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IRRIGATION CAPACITY IMPACT ON LIMITED IRRIGATION MANAGEMENT AND CROPPING SYSTEMS

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INTRODUCTION

Irrigation capacity is an important issue for irrigation management. Having enough capacity to supplement precipitation and stored soil moisture to meet crop water needs during the growing season to maximize grain yield is important. However, declines in the Ogallala Aquifer have resulted in decreases in well outputs to the point where systems on the fringe of the aquifer can no longer meet crop water needs during average growing seasons and especially during drought years. Changing cropping practices can impact the irrigation management by irrigating crops that have different water timing needs so that fewer acres are irrigated at any one point during the growing season and concentrating the irrigation capacity on fewer acres while still irrigating the majority or all acres during the year.

Many producers have not changed cropping practices with marginal capacity systems due to management increases and the potential for an above-average year. However, the risk of producing lower yields increases. Crop insurance has been used to offset those lower yields. However, the frequency of insurance claims has increased to the point where practices need to be changed on these systems.

LITERATURE REVIEW

System capacities are a function of soil type, crop water use and precipitation. The soil type acts as a bank where moisture reserves can be utilized during times when the irrigation system is not watering between cycles and during time periods when the system capacity is inadequate to meet crop water needs. Soils such as silt loams have a greater water holding capacity compared to sands which decreases the need for larger system capacities. Crop water use determines the total water utilized daily. Greater demand by the crop increases the amount of water needed for the crop over any time period. Precipitation is an important factor in irrigation capacity. A region with a greater probability of precipitation during the growing season will require less capacity to supplement crop growth.

Lamm (2004) found that irrigation capacities of 50% of the amount needed to meet crop water requirements resulted in approximately 40 bu/acre less corn yields. In above-average precipitation years, the yield difference is less and in drier than average years, the yield difference is greater. The economics of reducing irrigated acres until the irrigation capacity was equivalent to full irrigation capacities showed that irrigating those fewer acres was economically equal to or greater than irrigating all of the acres for a single crop.

Lower capacity systems generally are inadequate for meeting crop water needs during the peak water use growth stages which coincides with the reproductive growth stages and lower precipitation during those weeks of the summer. Water stress during that time period has more impact upon yield than during the vegetative and late grain-fill growth stages (Sudar et al, 1981; Shaw, 1976). Having water stress earlier or later is more desirable than during the reproductive growth stages of tasseling, silking and pollination.

The Crop Water Stress Index (CWSI; Idso et al., 1981; Garner et al., 1992) normalizes the canopy-air temperature differential for the drying capacity of the air. It is calculated from measurements of infrared canopy or leaf temperatures, air temperature, and vapor pressure deficit and varies between 0 (no water stress) and 1 (full water stress, no transpirational cooling of the leaf). CWSI has been shown to be highly correlated with other measurements of water stress (Nielsen, 1989; Li et al., 2010) such as leaf and canopy CO_2 exchange rate, leaf and canopy transpiration, leaf water potential, stomatal conductance, and plant available water in the soil profile. It is an effective index for quantifying the degree of water stress that a crop is growing under.

METHODS

The system capacity research was conducted at the Central Great Plains Research Station near Akron, CO from 2009 to 2011 and at the KSU-SWREC near Tribune, KS from 2006 to 2009.

Akron

The system capacity research was conducted at the Central Great Plains Research Station near Akron, CO. Three irrigation capacity strategies and timings were used to determine the response of corn to early season and late season water stress. The experimental field was divided into three sections and irrigated with a solid set irrigation system with an application rate of 0.42 inches per hour. The three capacities and timings were: 5 gallons per minute per acre (gpm/a) with season long irrigation (Full), 2.5 gpm/a with season long irrigation (Inadequate) and 6.7 gpm/a with irrigation delayed until 2 weeks prior to tassel emergence (Growth Stage Limited, GSL). These 3 capacities represent full irrigation capacity, inadequate capacity and growth stage timing with reduced acres for an inadequate capacity well. Three varieties were tested with varying relative maturity (99, 101 and 103 days to maturity).

Corn was planted in mid to late May at populations of 28,000 plants acre^{-1} in 2009 and 33,000 plants acre^{-1} in 2010 and 2011. Fertility management was according to soil tests. Total nitrogen applied was 175 lbs acre^{-1} and phosphorus at 40 lbs acre^{-1}.

Irrigation was applied for the full and inadequate capacity treatments if there was allowable storage for the application. During the early growth stages, irrigation applications were 0.5 inch per irrigation event while later applications were 0.75 inch per irrigation. Irrigation for the GSL treatment was withheld until 2 weeks prior to tassel emergence. Irrigation applications for this treatment were 1.0 inch per application.

Neutron probe access tubes were installed in the center of each plot (in the row) at the beginning of the experiment. Soil water was measured periodically throughout the growing season with a neutron probe (Model 503 Hydroprobe, Campbell Pacific Nuclear) at depths of 6, 18, 30, 42, 54, and 66 inches. Irrigation water was applied through a solid set irrigation system equipped with impact sprinkler heads producing an application rate of 0.42 inches hr^{-1}. Irrigation amounts were estimated from irrigation run times and sprinkler nozzle flow rates. Precipitation was measured with a standard rain guage (NWS-type with 8” receiving orifice) in the plot area. Water use (evapotranspiration) was calculated by the water balance method from the changes in soil water, applied irrigation, and precipitation. Deep percolation and runoff were assumed to be negligible.

Measurements of infrared leaf temperatures were made on one fully sunlit leaf oriented towards the sun in the upper canopy of the corn crop in the center of each of the 36 plots (three hybrids, three irrigation treatments, four replications) in 2009 and 2010 and in each of the 48 plot (four hybrids, three irrigation treatments, four replications) in 2011. Measurements were made using an Optris LS LaserSight infrared thermometer (IRT) beginning at 1300 MDT (approximately solar noon) after acclimating the IRT to ambient conditions for 60 minutes. Immediately prior to beginning the IRT measurements and following the last reading IRT measurement, the dry and wet bulb air temperatures were taken with an aspirated psychrometer positioned at 1.5 m above the soil surface at the edge of the plot area. Measurements were taken at approximately weekly intervals on days when the sun was not obstructed by cloud passages. IRT measurements were corrected for sensor drift by comparing the IRT output to that of a calibration blackbody reference at the beginning and end of the measurement period and at the end of each replication (18 plots in 2009 and 2010, 24 plots in 2011). The entire measurement sequence was completed in approximately 50 minutes.

The CWSI was calculated after the manner described by Gardner et al. (1992) using the non-water-stressed baseline for corn determined by Nielsen and Gardner (1987). The non-water-stressed baseline had a slope of -2.059^{o}C/kPa and an intercept of 2.67^{o}C. An upper maximum temperature differential of 3^{o}C was used in the calculation of CWSI.

Tribune

The study was a factorial design of well capacities (0.10, 0.15, and 0.20 in day^{-1} capacity), and seeding rate (22,500, 27,500 and 32,500 seeds a^{-1}). The irrigation treatments were whole plots and the plant populations were subplots. Each treatment combination was replicated four times and applied to the same plot each year. The irrigation treatments were applied with a lateral-move sprinkler with amounts limited to the assumed well capacities. In-season irrigations were applied from about mid-June to early September. The in-season irrigations were generally applied weekly except when precipitation was sufficient to meet crop needs. Corn was planted in late April or early May each year. The center two rows of each plot were machine harvested with grain yields adjusted to 15.5% moisture (wet basis). Soil water measurements (8 ft depth in 1 ft increments) were taken throughout the growing season using neutron attenuation. All water inputs, precipitation and irrigation, were measured.

Crop water use was calculated by summing soil water depletion (soil water at planting less soil water at harvest) plus in-season irrigation and precipitation. In-season irrigations were 9.6, 12.6, and 19.0 inches in 2006; 7.2, 10.1, 15.6 inches in 2007; 8.2, 11.0, 14.8 inches in 2008; and 8.8, 11.8, 17.9 inches in 2009 for the 0.10, 0.15, and 0.20 in day^{-1} well capacity treatments, respectively. In-season precipitation was 6.9 inches in 2006, 8.1 inches in 2007, 9.4 inches in 2008; and 14.4 inches in 2009. Non-growing season soil water accumulation was the increase in soil water from harvest to the amount at planting the following year. Non-growing season precipitation was 15.0 inches in 2007, 4.2 inches in 2008, and 8.6 inches in 2009 with an average of 9.3 in. Precipitation storage efficiency was calculated as non-growing season soil water accumulation divided by non-growing season precipitation. Crop productivity was calculated by dividing grain yield (lb a^{-1}) by crop water use (in). Local corn prices ($3.39, 4.80, 3.96, and 3.46 bu^{-1} in 2006, 2007, 2008, and 2009, respectively), crop input costs, and custom rates were used to perform an economic analysis to determine net return to land, management, and irrigation equipment for each treatment.

RESULTS

Akron

Irrigation capacity significantly decreased grain yields compared to full irrigation (Table 1). Inadequate capacities resulted in yield reductions of 26% on average compared to full irrigation. Yield reductions were as much as 46% in 2011. When water was limited during the vegetative growth stage, yield reductions were not significant compared with full irrigation.

The different irrigation treatments resulted in differential water stress development (Table 1). Water stress was generally less in 2009 compared with 2010 due to increased rainfall in 2009 (seasonal CWSI for the full irrigation treatment was 0.12 in 2009 and 0.24 in 2010). In all three years CWSI values were highest during the vegetative growth stages under the GSL treatment when irrigation was withheld during the vegetative period (CWSI = 0.59 in 2009, 0.47 in 2010 and 0.70 in 2011, averaged over hybrids). The water stress was relieved after tasseling for the GSL treatment when irrigation was applied on the same schedule as applied for the full treatment (CWSI = 0.11 in 2009, 0.24 in 2010 and 0.09 in 2011, averaged over hybrids during the reproductive stages). Because of the greater rain in 2009 the inadequate capacity treatment did not develop the high levels of water stress seen in 2010 or 2011 (CWSI = 0.09 during vegetative stages and 0.19 during reproductive stages in 2009 compared with CWSI = 0.32 during vegetative stages and 0.67 during reproductive stages in 2010 and 2011). There were no differences in CWSI due to hybrid. Yield was highly correlated with CWSI averaged over the reproductive period (Figure 1).

The ET values generally followed the same pattern as CWSI, with greater water use corresponding to lower CWSI. There were no differences in ET due to hybrid. Water use was about three inches less in 2010 than in 2009 for the full irrigation treatment, resulting in about 34 bu/a lower yield in 2010 compared with 2009 for the full irrigation treatment. Under the more favorable growing conditions of 2009, ND4903 produced higher yield than the other two hybrids under full irrigation

(252 vs. 214 bu/a) and under the growth stage limited irrigation. But all three hybrids produced the same yield under the inadequate capacity irrigation treatment (220 bu/a). In 2010 NE5321 had much lower yield (164 bu/a) than the other two hybrids (207 bu/a) under full irrigation; ND4903 had lower yield (188 bu/a) than the other two hybrids (204 bu/a) with the growth stage limited treatment. Yields were lowest in 2011 with the inadequate capacity treatment, with ND4903 yielding highest (127 bu/a) and NE5321 yielding lowest (105 bu/a).

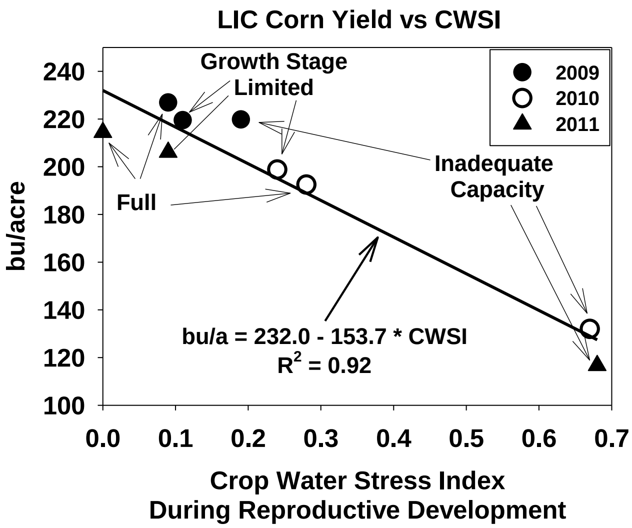

Figure 1. Corn yield vs crop water stress index.

Water use efficiency is important in production agriculture (Table 1). Crop water use efficiency (CWUE) measures the yield productivity of crops to total ET. This accounts for irrigation and precipitation uses by the crop. Overall, CWUE for Growth Stage was similar to Full irrigation management but significantly higher than Inadequate irrigation. Lower yields in 2010 and 2011 resulted in lower yields for Inadequate management. Since there is a specific amount of ET needed before crops begin to yield, that amount was a greater percentage of total ET resulting in a lower CWUE. An indication of irrigation water use efficiency (IWUE) shows the relative impact of irrigation water to crop yield increases. In 20 of the 3 years, Growth Stage had higher IWUE than either Full or Inadequate Irrigation management. Better utilization of stored soil moisture and precipitation with little to no impact on yield resulted in less irrigation needed for near Full irrigation yields. IWUE Growth Stage was similar to Full irrigation in 2011 since limited precipitation occurred during the winter and vegetative growth stages. The amount of irrigation required for both management practices was similar.

Tribune

As expected, grain yields increased with increased well capacity. Grain yields (averaged across seeding rate) were 36% greater when well capacity was increased from 0.1 to 0.2 in day^{-1} as compared to 11% when well capacity was increased from 0.1 to 0.15 in day^{-1}. Yearly yield differences ranged from as low as 10% to as much as 75% when comparing 0.1 to 0.2 in day^{-1} showing that precipitation variability is important in determining yields.

The optimum seeding rate varied with irrigation level. With the two lowest well capacities, a seeding rate of 22,500 seeds a^{-1} was generally adequate. With a well capacity of 0.2 in day^{-1}, a seeding rate of 32,500 seeds a^{-1} provided greater yields.

Crop productivity was not significantly affected by well capacity or seeding rate (Table 2), although the trend was for greater crop productivity with increased water supply. Similar to grain yields, the effect of seeding rate varied with irrigation level. With lower irrigation levels, a seeding rate of 27,500 seeds a^{-1} tended to optimize crop productivity. It was only at the highest well capacity that a higher seeding rate improved crop productivity.

Crop water use increased with well capacity (not shown). Soil water at harvest increased with increased well capacity, but this caused less soil water to accumulate during the winter. Non-growing season soil water accumulation averaged 2.7 in. Average non-growing season precipitation was 9.3 in giving an average non-growing season precipitation storage efficiency of 29%. Seeding rate had minimal effect on soil water at planting or crop water use but increased seeding rate tended to decrease soil water at harvest and increase over-winter water accumulation.

Allocations

If irrigation well capacity is not an issue for management decisions but a producer is regulated to a limited allocation of water to pump, irrigation management decisions of when and how much to pump are critical. In 2 out of the 3 years, Growth Stage management allowed a producer to grow more acres and produce more bushels of corn than Full irrigation management. On a 3 year average, a producer would have been able to irrigate 11% more acres and produce 11% more total bushels of corn utilizing Growth Stage management as compared to Full irrigation management with the same allocation.

Utilizing the Inadequate management strategy of applying small amounts of water during the entire growing season, a producer could have irrigated approximately 36% more acres than Full irrigation but would have only produced the same total bushels as Full irrigation management. Only in above average precipitation years does the inadequate management strategy produce more total bushels than Full irrigation with a given quantity of water.

Overall

Yield compared to ET at Akron, CO and Tribune, KS was a linear response (Figure 2). The yield response at Akron was slightly greater than the yield response observed at Tribune. A linear response at both locations shows that as irrigation system capacity is diminished, yield reductions will occur.

Economics of irrigation with limited well capacities is important in determining the acreage of corn to be grown with a specific well capacity. At Akron and Tribune, a limited well capacity resulted in net returns to risk and management of 58% of adequate capacities (Table 3). When well capacities are such that only 50% of the irrigated acreage can be fully irrigated, total returns are only reduced by less than $6,000 when irrigating only 50% of the acres. However, during years of drought such as 2008 at Tribune and 2010 and 2011 at Akron, yield reductions by irrigating all the acres resulted in losses.

CONCLUSIONS

Timing and capacity had an impact on grain yield when precipitation was below average. With an inadequate capacity well a 25% reduction in grain yields as compared with a full irrigation capacity well was observed. Timing irrigation towards reproductive growth with a higher capacity well resulted in similar grain yields to full season irrigation with a high capacity well. Reducing irrigation during the vegetative growth stage resulted in higher crop water stress indexes. However, an irrigation capacity which can meet crop water needs reduced the crop water stress index to values similar to full irrigation capacities and resulted in little or no yield loss during reproductive development.

When capacities are limited on the entire system, management strategies and cropping practices that result in fewer acres of an irrigated crop can alleviate the potential for severely reduced yields as compared with irrigating the entire system with inadequate capacities. Variety selection is important as the yield potential can vary by water management.

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Table 1. Evapotranspiration, yield, and crop water stress index for irrigation capacities and strategies for 2009, 2010, and 2011.

		Irrigation	ET	Yield	CWUE	IWUE	Average	Veg.	Reprod.	Allocation 1000 ac-in	
Year	Irrigation	(in)	(in)	(bu/ac)	(bu/ac-in	(bu/ac-in)	CWSI†	CWSI‡	CWSI ζ	Acres	Bu grown
2009	Full	10.2	25.4	226.0	8.9	16.3	0.12	0.09	0.09	98	22135
	Growth Stage	7.0	22.3	219.0	9.8	22.6	0.31	0.59	0.11	142	31108
	Inadequate	8.7	24.2	219.0	9.0	18.4	0.18	0.09	0.19	116	25318
2010	Full	11.7	22.4	192.0	8.6	11.6	0.24	0.22	0.28	86	16424
	Growth Stage	10.9	22.6	198.0	8.8	13.0	0.37	0.47	0.24	92	18132
	Inadequate	7.8	19.0	132.0	6.9	9.8	0.48	0.32	0.67	128	16945
2011	Full	12.7	21.4	214.0	10.0	12.4	0.02	0.04	0	79	16811
	Growth Stage	13.1	21.2	206.0	9.7	11.5	0.41	0.7	0.09	76	15749
	Inadequate	8.9	18.9	116.0	6.1	6.8	0.4	0.16	0.68	113	13078
Average	Full	11.5	23.1	210.7	9.2	13.2				87	18250
	Growth Stage	10.3	22.0	207.7	9.4	14.5				97	20071
	Inadequate	8.4	20.7	155.7	7.4	11.6				119	18451

†Averaged over all measurements taken: 7/1 to 9/8/2009, 6/29 to 8/31/2010, and 7/18 to 9/1/2011

‡Averaged over vegetative development

ζ Averaged over reproductive development

Table 2. Crop parameters of corn as affected by well capacity and seeding rate (without preseason irrigation), Tribune, KS, 2006 - 2009

Well Capacity			Seed rate	Avg. Grain Yield	2006 Grain Yield	2007 Grain Yield	2008 Grain Yield	2009 Grain Yield	Avg Crop Prod.
in day^{-1}			10^3 a^{-1}	bu a^{-1}	bu a^{-1}	bu a^{-1}	bu a^{-1}	bu a^{-1}	lb ac-in^{-1}
0.1			22.5	150	175	197	44	183	379
			27.5	155	174	202	51	192	389
			32.5	152	175	195	45	194	382
0.15			22.5	169	181	207	89	197	381
			27.5	170	194	216	77	193	387
			32.5	167	176	204	79	211	375
0.2			22.5	196	201	214	170	197	395
			27.5	207	219	235	165	207	405
			32.5	218	223	242	185	222	430
MEANS	Well	0.1		152	175	198	47	190	383
	cap.	0.15		169	184	209	82	200	381
		0.2		207	214	230	173	209	410
		$LSD_{0.05}$		20	26	20	39	15	43
	Seed	22,500		171	186	206	101	192	385
	rate	27,500		177	196	218	98	197	394
		32,500		179	191	214	103	209	395
		$LSD_{0.05}$		10	12	7	11	7	26

Table 3. Net return to risk and management from three irrigation well capacities and three seeding rates at Tribune, KS and irrigation well capacity and management at Akron, CO.

Tribune			
Well	Seeding rate (10^3 a^{-1})		
capacity	22.5	27.5	32.5
in day^{-1}	Net return, \$ a^{-1} yr^{-1}		
0.1	**\$346**	**\$359**	**\$334**
0.15	**\$419**	**\$414**	**\$389**
0.2	**\$533**	**\$575**	**\$620**

Akron	
	Net return, \$ a^{-1} yr^{-1}
Inad	**\$356**
GSL	**\$599**
Full	**\$620**

Figure 2. Yield vs Evapotranspiration for Akron, CO and Tribune, KS.