IRRIGATION SCHEDULING MODELS AS AN ECONOMICAL FARM MANAGEMENT TOOL

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SUMMARY

If irrigated agriculture is to remain viable in arid regions of the West, an effort must be made to improve its profit structure. One of the more promising technologies for improving irrigated producers' profits is the use of irrigation scheduling models. Producers will accept new technology only when the economic value of these models is proved. This analysis is an attempt to do so for a case study in the Roswell-Artesian Basin in New Mexico.

Two existing irrigation scheduling models were developed and validated for the major crops grown in the Roswell-Artesian Basin of New Mexico: (1) a profit maximization dynamic programming model (DPM), and (2) a physically based yield maximization model. The DPM takes into consideration the price of water before it makes an irrigation decision and applies irrigations only when the value of the water in use exceeds the cost of using it. The physically based model does not take the cost of using water into consideration, but will apply irrigations when the soil moisture level falls below a certain level.

Yield and water applications derived by both models were higher than current practices. The DPM increased yield and net returns for alfalfa, corn and grain sorghum above the physically based model in almost every case.

Results indicate that the irrigation water demand function for alfalfa is relatively elastic while the demand function for corn is relatively inelastic, and for sorghum it is intermediate. These findings imply that grain crops should be subjected to moisture stress, while

alfalfa should not. Furthermore, water prices would have to increase substantially before water conservation would result.

It can be concluded that both producers and water policymakers could benefit from the use of either of these irrigation scheduling models, but the use of the DPM would generally result in higher yields and net returns.

INTRODUCTION

Water resources in the western United States have recently become more scarce as population growth has increased faster than the national average. Increased activity in the minerals and mining sectors also have placed stress on these limited resources. In some areas, ground water resources have begun to decline. For example, the Ogallala aquifer in the Great Plains is declining at the rate of one to three feet a year. As ground water tables have declined, farmers have been forced to pump water from greater depths. Increased pumping costs due to pumping from greater depths and dramatically higher energy costs, combined with low crop prices have placed farmers who irrigate in a severe price-cost squeeze. This bind has encouraged them to look for alternative methods to increase farm level profits. One such method that might increase farm level profits is the use of systematic irrigation scheduling models and procedures.

Two recent models developed by researchers are physical, water balance yield maximization models, and water balance models that maximize profits through the incorporation of economic principles. Both types of models are adaptable for use at the farm level, but the potential economic gains from using such models have not been evaluated. This analysis was an attempt to perform such an evaluation for the Roswell-Artesian Basin of New Mexico.

Two existing irrigation scheduling models: (1) a profit maximization dynamic programming model (IRRG), and (2) a physically based yield maximization model (IRRSCH) were validated for a 35-year-period for three major crops (alfalfa, corn and grain sorghum) grown in the Roswell-Artesian Basin of New Mexico. IRRG takes into consideration the price of water before the model makes an irrigation decision and applies irrigations only when the value of the water in use exceeds the costs of using it. The physically based model does not take the cost of using water into consideration, but will apply irrigations when the soil moisture level falls below a certain level.

IRRG and IRRSCH are extremely versatile and can be used for several locations in New Mexico. Climatological data, irrigation application uniformity, information on soil types, and crop water production functions are all that need be known in order to operate the models.

MODELS

A Dynamic Programming Model-IRRG

IRRG is a stochastic dynamic programming irrigation scheduling model. The objective function of IRRG is to maximize the profits from the production of a single specified crop. The model was constructed to make a decision to irrigate only if the dollar returns from a unit of water exceeded the costs of using that unit of water. The model was constructed to account simultaneously for the probability and amounts of rainfall, the cost of pumping water, soil moisture, crop development, and crop price.

IRRG is conceptually divided into eight "control" equations and an objective function (gain in net income). The control equations describe the state of the system as measured by the change in soil moisture from one time period (stage) to the next, based on transpiration, evaporation, deep drainage and rainfall. The model uses, as its basis for making an irrigation decision, heat units accumulated over the growing season (instead of the calendar year) to model crop growth and development. Using accumulated heat units to determine irrigation decisions is unique in the literature. Each stage in the model was defined as a 20 heat unit increment of a particular crop's growing season. Mapel (1984) has written a detailed description of the model.

Figure 1 presents the dynamic irrigation decision process of IRRG and the ongoing process over the growing season. The data needed for IRRG to

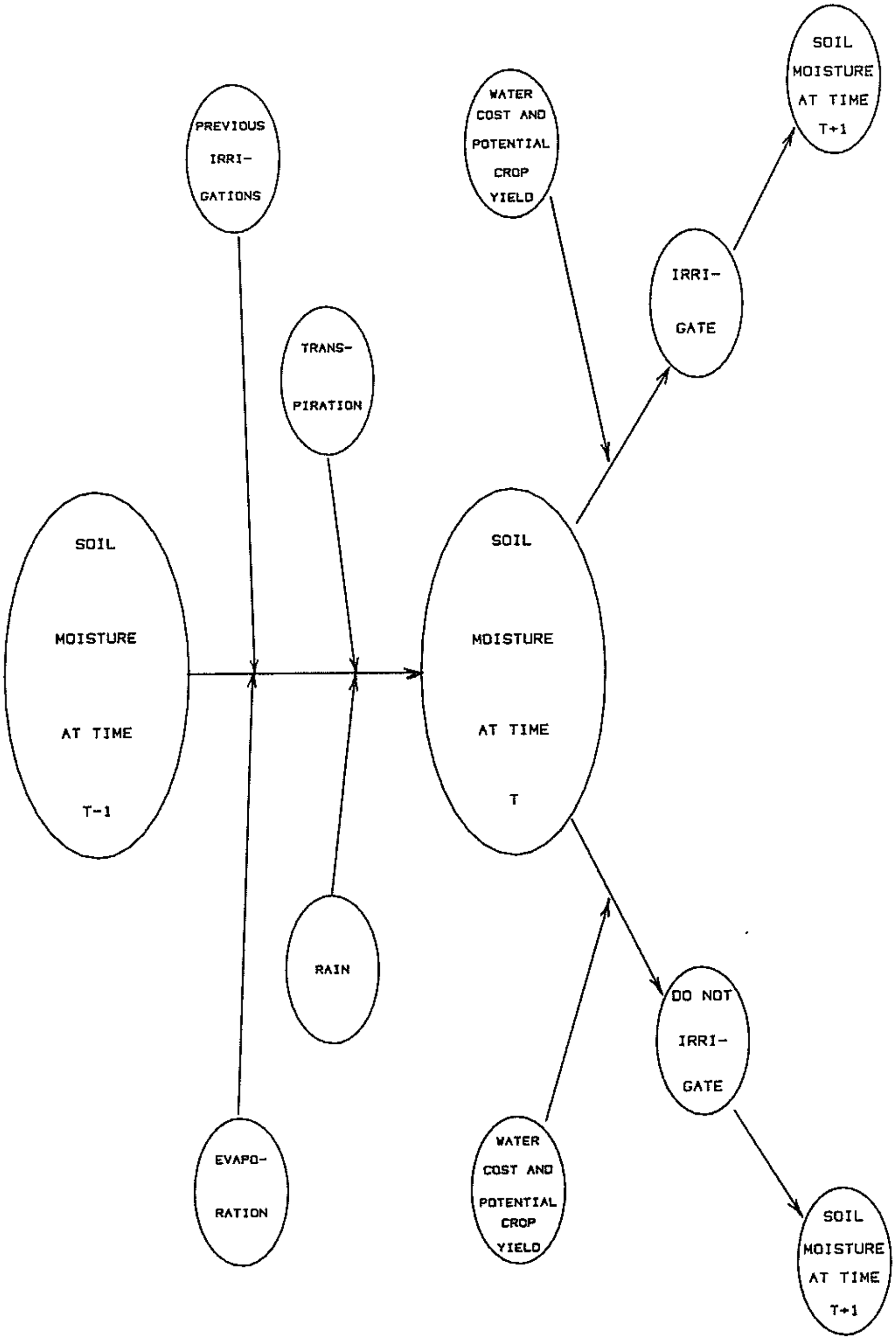

Figure 1. The Dynamic Irrigation Decision Process of IRRG.

make an irrigation decision--water costs, crop stress point, soil water holding characteristics, planting and harvesting dates based on heat units, and crop type and price--are entered into the model.

Conceptually, the model works backward in time, beginning with the last decision point, assigning a value to all "nodes" in each stage, where a node is a discrete level of the state variable. In this case, the nodes are discrete levels of soil moisture at a given number of stages into the growing season. To value the objective function associated with the current state node in time (t), the model calculates the t + 1 node positions derived from alternative irrigation decisions and adds it to the value for those nodes previously calculated. A selection is made for the optimal irrigation decision which simultaneously values the current node. The net return associated with each alternative irrigation decision is the cost of the irrigation subtracted from the expected value of the resulting nodes in stage i + 1. Because of the stochastic nature of precipitation, each decision has a range of possible outcomes.

In addition to the optimal irrigation schedule, the model also can be used to derive irrigation water demand functions. This is done by changing water price while holding all other variables constant (Varian 1978). These functions indicate the value of additional units of water in terms of net revenues.

A Linear Water Balance Model-IRRSCH

IRRSCH is an irrigation scheduling model developed by Sammis (1982) that determines the response of seasonal plant yield to irrigation timing and amount and is based upon a model introduced by Hanks (1974). The model takes into account differences in soil type, application uniformity, management practices and weather variation. Irrigation water is applied when user instructed or when the plant available water (PAV) falls below a certain predetermined level, usually 40 to 60 percent. PAV is a measure of the amount of soil moisture that is available for plant use. It is the ratio between field capacity and permanent wilting point. The model also can read any given irrigation schedule as input.

The model uses weather data from a specific site or from simulated weather data derived from a particular site. The model incorporates the effect of a non-uniform application of irrigation water over a field by modeling transpiration (T) at several locations within a given field. Model output includes estimated crop yield and estimates of seasonal T and soil evaporation [A more complete description of IRRSCH is developed by Hanks (1971) or Lansford et al. (1983).]

RESULTS

Crop prices used to calculate gross returns were taken from recently published data and are presented in Table 1. Water costs were calculated using the cost of a pumping model developed for the High Plains Ogallala Aquifer Study (Lansford et al. 1982) and are presented in Table 1 for a surface irrigation system. Natural gas was assumed to be the energy source used for pumping, and water costs were calculated for a pumping lift of 125 feet. Well output of 1,000 gallons per minute (GPM) and a pumping plant efficiency of 13.8 percent also were assumed. The other variables needed by both models to calculate soil moisture levels are presented in Table 2.

Model Comparisons

The water applications, yield and net returns that resulted from the optimal irrigation schedule of IRRG are presented on the left side of Table 3. The yield, water applications, and net returns resulting from the simulations of IRRSCH for the three different levels for PAV are presented to the right. Net returns are defined as gross returns (yield times crop price) minus the total cost of pumping water (amount of water in acre-inches times the cost of pumping per acre-inch). Since water is the only input that is assigned a cost, the net returns exclude costs of other factors of production, i.e., land, labor, management and capital exclusive of irrigation water.

The results from the physically based model (IRRSCH) specified for the 40, 50 and 60 percent PAV level indicate that net returns would be highest for alfalfa at the 50 percent level (Table 3). IRRSCH would apply 58.86 acre-inches of water per acre, which would result in a yield of 8.14 tons per acre and a net return of $420.90 per acre.

TABLE 1. CROP PRICES, WATER COSTS AND PUMPING ASSUMPTIONS USED FOR ANALYSIS

ITEM	PRICE	FURROW* IRRIGATION	PUMPING LIFT	GALLONS PER MINUTE
	(DOLLARS)	- - - ($/ACRE-INCH) - - -	(FEET)	(GPM)
CROP				
ALFALFA	67.00/TON			
CORN	.05/LB.			
SORGHUM	.05/LB.			
WATER COST				
FUEL		1.52		
REPAIRS		0.21		
LABOR		0.38		
TOTAL		2.11		
PUMPING ASSUMPTIONS			125	1,000

SOURCE: NEW MEXICO AGRICULTURAL STATISTICS, 1982
*ASSUMES A NATURAL GAS PRICE OF $4.57/MCF AND WELL EFFICIENCY OF 13.8%

TABLE 2. PARAMETERS ASSUMED FOR COMPARISON OF IRRG TO IRRSCH

ITEM	PARAMETER
SOIL TYPE	LOAM
FIELD CAPACITY	31 (PERCENT BY VOLUME)
PERMANENT WILTING POINT	15 (PERCENT BY VOLUME)
(PAV)	
ALFALFA	50 (PERCENT BY VOLUME)
CORN	60 (PERCENT BY VOLUME)
SORGHUM	50 (PERCENT BY VOLUME)

Table 3. Comparison of per acre net returns, yields and water applications-IRRG vs IRRSCH pumping lift of 125 feet & IRRSCH set at 40,50 and 60% of plant available water (PAV) surface irrigation on a loam soil-35 year average

	IRRG			IRRSCH		
Crop	Average Yield	Average Net Returns	Average Water Applied	Average Yield	Average Net Returns	Average Water Applied
	(tons/acre)	(dollars)	(acre-inches)	(tons/acre)	(dollars)	(acre-inches)
					40% PAV	
Alfalfa	8.41 ***	433.81 ***	61.49 ***	7.88	409.64	56.11
Corn	(lbs./acre) 9197 ***	360.05 ***	47.31 ***	8010	332.28	32.34
Sorghum	7878 ***	318.20 ****	35.89 ***	7670	322.97	28.69
					50% PAV	
Alfalfa	8.41 ***	433.81 ***	61.49 ***	8.14	420.90	58.86
Corn	(lbs./acre) 9197 ***	360.05 *	47.31 ***	8890	360.34	39.89
Sorghum	7878 *	318.20 *	35.89 *	7802	314.61	35.77
					60% PAV	
Alfalfa	8.41 ***	433.81 ***	61.49 *	8.16	419.83	60.23
Corn	(lbs./acre) 9197 *	360.05 *	47.31 *	9165	358.20	47.43
Sorghum	7878 *	318.20 ***	35.89 ***	7798	293.21	45.83

125 foot lift uses a water cost of $2.11 per acre-inch

* The means between IRRG and IRRSCH are statistically the same

** 95% Confidence that the means between IRRG and IRRSCH are statistically different

*** 99% Confidence that the means between IRRG and IRRSCH are statistically different

**** 90% Confidence that the means between IRRG and IRRSCH are statistically different

The water applications by IRRG would be significantly higher (more than 5 acre-inches) than those required by IRRSCH at the 40 percent PAV level, but it would generate a significantly higher yield (.53 tons per acre) and significantly higher net returns ($24.17 per acre). At the crop stress point of 50 percent, IRRG would require significantly higher per acre water applications (2.63 acre-inches), but would significantly increase net returns ($12.91 per acre). At the 60 percent PAV level, the irrigation schedule of IRRG would generate a significantly higher yield (0.25 tons per acre) and significantly higher net returns ($13.98 per acre) with no significant difference in water applications.

For corn, the physically based model would generate the highest net return when the PAV level default is set to 50 percent. The net return would be $2.14 per acre higher than under the 60 percent level (Table 3). At the 50 percent level, IRRSCH would apply 7.54 acre-inches less water than at the 60 percent level and would generate a higher net return. This indicates that some moisture stress on corn would be beneficial to producers needing to increase profit levels.

Comparisons between the two models for corn indicate that the irrigation schedule derived by IRRG would result in higher yields under all PAV levels, but the irrigation schedule of IRRSCH would result in the highest net revenue at the 50 percent level of PAV ($360.34 per acre). At the 60 percent level of PAV, yield, water applications, and net returns would not be statistically different between the two models.

The results from the simulations of IRRSCH set at the three levels of PAV indicate that for grain sorghum, net returns would be highest under IRRSCH set at the 40 percent PAV level. IRRSCH would apply 28.69 acre-inches of water at this default level and generate net returns of $322.97 per acre (Table 3). Yield would be substantially lower under the 40 percent level than at the 50 and 60 percent levels, but this would be offset by lower water costs as a result of the lower water applications.

Comparisons between models for grain sorghum indicate that IRRG would generate the highest yield at all PAV levels, but at the 40 percent level of PAV IRRSCH would increase net returns by a significant amount (Table 3). The irrigation schedule of IRRSCH would increase net returns by

$4.77 an acre and would require significantly less irrigation water per acre (7.2 acre-inches). At the crop stress point of 50 percent PAV yields, water applications, and net returns would not be statistically different. However, the irrigation schedule derived by IRRG would result in significantly higher net returns of $3.59 per acre, largely as a result of slightly higher yields. At the 60 percent PAV level, the yields from the two models would not be statistically different. However, per acre water application requirements by IRRG would be substantially less than those of IRRSCH (9.94 acre-inches) and would result in a significantly higher net return for IRRG of $24.99 per acre.

Irrigation Water Demand Functions

The demand function for an input--irrigation water, for example--shows the amount of irrigation water that will be required at each price, if profits are to be maximized. Knowledge of this relationship is useful, particularly to farmers attempting to maximize profits and to governmental agencies attempting to encourage water conservation.

The demand function for irrigation water for alfalfa is relatively elastic (price responsive) from $0.00 per acre-inch up to $5.00 per acre-inch (figure 2). Only when water prices are increased to more than $5.00 does the demand function begin to show more price responsiveness and even then it remains relatively elastic to $18.00 per acre-inch. Only at water prices more than $18.00 per acre-inch does the demand function become relatively inelastic.

The water demand function for corn is relatively elastic up to water prices of $5.00 an acre-inch (figure 3). As water prices are increased to more than $5.00 per acre-inch, the demand function begins to become increasingly inelastic. Like alfalfa, however, the function does not become relatively inelastic until water prices reach a high level ($30.00 per acre-inch).

The irrigation water demand function for grain sorghum is relatively elastic at water prices up to $5.00 per acre-inch (figure 4). The demand function becomes relatively less elastic at water prices from $5.00 to $18.00 an acre-inch, then relatively inelastic at water prices more than $18.00.

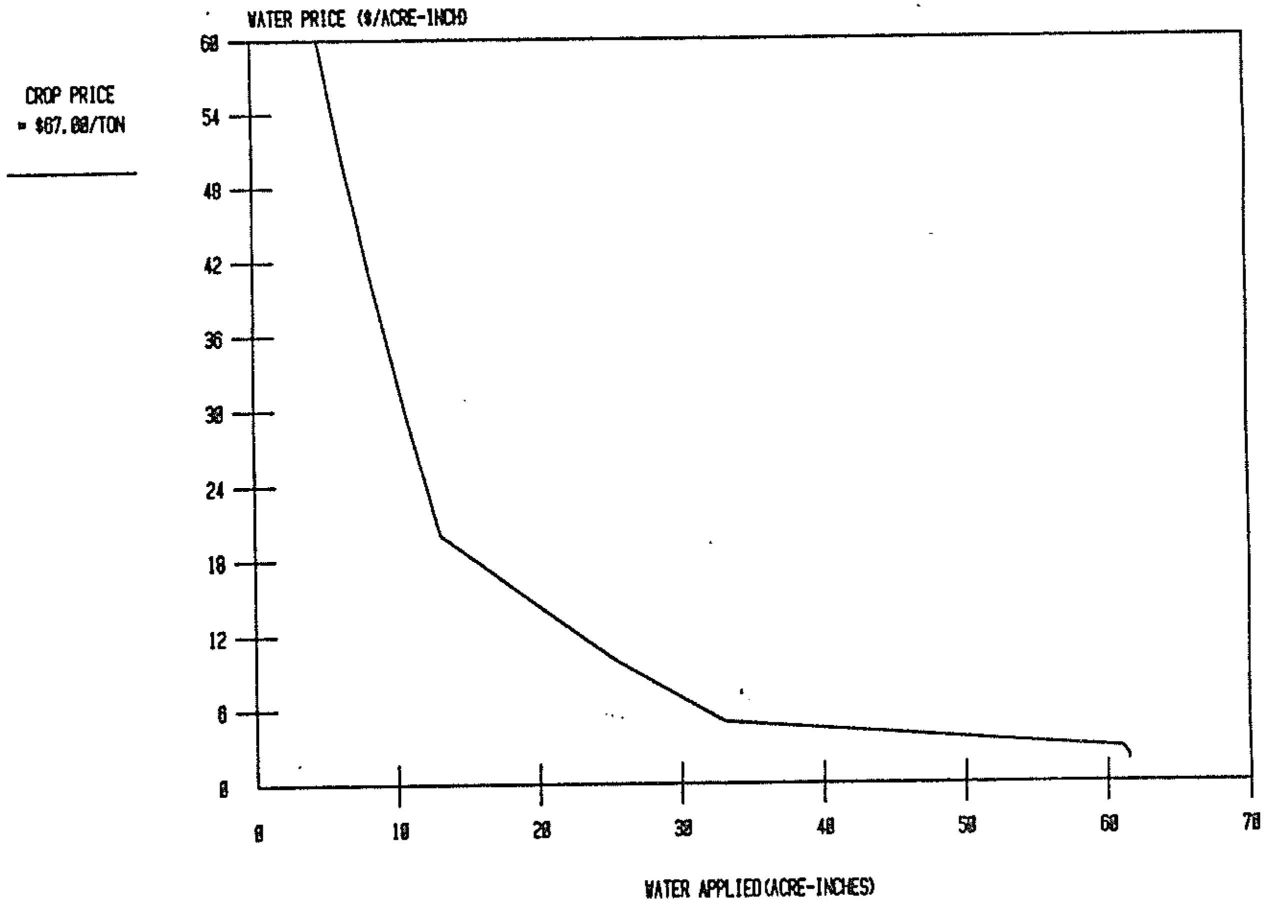

Figure 2. Stochastic irrigation water demand function for alfalfa, Roswell-Artesian Basin, NM.

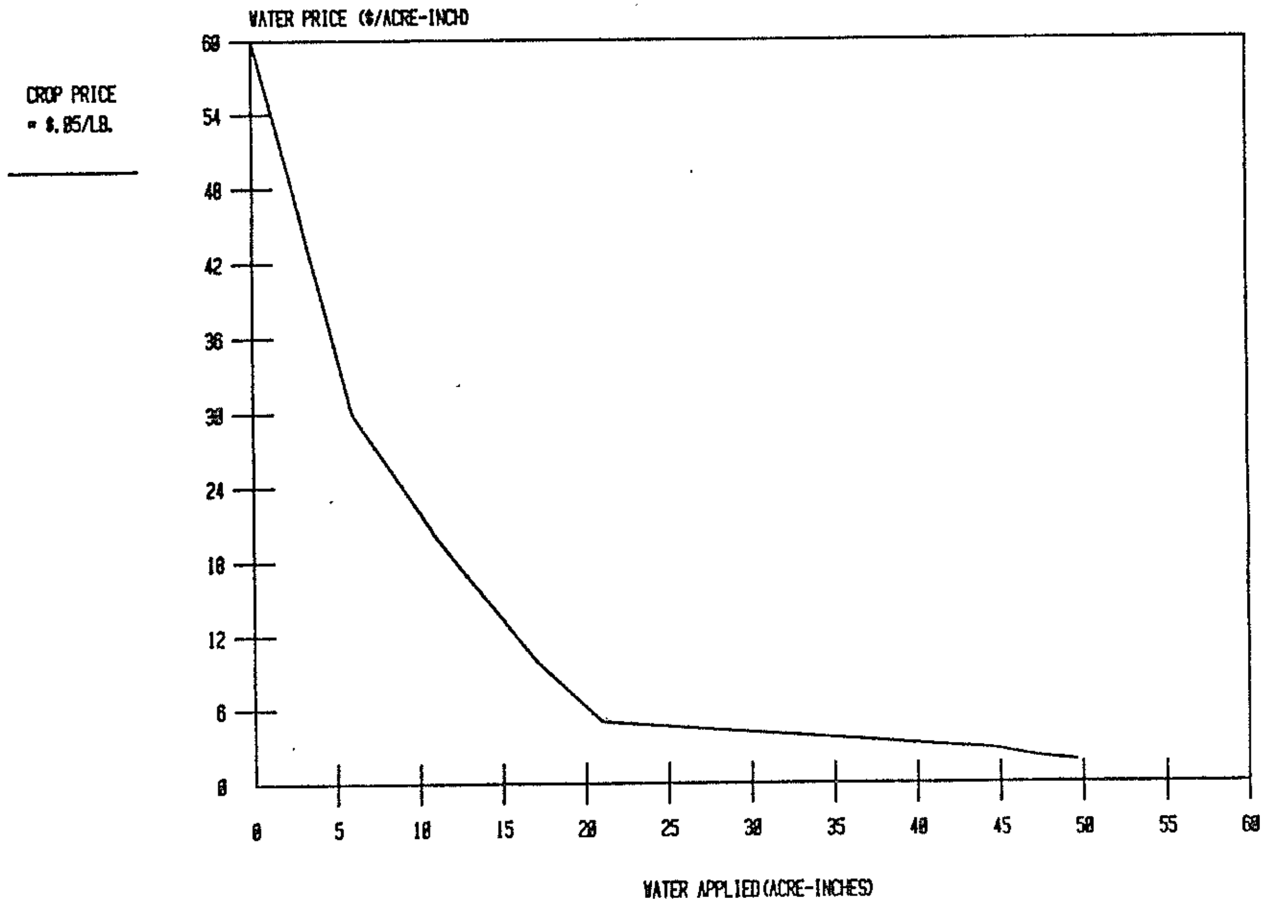

Figure 3. Stochastic irrigation water demand function for corn for grain, Roswell-Artesian Basin, NM.

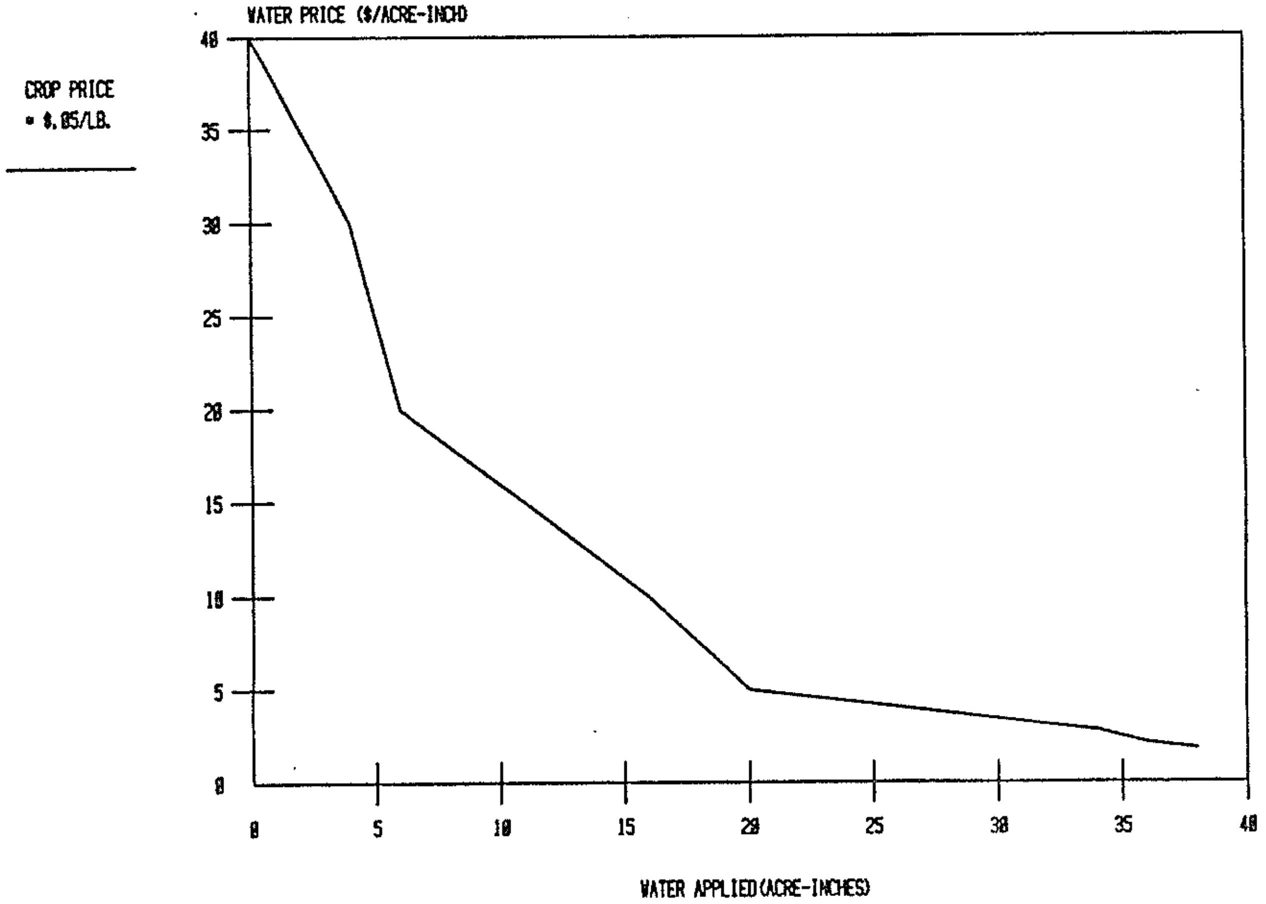

Figure 4. Stochastic irrigation water demand function for grain sorghum, Roswell-Artesian Basin, NM.

IMPLICATIONS

Upon examination of the generated data for the two models for surface irrigation, in almost every case, the irrigation schedule derived by IRRG resulted in higher yields and in higher net returns than IRRSCH. In some instances, the differences between the outputs of the two models in terms of yield and net returns were statistically nonsignificant.

Budgets compiled at New Mexico State University were representative of above average managed farms, they indicate that about 48 acre-inches of water is typically applied on surface irrigated mature alfalfa (Libbin 1984). This point is on the low price end of the alfalfa water demand function depicted in figure 2. Similar budgets prepared for grain sorghum indicate that 32 acre-inches is typically applied during the growing season (Libbin 1984). If the management practices reflected in the budgets are any indication of water applications in the area, producers are indeed operating at a point less than profit maximization given current water and grain prices.

Yield could be increased substantially by the application of more water than is now being applied. For example, from the same budget data for the Roswell-Artesian Basin, with 48 acre-inches of water, 6.25 tons of alfalfa is the budgeted yield on an above average managed farm (Libbin 1984). From the results of this analysis, by applying 60 acre-inches, producers could obtain about 8.5 tons per acre and substantially increase their profit levels.

Yield data from the area also indicate that for surface irrigated corn, yield on an above average managed farm is 6,440 pounds per acre. This level of production is achieved with a budgeted water application of 26 acre-inches (Lansford 1979). IRRSCH's and IRRG's irrigation schedule at the optimal stress point of 60 percent and a water price of $2.79 per acre inch resulted in yields of 9,165 pounds per acre and 9,197 pounds per acre, respectively, with the application of 47.43 and 47.31 acre-inches, respectively (Table 3). These findings imply that yields would be higher under both model's schedules given current water and crop prices. The results also imply that given the higher yields under IRRG resulting from the simulations of the models, the irrigation schedule of IRRG would result in higher yields and higher net returns than IRRSCH, if irrigation scheduling models were adopted by producers who irrigate.

The results indicate that producers should avoid moisture stress in the production of alfalfa and corn, and should subject grain sorghum to moisture stress to increase profits. Net returns were consistently greatest under the irrigation derived by IRRG for alfalfa production. IRRG will apply irrigations only when the value in use of the water exceeds the costs of using it. Therefore, alfalfa should not be allowed to stress, because the additional irrigation water should increase production. The situation is similar for corn, although it appears that the optimal stress point lies somewhere between 50 and 60 percent on the basis of the results from the simulations of IRRSCH.

In the production of sorghum, the results are the opposite. The net returns for sorghum production were consistently greatest under IRRSCH set at the 40 percent PAV level, given any water price. The higher level of net returns associated with subjecting grain sorghum to some moisture stress implies that lower water applications during the growing season would increase profits for producers.

The water demand functions are important to producers. The water prices producers are now faced with are low. The implications for producers are that they should increase their level of water applications in order to increase profit levels. It appears that producers are operating on the low price end of the water demand functions and that yield and net returns could be increased substantially by increasing the amount of water applied at given crop-water prices.

From water prices ranging from $1.00 to $5.00 an acre-inch, the water demand functions for all crops studied in this analysis are relatively elastic over this range (figures 2, 3 and 4). Along this elastic portion of the water demand function, the responsiveness of water demanded to water price increases is relatively large.

If the demand functions are as elastic as this analysis indicates, it is advantageous for producers to apply more water at current low water prices in order to maximize profits and if policymakers want to conserve water they should encourage producers to operate in the elastic portions of the water demand functions by allowing pricing mechanisms to operate.

All crops studied in this analysis have relatively elastic water demand functions at water prices up to $5.00 per acre-inch. It appears that current water prices would have to be increased substantially (in relative terms) before moderate levels of water conservation would result.

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