Corn Yields and Profitability for Low–Capacity Irrigation Systems

D. M. O'Brien, F. R. Lamm, L. R. Stone, D. H. Rogers

Abstract. *In many areas of the central U.S. Great Plains irrigation well capacities are decreasing due to declines in the Ogallala aquifer. Many producers using furrow surface irrigation are faced with a decision on whether they should convert to a higher efficiency center pivot sprinkler irrigation system. An irrigation scheduling model using 27 years of climatic data for western Kansas was combined with a corn yield production function and economic model to simulate crop yields and economics under four combinations of irrigation system and application efficiency for six different irrigation capacities. Center pivot sprinkler irrigation systems were found to give higher corn yields and greater profitability than furrow surface irrigation, particularly when system flow rates were less than 40 L/s. Sprinkler irrigation systems with application efficiencies of 100, 95, and 85% and a furrow surface irrigation system with 70% application efficiency produced simulated crop yields of 12.3, 12.2, 12.1, and 11.3 Mg/ha, respectively, when irrigation capacity was 6.35 mm/day. Reducing the irrigation capacity to 2.54 mm/day reduced yields to 9.4, 9.2, 8.9, and 8.3 Mg/ha for the respective irrigation systems. Net annual returns for a 65 ha field were increased by US$1000 to $4000 with center pivot sprinkler irrigation compared to furrow surface irrigation for system flow rates between approximately 20 and 40 L/s. Labor savings with sprinkler irrigation are a significant factor in profitability, but increased crop yields are also very important, particularly at lower system flow rates of approximately 20–30 L/s.*

Keywords. *Irrigation scheduling, Irrigation economics, Crop production functions.*

The profitability of converting from furrow surface irrigation to a center pivot sprinkler irrigation system in the U.S. Great Plains depends upon a number of engineering, agronomic, and economic factors. The most commonly considered elements in this decision are purchase and installation costs of the new sprinkler system, expenses of potential renovations on the existing pumping plant, changes in irrigated crop area, and potential labor savings. However, other elements often are overlooked in this investment decision due to lack of reliable information. The most important overlooked element is the yield differential between the furrow surface and the center pivot sprinkler irrigation system. Crop yield potential for the alternative systems is heavily dependent on the net system irrigation capacity, which is determined by the system flow rate, application efficiency, and irrigated area. Other overlooked elements include long–run expectations of crop prices, irrigated production cost differences for the two systems, and tax deductions for related depreciation and interest expenses for the investment in the center pivot sprinkler irrigation system.

Previous studies have indicated that a strong trend exists among irrigated crop producers in the Great Plains region to convert to more efficient irrigation systems and to adopt more water–efficient cropping systems in response to declining groundwater supplies (Lacewell, 1998; National Research Council (NRC), 1996; Council for Agricultural Science and Technology (CAST), 1996; Lee et al., 1985). However, results vary in the Great Plains and other regions regarding which type of irrigation system is most profitable to use.

Letey et al. (1990) found under California growing conditions that surface gravity flow systems were more profitable than pressurized irrigation systems when there was no constraint on the amount of drainage water generated or cost for its disposal. Conversely, when irrigation drainage water constraints and water disposal costs were accounted for, pressurized irrigation systems became more profitable. Wichelns et al. (1996) examined the economic viability of alternatives to siphon tube irrigation systems in California's San Joaquin Valley. They found that savings in water use from gated pipe and manually moved sprinkler systems was outweighed by the added energy and labor costs those systems entailed.

In a comparison of low energy precision application (LEPA), drip, sprinkler, and furrow irrigation systems under Texas conditions, Hall et al. (1988) found that LEPA sprinkler irrigation systems were the most profitable. However, Lee et al. (1985) found that converting from furrow

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surface to LEPA center pivot sprinkler irrigation systems was less profitable than improving the application efficiency of existing furrow surface systems. The study focused on cost of production and investment impacts of alternative irrigation systems and application efficiencies, but did not account for potential effects upon irrigated crop yields.

Dhuyvetter (1996) indicated that conversion from furrow surface to low–pressure center pivot sprinkler systems was profitable assuming cost and production factors common in Kansas. Some important assumptions in that analysis were that corn yields were equal under irrigation for both systems, but 51 ha of irrigated corn was produced with a full–sized center pivot sprinkler system whereas only 32 ha of irrigated corn were produced under furrow surface irrigation when the flow rate for both systems was 38 L/s.

Williams et al. (1997) concluded that surge and furrow surface irrigation systems were more profitable than LEPA sprinkler or low–pressure center pivot sprinkler systems for 50–L/s capacity. Full 65–ha irrigation–cropping systems were used for surface irrigation as opposed to 51 ha for center pivot sprinkler irrigation with the corners of the 65–ha field in dryland cropping systems. Yields of irrigated corn and grain sorghum were calculated with a crop yield model. Improved furrow irrigation system application efficiencies were estimated to range from 65% for conventional furrow surface to 75% for surge furrow surface irrigation. In comparison, water application efficiencies of unimproved and less well–managed furrow irrigation systems often fall as low as 50 to 60% in the Great Plains region. An 85% application efficiency was used for the low–pressure center pivot sprinkler irrigation system. The LEPA center pivot sprinkler irrigation systems were assumed to have 95% application efficiency. Such systems typically use suspended low drift spray or bubbler nozzles to apply water in–canopy at heights of 0.3 to 0.6 m above the ground.

Delano et al. (1997) also found that it was not profitable to convert from furrow surface to low in–canopy center pivot sprinkler systems with either 35– or 60–L/s well pumping capacities. The sensitivity analysis indicated that for conversion to low in–canopy center pivot sprinkler systems to be profitable, existing furrow surface systems had to either have very low application efficiency, sprinkler–irrigated corn yields had to be substantially higher than those for furrow surface irrigation, sprinkler investment costs had to be reduced, or deficit irrigation was not a desired option. The study also showed that when producer's options were furrow irrigating 63 ha or sprinkler irrigating 51 ha with 35–L/s pumping capacity wells, switching to center pivot sprinkler irrigation was profitable.

Strickland and Williams (1998) analyzed optimal irrigated area and crop mixes for a low in–canopy center pivot sprinkler system with a 25–L/s capacity. They found that growing irrigated corn or grain sorghum on a full–sized 51–ha center pivot sprinkler system was more profitable than reducing the irrigated area to allow increased water application.

In summary, earlier studies produced mixed results regarding the profitability of shifting from furrow surface to center pivot sprinkler irrigation systems. Those studies that found the transition to be unprofitable were affected by the high initial investment costs for the center pivot sprinkler irrigation systems and/or moderate–to–high irrigation pumping capacities that resulted in approximately equal crop yields for the two systems.

This study was conducted to analyze the profitability of converting from furrow surface to center pivot sprinkler irrigation systems as affected by system flow rate (15–48 L/s) for typical square 65–ha fields. The expected irrigated corn yields at various system flow rates were determined.

PROCEDURES

This analysis assumed that a crop producer with a typical, square, furrow surface–irrigated 65 ha of farmland was determining whether or not to convert to a center pivot sprinkler irrigation system. The existing furrow surface irrigation system covers 65 ha of irrigated corn and is assumed to have an improved application efficiency of 70%. The center pivot sprinkler irrigation system covers 51 ha of irrigated corn. The remaining 14 ha in the corners of the 65–ha field will no longer be irrigated, but instead are placed in a dryland wheat–corn–fallow rotation. Alternative application efficiencies of 85, 95, and 100% for the center pivot sprinkler irrigation system were examined. The 100% application efficiency is impossible to achieve but serves as a theoretical upper boundary for the purposes of this economic analysis.

Irrigation water budget schedules were simulated for the 1972–1998 period using climatic data from the Kansas State University (KSU) Northwest Research–Extension Center in Colby, Kansas (Lat. 39.39 N, Long. 101.07 W, Elevation, 975 m using WGS84 datum system). The continental climate can be described as semi–arid with an average annual precipitation of 474 mm and approximate annual lake evaporation of 1400 mm (Bark and Sunderman, 1990). The alfalfa–based reference evapotranspiration (ET_r) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heermann (1974). The specifics of the ET_r calculations used in this study were described fully by Lamm et al. (1987). Basal crop coefficients (K_{cb}) were generated with equations developed by Kincaid and Heermann (1974) based on work by Jensen (1969) and Jensen et al. (1970, 1971). The basal crop coefficients were calculated for the region by assuming 70 days from emergence to full canopy for corn and physiological maturity at 130 days. This method of calculating actual crop evapotranspiration (ET_c) as the product of K_{cb} and ET_r has been acceptable in past studies at Colby (Lamm and Rogers, 1983, 1985). In constructing the irrigation schedules, no attempt was made to modify ET_c with respect to soil evaporation losses or soil water availability as outlined by Kincaid and Heermann (1974).

Irrigation was scheduled as needed by the crop, but was limited to the frequencies for the furrow surface and the center pivot irrigation systems (table 1). The initial soil water at the beginning of each season was assumed to be at 85% of the maximum plant–available soil water (PAW) in the 1.52–m soil profile. Bidwell et al. (1980) describes in more detail the medium–textured, deep, well–drained, loessial, Keith silt loam (Aridic Argiustoll; fine silty, mixed, mesic), typical of many High Plains soils. The 1.52–m soil profile will hold approximately 370 mm of PAW at field capacity. The irrigation season was limited to the 90–day period between 5 June and 2 September. The first furrow surface

Table 1. Equivalent irrigation frequencies and flow rates for center pivot sprinkler and furrow surface irrigation systems.

Gross Irrigation Capacity (mm/day)	Center Pivot Sprinkler		Furrow Surface	
	Frequency and Application	Flow Rate (L/s for 51 ha)	Frequency and Application	Flow Rate (L/s for 65 ha)
6.35	25 mm in 4 days	37	76 mm in 12 days	48
5.08	25 mm in 5 days	30	76 mm in 15 days	38
4.24	25 mm in 6 days	25	76 mm in 18 days	32
3.18	25 mm in 8 days	19	76 mm in 24 days	24
2.54	25 mm in 10 days	15	76 mm in 30 days	19

irrigation event in each year was on 15 June, reflecting a typical date of the first irrigation following the final furrowing process. After that, furrow irrigation events were scheduled as the irrigation system capacity limitation allowed and if the calculated soil water deficit exceeded 76 mm. Center pivot sprinkler irrigation events were scheduled as the system capacity limitation allowed and if the calculated soil water deficit exceeded 25 mm. The root zone management depth was held constant over the entire season.

The daily water budget included effective precipitation (P) and irrigation (I) as deposits and ET_c and drainage (D) as withdrawals. Effective rainfall for corn grown in this region was assumed to be 88% of the rainfall amount as used by Stone et al. (1995). An overall limit on daily effective rainfall was set at a maximum of 57 mm to handle the occasional extreme events that occurred over the 27–year period. Amounts in excess of this maximum amount were discarded from the analysis as runoff. Daily drainage (D) from the soil was calculated as a function of profile water content using a drainage equation developed for the 1.52–m soil profile of the Keith silt loam soil at Colby, Kansas:

$$D = -24.5\ (W/598)^{25.39} \qquad (1)$$

where total soil water (W) including plant available and unavailable soil water was expressed in mm, and D was expressed in mm/day. The procedure to characterize drainage rates from the soil using equations of this type was discussed thoroughly by Miller and Aarstad (1974).

Irrigated corn yields for the various alternative irrigation systems and irrigation capacities were simulated for the same 27–year period using the cumulative seasonal ET_c estimates from the irrigation schedules and a yield production function developed by Stone et al. (1995). For the yield functions, the daily ET_c values were modified to reflect any water stress imposed by lower soil water availability. This soil water availability coefficient (K_a) as outlined by Hanks (1974) was calculated conditionally using locally derived factors as:

$$\text{If PAW} > 70\%\ \text{maximum PAW then } K_a = 1 \qquad (2)$$

$$\text{If PAW} < 70\%\ \text{maximum PAW then } K_a = \text{PAW} / (0.70\ \text{PAW}) \qquad (3)$$

Many functional forms for K_a have been proposed (Howell et al., 1979) and many researchers have used a lower limit of PAW of 0.5 before allowing K_a to change when using this functional form. However, data from Lamm et al. (1995, 1996) suggests that the traditional 0.5 cutoff is too low for these soils. Allowing a deep–rooted corn crop to extract water to 50% for a deep profile (>2 m) does not occur without reducing the maximum potential ETc

An additional potential weighting factor (WF_p) was used to reflect the effect of water stress on corn yields during particular growth stages. WF_p was 0.36, 0.33, 0.25, and 0.06 for the vegetative (66 days), flowering (9 days), seed formation (27 days), and ripening (18 days) growth stages, respectively (Stone et al. 1995). The actual weighting factor (Wf_{ai}) for a particular growth stage was determined by multiplying WF_p by the average of all daily K_a during the period. Wf_{ai} values for all four periods were then added together to reflect the fraction of maximum yield (i.e., sum of all four values less than or equal to 1.0). The overall yield production model was

$$Y = (\textstyle\sum_{i = 1 \text{ to } 4} Wf_a i) \times (-11.55 + \{0.04164\ [\textstyle\sum_{days = 1 \text{ to } 120} (Ka \times ETc)]\}) \qquad (4)$$

with yield (Y) expressed in Mg/ha and cumulative seasonal ET_c in mm. Stone et al. (1995) discussed in detail the weighting factors and their application to the model.

Cost projections from Kansas State University and irrigation industry were used to estimate the purchase cost of a sprinkler irrigation system (O'Brien and Dumler, 1999a). The total cost of the full–sized 51–ha center pivot sprinkler system was projected to be US$45,209, including the standard seven towers with low in–canopy nozzles on drops, underground pipe from the field edge to the center pivot point, electrical wiring and connectors, and an electric generator (table 2). An additional US$4,500 was budgeted to modify the existing turbine pump for the higher pressure requirements of sprinkler irrigation. These pump modification costs were similar to estimates in other studies (Dhuyvetter, 1996; Delano et al., 1997). The total system and pump modification costs were US$49,709.

The Modified Accelerated Cost Recovery System (MACRS) 150% Declining Balance method (7 years) of the U.S. Internal Revenue Service was used to calculate tax depreciation on the purchased center pivot sprinkler irrigation system and pump modification costs (Farmer's tax guide, 1999). Both principal and interest payments were calculated for a 5–year amortized note at 9% interest, with

Table 2. Capital requirements for a center pivot sprinkler irrigation system (51 ha).

Item	Length (m)	Price/m (US$)	Costs (US$)
Standard 7 tower center pivot			
System base price	402		28,000
Drop tubes			2,100
Low pressure spray heads			2,400
96.5–cm tires			3,000
20 cm underground pipe	402	8.26	3,326
Electrical wiring	402	6.23	2,508
Connectors			1,500
12–KVA generator			2,375
Total cost of center pivot system			45,209
Pump modification cost			4,500
Total system & pump cost			49,709

the total payment for each of the 5 years equaling US$12,780. The combined federal (15%), state (6%), and self employment (15.3%) tax rate used here was 36.30%. This same combined total tax rate was used in the final after–tax profitability calculations.

Crop production cost estimates for furrow surface– and center pivot sprinkler–irrigated corn, dryland wheat, and dryland corn came from the 1999 KSU Farm Management Guides (Dumler and O'Brien, 1999a and b; O'Brien and Dumler, 1999b; Dumler, et al. 1999b). The cost of seed, fertilizer, herbicide, insecticide, labor; crop insurance, operating interest, and crop production–related fuel, oil, and machinery maintenance were accounted for in these irrigated and dryland crop production budgets. Crop inputs such as fertilizer are less for the dryland corners, but do require separate application procedures. The costs of fuel, oil, and maintenance related to applying irrigation water were US$0.0075/$m^3$ for a center pivot sprinkler system and US$0.0065/$m^3$ for a furrow surface irrigation system. No additional water costs were used in the analysis as is typical for irrigation in Kansas. No land costs were assumed in these budget estimates to avoid the effects of varying land rental or purchase market conditions in the central Great Plains region. These analyses were performed both with and without KSU labor cost estimates included.

The long–term grain prices for corn and wheat in western Kansas for these profitability projections were US$0.093/kg and US$0.125/kg, respectively (Kastens et al., 1999). Dryland wheat and no–till corn yields on nonirrigated corners of center pivot sprinkler system–irrigated fields were assumed to average 2.8 and 5.1 Mg/ha, respectively. USDA Production Flexibility Contract payments on the original furrow surface–irrigated cornfield were assumed to be US$86.49/ha. Government payments on the 65–ha tract were assumed to be unchanged by the switch to a center pivot sprinkler irrigation system.

The time period for this analysis was 15 years, which is a conservative approximation of the expected life span of a newly purchased center pivot sprinkler system. No inflation or deflation in crop prices or input costs was assumed during the 15–year period for the baseline analysis. The yield results are presented as the average of the 27 years of simulation. The net returns are presented using a cash flow analysis. All computations were made in spreadsheet templates.

RESULTS AND DISCUSSION

Simulated irrigation schedules and the corn yield model were used to generate estimates of the irrigation application requirement and corn yields for the various irrigation systems and capacities for each year during the 1972 through 1998 period (table 3).

Center pivot sprinkler irrigation systems with application efficiencies of 95 and 100% (CP95 and CP100) and a capacity of 25 mm/4 days applied nearly the full irrigation requirement (approximately 355 mm) in most years. As a result, average corn yields were approximately equal (12.2–12.3 Mg/ha) for this capacity and fully irrigated conditions. Similar maximum and minimum yield ranges were also obtained for these two capacities. Average corn yields dropped slightly (12.1 Mg/ha) for the sprinkler system at 85% application efficiency (CP85) with a capacity of 25 rmm/4 days. A larger yield reduction occurred for the 70% efficient furrow surface irrigation system (FS70) at an equivalent irrigation capacity (76 mm/12 days), resulting in an average yield of 11.3 Mg/ha. Average irrigation requirements for FS70 were 518 and 429 mm, respectively, for full irrigation and the 76–mm/12–day irrigation capacity.

Table 3. Irrigation application amounts and irrigated corn yields at the indicated gross irrigation capacity.[a]

	6.35 mm/day		5.08 mm/day		4.24 mm/day		3.18 mm/day		2.54 mm/day		Full Irrigation	
	Depth (mm)	Yield (Mg/ha)	Depth (mm)	Yield (Mg/ha)	Depth (mm)	Yield (Mg/ha)	Depth (mm)	Yield (Mg/ha)	Depth (mm)	Yield (Mg/ha)	Depth (mm)	Yield (Mg/ha)
Center Pivot Sprinkler System at 100% application efficiency on 51 ha (CP100)												
Average	338	12.3	305	11.9	272	11.2	218	10.2	183	9.4	353	12.4
Std deviation	99	2.7	79	2.3	61	1.9	43	1.5	30	1.4	107	2.8
Maximum	508	16.4	432	16.1	356	14.7	279	12.0	229	11.2	533	16.8
Minimum	127	7.0	127	7.0	127	7.0	102	6.7	102	6.0	127	7.0
Average	351	12.2	312	11.8	277	11.1	221	10.0	183	9.2	371	12.4
Center Pivot Sprinkler System at 95% application efficiency on 51 ha (CP95)												
Std deviation	102	2.6	79	2.2	61	1.8	43	1.4	30	1.4	114	2.8
Maximum	508	16.4	432	15.8	356	14.2	279	11.9	229	11.2	559	16.8
Minimum	127	7.0	127	7.0	127	7.0	102	6.5	102	6.0	127	7.0
Center Pivot Sprinkler System at 85% application efficiency on 51 ha (CP85)												
Average	371	12.1	328	11.4	290	10.7	229	9.6	188	8.9	419	12.4
Std deviation	99	2.4	74	1.9	53	1.6	41	1.4	30	1.4	130	2.8
Maximum	508	16.3	432	15.0	356	13.2	279	11.8	229	11.2	635	16.8
Minimum	152	7.0	152	7.0	152	6.9	127	6.2	102	5.8	152	7.0
Furrow Surface Irrigation System at 70% application efficiency on 65 ha (FS70)												
Average	429	11.3	378	10.5	338	9.9	277	9.0	221	8.3	518	12.4
Std deviation	97	1.9	79	1.6	61	1.4	43	1.4	25	1.4	157	2.8
Maximum	533	14.9	457	13.2	381	11.9	305	10.8	229	10.5	762	16.8
Minimum	152	7.0	152	16.8	152	6.5	152	5.9	152	5.6	152	7.0

[a] Based on 1972–1998 climatic conditions at the Northwest Research Extension Center in Colby, Kansas, and on the Stone et al. (1995) corn yield prediction model.

As gross irrigation system capacities declined further, the projected yields for each of the four irrigation systems also declined. However, the higher application efficiencies for CP95 and CP100 resulted in higher yields and less total water pumped for a given irrigation capacity. As irrigation capacity becomes more and more limited, there is less chance for natural rainfall and soil water reserves to buffer the crop through the stressful period. In addition, the 30–day frequency for the lowest examined irrigation capacity for FS70 leaves the crop vulnerable to water stress for a long period of time as compared to the sprinkler irrigation systems. As irrigation capacity decreased, the range (maximum–minimum) in crop yields was generally less across the 27–year period (table 3). This reduction in yield variation was because less opportunity existed for lower irrigation capacity systems to compensate for higher irrigation needs in crop years that might otherwise be considered favorable to good yields.

Corn yields also were simulated for full irrigation (table 3). Adequate irrigation water was supplied to meet the crop's evapotranspiration needs without potential timing delays caused by inadequate irrigation system capacity. The analysis showed that if full irrigation were possible for all three systems, equal corn yields of 12.4 Mg/ha would be obtained. The average full irrigation requirement would be 353, 371, 419, and 518 mm for the CP100, CP95, CP85, and FS70 systems, respectively.

Quadratic relationships between corn yields and pumping capacity were generated for each alternative irrigation system–application efficiency scenario (table 4). Linear effects in these corn yield equations were all positive and statistically significant at the 0.01 probability level. In addition, the quadratic effects were all negative and statistically significant at the 0.01 level. Taken together, these results indicate that corn yields increased at a decreasing rate in response to increases in irrigation pumping capacity. Notable differences existed among irrigation systems across the range of irrigation capacities (fig. 1). Corn yields were 1.3–1.9 Mg/ha less for FS70 than for the center pivot sprinkler irrigation systems. These equations can be used by producers to project long–term yields for a given irrigation capacity and to allocate area for irrigated and dryland cropping. The equations also can be used as guides to yield potential in allocation decisions related to input resources such as seed and fertilizer.

The quadratic relationships between annual, average, after–tax, net returns to land and management and irrigation capacity also were estimated for each of the four irrigation systems (table 5). Similar to the grain yield models, the signs of all of the linear effects in these net revenue equations were positive, and each linear effect was statistically significant. In addition, the quadratic effects of these net returns models were all negative and statistically significant at the 0.01 level. Together, these results indicate that annual, average, after–tax, net returns increased at a decreasing rate in response to increases in irrigation pumping capacity.

The results indicate that across this range of low irrigation capacities, it was profitable to convert from FS70 to center pivot sprinkler irrigation systems with 85% or greater application efficiencies (fig. 2). For example, at 19 L/s pumping capacity for the full 65 ha area, annual net returns to land and management with the FS70% system were US$1,953, US$3,409, and US$3,929 lower than those for the CP85%, CP95%, and CP100% systems, respectively. For wells with 38 L/s pumping capacity, net returns for the FS70% system were US$1,029, US$1,809, and US$2,059 lower than those for the CP85%, CP95%, and CP100% systems, respectively, for the full 65–ha area. These results indicate that the advantage for converting to center pivot sprinkler systems was greater at lower capacities, and declined as well pumping capacity increased. The curvilinear nature of the equations indicates that converting from furrow

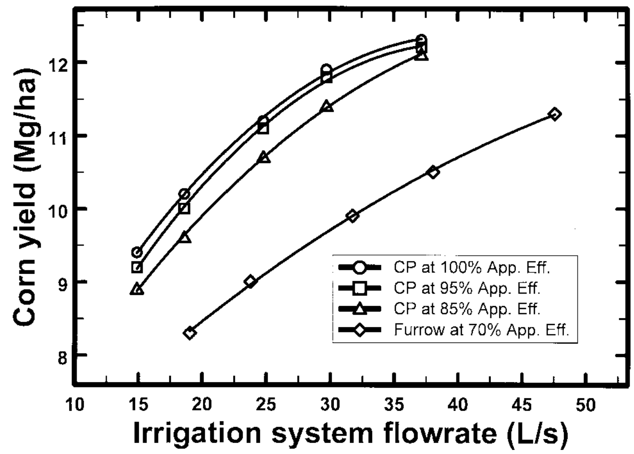

Figure 1. Irrigated corn yields as affected by irrigation system type, capacity, and application efficiency.

Table 4. Regression equations and statistics for irrigated corn yields (Y) as related to irrigation system type and flow rate (F).

System Type and Application Efficiency	Regression Equation[a]	R^2	Standard Error (Mg/ha)
Center pivot sprinkler (100%)	$Y = -0.005677 F^2 + 0.4298 F + 4.2$	0.999	0.04
Center pivot sprinkler (95%)	$Y = -0.005298 F^2 + 0.4149 F + 4.1$	0.999	0.06
Center pivot sprinkler (85%)	$Y = -0.004068 F^2 + 0.3582 F + 4.4$	0.999	0.05
Furrow surface (70%)	$Y = -0.001545 F^2 + 0.2069 F + 4.9$	0.999	0.04

[a] Yield (Y) in Mg/ha and flow rate (F) in L/s.

Table 5. Regression equations and statistics for annual net returns (NR) from a 65–ha field as related to irrigation system type and flow rate (F).

System Type and Application Efficiency	Regression Equation	R^2	Standard Error[a] (Mg/ha)
Center pivot sprinkler (100%)	$NR = -14.434 F^2 + 1065.60 F - 9012$	0.999	101
Center pivot sprinkler (95%)	$NR = -13.322 F^2 + 1016.62 F - 9003$	0.999	127
Center pivot sprinkler (85%)	$NR = -9.969 F^2 + 854.76 F - 8378$	0.999	109
Furrow surface (70%)	$NR = -4.347 F^2 + 591.61 F - 7584$	0.999	103

[a] Annual net returns (NR) in US$ for a 65 ha field and flow rate (F) in L/s.

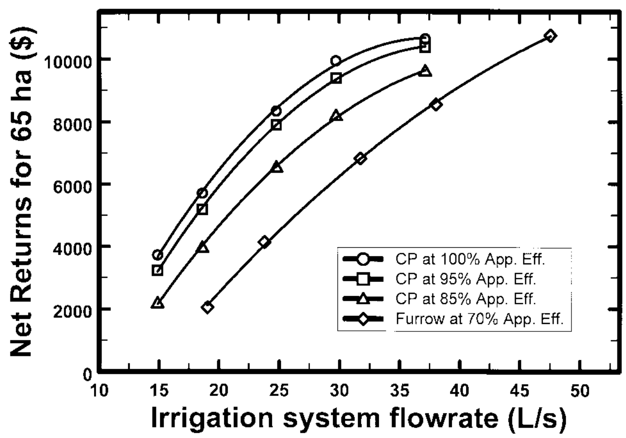

Figure 2. Annual after–tax net returns (returns to land and management) for a 65–ha field as affected by irrigation system type, capacity, and application efficiency.

surface to center pivot sprinkler irrigation systems may become unprofitable at irrigation system capacities of approximately 45 L/s or more.

The finding that converting from furrow surface to center pivot sprinkler systems was profitable is consistent with conclusions of Dhuyvetter (1996), but contradicts the general conclusions of Letey et al. (1990), Williams et al. (1997), and Delano et al. (1997). However, Delano et al. (1997) also found that such conversions were profitable when producers were forced to cover either 63 ha with furrow surface or 51 ha with low in–canopy center pivot sprinkler systems at 35–L/s flow rates.

In this study, labor expenses were reduced and profits were increased by switching from furrow surface to center pivot sprinkler irrigation systems. Labor costs for center pivot sprinkler–irrigated cropping systems were projected to be lower (US$2,385 or US$37/ha) than those for furrow surface irrigation (US$3,508 or US$54/ha) for the full 65 ha. Including labor costs in this analysis resulted in lower net returns for furrow surface irrigation relative to center pivot sprinkler system returns. Williams et al. (1997), Delano et al. (1997), and Wichelns et al. (1996) each included labor costs in their analyses. The latter two studies discussed how constraints on labor availability could be determining factors in the decision to convert from furrow surface to center pivot sprinkler irrigation systems. However, this study shows that reduction in crop yields for the furrow surface irrigation system with lower application efficiency is also a contributing factor. As irrigation capacity decreases, reduction in crop yields becomes an increasingly dominant factor in the relative profitability of center pivot sprinkler systems.

The results of the study were sensitive to assumptions about corn prices (data not shown). A US$0.004/kg increase (or decrease) in long term corn price lead to increases (decreases) in after–tax, annual, net returns of US$1,170 to US$1,630 for these center pivot sprinkler irrigation cropping systems and from US$1,375 to US$1,863 for the furrow surface irrigation cropping system on a 65–ha field. However, changes in corn prices within reasonable ranges do not change the conclusions of this study regarding the profitability of switching from furrow surface to center pivot sprinkler irrigation systems.

CONCLUSIONS

This study showed that as irrigation system capacity declines below moderate levels, it becomes more profitable to convert to center pivot sprinkler irrigation than to continue to use furrow surface systems. These findings are dependent upon assumptions about irrigation system investment costs, irrigated corn yields, crop production costs, and crop prices. The results hold true in spite of irrigators having to pay principal and interest costs for the debt associated with the purchase of the center pivot sprinkler irrigation system and pump modification costs and having to revert 14–irrigated ha to an intensive dryland cropping system.

Decreased irrigation capacity has negative effects upon both the production and the profitability of an irrigated corn enterprise. Average yield estimates for irrigated corn under furrow surface irrigation with 70% application efficiency were reduced appreciably (10.7 to 8.3 Mg/ha) as irrigation well capacity declined from 44 to 19 L/s for a 65–ha field. Average yield estimates for irrigated corn decreased from 12.2 to 9.2 Mg/ha as irrigation capacity declined from 38 to 13 L/s for a 51–ha center pivot sprinkler–irrigated field with 95% application efficiency. In response to declining irrigation capacity, crop producers typically reduce the irrigated area to the level for which they can still provide adequate water for crop growth. Further analysis might determine how irrigated corn yields and cropping system profitability respond to decreases in irrigated area as irrigation capacity declines, given the climate of the region. The associated economic analysis would be driven primarily by changes in irrigated corn yields and declines in irrigated area as producers seek to find the most productive and profitable irrigated area given their limited water pumping capacities.

These findings support the claims of irrigators that labor savings at least partially motivate the decision to convert from furrow surface irrigation to center pivot sprinkler irrigation systems. However, this analysis suggests that actual corn production levels attained with furrow surface irrigation are also very important, particularly for low system flow rates that cannot adequately supply corn water needs. Additionally, at very low system flow rates, the infrequency of furrow surface irrigation events may increase crop vulnerability to water stress.

REFERENCES

Bark, L. D., and H. D. Sunderman. 1990. Climate of northwestern Kansas. Rep. of Progress 594. Kansas Ag. Expt. Sta., Manhattan, Kans.

Bidwell, O. W., E. E. Banbury, W. L. Barker, and G. E. Muilenburg. 1980. The Colby Branch Experiment Station and agriculture in northwest Kansas with special mention of soils. Bulletin 635. Kansas Ag. Expt. Sta., Manhattan, KS.

Council for Agricultural Science and Technology (CAST). 1996. The Western Great Plains. Future of Irrigated Agriculture, 57–66. Task Force Rep. No. 127. Ames, Iowa: CAST.

Delano, D. R., J. R. Williams, and D. M. O'Brien. 1997. The economic feasibility of irrigation system modifications: an analysis of system characteristics and crop yields. Research Rep. No. 25. Dept. of Ag. Econ., Kansas State Univ., Manhattan, Kans.

Dhuyvetter, K. C. 1996. Converting from furrow irrigation to center pivot irrigation – Does it pay? *Proc. of the Central Plains Irrigation Short Course and Exposition,* 13–22. Fort Collins, Colo.:Colorado State Univ.

Dumler, T. J., and D. M. O'Brien. 1999a. Center pivot irrigated corn cost–return budget. KSU Farm Management Guide. MF–585. K–State Research and Extension, Kansas State Univ., Manhattan, Kans.

_____. 1999b. Flood irrigated corn cost–return budget. KSU Farm Management Guide. MF–578. K–State Research and Extension, Kansas State Univ., Manhattan, Kans.

Dumler, T. J., C. R. Thompson, and D. M. O'Brien. 1999b. No–till corn cost–return budget (W–C–F rotation) in western Kansas. KSU Farm Management Guide. MF–2150. K–State Research and Extension, Kansas State Univ., Manhattan, Kans.

Farmer's tax guide. 1999. MACRS. IRS, Department of Treasury, Publ. No 225. Washington, D.C.: U.S. Gov. Printing Office.

Hall, K. D., R. D. Lacewell, and W. M. Lyle. 1988. Yield and economic implications of alternative irrigation distribution systems: Texas High Plains. Dept. Technical Rep. No. 88–1.Dept. of Ag. Econ., Texas A&M Univ., College Station, Tex.

Hanks, R. J. 1974. Model for predicting plant yield as influenced by water use. *Agron. J.* 66(5): 660–665.

Howell, T. A., W. R. Jordan, and E. A. Hiler. 1979. Evaporative demand as a plant stress. Section 2.3 In *Modification of the Aerial Environment of Crops*, eds. B. J. Barfield and J. F. Gerber. St. Joseph, Mich.: ASAE.

Jensen, M. E. 1969. Scheduling irrigation using computers. *J. Soil and Water Cons*. 24(8): 193–195.

Jensen, M. E., C. E. Franzoy, and D. C. N. Robb. 1970. Scheduling irrigations using climate–crop–soil data. ASCE, *J. Irrig. and Drain.* 96(IRI): 25–38.

Jensen, M. E., B. J. Pratt, and J. L. Wright. 1971. Estimating soil and moisture depletion from climate, crop and soil data. *Transactions of the ASAE* 14(5): 954–959.

Kastens, T. L., K. C. Dhuyvetter, and R. Jones. 1999. Prices for crop and livestock cost–return budgets. KSU Farm Management Guide. MF–1013. K–State Research and Extension, Kansas State Univ., Manhattan, Kans.

Kincaid, D. E., and D. F. Heermann. 1974. Scheduling irrigation using a programmable calculator. Pub. ARS–NC–12. USDA, Washington, D.C.

Lamm, F. R., and D. H. Rogers. 1983. Scheduling irrigation using computed evapotranspiration. ASAE Paper No. MCR 83–109. St. Joseph, Mich.: ASAE.

_____. 1985. Corn yield response to different irrigation regimes. ASAE Paper No. MCR85–131. St. Joseph, Mich.: ASAE.

Lamm, F. R., D. A. Pacey, and H. L. Manges. 1987. Spreadsheet templates for the calculation of Penman reference evapotranspiration. ASAE Paper No. MCR 87–106. St. Joseph, Mich.: ASAE

Lamm, F. R., H. L. Manges, L. R. Stone, A. H. Khan, and D. H. Rogers. 1995. Water requirement of subsurface drip–irrigated corn in Northwest Kansas. *Transactions of the ASAE* 38(2): 441–448.

Lamm, F. R., D. H. Rogers, and G. A. Clark. 1996. Irrigation scheduling of corn: Macromanagement. In *Proc. of the Intl. Conf. onEvapotranspiration and Irrigation Scheduling.* St. Joseph, Mich.: ASAE.

Lacewell, R. D. 1998. Water and the economy of the Great Plains region. *Great PlainsSymposium 1998: The Ogallala Aquifer,* 12–17. Lubbock, Tex. Dodge City, Kans.: Great Plains Foundation.

Lee, J. G., J. R. Ellis, and R. D. Lacewell. 1985. Valuation of improved irrigation efficiency from an exhaustible groundwater source. Water Resources Bulletin, Paper No. 84244. Middleburg, Va.: Amer. Water Resources Assn.

Letey, J., A. Dinar, C. Woodring, and J. D. Oster. 1990. An economic analysis of irrigation systems*. Irrigation Sci.* 11(1): 37–43.

Miller, D. E., and J. S. Aarstad. 1974. Calculation of the drainage component of soil water depletion. *Soil Sci.* 118:11–15.

National Research Council (NRC). 1996. A new era for irrigation. Report from the Committee on the Future of Irrigation in the Face of Competing Demands. Washington, D.C.: National Academy Press.

O'Brien, D. M., and T. J. Dumler. 1999a. Irrigation capital requirements and energy costs. KSU Farm Management Guide. MF–836. K–State Research and Extension, Kansas State Univ., Manhattan, Kans.

_____. 1999b. Wheat cost–return budget (W–S–F rotation) in western Kansas. MF–903. K–State Research and Extension, Kansas State Univ., Manhattan, Kans.

Stone, L. R., O. H. Buller, A. J. Schlegel, M. C. Knapp, J. Perng, A. H. Khan, H. L. Manges, and D. H. Rogers. 1995. Description and use of Kansas water budget: Version T1 Software. Dept. of Agron., Kansas State Univ., Manhattan, Kans.

Strickland, V., and J. R. Williams. 1998. Strategies for irrigation water management and crop acreage allocation with a low flow rate well. Tillage, Water, and Soil Research Report of Progress No. 813. Agric. Exp. Stat. and Coop. Ext. Service, Kansas State Univ., Manhattan, Kans.

Williams, J. R., R. V. Llewelyn, M. S. Reed, F. R. Lamm, and D. R. Delano. 1997. Economic analysis of alternative irrigation systems for continuous corn and grain sorghum in western Kansas. Report of Progress No. 766 (revised). Kansas Ag. Expt. Sta., Manhattan, Kans.

Wichelns, D., L. Houston, D. Cone, Q. Zhu, and J. Wilen. 1996. Labor costs challenge sprinkler economic viability. *Irrig. Business and Tech.* 4(2): 24–27.