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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.

Heermann (1991) determined the net design capacity for Eastern Colorado along with probabilities of meeting the crop water needs for the growing season for full water needs (Figure 1). As capacities decline the probability of meeting crop water needs declines. A 50% probability means that on average, you will meet crop water needs one out of two years and you will not meet crop water needs the other year. The result will be less than desired yields.

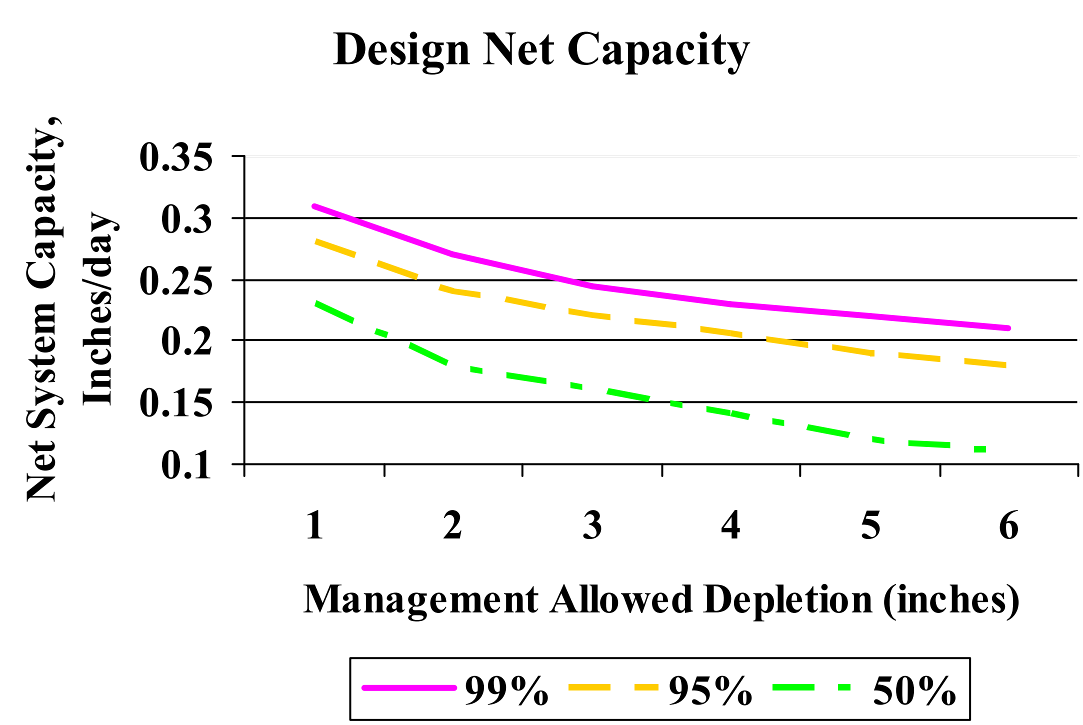

Figure 1. Net irrigation capacities for Eastern Colorado (Heermann).

Lamm (2004) found that irrigation capacities of 50% of 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 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. This also coincides with the reproductive growth stages and less average annual precipitation during that time period of a summer crop. 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 tassel, silking and pollination.

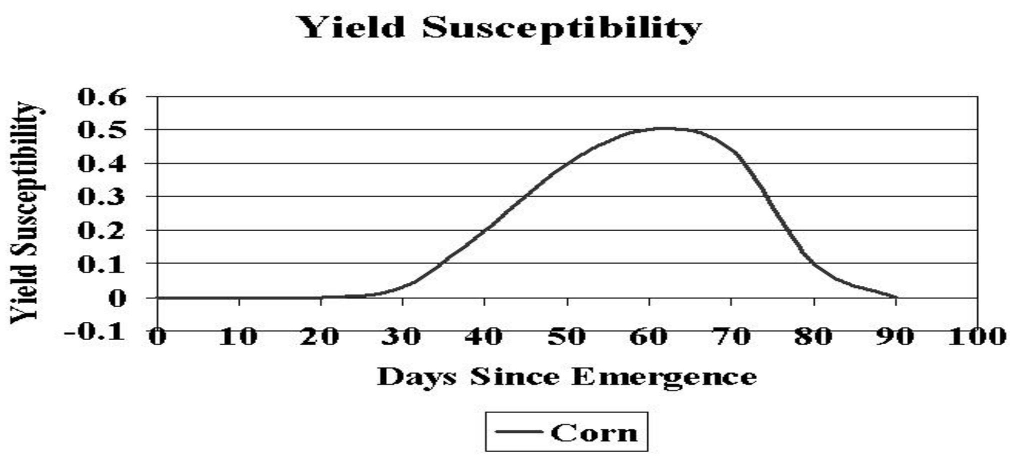

Figure 2. Yield susceptibility to water stress for corn (Sudar et al., 1981).

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.

Methods

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, GSL). These 3 capacities represent full irrigation capacities, inadequate capacities and growth stage timing with reduced acres for an inadequate capacity. Three varieties were tested with varying relative maturity (99, 101 and 103 day days to maturity).

Irrigation was applied for the full and inadequate capacity if there was allowable storage for the application. During the early growth stages, irrigation applications were 0.5 inch while later applications were 0.75 inch. Irrigation for the growth stage was withheld until 2 weeks prior to tassel emergence. Irrigation applications for growth stage 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 and 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 at a weather station approximately 1000 feet from 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). 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 (9 plots). 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.

Stomatal conductance measurements show the speed at which water vapor transpires from the leaf tissue to the atmosphere. Water stress results in lower conductance as compared to non-stressed vegetation. Stomatal conductance measurements were taken with a Decagon Leaf Porometer model SC-1. Three measurements were taken per plot on the most fully developed leaf in the upper canopy fully exposed to the sun. Measurements were taken between 1300 and 1600 MDT when water stress impacts on transpiration should be the greatest. Atmospheric conditions such as temperature and humidity have a significant impact on stomatal conductance so comparisons within a day are relevant as compared to day to day comparisons within a water treatment.

Results

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 both 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 and 0.47 in 2010, 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 and 0.24 in 2010,

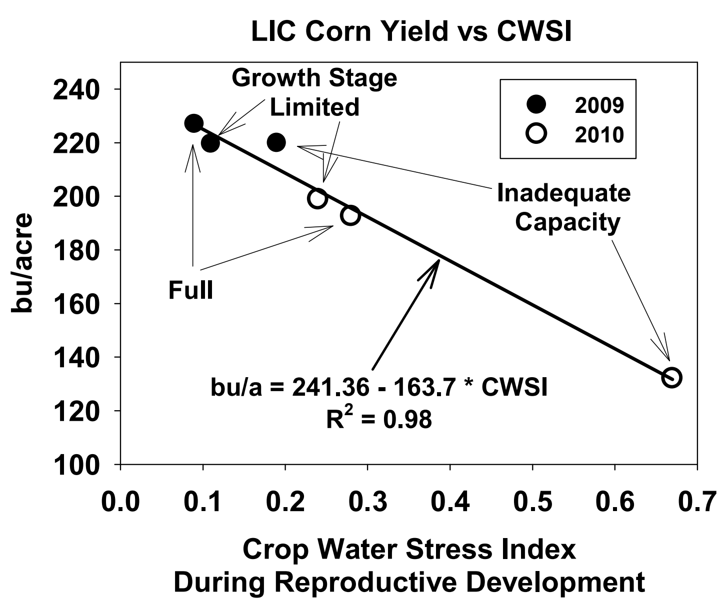

Figure 3. Corn yield vs crop water stress index.

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 (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). There were no differences in CWSI due to hybrid. Yield was highly correlated with CWSI averaged over the reproductive period (Figure 3).

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

Year	Irrigation	Hybrid	ET (in)	Yield (bu/a)	Average CWSI†	Vegetative CWSI‡	Repro-ductive CWSI ζ
2009	Full	ND4903	26.01	251.6	0.10	0.06	0.07
		EXP151	23.62	213.7	0.11	0.14	0.07
		NC5607	26.61	215.3	0.16	0.08	0.14
	Growth Stage	ND4903	22.37	239.5	0.29	0.58	0.11
		EXP151	22.19	202.4	0.40	0.76	0.16
		NC5607	22.40	216.6	0.23	0.43	0.08
	Inadequate Capacity	ND4903	24.25	218.7	0.27	0.09	0.32
		EXP151	24.73	218.0	0.13	0.05	0.14
		NC5607	25.42	222.9	0.14	0.12	0.12
	Avg. by Irrigation	Full	25.41	226.9	0.12	0.09	0.09
		GSL	22.32	219.5	0.31	0.59	0.11
		Inad Cap	24.80	219.8	0.18	0.09	0.19
	Averaged by Hybrid	ND4903	24.21	236.6	0.22	0.24	0.17
		EXP151	23.51	211.3	0.21	0.32	0.12
		NC5607	24.81	218.3	0.18	0.21	0.11
2010	Full	ND4903	22.83	203.8	0.26	0.24	0.30
		TXP151	22.39	209.5	0.24	0.20	0.30
		NE5321	21.98	164.1	0.23	0.22	0.24
	Growth Stage	ND4903	22.6	187.8	0.38	0.48	0.25
		TXP151	22.34	204.9	0.34	0.45	0.22
		NE5321	22.77	203.6	0.39	0.50	0.26
	Inadequate Capacity	ND4903	18.86	140.6	0.51	0.34	0.69
		TXP151	19.02	133.5	0.48	0.33	0.65
		NE5321	19.13	121.9	0.45	0.29	0.65
	Avg. by Irrigation	Full	22.40	192.5	0.24	0.22	0.28
		GSL	22.57	198.8	0.37	0.47	0.24
		Inad Cap	19.00	132.0	0.48	0.32	0.67
	Averaged by Hybrid	ND4903	21.43	177.4	0.38	0.35	0.41
		TXP151	21.25	182.6	0.35	0.33	0.39
		NE5321	21.30	163.2	0.35	0.34	0.38

†Averaged over all measurements taken: 7/1 to 9/8/2009 and 6/29 to 8/31/2010
‡Averaged over vegetative development
ζ Averaged over reproductive development

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 2010 with the inadequate capacity treatment, with ND4903 yielding highest (140 bu/a) and NE5321 yielding lowest (122 bu/a).

Irrigation capacities had a significant impact on stomatal conductance during the growing season in 2010 (Table 2). System capacities less than adequate had lower stomatal conductance as compared to adequate capacities. Early in the growing season, stomatal conductance for inadequate, growth stage and full irrigation were similar on June 29. Since irrigation was not initiated until just prior to tasseling on the growth stage treatment, lower stomatal conductance rates were observed in early July as compared to full irrigation while the inadequate capacity was similar to full. Lack of precipitation during late June and July resulted in reduced stomatal conductance on July 26 for both inadequate and growth stage management as compared to full irrigation. This water stress for inadequate and growth stage treatments was during tassel emergence. Irrigation was initiated on the growth stage treatment at this time with application amounts that would be similar to maximum transpiration rates. Stomatal conductance rates for the growth stage treatment on August 13 were similar to full irrigation while the conductances under the inadequate capacity treatment were less than under both growth stage and full irrigation. The difference in stomatal conductance between full irrigation and inadequate capacity increased later in the growing season (August 20) indicating that water stress levels were increasing in the inadequate capacity management.

Conclusions

Timing and capacity had an impact on grain yield when precipitation was below average. Grain yields with an inadequate capacity resulted in a 32% reduction in grain yields as compared to full irrigation capacities. Timing irrigation towards reproductive growth with a higher capacity resulted in similar grain yields. 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.

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 to irrigating the entire system with inadequate capacities. Variety selection is important as the yield potential can vary by water management.

Table 2. Stomatal conductance for irrigation capacities, strategies and varieties for 2010.

Inadequate Capacity

Date	ND4903	EXP151	NE5321	Avg
	mmol/m^2-sec			
6/29	249	194	212	218
7/12	463	342	446	417
7/26	200	179	298	226
8/13	175	197	203	192
8/20	187	180	214	194
Avg.	255	218	275	249

Growth Stage

Date	ND4903	EXP151	NE5321	Avg
	mmol/m^2-sec			
6/29	249	277	250	259
7/12	305	266	336	302
7/26	165	183	208	185
8/13	264	296	285	282
8/20	316	337	277	310
Avg.	260	272	271	268

Full Irrigation

Date	ND4903	EXP151	NE5321	Avg
	mmol/m^2-sec			
6/29	261	237	322	273
7/12	465	474	480	473
7/26	316	240	328	295
8/13	228	284	245	252
8/20	346	362	369	359
Avg.	323	319	349	330

References

Gardner, B.R., D.C. Nielsen, and C.C. Shock. 1992. Infrared thermometry and the Crop Water Stress Index. I. History, Theory, and Baselines. J. Prod. Agric. 5:462-466.

Idso, S.B., R.D. Jackson, P.J. Pinter, Jr., R.J. Reginato, and J.L. Hatfield. 1981. Normalizing the stress-degree-day parameter for environmental variability. Agri. Meteorol. 24: 45-55.

Heermann , D.F. 1991. Sprinkler Irrigation Basics. Central Plains Irrigation Short Course and Exposition. February 5-6, 1991,North Platte, Nebraska. Central Plains Irrigation Association, Colby, Kansas. pp.52-58.

Lamm, F.L., 2004. Corn production as related to sprinkler irrigation capacity. In Proceedings of the Central Plains Conference, Kearney, Nebraska, Feb 17-18, 2004. Available from CPIA 760 N. Thompson, Colby, Kansas. pp 23-36.

Li, L., D.C. Nielsen , Q. Yu., L. Ma, and L.R. Ahuja. 2010. Evaluating the Crop Water Stress Index and its correlation with latent heat and CO_2 fluxes over winter wheat and maize in the North China Plain. Agric. Water Manage. 97:1146-1155.

Nielsen, D.C., and R.L. Anderson. 1989. Infrared thermometry to measure single leaf temperatures for quantification of water stress in sunflowers. Agron. J. 81:840-842.

Nielsen, D.C., and B.R. Gardner. 1987. Scheduling irrigations for corn with the crop water stress index (CWSI). Appl. Agric. Res. 2:295-300.

Schneekloth, J.P., 2005. Response of irrigated sunflower to water timing. In Proceedings of the Central Plains Conference, Sterling, Colorado, Feb 17-18, 2005. Available from CPIA 760 N. Thompson, Colby, Kansas. pp 44-50.

Shaw, R.H. 1976. Climatic requirement. p. 591-623. *In* G.F. Sprague (ed.) Corn and corn improvement. Agron. Monogr. 18. ASA, CSSA, and SSSA, Madison, WI.

Sudar, R. A., K. E. Saxton, and R. G. Spomer. 1981. A predictive model of water stress in corn and soybeans. Transactions of ASAE, 24:97-102