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IRRIGATION SCHEDULES WITH SALINE WATER SUPPLIES – A REVIEW

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Abstract

Fresh water resources are limited in much of the irrigated west cotton areas including New Mexico. However, significant amounts of groundwater resources remain largely unused due to high salinity levels. The objective of this review is to present previous work that determined the extent to which saline water could serve to supplement fresh water sources for irrigated agriculture while maintaining economic farm viability. Two models were developed using a case farm in the Roswell-Artesia Basin. One model predicts yield based on weather and combinations of saline and fresh water. The other model is an economic driven assessment to determine the optimum combination of fresh and saline irrigation water when given a less than optimum cropping pattern and when the model is allowed to choose the best mix of crops and acreages. The results indicate that saline water can be used for irrigated agriculture and that allowing unlimited pumping of saline water could increase farm profitability. Alfalfa cropped with fresh or saline water is the most profitable crop but is dependent on an unlimited and unrealistic water supply. Maintaining cotton in the cropping system may be the best economic hope for using saline water provided pumping costs are kept low.

Introduction

Water will increasingly become scarce in New Mexico and in much of the irrigated west. Approximately 60 percent of the irrigated crops in New Mexico are served with groundwater and an additional 13 percent uses groundwater supplemented with surface sources. The majority of water is pumped from 200 or more feet below ground. Declining water tables, depth to water, increasing water prices, and competition with non-ag related enterprises put stress on good water quality sources. Supplementing agriculture with saline water supplies may prolong the lifespan of irrigated agriculture in New Mexico.

O'Connor (1980) focused a research study on a range of saline water that could be utilized for crop production before crop yields were reduced. There is also the possibility that saline water could be used as the sole source of water. Slightly saline water is now being used in a number of river systems with success. More acreage may be developed with slightly saline water but will also be dependent on the development of salt tolerant crops, the implementation of farming practices and management that will allow the use of more saline waters, and the availability of sophisticated decision models for almost all aspects of irrigated agriculture.

The extent to which saline water could serve to supplement fresh water for irrigated agriculture while maintaining economic on-farm viability is a continuing effort on the part of agronomists and economists. Several authors have investigated the impact of salinity on crop growth (Bresler and Yaron (1972), the effect of leaching on soil management and water movement (Davis and O'Connor, 1980), and the impact of irrigation efficiencies and timing on soil salinity and yield (Wierenga, 1979). The major concern is having enough water to leach excess salts without overdrawing groundwater resources that are low in salinity. All groundwater resources below 10,000 mg/kg TDS are protected from overdrawing in New Mexico which places some hope that these saline water resources will be available for use in the future. Saline water resources may become even more important to agriculture as municipalities increase their demand for good quality groundwater.

The primary objective of this project was to develop an irrigation scheduling model that would maximize profits from the combined use of both fresh and saline water. A secondary objective was to determine the extent that saline water could augment fresh water supplies for irrigation of various crops and still yield positive net benefits.

Methods

The objectives were accomplished by modifying an existing irrigation scheduling model (Sammis, 1983; Lansford, et al., 1983; Mapel, 1984). The model was initially developed assuming that fresh or low saline waters were available for irrigation. The model was adapted to incorporate the effects of saline irrigation water use on crop-yield, water-applications and soil structure. The principal concept behind the model is that irrigation with saline water will cause some degree of salinization. Once a threshold is reached there will be a yield decrease and decreased evapotranspiration. Increased leaching fractions can reduce salt build-up or dilute the amount of salt in the root zone and were reflected in the model. The irrigation model relies on a water balance method with the following components: 1) a climate estimated reference ET, 2) an index for relating expected crop water use to the reference ET, 3) an index for estimating additional soil water evaporation from a wet soil surface, 4) an index for estimating the effect of soil water depletion and salinity on actual transpiration, 5) an estimate of extractable soil water amount by specific crops from a specified soil, and 6) a relationship between crop production yield and crop water use since yield is a component to the model.

Crops were simulated at Artesia, NM, for 10 years. The salinity of the Artesia ground water and the salinity of the Gila River water (Table 1) were applied to the crops in the model at different plant available water levels in the soil resulting in different leaching fractions. The model predicted the salinity of the drainage water. The model reached steady state conditions after four years when the leaching fraction was between 0.5 and 0.3. Steady state was not reached with leaching fractions less than 0.3.

The economic analysis was to use water and soil data from actual farms plus 20 years of simulated weather data in the Pecos Valley to estimate an on-farm optimal irrigation schedule and a mix of alternative saline waters for selected crops. The economic model was also used to estimate the benefits in terms of farm profits when existing irrigation supplies were augmented with saline water.

An example farm was chosen near Hagerman, NM, to check the salinity models. The models were used to derive yield and water applications for selected crops for different mixes of fresh and saline water for a period of 20 years. After the water applications and respective yields had been determined, whole farm cost and return crop budgets were developed. A budget was generated for each operation performed on each crop. The budgets indicated the per-acre costs of purchased inputs, the labor, fuel, repairs, and fixed costs associated with preharvest and harvest operations, and overhead costs such as taxes, insurance, and interest. The generated budget also calculated gross revenues, total costs, and net returns. Profitability for each of the irrigation strategies was determined. A linear programming model was constructed to determine the optimal cropping pattern and irrigation strategy for limited water resources. The linear program incorporated a range of alternative irrigation strategies, feresh to saline water mixes, and cropping patterns were designed to simultaneously determine the optimal irrigation schedule, the mixture of saline and fresh water, and the profit maximizing crop enterprises.

The activities of the linear program were subdivided into three basic categories: 1) alternative irrigation schedules and saline to fresh water mixes for individual crops, 2) fresh and saline water use, and 3) land use and crop rotation. The alternative irrigation schedules were derived from multiple runs of the salinity simulation model. Irrigation schedules were specified as sequences of saline and fresh water irrigations applied in order to maintain a constant crop stress level. By varying the saline and fresh water sequences and the crop stress level, a production surface of alternative fresh to saline water mixes was derived. The production surface was incorporated into the linear program by specifying a range of activities corresponding to the alternative irrigation schedules.

Each irrigation schedule activity contained three coefficients, the net returns associated with a given activity, and the amount of fresh and saline water used during the season. The second sets of activities included in the linear program were variables representing fresh and saline water use. Fresh and saline waters were restricted to various exogenous levels depending on the scenario. The third set of activities constrained land use decisions to establish rotational procedures. The most common rotation in the Roswell-Artesia Basin consists of 50 percent alfalfa, 33 percent cotton and 17 percent barley.

Four alternative scenarios were developed for analysis. These are summarized in table 2. The models were designed such that irrigations would be applied at any desired amount of relative transpiration. Thus if the model were run at an 80 percent default, each time that relative transpiration dropped to 80 percent an irrigation would be applied.

Soil and water characteristics of the study site used in the simulation are given in Table 3. Water costs for flood irrigation were calculated using the cost of pumping model developed for the Ogallala aquifer by Lansford, et al., 1983. Water costs are given in Table 4 and crop prices used for the analysis are presented in Table 5.

Results

Figures 1 through 3 present the expected yield and quantity of irrigation water for alfalfa, cotton, and corn for the salinity model at various percentages of transpiration and various alternative percentages of fresh and saline water. For each of the transpiration levels at which irrigation water was applied by the irrigation scheduling model, the percentage of saline to fresh water was increased. For each transpiration level, a range of yields, and fresh and saline water application was derived. The end result was an expected yield for a variety of fresh and saline water irrigation strategies.

Increasing the percentage of saline water resulted in a corresponding decrease in yield as stress occurred due to salinity buildup in the soil. There was a corresponding increase in yield as the relative transpiration default for irrigation was increased from 50 to 80 percent. However, there were also large increases in the amount of applied water.

Yield can be maintained or increased when saline water is used for irrigation, but only through the application of more and more irrigation water. The application of more irrigation water serves to leach the accumulated salts from the root zone and reduce crop stress.

Cost and Return Budgets

There were 15 fresh and saline irrigation water strategies that were chosen from which to develop whole farm (500 acres) enterprise cost and return budgets. The per-acre returns to land, water and risk were positive for all 15 strategies of alfalfa, cotton, and spring planted barley.

For alfalfa, budgeted per-acre net returns ranged from a high of $269.96 with the application of 64 acre-inches of all fresh water to a low of $68.37 with the application of 36 acre-inches of fresh water and 128 acre-inches of saline water. Alfalfa yields ranged from 5.1 tons to 7.4 tons per acre.

Per acre net returns to land, water, and risk for cotton range from a high of $105.13 by applying 4 acre inches of fresh water and 45 acre inches of saline water, to a low of $60.55 per acre with the application of 29 acre-inches of fresh water and no saline water. Cotton yields ranged from 710 pounds to 881 pounds per acre.

Spring planted barley returns ranged from a high of $85.98 with water applications of 39 acre-inches of fresh water and no saline water, to a low of $37.21 with the application 31 acre-inches of fresh water and no saline water. Several of the irrigation strategies for cotton generated significantly higher returns to land, water, and risk by applying a majority of saline water. Barley yields ranged from 129 bushels to 162 bushels per acre.

Grain sorghum had only two irrigation water application levels (35 and 39 acre inches of fresh water) that generated positive per acre returns to land, water, and risk. These two fresh water irrigation strategies returned only $7.44 (35 acre inches) and $10.24 (39 acre inches) per acre. The highest return for corn was $17.28 per acre with the application of 49 acre inches of fresh water and 9 acre inches of saline water. The only other positive return for corn was $13.06, with the application of 41 acre inches of fresh water and 5 acre-inches of saline water. Corn yields ranged from 88 bushels to 168 bushels per acre. The least profitable irrigation strategy for corn was a negative return to land, water, and risk of $-122.50 per acre. This occurred when 32 inches of saline water plus 12 inches of fresh water.

Scenario 3

This scenario represents a cropping pattern that is more traditional for the Roswell-Artesia area and maintains the water restrictions of 42 acre-inches of fresh water with incremental amounts of saline water. The example farm was forced to produce 50 percent of its acreage in alfalfa, 33 percent cotton, and 17 percent barley. Saline irrigation water is increasingly used for cotton and barley production as supplemental saline water was added to the 42 acre inches of fresh water. Acreages do not change, but water costs are reduced by the substitution of cheaper saline water for more expensive fresh water. Returns to land and risk rise from $111 to $126 per acre as more saline water is made available for crop production under this scenario. This is a modeled 13.5% increase in return.

Scenario 4

For a very restricted fresh water scenario and the traditional cropping pattern, planted acreage was limited to 312 acres. All crops would be irrigated with highly saline water. Fresh water would be used for germination or for getting the alfalfa going in the spring. Increases in fresh water supply would be diverted to alfalfa, which yields a higher net return, and the saline water sources are applied to cotton and barley. The economic model initially applied 20 acre inches of water and generated $80.65 per acre returns to land and risk. Returns to land and risk increased to $126.16 as fresh water availability increased to 4 acre-inches.

Conclusions

The results from the economic model demonstrated that whole farm profitability could substantially increase if saline water were to be utilized to supplement the 42 acre inches per acre of fresh water. Saline water could supplement fresh water by 33 percent, producing 17 percent more acreage of profitable crops, and additional acreages of less profitable salt-tolerant crops. Cotton is most likely the best and most profitable crop for saline conditions if traditional cropping patterns remain the same and limitations to water quantity pumping are imposed.

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Table 1. Irrigation water composition used to grow crops at Artesia, NM.

Source	EC dS/m)	Ca^{+2}	Mg^{+2}	Na^{+}	$HCO3^{-}$	Cl^{-}	$SO4^{-2}$	SAR†
Gila River, AZ‡	3.14	7.22	5.88	18.55	3.17	20.17	8.48	7.3
Artesia Ground Water	9.16	53.9	14.9	29.1	65.2	29.6	3.14	4.96

† $SAR = Na^{+}/[Ca^{++} + Mg^{++}/2]^{1/2}$
‡ Rhoades et al., 1973

Table 2. Description of alternative scenarios development for economic analysis.

Scenario	Cropping pattern	Fresh water availability	Saline water availability
1	Optimal*	A constant amount of 42 acre-inches per acre	Incremented from 0 to 42 acre-inches per acre
2	Optimal*	Decreased incrementally from 42 acre-inches per acre to 0	Unlimited availability
3	Non-optimal**	A constant amount of 42 acre-inches per acre.	Incremented from 0 to 42 acre-inches per acre
4	Non-optimal**		Unlimited availability

* Optimal cropping pattern indicates that the economic model chose the cropping activity yielding the highest whole-farm profits.
** Non-optimal cropping pattern indicates that the economic model was forced to choose a cropping pattern of 50 percent alfalfa, 33 percent cotton and 17 percent spring barley. This cropping rotation is common in the study area.

Table 3. Soil and water chemical characteristics, Roswell-Artesian Basin.

	Chemical Constituents (mg/kg)						
	EC	**Ca**	**Mg**	**Na**	**Cl**	**SO_4**	**HCO_3**
Soil	2560	374	111	256	86	1662	69
Fresh water	1000	139	44	122	226	313	154
Saline water	5000	922	155	568	1964	1210	165
Rain	50	6.9	2.2	6.1	11.3	15.7	7.7

Table 4. Water costs per acre-inch, Roswell-Artesia basin, 1985.

Artesian Well (1,000 ppm TDS)		**Shallow Well (5,000 ppm TDS)**	
Pumping Depth	250 ft	Pumping Depth	95 ft
GPM	1250	GPM	850
Natural gas price	$3.75 MCF	Natural gas price	$3.75 MCF
Efficiency	0.138%	Efficiency	0.138%
Fuel cost per hour	$6.02	Fuel cost per hour	$1.58
Cost per acre-inch	$2.18	Cost per acre-inch	$0.84

Table 5. Crop prices used for analysis, Roswell-Artesian Basin, 1985.

Crop	**Price (USD)**
Alfalfa	$100/Ton
Barley	$2.80/bushel
Corn	$2.91/bushel
Sorghum	$2.69/bushel
Cotton	$0.62/lb

Prices derived from USDA reports from 1984.

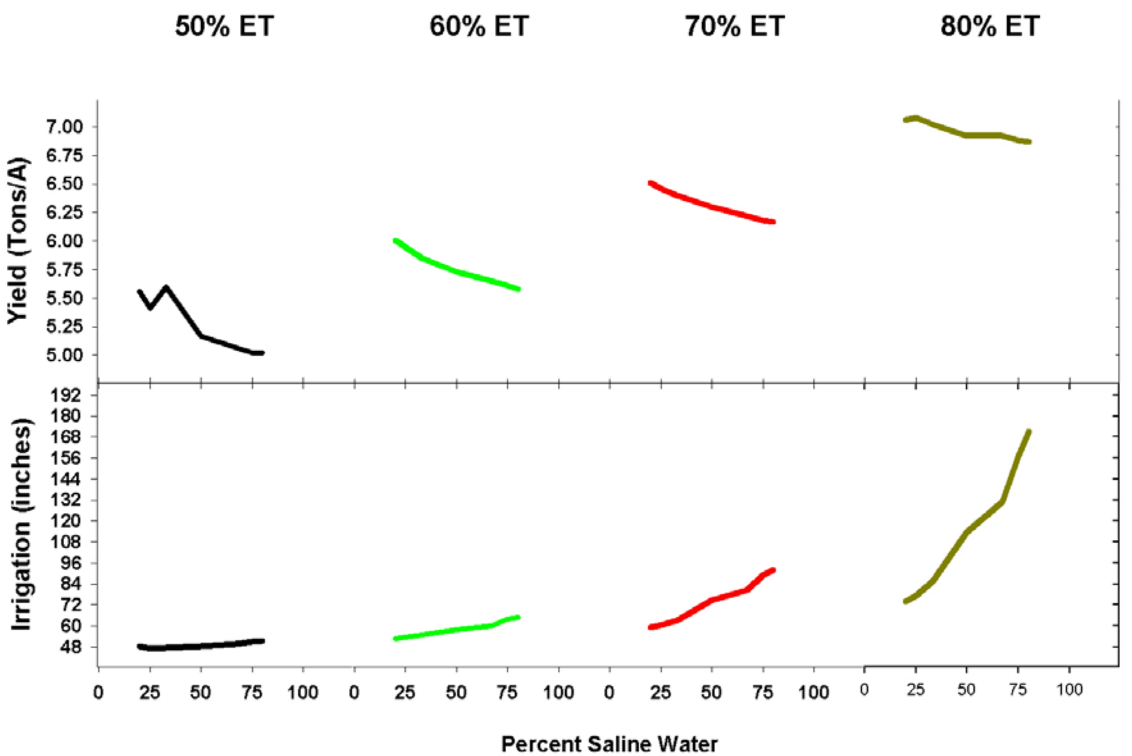

Figure 1. Alfalfa yield and irrigation requirements for given levels of relative transpiration and increasing percentage of saline water.

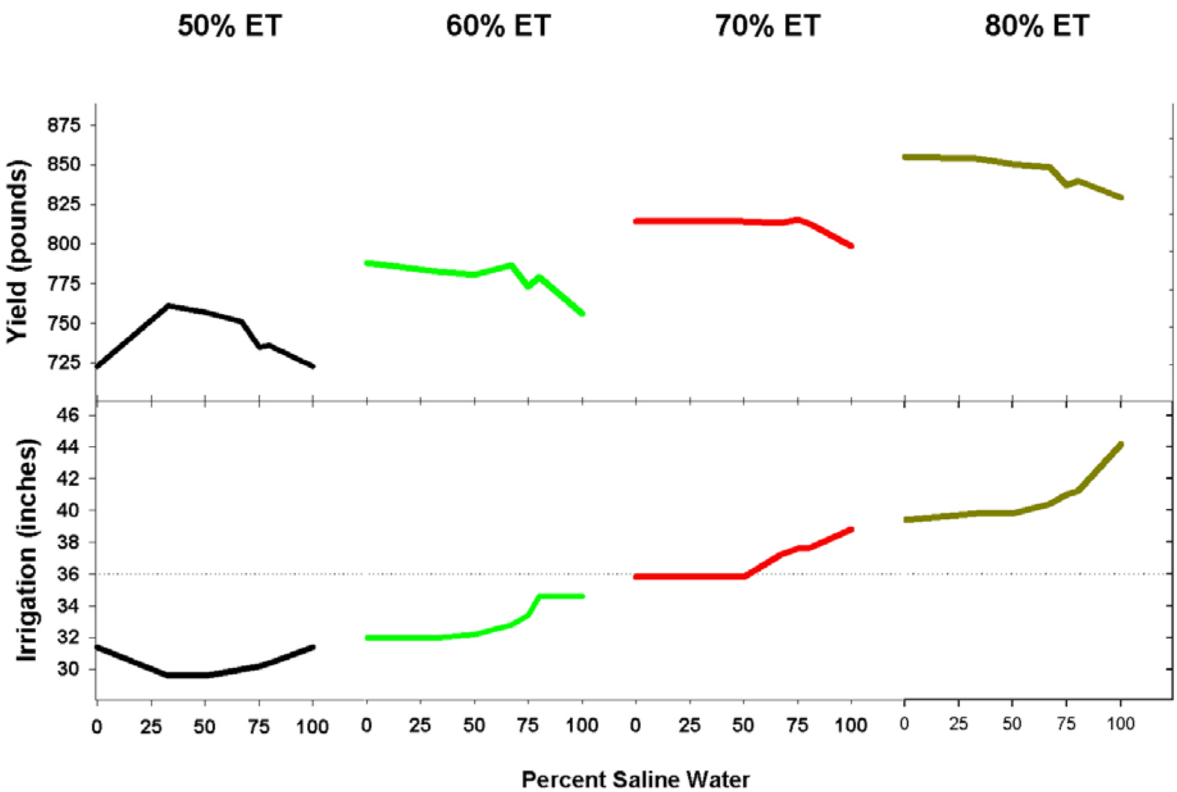

Figure 2. Cotton yield and irrigation requirements for given levels of relative transpiration and increasing percentage of saline water.

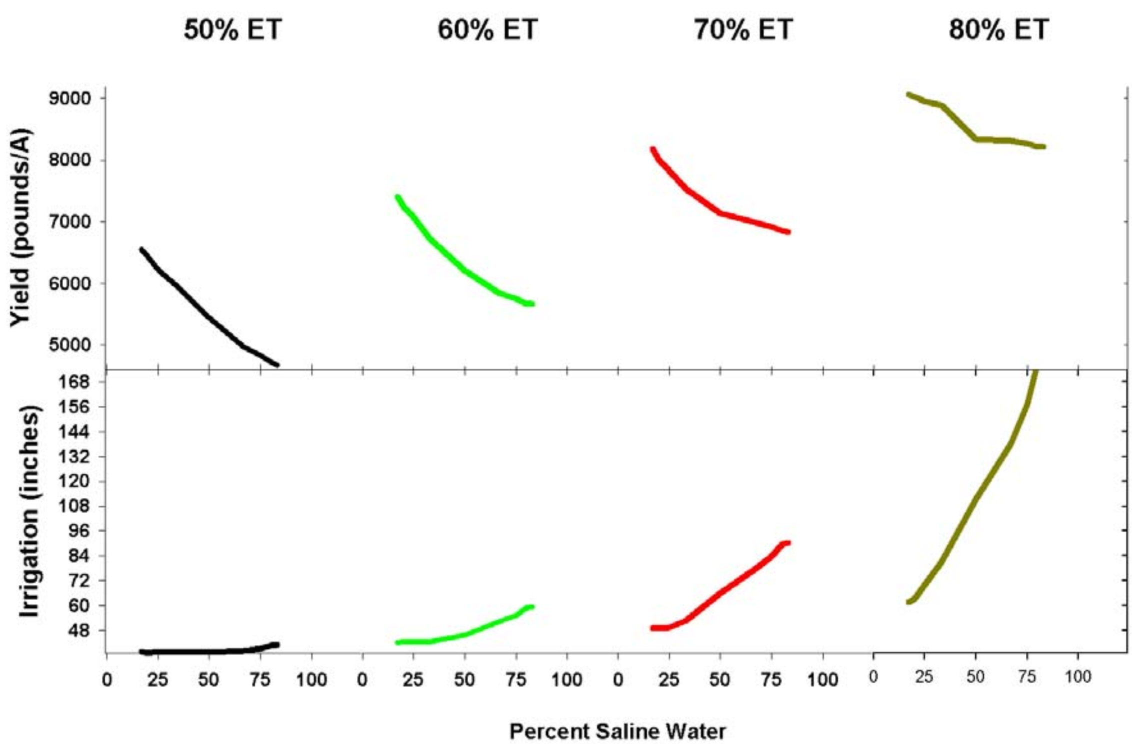

Figure 3. Corn yield and irrigation requirements for given levels of relative transpiration and increasing percentage of saline water.