# CROP PRODUCTION AND ECONOMICS IN NORTHWEST KANSAS AS RELATED TO IRRIGATION CAPACITY

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

**ABSTRACT.** *Crop production and economics of corn, grain sorghum, soybean, and sunflower under irrigated and dryland conditions were simulated using 34 years (1972-2005) of weather data in Northwest Kansas. Irrigation system capacities ranged from 2.5 to 8.5 mm/day. The simulated long-term annual average net irrigation requirements for corn, grain sorghum, soybean, and sunflower 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, projections for the year 2006 indicate soybean is a more profitable alternative. Net irrigation requirements for soybean are only about 2% lower than corn, so a shift to soybean will not result in significant water conservation. If the price of corn increased just 10% relative to stable prices for the other crops, it would become the most profitable irrigated crop. This indicates that net return projections are very volatile, subject to changes in crop prices and input costs.*

**Keywords.** *Irrigation management, Irrigation economics, Evapotranspiration, Modeling, Corn, Grain sorghum, Soybean, Sunflower, Ogallala aquifer.*

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 U.S. 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 (*Zea mays* L.), grain sorghum (Sorghum bicolor L. Moench), soybean (*Glycine max* L.), and sunflower (*Helianthus annuus* L.). Corn yield is very responsive to irrigation with responses of up to 0.05 Mg/ha-mm or higher possible in this region. Other major crops in the region are less responsive to irrigation and are sometimes grown on more marginal capacity irrigation systems. Since many of the systems have marginal capacity, it is important to have good information about how the various crops will perform in terms of grain yield and profitability as related to irrigation system capacity.

Irrigation water allocation and cropping strategies has been a research topic in numerous studies in the Great Plains region. Many of these studies focused on various fixed water application amounts and the resulting crop production (Martin and van Brocklin, 1985; Martin et al., 1989; Strickland and Williams, 1998; Klocke et al., 2004; Klocke et al., 2006; Stone et al., 2006).

Martin et al. (1989) developed a dynamic programming model to annually allocate a limited water supply over a multi-seasonal period. This model can also be used to help producers choose the correct mix of crops and balance of irrigated and non-irrigated land. These allocation procedures are very suitable to water-banking systems that are regularly discussed as possible water management alternatives being instituted under state authority. Martin and van Brocklin (1985) reported multi-seasonal allocation decisions depend on whether the objective is to maximize net income or to reduce economic risk by maximizing the lowest annual net income during the period. Maximizing net income will favor using the water earlier in the period. Reducing the risk of a low net income will favor saving some of the water for a drier than normal year.

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. However, they tempered their conclusions with the caution that the production risk would be higher utilizing the larger land area and that annual variation in weather conditions might result in wide variations in cropping profitability.

A comparison of several irrigation strategies on commercial farms in Nebraska has indicated that economic

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returns can be somewhat similar for a wide range of water applications depending on water costs (Klocke et al., 2004). Corn grain yields varied 16% (11.3 to 13.5 Mg/ha) over a irrigation range of 43% (323 to 183 mm) while economic returns only varied 9% at a water cost of \$0.012/m$^3$. These results show that opportunities exist to conserve water without drastically affecting economic returns.

A water allocation model for crop planning has been developed for use in the Central Great Plains (Klocke et al., 2006). This model simulates crop production and net economic returns with a minimal number of inputs (crop and land split, annual irrigation amount, annual precipitation amount and irrigation efficiency). This tool has been promoted as a decision aid for annual crop planning and received attention from the USDA Risk Management Agency as a means of reducing production risk.

Crop yield production functions as related to water use were presented for six crops (alfalfa, corn, grain sorghum, soybean, sunflower, and wheat) for the west-central Great Plains by Stone et al. (2006). These relationships can be used to optimize water allocations and maximize profit for crops grown under various precipitation and irrigation scenarios.

This article will discuss the simulated irrigation requirements 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 (1972-2005) 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) collected at the Kansas State University Northwest Research-Extension Center was used to calculate alfalfa-based reference evapotranspiration, $ET_r$, using a modified Penman equation (Lamm et al., 1987). This $ET_r$ estimation method is similar to the procedures outlined by Kincaid and Heermann (1974) and has been proven acceptable for this location (Lamm and Rogers, 1983; 1985). A two-year (2005 and 2006) comparison for weather data from Colby, Kansas, of this estimation method to the ASCE standardized reference evapotranspiration equation which is based on FAO-56 (Allen et al., 1998) indicates that the modified-Penman values are approximately 1.5% to 2.8% lower. This is well within the accuracy of the resultant scheduling procedures. The $ET_r$ was further modified with empirical crop coefficients for the region (fig. 1) to give the crop evapotranspiration, $ET_c$. The crop coefficients ($K_c$) for the four crops (corn, grain sorghum, soybean, and sunflower) were developed using procedures outlined in FAO-56 (Allen et al., 1998) with region-specific adjustments made to the various growth periods. Additionally the single time-averaged crop coefficients from FAO-56 for the various crops were approximately reduced by $1/K_{c\ \mathrm{FAO\text{-}56\ MidPoint}}$ to provide better crop water estimates for the alfalfa-based reference $ET_r$. This generally reduced the FAO-56 crop coefficients tabulated for short crops (FAO-56 table 12, Allen et al., 1998) by approximately 15% to 20%. Alfalfa-based

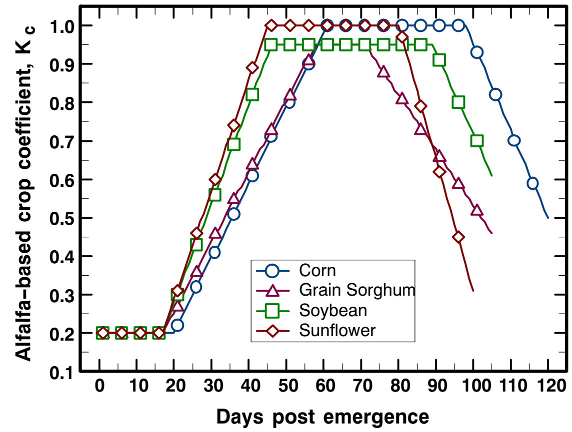


**Figure 1. Alfalfa-based crop coefficients used in the simulated irrigation schedules and crop yield modeling.**

$ET_r$ is considered to give better estimates than short-grass $ET_o$ in this region (Howell, 2007).

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 the calculated $ET_c$. The water budget included effective precipitation (P) and irrigation (I) as deposits and $ET_c$ and drainage (D) as withdrawals. Typical emergence, physiological maturity, and irrigation season dates for Northwest Kansas were used in the simulation (table 1). The simulations assumed a medium-textured, deep, well-drained, loessial Keith silt loam (Aridic Argiustoll; fine silty, mixed, mesic), typical of many High Plains soils and is described in more detail by Bidwell et al. (1980). The 1.52-m soil profile will hold approximately 370 mm of plant available soil water (PAW) at field capacity. The initial soil water at the beginning of each crop season was assumed to be at 85% of the PAW in the 1.52-m soil profile. Effective summer rainfall for this region was assumed to be 88% of the rainfall amount as used by Stone et al. (1995). An overall limit on effective rainfall was set at a maximum of 57.2 mm within a 24-h period to handle the occasional extreme events that occurred over the 34-yr period. Daily drainage from the soil was calculated as a function of time using a drainage equation developed for the 1.52-m soil profile for the Keith silt loam soil at Colby, Kansas (Darusman, 1994):

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

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

The irrigation-scheduling model was coupled with a crop yield model to calculate crop grain yields as affected by irrigation capacity. Irrigation levels or capacities such as no irrigation and 25.4 mm every 3, 4, 5, 6, 8, or 10 d were used in these simulations. Irrigation was scheduled according to climatic needs, but was limited to these capacities.

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

| | Corn | Grain Sorghum | Soybean | Sunflower |
|---|---|---|---|---|
| Parameter | | | | |
| Emergence date | 15 May | 1 June | 25 May | 15 June |
| Physiological maturity date | 11 Sept | 13 Sept | 16 Sept | 11 Sept |
| Crop season (d) | 120 | 105 | 115 | 100 |
| End of irrigation season | 2 Sept | 4 Sept | 7 Sept | 2 Sept |
| Irrigation season (d) | 110 | 95 | 105 | 90 |
| Factors for crop yield model | | | | |
| Vegetative period (d) | 66 | 54 | 38 | 53 |
| Susceptibility factor (vegetative)[a] | 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 |
| $S_y$, Slope on yield eq. (Mg/ha-mm) | 0.0416 | 0.0301 | 0.0121 | 0.0096 |
| $I_y$, Intercept on yield eq. (Mg/ha) | -11.55 | -5.32 | -2.40 | -1.33 |

[a] Susceptibility factors in this table are the water stress weighting factors, $WF_{ai}$, from equation 5.

Crop yields for the various irrigation capacities were simulated for the 34-yr 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:

$$Y = (S_y \cdot ET_c) + I_y \tag{2}$$

with yield (Y) expressed in Mg/ha, yield intercept ($I_y$) and slope ($S_y$) as shown in table 1, and $ET_c$ in mm.

For the yield functions, the daily $ET_c$ values were modified to reflect any water stress imposed by lower soil water availability by using a soil water availability coefficient. This soil water availability coefficient ($K_a$) as outlined by Hanks (1974) was conditionally calculated using locally derived factors as:

$$\text{If PAW} > 70\% \text{ maximum PAW then } K_a = 1 \tag{3}$$

$$\text{If PAW} < 70\% \text{ maximum PAW then } K_a = \text{PAW} / 0.70\ \text{PAW} \tag{4}$$

The 70% PAW threshold for $K_a$ reduction is higher than typical values expressed in the literature that are often near 50%, but is supported by experimental studies for this soil type in this region (Lamm et al., 1996). The threshold values for $K_a$ reduction and the functional relationships for the reduction remain widely debated and often reflect crop, climate, and soil differences. A summary of the many forms and their rationale is presented by Howell et al. (1979).

Further application of the yield model reflects crop susceptibility weighting factors for specific growth period (table 1). These additional weighting factors were incorporated into the simulation to better estimate the effects of irrigation timing at the various crop stages 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 using yield response factors of Doorenbos and Kassam (1979).

The actual weighting factor ($WF_{ai}$) for a particular growth period was multiplied by the average of all $((K_a \times ET_c)/ET_c)$ ratios during the period. $WF_{ai}$ values for all four periods were 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:

$$Y = \left[\sum_{i=1}^{4} WF_{ai}\right] \cdot \left[I_y + \left\{S_y \cdot \sum_{days=1}^{End} \left(K_a \cdot ET_c\right)\right\}\right] \tag{5}$$

where End is the total crop period in days and all other variables are previously defined.

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 as 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 items 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. Additionally, since crop prices are relatively volatile in this period of high

**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 1/2 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 |

energy costs, a sensitivity analysis was performed by examining each individual crop increasing 10% relative to the base price assumption from 2006 input costs.

The probability of exceeding a given crop yield or net return as affected by irrigation capacity was computed using a normal distribution for the mean and standard deviation of the 34 years.

## 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, Kans.) were calculated to be 6.8 and 6.3 mm/d, respectively (fig. 2). 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. 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 crop 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-yr period was 375, 272, 367, and 311 mm, respectively

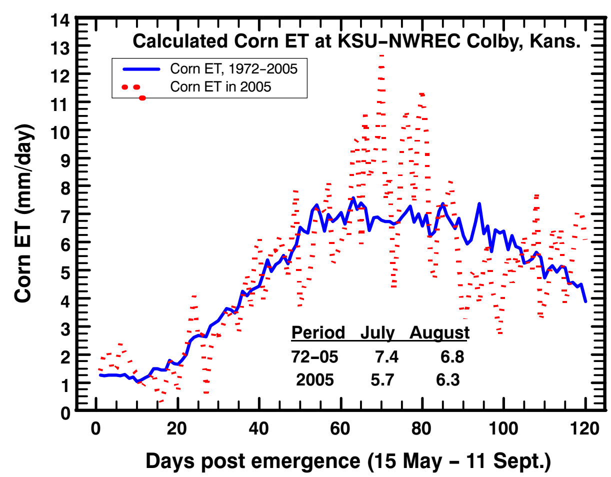


**Figure 2. Calculated daily corn evapotranspiration at Colby, Kansas, for the long-term average (1972 to 2005) as compared to the crop year 2005. Average daily July and August ET values are shown in the table inset.**

(table 4.). The maximum SNIR for the crops was in 1976 and 1983 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.

Simulation results indicated that July and August required the highest amounts of irrigation for all four summer crops with the two months accounting for about 86% of the total seasonal needs (table 4). However, it might be more appropriate to look at the SNIR and seasonal distribution in relation to probability, similar to the exceedance 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 5). 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 probability levels) for corn, grain sorghum, soybean, and sunflower, respectively, using center-pivot sprinklers operating at 85% Ea (table 5).

It should be noted that this simulation procedure only allows significant soil water depletion at 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 in-season irrigation emphasis does follow the general philosophy expressed by Stone et al. (1994) that concluded in-season irrigation is more efficient than off-season 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 for corn in this region 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 inefficiencies (deep percolation or low rainfall utilization) caused by irrigating at a 25-mm deficit becomes moot, since the deficit often increases well above 25 mm as the season progresses.

## 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 crop yield as related to irrigation capacity is simulated over a number of years, the curve becomes quite smooth (fig. 3). Using the yield model (eq. 5.), the 34 years of irrigation schedules and assuming a 95% Ea, the 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% Ea can be calculated from the polynomial equations in table 6. Corn has a much steeper slope than the other three crops when the capacity is less than 6.5 mm/d.

In a probabilistic sense, corn and soybean yields are similar in response to irrigation capacity and their chances of

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

| Parameter | Corn | Grain Sorghum | Soybean | Sunflower |
|---|---|---|---|---|
| Seasonal cumulative SNIR (mm) | | | | |
| Maximum from 34 yr | 533 | 432 | 533 | 483 |
| Minimum from 34 yr | 127 | 76 | 127 | 102 |
| Mean | 375 | 272 | 367 | 311 |
| Standard Dev. | 110 | 92 | 109 | 100 |
| Monthly distribution of SNIR (%) | | | | |
| June | 13.7 | 6.0 | 10.0 | 2.3 |
| July | 42.6 | 38.9 | 43.2 | 25.5 |
| August | 41.9 | 50.5 | 40.5 | 53.2 |
| September | 1.8 | 4.6 | 6.4 | 19.1 |

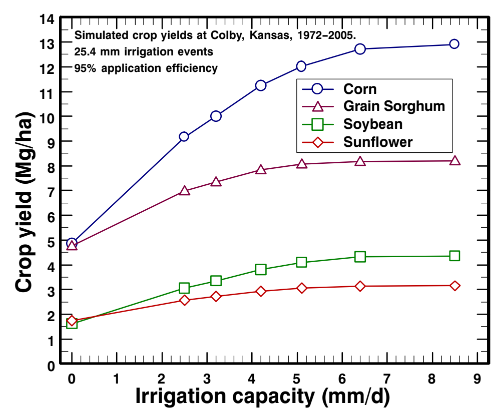


**Figure 3. Simulated summer crop yields in relation to irrigation system capacity for the 34 years, 1972 to 2005, Colby, Kans.**

**Table 5. Simulated net irrigation requirements (SNIR) of four 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 the critical July through August irrigation needs (Colby, Kans.).**

| | Corn | | G. Sorghum | | Soybean | | Sunflower | |
|---|---|---|---|---|---|---|---|---|
| Criteria | SNIR | July-August | SNIR | July-August | SNIR | July-August | SNIR | July-August |
| SNIR value not exceeded in 80% of the years | 483 mm | 93.80% | 356 mm | 100.00% | 483 mm | 88.90% | 381 mm | 84.20% |
| | | 452 mm | | 356 mm | | 429 mm | | 342 mm |
| July – August capacity requirement | 7.3 mm/d | | 5.7 mm/d | | 6.9 mm/d | | 5.5 mm/d | |
| Min. gross capacity at 85% application efficiency | 8.6 mm/d | | 6.7 mm/d | | 8.1 mm/d | | 6.5 mm/d | |
| Min. 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 | 87.50% | 279 mm | 90.90% | 381 mm | 84.20% | 356 mm | 80.00% |
| | | 355 mm | | 254 mm | | 321 mm | | 285 mm |
| July – August capacity requirement | 5.7 mm/d | | 4.1 mm/d | | 5.2 mm/d | | 4.6 mm/d | |
| Min. gross capacity at 85% application efficiency | 6.7 mm/d | | 4.8 mm/d | | 6.1 mm/d | | 5.4 mm/d | |
| Min. gross capacity at 95% application efficiency | 6.0 mm/d | | 4.3 mm/d | | 5.4 mm/d | | 4.8 mm/d | |

Table 6. Relationship of crop yield, Mg/ha, to irrigation capacity for four summer crops at Colby, Kans. for 34 years (1972-2005) of simulation at a 95% application efficiency.

| Crop | Crop Yield Relationship (Y) in Mg/ha 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 |

significant yield reductions are greater under deficit irrigation than for grain sorghum and sunflower (fig. 4). There are little or no differences in exceedance probability of yield reduction for each of the four individual crops when comparing the highest two capacities (25 mm every 3 or 4 days). This further emphasizes that the lower 25-mm/day irrigation capacity is sufficient for this soil type in this region, provided center pivot irrigation equipment is in good working condition and that no downtime for repairs is needed and that there is relatively high PAW at crop emergence. At the 50% exceedance probability level, corn and soybean yields are reduced by 6.2% and 5.5%, respectively, for the 25 mm/6 day irrigation regime while grain sorghum and sunflower yields were reduced only by 1.5% and 3.0%, respectively.

## Simulation of Economic Net Returns as Affected by Irrigation Capacity

The net returns for the four summer crops can be estimated for the different irrigation system capacities (fig. 5). Although corn is currently the predominant irrigated crop in western Kansas, current 2006 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 economically competitive. Net irrigation requirements for soybean are only about 2% lower than corn (table 4), so a shift to soybean will not result in significant water conservation.

Sunflower and grain sorghum are better economic alternatives than corn under dryland and extremely deficit irrigation, but with current 2006 yield projections and prices, they are noncompetitive at the higher irrigation capacities. They do offer the opportunity for stable production at a wider

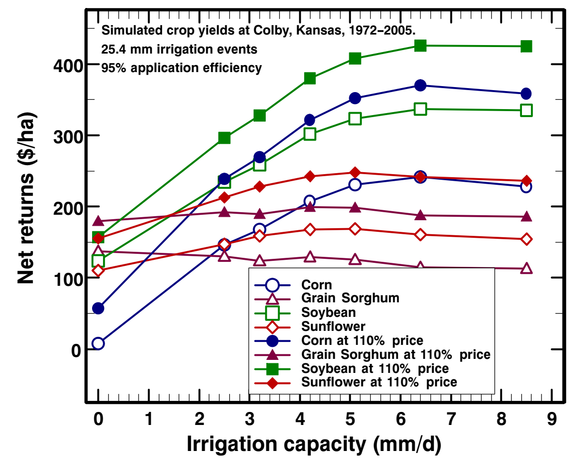


Figure 5. Simulated net returns above direct cash costs for four summer crop yields in relation to irrigation system capacity for the 34 years, 1972 to 2005, Colby, Kans. The open symbols are for the base assumption 2006 crop price and the closed symbols are for a crop price increase of 10%.

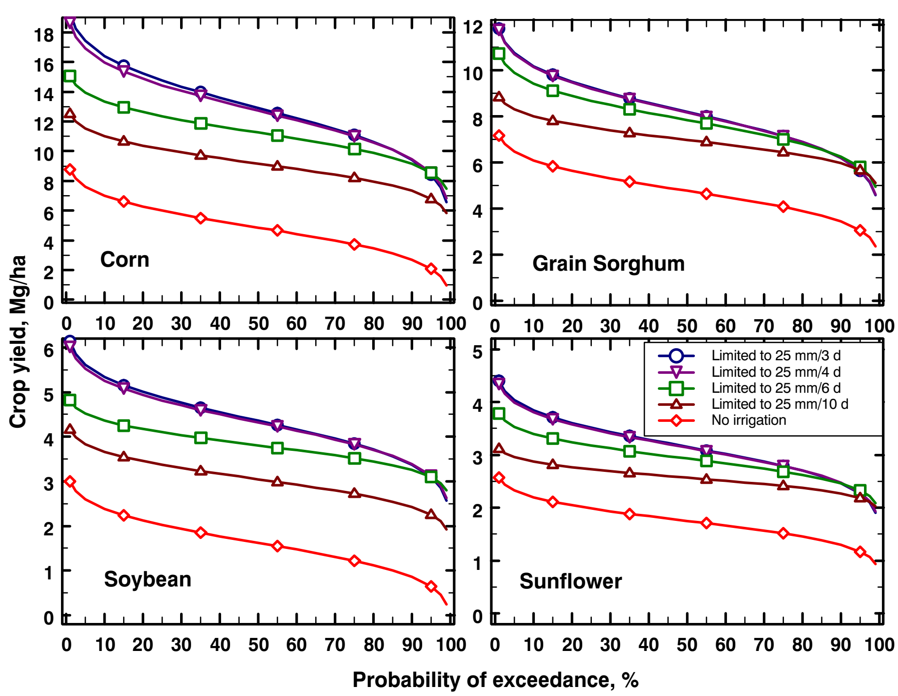


Figure 4. Probability of exceedance of a given crop yield as affected by irrigation capacity for corn, soybean, grain sorghum, and sunflower assuming a normally distribution, based on simulations for the 34 years, 1972 to 2005, Colby, Kans.

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 typically chosen by producers in the area. This may be related to the fact that higher elevations and the resulting cool nights in the region during August and September limit higher grain yields from occurring.

An increase in all crop prices of 10% (comparison of solid vs. the same open symbol in fig. 5) indicates that a rise in prices generally has more benefit at the higher irrigation capacities. If price of one crop rises 10% relative to the others (comparison of one solid vs. all the open symbols in fig. 5) then in some cases the relative ranking of crops may change. For instance if corn prices increase by 10% relative to stable prices for the other three commodities, corn becomes the most profitable irrigated crop but not so under dryland conditions. This shows the volatility of net return projections and such crop shift scenarios are not that unreasonable. Ethanol and bioenergy demand is driving up corn price projections for 2007 at a much higher rate than for the other crops. Similarly, a 10% increase in sunflower prices relative to stable corn indicates that it can be a better and more economically stable crop than corn at all irrigation capacities. Grain sorghum even with a price increase appears to be a poor irrigated crop choice in this region.

Estimates of the economic net returns above direct cash costs for the base 2006 assumptions as affected by irrigation capacity at a 95% Ea can be calculated from the polynomial equations in table 7.

Similar to crop yields, the economic net returns can be shown in a probabilistic sense (fig. 6). Soybean net returns are more stable for a much broader range of probability than corn particularly at irrigation capacities of 25 mm/6 days or greater. There is a 75% exceedance probability of net returns exceeding approximately \$125/ha for corn for the upper three capacities while net returns for the same exceedance probability for soybean exceeds approximately \$275/ha. Grain sorghum and sunflowers have similar probabilities of net returns and are relatively unaffected by irrigation capacity compared to corn and soybean.

### 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 and net return relationships in table 6 and 7 and comparing these values to the maximum yield and net returns (table 8).

The results indicate there is not much yield advantage and no economic advantage on average for planning for the higher 8.5-mm/d irrigation capacity and its associated higher crop production inputs. The most profitable design capacity for corn and soybean is 6.4 mm/d, 5.1 mm/d for sunflower, and dryland production for grain sorghum.

**Table 7. 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) in \$/ha 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 | 0.01 |

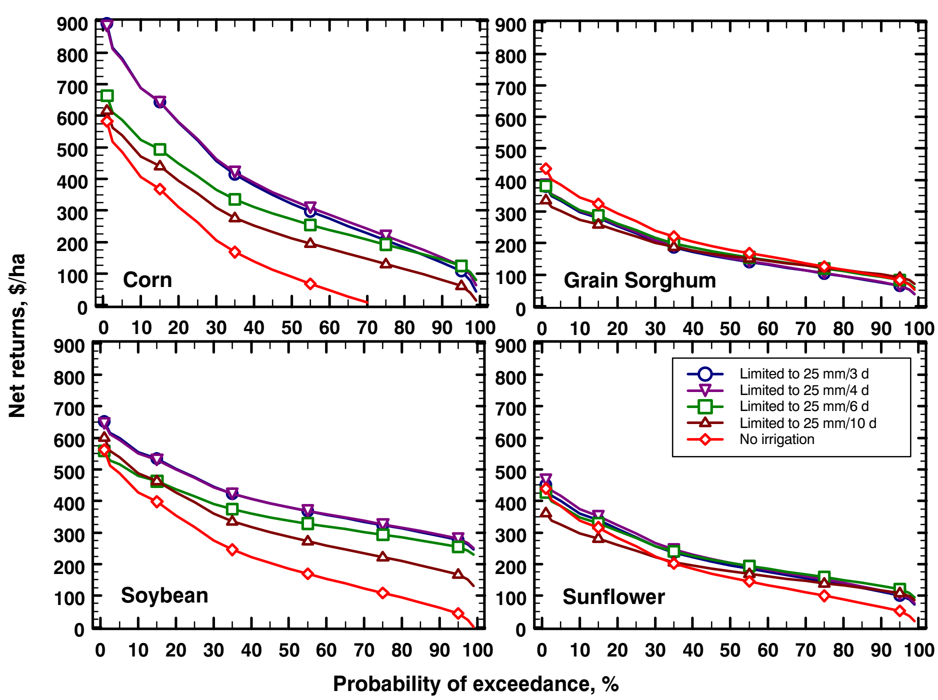


**Figure 6. Probability of exceedance of a given crop net return as affected by irrigation capacity for corn, soybean, grain sorghum, and sunflower assuming a normally distribution, based on simulations for the 34 years, 1972 to 2005, Colby, Kans.**

Table 8. Penalty to crop yields for center pivot irrigated crop production at 95% application efficiency when irrigation capacity is below 8.5 mm/d.[a]

| Irrigation Capacity (mm/d) | Penalty to Crop Yield (Mg/ha) | | | | Penalty to Economic Net Returns ($/ha)[b] | | | |
|---|---|---|---|---|---|---|---|---|
| | 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 | 0.9 | 0.12 | 0.26 | 0.1 | -$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 | 2.9 | 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 | 1.4 | $220.14 | -$23.93 | $211.29 | $44.22 |

[a] Results are from simulations of irrigation scheduling and yield for the 34 years, 1972 to 2005, Colby, Kans.
[b] Negative net return penalties indicate a more economically favorable capacity than 8.5 mm/d.

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 3. Differences in yield improvements between crops could also affect the relative net returns position of the crops.

### Water Use and Water Use Efficiency of Corn

Corn is the major irrigated crop in the region, so additional discussion of this crop is warranted. 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 not true. The actual water use ($ET_c$) of a fully irrigated corn crop probably has not decreased in the last 100 years. Summarizing five studies conducted by different investigators worldwide from 1886 to 1913, Briggs and Shantz (1913) found the average water requirement of corn to be 335 mm. Further examination of these studies indicates that water requirements varied with crop production, fertilization, and soil texture. In one of these studies from Logan, Utah (Widtsoe, 1909), water requirements ranged from 386 to 601 mm depending on soil texture. Considering the yield potential, fertilization and cropping cultures of that earlier period, the range in corn water use appears comparable to the total calculated $ET_c$ for today's corn of about 585 mm in this region (34 years, 1972-2005, Colby, Kans.). The more correct statement is more corn grain can be produced 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.

### Opportunities to Increase Deficient Irrigation Capacities

There are many center pivot sprinkler systems in the region that this article would suggest have deficient irrigation capacities. There are some practical ways irrigators might use to effectively increase irrigation capacities for summer crop production. These include: 1) plant a portion of the field to a winter irrigated crop (e.g., wheat, barley canola); 2) remove end guns or extra overhangs to reduce system irrigated area; 3) clean or chlorinate well screen and gravel pack to see if irrigation capacity has declined due to encrustation or bacterial contamination; 4) determine if the well and pumping plant capacity are appropriate for the irrigation system capacity; 5) check well, pump, and engine/motor efficiencies, and repair or replace if needed.

## Conclusions

Corn and soybean have similar net irrigation requirements that are approximately 27% greater than grain sorghum and sunflower.

The minimum recommended gross irrigation capacities (62 d, July-August period) were 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.

Using the base economic assumptions from 2006, soybean was a more profitable alternative to irrigated corn. If corn prices rise at least 10% relative to stable soybean prices due to higher demand that may be driven by ethanol production, corn then becomes the more profitable irrigated crop. Grain sorghum is a poor crop choice for irrigation in this region and is more profitable under dryland conditions.

Penalties to yield and net returns for corn increase rapidly when irrigation capacity falls below 5.1 mm/d with soybean beginning to decrease rapidly at capacities less than 6.4 mm/d. Soybeans have a shorter period of irrigation and overall use slightly less irrigation water, but the penalty increases at a faster rate because there is a shorter period to buffer inadequate irrigation capacity with the summer precipitation that does occur.

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. Corn, grain sorghum, soybean, and sunflower 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 presented in this article 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 article 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.

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