OPTIMIZATION OF IRRIGATION SCHEDULING WITH ALTERNATIVE SALINE WATER SUPPLIES IN THE ROSWELL-ARTESIA BASIN, 1985

by

Robert R. Lansford
Principal Investigator
Department of Agricultural Economics

and

J.T. McGuckin, Assistant Professor, Agricultural Economics
Craig L. Mapel, Research Specialist, Agricultural Economics
Bobby J. Creel, College Assistant Professor, Agricultural Economics
T.W. Sammis, Assistant Professor, Agricultural Engineering

PARTIAL TECHNICAL COMPLETION REPORT

Project No. WRRI 1423621

June 1986

New Mexico Water Resources Research Institute

in cooperation with

Departments of Agricultural Economics and Agricultural
Engineering and Agricultural Experiment Station, NMSU

The work upon which this publication is based was supported in part by funds provided by the State of New Mexico through the New Mexico Water Resources Research Institute.

DISCLAIMER

The purpose of Water Resources Research Institute technical reports is to provide a timely outlet for research results obtained on projects supported in whole or in part by the institute. Through these reports, we are promoting the free exchange of information and ideas and hope to stimulate thoughtful discussion and action that may lead to resolution of water problems. The WRRI, through peer review of draft reports, attempts to substantiate the accuracy of information contained in its reports, but the views expressed are those of the author(s) and do not necessarily reflect those of the WRRI or its reviewers.

Contents of this publication do not necessarily reflect the views and policies of the United States Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States Government.

ABSTRACT

New Mexico's fresh water resources are limited, but significant amounts of groundwater resources remain largely unused due to high salinity levels. Little effort has been made to utilize these aquifers for agricultural production.

The primary objective of this report is to develop an irrigation scheduling model that maximizes profits in irrigation from combined use of fresh and saline water and to determine the extent to which saline water can augment fresh water supplies for irrigation. The study area analyzed is the Roswell-Artesia Basin, one of New Mexico's prime agricultural areas that has abundant saline water resources.

Three models were developed. Two of the models are irrigation scheduling models that predict yield based upon weather patterns and combinations of saline and fresh irrigation water. The third model, developed to interface with either of the first two, is an economic model that determines the optimal combination of fresh and saline irrigation water. The value of saline water to agriculture can also be determined by the economic model.

The results from the study indicate that saline water can be used for irrigated agriculture and that allowing unlimited pumping of saline water in the basin probably could increase farm profitability.

Key words: saline water, fresh water, irrigation scheduling, farm profits, optimal water use, Roswell-Artesia Basin, water value

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Water is becoming an increasingly scarce resource in New Mexico and the arid West. Agriculture consumes more than 85 percent of the water used in the region. Approximately 60 percent of the irrigated cropland in New Mexico is served with groundwater and an additional 13 percent uses groundwater to supplement surface sources. About 60 percent of the cropland irrigated with groundwater is pumped from a depth of 200 feet or more (Sorenson 1982).

Present estimates indicate that New Mexico consumes 1.7 times its annual ground and surface water replenishment which results in substantial groundwater mining. At least three factors have prevailed and will continue to decrease the availability of water for irrigation: (1) water tables are often deep and declining, (2) energy prices are increasing rapidly, and (3) sectors other than agriculture compete for the limited water supply.

While fresh water resources are limited, significant amounts of groundwater resources in New Mexico remain largely unused due to high salinity levels. Only about 25 percent of the approximately 20 billion acre-feet of groundwater reserves in New Mexico is classified as fresh or slightly saline (U.S. Department of Interior 1976). The remaining 15 billion acre-feet is characterized as moderately saline to very saline, or as brine. The recoverability of this huge reservoir is largely unknown. Much of the water is so saline that there has been little effort to use these aquifers for agricultural production. While the brackish waters may never be used for irrigated agriculture, the less extreme saline waters may have potential for use.

Recent research (O'Conner 1980) has focused on the range of saline water that could be utilized in crop production before crop yields were reduced. This research suggested that fresh water could be supplemented by saline water to irrigate crops while still maintaining crop yields. The other possibility is the sole use of saline waters for agricultural purposes. The ability to successfully use saline water to produce common crops could: (1) expand the acreage of irrigated agriculture and hence increase production and (2) conserve higher quality water for future use or for industrial and domestic uses.

Some slightly saline waters (1000 to 3000 mg/l total dissolved solids) are now used for irrigation in a number of major river basins in West Texas and New Mexico. While there may not be a significant increase in the acreage irrigated with these poorer quality waters in the next decade, there are a number of factors that could lead to greater acceptance and application. These are:

1. The progress being made in the development of salt tolerant crops that will result in greater yields and a greater range of choice in crop selection and rotation.
2. The progress being made in implementing farming practices and management that will allow the use of waters with higher concentrations of dissolved solids.
3. The availability of sophisticated decision models for almost all aspects of irrigated agriculture.

EPA's 1984 groundwater strategy and its groundwater injection control program and New Mexico's water statutes call for the protection of the existing quality of groundwaters where the total dissolved solid content is presently equal to or less that 10,000 mg/l. The implication of this action is that both state and federal governments anticipate that waters with dissolved solid contents up to 10,000 mg/l may be used in the future as potable sources. Saline resources in this range also deserve long-term protection for use as potential sources for irrigated agriculture.

The extent to which saline water could serve to supplement fresh water for irrigated agriculture while maintaining economic on-farm viability has not been throughly investigated. Preliminary economic analysis of utilizing saline water in New Mexico was done by Dregne, Garnett and Lansford (1967) and Dregne (1969) and indicated the feasibility of using moderately saline water for traditional New Mexico crops.

Several authors have investigated the impact of salinity on crop growth utilizing irrigation scheduling. Bresler and Yaron (1972) developed a dynamic model that accounts for salinity, although it does not account for stochastic factors such as rainfall and would require modification for use in the western United States, Davis and O'Connor (1980) investigated minimum leaching fractions for the Pecos River in New Mexico and concluded that less water could be used without detrimental effects on yields and soil conditions. Wierenga (1979) also investigated the impact of alternative irrigation efficiencies and timing on soil salinity and yields. These studies provide the foundation for the development of a comprehensive management model that can be used on-farm to optimize profits from irrigations without seriously increasing soil and return flow salinity.

Study Area

Several locations in New Mexico meet the criteria for utilizing saline groundwater for irrigation. The Roswell-Artesian Basin is an important irrigated agricultural producing area with a history of water problems (figure 1). Many of these are typical of the water problems faced by agriculture in many areas of the arid West. Irrigation has been practiced for many years in the Roswell-Artesian Basin. As early as the 1870s, water was diverted from surface water flows for irrigation. Groundwater development began about 1900, expanded rapidly and, to a great extent, was overdeveloped. As a result of the rapid groundwater development, groundwater levels began to decline, surface water flows were reduced and some salt water intrusion began to occur after 1916 (Lansford and Creel 1969).

As a result of these occurrences, the New Mexico state engineer declared the area an administrative groundwater basin in 1931. Water withdrawals from the Artesian aquifer were restricted to 3 acre-feet per acre per year. In 1937, the basin was closed to further appropriation. In spite of these restrictions, the water levels continued to decline. As of 1967, water levels had declined by more than 200 feet in the southern portions of the basin (Garnett 1968). This decline in groundwater tables has stabilized in the past few years due to actions taken by the State Engineer Office (Welder 1983).

Depth-to-water varies widely in the basin and as of 1983 ranged from 50 to more than 200 feet. Water resources in the basin include the artesian aquifer, a relatively deep water supply, and a shallow alluvial aquifer (Welder 1983). The region has considerable variability in the salinity of the water supply available for agriculture. Many producers own dual water rights; one right for shallow, relatively saline aquifers and another for deeper, high-quality artesian water.

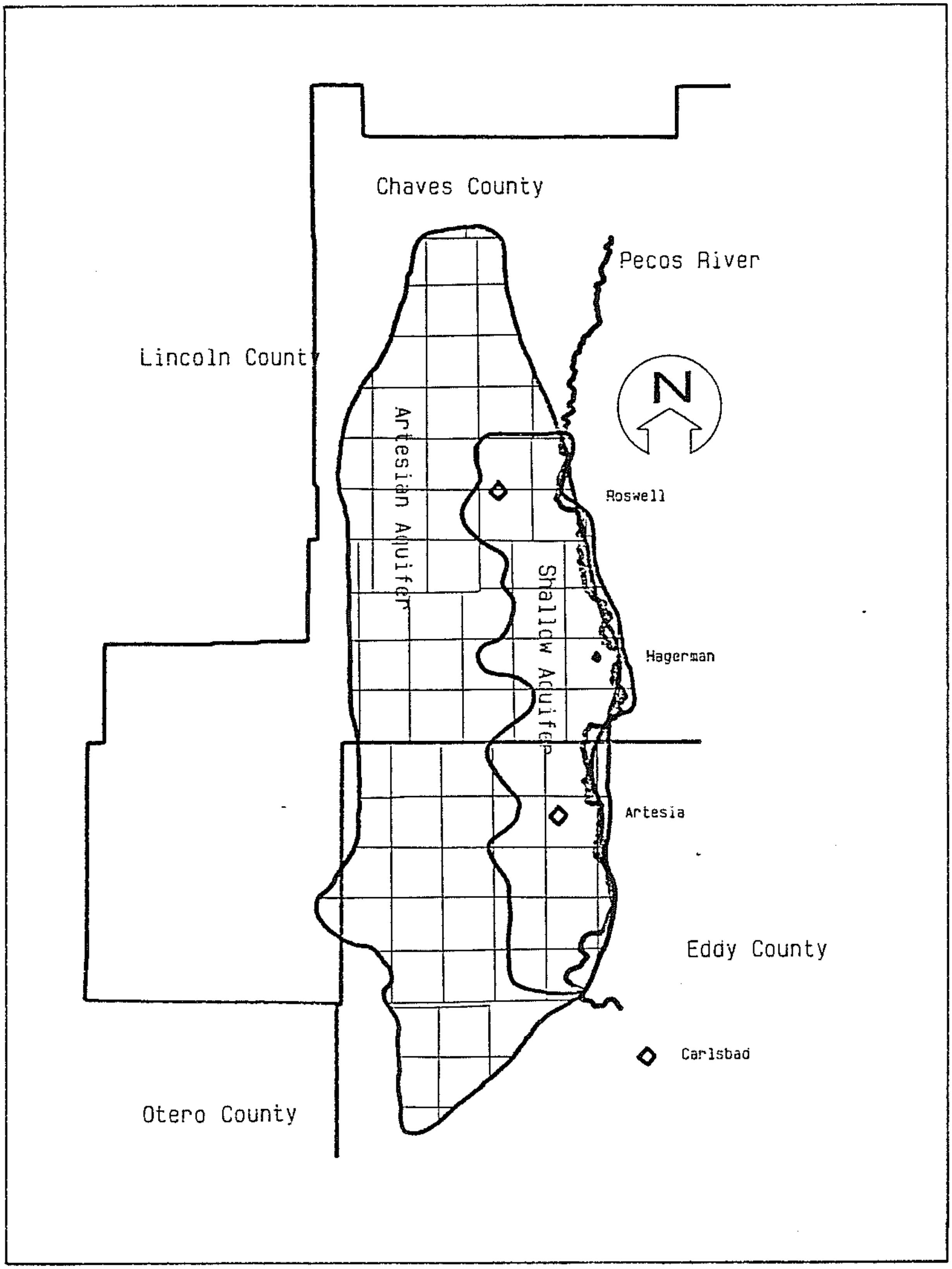

Fig. 1. Location of the Roswell-Artesia Basin, New Mexico

In 1940, about 100,000 acres were in irrigated cropland production. The acreage irrigated peaked around 1970 at about 134,000 acres, then began to decline and stabilize at about 132,000 acres in the early 1980s; an overall increase in acreage from 1940 to 1983 of 33 percent (Lansford 1984). Alfalfa is the major crop grown in the area, followed by upland cotton and small grains.

Today, the majority of irrigation water supplies still comes from groundwater sources. Water diversions for 1983 totaled 350,833 acre-feet. Sixty-two percent of the water diverted was from the artesian aquifer, 33 percent came from shallow wells in the basin and 5 percent came from surface water sources. Eighty-nine percent of all water diverted in 1983 was used for irrigated agriculture (Welder 1983). While municipal and industrial uses do not currently represent a large percentage (10 percent) of the withdrawals, population increases in the area probably will change that. Population from 1970 to 1980 increased by more than 13 percent in the two largest cities in the basin (Roswell and Artesia) (U.S. Bureau of the Census 1981). Increases in population are projected to continue. There has also been a large increase in oil and gas drilling, industries that use large quantities of water. The implication for agriculture in the area is that it will face increasing pressure to reduce its water usage in order for the water to be used for greater economic gain. If irrigated agriculture is to remain viable in the basin, it must place an increased emphasis on the economy of its use of the groundwater resources and more fully use available saline water resources.

OBJECTIVES

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

Specific objectives were to:

1. Optimize an irrigation schedule for alternative saline water supplies and determine an optimal mix of saline and nonsaline water where available.
2. Determine the economic value of saline water when used in agricultural production.
3. Identify those geographical areas in New Mexico that are best suited to the use of saline waters for irrigation and to consider the structure of a mathematical model that could be designed for this purpose.

Specific objective 3 is addressed in a separate Water Resources Research Institute Report (Hernandez, WRRI Report No. 208).

The first two objectives were accomplished by modifying an existing irrigation scheduling model designed by the New Mexico State University (NMSU) Agricultural Engineering Department (a physically-based model). After the results of saline irrigation water use on crop yield were determined, they were incorporated into an economic analysis, which was done using results from the model.

The model was developed for New Mexico use by Sammis (1983), Lansford, et al. (1983) and Mapel (1984). The model tracks soil moisture in the root zone throughout the growing season and makes irrigation decisions based on soil conditions predicted by wind, solar radiation, evapotranspiration and other variables. This model was initially developed assuming that fresh or low saline waters were available for irrigation. The model was then adapted to incorporate the effects of saline irrigation water use on crop-yield, water-applications and soil structure.

IRRIGATION SCHEDULING MODELS

One objective of this research was to develop a simple, non-interactive irrigation scheduling model that incorporated the effect of soil moisture and salinity stress on crop production. A sub-objective was to develop another irrigation scheduling model that incorporated the effect of the chemistry on the dynamic interaction among water, soil salinity and yield.

Many irrigation scheduling models have been developed to determine the optimal timing and amount of water application for any desired yield (Hanks, 1974; Rasmussen and Hanks, 1978; Lansford, et al. 1984). When salinity and water stress effects on evapotranspiration and yield are combined, models can be developed for developing water salinity production functions. These models have been developed on a yearly time basis (Letey, Dinar and Knapps 1985; Soloman 1984) and make simplified assumptions including the one that no chemistry occurs in terms of precipitation and redissolving of salts in the soil profile. Other models are on a daily time step (Bresler 1982) and do not assume steady state conditions in the soil profile. Models that incorporate chemistry but assume steady state conditions in the soil profile are described by Rhoades, et al. (1973) and Oster (1975).

The principal concept behind these models is that irrigation with saline water will cause some degree of salinization in the soil. When the salinity builds up sufficiently, it will cause a decrease in yield daily and seasonal evapotranspiration. For any given amount of saline irrigation water use, there will be some point at which the value of yield, E_t, leaching and soil salinity are consistent with one another. Equilibrium conditions result from a dynamic process that occurs throughout the growing season as salinity in the soil profile builds up and daily evapotranspiration relative to non-stress conditions decreases. Increased leaching fractions can remove the salt build-up or the application of water with lower salinity content can dilute the amount of salt in the root zone.

Procedures

An existing irrigation scheduling model, based upon a model described by Hanks (1974) and Sammis, et al. (1983, 1985), was modified to include the effects of salinity on crop yield in calculating E_t and yield. Like all water balance irrigation scheduling models, the model is based on the following components: (1) a climate estimated reference evapotranspiration (E_{to}), (2) an index for relating expected crop water use to the reference E_{to}, (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 crop from the specified soil, and (6) because yield is a component, the model also incorporated the relationship between crop production yield and crop water use.

Two models were developed. The first was a simple salinity model requiring only the electric conductivity of the irrigation water and the initial electric conductivity of the soil water. The second, more complex salinity model, was based upon the chemistry of the soil and water chemical constituents (Dutt, et al. 1972). This model required the chemical constituents of the salinity of both the soil water and the irrigation water as input data. These constituents were calcium, magnesium, sodium, sulfate, chloride, bicarbonate and carbonate.

In the models, water entered the compartments making up the root zone in small increments specified internally in the model and currently set at 8.4 mm of water application. Salinity of the irrigation water was mixed with the salinity of the water in the first compartment of the soil profile. The average salinity of that water, in excess of the water holding capacity of the top compartment of the soil profile, passed into the next depth where it was again mixed with the current water in that depth, resulting in an average salinity. If any excess water existed that amount passed to the following depth and so forth as described by equation 1.

$$S(I) = \frac{S(I)\ DW(I-1) + S(I)\ W(I)}{DW(I-1) + W(I)} \tag{1}$$

where:

$S(I)$ = Salinity of compartment depth(I)

$W(I)$ = Water content of depth(I)

$DW(I)$ = Drainage water from depth(I)

$DW(0)$ = 8.4 mm of irrigation water

$S(0)$ = Salinity of irrigation water

The increments of water were added to the soil profile at the top (I=0) until the total irrigation application had been applied and a new salinity in the soil profile was determined. Following an irrigation, the salinity in the soil profile was concentrated by extraction of water in each of the depths by the process of transpiration and in the top foot by evaporation. The average salinity in the root zone was computed. This salinity amount reduced daily potential transpiration along with the reduction due to soil moisture stress, calculated from average plant available water, as described by equation 2.

$$T = T_o K_s . K_{sw} \tag{2}$$

where:

T = Actual Transpiration

T_o = Nonstress potential transpiration

K_s = Coefficient to reduce transpiration as a function of soil salinity

K_{sw} = Coefficient to reduce transpiration as a function of plant available water

The soil water and salinity stress coefficients are described by equation 3 and 4:

$$K_s = a + b\ S_a \qquad \text{if } S_a > C \tag{3}$$

$$K = 1 \qquad \text{if } S_a < C$$

S_a is average salinity in the root zone

a and b are empirical constants that are a function of the crop

C is threshold level of salinity above which a reduction in T occurs

$$K_{sw} = a_{sw} + b_{sw}\ W \qquad \text{if } W < C \tag{4}$$

$$K_{sw} = 1 \qquad \text{if } W > C$$

a_{sw} and b_{sw} are empirical constants that are a function of the crop

$W = AW/SWS$

SWS = Soil water stored in the root zone (cm) between permanent wilting point and field capacity

AW = Available water in root zone equal to the difference between water content and permanent wilting point

C = Level of W equal below which soil moisture stress occurs to reduce T which is crop dependent

Transpiration over the whole growing season was accumulated and the resulting yield (Y) was determined from the water production function that is input data into the model.

where:

$$Y = a_Y + b_y \; T \tag{5}$$

It was assumed that moisture and salinity stress affect T and were interchangeable and consequently the water production function, relating T to yield was independent of the form of stress.

Model Validation

Simple Salinity Model. In order to test the simple salinity model, the salinity constants A and B were determined based on salinity functions published by Maas and Hoffmann (1977), which relate average salinity in the root zone to relative yield, and the functions presented by Doorenbos and Kassam (1979), which relate relative yield to relative E_t. These two functions were combined to develop the salinity function, which reduces nonstress T to stress T due to salinity. Table 1 presents the derived constants and the threshold level above which average salinity in the soil profile causes no decrease in transpiration. After deriving the constants for the different crops needed as input data to the model, the model was run with different levels of leaching fractions

Table 1

Yield and salinity coefficients used in the irrigation scheduling model needed to model the effect of irrigation and soil salinity on the yield of selected crops at Artesia, New Mexico

	CROPS				
	Barley	Corn	Alfalfa	Sorghum	Cotton
Salinity coefficient intercept (a)	1.38	1.14	1.15	1.29	1.42
Salinity coefficient slope $(dS/m)^{-1}$ (b)	-0.0243	-0.0396	-0.0371	-0.0364	-0.0275
Yield coefficient intercept (lbs/acre) (a_y)	-198	-5081.9	52	146	21.02
Yield coefficient slope (lbs/acre-inch) (b_y)	366	443	280	340	34
Rooting Depth (feet)	4	5	5	3	4
Threshold Level at which transpiration is reduced by salinity (dS/m average salinity of soil water = 2 times salinity of saturation extract)	15.6	3.5	4.0	8.0	15.2

and an irrigation salinity level of 7.8 dS/m. The leaching fractions were changed by setting the relative transpiration level at which irrigation was applied to 90 percent, 80 percent, 70 percent and 60 percent. Initial soil salinity was set at 2560 PPM. The model was run for ten years and steady state conditions occurred after four years. The model computed yield and average salinity (figures 2-6) in the soil profile, and are compared to the original yield soil salinity functions presented by Maas and Hoffman (1977). The figures show that the model predicts the same yields as Maas and Hoffmann data for a given soil salinity averaged over the growing season.

A second test of the simple salinity model was conducted by comparing the model simulation of grain sorghum grown at Brawley, California, to the measured values reported by Francois, et al. (1984). The dates and amounts of irrigation and the salinity of the applied water from Francois' experiment were input data into the model (table 2). The climate data from Brawley, California, was also input data into the model along with the initial salinity of the root zone.

The water production function, which was input data to the model, had a much steeper slope and greater negative intercept than would normally be expected (table 1) under conditions of uniform stress throughout the growing season (table 2). However, the experiment in Brawley was conducted so salinity stress did not occur until after the vegetative stage had passed and consequently, a water production function, as discussed by Doorenbos and Kassman (1979), for stress during the flowering period was used in the model. Comparison of measured and modeled yields for the different irrigation salinity levels are presented in figure 7 and table 3.

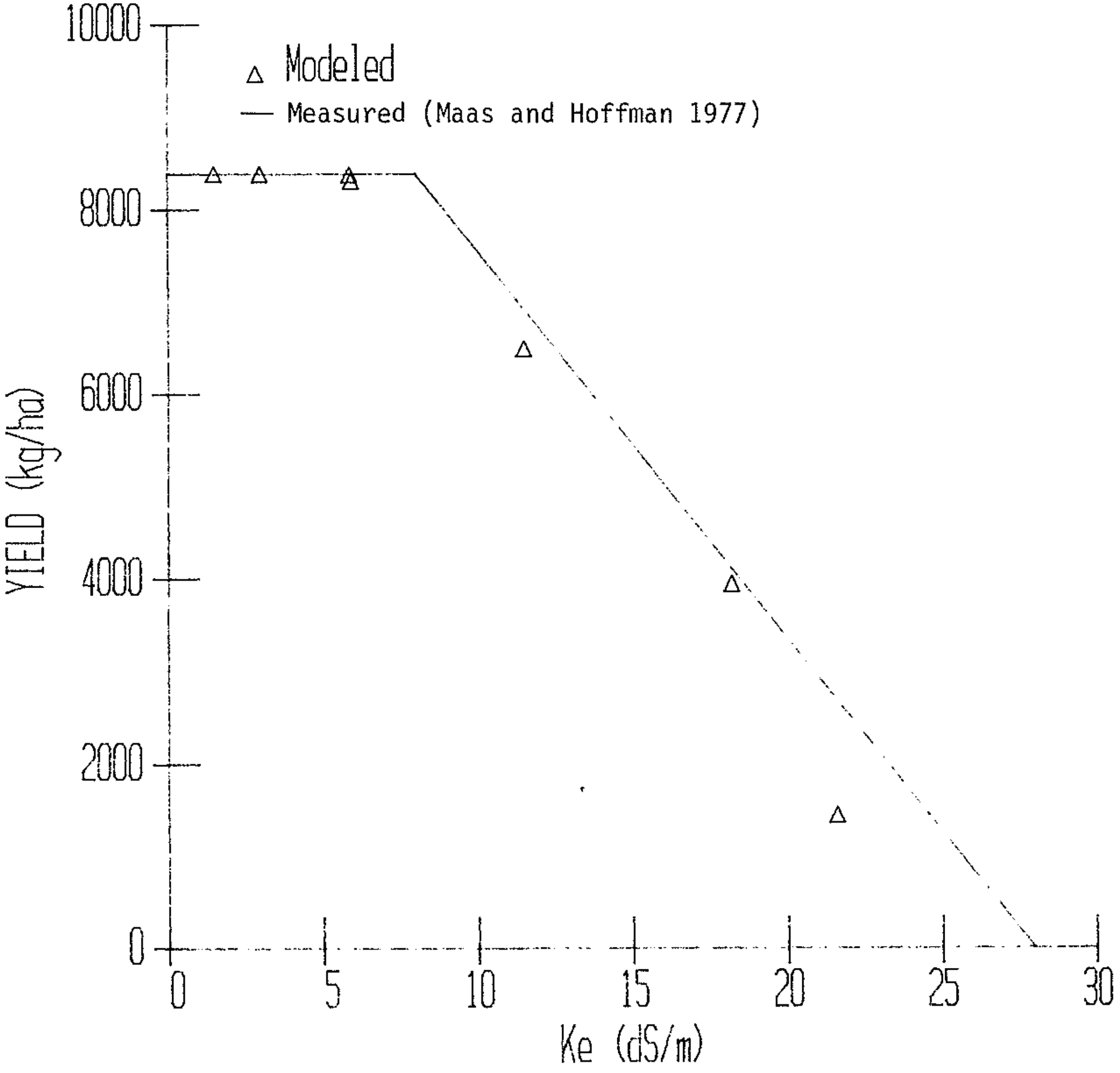

Fig. 2. Barley yield as a function of increasing average soil salinity in the root zone

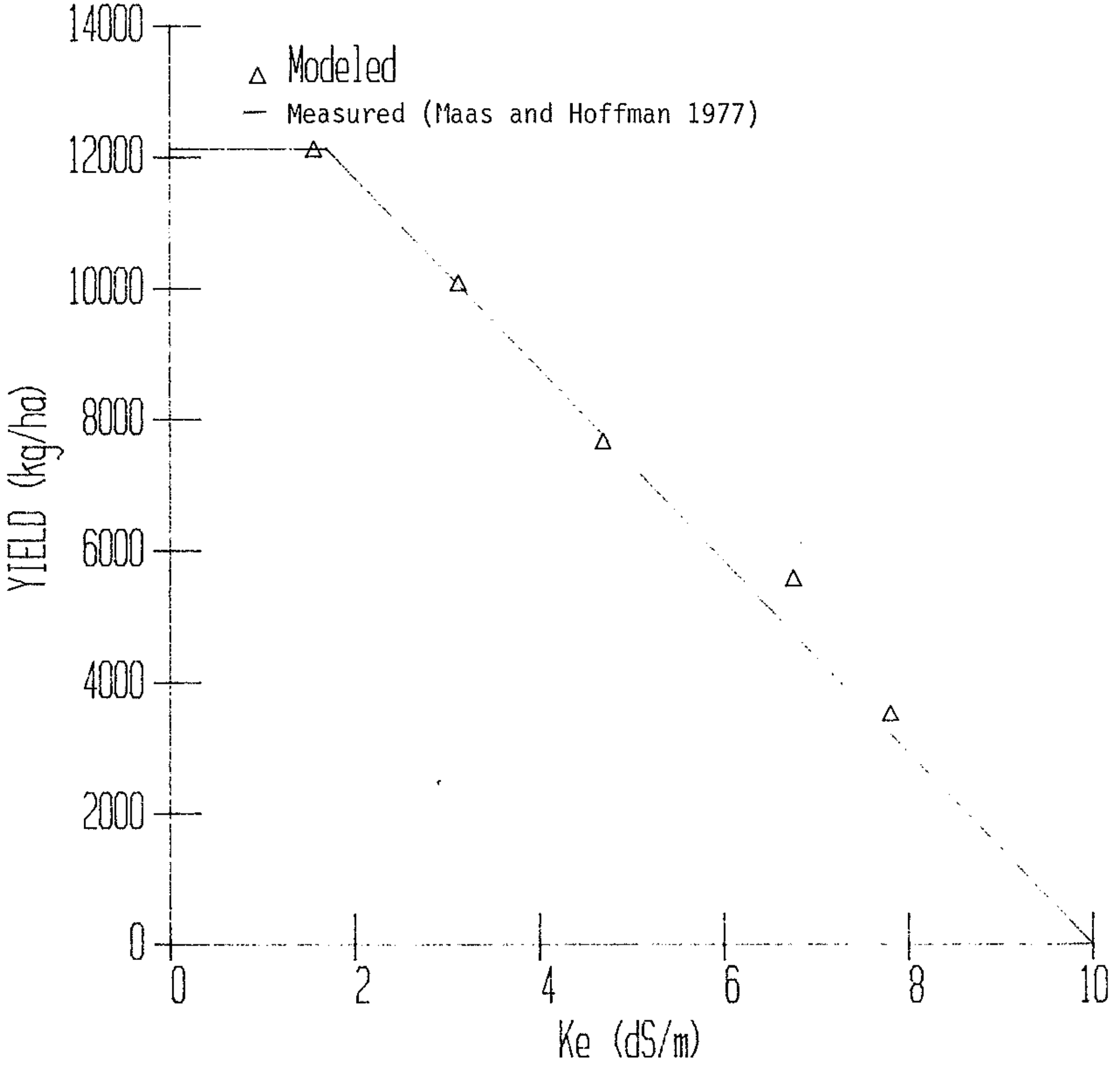

Fig. 3. Corn yield as a function of increasing average soil salinity in the root zone

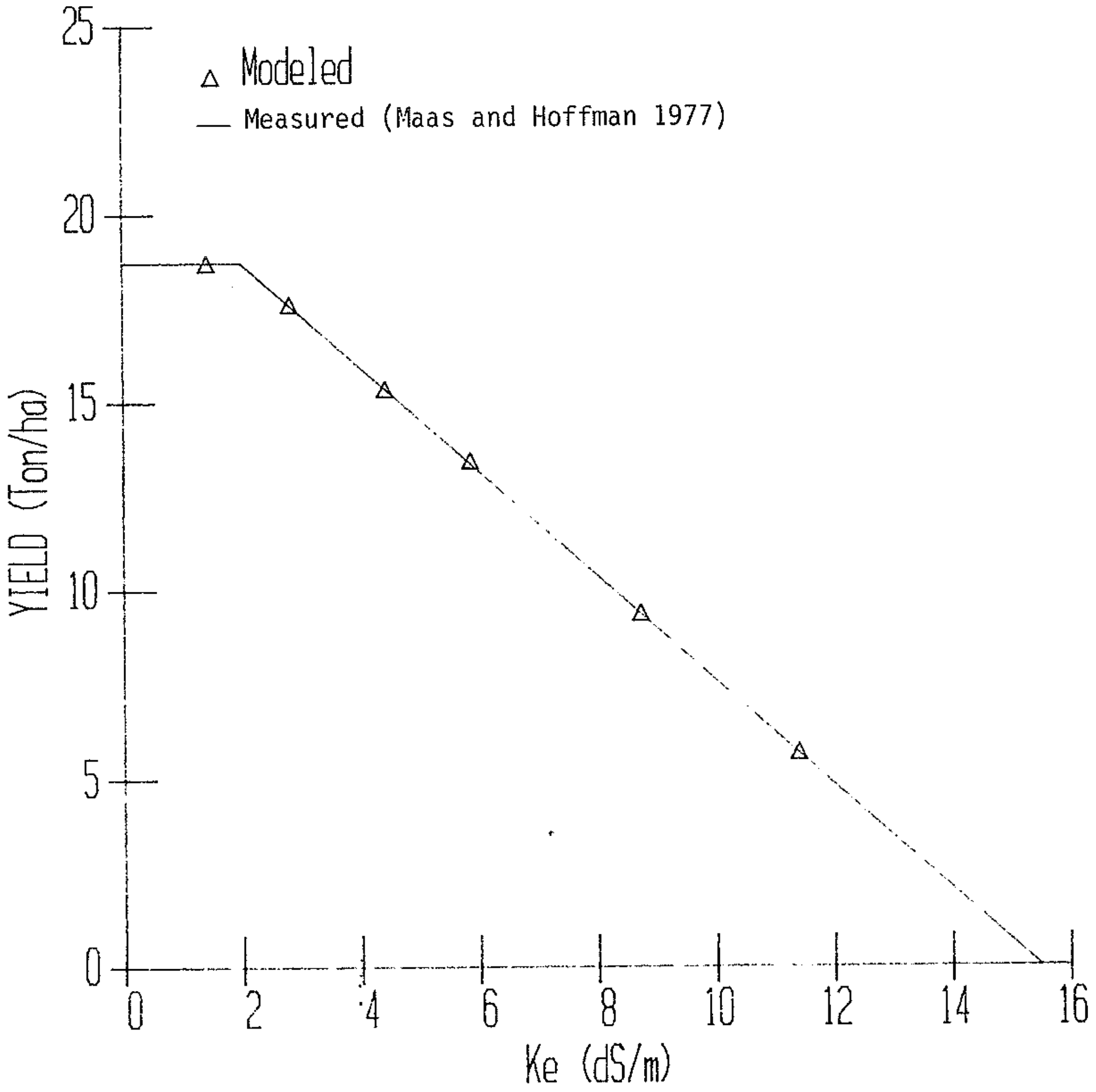

Fig. 4. Alfalfa yield as a function of increasing average soil salinity in the root zone

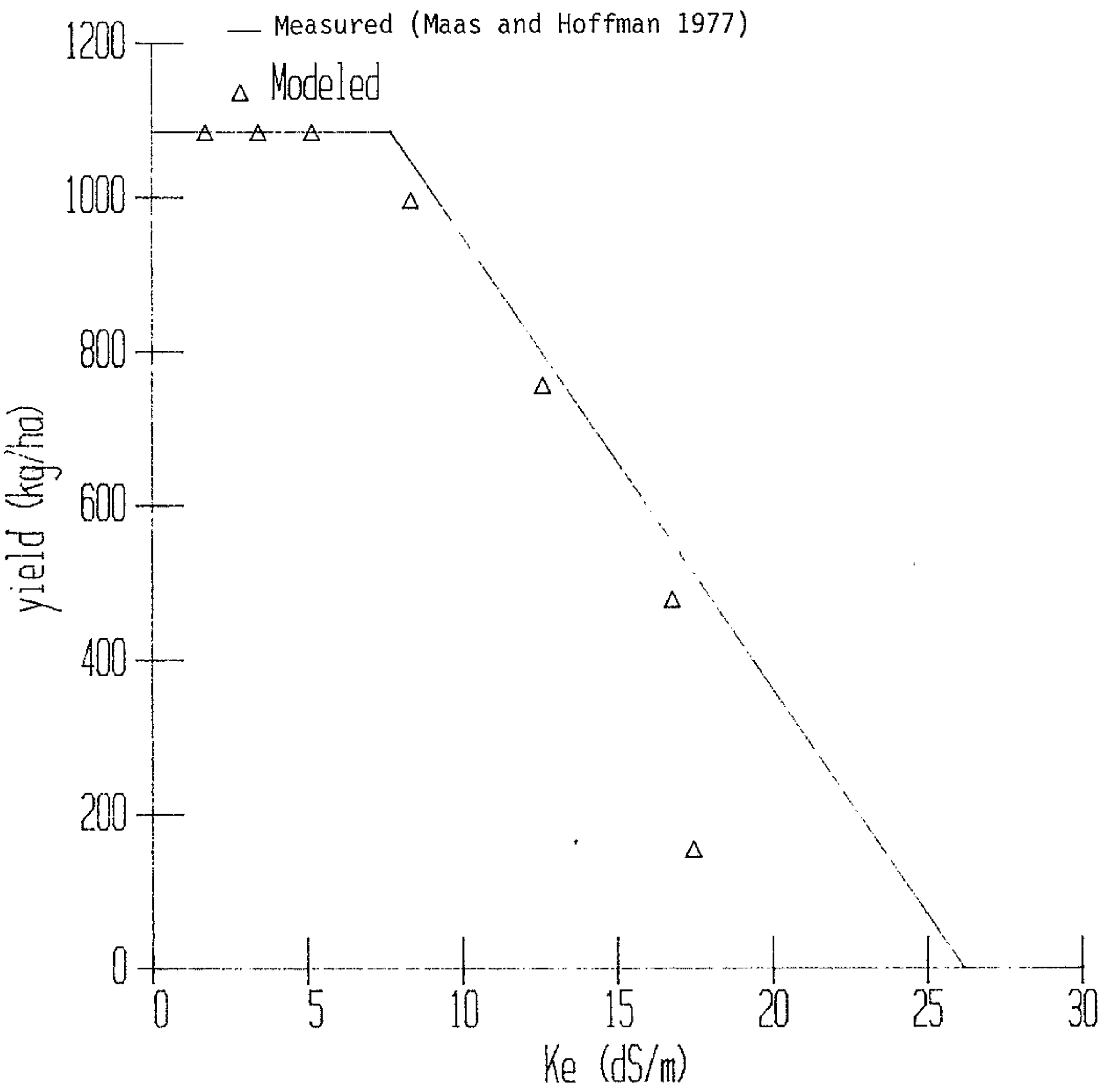

Fig. 5. Cotton yield as a function of increasing average soil salinity in the root zone

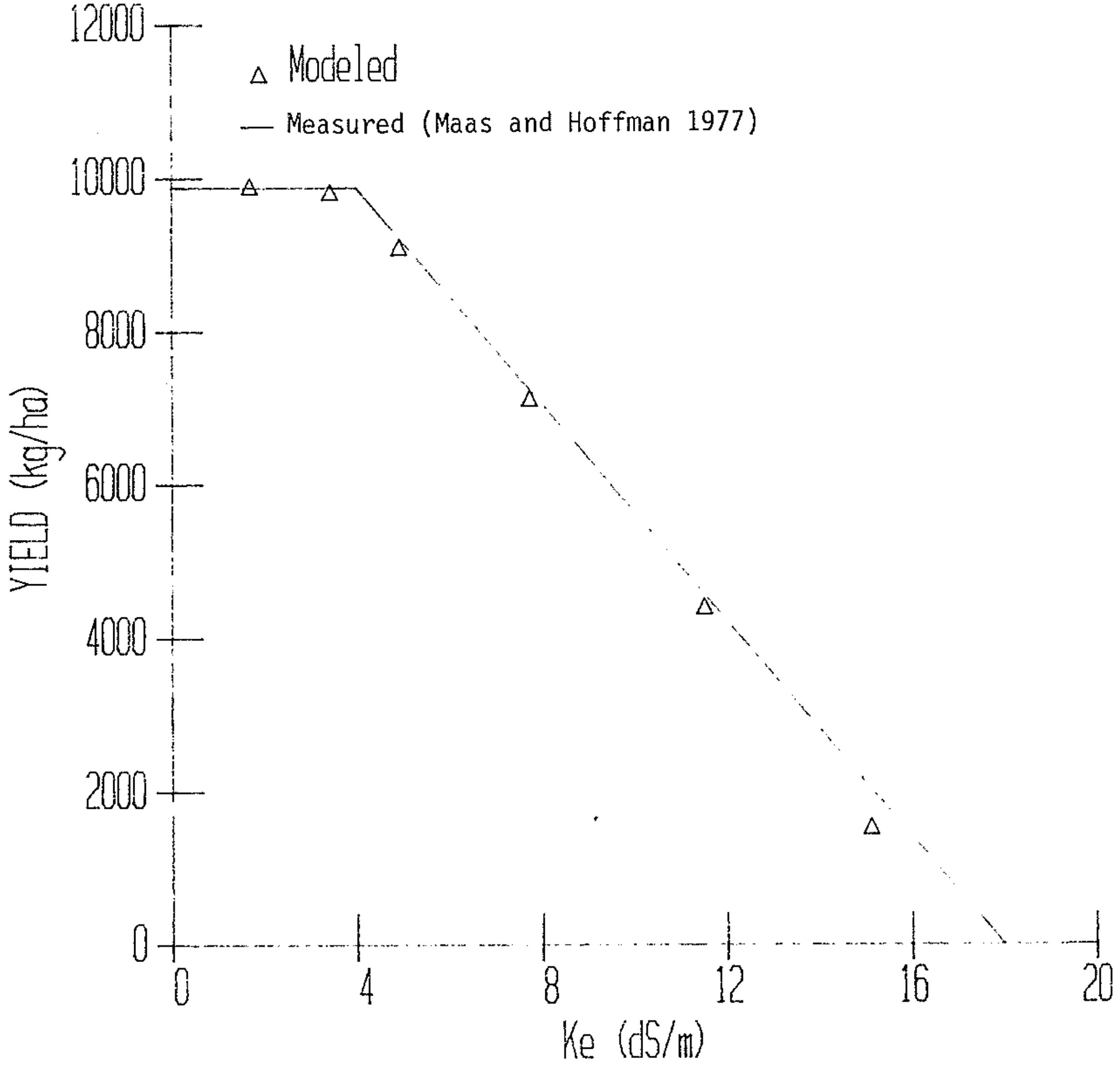

Fig. 6. Sorghum yield as a function of increasing average soil salinity in the root zone

Table 2

Yield and salinity coefficients used in the irrigation scheduling model to model the effect of irrigation and soil salinity on sorghum yield at Brawley, California

Salinity coefficient intercept (a) = 1.104

Salinity coefficient slope $(dS/m)^{-1}$ = -0.0174

Yield coefficient intercept (lbs/acre) = -10488

Yield coefficient slope (lbs/acre-inch) = 408

Rooting depth (feet) = 3

SALINITY INPUT

Level	Initial Soil Salinity dS/m	Irrigation Salinity dS/m						
1	3.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2	5.2	1.5	2.7	2.7	2.7	2.7	2.7	2.7
3	7.0	1.5	1.5	5.0	5.0	5.0	5.0	5.0
4	9.7	1.5	2.7	7.4	7.4	7.4	7.4	7.4
5	12.0	1.5	5.0	9.8	9.8	9.8	9.8	9.8
6	12.8	1.5	7.4	12.1	12.1	12.1	12.1	12.1
Amount of Irrigation Water (inches)		20.6	15.5	20.6	20.6	23.1	23.1	23.1

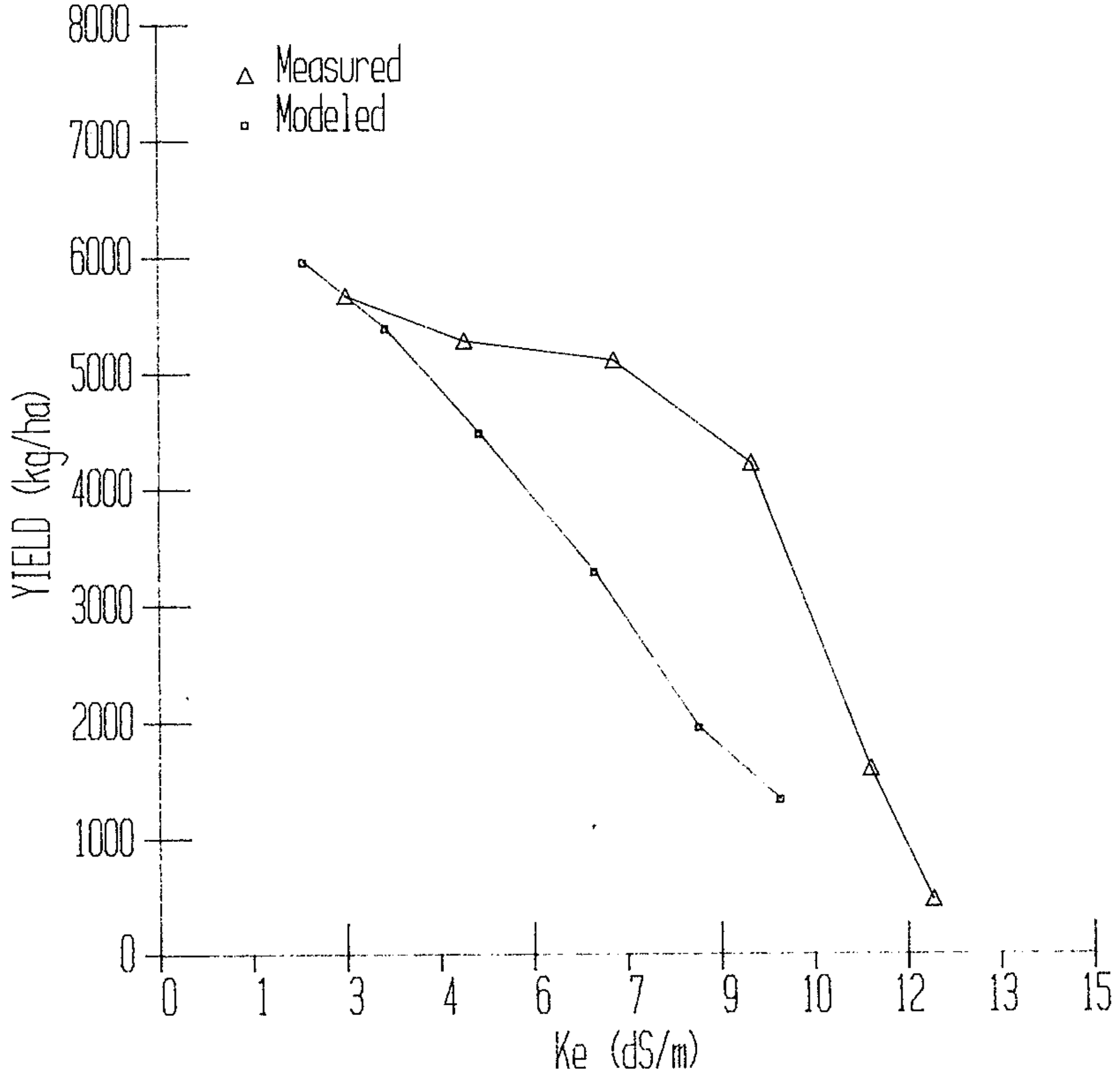

Fig. 7. Measured and Modeled Grain Sorghum Yield as a Function of Increasing Average Soil Salinity in the Root Zone Expressed as a Saturation Extract (kc) Brawley, California in 1982.

Table 3

Measured and modeled root zone salinity and yield of grain sorghum irrigated with different levels of saline water at Brawley, California

Mean Root Zone Salinity of Saturated Extract	Measured Yield	Modeled Yield	Modeled Root Zone [1/] Salinity Converted to Saturated Extract
(dS/m)	(lbs/acre)	(lbs/acre)	(dS/m)
.3	5062	5362	2.4
8.9	4741	4813	3.7
7.3	4562	4003	5.2
11.4	1429	1746	8.7
12.4	419	1192	10.0

[1/] Average root zone salinity averaged over growing season and converted (by dividing by 2) to equal saturated extract equivalent.

The salinity function used in the model was derived by the linearization of the field data which explains why the model predicts satisfactorily the yield-salinity relationship under the nonstressed conditions and the severe stress conditions but over predicts, compared to the measured values, the reduction in yield when the soil salinity (expressed in terms of saturation extract), is in the 4 to 9 dS/m range. When the irrigation amounts and salinities were supplied to the model as input, the modeled soil salinity was less than the salinity measured in the field. Francois indicated that fresh water irrigations were applied for germination and that the salinity was increased step wise over the time period until the salinity equaled the salinity level designated for the experiment. When these irrigation salinities and amounts were incorporated into the model, a large leaching fraction occurred at the beginning of the growing season. If there was solid phase gypsum and lime in the soil, they may have dissolved to maintain the initial salinity during that growing period at a higher level than that predicted by the simple model, which does not take into account the chemistry occurring in the soil solution. This chemical reaction might account for the model underpredicting the average soil salinity during the growing season compared to that measured in the field experiment.

Chemical Salinity Model. The chemical salinity model was tested by comparing it to the simple salinity model using two waters of different salinities. Corn growth was simulated at Artesia for 10 years. The salinity of the Artesia ground water and the salinity of Gila River water were applied to the corn field in the model at different plant available water levels in the soil resulting in different leaching fractions. The model predicts the salinity of the drainage water. Salinities of the input water are presented in table 4. The model reached steady state conditions after four years when the leaching fraction was between 0.5 and 0.3. Steady state conditions were not reached in the model after 10 years when leaching fractions were less than 0.3. Grain yields were 8045 and 5204 lbs/acre for leaching fractions of 0.5 and 0.3 respectively when Gila water was applied, and yields were 3230 and 0 lbs/acre when Artesia ground water was applied at leaching fractions of 0.5 and 0.3.

The simple chemical model predicts slightly lower drainage water salinities than the chemical salinity model over the range of leaching fractions applying Gila River water (figure 8). This result is identical to results reported by Oster and Rhoades (1974). The chemical model dissolves solid phase gypsum and lime into solution increasing the drainage water salinity. However, when Artesia ground water, which is high in calcium and magnesium, is applied through the model precipitation occurs and the chemical salinity model predicts salinities much lower than the simple salinity model (figure 8) and a corresponding increase in the predictive yield. These results are compatible with those reported by Oster and Rhoades (1974).

Table 4

Composition of irrigation water used to grow corn at Artesia, New Mexico

Source	EC dS/cm	Ca^{+2}	Mg^{+2}	Na^{+1}	HCO_3^{-1} meq/ liter	Cl^{-1}	SO_4^{-2}	SAR[1/]
Gila River[2/] below Gillespie Dam, Arizona	3.14	7.22	5.88	18.55	3.17	20.17	8.48	7.3
Artesia Ground Water - Saline Water	9.16	53.9	14.9	29.1	65.2	29.6	3.14	4.96

[1/] $SAR = Na^{+} / [Ca^{++} + Mg^{++} / 2]^{\frac{1}{2}}$

[2/] Rhoades et al., 1973

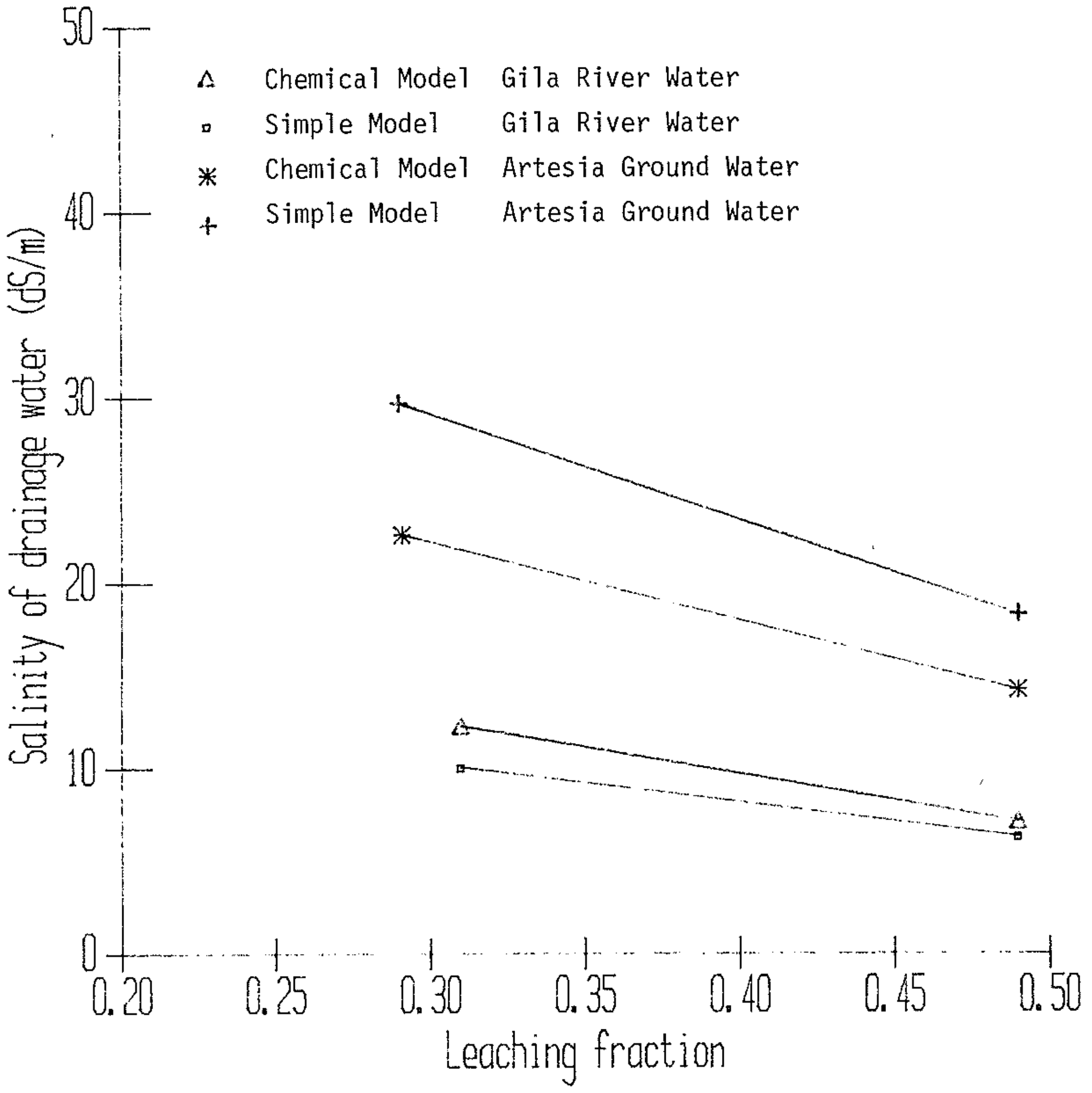

Figure 8 . Average Salinity of the Drainage Water for Different Leach Fraction of Gila River Water and Artesia Ground Water Applied to Corn Grown at Artesia, New Mexico for 10 Years Using a Simple Salinity Model and a Salinity Model that Accounts for the Chemical Interaction of the Constituents in the Water and Soil.

ECONOMIC ANALYSIS

The objective of 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. A sub-objective was to use the economic model to estimate the benefits in terms of farm profits of augmenting existing irrigation supplies with saline water.

Procedures

A farm site was selected in the Hagerman area that has several of the characteristics desired for this analysis. The farm has three wells. Two are shallow wells with high salinity levels. The third well contains fresher water from the Artesian aquifer. The case study farm was used to check the calibration of the simple and the more complex salinity models.

The models were then used to derive yield and water applications for selected crops for different mixes of fresh and saline water applications for 20 years of simulated weather for the area. After the water applications and respective yields had been determined, whole farm cost and return crop budgets were developed using NMSU's crop budget generator (Creel, et al. 1980). With an engineering cost approach, the budget generator developed per-acre costs for each operation performed on each crop. The budgets indicated the per-acre costs of purchased inputs (materials such as seed and fertilizer), the labor, fuel and repairs, and fixed costs associated with preharvest and harvest operations, and overhead costs such as taxes, insurance and interest costs.

The budget generator also provided estimates of per-acre machinery costs, based on a prorated share of the farm's variable and fixed costs of owning and operating the required farm machinery. The budget generator also calculated gross revenues, total costs, and net returns. From the budgets, profitability for each of the irrigation strategies was determined.

Economic Model Description. A linear programming (LP) model was constructed to determine the optimal cropping pattern and irrigation strategy for limited water resources. LP was chosen over an optimal control model because of institutional and legal constraints placed on the total water use of the farms in the Roswell-Artesia Basin. Single crop optimal control models cannot maximize profits for the whole farm because they do not consider the allocation of both saline and fresh water to their highest value use, which is determined by the cropping alternatives. An LP model that incorporates a range of alternative irrigation strategies, fresh to saline water mixes, and cropping patterns was designed to simultaneously determine the optimal irrigation schedule, the mixture of saline and fresh water, and the profit maximizing crop enterprises.

Mathematically, the linear program model will maximize or minimize an objective function:

$$Z = C_1X_1 + C_2X_2 + \ldots C_jX_j$$

subject to

$$a_{11}X_1 + a_{12}X_2 + \ldots a_{ij}X_j \leq b_1$$

$$a_{21}X_1 + a_{22}X_2 + \dots a_{2j}X_j \leq b_2$$

$$a_{n1}X_1 + a_{n2}X_2 + \dots a_{nj}X_j \leq b_n$$

such that

$$X_j \geq 0 \text{ for all } j$$

where

X_j's are the possible alternative activities

C_j's are the costs of the activities

a_{ij}'s are the input/output relationships between the i-th resource and the j-th activity

b_i's are the given resource levels or activity restrictions.

In the LP model developed for this analysis, the objective functions are: Cx

$$\begin{aligned} \text{Maximize } Z = {} & C_1X_1 + C_2X_1 + C_3X_1 + \dots C_{15}X_1 + \\ & C_1X_2 + C_2X_2 + C_3X_2 + \dots C_{15}X_2 + \\ & C_1X_3 + C_2X_3 + C_3X_3 + \dots C_{15}X_3 + \\ & C_1X_4 + C_2X_4 + C_3X_4 + \dots C_{15}X_4 + \\ & C_1X_5 + C_2X_5 + C_3X_5 + \dots C_{15}X_5 \end{aligned}$$

Subject to

Ax RHS

$$\begin{aligned} & a_{11}X_1 + a_{12}X_1 + a_{13}X_1 + \dots a_{1,15}X_1 + \\ & a_{21}X_2 + a_{22}X_2 + a_{23}X_2 + \dots a_{2,15}X_2 + \\ & a_{31}x_3 + a_{32}X_3 + a_{33}X_3 + \dots a_{3,15}X_3 + \\ & a_{41}X_4 + a_{42}X_4 + a_{43}X_4 + \dots a_{4,15}X_4 + \\ & a_{51}X_5 + a_{52}X_5 + a_{53}X_5 + \dots a_{5,15}X_5 \leq \quad b_1 \end{aligned}$$

$$\begin{aligned}
&a_{11}X_1 + a_{12}X_1 + a_{13}X_1 + \cdots a_{1,15}X_1 + \\
&a_{21}X_2 + a_{22}X_2 + a_{23}X_2 + \cdots a_{2,15}X_2 + \\
&a_{31}x_3 + a_{32}X_3 + a_{33}X_3 + \cdots a_{3,15}X_3 + \\
&a_{41}X_4 + a_{42}X_4 + a_{43}X_4 + \cdots a_{4,15}X_4 + \\
&a_{51}X_5 + a_{52}X_5 + a_{53}X_5 + \cdots a_{5,15}X_5 \leq \qquad b_2
\end{aligned}$$

$$\begin{aligned}
&a_{11}X_1 + a_{12}X_1 + a_{13}X_1 + \cdots a_{1,15}X_1 + \\
&a_{21}X_2 + a_{22}X_2 + a_{23}X_2 + \cdots a_{2,15}X_2 + \\
&a_{31}x_3 + a_{32}X_3 + a_{33}X_3 + \cdots a_{3,15}X_3 + \\
&a_{41}X_4 + a_{42}X_4 + a_{43}X_4 + \cdots a_{4,15}X_4 + \\
&a_{51}X_5 + a_{52}X_5 + a_{53}X_5 + \cdots a_{5,15}X_5 \leq \qquad b_3
\end{aligned}$$

$$\begin{aligned}
&a_{11}X_1 + a_{12}X_1 + a_{13}X_1 + \cdots a_{1,15}X_1 + \\
&a_{21}X_2 + a_{22}X_2 + a_{23}X_2 + \cdots a_{2,15}X_2 + \\
&a_{31}x_3 + a_{32}X_3 + a_{33}X_3 + \cdots a_{3,15}X_3 + \\
&a_{41}X_4 + a_{42}X_4 + a_{43}X_4 + \cdots a_{4,15}X_4 + \\
&a_{51}X_5 + a_{52}X_5 + a_{53}X_5 + \cdots a_{5,15}X_5 \leq \qquad b_4
\end{aligned}$$

where

X_1 = corn crop

X_2 = alfalfa crop

X_3 = barley crop

X_4 = sorghum crop

X_5 = cotton crop

C_j = profit in dollar/acre for 1 year for the various crops

a_{1j} = 1 acre land used by crop X_j

a_{2j} = amount of fresh water (1,000 ppm) used for irrigation of crop X_j

a_{3j} = amount of saline water (5,000 ppm) used for irrigation of crop X_j

a_{4j} = amount of crop rotation used by crop X_j

b_1 = total farm land available

b_2 = total fresh water available

b_3 = total saline water available

b_4 = total crop rotation available.

The activities of the LP 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 rotations. 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 LP model 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 set of activities included in the LP model were variables representing fresh and saline water use. Depending on the scenario, fresh and saline waters were restricted to various exogenous levels.

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 of planted acreage in alfalfa, 33 percent in cotton and 17 percent in barley. Other rotations included 80 percent alfalfa with 20 percent barley, and 50 percent alfalfa, 33 percent corn and 17 percent barley. A mathematical description of the model is provided in appendix A.

Four alternative scenarios were developed for analysis. These scenarios are presented in table 5.

Scenario 1. This scenario restricted fresh water resources to 42 acre-inches per acre, and increased the amount of saline irrigation water. Saline water availability was initially set at zero and was increased in 4 acre-inch per acre increments to 42 acre-inches per acre. In this scenario, the economic model chose the cropping pattern and the corresponding amount of saline and fresh irrigation water that resulted in the highest whole farm profits (table 5).

Scenario 2. This scenario increasingly restricted fresh water resource availability and provided unlimited quantities of saline water for irrigation. Fresh water was increasingly restricted in 4 acre-inch per acre increments, from 42 acre-inches per acre to 0 acre-inches. In this scenario, the economic model also chose the cropping pattern and the corresponding fresh and saline water utilization that would maximize whole farm profits (table 5).

Scenario 3. This scenario followed the same water resources availabilities as in scenario 1. In this scenario, however, the cropping pattern was restricted to a non-optimal rotation of 50 percent alfalfa, 33 percent cotton and 17 percent barley, which is a typical

Table 5

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**	decreased incrementally from 42 acre-inches per acre to 0	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.

crop rotation for the region. The LP model selected the optimal irrigation schedule, given the cropping pattern restriction, and the saline to fresh water mix for the rotation (table 5).

Scenario 4. This scenario followed the same water resources availabilities as in scenario 2, but again the economic model was forced to choose the non-optimal crop rotation of 50 percent alfalfa, 33 percent cotton and 17 percent spring barley (table 5).

This comprehensive analysis of alternative cropping decisions, irrigation schedules and fresh/saline water mixes was designed to derive the optimal irrigation schedule for alternative water resource availabilities and to determine the value of supplemental saline water resources.

Results

Historically, the major crops produced in the Roswell-Artesian Basin have been small grains, alfalfa and cotton. In addition, relatively smaller acreages of corn for grain and grain sorghum have been produced in this area. For these reasons, these crops were selected for inclusion into the cropping pattern for this analysis. Table 6 presents these crops, their respective planting and harvest dates and their modeled rooting depths.

The initial water production functions used for this analysis are presented in table 7. These production functions are based on the assumption that stress due to lack of water or salinity build-up occurs uniformly throughout the growing season.

In order to ensure that stress occurred uniformly throughout the growing season, the salinity models were designed to irrigate when relative transpiration (T) reached a predetermined amount. For example, crops grown under total non-stress conditions indicate that the maximum amount of T had been achieved (100 percent) and the maximum yield was obtained. The models were designed such that an irrigation would be applied at any desired amount of relative T. Thus, if the model were run at an 80 percent default, each time that relative T dropped to 80 percent, an irrigation would be applied. In this manner, it was ensured that stress occurred on a consistent and uniform basis and that the basic assumption underlying the production functions held.

Table 6

Crop varieties, planting and harvesting dates, and modeled rooting depths, Roswell-Artesia Basin, New Mexico, 1985

Crop	Planting Date	Harvest Date	Rooting Depth (feet)
Mature Alfalfa	---Perennial---		5
Corn	April 15	October 1	5
Cotton	April 15	November 1	4
Sorghum	May 1	October 1	3
Spring Barley	January 15	July 1	4

Table 7

Crop water production functions used for analysis, Roswell-Artesia Basin, 1985

Crop	Function
Alfalfa	$Y = .026 + .14T$
Corn	$Y = -5081.89 + 443.05T$
Cotton	$Y = 21.02 + 34.44T$
Sorghum	$Y = 146.34 + 339.65T$
Spring Barley	$Y = -198.0 + 366.3T$

Where: Y is measured in pounds per acre for all crops but alfalfa and T is measured in inches of transpiration. Y alfalfa is in tons per acre.

Farm Characteristics

The soil and water characteristics of the case study farm selected for this analysis are presented in table 8. Well characteristics (depth to water, gallons per minute) for both the shallow and artesian wells are presented in table 9. Water costs for flood irrigation were calculated using the cost of pumping model developed for the High Plains Ogallala Aquifer Study (Lansford, et al. 1983). Crop prices used for the analysis are presented in table 10.

Crop Yield Responses

Tables 11 through 15 present the expected yield and quantity of irrigation water for grain sorghum, cotton, alfalfa, corn for grain and spring barley for the simple and complex salinity models for various percentages of transpiration and various alternative percentages of

Table 8

Soil and water chemical characteristics, Roswell-Artesia Basin, 1985*

	Chemical Constituents (PPM)						
	EC	Ca	Mg	Na	Cl	SO_4	HCO_3
Soil Makeup	2560	374.3	111.1	255.9	86.1	1662.7	69.3
Water Makeup							
Fresh Water	1000	138.8	43.7	122.1	226.1	313.3	154.2
Saline Water	5000	921.7	154.7	568.3	1964.4	1209.6	164.6
Rainfall	50	6.9	2.2	6.1	11.3	15.7	7.7

*Water and soil chemistries derived from soil and water samples taken from the case study farm in the study area.

Table 9

Water Costs per acre-inch, Roswell-Artesia Basin, 1985

Artesian Well (1,000 PPM)		Shallow Well (5,000 PPM)	
Pumping Depth	250.0 ft.	Pumping Depth	95.0 ft.
GPM	1,250.0	GPM	850.0
Natural Gas Price	$3.75 MCF	Natural Gas Price	$3.75 MCF
Efficiency	.138%	Efficiency	.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 10

Crop prices used for analysis, Roswell-Artesia Basin, 1985*

Crop	Price (dollars)
Alfalfa	$100/ton
Barley	2.80/bushel
Corn	2.91/bushel
Sorghum	2.69/bushel
Cotton	0.62/lb.

*Prices derived from U.S. Department of Agriculture and represent 1984 prices.

Table 11

Percentage transpiration, fresh and saline water ratio, yield and applied water for sorghum for simple and complex salinity models, Roswell-Artesia Basin, 1985

	Irrigation Diversion		Simple Model		Complex Model	
Transpiration	Fresh Water (1,000 PPM)	Saline Water (5,000 PPM)	Yield	Water	Yield	Water
(percent)	(percent)	(percent)	(lbs.)	(acre - inches)	(lbs.)	(acre - inches)
50	100	0	7,497	32.0	7,500	32.6
50	80	20	7,378	33.0	7,341	32.8
50	67	33	7,234	34.0	7,165	33.8
50	50	50	6,948	37.0	6,878	34.0
50	33	67	6,643	36.0	6,607	32.6
50	25	75	6,545	39.0	6,497	34.0
50	20	80	6,463	39.0	6,479	33.8
50	10	90	6,368	40.0	6,308	35.0
60	100	0	7,903	35.0	7,905	35.6
60	80	20	7,803	35.0	7,747	35.4
60	67	33	7,616	36.0	7,530	35.6
60	50	50	7,265	40.0	7,195	36.2
60	33	67	7,095	44.0	6,903	36.4
60	25	75	6,969	43.8	6,805	39.0
60	20	80	6,901	44.6	6,778	39.4
60	10	90	6,781	44.8	6,691	41.2
70	100	0	8,223	38.6	8,217	38.6
70	80	20	8,154	42.0	8,059	38.8
70	67	33	7,887	41.2	7,770	39.0
70	50	50	7,663	47.0	7,504	42.8
70	33	67	7,473	50.4	7,384	46.6
70	25	75	7,389	52.6	7,290	47.4
70	20	80	7,350	53.4	7,211	48.2
70	10	90	7,268	56.6	7,162	51.4
80	100	0	8,065	41.2	8,467	41.4
80	80	20	8,395	44.6	8,306	42.8
80	67	33	8,250	49.6	8,119	47.4
80	50	50	8,068	56.2	7,900	51.6
80	33	67	7,944	60.2	7,781	57.4
80	25	75	7,833	63.8	7,713	59.6
80	20	80	7,792	66.8	7,668	62.6
80	10	90	7,686	71.2	7,598	65.8

Table 12

Percentage transpiration, fresh and saline water ratio, yield and applied water for cotton for simple and complex salinity models, Roswell-Artesia Basin, 1985

	Irrigation Diversion		Simple Model		Complex Model	
Transpiration	Fresh Water (1,000 PPM)	Saline Water (5,000 PPM)	Yield	Water	Yield	Water
(percent)	(percent)	(percent)	(lbs.)	(acre - inches)	(lbs.)	(acre - inches)
50	100	0	745	28.6	723	31.4
50	67	33	729	30.4	761	29.6
50	50	50	761	31.4	757	29.6
50	33	67	746	31.6	751	30.0
50	25	75	735	31.8	735	30.2
50	20	80	731	32.4	736	30.4
50	0	100	719	35.2	723	31.4
60	100	0	793	32.0	793	32.0
60	67	33	788	32.4	787	32.0
60	50	50	788	33.2	785	32.2
60	33	67	779	34.6	791	32.8
60	25	75	769	34.8	777	33.4
60	20	80	763	35.0	783	34.6
60	0	100	733	36.8	759	34.6
70	100	0	819	35.8	820	35.8
70	67	33	819	36.6	820	35.8
70	50	50	823	37.8	820	35.8
70	33	67	817	38.6	819	37.2
70	25	75	816	39.6	821	37.6
70	20	80	807	39.0	819	37.6
70	0	100	783	42.2	804	38.8
80	100	0	858	39.4	863	39.4
80	67	33	857	39.8	862	39.8
80	50	50	851	40.6	858	39.8
80	33	67	835	42.0	856	40.4
80	25	75	839	43.8	844	41.0
80	20	80	836	45.0	847	41.2
80	0	100	826	49.4	836	44.2

Table 13

Percentage transpiration, fresh and saline water ratio, yield and applied water for alfalfa for simple and complex salinity models, Roswell-Artesia Basin, 1985

	Irrigation Diversion		Simple Model		Complex Model	
Transpiration	Fresh Water (1,000 PPM)	Saline Water (5,000 PPM)	Yield	Water	Yield	Water
(percent)	(percent)	(percent)	(tons)	(acre - inches)	(tons)	(acre - inches)
50	80	20	5.61	49.2	5.56	48.4
50	75	25	5.44	47.2	5.41	47.2
50	67	33	5.40	49.0	5.60	47.6
50	50	50	5.26	52.0	5.17	48.6
50	33	67	5.18	54.4	5.07	49.8
50	25	75	5.10	57.2	5.02	51.2
50	20	80	5.07	59.2	5.02	51.4
60	80	20	6.17	54.7	6.01	52.8
60	75	25	6.01	53.8	5.95	53.6
60	67	33	5.92	55.8	5.85	54.8
60	50	50	5.90	64.0	5.73	57.8
60	33	67	5.75	66.6	5.65	60.2
60	25	75	5.66	72.0	5.61	64.0
60	20	80	5.62	72.4	5.58	64.8
70	80	20	6.70	62.5	6.51	59.2
70	75	25	6.60	62.2	6.46	60.6
70	67	33	6.58	66.0	6.40	63.2
70	50	50	6.40	78.6	6.30	75.0
70	33	67	6.30	85.4	6.22	80.6
70	25	75	6.20	97.0	6.18	89.0
70	20	80	6.20	98.8	6.17	92.0
80	80	20	7.23	71.4	7.06	74.0
80	75	25	7.22	74.6	7.08	77.4
80	67	33	7.16	81.8	7.02	85.6
80	50	50	6.95	110.1	6.92	113.6
80	33	67	6.92	322.8	6.92	130.8
80	25	75	6.85	357.8	6.88	157.0
80	20	80	6.85	163.0	6.87	171.2

Table 14

Percentage transpiration, fresh and saline water ratio, yield and applied water for corn for simple and complex salinity models, Roswell-Artesia Basin, 1985

	Irrigation Diversion		Simple Model		Complex Model	
Transpiration	Fresh Water (1,000 PPM)	Saline Water (5,000 PPM)	Yield	Water	Yield	Water
(percent)	(percent)	(percent)	(lbs.)	(acre - inches)	(lbs.)	(acre - inches)
50	83	17	6,993	35.4	6,545	37.6
50	80	20	6,980	35.4	6,445	37.0
50	75	25	6,654	36.6	6,220	37.8
50	67	33	6,007	36.6	5,990	37.2
50	50	50	5,747	38.4	5,444	37.4
50	33	67	5,343	41.0	4,964	38.2
50	25	75	5,131	41.6	4,836	39.0
50	20	80	4,936	44.4	4,724	40.8
50	17	83	4,900	45.0	4,672	41.0
60	80	17	7,943	40.4	7,412	42.0
60	83	20	7,755	41.2	7,247	42.4
60	75	25	7,512	41.4	7,081	42.4
60	67	33	7,112	42.4	6,718	42.6
60	50	50	6,244	46.0	6,210	45.6
60	33	67	6,229	52.2	5,840	52.2
60	25	75	6,120	57.4	5,750	55.4
60	20	80	6,091	59.8	5,671	58.8
60	17	83	5,916	60.6	5,664	59.4
70	80	17	8,735	45.6	8,182	49.2
70	83	20	8,466	46.2	8,006	49.0
70	75	25	8,253	47.0	7,828	49.6
70	67	33	7,982	50.4	7,527	52.6
70	50	50	7,536	64.2	7,133	65.7
70	33	67	7,295	73.6	6,985	77.6
70	25	75	7,237	77.8	6,914	83.8
70	20	80	7,126	85.6	6,862	89.4
70	17	83	7,123	84.2	6,833	90.2
80	80	17	9,419	57.8	9,067	61.4
80	83	20	9,245	58.4	9,027	63.4
80	75	25	9,171	64.0	8,959	70.0
80	67	33	8,987	73.6	8,892	80.8
80	50	50	8,477	100.0	8,340	111.4
80	33	67	8,352	121.0	8,319	138.2
80	25	75	8,350	147.0	8,268	157.6
80	20	80	8,309	162.0	8,224	177.4
80	17	83	8,308	176.0	8,213	195.2

Table 15

Percentage transpiration, fresh and saline water ratio, yield and applied water for spring barley for simple and complex salinity models, Roswell-Artesia Basin, 1985

	Irrigation Diversion		Simple Model		Complex Model	
Transpiration	Fresh Water (1,000 PPM)	Saline Water (5,000 PPM)	Yield	Water	Yield	Water
(percent)	(percent)	(percent)	(lbs.)	(acre - inches)	(lbs.)	(acre - inches)
50	100	0	6,393	31.4	6,380	31.4
50	67	33	6,521	34.4	6,512	33.6
50	80	20	6,517	34.0	6,477	32.8
50	50	50	6,487	36.6	6,490	33.8
50	33	67	6,427	36.8	6,741	34.4
50	25	75	6,409	37.4	6,410	34.6
50	20	80	6,378	37.6	6,406	34.6
50	10	90	6,286	38.8	6,321	35.2
60	100	0	6,735	35.8	6,736	35.8
60	67	33	6,749	36.4	6,737	36.0
60	80	20	6,794	37.8	6,776	36.4
60	50	50	6,781	39.2	6,788	36.8
60	33	67	6,737	40.0	6,745	37.8
60	25	75	6,692	40.6	6,784	37.8
60	20	80	6,322	40.6	6,748	38.6
60	10	90	6,221	42.0	6,667	39.6
70	100	0	7,752	39.0	7,051	39.0
70	67	33	7,046	39.4	7,049	39.2
70	80	20	7,048	40.6	7,046	39.6
70	50	50	7,033	41.8	7,053	40.2
70	33	67	6,987	44.0	7,023	41.2
70	25	75	6,956	43.8	7,007	42.2
70	20	80	6,900	43.6	6,989	42.0
70	10	90	6,809	46.8	6,898	42.6
80	100	0	7,270	42.6	7,269	42.6
80	67	33	6,898	42.6	7,270	42.6
80	80	20	7,266	44.4	7,267	43.2
80	50	50	7,196	47.2	7,237	44.2
80	33	67	7,245	44.6	7,266	43.8
80	25	75	7,168	48.0	7,219	44.8
80	20	80	7,134	49.4	7,181	45.8
80	10	90	7,086	52.0	7,134	47.4

fresh and saline water diversions. For each of the transpiration levels at which irrigation water will be applied by the irrigation scheduling model, the percentage of saline to fresh water is increased. Thus, for each transpiration level, a range of yields, and fresh and saline water application is derived. The end result is an expected yield for a variety of fresh and saline water irrigation strategies. These results are also graphically presented in figures 8 through 17.

As the amount of saline water irrigations is increased, there is a corresponding decrease in yield as stress occurs because of salinity build-up in the soil. As the relative transpiration default is increased from 50 percent to 80 percent, there is a corresponding increase in yield and a large increase in applied water. In almost all cases, the use of the more complex salinity model results in slightly less water applied and in slightly lower yields. These differences are not highly significant. The major difference is that there are less pronounced swings in yield and water applications with the complex model when the transpiration default is changed from one level to the next.

As the results indicate, 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. For example, for grain sorghum, yield can actually be increased from 7,497 pounds per acre at the 50 percent relative transpiration level using all fresh water to 7,686 pounds per acre at the 80 percent relative transpiration level using almost all saline water, with a fresh water pre-irrigation and some fresh water applied during the growing season. However, this yield increase can only be

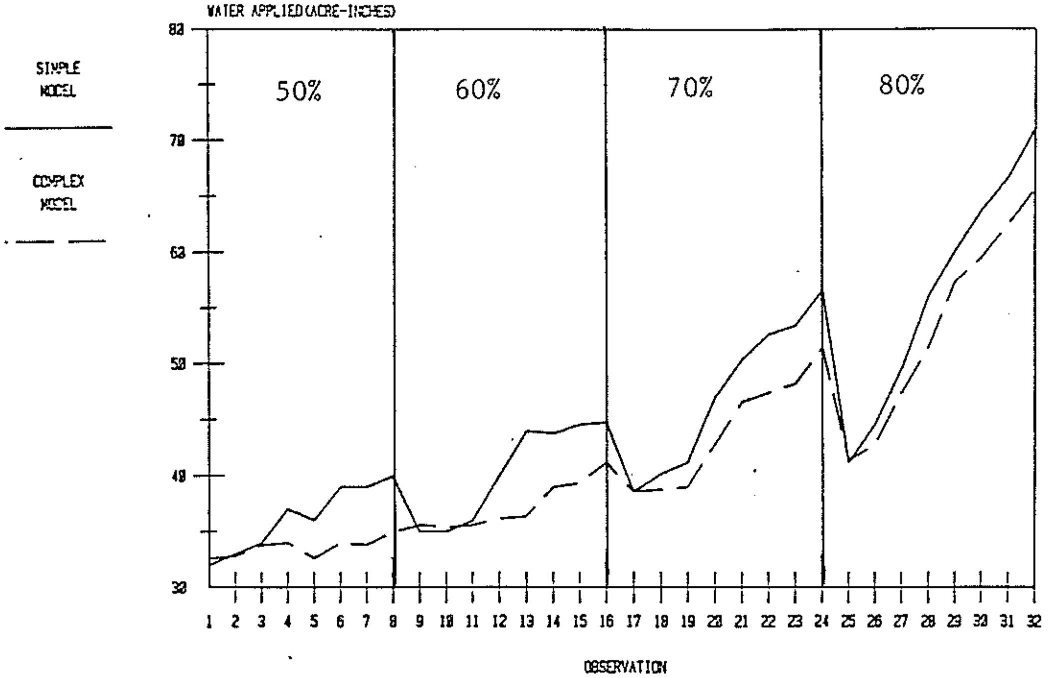

Fig. 9 Comparison of complex and simple salinity models for grain sorghum water applications in the Roswell-Artesia Basin, 1985

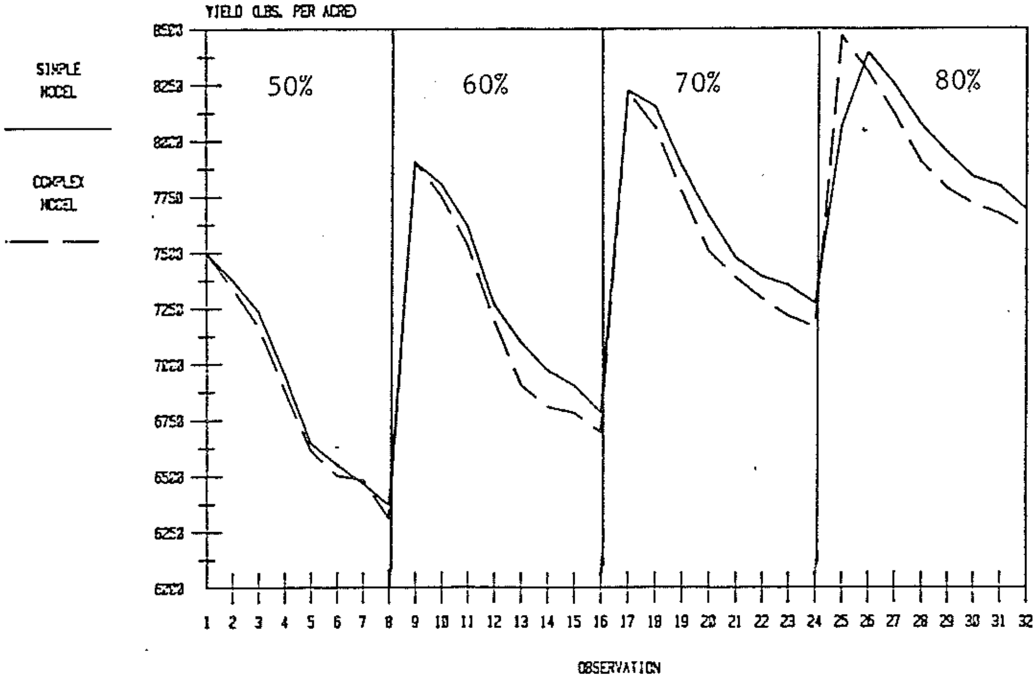

Fig. 10 Comparison of complex and simple salinity models for grain sorghum yield in the Roswell-Artesia Basin, 1985

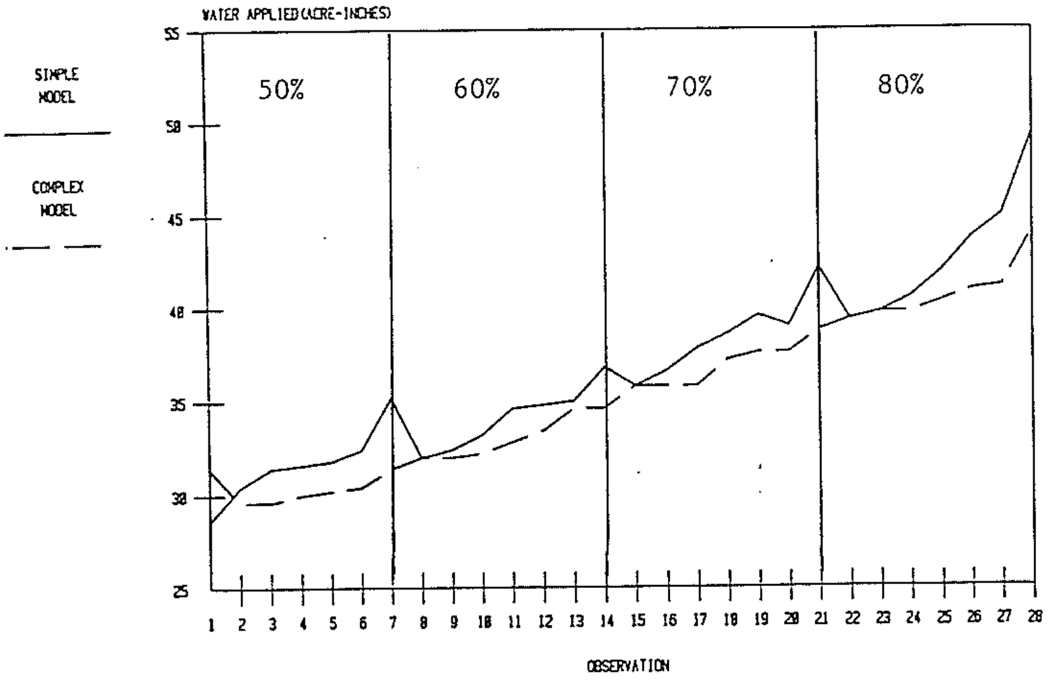

Fig. 11 Comparison of complex and simple salinity models for cotton water applications in the Roswell-Artesia Basin, 1985

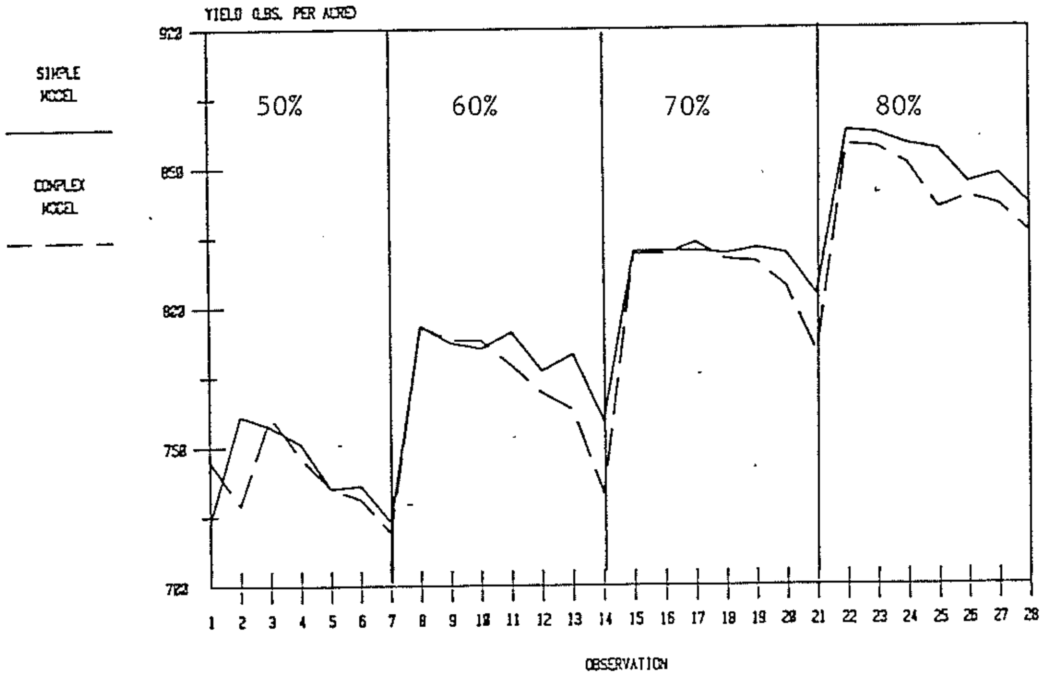

Fig. 12 Comparison of complex and simple salinity models for cotton yield in the Roswell-Artesia Basin, 1985

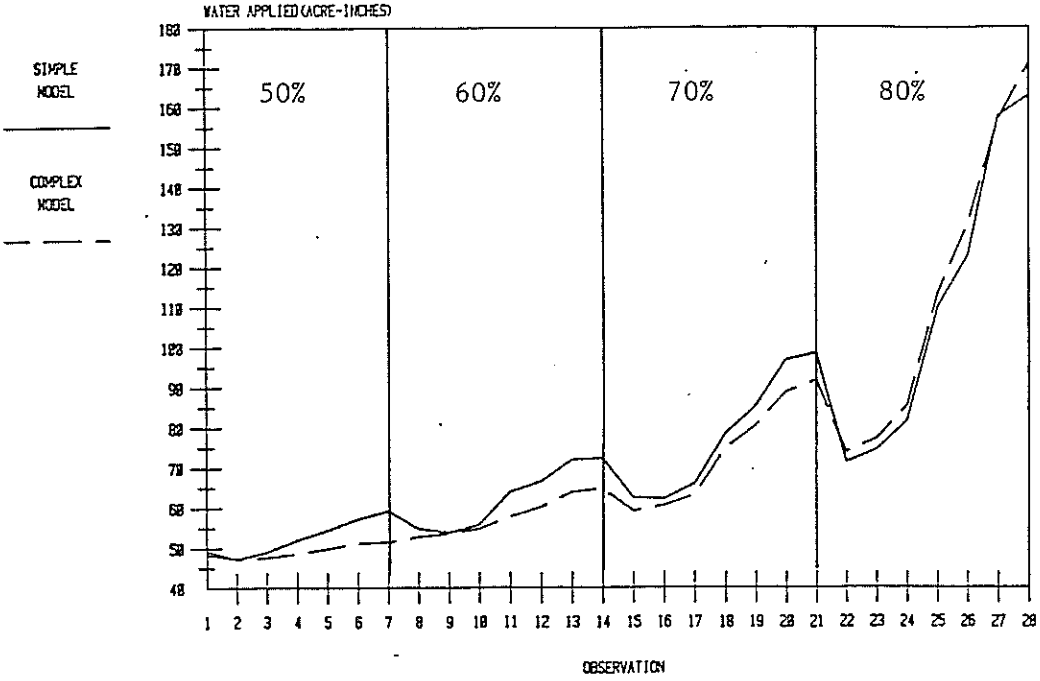

Fig. 13 Comparison of complex and simple salinity models for alfalfa water applications in the Roswell-Artesia Basin, 1985

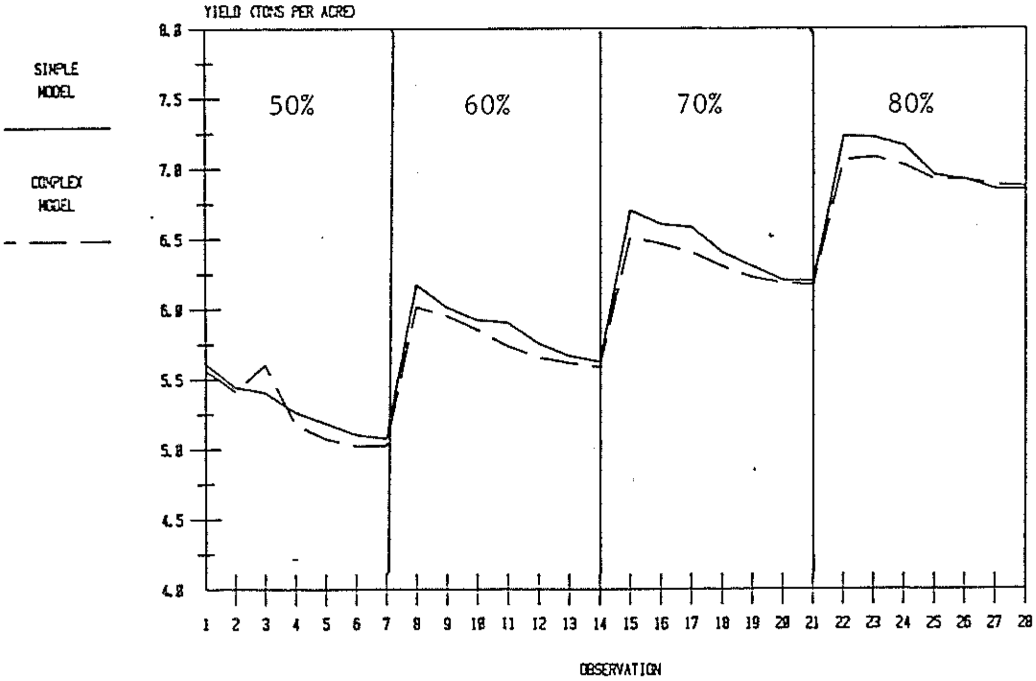

Fig. 14 Comparison of complex and simple salinity models for alfalfa yield in the Roswell-Artesia Basin, 1985

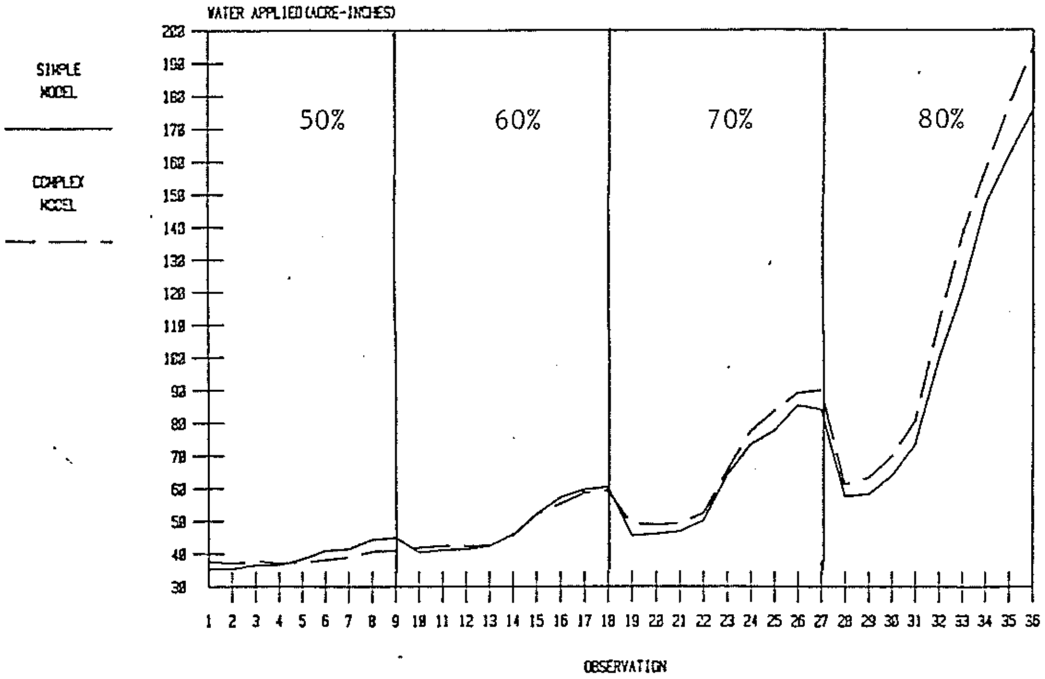

Fig. 15 Comparison of complex and simple salinity models for corn water applications in the Roswell-Artesia Basin, 1985

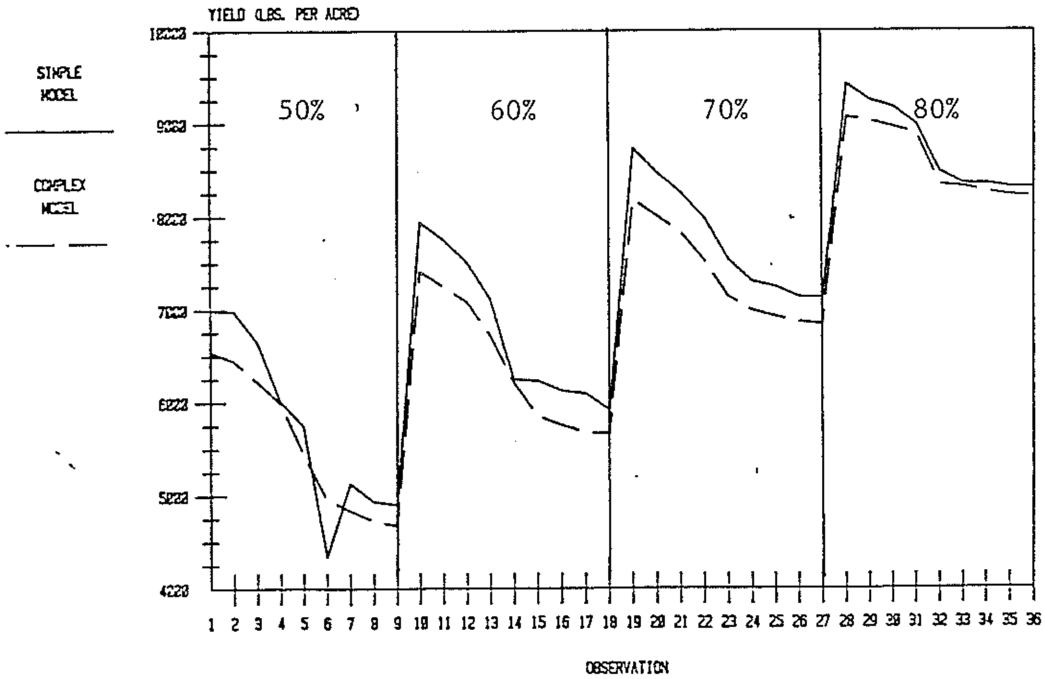

Fig. 16 Comparison of complex and simple salinity models for corn yield in the Roswell-Artesia Basin, 1985

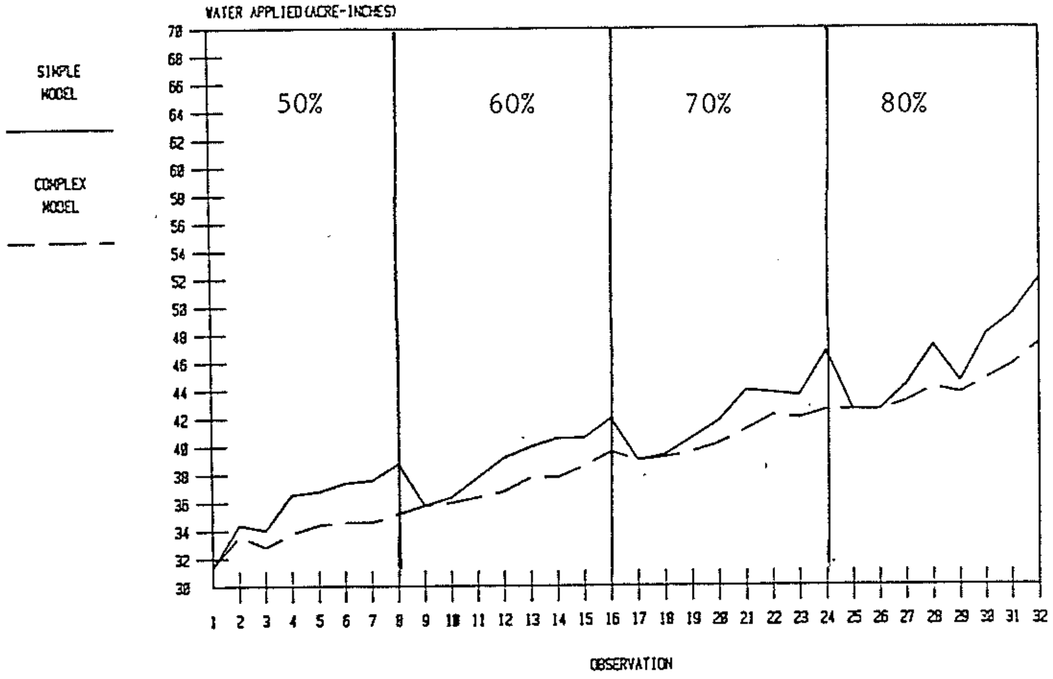

Fig. 17 Comparison of complex and simple salinity models for spring barley water appliciations in the Roswell-Artesia Basin, 1985

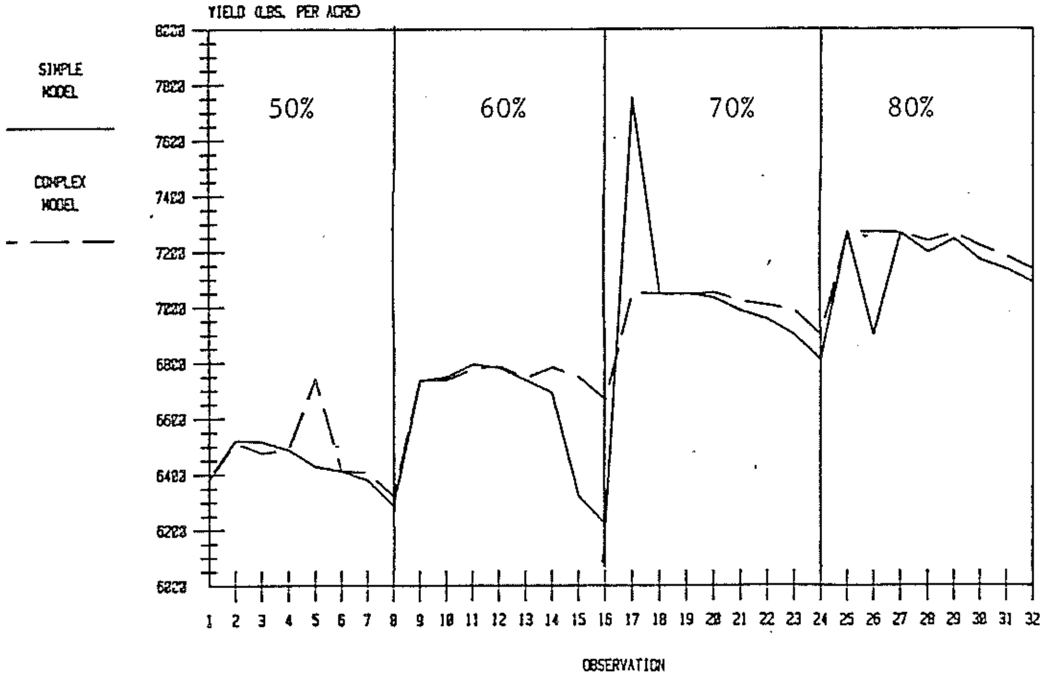

Fig. 18 Comparison of complex and simple salinity models for spring barley yield in the Roswell-Artesia Basin, 1985

obtained by applying almost 2.5 times more water at the 80 percent relative transpiration level (table 11). Results are similar for the other crops (tables 12-15).

Cost and Return Budgets

From the initial water application and yield data determined by the simple salinity model for each crop, 15 fresh and saline irrigation water strategies were chosen from which to develop whole farm enterprise cost and return budgets. The irrigation strategies selected represent a broad spectrum of the results presented in tables 11 through 15. They were chosen on the basis of yield, applied water and different percent transpiration defaults to ensure that a broad representation of the initial results from the various irrigation strategies were selected.

The crop budgets were developed assuming a 500 acre farm. The other basic assumptions used to derive the crop budgets are presented in table 16. Data were developed for yields and the amounts of saline and fresh water applications for each of the 15 irrigation strategies. Also, the number of irrigations, and the calculated net returns to land, water and risk derived from the whole farm crop were developed for each of the strategies. Cost and return summaries are presented in appendix A.

The per-acre returns to land, water and risk are positive for all 15 strategies for alfalfa, cotton and spring planted barley. For alfalfa, budgeted per-acre net returns range 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. Per-acre yields range from 5.1 tons to 7.4 tons (table 17).

Table 16

Basic cost information for the Roswell-Artesia area, 1985

Item	Unit	
Labor Wage Rate:		
Equipment Operators	\$/hour	5.00
General and Irrigators	\$/hour	4.00
Purchased Inputs		
Nitrogen (N)	\$/lb.	.24
Phosphate (P_2O_5)	\$/lb.	.30
Gasoline	\$/gal.	1.10
Diesel Fuel	\$/gal.	.90
Electricity	¢/KWH	7.00
Labor Downtime	\$ of direct time	25
Interest on Operating Capital	percent	14
Interest Rate on Equipment	percent	13
Nonproductive Machine Adjustment Factor[a]	% of machine-hours	25
Employee Benefits	% of total labor cost	15
Management	% of gross return	5
Farm Insurance	\$/acre	1.65/acre
Insurance (employee liability)	\$/\$1000 wage	15
Taxes	\$/acre	4.50/acre
Property Taxes	\$/\$ assessed valuation	.025

---

[a] Allowance for machine-hour accumulations not directly associated with crop operations such as travel to and from fields and general farm clean-up operations.

Table 17

ALFALFA--Fresh and saline water applications, number of irrigations, yields and budgeted per acre returns to land, water and risk for selected irrigation strategies, Roswell-Artesia Basin, 1985

Total Water	Total Fresh	Total Saline	Number of Irrigations	Yield per acre	Returns to land, water and risk per acre
- - - -(acre-inch per acre)- - - -				(tons)	($)
52	52	0	13	6.1	189.75
57	57	0	14	6.6	222.56
61	61	0	15	7.1	250.99
64	64	0	16	7.4	269.96
49	41	8	12	5.6	116.25
52	28	24	13	5.3	98.11
59	13	46	15	5.1	90.50
55	47	8	14	6.2	151.52
64	32	32	16	5.9	132.38
72	16	56	18	5.6	117.55
62	49	13	16	6.7	183.78
78	41	37	20	6.4	145.05
99	21	78	25	6.2	122.99
72	58	13	18	7.2	202.92
110	57	53	28	7.0	127.21
163	36	128	41	6.8	68.37
57	14	43	14	5.1	95.44
72	14	58	18	5.6	119.56
99	20	79	25	6.2	124.77

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. Per-acre yields range from 710 pounds to 881 pounds (table 18).

For spring planted barley, per-acre returns to land, water and risk range 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 of 31 acre-inches of fresh water and no saline water. Several of the irrigation strategies for this crop generated significantly higher returns to land, water and risk by applying a majority of saline water. Per acre yields range from 129 bushels to 162 bushels (table 19).

Only two irrigation water application levels (35 and 39 acre inches of fresh water, with no application of saline water) generated positive per-acre returns to land, water and risk for grain sorghum (table 20). These irrigation strategies generate per-acre returns to land, water and risk of $7.44 and $10.24, respectively. Per acre yields range from 114 bushels to 147 bushels. The least profitable irrigation strategy for grain sorghum production is a negative per-acre return to land, water and risk of $28.83. The yield produced under this irrigation strategy is 114 bushels per acre, generated by applying 8 acre inches of fresh water, and 32 acre inches of saline water.

Only two irrigation strategies generate positive per-acre returns to land, water and risk for grain corn (table 21). The highest returns to land, water and risk for an irrigation strategy is $17.28 per acre, with the application of 49 acre inches of fresh water and 9.0 acre-inches of saline water. The only other positive per-acre return to land, water

Table 18

COTTON--Fresh and saline water applications, number of irrigations, yields and budgeted per-acre returns to land, water and risk for selected irrigation strategies, Roswell-Artesia Basin, 1985

Total Water	Total Fresh	Total Saline	Number of Irrigations	Yield per acre	Returns to land, water and risk per acre
- - - (acre-inch per acre)- - -				(lbs.)	($)
29	29	0	7	745	60.55
31	18	13	8	761	77.68
35	4	31	9	719	70.17
32	32	10	8	793	74.73
33	20	13	8	788	87.33
37	4	33	9	733	75.62
36	36	10	9	819	75.99
37	21	16	9	823	97.48
42	4	38	11	783	94.34
39	39	10	10	858	86.58
40	24	16	10	881	102.46
49	4	45	12	826	105.13
35	4	31	9	710	70.01
35	7	28	9	763	88.05
49	4	45	12	826	104.63

Table 19

BARLEY--Fresh and saline water applications, number of irrigations, yields and budgeted per-acre returns to land, water and risk for selected irrigation strategies, Roswell-Artesia Basin, 1985

Total Water	Total Fresh	Total Saline	Number of Irrigations	Yield per acre	Returns to land, water and risk per acre
- - - -(acre-inch per acre)- - -				(bushels)	($)
31	31	0	8	133	37.21
36	20	16	9	135	50.34
39	8	31	10	131	51.28
36	36	10	9	140	41.84
39	20	19	10	141	60.85
42	8	34	10	129	43.05
39	39	0	10	162	85.98
42	21	21	10	147	67.84
47	9	38	12	141	65.73
42	42	0	10	151	52.09
44	24	20	11	151	73.21
52	16	36	13	148	64.31
39	4	35	10	131	56.73
42	4	38	10	130	48.29
47	5	42	12	142	71.38

Table 20

GRAIN SORGHUM--Fresh and saline water applications, number of irrigations, yields and budgeted per-acre returns to land, water and risk for selected irrigation strategies, Roswell-Artesia Basin, 1985

Total Water	Total Fresh	Total Saline	Number of Irrigations	Yield per acre	Returns to land, water and risk per acre
- - - - (acre-inch per acre)	- - - -			(bushels)	($)
32	32	0	8	134	- 3.40
37	21	16	9	124	-16.60
40	8	32	10	114	-28.83
35	35	10	9	141	7.44
40	24	16	10	130	-11.68
45	9	36	11	121	-18.87
39	39	10	10	147	10.24
47	26	21	12	137	- 7.69
56	12	44	14	129	-18.02
41	41	10	10	144	- .75
56	32	24	14	144	-10.42
71	13	58	18	137	-23.17
40	4	36	10	114	-23.50
45	8	37	11	121	-17.34
57	8	49	14	130	-13.31

Table 21

CORN FOR GRAIN--Fresh and saline water applications, number of irrigations, yields and budgeted per-acre returns to land, water and risk for selected irrigation strategies, Roswell-Artesia Basin, 1985

Total Water	Total Fresh	Total Saline	Number of Irrigations	Yield per acre	Returns to land, water and risk per acre
- - - -(acre-inch per acre)		- - - -		(bushels)	($)
38	34	4	9	125	- 47.46
40	24	16	10	103	- 96.06
44	12	32	11	88	-122.50
40	36	4	10	142	- 9.84
46	25	21	11	112	- 81.45
60	16	44	15	106	-105.72
46	41	5	11	156	13.06
64	36	28	16	135	- 62.65
84	20	64	21	127	- 88.77
58	49	9	14	168	17.28
100	52	48	25	151	- 91.11
176	36	14	44	148	-111.53
45	9	36	11	88	-121.88
61	13	48	15	106	-101.76
60	12	48	15	109	- 91.94

and risk for corn is $13.06, with the application of 41.0 acre-inches of fresh water and 5.0 acre-inches of saline water. Corn yields range from 88 bushels per acre to 168 bushels per acre. The least profitable irrigation strategy for corn is a negative return to land, water and risk of $122.50 per acre. This irrigation strategy would apply 12 acre inches of fresh water, 32 acre inches of saline water, and generate a yield of 88 bushels per acre (table 21).

Whole Farm Analysis

The following section presents the results derived from the economic model for alternative cropping patterns and water scenarios. These results include the optimal fresh to saline irrigation water mix, and the on-farm economic impacts of using saline water.

Scenario 1

Optimal Water Use. Under this scenario, saline water is used to supplement the 42 acre-inches per acre of fresh water. When 4 acre-inches per acre of saline water is available to augment the fresh water supply, alfalta acreage is produced with all fresh water and barley is produced utilizing almost all saline water (table 22). Only 366 acres of cropland would be under irrigation. When 8.0 acre inches of saline water is available to supplement the 42 acre-inches of fresh water, additional alfalfa acreage is brought into production with a fresh-saline irrigation water sequence. The total acreage irrigated is increased to 394 acres. Alfalfa acreage increases by 7 percent, from 306 acres to 328 acres. At the maximum economic utilization of saline water (14 acre-inches per acre), alfalfa acreage is increased by 17 percent to 357 acres thereby increasing the acreage irrigated to 428 acres. The

Table 22

SCENARIO 1--Optimal irrigation schedule with 42 acre inches of fresh water and alternative levels of saline water

Supplemental Saline Water by Crop	Optimal Irrigation Sequence 1/	Number of Irrigations	Crop Acreage 2/	Saline Water	Total Water
			(acres)	(percent)	(acre inches per acre)
4 acre inches per acre					
Alfalfa	F (all)	16	306	0	64
Barley	F (all)	10	3	0	40
Barley	F-S-S-S-S-S-S-S-S	12	57	90	48
8 acre inches per acre					
Alfalfa	F (all)	16	232	0	64
Alfalfa	F-F-F-F-S	18	96	20	62
Barley	F-S-S-S-S-S-S-S-S	12	66	90	48
14 acre inches per acre					
Alfalfa	F (all)	16	286	0	64
Alfalfa	F-S-S-S	18	71	78	72
Barley	F-S-S-S-S-S-S-S-S	12	71	90	48

1/ The irrigation sequence F-S indicates a fresh water application followed by a saline water application. This sequence is repeated until the end of the irrigation season. This F-S-S-S is repeated 4½ times for 18 applications.

2/ This acreage does not include establishment acreage for alfalfa on fallow land.

additional alfalfa acreage would have an irrigation sequence of one fresh water application followed by three applications of saline water.

Economic Impact. As the amount of saline water utilized by the model is increased from 0 acre-inches to 14 acre inches, per-acre returns to land and risk increase from $132.34 to $152.64, an increase of 15.3 percent (table 23 and figure 19). After 14 acre-inches per acre, no further utilization of the saline water resource occurred, indicating that saline water can economically supplement fresh water by 33 percent. The shadow price (an estimate of the increase of net revenues of an additional acre-inch) of the saline irrigation water is zero i.e. has no economic value to a farm after 14 acre-inches per acre is used (table 23). Therefore, the most profitable use of fresh and saline irrigation water is 42 acre-inches of fresh water and 14 acre-inches of saline water per acre.

Scenario 2

Optimal Water Use. Table 24 indicates the optimal irrigation sequence when fresh water resources are severely restricted but unlimited quantities of saline water are available. With limited fresh water (8.0 acre-inches per acre), all crops are irrigated initially with fresh water followed by numerous saline water applications. Cotton, which is a more salt tolerant crop, is substituted for alfalfa in the cropping pattern. As fresh water resources are increased from 16 to 30 to 35 acre-inches per acre, more fresh water is applied to alfalfa and saline water is allocated to barley production. Alfalfa is produced instead of cotton because returns to land and risk are higher for alfalfa, and cotton drops out of the cropping pattern (table 24). This

Table 23

SCENARIO 1--Saline water utilization, net returns to land and risk and the shadow price of saline water for 42 acre inches per acre of fresh water and increasing increasing amounts of saline water, Roswell-Artesia Basin, 1985

Available Saline Water (per acre)	Saline Water Utilized (per acre)	Net Returns (dollars per acre)	Shadow Price of Saline Water (dollars per acre inch)
0	0	132.34	2.77
4	4	141.66	2.33
8	8	146.81	1.08
12	14	151.09	.79
16	14	152.64	0
20	14	152.64	0
32	14	152.64	0
42	14	152.64	0

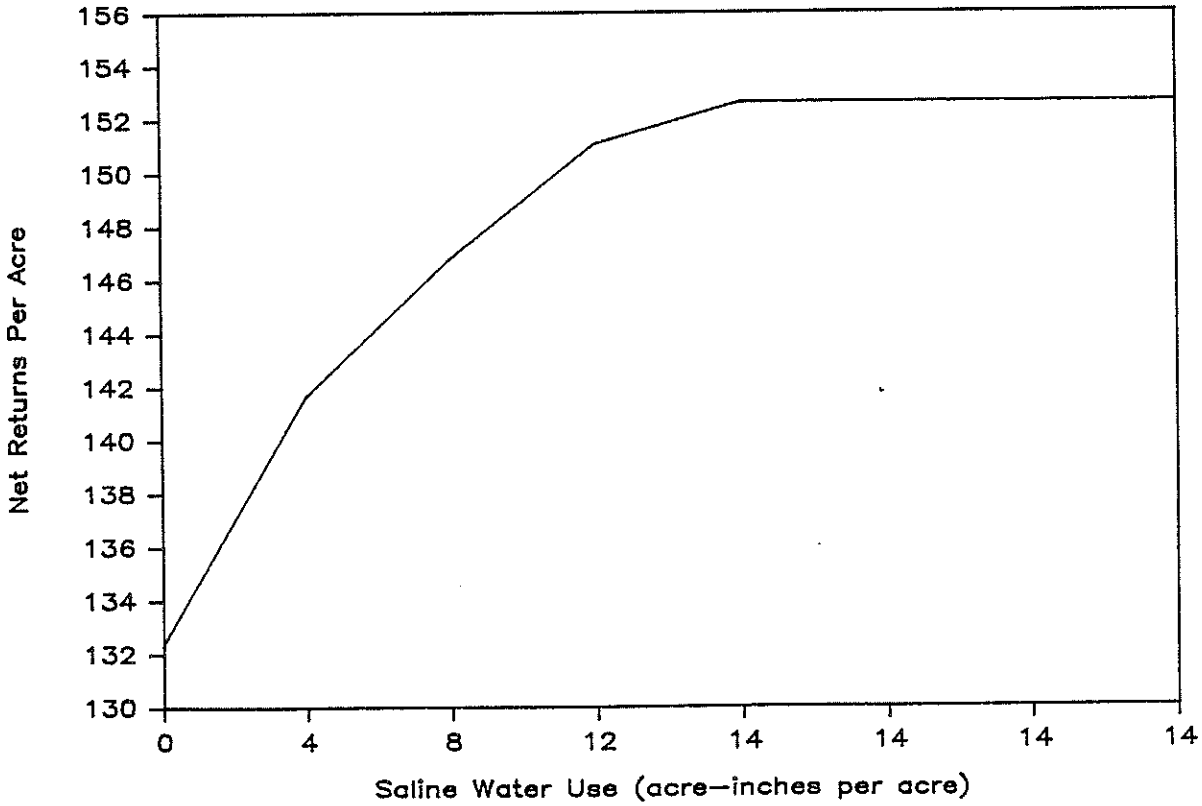

Fig. 19. Saline water use and per acre net returns for unforced cropping patterns Roswell-Artesia Basin, 1985

Table 24

SCENARIO 2--Optimal irrigation schedule with unlimited saline and alternative levels of fresh water

Available Fresh Water/Crop	Optimal Irrigation Sequence 1/	Number of Irrigations	Crop Acreage 2/	Saline to Total Water	Total Water Applications
			(acres)	(percent)	(acre-inches per acre)
8 acre-inches per acre					
Alfalfa	F-S-S-S	18	155	78	72
Cotton	F-S-S-S-S-S-S-S-S-S-S-S	12	104	92	48
Barley	F-S-S-S-S-S-S-S-S	12	52	90	48
16 acre-inches per acre					
Alfalfa	F (all)	16	16	0	64
Alfalfa	F-F-F-F-S	15	341	20	60
Barley	F-S-S-S-S-S-S-S-S	12	71	90	48
30 acre-inches per acre					
Alfalfa	F (all)	16	162	0	64
Alfalfa	F-S-S-S	18	196	78	72
Barley	F-S-S-S-S-S-S-S-S	12	71	90	48
35 acre-inches per acre					
Alfalfa	F (all)	16	213	0	64
Alfalfa	F-S-S-S	18	144	78	72
Barley	F-S-S-S-S-S-S-S-S	12	71	90	48

1/ The irrigation sequence F-S indicates a fresh water application followed by a saline water application. This sequence is repeated until the end of the irrigation season. This F-S-S-S is repeated 4½ times for 18 applications.

2/ This acreage does not include establishment acreage for alfalfa on fallow land.

indicates that the highest returns to land and risk result from the application of fresh water to alfalfa and that supplemental saline water can support additional alfalfa acreage.

Economic Impact. In this scenario, the available fresh irrigation water was decreased in increments from 42 acre-inches per acre for farm use to 4.0 acre inches per acre, while saline water resources remained unlimited (table 25). As fresh water availability was curtailed, the saline water utilized by the economic model increased from 14 acre-inches per acre to a high of 44 acre-inches per acre, then decreased to 15.5 acre-inches per acre. Per-acre returns to land and risk declined from $152.64 to $29.20 (table 25 and figure 20). An important result is that with unlimited saline water availability, a farm can decrease fresh water use by 30 percent before profits are reduced. This supplement would conserve fresh water, without unduly affecting total water consumption, which averages 56 acre inches per acre.

Scenario 3

Optimal Water Use. Scenario 3 represents a cropping pattern that is more traditional in the Roswell-Artesia area and maintains the water restrictions of scenario 1. The farm was forced to produce 50 percent alfalfa, 33 percent cotton and 17 percent barley. As supplemental saline water is added to the 42 acre-inches of fresh water per acre, saline irrigation water is increasingly used for cotton and barley production (table 26). The only fresh water used on cotton and barley is for germination. Both cotton and barley are relatively salt tolerant. Acreages do not change, but water costs are reduced by the substitution of cheaper saline water for more expensive fresh water.

Table 25

SCENARIO 2--Saline water utilization, net returns and the shadow price of fresh water for unlimited quantities of saline water and decreased fresh water availability, unforced cropping rotation, Roswell-Artesia Basin, 1985

Available Fresh Water	Saline Water Utilized	Net Returns	Shadow Price of Fresh Water
- - - -(acre-inch	per acre) - - -	(dollars per acre)	(dollars per acre-inch)
42	14	152.64	2.11
35	22	137.80	2.11
32	25.5	131.44	2.11
30	28	127.20	2.11
16	44	97.53	2.11
8	31	58.30	7.30
4	15.5	29.20	7.30

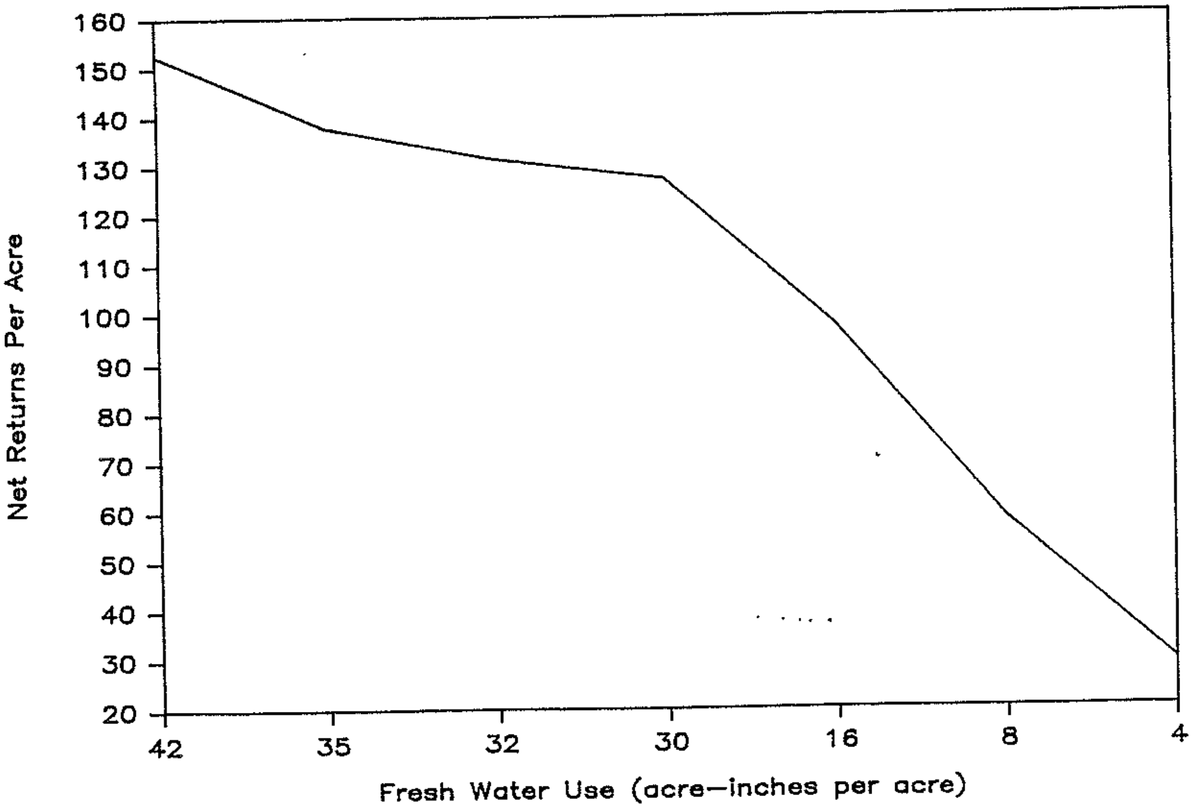

Fig. 20. Fresh water use and per acre net returns for unforced cropping patterns, Roswell-Artesia, 1985

Table 26

SCENARIO 3--Optimal irrigation schedule with 42 acre-inches of fresh water and alternative levels of saline water

Supplemental Saline Water/Crop	Optimal Irrigation Sequence 1/	Number of Irrigations	Crop Acreage 2/ (acres)	Saline to Total Water (percent)	Total Water Use (acre-inches per acre)
4 acre-inches per acre					
Alfalfa	F (all)	16	214	0	64
Cotton (10)	F (all)	10	16	0	39
Cotton (8)	F-S-F-S-F-S	9	125	43	37
Barley (7)	F (all)	10	71	0	39
8 acre-inches per acre					
Alfalfa	F (all)	16	214	0	64
Cotton (11)	F-F-F-S-S	10	84	40	40
Cotton (12)	F-S-S-S-S-S-S-S-S-S-S-S	12	59	92	48
Barley (7)	F (all)	10	71	0	39
14 acre-inches per acre					
Alfalfa	F (all)	16	214	0	64
Cotton (12)	F-S-S-S-S-S-S-S-S-S-S-S	12	143	92	48
Barley	F-S-S-S-S-S-S-S-S	12	71	90	47

1/ The irrigation sequence F-S indicates a fresh water application followed by a saline water application. This sequence is repeated until the end of the irrigation season. This F-S-S-S is repeated 4½ times for 18 applications.

2/ This acreage does not include establishment acreage for alfalfa on fallow land.

Economic Impact. As more saline water is made available for crop production, per-acre returns to land and risk rise from $111.00 to $126.00, an increase of 13.5 percent (table 27 and figure 21). Saline water utilized for crop production rises to 8.0 acre inches per acre, supplementing fresh water by 19 percent. The shadow price of an acre-inch of saline water is initially $3.40, then drops to zero when no additional saline water is applied (table 27).

Scenario 4

Optimal Water Use. For very restricted fresh water and the traditional cropping pattern, planted acreage is limited to 312 acres. All crops are irrigated with highly saline water (table 28). Fresh water is used for germination or for getting the alfalfa going in the spring. As the fresh water supply is increased, it is applied to alfalfa, which yields a higher net return, and the saline waters are applied to cotton and barley.

Economic Impact. In this scenario, as fresh water was constrained and unlimited quantities of saline water were available for crop production, the economic model initially applied 9,787 acre inches (20 acre inches per acre) of water and generated $80.65 per-acre returns to land and risk. Returns to land and risk then increased to $126.16 as fresh water availability was increased to 4 acre-inches per acre (table 29 and figure 22).

Table 27

SCENARIO 3--Saline water utilization, net returns and the shadow price of saline water for 42 acre-inches per acre of fresh water and increasing amounts of saline water, forced cropping rotation, Roswell-Artesia Basin, 1985

Available Saline Water (acre-inches)	Saline Water Utilized (acre-inches)	Net Returns (dollars per acre)	Shadow Price of Saline Water (dollars per acre-inch)
0	0	111	3.40
2,000	2,000	123	2.58
4,000	4,000	125	.09
6,000	6,000	126	0
8,000	6,428	126	0
10,000	6,428	126	0
16,000	6,428	126	0
21,000	6,428	126	0

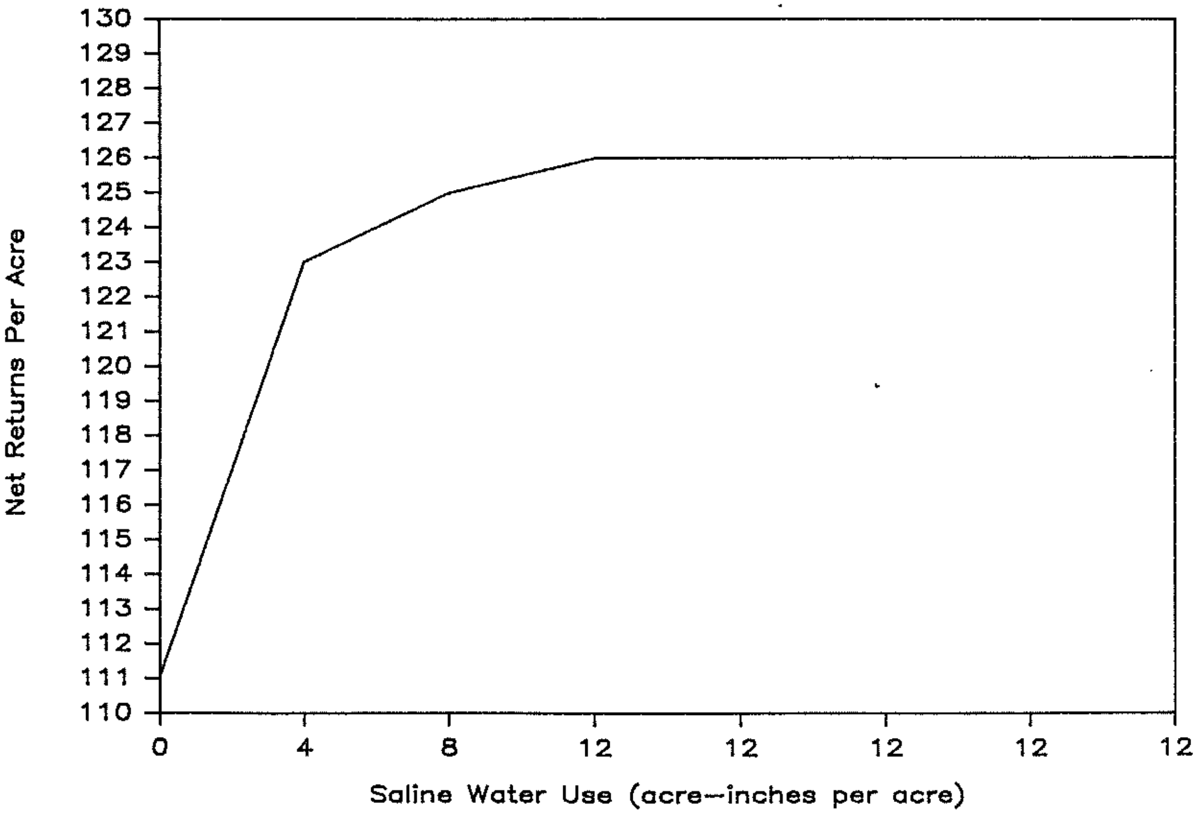

Fig. 21. Saline water use and per acre net returns for forced cropping patterns, Roswell-Artesia Basin, 1985

Table 28

SCENARIO 4--Optimal irrigation schedule with unlimited saline and alternative levels of fresh water

Available Fresh Water/Crop	Optimal Irrigation Sequence 1/	Number of Irrigations	Crop Acreage 2/	Saline to Total Water	Total Water
			(acres)	(percent)	(acre-inches per acre)
8 acre-inches per acre					
Alfalfa	F-S-S-S	18	156	78	72
Cotton	F-S-S-S-S-S-S-S-S-S-S-S	15	104	92	62
Barley	F-S-S-S-S-S-S-S-S	12	52	90	47
16 acre-inches per acre					
Alfalfa	F (all)	16	52	0	64
Alfalfa	F-S-S-S	18	162	78	72
Cotton	F-S-S-S-S-S-S-S-S-S-S-S	15	143	92	62
Barley	F-S-S-S-S-S-S-S-S	12	71	90	47
30 acre-inches per acre					
Alfalfa	F (all)	16	197	0	64
Alfalfa	F-S-S-S	18	17	78	72
Cotton	F-S-S-S-S-S-S-S-S-S-S-S	15	143	92	62
Barley	F-S-S-S-S-S-S-S-S	12	71	90	47
35 acre-inches per acre					
Alfalfa	F (all)	16	214	0	64
Cotton	F-S-S-S-S-S-S-S-S-S-S-S	15	143	92	62
Barley	F-S-S-S-S-S-S-S-S	12	71	90	47

1/ The irrigation sequence F-S indicates a fresh water application followed by a saline water application. This sequence is repeated until the end of the irrigation season. This F-S-S-S is repeated 4½ times for 18 applications.

2/ This acreage does not include establishment acreage for alfalfa on fallow land.

Table 29

SCENARIO 4--Saline water utilization, net returns and the shadow price of fresh water for unlimited quantities of saline water and decreased fresh water availability, forced cropping rotation, Roswell-Artesia Basin, 1985

Available Fresh Water (acre-inches)	Saline Water Utilized (acre-inches)	Net Returns (dollars per acre)	Shadow Price of Fresh Water (dollars per acre-inch)
4	13	126.16	0
8	15	125.50	.42
16	18	124.22	.42
30	21	120.56	2.11
32	37	90.89	2.11
35	31	79.88	7.29
42	15.5	80.65	7.29

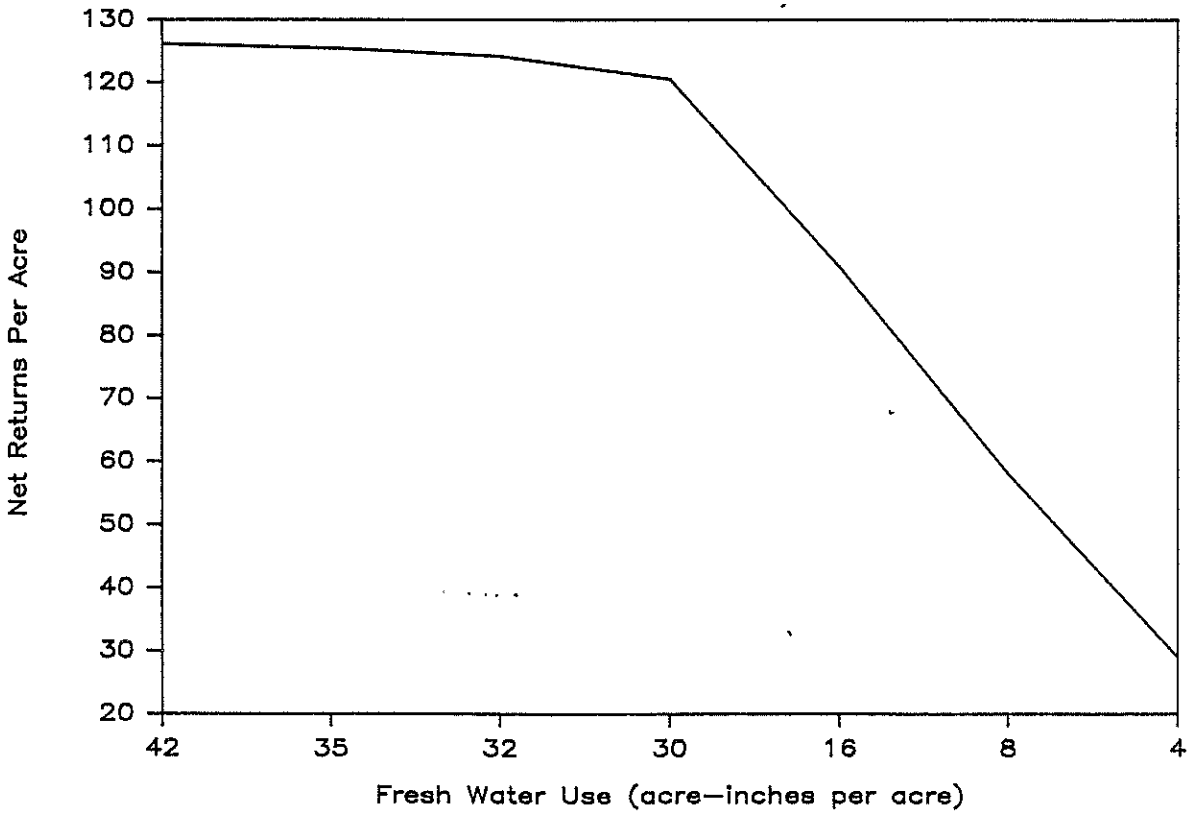

Fig. 22. Fresh water use and per acre net returns for forced cropping patterns, Roswell-Artesia Basin, 1985

Demand for Saline Water

Using the results of the LP analysis from the first and third scenarios, the input demand functions for saline irrigation water were derived. Typically, an input demand function indicates how much of an input will be purchased at a given price, for producers who seek to maximize profits. The demand functions presented in this section indicate the profit maximizing amount of saline water that will be demanded for crop production at alternatives water prices and cropping patterns. This saline water is a supplement to the 42 acre-inches per acre of fresh irrigation water. Optimal use of an input is determined, once the demand function is derived, by locating that point where the price of the input intersects the demand function.

The demand function derived from using the data from scenario 1 indicates the value of the saline water when all alternative crops are considered. The demand function derived using the data from scenario 3 indicates the value of saline water when the cropping alternatives are restricted to a traditional cropping pattern in the Roswell-Artesia Basin.

Figure 23 indicates the demand function for saline water when it is used to supplement the 42 acre-inches per acre of fresh water. The variable pumping costs of the saline water of $.84 per acre-inch results in an optimal use of the additional saline water of 14 acre-inches per acre, or when saline water supplements fresh water by 33 percent. The demand function is relatively elastic, indicating that at low water prices additional saline water will be demanded, and conversely, if the cost of the resource were to increase, demand for saline water would decrease.

Figure 24 presents the demand function for saline irrigation water when the cropping pattern is restricted to 50 percent alfalfa, 33 percent

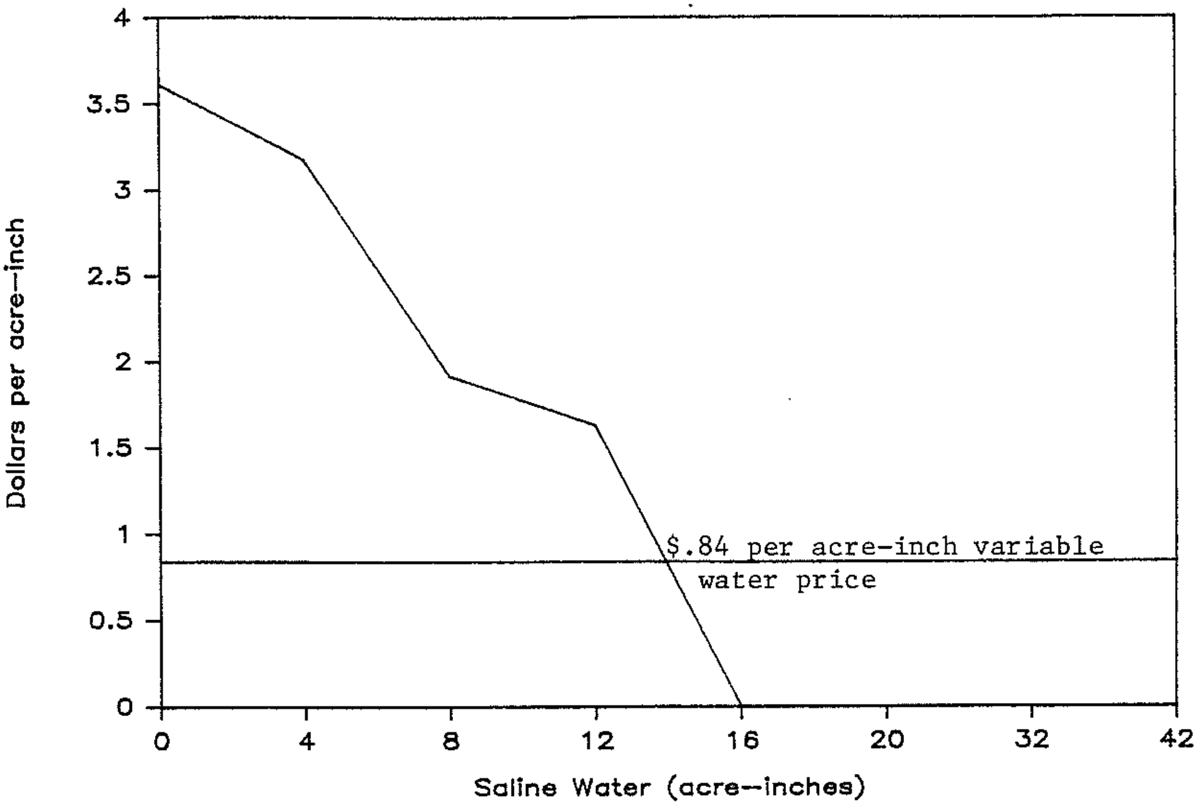

Fig. 23. Marginal value of saline water with a forced crop rotation, Roswell-Artesia Basin, 1985

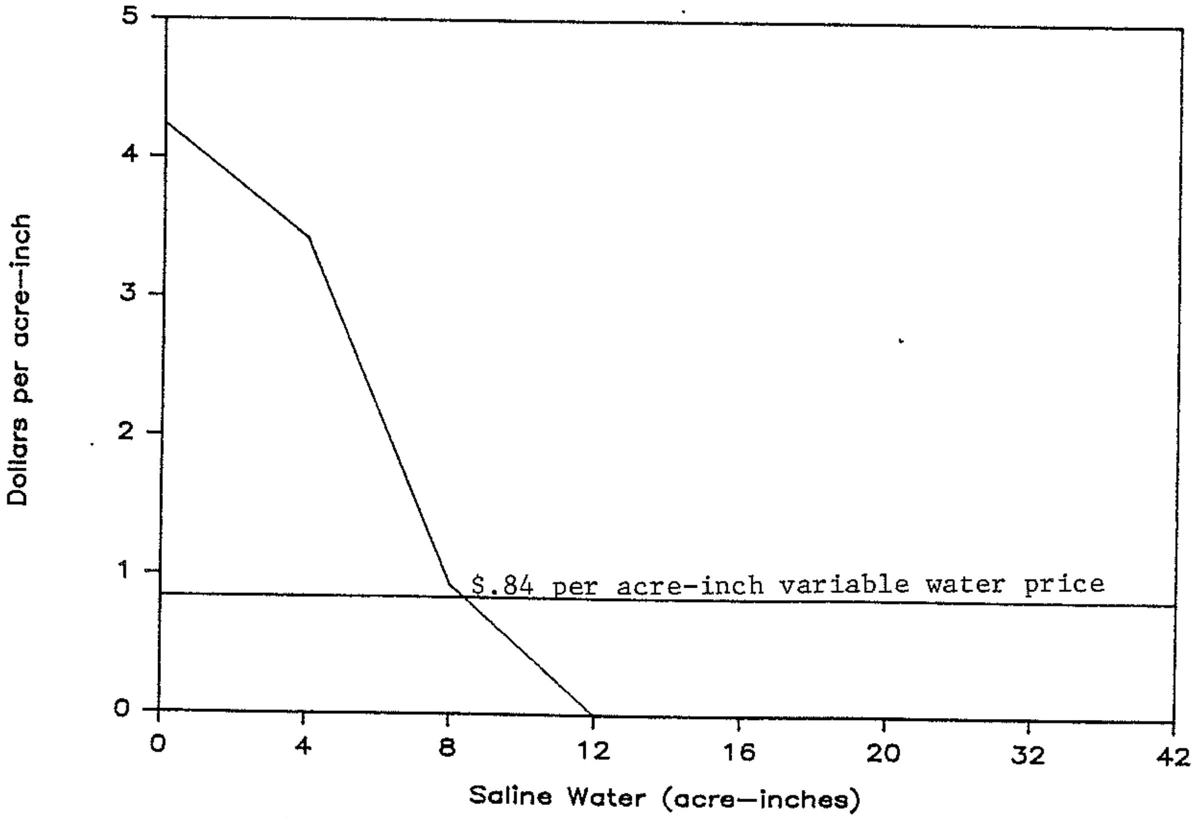

Fig. 24. Marginal value of saline water with unforced crop rotation, Roswell-Artesia Basin, 1985

cotton and 17 percent of spring barley. This demand function indicates that for this cropping pattern, and given the variable pumping costs of $.84 per acre-inch, the optimal use of the saline water is 8 acre-inches per acre. The demand function for this scenario is more inelastic than that for scenario 1. This indicates that little additional saline water will be used at lower prices and implies that saline water is more valuable to farmers who consider alternative cropping patterns in their management decisions.

SUMMARY AND CONCLUSIONS

The three objectives of this report were to: (1) incorporate a salinity component into an existing irrigation scheduling model, (2) determine the optimal mix of saline and fresh water applications for irrigated crop production, and (3) determine the value in use of saline water in irrigated agriculture.

Three models were developed, a simple non-interactive salinity model that utilizes the EC of the soil and the irrigation water, a more complex salinity model that requires the chemical constituents of the irrigation water, and an economic model that interfaces with either of the salinity models. The first two models were designed to determine crop yields based on weather patterns and fresh and saline irrigation water applications. The economic model was developed to determine the optimal irrigation regimen of fresh and saline water and the value of saline water for irrigated crop production.

The area in New Mexico selected for analysis was the Roswell-Artesia Basin. This area contains prime agricultural farmlands and has abundant saline ground water supplies that are readily accessible.

The simple and the complex salinity irrigation scheduling models were calibrated using published data and a case study farm near Hagerman, New Mexico. The output of both models agreed with published data and are reliable indicators of expected yield results under variable weather conditions.

The results from the economic model demonstrate that whole farm profitability could substantially increase if saline water is utilized to supplement the 42 acre-inches per acre of fresh water now permitted by the state engineer. Saline water can supplement fresh water by 33 percent, producing 17 percent more acreage of profitable crops, and additional acreages of less profitable salt-tolerant crops.

All crops can be irrigated with saline water, but the highest return to fresh water is for alfalfa production. Saline water, should, in general, be applied to cotton and barley acreages. Once fresh water resources are fully employed, additional alfalfa production can be sustained with saline water augmentation.

The optimal irrigation sequence for fresh and saline water depends on the relative availability of the two resources. In general, alfalfa production requires a minimum of a fresh water irrigation for every three saline water irrigations. Cotton and barley can be produced with a fresh water application at the beginning of the growing season to leach accumulated salts from the root zone for germination, followed by almost continuous applications of saline water during the season.

The current 42 acre-inch pumping restriction does not differentiate between fresh and saline groundwater resources. In order to implement the irrigation strategies for saline and fresh water resources developed in this report, this restriction needs to be modified to differentiate between the fresh and saline groundwater resource. The recommended revised policy for the Roswell-Artesia Basin would be to restrict only fresh water to 42 acre-inches per acre and to allow unlimited pumping of the saline water resource. This revision would result in an increase in whole farm profitability.

The demand function derived for saline irrigation water, assuming a flexible cropping pattern, indicates that the optimal use of the supplemented saline water was 14 acre-inches per acre. At this point, the variable pumping costs of the saline water ($.84 per acre-inch) are equal to the marginal revenue from its use. Because the demand function is relatively elastic, at lower water prices, additional quantities of saline water will be demanded and, at higher water prices, lower quantities will be demanded. With a traditional cropping pattern of alfalfa, cotton and barley, the optimal use of supplemental saline water was 8 acre-inches per acre. The demand function derived for this cropping pattern was more inelastic and therefore, with changes in the price (pumping cost), smaller changes in the quantity demanded of saline water would result.

REFERENCES

Bresler, E. and D. Yaron, 1972. "Soil Water Regime in Economic Evaluation of Salinity in Irrigation, Water Resource Res., 8, 791-800.

Bresler, E., B.L. McNeal, and D.L. Caster, 1982. Saline and Sodic Soils: Principles, Dynamics, Modeling, Berlin, New York, Springer Verlag.

Davis, J.G. and G.A. O'Connor, 1980. Minimized Leaching Studies with Pecos River Water, New Mexico Agricultural Experiment Station Bul. No. 674. New Mexico State University, Las Cruces, New Mexico.

Doorenbos, J. and A.H. Kassam. 1979. Yield response to water. FAO Irrig. Drain. Paper No. 33. FAO, Rome.

Dregne, Harold E., E.T. Garnett, and Robert R. Lansford, 1967. "The Effect of Soil and Water Quality and Rate of Irrigation Application on Farm Income," (Unpublished Manuscript, Department of Agronomy and Department of Agricultural Economics and Agricultural Business, New Mexico State University), Las Cruces, New Mexico.

Dregne, H.E., 1969. Prediction of Crop Yields from Quantity of Salinity in Irrigation Water, New Mexico Agricultural Experiment Station Bul. No. 543. New Mexico State University, Las Cruces, New Mexico.

Dutt, G.R., M. J. Shaffer and W.J. Moore. 1972. Computer simulation model of dynamic bio-physicochemical processes in soils. Dept. of Soils, Water and Engineering, Ag. Exp. Sta., Univ. of Arizona, Technical Bulletin 196.

Francois, L.E., T. Donovan and E.V. Maas, 1984. Salinity effects on seed yield, growth, and germination of grain sorghum. Agronomy Journal, Vol. 76, pp. 741-744.

Garnett, Edwin, 1968. "Economic Classification of the Irrigated Cropland in the Roswell-Artesian Basin, New Mexico." Unpublished master's thesis, New Mexico State University, Las Cruces, New Mexico.

Hanks, R. J., 1974. "Model for Predicting Plant Yield as Influenced by Water Use." Agron. J. 66, 1974, 660-665.

Hanks, R.J. and V.P. Rasmussen, 1982. Predicting crop production as related to plant water stress. Advances in Agronomy, Vol. 48, No. 2, pp. 58-63.

Heckler, Wilbur L., 1965. "Surface Water Availability and Quality Characteristics in the Pecos River Basin in New Mexico," Proceedings of the Tenth Annual New Mexico Water Conference, New Mexico State University, Las Cruces, New Mexico.

Hood, J.W., R.W. Mower, and M.J. Grogin, 1960. The Occurrence of Saline Ground Water Near Roswell, Chaves County, New Mexico, New Mexico State Engineer, Santa Fe, New Mexico.

Lansford, Robert R., et al., 1983. "Irrigated Agricultural Decision Strategies for Variable Weather Conditions." New Mexico Water Resources Research Institute Report 170, New Mexico State University, Las Cruces, New Mexico.

Lansford, Robert R., et al. 1984. Irrigation scheduling models: an economic analysis. Journal of the Amer. Soc. of Farm Managers and Rural Appraisers, Vol. 48, No. 2, pp. 58-63.

Lansford, Robert R. and Bobby J. Creel, 1969. "Irrigation Water Requirements in the Roswell-Artesian Basin, New Mexico: An Economic Analysis and Data Base." New Mexico Water Resources Research Institute Report 4, Part II, New Mexico State University, Las Cruces, New Mexico.

Letey, J.A., A. Dinar and K.C. Knapp, 1985. Crop-water production function model for saline irrigation water under steady state conditions. Soil Sci. Soc. Amer. J., In Review.

Maas, E.V. and G.J. Hoffman, 1977. Crop salt tolerance-current assessment. J. Irrig. Drain Div. ASCE, 103(IR2):115-134.

Maddox, George E., 1965. "Availability and Quality of Ground Water in the Pecos River Basin," Proceedings of the Tenth Annual New Mexico Water Conference, New Mexico State University, Las Cruces, New Mexico.

Mapel, Craig L., 1984. "A Comparison of Two Irrigation Scheduling Models for the Roswell-Artesian Basin, New Mexico," unpublished Master's Thesis, New Mexico State University, Las Cruces, New Mexico.

Moore, J. and J.M. Murphy, 1978. "Sprinkler Irrigation With Saline Water in West Texas," Texas Agric. Proc., 24:26-27.

O'Connor, George A., 1980. "Using Saline Water for Crop Production in New Mexico," New Mexico Water Resources Research Institute Report 127, New Mexico State University, Las Cruces, New Mexico.

Oster, J.D. and J.D. Rhoades, 1974. Calculated drainage water compositions and salt burdens resulting from irrigation with river waters in the Western United States. J. Environ. Qual., Vol. 4, No. 1, pp. 73-79.

Rasmussen, V.P. and R.J. Hanks, 1978. Spring wheat yield model for limited moisture conditions. Agronomy Jour., Vol. 70, pp. 940-944.

Rhoades, J.D., R.D. Ingvalson, J.M. Tucker and M. Clark, 1973. Salts in irrigation drainage waters: I. Effects of irrigation water composition, leaching fraction, and time of year on the salt compositions of irrigation drainage waters. Soil Sci. Soc. Amer. Proc., Vol. 37, pp. 770-774.

Sammis, Theodore, 1979. "Consumptive Use and Yields of Crops in New Mexico." New Mexico Water Resources Research Institute Report 115. New Mexico State University, Las Cruces, New Mexico.

Sammis, T.W., A.S. Abdul-Jabbar and D.G. Lugg, 1983. Influence of available soil water on modeling crop growth. American Society of Agricultural Engineers Paper No. 83-2125, Bozeman, Montana.

Sammis, Theodore, and Dan Smeal, 1983. "The Effects of Moisture Stress on Corn Yields in the High Plains." New Mexico Water Resources Research Institute, Report 171, New Mexico State University, Las Cruces, New Mexico.

Sammis, T.W., William Riley and Scott Williams, 1985. Pecan nut yield yield and tree growth as influenced by irrigation. New Mexico Water Resources Research Institute, Report 196, New Mexico State University, Las Cruces, New Mexico. Submitted.

Stewart, A.E., 1967. Establishing Vegetative Cover with Saline Water, New Mexico Agricultural Experiment Station Bul. No. 513. New Mexico State University, Las Cruces, New Mexico.

Soloman, K.H., 1984. Water-Salinity-Production Functions. ASAE Proc., New Orleans, Louisiana.

Sorensen, R.F., 1982. Water Use by Categories in New Mexico Counties and River Basins and Irrigated and Dry Cropland Acreage in 1980, New Mexico State Engineer Office, Technical Report 44, Santa Fe, New Mexico.

United State Bureau of Census, 1981. "Final Population and Housing Unit Counts-New Mexico." U.S. Department of Commerce Advance Report, No. PHC80-V-33.

U.S. Department of Interior, Bureau of Reclamation and the State of New Mexico, 1976. New Mexico Water Resources. Assessment for Planning Purposes.

Vaux, H.J. and W.O. Pruitt, 1983. Crop-water production functions, in Hillel, D. ed.) Advances in Irrigation, Vol. 2, Academic Press, Inc., New York, New York.

Welder, G. E., 1983. "Geologic Framework of the Roswell Groundwater Basin, Chaves and Eddy Counties, New Mexico." Technical Report 42, New Mexico State Engineer Office. Sante Fe, New Mexico.

Wierenga, P.J., 1979. "Soil Salinity and Cotton Yields as Affected by Surface and Trickle Irrigation," New Mexico Water Resources Research Report No. 106. Las Cruces, New Mexico.

Yaron, Dan, and Ariel Dinar, 1982. "Optimal Allocation of Farm Irrigation Water During Peak Seasons." Am. J. Agr. Economics, 82(4), 681-689.

APPENDIX A

Table A-1

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 1	BARLEY SCENARIO NUMBER 1	CORN FOR GRAIN SCENARIO NUMBER 1	GRAIN SORGHUM SCENARIO NUMBER 1	UPLAND COTTON SCENARIO NUMBER 1
YIELD		5.61	133.19	124.88	133.88	745.00
GROSS RETURN		561.00	372.93	363.40	360.14	517.76
COSTS						
PURCHASED INPUTS	94.50	139.16	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	20.10	21.85	28.65	27.05	29.30
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.68	0.84	9.91	12.42	12.42	16.49
TOTAL PRE-HARVEST	45.44	21.77	49.16	60.80	59.20	74.99
HARVEST						
CUSTOM			24.98	28.73	30.08	57.37
LABOR		16.25				10.20
FUEL, OIL AND LUBE		14.56				12.58
REPAIRS		15.36				33.62
FIXED		21.59				7.35
TOTAL HARVEST		67.76	24.98	28.73	30.08	121.12
OVERHEAD	32.60	84.93	69.11	71.57	70.80	85.01
TOTAL OPERATING EXPENSES	172.54	313.61	243.75	302.10	263.08	352.82
NET OPERATING PROFIT	-172.54	247.39	129.18	61.30	97.06	164.94
INTEREST ON OPERATING CAPITAL		13.10	13.12	16.52	13.76	13.40
INTEREST ON EQUIPMENT INVESTMENT	12.48	21.94	11.27	14.76	14.76	28.65
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.02	212.35	104.79	30.02	68.54	122.89

Table A-2

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 2	BARLEY SCENARIO NUMBER 2	CORN FOR GRAIN SCENARIO NUMBER 2	GRAIN SORGHUM SCENARIO NUMBER 2	UPLAND COTTON SCENARIO NUMBER 2
YIELD		5.26	135.15	102.63	124.07	761.00
GROSS RETURN		526.00	378.42	298.65	333.75	528.90
COSTS						
PURCHASED INPUTS	94.50	139.16	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	21.70	23.45	30.25	28.65	30.90
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.68	0.85	9.91	12.47	12.47	16.54
TOTAL PRE-HARVEST	45.44	23.38	50.76	62.45	60.85	76.64
HARVEST						
CUSTOM			25.27	25.39	28.61	58.60
LABOR		15.50				10.50
FUEL, OIL AND LUBE		13.86				12.95
REPAIRS		14.95				34.53
FIXED		21.52				7.47
TOTAL HARVEST		65.83	25.27	25.39	28.61	124.05
OVERHEAD	32.60	83.42	69.98	68.93	70.09	86.32
TOTAL OPERATING EXPENSES	172.54	311.78	246.51	297.77	262.55	358.71
NET OPERATING PROFIT	-172.54	214.22	131.91	0.88	71.20	170.19
INTEREST ON OPERATING CAPITAL		13.03	13.24	16.35	13.75	13.57
INTEREST ON EQUIPMENT INVESTMENT	12.49	21.88	11.29	14.83	14.83	28.78
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.03	179.31	107.38	-30.30	42.62	127.84

Table A-3

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 3	BARLEY SCENARIO NUMBER 3	CORN FOR GRAIN SCENARIO NUMBER 3	GRAIN SORGHUM SCENARIO NUMBER 3	UPLAND COTTON SCENARIO NUMBER 3
YIELD		5.07	130.96	88.48	113.71	719.00
GROSS RETURN		507.00	366.69	257.48	305.88	499.69
COSTS						
PURCHASED INPUTS	94.50	139.16	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	24.90	25.05	31.85	30.25	32.50
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.69	0.85	9.92	12.48	12.48	16.55
TOTAL PRE-HARVEST	45.45	26.58	52.37	64.06	62.46	78.25
HARVEST						
CUSTOM			24.64	23.27	27.06	55.36
LABOR		15.25				9.90
FUEL, OIL AND LUBE		13.63				12.20
REPAIRS		14.83				32.70
FIXED		21.51				7.29
TOTAL HARVEST		65.22	24.64	23.27	27.06	117.45
OVERHEAD	32.60	83.56	70.00	67.48	69.29	85.16
TOTAL OPERATING EXPENSES	172.55	314.52	247.51	295.81	261.81	352.56
NET OPERATING PROFIT	-172.55	192.48	119.18	-38.33	44.07	147.13
INTEREST ON OPERATING CAPITAL		13.15	13.29	16.28	13.73	13.49
INTEREST ON EQUIPMENT INVESTMENT	12.49	21.85	11.30	14.85	14.85	28.71
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.04	157.48	94.59	-69.46	15.49	104.93

Table A-4

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 4	BARLEY SCENARIO NUMBER 4	CORN FOR GRAIN SCENARIO NUMBER 4	GRAIN SORGHUM SCENARIO NUMBER 4	UPLAND COTTON SCENARIO NUMBER 4
YIELD		6.17	140.31	141.84	141.13	793.00
GROSS RETURN		617.00	392.87	412.75	379.64	551.12
COSTS						
PURCHASED INPUTS	94.50	139.15	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	21.70	23.45	30.25	28.65	30.90
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.67	0.84	9.89	12.35	12.35	16.40
TOTAL PRE-HARVEST	45.43	23.37	50.74	62.33	60.73	76.50
HARVEST						
CUSTOM			26.05	31.28	31.17	61.06
LABOR		17.25				10.90
FUEL, OIL AND LUBE		15.48				13.45
REPAIRS		15.89				35.87
FIXED		21.64				7.56
TOTAL HARVEST		70.26	26.05	31.28	31.17	128.84
OVERHEAD	32.60	88.83	70.70	74.64	72.38	87.63
TOTAL OPERATING EXPENSES	172.53	321.61	247.99	309.25	267.28	364.67
NET OPERATING PROFIT	-172.53	295.39	144.88	103.50	112.36	186.45
INTEREST ON OPERATING CAPITAL		13.45	13.30	16.82	13.94	13.70
INTEREST ON EQUIPMENT INVESTMENT	12.47	22.02	11.26	14.68	14.68	28.66
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.00	259.92	120.32	72.00	83.74	144.09

Table A-5

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 5	BARLEY SCENARIO NUMBER 5	CORN FOR GRAIN SCENARIO NUMBER 5	GRAIN SORGHUM SCENARIO NUMBER 5	UPLAND COTTON SCENARIO NUMBER 5
YIELD		5.90	141.27	111.50	129.73	788.00
GROSS RETURN		590.00	395.56	324.47	348.97	547.68
COSTS						
PURCHASED INPUTS	94.50	139.15	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	26.50	25.05	31.85	30.25	30.90
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.67	0.84	9.89	12.37	12.37	16.43
TOTAL PRE-HARVEST	45.43	28.17	52.34	63.95	62.35	76.53
HARVEST						
CUSTOM			26.19	26.73	29.46	60.68
LABOR		16.75				10.80
FUEL, OIL AND LUBE		15.02				13.34
REPAIRS		15.63				35.44
FIXED		21.61				7.55
TOTAL HARVEST		69.01	26.19	26.73	29.46	127.81
OVERHEAD	32.60	89.05	71.45	70.83	71.45	87.41
TOTAL OPERATING EXPENSES	172.53	325.38	250.48	302.51	266.26	363.45
NET OPERATING PROFIT	-172.53	264.62	145.08	21.96	82.71	184.23
INTEREST ON OPERATING CAPITAL		13.62	13.41	16.55	13.91	13.67
INTEREST ON EQUIPMENT INVESTMENT	12.48	21.98	11.26	14.72	14.72	28.71
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.01	229.02	120.41	-9.31	54.08	141.85

Table A-6

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 6	BARLEY SCENARIO NUMBER 6	CORN FOR GRAIN SCENARIO NUMBER 6	GRAIN SORGHUM SCENARIO NUMBER 6	UPLAND COTTON SCENARIO NUMBER 6
YIELD		5.62	129.60	105.64	121.09	733.00
GROSS RETURN		562.00	362.88	307.41	325.73	509.44
COSTS						
PURCHASED INPUTS	94.50	139.16	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	29.70	26.65	38.25	31.85	32.50
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.68	0.84	9.91	12.42	12.42	16.49
TOTAL PRE-HARVEST	45.44	31.37	53.96	70.40	64.00	78.19
HARVEST						
CUSTOM			24.44	25.85	28.16	56.44
LABOR		16.25				10.10
FUEL, OIL AND LUBE		14.56				12.47
REPAIRS		15.36				33.19
FIXED		21.59				7.34
TOTAL HARVEST		67.76	24.44	25.85	28.16	119.54
OVERHEAD	32.60	88.62	70.41	72.40	70.90	85.75
TOTAL OPERATING EXPENSES	172.54	326.90	249.31	309.65	266.06	355.18
NET OPERATING PROFIT	-172.54	235.10	113.57	-2.24	59.67	154.26
INTEREST ON OPERATING CAPITAL		13.69	13.37	16.88	13.92	13.55
INTEREST ON EQUIPMENT INVESTMENT	12.48	21.94	11.27	14.76	14.76	28.65
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.02	199.47	88.93	-33.88	30.99	112.06

Table A-7

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 7	BARLEY SCENARIO NUMBER 7	CORN FOR GRAIN SCENARIO NUMBER 7	GRAIN SORGHUM SCENARIO NUMBER 7	UPLAND COTTON SCENARIO NUMBER 7
YIELD		6.70	161.50	155.98	146.84	819.00
GROSS RETURN		670.00	452.20	453.90	395.00	569.19
COSTS						
PURCHASED INPUTS	94.50	139.15	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	24.90	25.05	31.85	30.25	32.50
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.66	0.83	9.87	12.29	12.29	16.32
TOTAL PRE-HARVEST	45.42	26.56	52.32	63.87	62.27	78.02
HARVEST						
CUSTOM			29.23	33.40	32.03	63.06
LABOR		18.50				11.30
FUEL, OIL AND LUBE		16.64				13.94
REPAIRS		16.58				37.20
FIXED		21.74				7.61
TOTAL HARVEST		73.46	29.23	33.40	32.03	133.11
OVERHEAD	32.60	93.31	74.28	77.31	73.75	89.33
TOTAL OPERATING EXPENSES	172.52	332.48	256.33	315.58	271.05	372.16
NET OPERATING PROFIT	-172.52	337.52	195.87	138.32	123.95	197.03
INTEREST ON OPERATING CAPITAL		13.90	13.64	17.09	14.10	13.90
INTEREST ON EQUIPMENT INVESTMENT	12.46	22.10	11.23	14.59	14.59	28.66
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-184.98	301.52	171.00	106.64	95.26	154.47

Table A-8

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 8	BARLEY SCENARIO NUMBER 8	CORN FOR GRAIN SCENARIO NUMBER 8	GRAIN SORGHUM SCENARIO NUMBER 8	UPLAND COTTON SCENARIO NUMBER 8
		6.40	146.52	134.57	136.84	823.00
YIELD						
		640.00	410.26	391.60	368.10	571.96
GROSS RETURN						
COSTS	94.50	139.15	100.50	141.00	103.00	71.70
PURCHASED INPUTS						
PRE-HARVEST						
CUSTOM	14.95	31.30	26.65	39.85	33.45	32.50
LABOR	11.79	0.64	9.92	13.06	13.06	17.80
FUEL, OIL AND LUBE	8.02	0.19	7.48	6.67	6.67	11.40
REPAIRS	10.67	0.84	9.88	12.31	12.31	16.35
FIXED	45.43	32.97	53.93	71.89	65.49	78.05
TOTAL PRE-HARVEST						
HARVEST			26.98	30.19	30.53	63.37
CUSTOM		18.00				11.30
LABOR		16.17				13.94
FUEL, OIL AND LUBE		16.30				37.20
REPAIRS		21.69				7.61
FIXED		72.16	26.98	30.19	30.53	133.42
TOTAL HARVEST	32.60	93.99	72.78	77.22	73.63	89.47
OVERHEAD	172.53	338.27	254.19	320.30	272.65	372.64
TOTAL OPERATING EXPENSES						
NET OPERATING PROFIT	-172.53	301.73	156.07	71.30	95.45	199.32
INTEREST ON OPERATING CAPITAL		14.16	13.57	17.32	14.19	13.92
INTEREST ON EQUIPMENT INVESTMENT	12.47	22.07	11.24	14.63	14.63	28.70
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.00	265.50	131.26	39.35	66.63	156.70

Table A-9

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 9	BARLEY SCENARIO NUMBER 9	CORN FOR GRAIN SCENARIO NUMBER 9	GRAIN SORGHUM SCENARIO NUMBER 9	UPLAND COTTON SCENARIO NUMBER 9
YIELD		6.20	141.85	127.20	129.79	783.00
GROSS RETURN		620.00	397.18	370.15	349.14	544.19
COSTS						
PURCHASED INPUTS	94.50	139.15	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	40.90	28.25	47.85	36.65	34.10
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.67	0.84	9.88	12.33	12.33	16.38
TOTAL PRE-HARVEST	45.43	42.57	55.53	79.91	68.71	79.68
HARVEST						
CUSTOM			26.28	29.08	29.47	60.29
LABOR		17.50				10.70
FUEL, OIL AND LUBE		15.72				13.17
REPAIRS		16.03				35.38
FIXED		21.68				7.46
TOTAL HARVEST		70.93	26.28	29.08	29.47	127.00
OVERHEAD	32.60	96.38	72.74	79.18	73.89	88.39
TOTAL OPERATING EXPENSES	172.53	349.03	255.05	329.17	275.07	366.77
NET OPERATING PROFIT	-172.53	270.97	142.13	40.98	74.07	177.42
INTEREST ON OPERATING CAPITAL		14.65	13.61	17.73	14.31	13.85
INTEREST ON EQUIPMENT INVESTMENT	12.47	22.03	11.25	14.66	14.66	28.59
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.00	234.29	117.27	8.59	45.10	134.98

Table A-10

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 10	BARLEY SCENARIO NUMBER 10	CORN FOR GRAIN SCENARIO NUMBER 10	GRAIN SORGHUM SCENARIO NUMBER 10	UPLAND COTTON SCENARIO NUMBER 10
YIELD		7.23	151.46	168.20	144.02	858.00
GROSS RETURN		723.00	424.09	489.46	387.41	596.29
COSTS						
PURCHASED INPUTS	94.50	139.15	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	29.70	26.65	36.65	30.25	34.10
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.66	0.83	9.86	12.23	12.23	16.26
TOTAL PRE-HARVEST	45.42	31.36	53.91	68.61	62.21	79.56
HARVEST						
CUSTOM			27.72	35.23	31.60	66.07
LABOR		19.50				11.80
FUEL, OIL AND LUBE		17.56				14.54
REPAIRS		17.11				38.98
FIXED		21.79				7.70
TOTAL HARVEST		75.96	27.72	35.23	31.60	139.09
OVERHEAD	32.60	98.27	73.47	80.90	73.37	91.54
TOTAL OPERATING EXPENSES	172.52	344.74	255.60	325.74	270.18	381.89
NET OPERATING PROFIT	-172.52	378.26	168.49	163.72	117.23	214.40
INTEREST ON OPERATING CAPITAL		14.44	13.62	17.53	14.07	14.16
INTEREST ON EQUIPMENT INVESTMENT	12.46	22.16	11.22	14.53	14.53	28.64
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-184.98	341.66	143.65	131.66	88.63	171.60

Table A-11

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 11	BARLEY SCENARIO NUMBER 11	CORN FOR GRAIN SCENARIO NUMBER 11	GRAIN SORGHUM SCENARIO NUMBER 11	UPLAND COTTON SCENARIO NUMBER 11
YIELD		6.95	150.94	151.41	144.07	851.00
GROSS RETURN		695.00	422.63	440.60	387.55	591.47
COSTS						
PURCHASED INPUTS	94.50	139.15	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	44.10	26.65	54.25	36.65	34.10
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.66	0.83	9.86	12.25	12.25	16.29
TOTAL PRE-HARVEST	45.42	45.76	53.91	86.23	68.63	79.59
HARVEST						
CUSTOM			27.64	32.71	31.61	65.53
LABOR		19.00				11.70
FUEL, OIL AND LUBE		17.10				14.43
REPAIRS		16.84				38.55
FIXED		21.75				7.70
TOTAL HARVEST		74.69	27.64	32.71	31.61	137.91
OVERHEAD	32.60	102.08	73.40	85.12	75.81	91.24
TOTAL OPERATING EXPENSES	172.52	361.68	255.45	345.06	279.05	380.44
NET OPERATING PROFIT	-172.52	333.32	167.18	95.54	108.50	211.03
INTEREST ON OPERATING CAPITAL		15.20	13.62	18.41	14.47	14.13
INTEREST ON EQUIPMENT INVESTMENT	12.46	22.13	11.23	14.56	14.56	28.68
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-184.98	295.99	142.33	62.57	79.47	168.22

Table A-12

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 12	BARLEY SCENARIO NUMBER 12	CORN FOR GRAIN SCENARIO NUMBER 12	GRAIN SORGHUM SCENARIO NUMBER 12	UPLAND COTTON SCENARIO NUMBER 12
YIELD		6.85	147.63	148.36	137.25	826.00
GROSS RETURN		685.00	413.36	431.73	369.20	574.07
COSTS						
PURCHASED INPUTS	94.50	139.15	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	66.50	29.85	33.45	43.05	37.30
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.66	0.83	9.87	12.28	12.28	16.32
TOTAL PRE-HARVEST	45.42	68.16	57.12	65.46	75.06	82.82
HARVEST						
CUSTOM			27.14	32.25	30.59	63.60
LABOR		18.75				11.30
FUEL, OIL AND LUBE		16.86				13.94
REPAIRS		16.71				37.20
FIXED		21.75				7.61
TOTAL HARVEST		74.07	27.14	32.25	30.59	133.65
OVERHEAD	32.60	109.93	74.16	76.81	77.31	91.39
TOTAL OPERATING EXPENSES	172.52	391.31	258.92	315.52	285.96	379.56
NET OPERATING PROFIT	-172.52	293.69	154.44	116.21	83.24	194.51
INTEREST ON OPERATING CAPITAL		16.53	13.78	17.09	14.78	14.22
INTEREST ON EQUIPMENT INVESTMENT	12.46	22.12	11.23	14.57	14.57	28.64
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-184.98	255.04	129.43	84.55	53.89	151.65

Table A-13

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 13	BARLEY SCENARIO NUMBER 13	CORN FOR GRAIN SCENARIO NUMBER 13	GRAIN SORGHUM SCENARIO NUMBER 13	UPLAND COTTON SCENARIO NUMBER 13
YIELD		5.10	131.00	87.50	113.70	719.00
GROSS RETURN		510.00	366.80	254.63	305.85	499.69
COSTS						
PURCHASED INPUTS	94.50	139.16	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	23.30	25.05	31.85	30.25	32.50
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.69	0.85	9.92	12.48	12.48	16.55
TOTAL PRE-HARVEST	45.45	24.98	52.37	64.06	62.46	78.25
HARVEST						
CUSTOM			24.65	23.13	27.06	55.36
LABOR		15.25				9.90
FUEL, OIL AND LUBE		13.63				12.20
REPAIRS		14.83				32.70
FIXED		21.51				7.29
TOTAL HARVEST		65.22	24.65	23.13	27.06	117.45
OVERHEAD	32.60	83.10	70.01	67.34	69.29	85.16
TOTAL OPERATING EXPENSES	172.55	312.46	247.53	295.53	261.81	352.56
NET OPERATING PROFIT	-172.55	197.54	119.27	-40.90	44.04	147.13
INTEREST ON OPERATING CAPITAL		13.06	13.29	16.27	13.73	13.49
INTEREST ON EQUIPMENT INVESTMENT	12.49	21.85	11.30	14.85	14.85	28.71
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.04	162.63	94.68	-72.02	15.46	104.93

Table A-14

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 14	BARLEY SCENARIO NUMBER 14	CORN FOR GRAIN SCENARIO NUMBER 14	GRAIN SORGHUM SCENARIO NUMBER 14	UPLAND COTTON SCENARIO NUMBER 14
YIELD		5.62	129.60	105.60	121.10	763.00
GROSS RETURN		562.00	362.88	307.30	325.76	530.28
COSTS						
PURCHASED INPUTS	94.50	139.16	100.50	141.00	103.00	71.70
PRE-HARVEST						
CUSTOM						
LABOR	14.95	29.70	26.65	38.25	31.85	32.50
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.80
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.40
FIXED	10.68	0.84	9.91	12.42	12.42	16.49
TOTAL PRE-HARVEST	45.44	31.37	53.96	70.40	64.00	78.19
HARVEST						
CUSTOM			24.44	25.84	28.17	58.75
LABOR		16.25				10.50
FUEL, OIL AND LUBE		14.56				12.95
REPAIRS		15.36				34.53
FIXED		21.59				7.47
TOTAL HARVEST		67.76	24.44	25.84	28.17	124.20
OVERHEAD	32.60	88.62	70.41	72.40	70.90	86.98
TOTAL OPERATING EXPENSES	172.54	326.90	249.31	309.64	266.07	361.07
NET OPERATING PROFIT	-172.54	235.10	113.57	-2.34	59.69	169.21
INTEREST ON OPERATING CAPITAL		13.69	13.37	16.88	13.92	13.67
INTEREST ON EQUIPMENT INVESTMENT	12.48	21.94	11.27	14.76	14.76	28.71
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.02	199.47	88.93	-33.98	31.01	126.83

Table A-15

Whole Farm Summary Budget, Roswell-Artesia Basin, 1985

		ALFALFA HAY SCENARIO NUMBER 15	BARLEY SCENARIO NUMBER 15	CORN FOR GRAIN SCENARIO NUMBER 15	GRAIN SORGHUM SCENARIO NUMBER 15	UPLAND COTTON SCENARIO NUMBER 15
YIELD		6.20	141.90	108.80	129.80	826.0
GROSS RETURN		620.00	397.32	316.61	349.16	574.0
COSTS						
PURCHASED INPUTS	94.50	139.15	100.50	141.00	103.00	71.7
PRE-HARVEST						
CUSTOM						
LABOR	14.95	40.90	28.25	38.25	36.65	37.3
FUEL, OIL AND LUBE	11.79	0.64	9.92	13.06	13.06	17.8
REPAIRS	8.02	0.19	7.48	6.67	6.67	11.4
FIXED	10.67	0.84	9.88	12.33	12.33	16.3
TOTAL PRE-HARVEST	45.43	42.57	55.53	70.31	68.71	82.8
HARVEST						
CUSTOM			26.29	26.32	29.47	63.6
LABOR		17.50				11.3
FUEL, OIL AND LUBE		15.72				13.9
REPAIRS		16.03				37.2
FIXED		21.68				7.6
TOTAL HARVEST		70.93	26.29	26.32	29.47	133.6
OVERHEAD	32.60	96.38	72.75	72.86	73.89	91.3
TOTAL OPERATING EXPENSES	172.53	349.03	255.07	310.49	275.07	379.6
NET OPERATING PROFIT	-172.53	270.97	142.25	6.12	74.09	194.4
INTEREST ON OPERATING CAPITAL		14.65	13.61	16.92	14.31	14.2
INTEREST ON EQUIPMENT INVESTMENT	12.47	22.03	11.25	14.66	14.66	28.7
INTEREST ON LAND INVESTMENT						
RETURN TO LAND, RISK, AND WATER	-185.00	234.29	117.39	-25.46	45.12	151.4