An ASABE Meeting Presentation

Paper Number: 062208

Crop Production in Western Kansas as Related to Irrigation Capacity

Freddie R. Lamm, Professor and Research Irrigation Engineer, PhD

KSU Northwest Research Extension Center, Colby, Kansas. flamm@ksu.edu

Loyd R. Stone, Professor and Research Soil Physicist, PhD

KSU Department of Agronomy, Manhattan, Kansas. stoner@ksu.edu

Daniel M. O'Brien, Area Director and Agricultural Economist, PhD

KSU Northwest Research Extension Center, Colby Kansas. dobrien@oznet.ksu.edu

Contribution No. 06-319-A, Kansas Agricultural Experiment Station

Written for presentation at the
2006 ASABE Annual International Meeting
Sponsored by ASABE
Oregon Convention Center
Portland, Oregon
9 - 12 July 2006

***Abstract*.** Crop production and economics of irrigated corn, grain sorghum, soybean and sunflower were simulated for 34 years of weather data in Northwest Kansas at irrigation system capacities ranging from dryland production up to 8.5 mm/day. The simulated net irrigation requirements for corn, grain sorghum, soybean and sunflower for the 34-year period were 375, 272, 367, and 311 mm, respectively. Assuming a 95% application efficiency (Ea), the average long term crop yield is approximately 12.9, 8.2, 4.4 and 3.2 Mg/ha for corn, grain sorghum, soybean and sunflower, respectively. Although corn is currently the predominant irrigated crop in western Kansas, current projections indicate soybean is a more profitable alternative. Soybean net irrigation requirements are only about 2% lower than corn, so a shift to soybean will not result in significant water conservation.

Keywords. Irrigation system capacity, irrigation management, irrigation economics, evapotranspiration, modeling, corn, grain sorghum, soybean, sunflower

Introduction

In arid regions, it has been a design philosophy that irrigation system capacity should be sufficient to meet the peak evapotranspiration needs of the crop to be grown. This philosophy has been modified for areas having deep silt loam soils in the semi-arid US Central Great Plains to allow peak evapotranspiration needs to be met by a combination of irrigation, precipitation and stored soil water reserves. The major irrigated summer crops in the region are corn, grain sorghum, soybean and sunflower. Corn is very responsive to irrigation, both positively when sufficient and negatively when insufficient. The other crops are less responsive to irrigation and are sometimes grown on more marginal capacity irrigation systems. This paper will discuss the simulated irrigation requirements rates and the effect of irrigation system capacity on summer crop production and net returns. Although the results presented here are based on simulated irrigation schedules for 34 years of weather data from Colby, Kansas (Thomas County in Northwest Kansas) for deep silt loam soils, the concepts have broader application to other areas in showing the importance of irrigation capacity for summer crop production.

Procedures

Weather data from 1972 through 2005 for Colby, Kansas (Thomas County) was used to calculate reference evapotranspiration, ET_r, using a modified Penman equation (Lamm, et al., 1987). The reference evapotranspiration was further modified with empirical crop coefficients for the region (Figure 1) to give the crop evapotranspiration, ET_c.

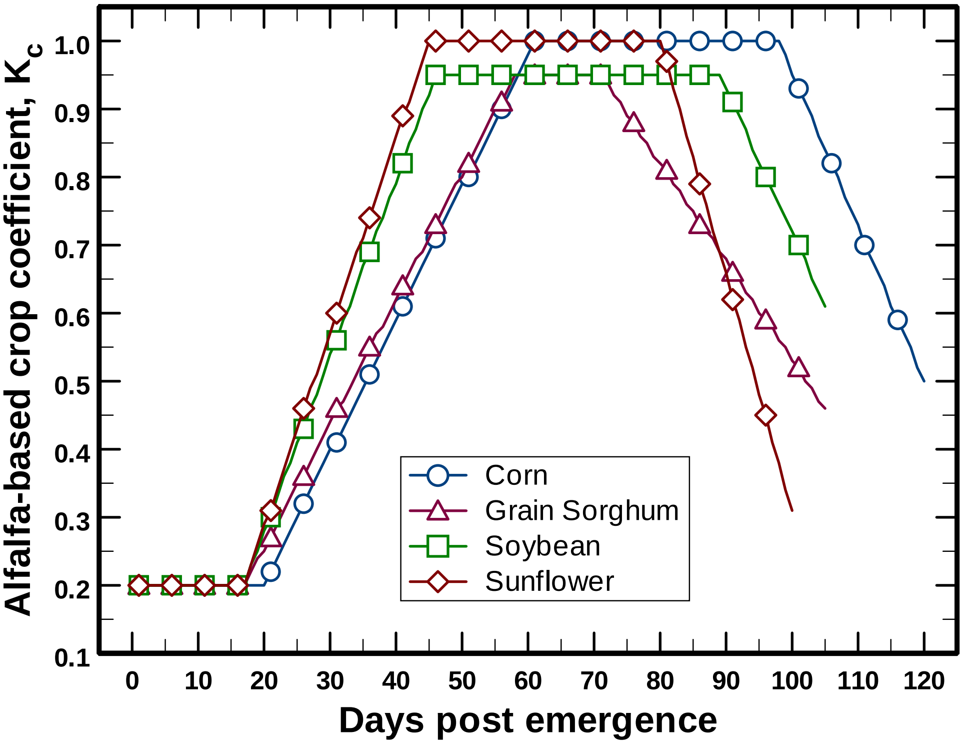

Figure 1. Alfalfa-based crop coefficients used in the simulated irrigation schedules and crop yield modeling.

Irrigation schedules (water budgets) for the major summer crops (corn, grain sorghum, soybean and sunflower) were simulated with a daily time-step for the same 34 year period using precipitation and calculated ET_c. Typical emergence, physiological maturity, and irrigation season dates were used in the simulation (Table 1). The 1.5 m soil profile was assumed to be at 85% of field capacity at corn emergence (May 15) in each year. Effective rainfall was allowed to be 88% of each event up to a maximum effective rainfall of 57.2 mm/event. The application efficiency, Ea, was initially set to 100% to calculate the simulated full net irrigation requirement, SNIR. Center pivot sprinkler irrigation events were scheduled if the calculated irrigation deficit exceeded 25.4 mm.

Table 1. Parameters and factors used in the simulation of irrigation schedules and crop yield modeling.

Parameter	**Corn**	**Grain Sorghum**	**Soybean**	**Sunflower**
Emergence date	May 15	June 1	May 25	June 15
Physiological maturity date	September 11	September 13	September 16	September 11
Crop season, d	120	105	115	100
End of irrigation season	September 2	September 4	September 7	September 2
Irrigation season, d	110	95	105	90
Factors for crop yield model				
Vegetative period, d	66	54	38	53
Susceptibility factor (vegetative)	36.0	44.0	6.9	43.0
Flowering period, d	9	19	33	17
Susceptibility factor (flowering)	33.0	39.0	45.9	33.0
Seed formation period, d	27	22	44	23
Susceptibility factor (formation)	25.0	14.0	47.2	23.0
Ripening period, d	18	10	-	7
Susceptibility factor (ripening)	6.0	3.0	-	1.0
Slope on yield model, Mg/ha-mm	0.0416	0.0301	0.0121	0.0096
Intercept on yield model, Mg/ha	-11.55	-5.32	-2.40	-1.33

The irrigation scheduling model was coupled with a crop yield model to calculate crop grain yields as affected by irrigation capacity. In this case, the irrigation level is no longer full irrigation but was allowed to have various capacities (no irrigation and 25.4 mm every 3, 4, 5, 6, 8 or 10 d). Irrigation was scheduled according to climatic needs, but was limited to these capacities.

Crop yields for the various irrigation capacities were simulated for the same 33 year period (1972-2005) using the irrigation schedules and a yield production function developed by Stone et al. (1995). In its simplest form, the model results in the following equation,

$$\text{Yield} = (\text{YldSlope} \times ET_c) + \text{Yldintercept}$$

with yield expressed in Mg/ha, yield intercept and slope as shown in Table 1 and ETc in mm. As an example, the equation for corn would be,

$$\text{Yield} = (0.0416 \times ET_c) - 11.55 \text{ Mg/ha}$$

Further application of the yield model reflects crop susceptibility weighting factors for specific growth periods (Table 1). These additional weighting factors were incorporated into the simulation to better estimate the effects of irrigation timing for the various system capacities. The weighting factors and their application to the model are discussed in detail by Stone et al. (1995). Soybean weighting factors were developed by use of yield response factors of Doorenbos and Kassam (1979).

The economic component of this analysis estimates economic returns from crop production over annual variable cash production costs. The 2006 cost estimates used here (Table 2 and 3) include variable cash crop production costs for seed, herbicides, insecticides, fertilizer, crop consulting and custom harvest. Also included are annual irrigation fuel, oil, repair and irrigation labor costs, as well a custom rates-based estimate of machinery expenses. Crop price, farm program revenue, interest cost, and other crop production enterprise assumptions in this study are consistent with 2006 Farm Management Guide Crop Production Budgets for irrigated and dryland crops developed by K-State Research and Extension. In this analysis, cost items that do not vary across the alternative crop enterprises were not considered. These include land charges, depreciation and interest on irrigation equipment, a $ 25/ha miscellaneous crop expense charge, and non-machinery labor charges. Crop insurance was not included in these budgets.

Table 2. Economic Parameters Varying by Crop

	Corn	Grain Sorghum	Soybean	Sunflower
Crop Price, $/kg	$0.1012	$0.0894	$0.2065	$0.2575
Herbicide. $/ha	$75.48	$66.98	$36.74	$46.60
Insecticide, $/ha	$95.63	$0.00	$0.00	$35.40
Seed Cost, $/unit	$1.49/K	$5.88/kg	$0.21/K	$1.34/K
Consulting, $/ha	$16.06	$15.44	$15.44	$16.06
Custom Rates Machinery, $/ha	$74.67	$66.53	$62.56	$74.15
Yield Threshold for Extra Harvest Charge, Mg/ha	4.77	2.26	1.75	NA
Extra Charge for Yield, $/Mg	$6.06	$5.71	$5.33	NA
Crop Hauling Cost, $/Mg	$5.00	$5.59	$5.10	$4.96

Net Government Payments, All Crop and Irrigation Scenarios, $88.21/ha

Interest Rate Used On ½ Production Costs, All Crop and Irrigation Scenarios, 8%

Irrigation Labor, All Crop and Irrigation Scenarios, $12.36/ha

Irrigation Fuel and Oil, All Crop and Irrigation scenarios, $0.2657/mm

Irrigation Repairs and Maintenance, All Crop and Irrigation Scenarios $0.01299/mm

Table 3. Economic Parameters Varying by Crop and Irrigation Capacity

Crop and Item	***Irrigation Capacity, mm/d***						
	8.5	**6.4**	**5.1**	**4.2**	**3.2**	**2.5**	**Dryland**
Corn Seeding Rate, 1000 p/ha	84.0	79.1	74.1	69.2	64.2	59.3	44.5
Corn Seed Cost, $/ha	$125.18	$117.82	$110.45	$103.09	$95.73	$88.36	$66.27
Corn N-Rate at $0.639/kg, kg/ha	286	280	263	252	224	202	112
Corn N Fertilizer Cost, $/ha	$182.73	$179.15	$168.40	$161.23	$143.32	$128.99	$71.66
Corn P-rate at $0.551/kg, kg/ha	95	90	84	78	73	67	34
Corn P Fertilizer Cost, $/ha	$52.51	$49.42	$46.33	$43.24	$40.15	$37.07	$18.53
Grain Sorghum Seeding Rate, kg/ha	7.3	7.3	7.3	7.3	7.3	6.7	3.4
Grain Sorghum Seed Cost, $/ha	$42.88	$42.88	$42.88	$42.88	$42.88	$39.59	$19.79
Grain Sorghum N-Rate at $0.639/kg, kg/ha	118	118	118	112	112	101	67
Grain Sorghum N Fertilizer Cost, $/ha	$75.24	$75.24	$75.24	$71.66	$71.66	$64.49	$43.00
Grain Sorghum P-rate at $0.551/kg, kg/ha	62	62	62	62	56	50	34
Grain Sorghum P Fertilizer Cost, $/ha	$33.98	$33.98	$33.98	$33.98	$30.89	$27.80	$18.53
Soybean Seeding Rate, 1000 p/ha	371	371	371	358	346	334	297
Soybean Seed Cost, $/ha	$77.84	$77.84	$77.84	$75.24	$72.65	$70.05	$62.27
Soybean P-rate at $0.551/kg, kg/ha	62	62	62	62	56	50	34
Soybean P Fertilizer Cost, $/ha	$33.98	$33.98	$33.98	$33.98	$30.89	$27.80	$18.53
Sunflower Seeding Rate, 1000 p/ha	43.5	43.5	43.5	43.5	43.5	43.5	39.5
Sunflower Seed Cost, $/ha	$58.28	$58.28	$58.28	$58.28	$58.28	$58.28	$52.98
Sunflower N-Rate at $0.639/kg, kg/ha	157	157	151	146	135	129	90
Sunflower N Fertilizer Cost, $/ha	$100.32	$100.32	$96.74	$93.16	$85.99	$82.41	$57.33
Sunflower P-rate at $0.551/kg, kg/ha	56	56	53	50	47	45	34
Sunflower P Fertilizer Cost, $/ha	$30.89	$30.89	$29.03	$27.80	$25.95	$24.71	$18.53

Results and Discussion

Summer Crop Evapotranspiration Rates

Crop evapotranspiration (ET) rates varied throughout the summer reaching peak values during the months of July and August in the Central Great Plains. Long term (1972-2005) July and August corn ET rates at the KSU Northwest Research Extension Center, Colby, Kansas were calculated to be 6.8 and 6.3 mm/d, respectively. However, it is not uncommon to observe short-term peak corn ET values in the 9 to 10 mm/d range. Occasionally, calculated peak corn ET rates may approach 13 mm/d in the Central Great Plains, but it remains a point of discussion whether the corn actually uses that much water on those extreme days or whether corn growth processes essentially shut down further water losses. Individual years are different and daily rates vary widely from the long term average corn ET rates. Irrigation systems must supplement precipitation and soil water reserves to match average corn ET rates and also provide some level of design flexibility to attempt covering year-to-year variations in crop ET rates and precipitation.

Design Irrigation Capacities

The mean simulated net irrigation requirement (SNIR) for corn, grain sorghum, soybean and sunflower for the 34-year period was 375, 272, 367, and 311 mm, respectively (Table 4.). The maximum SNIR for the crops was in 1976, ranging from 432 for grain sorghum to 533 mm for corn and soybean. The minimum SNIR occurred in 1992, ranging from 76 mm for grain sorghum to 127 mm for corn and soybean. This emphasizes the tremendous year-to-year variance in irrigation requirements. Good irrigation management will require the irrigator to use effective and consistent irrigation scheduling.

July and August required the highest amounts of irrigation for all four summer crops with the two months averaging 86% of the total seasonal needs (Table 5). However, it might be more appropriate to look at the SNIR and seasonal distribution in relation to probability, similar to the probability tables from the USDA-NRCS irrigation guidebooks. In this sense, SNIR values will not be exceeded in 80 and 50% of the years, respectively (Table 6). The minimum gross irrigation capacities (62 d, July-August period) generated using the SNIR values are 6.7, 4.8, 6.1, and 5.4 mm/d (50% exceedance levels) for corn, grain sorghum, soybean and sunflower, respectively, using center pivot sprinklers operating at 85% Ea (Table 6).

It should be noted that this simulation procedure shifts nearly all of the soil water depletion to the end of the growing season after the irrigation season has ended and that it would not allow for the total capture of major rainfall amounts (greater than 25 mm) during the irrigation season. Thus, this procedure is markedly different from the procedure used in the USDA-NRCS-Kansas guidelines (USDA-NRCS-KS, 2000, 2002). However, the additional inseason irrigation emphasis does follow the general philosophy expressed by Stone et al. (1994), that concluded inseason irrigation is more efficient than offseason irrigation in corn production. It also follows the philosophy expressed by Lamm et al. (1994), that irrigation scheduling with the purpose of planned seasonal soil water depletion is not justified from a water conservation standpoint, because of yield reductions occurring when soil water was significantly depleted. Nevertheless, it can be a legitimate point of discussion that the procedure used in these simulations would overestimate full net irrigation requirements because of not allowing large rainfall events to be potentially stored in the soil profile. In simulations where the irrigation capacity is restricted to levels significantly less than full irrigation, any problem in irrigating at a 25-mm deficit becomes moot, since the deficit often increases well above 25 mm as the season progresses.

Table 4. Simulated net irrigation requirements, mm, for four major irrigated summer crops for Colby, Kansas, 1972-2005.

Year	Corn	Grain Sorghum	Soybean	Sunflower
1972	229	152	203	178
1973	381	279	381	305
1974	432	330	432	356
1975	330	254	356	305
1976	533	432	533	457
1977	254	178	254	203
1978	483	356	483	432
1979	203	127	203	203
1980	483	356	483	381
1981	381	279	356	279
1982	279	229	254	254
1983	533	406	533	483
1984	483	381	483	432
1985	406	254	356	254
1986	432	330	406	330
1987	406	305	406	356
1988	483	356	483	406
1989	356	254	356	279
1990	432	330	406	356
1991	406	305	406	356
1992	127	76	127	102
1993	203	127	203	127
1994	406	279	381	356
1995	406	305	406	381
1996	178	102	178	102
1997	330	203	305	229
1998	305	178	279	229
1999	254	178	279	229
2000	508	356	483	381
2001	508	381	483	406
2002	508	356	483	381
2003	457	330	457	406
2004	330	229	330	330
2005	381	279	381	356
Maximum	533	432	533	483
Minimum	127	76	127	102
Mean	375	272	367	311
St. Dev.	110	92	109	100

Table 5. Average (34 year, 1972-2005) monthly distribution, %, of simulated net irrigation requirements for four major irrigated crops at Colby, Kansas.

Crop	June	July	August	September
Corn	13.7	42.6	41.9	1.8
Grain Sorghum	6.0	38.9	50.5	4.6
Soybean	10.0	43.2	40.5	6.4
Sunflower	2.3	25.5	53.2	19.1

Table 6. Simulated net irrigation requirements (SNIR) of 4 summer crops not exceeded in 80 and 50% of the 34 years 1972-2005, associated July through August distributions of SNIR, and minimum irrigation capacities to meet July through August irrigation needs, Colby, Kansas.

Criteria	***Corn***		***G. Sorghum***		***Soybean***		***Sunflower***	
	SNIR	***July-August***	***SNIR***	***July-August***	***SNIR***	***July-August***	***SNIR***	***July-August***
SNIR value not exceeded in 80% of the years	483 mm	93.8% 452 mm	356 mm	100.0% 356 mm	483 mm	88.9% 429 mm	381 mm	84.2% 342 mm
July – August capacity requirement	7.3 mm/d		5.7 mm/d		6.9 mm/d		5.5 mm/d	
Minimum gross capacity at 85% application efficiency	8.6 mm/d		6.7 mm/d		8.1 mm/d		6.5 mm/d	
Minimum gross capacity at 95% application efficiency	7.7 mm/d		6.0 mm/d		7.3 mm/d		5.8 mm/d	
SNIR value not exceeded in 50% of the years	406 mm	87.5% 355 mm	279 mm	90.9% 254 mm	381 mm	84.2% 321 mm	356 mm	80.0% 285 mm
July – August capacity requirement	5.7 mm/d		4.1 mm/d		5.2 mm/d		4.6 mm/d	
Minimum gross capacity at 85% application efficiency	6.7 mm/d		4.8 mm/d		6.1 mm/d		5.4 mm/d	
Minimum gross capacity at 95% application efficiency	6.0 mm/d		4.3 mm/d		5.4 mm/d		4.8 mm/d	

Simulation of Crop Yields as Affected by Irrigation Capacity

Although crop grain and oilseed yields are generally linearly related with ET_c from the point of the yield threshold up to the point of maximum yield, the relationship of crop yield to irrigation capacity is a polynomial. This difference is because ET_c and precipitation vary between years and sometimes not all the given irrigation capacity is required to generate the crop yield. In essence, the asymptote of maximum yield in combination with varying ETc and precipitation cause the curvilinear relationship. When the results are simulated over a number of years the curve becomes quite smooth (Figure 2). Using the yield model, the 34 years of irrigation schedules and assuming a 95% application efficiency (Ea), the average maximum yield is approximately 12.9, 8.2, 4.4 and 3.2 Mg/ha for corn, grain sorghum, soybean and sunflower, respectively. Estimates of crop yields as affected by irrigation capacity at a 95% application efficiency can be calculated from the polynomial equations in Table 7. Corn has a much steeper slope than the other 4 crops up to about the 6.5 mm/d irrigation capacity.

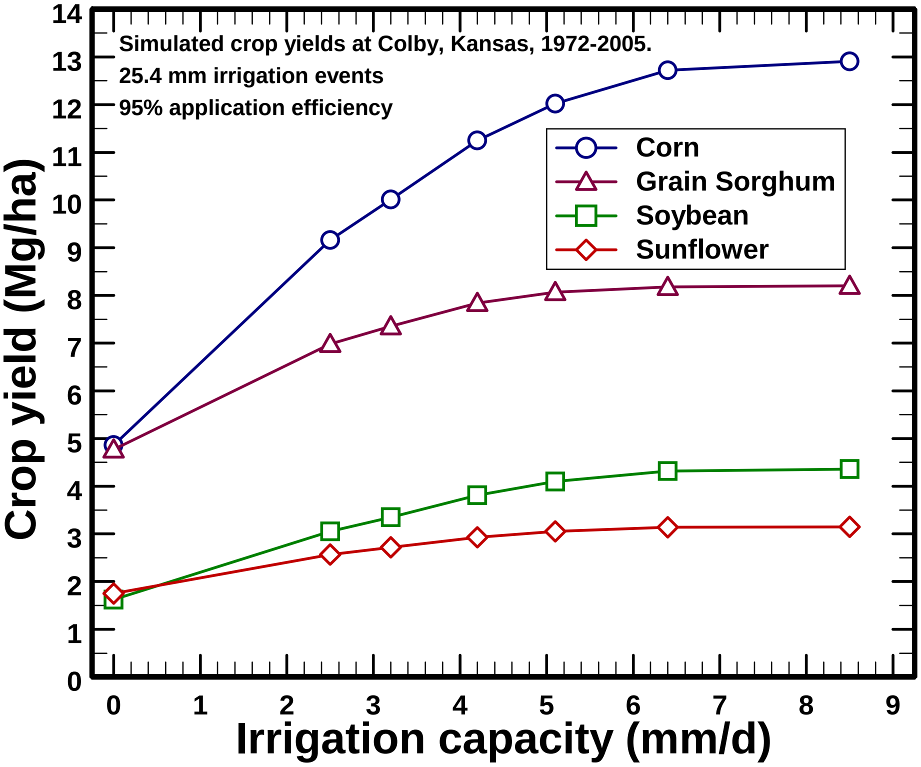

Figure 2. Simulated summer crop yields in relation to irrigation system capacity for the 34 years, 1972 to 2005, Colby, Kansas.

Table 7. Relationship of crop yield, Mg/ha, to irrigation capacity for four summer crops at Colby, Kansas for 34 years (1972-2005) of simulation at a 95% application efficiency.

Crop	Crop yield relationship (Y) to irrigation capacity (IC) in mm/d	R^2	Standard Error
Corn	$Y = 4.85 + 1.9507\ IC – 0.0915\ IC^2 - 0.0031\ IC^3$	1.000	0.027
Grain Sorghum	$Y = 4.76 + 1.1730\ IC – 0.1232\ IC^2 + 0.0038\ IC^3$	0.999	0.041
Soybean	$Y = 1.62 + 0.6173\ IC - 0.0137\ IC^2 - 0.0025\ IC^3$	0.999	0.024
Sunflower	$Y = 1.75 + 0.3973\ IC – 0.0291\ IC^2 + 0.0002\ IC^3$	1.000	0.010

Simulation of Economic Net Returns as Affected by Irrigation Capacity

Similarly, the net returns for the four summer crops can be estimated for the different irrigation system capacities (Figure 3). Although corn is currently the predominant irrigated crop in western Kansas, current projections indicate soybean is a more profitable alternative. Production costs which are typically tied to energy costs (irrigation pumping, fertilizer, pesticides, seed production, etc.) are much greater for corn than soybean, so during these times of rapidly increasing energy costs, corn is less competitive. Soybean net irrigation requirements are only about 2% lower than corn (Table 4), so a shift to soybean will not result in significant water conservation.

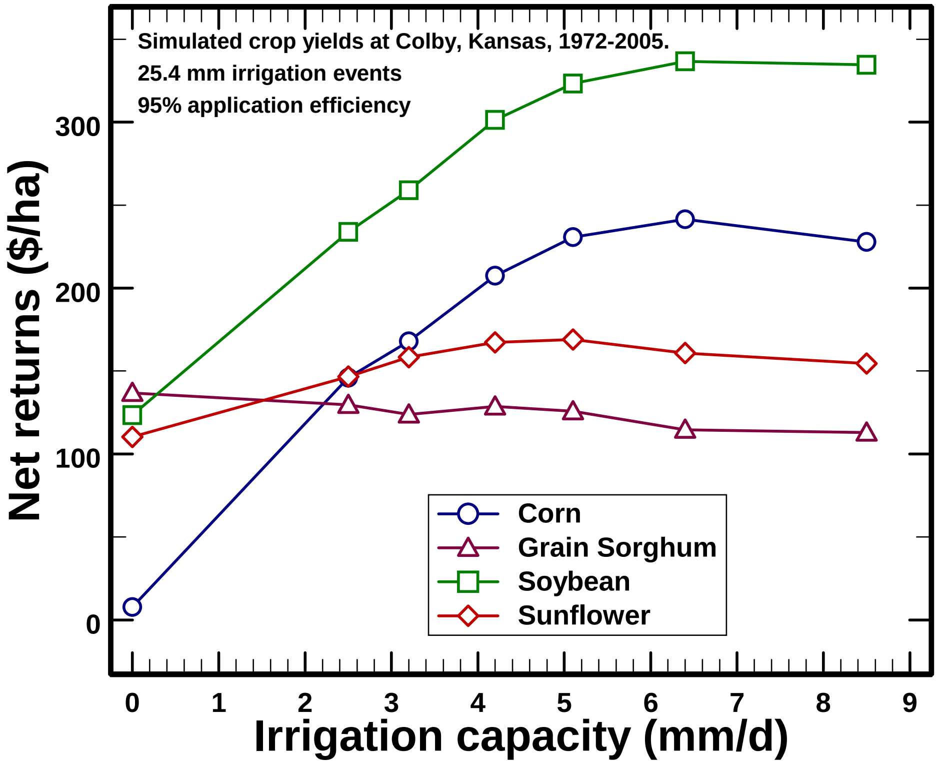

Figure 3. Simulated net returns above direct cash costs for four summer crop yields in relation to irrigation system capacity for the 34 years, 1972 to 2005, Colby, Kansas.

Sunflower and grain sorghum are better economic alternatives than corn under dryland and extremely deficit irrigation, but with current yield projections and prices, they are noncompetitive at the higher irrigation capacities. They do offer the opportunity for stable production at a wider range of irrigation capacity. This analysis shows that dryland grain sorghum is more profitable than any level of irrigated grain sorghum. This is reinforced by the fact that irrigated grain sorghum is also not chosen by producers in the area. This may be related to the fact that higher elevations and the resulting cool nights in the region limit higher grain yields from occurring.

Estimates of the economic net returns above direct cash costs as affected by irrigation capacity at a 95% application efficiency can be calculated from the polynomial equations in Table 8.

Table 8. Relationship of net returns above direct costs, \$/ha, to irrigation capacity for four summer crops at Colby, Kansas for 34 years (1972-2005) of simulation at a 95% application efficiency.

Crop	Crop net return relationship (NR) to irrigation capacity (IC)in mm/d	R^2	Standard Error
Corn	$NR = 7.58 + 62.614\ IC – 3.0145\ IC^2 - 0.1552\ IC^3$	0.999	3.03
Grain Sorghum	$NR = 136.46 – 2.713\ IC + 0.0112\ IC^2 - 0.0036\ IC^3$	0.726	4.43
Soybean	$NR = 122.77 + 46.32\ IC + 0.1101\ IC^2 - 0.3117\ IC^3$	0.996	4.58
Sunflower	$NR = 109.61 + 22.112\ IC – 2.3911\ IC^2 + 0.0463\ IC^3$	1.000	0.010

Crop Yield and Net Return Penalties for Insufficient Irrigation Capacity

The crop yield and net return penalties for insufficient irrigation capacity at a 95% Ea can be calculated for various irrigation capacities by using the yield relationships in Table 5 and 6 and comparing these values to the maximum yield and net returns (Table 9).

Table 9. Penalty to crop yields for center pivot irrigated crop production at 95% application efficiency when irrigation capacity is below 8.5 mm/d. Negative net return penalties indicate a more economically favorable capacity than 8.5 mm/d. Results are from simulations of irrigation scheduling and yield for the 34 years, 1972 to 2005, Colby, Kansas.

Irrigation capacity	***Penalty to crop yield, Mg/ha***				***Penalty to economic net returns, \$/ha***			
mm/d	Corn	Grain Sorghum	Soybean	Sunflower	Corn	Grain. Sorghum	Soybean	Sunflower
8.5	0	0	0	0	\$0.00	\$0.00	\$0.00	\$0.00
6.4	0.19	0.02	0.04	0.01	**-\$13.70**	**-\$1.72**	**-\$2.00**	**-\$6.34**
5.1	0.90	0.12	0.26	0.10	**-\$2.88**	**-\$12.82**	\$11.32	**-\$14.51**
4.2	1.66	0.35	0.55	0.22	\$20.37	**-\$15.79**	\$33.20	**-\$12.78**
3.2	2.90	0.85	1.01	0.44	\$59.87	**-\$10.91**	\$75.66	**-\$3.87**
2.5	3.75	1.21	1.31	0.58	\$81.86	**-\$16.72**	\$100.81	\$7.84
Dryland	8.06	3.43	2.74	1.40	\$220.14	**-\$23.93**	\$211.29	\$44.22

The results indicate there is not much yield advantage and no economic advantage on average for planning for the higher 8.3 mm/d irrigation capacity and it's associated higher crop production inputs. The most profitable design capacity for corn, soybean and soybean is 6.4 mm/d, 4.2 mm/d for sunflower, and dryland production for grain sorghum.

Discussion of the Simulation Models

The results of the simulations indicate corn yields decrease when irrigation capacity falls below 6.4 mm/d. The argument is often heard that with today's high yielding corn hybrids it takes less water to produce corn. So, the argument continues, we can get by with less irrigation capacity. These two statements are misstatements. The actual water use (ET_c) of a fully irrigated corn crop really has not changed appreciably in the last 100 years. Total ET_c for corn is about 585 mm in this region. The correct statement is we can produce more corn grain for a given amount of water because yields have increased not because water demand is less. There is some evidence that modern corn hybrids can tolerate or better cope with water stress during pollination. However, once again this does not reduce total water needs. It just means more kernels are set on the ear, but they still need sufficient water to ensure grain fill. Insufficient capacities that may now with corn advancements allow adequate pollination still do not adequately supply the seasonal needs of the corn crop.

It should be noted that the yield model used in the simulations was published in 1995. The model may need updating to reflect yield advancements. However, it is likely that yield improvements would just shift the curves upward in Figure 2. Differences in yield improvements between crops could also affect the relative net returns position of the crops.

Opportunities to Increase Deficient Irrigation Capacities

There are many center pivot sprinkler systems in the region that this paper would suggest have deficient irrigation capacities. There are some practical ways irrigators might use to effectively increase irrigation capacities for crop production:

- Plant a portion of the field to a winter irrigated crop.
- Remove end guns or extra overhangs to reduce system irrigated area
- Clean well to see if irrigation capacity has declined due to encrustation
- Determine if pump in well is really appropriate for the center pivot design
- Replace, rework or repair worn pump

Conclusion

The question often arises, *"What is the minimum irrigation capacity for an irrigated crop?"* This is a very difficult question to answer because it greatly depends on the weather, your yield goal and the economic conditions necessary for profitability. These crops can be grown at very low irrigation capacities and these crops are grown on dryland in this region, but often the grain yields and economics suffer. Evidence is presented in this paper that would suggest that it may be wise to design and operate center pivot sprinkler irrigation systems in the region with irrigation capacities in the range of 6.4 mm/d for corn and soybean. In wetter years, lower irrigation capacities can perform adequately, but not so in drier years. It should be noted that the entire analysis in this paper is based on irrigation systems running 7 days a week, 24 hours a day during the typical 90 day irrigation season if the irrigation schedule (water budget) demands it. So, it should be recognized that system maintenance and unexpected repairs will reduce these irrigation capacities further.

References

Doorenbos, J. and A. H. Kassam. 1979. Yield response to water. FAO Irriagtion and Drainage Paper 33. Food and Agricultural Organization of the United Nations, Rome Italy.

Lamm, F. R., D. H. Rogers, and H. L. Manges. 1994. Irrigation scheduling with planned soil water depletion. Trans. ASAE. 37(5):1491-1497. Also available at http://www.oznet.ksu.edu/irrigate/Reports/ISchedPlanWD.pdf

Lamm, F. R., D. A. Pacey, and H. L. Manges. 1987. Spreadsheet templates for the calculation of Penman reference evapotranspiration. Presented at the Mid-Central Regional Meeting of the ASAE, St. Joseph, Missouri, March 6-7, 1987. ASAE Paper No. MCR87-106. 23 pp.

O'Brien, D. M., F. R. Lamm, L. R. Stone, and D. H. Rogers. 2001. Corn yields and profitability for low-capacity irrigation systems. Applied Engr. in Agric. 17(3):315-321. Also available at http://www.oznet.ksu.edu/irrigate/Reports/cylc.pdf

O'Brien, D. M., F. R. Lamm, L. R. Stone, and D. H. Rogers. 2000. The economics of converting from surface to sprinkler irrigation for various pumping capacities. Irrigation water management series, MF-2471. K-State Research and Extension, Manhattan, KS. 8 pp. Also available at http://www.oznet.ksu.edu/library/ageng2/MF2471.pdf

Stone, L. R., A. J. Schlegel, F. R. Lamm, and W. E. Spurgeon. 1994. Storage efficiency of preplant irrigation. J. Soil and Water Cons. 49(1):72-76.

Stone, L. R., O. H. Buller, A. J. Schlegel, M. C. Knapp, J-I. Perng, A. H. Khan, H. L. Manges, and D. H. Rogers. 1995. "Description and use of KS Water Budget v. T1 Software. Resource Manual, Dept of Agronomy, Kansas State University, Manhattan, Kansas. 20 pp.

USDA-NRCS-KS. 2000. Chapter 4, Water Requirements. A Kansas revised supplement to National Engineering Handbook, Part 652, Irrigation Guide. KS652.0408 State Supplement. February 2000 updates.

USDA-NRCS-KS. 2002. Chapter 4, Water Requirements. A Kansas revised supplement to National Engineering Handbook, Part 652, Irrigation Guide. KS652.0408 State Supplement. April 2002 updates.

Yonts, C. D., F. R. Lamm, W. Kranz, J. Payero and D. Martin. 2005. Impact of wide drop spacing and sprinkler height for corn production. In proceedings of the Central Plains Irrigation Conference, Kearney, NE, Feb. 17-18, 2004. Available from CPIA, 760 N.Thompson, Colby, KS. pp. 99-106. Also available at http://www.oznet.ksu.edu/irrigate/OOW/P05/Yonts2.pdf