Resource Allocation in Corn Production with Water Resource Constraints

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Abstract. *Corn (Zea mays L.) is the irrigated crop of choice for many irrigators in the Central Great Plains, but it requires significant amounts of irrigation water to produce high yields. Declining water resources in some areas have resulted in increased public scrutiny of corn irrigation practices. Some irrigators are responding by practicing deficit irrigation of corn, even though it is economically risky and sometimes complicated to successfully implement. A three-year study was initiated in the fall of 1985 on a Keith silt loam soil (Aridic Argiustoll) in northwest Kansas to determine the agronomic and economic feasibility of nine different resource-allocation management schemes for irrigated corn. Irrigation timing and amount, nitrogen fertilization, and corn seeding rate were the three allocated resources. Average corn yields ranged from 6.09 to 9.98 Mg/ha (97 to 159 bu/acre) with average irrigation amounts ranging from 100 to 380 mm (4 to 15 in.). Fully irrigated corn using the standard recommended seeding rate and full fertilization had a higher net income than did any of the other resource-allocation schemes for deficit-irrigated corn. This scheme not only maximized the mean net income but also minimized the standard deviation of net income. Assuming a corn cash market price of $0.089/kg ($2.25/bu), there was an approximately $285/ha ($700/acre) difference between the highest and lowest net incomes for the various management schemes. Management-induced variations in crop production caused a much greater shift in net income than did variations in resource costs among the management schemes, emphasizing the need for resource-allocation management schemes that produce high corn yields. If irrigation is limited, moderate amounts of water stress hardening during the corn vegetative stage with proper matching of the fertilizer and seeding rate will stretch the irrigation season. This type of management scheme increased corn yields by 20% when the water allocation was restricted to 150 mm (6 in.). Federal farm deficiency payments had a marked effect of changing the profitability status from negative to positive for seven of the nine management schemes, when the corn cash market price was $0.069/kg ($1.75/bu).* **Keywords.** *Irrigation management.*

Irrigated agriculture in the Central Great Plains improves net farm income and provides more economic stability for a region often subject to drought.

Irrigation development in the Central Great Plains occurred in areas with little municipal or industrial use of the water. Irrigation management generally provided water for fully irrigated crop production. As irrigation development continued, more marginal water resources were developed, and overdevelopment of some sources occurred. During the same time, other water uses have become more important as urban areas seek to meet water needs.

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Irrigation systems and management techniques have responded to conserve limited water supplies and maintain economic productivity. Changing physical and institutional constraints continue to require new or different methods to allocate water. Scientists and water planners have examined many different methods for using water efficiently. Many factors can affect management schemes, such as water supply, irrigation capacity, crop yield potential, crop-marketing opportunities, dryland cropping alternatives, structure of individual state water law, federal-farm programs and even farmer preference.

When irrigation water supply is the major constraint, management takes into account the available cropping system alternatives, available land area to be irrigated, and any peculiarities imposed if the constraint is institutional. Constraints on water use can be single-season or multiseasonal.

Bernardo et al. (1988), using a multiseasonal simulation model to simulate a surface-irrigated farm in the Columbia River Basin, reported a 40% reduction of annual water allocation could be imposed without a severe impact on net farm income.

Martin et al. (1989) developed a dynamic programming model to annually allocate a limited water supply over a multiseasonal period. This model can also be used to help producers choose the correct mix of crops and balance of irrigated and nonirrigated land. A water-banking system implemented in southwest Nebraska, limiting the amount of water utilized in a five-year period, provides an excellent opportunity to utilize this model. Martin and van Brocklin (1985) reported multiseasonal allocation decisions depend on whether the objective is to maximize net income or to maximize 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.

Crop rotations can result in more efficient use of limited irrigation supplies (Schneekloth et al., 1991). Rotation of a higher irrigation-use crop, such as corn, with a lower irrigation-use crop, such as wheat, allows efficient use of residual soil water and increases the effective storage of overwinter precipitation. Rotations also permit a higher ratio of irrigated to nonirrigated area. The advantage is reduced yield variation due to drought because a larger area receives some irrigation.

In western Kansas, corn yields have increased dramatically over the last 20 years and at a much higher rate than grain sorghum yields. Grain sorghum production can be marginal because of cool nighttime temperatures at the higher elevations. Corn is a major feed grain for the large red meat industry in Kansas. These factors, coupled with federal farm programs, make corn the irrigated crop of choice for most western Kansas producers. However, deficit irrigation of corn is a questionable enterprise. Yields usually decrease when irrigation is less than required to meet the full evapotranspiration requirements of corn.

In an irrigated-corn study in the Southern High Plains, Eck (1986) found water stress reduced yields but did not increase water-use efficiency. He concluded deficit irrigation of corn was not feasible for that area. Musick and Dusek (1980) in a study at Bushland, Texas, reached a similar conclusion, stating "limited irrigation of corn should not be practiced." Stewart et al. (1975), although not thoroughly discounting the practice, admitted that limited irrigation of corn is much more complex than limited irrigation of grain sorghum. They concluded water stress during the reproductive and early grain-filling stages should be avoided, unless there was a conditioning or stress-hardening period during the vegetative stage. Rhodes and Bennett (1990) reported after reviewing numerous studies, that water stress imposed at any growth stage on corn will generally lower the efficiency of the water used in transpiration.

Still, western Kansas irrigators desire to grow corn and, in many cases, are practicing deficit irrigation. Producers are familiar with corn production techniques and are sometimes reluctant to change to alternative cropping systems. Kansas water law ties an irrigation water right to a parcel of land, so there are some practical concerns to using irrigated and nonirrigated rotations on the same parcel of land.

A three-year study was initiated in the fall of 1985 to determine the potential for deficit irrigation of corn, by not only managing the allocation of irrigation, but also nitrogen fertilization and plant population. The study did not determine the optimum fertilization and plant population within a given irrigation constraint. Rather it sought to evaluate several possible management schemes in terms of net income. Fertilizer and seeding rates incorporated into the various irrigation management schemes were based on previous experience with corn production in northwest Kansas.

Procedures

The project was conducted from 1985 to 1988 at the KSU Northwest Research-Extension Center at Colby, Kansas, on a deep, well-drained, loessial Keith silt loam (Aridic Argiustoll). This medium-textured soil, typical of many western Kansas soils, is described in more detail by Bidwell et al. (1980). The 1.5-m (5-ft) soil profile will hold approximately 250 mm (10 in.) of available water at field capacity corresponding to a volumetric soil water content of approximately 0.30 and a profile bulk density of approximately 1.3 gm/cm^3 (81 lbs/ft^3).

The climate is semi-arid with an average annual precipitation of 474 mm (18.7 in.) and approximate annual lake evaporation of 1400 mm (55 in.). Daily climatic data used to schedule irrigation were obtained from a weather station located approximately 250 m (800 ft) east of the study site.

The study was conducted in a 0.6 ha (1.5 acre) dead level irrigation basin, approximately 180 m long × 30 m wide (600 × 100 ft) with plots 4.6 m wide and 30 m long (15 × 100 ft) running perpendicular to the level basin length. The plots accommodated six corn rows spaced 76 cm (30 in.) apart. Small dikes were constructed around each plot to prevent runoff between plots. The study treatments were replicated three times in a randomized complete block design.

The reference evapotranspiration (ET_r) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heerman (1974). The specifics of the ET_r calculations used in this study are fully described by Lamm et al. (1987). Basal crop coefficients (K_{cb}) were generated by equations developed by Kincaid and Heerman (1974) based on work by Jensen (1969) and Jensen et al. (1970, 1971). The basal crop coefficients were calculated for the area by assuming 70 d from emergence to full canopy for corn with physiological maturity at 130 d. This method of calculating actual evapotranspiration (AET) as the product of K_{cb} and ET_r has been applied in past studies at Colby and it has been found to accurately estimate AET (Lamm and Rogers, 1983, 1985). In constructing the irrigation schedules, no attempts was made to modify AET with respect to soil-evaporation losses or soil-water availability as outlined by Kincaid and Heerman (1974).

Nine treatments were devised to examine several reasonable irrigation schemes within three given constraints on total water allowance. The irrigation season ceased for a particular treatment when the irrigation constraint was reached. All plots started the season with a full soil water profile and any applied preseason irrigation was not considered a part of the allowance. Preseason irrigation is not typically needed in northwest Kansas. The treatments or management schemes were as follows,

Water allowance not to exceed 455 mm (18 in.).

- 100% of calculated AET
- 75% of calculated AET
- 50% of calculated AET

Water allowance not to exceed 305 mm (12 in.).

- 100% of calculated AET
- 75% of calculated AET during vegetative stage, 100% thereafter
- 50% of calculated AET during vegetative stage, 100% thereafter

Water allowance not to exceed 150 mm (6 in.).

- 100% of calculated AET
- 75% of calculated AET during vegetative stage, 100% thereafter
- 50% of calculated AET during vegetative stage, 100% thereafter

Irrigation water was metered separately onto each plot through gated pipe according to the following criteria:

- Set allowable calculated depletion in the corn root zone to be 75 to 100 mm (3 to 4 in.).
- Add rainfall and irrigation amounts as deposits to the water budget. If depletion amount is negative, set to zero.
- Calculate daily actual water use or AET for corn. (Modified Penman Equation with basal crop coefficients)
- Multiply AET amount by treatment level percentage to obtain modified AET value for the particular treatment.
- Subtract modified AET value from water budget for each treatment.
- Irrigate a treatment with an amount equal to the calculated root-zone depletion when the treatment reaches the allowable calculated depletion. Application efficiency for the small basins was assumed to be 100%.

The maximum irrigation rate in the corn study was not allowed to exceed 7.5 mm/day (0.30 in./d) or a 75 mm (3 in.) irrigation in a 10-d period. This maximum irrigation rate reflected the typical capacity of irrigation systems in northwest Kansas. If the cumulative AET by the corn exceeded the maximum irrigation rate in a given time period, the calculated depletion would not be returned to zero after irrigation. Tassel initiation was used as the point at which to shift from the initial AET factor to the final AET factor for treatments 5, 6, 8, and 9.

The corn was grown using standard regional production practices for furrow-irrigated corn with the exception of three production inputs, nitrogen fertilizer, seeding rate, and irrigation. Different fertilizer rates and plant populations were used with the different irrigation schemes to minimize production costs.

The nitrogen fertilizer (ammonium nitrate, 32-0-0) was broadcast applied in mid-October of each year preceding planting in the following spring. Irrigation treatments with an initial AET factor of 100% (Trts. 1, 4, and 7) received an actual nitrogen amount of 235 kg/ha (210 lbs/acre) and were seeded at a rate of 56,800 seeds/ha (23,000 seeds/acre). The 75% AET factor treatments (Trts. 2, 5, and 8) received a nitrogen amount of 200 kg/ha (180 lbs/acre) and were seeded at a rate of 51,600 seeds/ha (20,900 seeds/acre). Those treatments scheduled with an AET factor of 50% (Trts. 3, 6, and 9) received a nitrogen amount of 170 kg/ha (150 lbs/acre) and were seeded at a rate of 42,300 seeds/ha (17,100 seeds/acre). Corn (Pioneer brand 3377) was planted on 2 May, 28 April, and 29 April for 1986, 1987, and 1988, respectively.

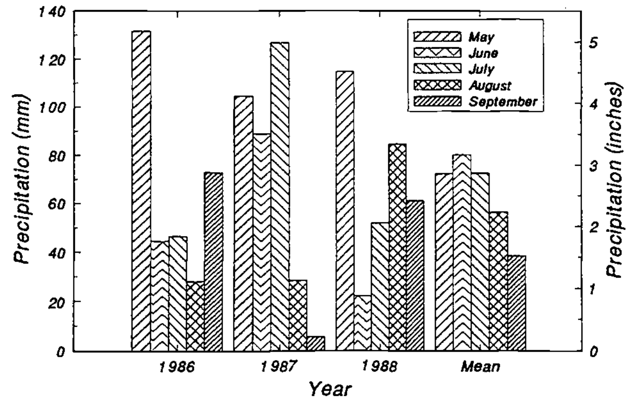

Figure 1–Summer precipitation during the study period and the long-term mean (1893 to 1991) precipitation at Colby, Kansas.

An approximately 6-m (20-ft) length of one corn row from the center of each plot was hand harvested in the fall (9-25-86, 9-19-87, and 9-12-88) for yield determination.

An enterprise analysis was conducted by comparing the total income and production expenses of each treatment. Total income assumed a cash market price of $0.089/kg ($2.25/bu) and a federal farm program deficiency payment of $154.43/ha ($62.50/acre). The deficiency payment was calculated as the product of an estimated northwest Kansas farm program yield of 7.85 Mg/ha (125/bu/acre) and the difference between the federal corn target price of $0.108/kg ($2.75/bu) and the cash market price of $0.089/kg ($2.25/bu). Fixed costs for land and equipment, including taxes, insurance, interest, and depreciation totaling $231.26/ha ($93.59/acre), were obtained from Dhuyvetter and Nelson (1992) and were held constant among all treatments. An irrigation energy cost of $0.0141/m^3 ($1.45/acre-in.) of water pumped was used in the analysis and was based on a total dynamic head of 79.2 m (260 ft) and a natural gas price of $0.0795/m^3 ($0.00225/ft^3). Nitrogen fertilizer costs were calculated assuming an anhydrous ammonia cost of $0.243/kg ($0.11/lb) of actual nitrogen. Corn seed costs were based on a price of $63.00/bag and 80,000 seeds/bag. Other variable costs (excluding irrigation energy, nitrogen fertilizer and seed) used in the analysis were labor, pesticides, fuel for tillage, machinery repairs, crop insurance, crop drying, crop consulting, and interest. These costs were also obtained from Dhuyvetter and Nelson (1992) and ranged among treatments from approximately $440 to $460/ha ($178 to $186/acre) with the small differences being the interest costs associated with the three changing inputs.

RESULTS AND DISCUSSION

CLIMATIC CONDITIONS

Seasonal precipitation (May to September) was 324 mm (12.74 in.) in 1986, 352 mm (13.87 in.) in 1987 and 334 mm (13.15 in.) in 1988 which was slightly above the average seasonal amount (1893 to 1991) of 321 mm (12.65 in.). In each year one or more of the principal growth months, (June, July, or August) had considerably less than the long term mean (1893 to 1991) precipitation (fig. 1). The cumulative calculated actual evapo-

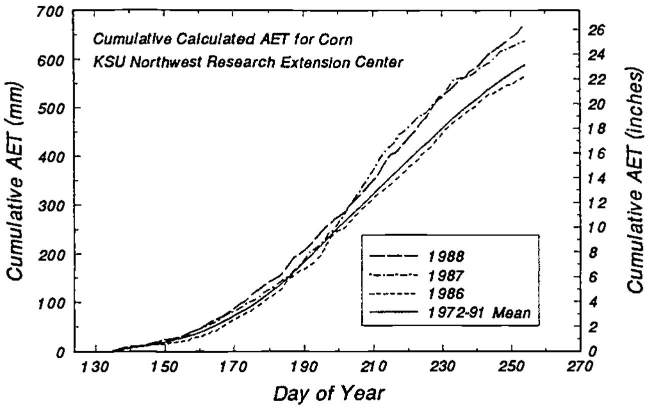

Figure 2–Cumulative calculated water use (AET) of corn for 1986 to 1988 and the long term mean (1972 to 1991) at Colby, Kansas.

transpiration (AET) was approximately 10% greater than the 20-year mean for both 1987 and 1988 and was near normal for 1986 (fig. 2).

The timing of precipitation events and evapotranspiration resulted in net irrigation requirements for fully irrigated corn of 380, 305, and 457 mm (15, 12, and 18 in.) for 1986, 1987, and 1988, respectively (table 1). The net irrigation requirement for corn in Thomas County, Kansas, where the study was conducted, is 391 mm (15.4 in.) with 80% chance precipitation (Soil Conservation Service, 1977).

Corn Yields and Irrigation

Corn yields varied widely among treatments (table 1) for the three years of the study, ranging from a low of 3.95 Mg/ha (63 bu/acre) for Treatments 3 and 7 in 1988, the year with the highest irrigation requirements, to a high of 10.61 Mg/ha (169 bu/acre) for Treatment 4 in 1986, the year with lowest, cumulative, seasonal AET.

An irrigation constraint of 455 mm (18 in.) of net irrigation generally will not limit corn production in northwest Kansas, as was the case in this study. Averaged over the three years, fully irrigated (1.00 ET) Treatment 1, fertilized with 235 kg/ha (210 lb/acre) of nitrogen and using a seeding rate of 56,800 seeds/ha (23,000 seeds/acre), had the highest yield of 9.98 Mg/ha (159 bu/acre). Averaged over the three years, Treatment 1 had significantly higher ($P = 0.05$) yields than all treatments except for Treatment 4 and 5. Results for Treatment 3 illustrate the effect of season-long restrictions in irrigation. Yields for Treatments 3 were consistently lower than those of Treatments 6 and 9, in which irrigation was restricted only during the vegetative stage. A similar comparison could be made for Treatment 2 and 5. Season-long restriction of irrigation resulted in lower amounts of irrigation but also usually resulted in a substantial yield reduction. Tassel initiation, the end of the vegetative stage, occurred on 19 July 1986, and on 15 July for both 1987 and 1988.

All treatments with the 305-mm (12-in.) irrigation constraint (Trts. 4-6) had statistically similar yields in the range of 8.66-9.23 Mg/ha (138-147 bu/acre). These data indicate a good balance in matching the three resources of

Table 1. Resource management schemes and their effects on irrigation requirements and yields of corn, KSU Northwest Research-Extension Center, 1986 to 1988, Colby, Kansas

Trt	ET Factor	Irrigation Constraint mm (in.)	Nitrogen Fertilizer kg / ha (lbs / acre)	Seeding Rate seeds / ha (seeds / acre)	Irrigation Amount — mm (in.) 1986	1987	1988	Mean	Corn Grain Yield — Mg / ha (bu / a) 1986	1987	1988	Mean
1.	1.00ET	455 (18)	235 (210)	56800 (23000)	380 (15)	305 (12)	455 (18)	380 (15)	10.0 (159)	10.1 (161)	9.9 (157)	10.0 (159)
2.	0.75ET	455 (18)	200 (180)	51600 (20900)	230 (9)	230 (9)	305 (12)	255 (10)	9.7 (154)	7.6 (121)	7.8 (125)	8.3 (133)
3.	0.50ET	455 (18)	170 (150)	42300 (17100)	75 (3)	75 (3)	150 (6)	100 (4)	7.8 (125)	6.4 (102)	4.0 (63)	6.1 (97)
4.	1.00ET	305 (12)	235 (210)	56800 (23000)	305 (12)	305 (12)	305 (12)	305 (12)	10.6 (169)	9.2 (147)	7.5 (120)	9.1 (145)
5.	0.75 / 1.00ET	305 (12)	200 (180)	51600 (20900)	305 (12)	230 (9)	305 (12)	280 (11)	10.2 (162)	9.5 (152)	8.0 (127)	9.2 (147)
6.	0.50 / 1.00ET	305 (12)	170 (150)	42300 (17100)	230 (9)	230 (9)	305 (12)	255 (10)	9.2 (147)	9.0 (143)	7.8 (125)	8.7 (138)
7.	1.00ET	150 (6)	235 (210)	56800 (23000)	150 (6)	150 (6)	150 (6)	150 (6)	7.7 (123)	7.0 (112)	4.0 (63)	6.2 (99)
8.	0.75 / 1.00ET	150 (6)	200 (180)	51600 (20900)	150 (6)	150 (6)	150 (6)	150 (6)	8.7 (139)	8.5 (136)	4.6 (74)	7.3 (116)
9.	0.50 / 1.00ET	150 (6)	170 (150)	42300 (17100)	150 (6)	150 (6)	150 (6)	150 (6)	8.7 (139)	7.5 (120)	6.4 (102)	7.5 (120)
Mean									9.2 (146)	8.3 (132)	6.7 (106)	8.0 (128)
$LSD_{0.05}$									1.4 (23)	2.1 (34)	1.6 (25)	1.3 (21)

Table 2. Irrigation dates and amounts for the various treatments, 1986 to 1988

Date	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Trt 7	Trt 8	Trt 9
	mm (in.)								
1986									
Jul 7	109 (4.28)	78 (3.08)	—	109 (4.28)	78 (3.08)	—	109 (4.28)	78 (3.08)	—
Jul 25	110 (4.35)	74 (2.92)	76 (3.00)	110 (4.35)	74 (2.92)	76 (3.00)	110 (1.72)	74 (2.92)	76 (3.00)
Aug 7	—	—	—	—	—	76 (3.00)	—	—	76 (3.00)
Aug 13	86 (3.37)	—	—	86 (3.37)	76 (3.00)	—	—	—	—
Aug 20	—	76 (3.00)	—	—	—	76 (3.00)	—	—	—
Aug 28	76 (3.00)	—	—	—	76 (3.00)	—	—	—	—
Total	380 (15.00)	230 (9.00)	75 (3.00)	305 (12.00)	305 (12.00)	230 (9.00)	150 (6.00)	150 (6.00)	150 (6.00)
1987									
Jul 22	76 (3.00)	—	—	76 (3.00)	—	—	76 (3.00)	—	—
Jul 29	—	76 (3.00)	—	—	76 (3.00)	76 (3.00)	—	76 (3.00)	76 (3.00)
Aug 4	76 (3.00)	—	76 (3.00)	76 (3.00)	—	—	76 (3.00)	—	—
Aug 13	—	76 (3.00)	—	—	76 (3.00)	76 (3.00)	—	76 (3.00)	76 (3.00)
Aug 15	76 (3.00)	—	—	76 (3.00)	—	—	—	—	—
Aug 25	76 (3.00)	—	—	76 (3.00)	76 (3.00)	76 (3.00)	—	—	—
Sep 1	—	76 (3.00)	—	—	—	—	—	—	—
Total	305 (12.00)	230 (9.00)	75 (3.00)	305 (12.00)	230 (9.00)	230 (9.00)	150 (6.00)	150 (6.00)	150 (6.00)
1988									
Jun 22	76 (3.00)	—	—	76 (3.00)	—	—	76 (3.00)	—	—
Jun 27	—	76 (3.00)	—	—	76 (3.00)	—	—	76 (3.00)	—
Jul 5	76 (3.00)	—	76 (3.00)	76 (3.00)	—	76 (3.00)	76 (3.00)	—	76 (3.00)
Jul 18	76 (3.00)	76 (3.00)	—	76 (3.00)	76 (3.00)	—	—	76 (3.00)	—
Jul 29	—	—	—	—	—	76 (3.00)	—	—	76 (3.00)
Jul 31	76 (3.00)	—	—	76 (3.00)	76 (3.00)	—	—	—	—
Aug 10	—	76 (3.00)	—	—	—	76 (3.00)	—	—	—
Aug 13	76 (3.00)	—	76 (3.00)	—	76 (3.00)	—	—	—	—
Aug 28	—	—	—	—	—	76 (3.00)	—	—	—
Sep 2	76 (3.00)	76 (3.00)	—	—	—	—	—	—	—
Total	455 (18.00)	305 (12.00)	150 (6.00)	305 (12.00)	305 (12.00)	305 (12.00)	150 (6.00)	150 (6.00)	150 (6.00)

irrigation, nitrogen fertilizer and seed within the irrigation constraint. Although the average yields for these three treatments were considerably lower than for the fully irrigated Treatment 1, relatively high yields were obtained except in 1988, the year with the highest irrigation needs. A comparison of the irrigation schedules for 1986 to 1988 (table 2) shows that Treatment 1 and 4 were identical until the 305-mm (12-in.) limit was reached in mid-August. This late date was within approximately two weeks from the end of the irrigation seasons for all three years.

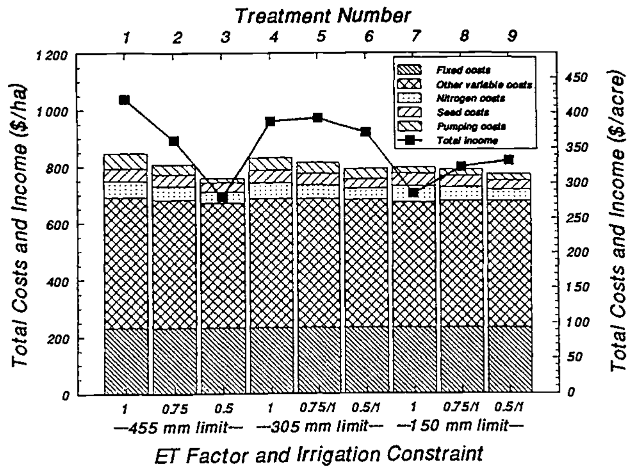

Figure 3–Production costs and total income for the various resource-allocation management schemes for corn. Net income is the difference between total income (line) and production costs (bars).

Average yields for treatments limited to receiving 150 mm (6 in.) of irrigation ranged from 6.21 to 7.53 Mg/ha (99 to 120 bu/a). Under this severe constraint, the highest yields were obtained when the limited amount of irrigation was shifted toward the critical reproductive and grain filling stages (Treatments 8 and 9). Limiting irrigation during the vegetative stage (Treatment 8 and 9) generally delayed the last irrigation to about 20 d later than when full irrigation (Treatment 7) was applied (table 2).

Effect of Resource Allocation on Net Income

An enterprise analysis was performed to determine the effect of resource-allocation on net income. Cash corn prices, farm program payments and fixed costs were held constant. The total costs of the irrigation energy, nitrogen fertilizer and seed among treatments ranged from $88 to $156/ha ($36 to $63/acre). Other variable costs among treatments ranged from approximately $440 to $460/ha ($178 to $186/acre) with the small differences being the interest costs associated with the three changing inputs. Total income was calculated as the sum of the federal farm deficiency payment and the product of corn yield and cash market price. Net income was calculated as the difference between total income and total fixed and variable costs.

Net income is influenced by the effect of resource allocation on both production costs and crop production. Although minimizing costs is desirable, it is more important to manage and balance the resource inputs to obtain high crop yields, as illustrated in figure 3. The height difference between the total income (line) and total costs (bar) equals net income. The amplitude of the total income line varies much more than the amplitude of the cost bars. Therefore, changes in total income caused the greatest shift in net income. Proper resource management, resulting in high production and, therefore, high total income, had a greater effect on net income than the differential costs of the resources.

The highest net income (fig. 3) was obtained when resources were not limited (Treatment 1). However, Treatments 4 to 6, in which irrigation was limited to

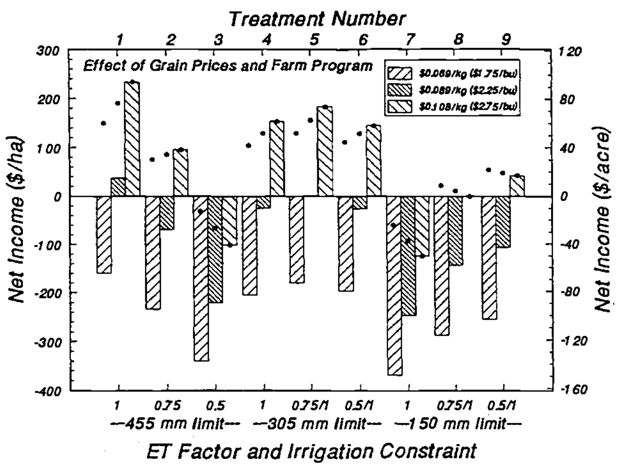

Figure 4–Effect of different grain prices and the presence (dots) or absence (bars) of farm deficiency payment on net income for the various resource-allocation management schemes for corn.

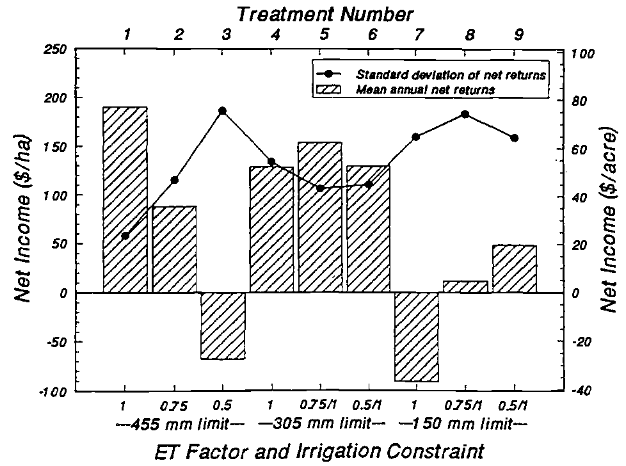

Figure 5–Mean annual and standard deviation of net income for the various resource-allocation management schemes for corn.

305 mm (12 in.), also had positive net returns and might be acceptable management alternatives if fully irrigated corn was not an option. If the farm program deficiency payment were eliminated, only Treatments 1 and 5 would have positive net incomes of \$37.31/ha and \$1.61/ha (\$15.10/acre and \$0.65/acre), respectively, using the assumed cash market price of \$0.089/kg (\$2.25/bu) and production costs. When irrigation was restricted to 150 mm (6 in.), net income was negative or very low for all treatments even with the farm program deficiency payment.

Effect of Corn Grain Price and Deficiency Payments on Net Income

Further economic analysis was performed to illustrate the effect different grain prices and deficiency payments had on net incomes of the various management schemes. Farm deficiency and production costs were calculated as described in the previous section.

No management schemes were profitable assuming a cash market price of \$0.069/kg (\$1.75/bu) and no deficiency payment (fig. 4). However, if the deficiency payment was included, seven of the nine management schemes had positive net incomes.

Several profitable management schemes existed at a cash market price of \$0.108/kg (\$2.75/bu), the point at which the deficiency payment is zero. The profitability increased dramatically for Treatments 4, 5, and 6, in which irrigation was moderately constrained to 305 mm (12 in.) as the cash market price increased from \$0.089/kg to \$0.108/kg (\$2.25/bu to \$2.75/bu). This might make them acceptable alternatives to fully irrigated corn (Treatment 1) if irrigation were constrained.

Corn can be grown with a 150-mm (6-in.) water allocation at a low profit potential when the deficiency payment is included but requires careful management of irrigation, nitrogen fertilizer and seed (Treatment 9 as compared to Treatments 7 and 8). When irrigation allocations are restricted and result in low yields below the farm program yield, a paradox can occur, higher cash market grain prices can result in less net income (fig. 4). As the market price approaches the federal target price the deficiency payment rate is reduced. Thus when the market price is high and the crop yield is below the program yield, the reductions in deficiency payments are not fully offset by the increases in market sales.

Means and Standard Deviations of Net Income

The means and standard deviations of net income were calculated (three replications in each of the three years) to examine the average profit potential and the variation of profit (net income) for the various treatments. Annual irrigation requirements and corn yields for the treatments varied and were reflected in the individual calculations (nine data points) of the means and standard deviations of net income. The standard cash grain price, deficiency payment and production costs, as previously described, were used in this portion of the analysis. Risk-aversion techniques strive to maximize the mean net income, while minimizing the standard deviation of net income. Analysis of the means and standard deviations of net income revealed that the best management scheme was the fully irrigated Treatment 1 (fig. 5). Both maximum mean and minimum standard deviation of net income were obtained by Treatment 1.

Treatments 3, 7, 8, and 9 should be avoided because they have the lowest means and highest standard deviations of net income. In these schemes, the standard deviation of net income is greater than the mean (fig. 5). When mean net income is positive, a producer should survive financially in the long run. However, many producers would not survive because of the large variations in annual cash flow. Risk-averse producers should not practice marginal management schemes.

Treatments 2 and 4, although possessing mid-range mean net incomes compared to the other treatments, have standard deviations higher than the mean (fig. 5). This would classify them as relatively risky management schemes, especially when compared to Treatments 1, 5 and 6.

The analysis revealed that Treatment 5 was best when irrigation was constrained to 305 mm (12 in.). In essence, though the differences are not great, Treatment 5 manages a better balance of resources than Treatments 4 and 6 as indicated by the higher mean and lower standard deviation (fig. 5).

CONCLUSIONS

Fully irrigated corn using the standard recommended seeding rate and full fertilization was found to be a more profitable enterprise than any of the other resource-allocation schemes for deficit-irrigated corn examined in this study. Irrigators wishing to continue to grow corn when irrigation is limited by physical (water supply) or institutional constraints should seriously consider reducing irrigated land area to match the severity of the constraint. This should not be construed to mean that no opportunities exist to reduce the amount of water typically used to fully irrigate corn. Many irrigators are already upgrading irrigation systems and management of their present systems to "stretch" water. This does not result in more corn production for each unit of water transpired, but because inefficiencies, such as evaporation and percolation are reduced, more water is available for plant transpiration.

If the irrigation amount for a given land area is constrained at a deficit amount, moderate periods of stress hardening during the corn vegetative stage with proper matching of the fertilizer and seeding rate will stretch the irrigation season. This may result in more water being available for irrigation during the critical reproductive and grain-filling stages. Such stretching of the irrigation season increased corn yields by 20% (Treatment 9) when the water allocation was restricted to 150 mm (6 in.).

Net income is influenced by the effect of resource-allocation on both production costs and crop production. However, at the price levels used in this study, producers should allocate irrigation, nitrogen fertilizer and corn seed to ensure high production rather than to obtain significant production cost savings. Crop production variations affected net income much more than variations in resource costs.

Federal farm deficiency payments had a marked effect on the overall profitability of the various management schemes examined in this study. If the corn cash market price was \$0.069/kg (\$1.75/bu) and the deficiency payment was included, seven of the nine management schemes had positive net income. No schemes had positive net income without the deficiency payment.

Higher grain prices in the range of \$0.108/kg (\$2.75/bu) dramatically increased the profitability of the management schemes in which irrigation was moderately constrained to 305 mm (12 in.) even without the deficiency payment. Although these schemes are still less profitable than fully irrigated corn, they might be acceptable alternative strategies if irrigation water is limited.

Analysis of the means and standard deviations of net income for the nine management schemes revealed that full irrigation with the standard recommended amounts of nitrogen fertilizer and seed was best. This scheme not only maximized the mean net income but also minimized the standard deviation of net income. Risk-averse producers should not practice the severely restricted irrigation management schemes because the standard deviation of net income is greater than the mean net income, which means large variations in annual cash flow.

Comparison of the profitability of these management schemes for corn production to other enterprises, such as irrigated wheat or irrigated grain sorghum production, lies beyond the scope of the study, so no conclusions in this area can be drawn or should be inferred.

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