# IRRIGATION AND CROP MANAGEMENT FOR LIMITED WATER SUPPLIES

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## ABSTRACT

A field study has been conducted for the past 10 years to compare a crop rotation of winter wheat-corn-soybean (W-C-S) with continuous corn (CC) in the semi-arid climate of west central Nebraska. These crop rotations have been grown with dryland, limited irrigation (6 inches per year), and full irrigation (evapotranspiration demand with maximum 50% soil water depletion) water management system under conservation tillage on a Cozad silt loam soil. The effects of the cropping systems on crop yield, water use, soil water storage, and economic return have been evaluated.

## INTRODUCTION

Farmers in irrigated areas may need to adopt cropping systems that sustain and/or improve economic return from both rainfall and irrigation, especially in areas with declining water supplies. Management practices, which maximize profits based on unlimited water availability, will hasten conversion of irrigated farmland to rainfed management where irrigation water supplies are limited and declining.

One approach to managing declining groundwater aquifers in southwest Nebraska has been to allocate an amount of water which will slow or halt ground water declines. Currently one Natural Resources District, which is governed by a locally elected board of directors, limits irrigators to 14.5 inches of water per year. With good irrigation system efficiency and management, water can be applied so that it is not a limiting input for corn production. However, in dry years the aquifer continues to decline. Less water may be allocated in future years to sustain the aquifer. As water allocations are reduced, different crops that use less water than corn need to be selected and sequenced to maintain economic return while using less water. Timely and efficient water management is required to make the best use of precipitation and limited water supplies.

The study summarized in this paper was designed to determine the grain production and economic returns to irrigators if water allocations for irrigation are reduced or eliminated. Crop rotations including corn, soybean, and winter wheat plus best management practices for crop production were studied to make efficient use of precipitation and irrigation.

## METHODS

### Site Description and Experimental Design

Crop rotation research was conducted at the West Central Research and Extension Center of the University of Nebraska at North Platte, Nebraska since 1981 (Schneekloth et al., 1991; Hergert et al., 1993). Data interpretation began in 1985 after all crop rotations and water treatments were in place. The predominant soil type was a Cozad silt loam with a pH of 7.5. Plant available water holding capacity was 0.17 $ft^3/ft^3$ from the 0 to 10 ft depth. Slope within the research site was from 0 to 1 percent.

### Cropping Practices

All crops grown in the study were surface planted with no-till equipment. Crop residues were maintained on the surface for maximum moisture preservation. Seeding rates for corn were adjusted in accordance with the amount of water which would be available to each of the three water levels. Fertilizer rates were based on residual nitrate in the soil and anticipated crop yields. The nitrogen application rate was assumed to be non-limiting for grain yield. Pest management for weeds and insects was based on current University recommendations.

## Irrigation Practices

Full irrigation plots were irrigated to meet ET demands and to keep the soil wetter than 50% depletion of plant available water. Irrigations were scheduled weekly by monitoring soil water with the neutron attenuation method. Water was applied to fully irrigated corn weekly starting late in the vegetative growth period until late in the grain filling period. Water was applied with a permanent solid-set sprinkler irrigation system at a rate of 0.4 inch per hour.

Limited irrigation was defined as the application of less water than required to meet the full evapotranspiration (ET) demand of a crop. Plots in the limited irrigation treatment received a maximum of 6 inches of irrigation during the growing season for each crop.

Limited irrigation corn was irrigated during pollination and early grain fill. Water was applied in three 2 inch irrigations beginning at tassel emergence. The two subsequent irrigations were beginning at tassel emergence. The two subsequent irrigations were applied two and four weeks after the initial irrigation. Water was applied before the pollination stage only if: 1) moisture was not adequate for germination or 2) greater than 75% of plant available water was depleted. Due to dry weather 2 inches of the 6 inch water allocation was applied at planting during the 1989 cropping season for germination.

Limited irrigation soybean received irrigation during pod elongation and pod fill. One 2 inch irrigation was applied at initial pod elongation with subsequent irrigations applied two and four weeks after the initial irrigation. During the study period, no water was applied earlier than pod elongation. Irrigation for full irrigation soybean ended by late August to accelerate the maturity of the soybean. Soybean was harvested in mid-September, typically two to three weeks earlier than normal, and winter wheat was planted by October 1.

The first irrigation for wheat was during mid-September in mature standing soybean. This application of 2 inches prepared the dry soil surface for planting wheat immediately after soybean harvest. The remaining 4 inches for limited irrigation wheat was applied in two 2 inch applications during boot and soft dough stages.

## Economic Analysis

Net returns were defined as gross value at harvest minus materials cost and custom rates for field operations which included labor, machine operating costs, and some capital costs for equipment used by the custom operation. Net returns, therefore, were net to land, overhead, irrigation equipment (capital), management, and risk. Production costs for field operations were estimated by average custom rates for southwest Nebraska. Material costs included herbicide, fertilizer, seed, insecticide, and irrigation pumping costs. Herbicide costs were estimated with approximate retail prices. The price of nitrogen was based on anhydrous ammonia. Pumping cost ($3.25/ac-in) was estimated for a center pivot irrigation system operating at 45 psi, 150 ft lift, and diesel power. Fuel price was estimated to be $0.80/gal. The cost of water included $1.00/ac-in for repairs and maintenance. A summary of these production costs for corn, soybean, winter wheat, and fallow are shown in Table 1.

TABLE 1. Average cost of production for continuous corn, corn-soybean, corn-soybean-wheat, corn-fallow-wheat based upon 1990 costs

| Rotation and Crop | Water Treatments<br>Dryland<br>$\$ ac^{-1}$ | <br>Limited<br>$\$ ac^{-1}$ | <br>Full<br>$\$ ac^{-1}$ |
|---|---|---|---|
| CC (Corn) | 128 | 165 | 210 |
| C-S (Corn) | 97 | 146 | 192 |
| S-C (Soybean) | 99 | 125 | 146 |
| C-S-W (Corn) | 97 | 146 | 192 |
| C-S-W (Soybean) | 99 | 125 | 146 |
| C-S-W (Wheat) | 56 | 77 | 90 |

Price scenarios for corn and winter wheat were based on government target prices and the average market price for the prior 10 yr (Nebraska Agricultural Statistics Service, 1991). Average market prices for corn, soybean, and winter wheat were $2.38/bu, $5.48/bu, and $3.20/bu, respectively, with a standard deviation of $0.40/bu, $0.85/bu, and $0.60/bu. Government target prices for corn and wheat were $2.75/bu and $4.00/bu. Payment yields for rainfed corn and winter wheat were 52 and 36 bu/ac, respectively. Payment yields for irrigated corn and winter wheat were 126 and 54 bu/ac, respectively. Payment yields were based upon those typical for Lincoln County, Nebraska.

## RESULTS AND DISCUSSION

### Precipitation and Irrigation

Growing season (June 1 to Sept. 30) rainfall varied from 6.2 to 13.7 inches during the study period (Table 2). Precipitation (rain + snow) available for increasing stored soil water (October through May) varied from 4.5 to 13.5 inches.

Table 2. Precipitation during 1985 to 1993 at North Platte, NE.

| Year | Non-Growing Season (Oct 1-May 31) | Growing Season (June 1-Sept 30) | Total (Oct 1-Sept 30) |
|---|---|---|---|
| | --------in-------- | -------in------- | ------in------- |
| 1985-86 | 13.5 (+) | 7.4 (-) | 20.9 (+) |
| 1986-87 | 10.0 () | 10.8 () | 20.8 (+) |
| 1987-88 | 12.0 (+) | 13.7 (+) | 25.7 (+) |
| 1988-89 | 4.5 (-) | 9.3 () | 13.8 (-) |
| 1989-90 | 8.7 () | 6.2 (-) | 14.9 (-) |
| 1990-91 | 11.8 (+) | 8.0 (-) | 19.8 () |
| Normal | 9.4 | 10.0 | 19.4 |

(+) Above normal precipitation
(-) Below normal precipitation
() Normal precipitation

Irrigation applications are in Table 3. Winter wheat received less than the 6 inch allocation in all years except 1987 and 1991. Rainfall patterns did influence irrigation applications for the fully irrigated crops.

Table 3. Irrigation water applied to crops in the continuous corn and winter wheat-corn-soybean rotations.

| Year | Corn | | Winter-Wheat | | Soybean | |
|---|---|---|---|---|---|---|
| | Limited | Full | Limited | Full | Limited | Full |
| | in. | | | | | |
| 1986 | 6.2 | 15.7 | 3.8 | 3.8 | 4.6 | 13.0 |
| 1987 | 6.0 | 15.4 | 6.0 | 6.6 | 6.0 | 12.4 |
| 1988 | 5.9 | 10.0 | 6.1 | 10.7 | 6.0 | 7.8 |
| 1989 | 6.0 | 19.4* | 6.1 | 9.5 | 6.0 | 11.6 |
| 1990 | 6.0 | 12.7 | 6.0 | 9.3 | 6.0 | 9.6 |
| 1991 | 6.2 | 11.3 | 5.1 | 6.7 | 6.0 | 9.9 |
| Average | 6.1 | 14.3 | 5.6 | 7.9 | 5.8 | 10.9 |

* CC rotation received 21.5 in. due to lower soil water storage compared with W-C-S.

Soil Water Increases During Non-Growing Season

Soil water increased due to precipitation during the non-growing season, which was an important component in rainfed and limited irrigation cropping systems (Table 4). The fallow period after winter wheat harvest started by July 15, 75 days sooner than corn or soybean harvest. This time difference allowed for significantly more accumulation of soil water following wheat than following either corn or soybean in all water treatments. At the end of the growing season, soils was driest in the rainfed treatment and wettest in the fully irrigated treatment, which led to the most soil water increase in the rainfed treatment even though all water treatments received the same precipitation.

Table 4. Average gains in soil water during the non-growing season for W-C-S and CC rotations (1986-92).

| Year | Rainfed | | | Limited | | | Full | | |
|---|---|---|---|---|---|---|---|---|---|
| | Wheat to corn | CC | Corn to soy | Wheat to corn | CC | Corn to soy | Wheat to corn | CC | Corn to soy |
| | inches | | | | | | | | |
| Avg. | 8.6a | 6.5b | 6.9b | 8.2ab | 5.7c | 6.8bc | 6.6a | 3.8c | 3.7c |

* Means within the same water treatment followed by the same letter are not significantly different at the P = .05 level using Duncan's multiple range test.

Stored Soil Water Usage During Growing Season

Rainfed crops and limited irrigated crops were forced to extract more stored soil water during the growing season than the fully irrigated crops (Table 5). Corn following winter wheat tended to utilize more stored soil water than continuous corn because more water was stored following wheat. Fully irrigated crops relied more on irrigation for evapotranspiration.

Table 5. Average decrease in soil water from beginning of growing season to end of growing season in two crop rotations and three water treatments. (1986-92).

| Crop | Rainfed | | Limited | | Full | |
|---|---|---|---|---|---|---|
| | W-C-S | CC | W-C-S | CC | W-C-S | CC |
| | inches | | | | | |
| Corn | 8.7a | 6.3b | 7.4a | 5.7bc | 3.5a | 3.2a |
| Soybean | 6.4b | ---- | 4.8c | ---- | 2.6a | ---- |
| Wheat | 3.3c | ---- | 5.5bc | ---- | 3.3a | ---- |

* Means within the same water treatment followed by the same letter are not significantly different at the P = .05 level using Duncan's multiple range test.

## Grain Yield and Evapotranspiration Relationship

Grain yield (Table 6) versus ET relationships were developed to compare yield responses of wheat, soybean, and corn grown in both rotations to evapotranspiration. A grain yield-ET function permits the determination of the minimum amount of water needed for ET before grain yield will occur. This is an important factor in determining and comparing the economic response of a crop to irrigation.

The response of corn to ET was approximately 1.5 times greater than the response of soybean to ET. Corn's response to ET was approximately 3 times greater than the response of wheat to ET (Figure 1). Corn and soybean showed a more favorable response of ET to irrigation while the response of wheat would favor rainfed production. The next use of the yield-ET functions would be that of economic comparisons between water applications for a crop and between crops.

If crops were 100% efficient in using water from irrigation, yield versus ET would have a linear relationship. However, crop yields and irrigation have a curvilinear relationship (Figure 2). The most efficient use of irrigation was with limited irrigation, where full ET demand was not met. As more irrigation was added to meet full ET, more water losses occurred.

Table 6. Average grain yields for corn, soybean, and wheat in different rotations at North Platte, NE from 1986-1991.

| | Water Treatments | | |
|---|---|---|---|
| Rotation & Crop* | Dryland | Limited | Full |
| | Bu/ac | Bu/ac | Bu/ac |
| CC (Corn) | 54 | 128 | 173 |
| C-S (Corn) | 0 | 126 | 173 |
| C-S (Soybean) | 17 | 42 | 48 |
| C-S-W (Corn) | 86 | 146 | 173 |
| C-S-W (Soybean) | 23 | 47 | 48 |
| C-S-W (Wheat) | 23 | 54 | 54 |

* CC=continuous corn, C-S=corn-soybean, C-S-W=corn-soybean-wheat

## Economic Return

Adoption of a crop rotation depends at least in part on the net economic returns to the farmer. Maximizing net returns when water for pumping is limited is also important. The crop rotations under the three water treatments were evaluated for net returns to land, irrigation equipment, management and risk. The impact of the government farm program upon choice of rotations was also considered.

Rainfed (Dryland) The W-C-S rotation had higher net returns than continuous corn with target or market prices (Table 7). Inclusion of a fallow period, such as after wheat, increased net returns to investment because of the water stored during the fallow period.

Limited irrigation The W-C-S rotation has somewhat higher average net returns than continuous corn with market prices (Table 7). With government programs, this difference disappeared.

Table 7. Mean annual return and standard deviations to land management, overhead and risk for three irrigation regimes on 130 acres.

| | Rotation | Mean Return $/year | Standard Deviation $ |
|---|---|---|---|
| | **Full irrigated by center pivot** | | |
| No Government Program | CC | 25,700 | 5,600 |
| | C-S | 24,000 | 3,800 |
| | C-S-W | 19,700 | 2,800 |
| 10% ACR for Corn & Wheat | CC | 27,600 | 2,100 |
| | C-S | 25,300 | 2,300 |
| | C-S-W | 21,500 | 1,500 |
| | **Dryland Production** | | |
| No Government Program | CC | -100 | 1,700 |
| | C-S-W | 7,000 | 1,300 |
| 10% ACR for Corn & Wheat | CC | 1,800 | 300 |
| | C-S-W | 8,300 | 800 |
| | **Limited Irrigation Production** | | |
| No Government Program | CC | 18,100 | 4,200 |
| | C-S | 17,400 | 2,900 |
| | C-S-W | 19,100 | 2,400 |
| 10% ACR for Corn & Wheat | CC | 20,700 | 800 |
| | C-S | 19,100 | 1,600 |
| | C-S-W | 20,900 | 1,300 |

Full irrigation Continuous corn had higher average net returns than W-C-S rotation when support prices were used. When market prices were used for corn and wheat, continuous corn still dominated the W-C-S rotation. Corn's response to full irrigation was more than the response of either wheat or soybean. When water resources are not limiting, full irrigation of continuous corn had the highest return under all price scenarios.

Return to irrigation Return to irrigation is an important consideration when water supplies are limited. Return to irrigation determines the feasibility of irrigating specific crops. Returns to irrigation were more for continuous corn for all price strategies than for either corn following wheat, soybean, and wheat (Figure 3). Wheat was the only crop which did not positively respond to full irrigation. Returns to irrigation were more when the first increments of water were applied to rainfed crops. As additional water was applied, crops had less of a response to the water and less of a return. Although continuous corn had more of a response to limited irrigation, the overall return of continuous corn was less than that of a W-C-S rotation.

## SUMMARY

The impact of rotation upon corn grain yields was significant for rainfed and limited irrigation. Rotation had no impact upon corn grain yields when crop ET demands were met with irrigation. The linear yield-ET function for continuous corn and corn following wheat were not significantly different. This indicates that rotation has no influence in producing corn more efficiently with respect to water. To produce a specific amount of grain requires a similar amount of water for both continuous corn or corn following wheat. This research showed that yield differences between rotation and continuous corn were dependent on water when all other variables were non-limiting.

Cultural practices and water management were important in storing soil water. No-till management and crop residues on the surface reduced evaporation from soil and increased infiltration. Limited irrigation and rainfed crops used more of the soil water out of necessity. More soil water could be stored during the non-growing season without leaching than in the fully irrigated crops. With this off-season water storage, crops used stored soil water through vegetative growth.

When water supplies were not limited, continuous corn gave the most return to investment. When irrigation was limited to 6 inches each year, the W-C-S rotation gave the best return to investment.

When research is taken to the farm level, issues including farm program restrictions, management options, and social and economic implications must be considered. The 1990 Food, Agriculture, Conservation, and Trade Act does not allow farmers to expand program base acres for either corn or wheat while participating in farm price protection programs. some producers may decide not to participate in a program to build base and continue current practices. With full irrigation and limited irrigation, net returns were highest for CC when support price was in effect. Higher, more stable prices for wheat and corn that result from the farm program tend to encourage monoculture of corn under both limited and full irrigation. Permitting prices to reflect market conditions may encourage more rotations when irrigation is used.

Management practices will need to change as crop rotations are adopted. Management of crops must become more intensive. Cultural practices in one crop, especially herbicide selection and crop residue management, impact the next crop. Weeds, which use stored soil water, must be controlled with combinations of either tillage or herbicide. Herbicide selection will also be more selective since carryover may be a problem with crop rotations on high pH soils. Proper determination of when irrigation water must be applied and in what quantities must be more advanced than current practices. Soil moisture monitoring must become a weekly or bi-weekly practice to optimize the use of limited quantities of water. Irrigation water was applied in a relatively short time period for this research. Typical systems must apply the same amount of water over several days rather than several hours. With crops responding linearly to ET, irrigation water can be applied in a timely matter which may not reduce yields significantly. However, anticipation of critical water needs will be important for proper management of field scale operations.

## REFERENCES

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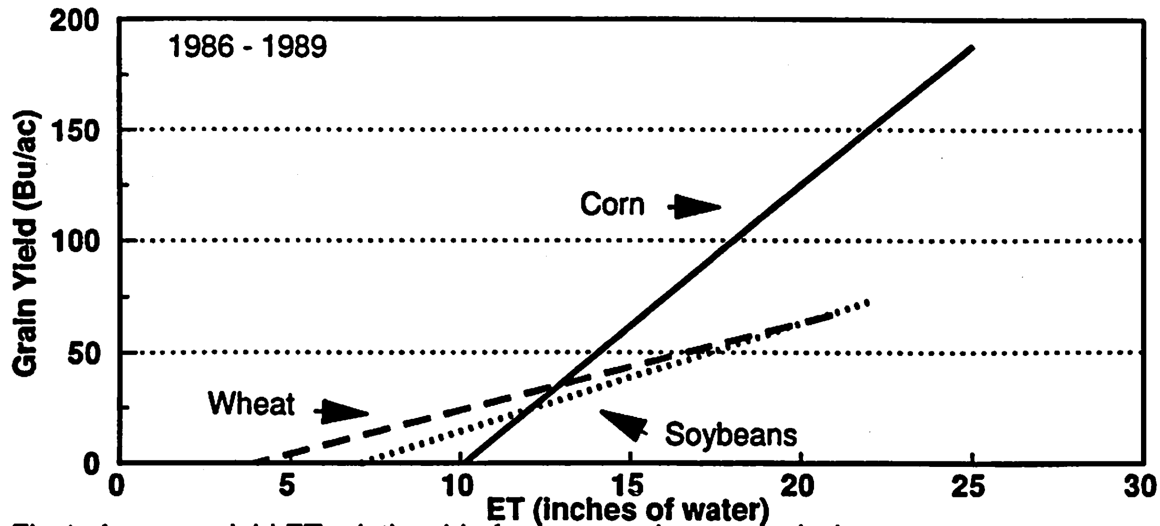


Fig 1. Average yield ET relationship for corn, soybeans, and wheat.

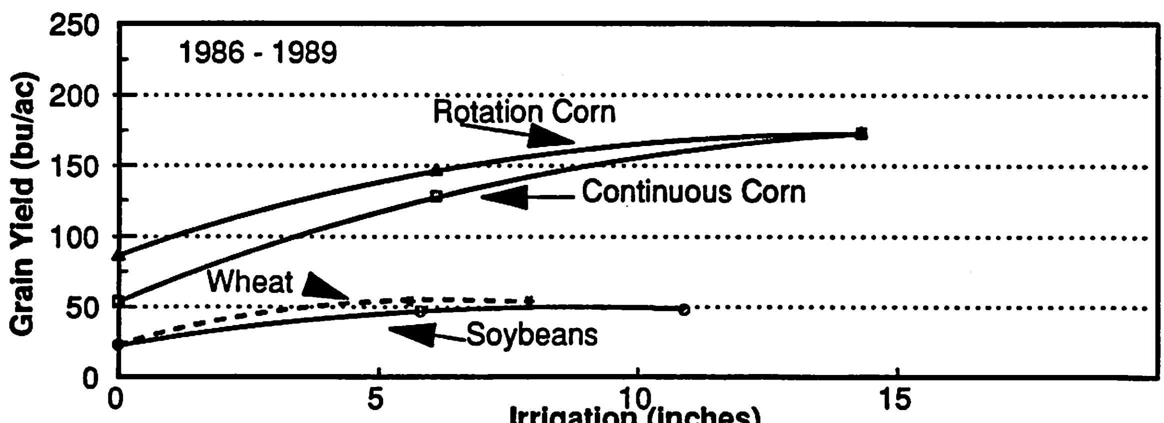


Fig 2. Average yield versus irrigation response for continuous corn, corn after wheat, soybeans, and wheat.

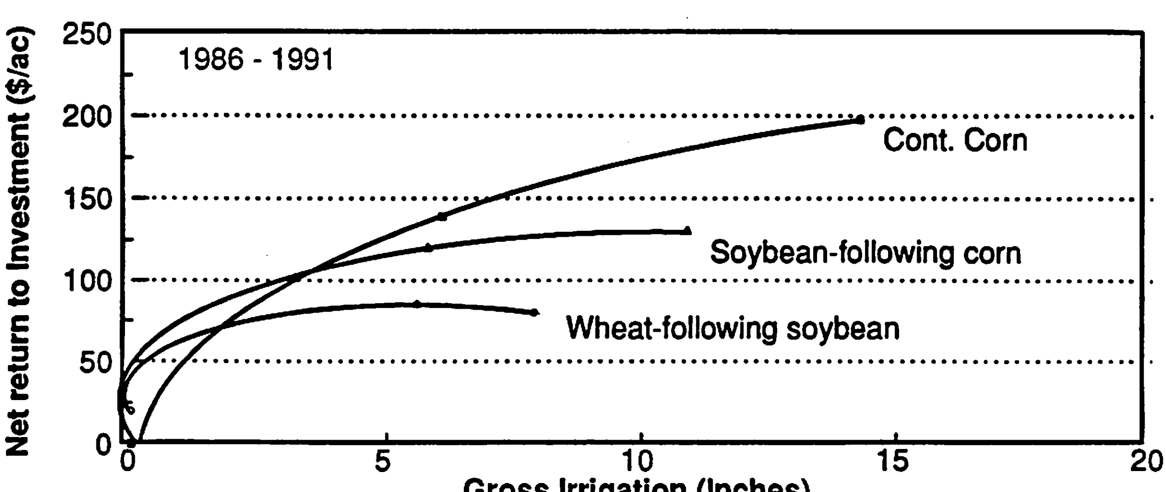


Fig 3. Net return to investment for crops grown with sprinkler irrigation at North Platte, Ne. Notes: Grain prices from 10 year historical average: Corn $2.40/bu; Soybean $5.80/bu; Wheat $3.20/bu. Production costs from 1990.