to evaluate the long-term effects of reduced irrigation amounts in a 2-year corn and dry bean rotation. Soil water amounts were not intentionally evened out before the start of each irrigation season nor were the irrigation treatments randomized from year to year for each plot.

IRRIGATION EQUIPMENT

The SDI system consisted of Typhoon dripline (Netafim USA, Fresno, Calif.) with an inside diameter of 16 mm and wall thickness of 0.32 mm. The emitters were spaced 0.61 m apart and had a 0.90 L/h discharge (at 69 kPa). Driplines were installed between alternate crop rows (1.12 m dripline spacing) at a depth of 0.28 m. Both corn and dry bean plots were planted using 0.56 m row spacing. Each plot had a 103 kPa pressure regulator to protect the dripline from inadvertent high pressure and a flow meter with totalizer. The water source was diverted river water and a 7.62 cm disc filter (Arkal 120 mesh) was used for filtering the water, which was the level of filtration recommended by the manufacturer.

AGRONOMY

Agronomic practices were similar to those used by sprinkler irrigated farms in the Nebraska Panhandle for irrigated corn production (table 1) and dry bean production (table 2). DeKalb 4295 corn hybrid was planted 2005-2007 and DeKalb 4291 2008. Beryl Great Northern dry bean variety was planted 2005-2008. Herbicides included Glyphosate for corn and a pre-emergence mixture of Dual/Magnum along with a post-emergence mixture of Raptor/Basagran for dry beans. No insecticide was used for either crop during the study. Plant densities were 9 plants m^{-2} for corn and 22 plants m^{-2} for dry beans. The soil surface was kept flat with only disking prior to planting. The crops were rotated each year which caused the corn to always be planted on plots with dry bean residue and dry beans following corn. Global position system (GPS) equipment was not used for installation of the SDI system, therefore it was an annual challenge to keep crop rows equally spaced over driplines.

All nitrogen fertilizer applications were injected using the SDI system. Application amounts were based on annual soil samples and nutrient recommendations for corn yield goal of 12.6 Mg ha^{-1}. Total seasonal nitrogen applied for corn ranged from 157 to 213 kg ha^{-1} (table 1). All corn plots received two equal amounts of nitrogen applied generally near the middle and end of July except 2006, in which corn received three applications (7, 13, and 31 July). Nitrogen applications for dry beans ranged from 79 to 157 kg ha^{-1} (table 2). One application was made each year in mid-July except 2005, which received two equal applications (12 and 25 July).

Forty feet of crop row was hand harvested in the center of each plot for both crops. Corn samples were threshed, weighed and adjusted to 15.5% grain moisture content. Dry bean samples were not adjusted for moisture. Samples were gathered, then stored inside during the fall and processed later allowing a natural dry-down.

SOIL WATER MEASUREMENTS

Volumetric soil water measurements were determined using a neutron soil moisture probe (Campbell Pacific Nuclear 503 DR) several times throughout each season. Aluminum access tubes were installed in the crop row, approximately 0.28 m from the dripline each season in each plot in similar locations. Measurements (30 s sampling time) were taken from 0.15 to 1.37 m in 0.3 m increments in each plot for corn with the exception of 2007 when the lowest depth measured was 1.07 m. All dry bean plots were measured to a depth of 1.07 m. The volumetric soil water values were calculated using a previously determined calibration, which was done using gravimetric samples of the same soil type.

Soil water measurements were limited so true water use efficiency could not be calculated. Irrigation water use efficiency was calculated by subtracting a representative dryland yield from the measured yield then dividing by the irrigation amount as described by Howell (2000). Dryland corn yield used was 2.97 Mg ha^{-1} and was obtained from USDA (NASS, 2013) for area counties during the study period of 2005-2008. Dryland bean yield used was 1.12 Mg ha^{-1} (J. Schild, personal communication, 16 July 2013).

RESULTS AND DISCUSSION

WEATHER CONDITIONS

Cumulative precipitation amounts during the study were generally below the long-time average (fig. 1). Beginning in early June 2005 received above average precipitation. Years 2006 and 2007 received below average precipitation amid long periods without precipitation in July and August. Although 2008 also received below average precipitation,

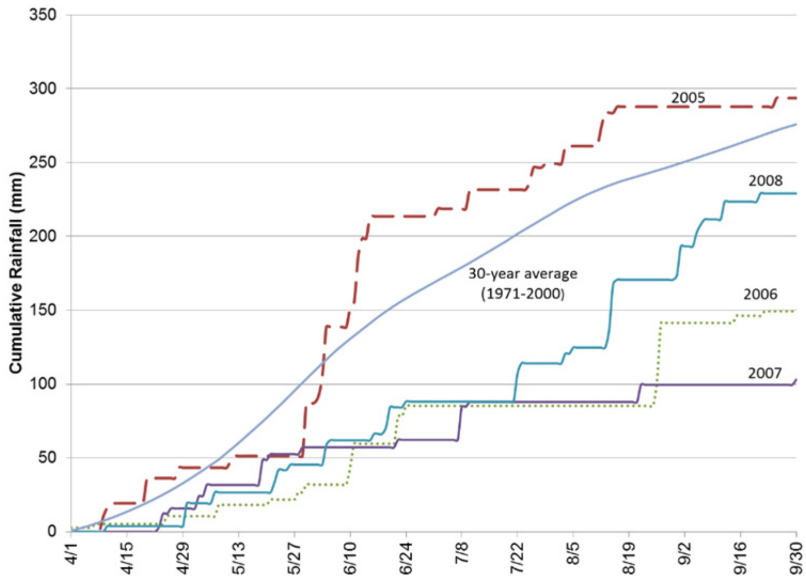

Figure 1. Precipitation at Mitchell, Nebraska for 2005-2008.

frequency was greater and the total amount was closer to the average, mainly due to precipitation occurring in September. A freeze occurred 8 June 2007, which may have reduced corn yields. The dry beans had not yet emerged and were unaffected. In-season precipitation amounts are given in tables 3 and 4 for corn and dry beans, respectively.

Soil Water

The soil water content data in the figures represent the average of three replications for each data point. Soil water data was collected in all plots from 2005 to 2008; data for 2006 for corn is shown. Total soil water content did not respond as expected to increased irrigation amounts. This may have occurred due to crop rows not being centered over the driplines.

Table 3. Corn precipitation and irrigation data for 2005-2008.

Variable[a]	2005 (mm)	2006 (mm)	2007 (mm)	2008 (mm)
I_{50} total	174	206	223	231
I_{75} total	240	308	357	315
I_{100} total	322	410	456	366
I_{125} total	395	512	489	516
Precipitation[b]	274	144	88	202

[a] Irrigation treatments were applied as a percentage of the nominal full ET_c amount. All treatments for each irrigation event were applied within a 24 h time period.

[b] Precipitation is in-season measured from emergence to senescence.

Table 4. Dry bean precipitation and irrigation data for 2005-2008.

Variable[a]	2005 (mm)	2006 (mm)	2007 (mm)	2008 (mm)
I_{50} total	108	153	146	126
I_{75} total	174	233	245	236
I_{100} total	219	318	292	283
I_{125} total	285	421	363	292
Precipitation[b]	236	123	54	149

[a] Irrigation treatments were applied as a percentage of the nominal full ET_c amount. All treatments for each irrigation event were applied within a 24 h time period.

[b] Precipitation is in-season measured from emergence to senescence.

All corn irrigation treatments, except the deficit irrigation treatments (I_{75} and I_{50}), show the largest volumetric soil water content values occurred near the surface (fig. 2). In 2006, both deficit irrigation treatments (I_{75} and I_{50}) show a slight increase in volumetric water content with depth occurring at 0.45 m from the soil surface. This may indicate a slight downward movement or redistribution of the applied water just below the dripline (0.28 m depth). There is an increase in volumetric soil water content with depth in all treatments occurring at 0.75 to 1.35 m depths, indicating the difficulty of extracting soil water at the deeper depths for a very fine sandy loam soil during long dry periods. Full and excess irrigation treatments also show a general increase in water content with time over the season. This indicates an accumulation of soil water, especially in the top portion of the root zone. Although the difference is smaller, the deficit irrigation treatments show a decrease in soil water with time for the lower portion of the root zone.

Yield and Irrigation Water Applied

Table 5 shows irrigation amount, corn yield, in-season irrigation and rain, and irrigation water use efficiency (I_{WUE}) by irrigation treatment and year for 2005-2008. I_{WUE} was calculated by subtracting the nominal dryland yield from the measured yield and then dividing by the amount of irrigation water applied. Corn yield ranged from 6.84 to 12.47 Mg ha^{-1} during the four years of the study. The greatest yields occurred in 2006, which was nearly the greatest water use year. Less yield generally occurred in 2007, which was also the driest year of the study. Smaller yield may have occurred due to near freezing temperature occurring 8 June. Year 2005 received above average precipitation and had the least yield range. Statistics were run on both corn and bean data and a year interaction was present. All statistics therefore, are reported for individual years for each crop. Corn yield was generally smaller for the deficit irrigation treatments (I_{75} and I_{50}). There were

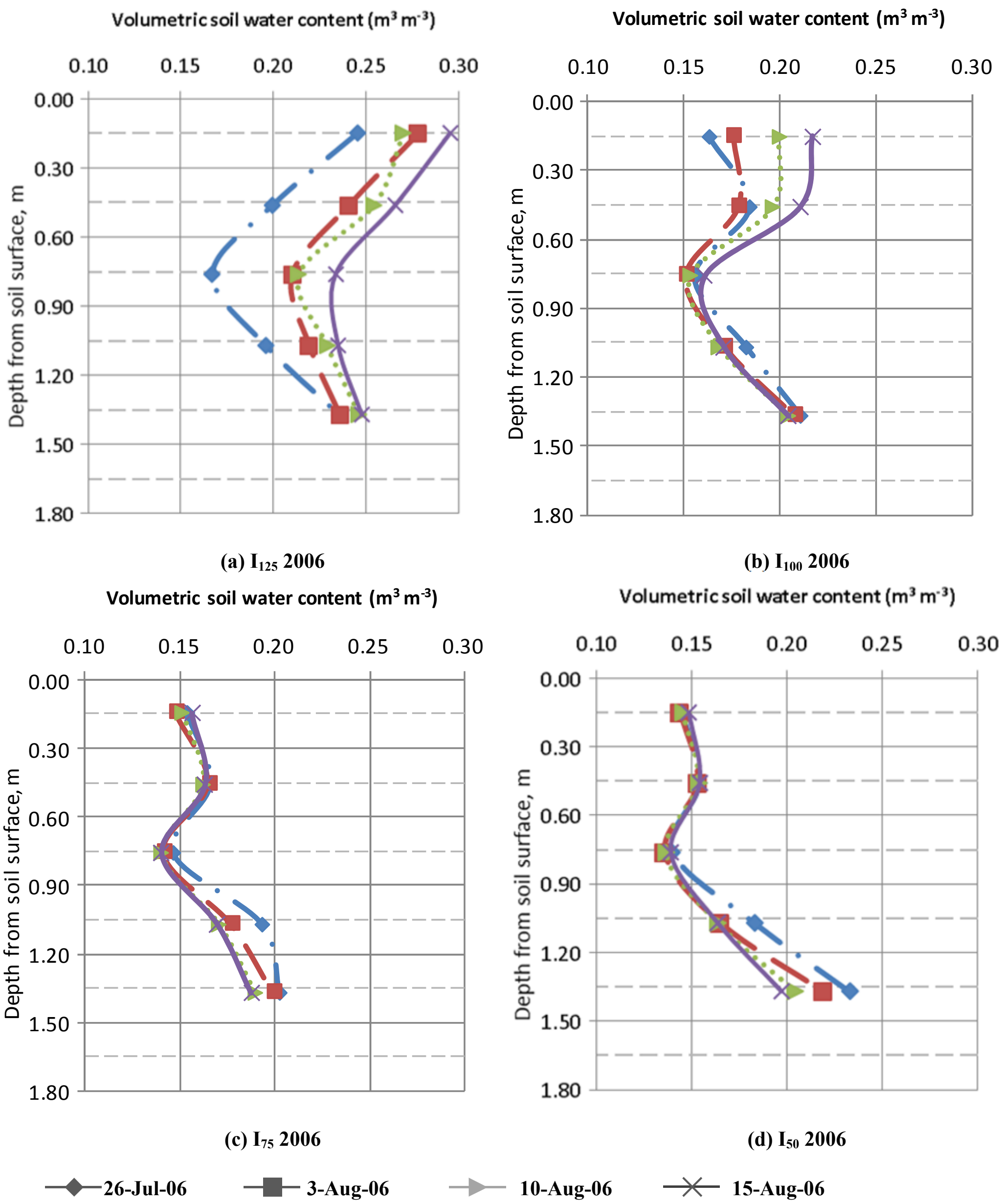

Figure 2. Volumetric soil water contents in the 1.5 m profile for corn in 2006.

small differences for the full and excess irrigation treatments. Calculated I_{WUE} was generally increased as irrigation water applied values decreased. Corn I_{WUE} values were significantly different between I_{50} and I_{125} irrigation treatments in nearly all years. Values for corn I_{WUE} were similar for I_{100} and I_{75} treatments.

Corn yield variation from year to year is shown in figure 3. Wet and dry years are indicated on the chart. Irrigation treatments were kept in the same location every year, though the crop was rotated. Yield was reduced for all treatments in 2007, a very dry year (and 8 June freeze) that followed a dry year. However, in 2008, an average year, yield recovered similar to 2006 levels.

Table 6 shows irrigation amount, dry bean yield, in-season irrigation and rain, and I_{WUE} by irrigation treatment and year for 2005-2008. Yield ranged from 1.44 to 3.63 Mg ha^{-1} for the duration of the study. Bean yields were more variable than corn yields. The greatest bean yields occurred in 2007, which was the driest year of the study which is opposite of the results for corn, when the least corn yield occurred. The least bean yield occurred for the I_{50} treatment in 2008 and the least yield for the I_{125} treatment occurred in 2005. Bean yield was generally not statistically different. Bean yield variation from year to year is shown in figure 4. Calculated bean I_{WUE} was generally greater for the I_{50} treatment compared to the other irrigation treatments especially in dry years.

Table 5. Measured and computed values by year and irrigation treatment for corn.

Year	Irrigation Treatment[a]	Yield[b] (Mg ha^{-1})	Irrig + Rain Applied (mm)	I_{WUE} (kg ha^{-1} mm^{-1})
2005	I_{50} (174 mm)	10.07 a[c]	376	40.8 a
	I_{75} (240 mm)	10.68 a	441	32.2 b
Very wet	I_{100} (322 mm)	11.28 a	524	25.8 b
	I_{125} (395 mm)	10.19 a	597	18.3 c
2006	I_{50} (206 mm)	9.87 c	323	33.5 a
	I_{75} (308 mm)	11.47 b	426	27.6 b
Dry	I_{100} (410 mm)	12.47 a	528	23.2 c
	I_{125} (512 mm)	12.37 ab	629	18.4 d
2007	I_{50} (194 mm)	6.84 c	249	19.9 a
	I_{75} (329 mm)	7.69 bc	384	14.3 bc
Very dry	I_{100} (456 mm)	8.59 ab	510	12.3 c
	I_{125} (420 mm)	9.93 a	474	16.6 ab
2008	I_{50} (231 mm)	9.92 c	415	30.1 a
	I_{75} (315 mm)	10.67 b	498	24.5 b
Avg.	I_{100} (366 mm)	12.20 a	549	25.3 b
	I_{125} (516 mm)	12.28 a	700	18.0 c
	Averages			
	I_{50} (201 mm)	9.17	341	31.1
	I_{75} (298 mm)	10.13	437	24.6
	I_{100} (388 mm)	11.14	528	21.6
	I_{125} (461 mm)	11.19	600	17.8

[a] Numbers in parenthesis are seasonal irrigation totals for each irrigation treatment (mm).
[b] Yields converted from dry mass to 15.5% moisture content by mass.
[c] Numbers followed by the same letter are not significantly different ($P \leq 0.05$) between irrigation treatment averages.

Table 6. Measured and computed values by year and irrigation treatment year for dry beans.

Year	Irrigation Treatment[a]	Yield[b] (Mg ha^{-1})	Irrig + Rain Applied (mm)	I_{WUE} (kg ha^{-1} mm^{-1})
2005	I_{50} (108 mm)	2.07 a[c]	182	8.75 a
	I_{75} (174 mm)	1.79 a	249	3.88 a
Very wet	I_{100} (219 mm)	2.18 a	293	4.83 a
	I_{125} (285 mm)	1.88 a	359	2.68 a
2006	I_{50} (153 mm)	2.29 a	235	7.65 a
	I_{75} (233 mm)	2.51 a	314	5.97 ab
Dry	I_{100} (318 mm)	2.53 a	400	4.44 b
	I_{125} (421 mm)	2.79 a	502	3.96 b
2007	I_{50} (142 mm)	3.63 a	185	17.65 a
	I_{75} (241 mm)	3.36 a	284	9.25 b
Very dry	I_{100} (292 mm)	2.80 a	335	5.75 b
	I_{125} (363 mm)	3.36 a	406	6.17 b
2008	I_{50} (126 mm)	1.44 c	253	2.57 a
	I_{75} (236 mm)	1.93 b	363	3.43 a
Avg	I_{100} (283 mm)	2.31 ab	410	4.20 a
	I_{125} (292 mm)	2.70 a	419	5.40 a
	Averages			
	I_{50} (133 mm)	2.36	214	9.15
	I_{75} (221 mm)	2.40	303	5.63
	I_{100} (278 mm)	2.46	360	4.81
	I_{125} (340 mm)	2.68	422	4.55

[a] Numbers in parenthesis are seasonal irrigation totals for each irrigation treatment (mm).
[b] Yield samples were kept inside for an extended time before threshing and had no moisture correction.
[c] Numbers followed by the same letter are not significantly different ($P \leq 0.05$) between irrigation treatment averages.

Yield and Irrigation Water Applied Relationships

Corn yield, as a function of irrigation water for all years and all treatments, has a slope of 6.9 kg ha^{-1} mm^{-1} (fig. 5). Regression was also performed on treatment averages for corn without the I_{125} treatment, which resulted in a slope of 10.5 kg ha^{-1} mm^{-1}. Bean yield response to applied irrigation for all irrigation treatments (including I_{125}) was 1.5 kg ha^{-1} mm^{-1}.

The year effect on irrigation response can be seen from the individual year regression analysis (fig. 6). Regression results for individual years (all treatments), show that all years except the wet year, 2005, had slope ranging from 8.3 to 9.4 kg ha^{-1} mm^{-1} and R^2 ranged from 0.69 to 0.83. Excluding I_{125} treatments in years 2006 and 2008 results in greater slopes, 12.7 and 16.3 kg ha^{-1} mm^{-1}, respectively, with R^2 of 0.98 and 0.89, respectively. These slopes are similar to those reported by Lamm et al. (1995) or van Donk et al. (2009), which ranged from 12 to 15 kg ha^{-1} mm^{-1}.

Figure 6 indicates that maximum corn yield was reached in the very wet year of 2005 with about 300 mm of irrigation water. In dry years, maximum yield was obtained with approximately 375 mm of irrigation water. Dry bean yields however, showed little differences among irrigation treatments, in fact the I_{50} treatment was similar to the yield found for the I_{75} treatment. There was minimal value of applying more than 300 mm of irrigation water for beans. Timing of irrigation in relationship to plant growth stage,

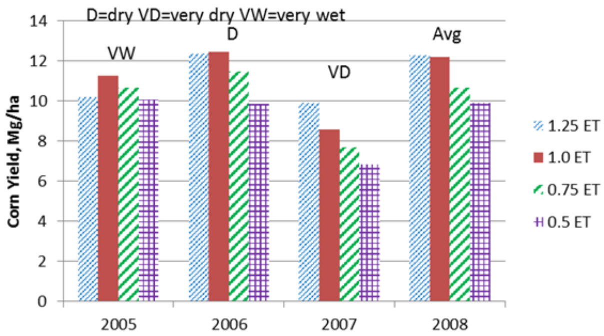

Figure 3. Corn grain yield by year for each irrigation treatment.

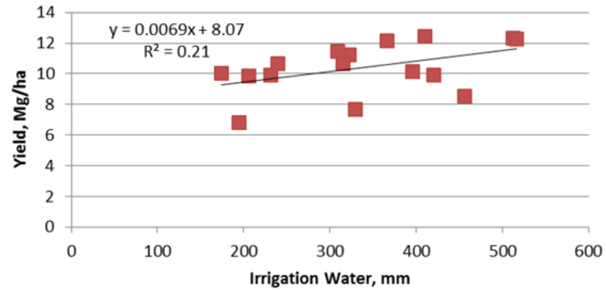

Figure 5. Corn grain yield as a function of irrigation water applied for the 2005-2008 growing seasons (all treatments and all years).

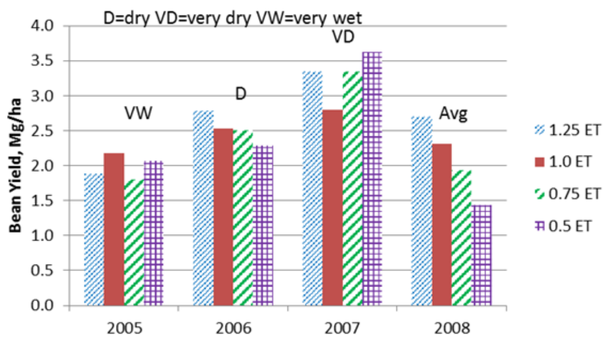

Figure 4. Dry bean yield by year for each irrigation treatment.

especially bloom and pod set, may be more critical than simply greater amounts of irrigation water.

Areas of Western Nebraska have been subject to greater water restrictions levied by local Natural Resource Districts. This is due to the severity of the recent drought. The results of this 4-year study were obtained under a variety of climate conditions. The Nebraska panhandle has, only during the last year of the study, officially recovered from drought conditions similar to those that occurred during the 1930s. Timely precipitation however, did occur during some of the years of the study.

CONCLUSIONS

The average corn yield response to applied irrigation water was 10.5 kg ha^{-1} mm^{-1} (excluding the I_{125} treatment). Corn yield was generally statistically different between the I_{125} and I_{100} treatments and each of the I_{75} and I_{50} treatments in dry years. Average dry bean yield response to irrigation was 1.5 kg ha^{-1} mm^{-1}. Bean yield varied greatly and was not statistically different among irrigation treatments. Average I_{WUE} values for corn ranged from 17.8 kg ha^{-1} mm^{-1} for I_{125} to 31.1 kg ha^{-1} mm^{-1} for I_{50} and was not statistically different among all treatments overall due to a year interaction. Corn I_{WUE} values were generally statistically different between I_{50} and I_{125} in most years. Values for corn I_{WUE} were similar for I_{100} and I_{75} treatments. Average I_{WUE} for dry beans ranged from 4.55 kg ha^{-1} mm^{-1} for I_{125} to 9.15 kg ha^{-1} mm^{-1} for I_{50}. Bean I_{WUE} values for the I_{50} irrigation treatment were generally greater than the others especially in dry years. In a wet year maximum corn yield occurred with 300 mm of irrigation water while in dry years approximately 375 mm was needed. For this study, dry bean yield was highly variable, partly due to treatments being over-watered when based on ET_c estimates developed for sprinkler irrigation. There was however, minimal bean yield increase for irrigation amounts greater

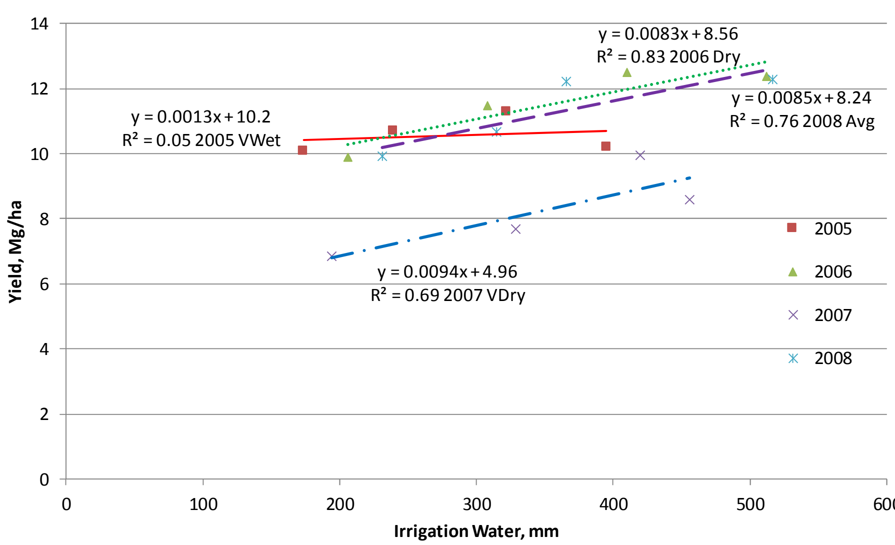

Figure 6. Corn grain yield as a function of irrigation water applied for the individual 2005-2008 growing seasons.

than 300 mm. Further research is needed examining smaller levels of irrigation, including dryland treatments as well as different timing treatments based on actual soil water and crop stage of growth.

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