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ECONOMIC EVALUATION OF THE RATE OF SUBSTITUTION BETWEEN QUANTITY AND QUALITY (SALINITY) OF WATER IN IRRIGATION

by

D.Yaron, A. Dinar, H. Voet & A. Ratner

Rehovoth, Israel P.O.B. 12

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CONTENTS

SUMMARY AND MAJOR FINDINGS

ECONOMIC EVALUATION OF THE RATE OF SUBSTITUTION BETWEEN QUANTITY AND QUALITY (SALINITY) OF WATER IN IRRIGATION

The system of water supply in Israel has been facing a long run trend of deterioration of water quality and increased salinity content. This trend generates new problems to be addressed by farmers, researchers, extension workers and policy makers, the essence of which is the need to introduce the water quality (salinity) dimension into their considerations, both at the planning and the management phases. Accordingly, given this background, the interest in the assessment of losses to farms' income, due to increased water salinity and the rates of substitution between quantity and quality, provided the motivation for this study.

The major features and the findings of the study can be summarized as follows:

1) The objectives of the study are: (i) to assess the losses to farms' income due to increased water salinity in the South and the Negev regions in Israel; (ii) to evaluate, with respect to the kibbutz farms, the marginal rates of substitution between water quality and salinity.
2) Samples of 10 kibbutz farms and 10 moshav villages in the region provided the empirical background for the study.

Kibbutz Farms

3) The approach of the study to kibbutz farms was aimed to estimate their production functions with water quantity and quality (salinity) as arguments.

4) In view of the scarcity of data for the statistical estimation of the production functions, a normative planning approach was applied. It was assumed that the sample farms will attempt to maximize their incomes under conditions varying with respect to the quantity and quality of their water supply.

The study referred to sprinkler irrigation as the predominating irrigation technology on kibbutz farms. The option of adaptation of the crop mix to increased salinity was included in the analysis.

5) Irrigation with saline water is a dynamic stochastic process, with rainfall being the major stochastic element. An integrated system linking a dynamic stochastic programming model with a static linear programming model has been designed and applied. The application lead to the conclusion that, with reference to the specific data set relevant to our empirical analysis, adaptive control type decisions were not justified and the dynamic stochastic model could be substituted by a static approach, addressing steady state conditions (Chapter Two).

6) Linear programming was applied to the determination of the long run optimal mix of crops and the optimal water allocation on the sample kibbutzim. By parametric runs with reference to various combinations of water quantity and quality and other parameters, vectors of "observations" indicating the income, quantity and salinity of water and other parameters' were generated.

7) The relationship between income, quantity and quality of water was estimated for each kibbutz farm by the regression technique. MVP values of water with differing levels of salinity content were derived from the estimated regressions.

8) The marginal rates of substitution (MRS) between water of "poor" and "good" quality was computed as the ratios of the corresponding MVP values (Tables 3.4-3.8).

The results suggest that considerable heterogeneity prevails in the MVP and MRS values, attributable primarily to the crop mix, and not to the agroclimatic conditions. In an attempt to generalize the results we suggest as our subjective summary that the marginal rate of substitution (MRS) of "poor" quality of 300 ppm Cl for "good" quality of 220 ppm Cl be 1.10 as a conservative measure, and 1.20 as a liberal one (pp. 37-39). These estimates relate to the current irrigation technology.

9) Increasing water salinity leads to structural changes on the farms, namely, emphasized eradication of fruit groves and increased dependence on cotton. This is one of the most important negative effects induced by salinity.

Additional, both theoretical and empirical work is needed in order to explore the potential of new irrigation technologies, in citrus, avocado and other fruit crops, to reduce salinity induced losses.

Moshav Villages (Supplement)

10) A simulation model (especially designed for this purpose) was applied to the study of the effect of increased water salinity on the income of moshav villages, at the aggregate level.*) The resources available to the research were not sufficient for the analysis at the family farm level and of their interaction with the village cooperatives.

11) The estimates address two alternatives of water supply to the villages: (i) a unified water quality supplied to all land plots of the family farms and those operated by the village cooperative, and, (ii) a dual water supply to the family farms with the plots adjacent to the homesteads only (Plots A) being supplied with good quality water, and the other plots being subject to varying levels of water salinity (up to 400 ppm Cl).

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*The simulation model was used, as well, to compute yield and income losses in fruit and field crops under irrigation with saline water, in the kibbutzim sample.

12) The estimates were restricted to losses accrued to fruit groves under sprinkler irrigation as the major component of the overall farm losses. This was due to:

(i) Estimated losses per land unit area of vegetable crops are not large (Supplement, p. 3).

(ii) The losses can be, and in reality are reduced by new irrigation technology - drip irrigation.

Regarding citrus, avocado and other fruit crops sprinkler irrigation is the predominating technology. The potential of new irrigation technologies to reduce salinity - induced losses is thus far, not fully explored in quantifiable terms.

13) The estimates derived provide information needed for policy decisions regarding the salinity aspect of water supply to the region's moshavim.

14) The following findings should be especially emphasized:

(a) The share of the potential losses on Plots A comprises on the average about 16% of the total potential losses (Table 2).

(b) The benefits attributable to low salinity, due to the policy alternative of dual quality supply are small relative to cost. The salinity factor by itself does not justify dual supply, with good water being supplied to Plots A only.

Chapter 1

INTRODUCTION

Soil salinity problems and irrigation with saline water are widespread in humid as well in arid and semi-arid regions. According to available estimates 100,000 acres of land per year are no longer productive because of salinization. Most of the irrigated land of Iran, and more than 50% of the irrigated land in Syria are affected by salinity. In the U.S. about 28% of irrigated land suffers from depressed yields due to salinity.

In Israel problems of water salinity and irrigation with saline water are of increasing interest to farmers and institutions in charge of water resource development and management. This is due to the following reasons: (a) The relative scarcity of good quality water and the necessity of utilization of water resources of poor quality (including large scale utilization of reclaimed sewage;(b) the potential for development of brackish water resources; (c) the process of gradual deterioration in quality of water in aquifers, and (d) existing plans for desalination of brackish and/or seawater on an experimental as large scale basis. A recent projection by Tahal(1 (1979, Hebrew) suggests that by the year 2000 only 50% of the water supply to Israeli agriculture will be from fresh water sources, with the residual quantity being supplied from brackish water and reclaimed effluent, which is typically more saline than fresh water. Taking into consideration selected regions and their water supply, the share of the reclaimed effluent and brackish water is projected to be considerably higher than the average (Table 1.1).

(1 Tahal is an engineering consulting firm in charge of water planning in Israel.

Table 1.1 The Share of Marginal Water Sources in the Total Water Supply to Agriculture in Selected Regions in the Years 1976 and 2000

Region	Total Water Supply 10^6 m³	Share of reclaimed effluent %	Share of brackish water %
	1 9 7 6		
Arava	17	12	41
Upper Galilee - Acre Region	60	8	15
Negev	268	2	1
Rehovot	179	3	1
Afula	284	0	20
	2 0 0 0		
Arava	38	39	61
Upper Galilee - Acre Region	63	54	14
Negev	306	46	11
Rehovot	174	48	1
Afula	274	18	20

Source: Tahal (1979, Hebrew)

In many cases agricultural regions and farms in Israel will have a dual water supply, differentiated on the basis of water salinity and other quality parameters. This is due to the fact that agricultural crops differ in their sensitivity to salinity. Supply of water of the same quality with a low salinity content, to a region with only a certain share of sensitive crops implies "waste of quality." On the other hand supply of water of poor quality (high salinity) only to a region with a certain acreage of sensitive crops will cause yield and income losses to these crops. In effect dual water supply systems are already operated in certain regions of Israel (e.g. Beissan Valley) and on farms in numerous regions of Israel which use reclaimed sewage for irrigation.

The physical relationships involved in irrigation with saline water can be split into two subsystems: 1) Soil salinity accumulation and leaching functions, and 2) crop response to soil salinity. These functions have been extensively studied and discussed in the professional literature. Review summaries can be found in Yaron (1974), Maas and Hoffman (1977), Bernstein (1981) and Yaron (1981).

The interest in the economic analysis of irrigation with saline water has been rising in recent years due to the salinity problem faced by numerous regions in the world on the one hand, and the development of computer oriented techniques which open new possibilities for economic analyses, on the other. The early economic studies of water quality (e.g. Timmons and Dougal (1967), Pincock (1969)) did not utilize the available optimization technuqies. (Parkinon et al (1970), Moore et al (1974), and Hanks and Andersen (1981) overcame this shortcoming by reference to the optimization of whole farm systems; however these studies adopted a static framework, and neglected the dynamics of the system, without testing whether a static approach was justified. Note that irrigation with saline water is a dynamic stochastic process. Salt is accumulated in the soil during irrigation and is periodically leached by rainfall and/or irrigation. The major natural stochastic element is rainfall; other stochastic phenomena are related to uncertainty (or insufficient knowledge) regarding the physical relationships involved. A dynamic approach and stochastic elements have been introduced into the system by Yaron and Olian (1973), Cummings and McFarland (1974) and others. The major problem inherent to such approach is the so called "curse of dimensionality" - large dynamic stochastic problems are technically difficult to solve. We return to this issue in Chapter Two of this report.

This research is concerned with the effect of increasing salinity of irrigation water on agriculture in the South and the Negev regions of Israel. There are four water supply sources to the region:

(1) The National Water Carrier.

(2) Regional aquifers with water of "good" quality in terms of its salinity content. (2

(3) Regional aquifers with water of poor quality.

(4) A large scale reclaimed sewage project aimed at the diversion of reclaimed sewage from the Dan region (Tel-Avid area) to the South and the Negev. Note that reclaimed sewage water is typically more saline than the original fresh water source.

(2 No attempt is made here to suggest a classification of water sources according to their salinity levels.

By proper management policy the salinity content of the water supplied by the National Water Water Carrier and the reclaimed sewage project could be monitored: higher water quality can be supplied at a higher cost.

The objective of the research reported here is (1) to assess the potential losses to farms' income in the region due to increasing salinity of water supply and (2) to evaluate the marginal rate of substitution (MRS) between quantity and quality (salinity) of water needed to maintain the farms' income unchanged.

Two samples of 10 kibbutz farms and 10 moshav villages in the region provided the empirical framework for the study.

Several managerial policies aimed to reduce farm losses induced by increased water salinity are open to farmers; they include adaptation to salinity of the crop mix and of the irrigation technology. The frame of reference of the study regarding these issues is discussed in Chapter 2 (pp. 7-8) with respect to kibbutzim and in the Supplement (pp. 3-4) with respect to moshav villages.

The study and its results provide information needed for policy decision with respect to water supply to the South and the Negev regions and its allocation among the regions' farms, with both parameters of quantity and quality taken into consideration.

Following this introduction Chapter Two reviews some background analyses performed, and presents the approach developed for the analysis of the kibbutz farms, while Chapter Three presents the empirical analysis of the kibbutzim. Chapters Two and Three, concerning the kibbutz farms, are analytical and can be of interest to both the analytical and the policy oriented readers. On the other hand the study of the moshav villages can be of interest to policy oriented readers only; accordingly it is presented in the Supplement to the main body of the report. The major findings of the study are summarized in the Summary section previously presented.

Chapter 2

KIBBUTZ FARMS - THE APPROACH AND BACKGROUND ANALYSES

The necessary background for the derivation of the relationships of interest are estimates of the production functions of the sample farms with varying inputs of quantity and quality of irrigation water:

$$Y = f\,(\underline{Q},\ S,\ \underline{F}\,|\,\underline{K}) \tag{2.1}$$

where: Y - is the output (value added) of the farm;

$\underline{Q}$ - vector of quantities of irrigation water at different periods;

S - water salinity;

$\underline{F}$ - vector of other production factors, and

$\underline{K}$ - vector of all other factors assumed to be constant.

Whenever applicable, function (2.1) can be modified into (2.1a) to include, as an additional argument, the vector $\underline{N}$ of other quality parameters (e.g. the concentration of nitrates and phosphates in the irrigation water.)

$$Y = f(\underline{Q},\ S,\ \underline{N},\ \underline{F}\ \underline{K}) \tag{2.1a}$$

In the case of our study the relevant function is (2.1).

In view of the scarcity of data for the statistical estimation of function (2.1) a normative planning approach has been applied. It has been assumed that the sample farms will attempt to maximize their incomes under conditions varying with respect to the quantity and quality of their water supply.

A variety of adaptation policies aimed to reduce salinity-induced losses are open to farmers. The main groups include adaptation of the crop mix and adaptation of irrigation technology. Adaptation of the crop mix implies the substitution of salinity sensitive crops (e.g. citrus, avocado) by relatively resistant crops (e.g. cotton, wheat). The adaptation of irrigation technology involves a variety of methods which can be grouped under two major headings (i) Salt leaching, and (ii) Maintenance of high soil moisture content during the irrigation season, which dilutes the concentration of salts in the soil solution. This can be achieved by shortening the intervals between irrigations either by sprinkler or by drip irrigation. (Note that short intervals are inherent to drip irrigation). Fig. 2.1 presents hypothetical salinity-induced losses of farms under three situations:

(a) Currently practical crop mix and irrigation technology;

(b) Crop mix adapted to increased salinity and currently practiced irrigation technology;

(c) Adaptation of both crop mix and irrigation technology to increased salinity.

Obviously the distinction between these three situations is not clear-cut; the transition from one situation to another is gradual.

The curves in Fig. 2.1 are drawn on the basis of theoretical considerations and the assumption that by increasing the number of options open to farmers, the salinity losses can be decreased (at a priori grounds).

The analysis of kibbutz farms in our study refers to situation (b). The reference to curve (c) was not possible due to lack of quantitative knowledge regarding the overall effect of new technologies on reducing salinity losses to fruit crops. Information regarding various aspects of the performance of new irrigation terhnologies in fruit crops is gradually being accumulated, but thus far it does not provide a sound basis for quantitative estimates. Moreover, there are doubts whether the new irrigation technologies have indeed a real potential to overcome the salinity induced losses. (1 If they do not,

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(1 Salt leaching technology is evaluated in the text pp. 17-18. Sprinkler irrigation with short intervals between irrigation applications maintains high soil moisture and dilutes salts in the soil solution on the one hand, but induces higher evapotranspiration and water use on the other hand. The overall effect is not sufficiently known to be quantified in a generalized way.

The most debatable is the effect of drip irrigation in citrus and avocado. Drip irrigation leads to a continuous high moisture regime in a limited portion of the soil volume, within which salts are diluted. However, at the edge of the wetted zone, salts are highly concentrated. The overall effect of these two soil salinity zones is debated. Other salinity oriented issues, under drip irrigation, which thus far - to our knowledge - have not been properly quantified, are concerned with the processes of salt accumulations in the soil during a single season and over a sequence of years, and the processes of salt leaching by rainfall and/or sprinkler irrigation, occassionally applied.

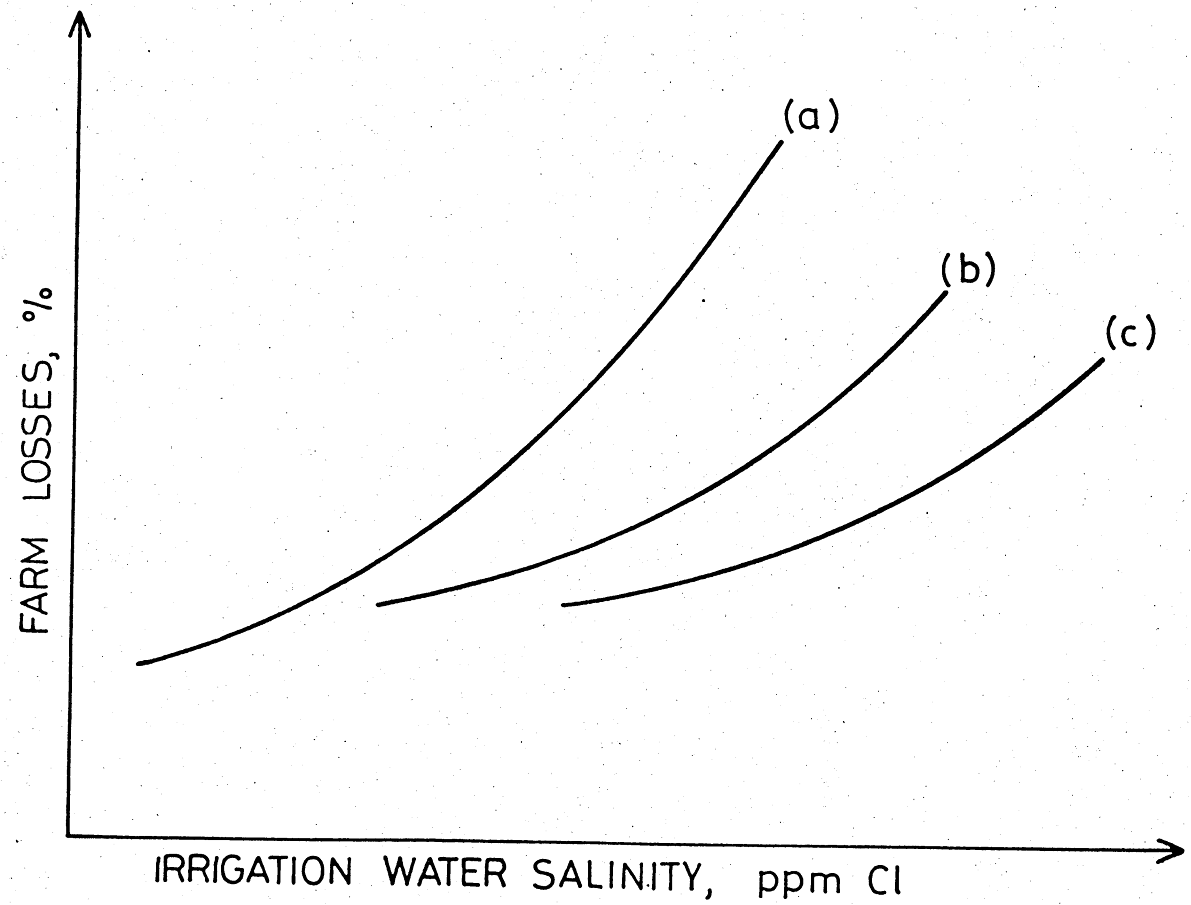
Additional, both theoretical and empirical work is needed in order to be able to quantify these processes.

curve (c) in Fig. 2.1 will coincide with (or be very close to) curve (b).

Drip irrigation has proved itself as a technology with potential to overcome salinity losses in irrigation of most vegetable crops, but these, except for a few - carrots, potatoes and onions - are not grown on kibbutz farms.

Irrigation with saline water is a dynamic stochastic process. Salt is accumulated in the soil during irrigation and is periodically leached by rainfall and/or irrigation. The major "natural" stochastic element is

Fig. 2.1 : Hypothetical salinity - induced ~~from~~ FARM losses under three situations.



(a) Currently practiced crop mix and irrigation technology;
(b) Crop mix adapted to salinity and currently practiced irrigation technology;
(c) Both crop mix and irrigation technology adapted to salinity.

rainfall; other stochastic phenomena are related to uncertainty (or insufficient knowledge) regarding the physical relationships involved.

The dynamic process of irrigation with saline water of a single plot can be characterized by one state variable representing variations of the soil salinity of the plot over time. For several plots the process can be characterized by the corresponding number of state variables, thus leading to a multi-state dynamic problem. As is well known the solutions of multi-state dynamic problems are technically difficult ("curse of dimensionality"), and sometimes impossible, without far reaching simplifications. However, as explained in the following sections in the particular case of our study, it is possible to refer to the essentially multi-state dynamic problem as a steady state - quasi static phenomenon. This chapter aims to justify this approach.

Optimization of irrigation of a single plot with saline water with the aid of a dynamic programming model

In this section we present a simple formulation of the stochastic dynamic problem of irrigation of a single fruit grove with reference to a multi-year planning horizon. Following the simple model, an extension to a more realistic situation with two (perennial) salinity sensitive fruit groves and several annual field crops,insensitive to salinity is presented.

The basic conception of the long-run problem, is one of a K-stage dynamic system, with a given number (M) of states, a succession of irrigation decisions, random events, transformation functions of the system from one state to another, and a profit (or loss) function related to the decision options and the states of the system. The nature of the problem fits well the dynamic programming model in Markov chains (Howard, 1960).

A planning horizon of K years (stages) is considered, a single year being a basic unit in the sequence. Each year begins at the end of the rainy season, confined to the winter. The analysis relates to a subhumid region in which the need for supplementary irrigation during the winter is negligible.

The following elements comprise the model:

$\xi_k(m)$ - denotes state m at the beginning of year k, at the termination of the rainy season of the previous year;

$d^i(m)$ - is the i-th decision ($i = 1,2,\ldots I$) taken at state m, at the beginning of any year. The definition of the feasible decisions set, from which the i-th decision is selected, is independent of the state of the system and the year in the sequence; it is assumed that in all states and years the same decisions are a priori feasible. The d^i decisions are defined in terms of: (a) method of irrigation; (b) timing, quantity and quality of water applied in irrigation; and (c) timing, quantity and quality of water applied for leaching.

Denote by $r(k)$ the discrete r-th level of rainfall in year k, with a probability $P(r)$; $(\sum_{r=1}^{R} P(r) = 1)$. It is assumed that the probability distribution of rainfall in year k is independent of the rainfall in previous years. The transformation probability of the system from state m to state m' following the i-th decision is $P^i_{m\,m'}$, with the corresponding transformation function:

$$\xi_{k+1}(m') = t[\xi_k(m),\ d^i(m),\ r(k)] \quad . \tag{2.2}$$

The immediate net return in any year k derived from decision i at state m is f_m^i. It comprises negative or zero returns, due to cost of leaching at the end of the winter and a positive return due to the yield achieved in response to decision i at state m. This return takes into account the loss accrued to the yield due to salt concentration in the soil profile, in the course of a single year.

Denote $\Lambda_k(m)$ - the maximal expected value of the cumulative net return at state m in year k computed as in (3) below.

The problem is to maximize $\Lambda_0(m)$ for any initial state m, using the recursive equation:

$$\Lambda_k(m) = \max_i \left[f_m^i + \frac{1}{1+\alpha} \sum_{m'=1}^{M} P_{m\,m'}^i \, \Lambda_{k+1}(m')\right] \qquad k = 0,1,\ldots,K-1 \tag{2.3}$$

where $\frac{1}{1+\alpha}$ is a time discount factor with rate of interest α and $\Lambda_K(m) = 0$ for all m, when K is sufficiently large. Note that $k=0$ denotes the first year in the sequence and K- the last one.

The model has been applied to an empirical analysis of citrus irrigation in the northern coastal plain of Israel (Yaron and Olian, 1973). The following section deals with the extension of the above model to a more complicated situation, namely, a farm with two groves in addition to field crops.

An application of an integrated dynamic and linear programming model to the analysis of optimal irrigation with saline water

In this section we consider a hypothetical farm with two fruit groves and several field crops. The fruit groves are sensitive to salinity while the field crops (mainly cotton) are not. The farm has at its disposition a given quota of water of low quality. In the case of excessive salt accumulation in the soil of the fruit goves, due to irrigation, leaching irrigation may be applied. If economically justified high quality water for leaching might be allocated to the farm by the proper authority without changing the farm's annual quota (implying substitution of some of the farm's poor quality by high quality water at 1:1 ratio). The farm's problem is the allocation of its irrigation water to the two groves and the field crops, with emphasis on the justification of leaching irrigation.

For each grove a given number of leaching and irrigation strategies may be conceived. A strategy is defined in terms of a quantity of water of given quality for a given year. A pair of leaching-irrigation strategies for the two groves, implicitly determines the amount of water remaining for the field crops. A linear programming model determines parametrically: 1) the optimal irrigation of the field crops (depending on the quantity of water remaining) and 2) the corresponding income derived from the field crops. Thus the income from the field crops is an implicit function of the irrigation and leaching decisions regarding the fruit groves.

For a given year k, given initial states of salinities of the soil of the two groves $\underline{\xi}_o = (\xi_o^1 , \xi_o^2)$ and a pair of leaching-irrigation strategies $\underline{d} = (d_1 , d_2)$, the immediate return can be calculated by

$$f(\underline{d} \mid \underline{\xi}_o) + g(d) \tag{2.4}$$

where

d_1 , d_2 define the quantity and quality of leaching and irrigation water for the first and second groves respectively;

$f(\underline{d} \mid \underline{\xi}_o)$ is the immediate return from the groves using $\underline{d}$, given the initial salinites $\underline{\xi}_o$;

$g(\underline{d})$ is the profit from field crops with optimal use of the water remaining, having used $\underline{d}$ for the groves;

Note that $\underline{\xi}_o$ is a function of leaching-irrigation strategies used in year $k-1$ and of the winter rainfall at the end of year $k-1$.

Denote by $\Lambda_{k+1}(\underline{\xi}_o(r))$, the total accumulated profit obtainable by using optimal strategies from year $k+1$ onwards, with $\underline{\xi}_o(r)$ being the vector of states of soil salinities at the beginning of year $k+1$ if the r-th rain level occurs. Using the backward induction approach of dynamic programming, at the beginning of year k the following function should be maximized with respect to $\underline{d}$ for each $\underline{\xi}_o$:

$$(2.5) \qquad \Omega_k(\underline{d}|\underline{\xi}_o) = f(\underline{d}|\underline{\xi}_o) + g(\underline{d}) + \frac{1}{1+\alpha}\sum_{r=1}^{R} \Lambda_{k+1}(\underline{\xi}_o(r)) \cdot P(r)$$

where $\frac{1}{1+\alpha}$ is the discounting factor corresponding to rate of interest α. Given $\Lambda_{k+1}(\underline{\xi}_o(r))$, $\Omega_k(\underline{d}|\underline{\xi}_o)$ can be calculated for each $\underline{d}$ and $\underline{\xi}_o$ in order to find:

$$(2.6) \qquad \Lambda_k(\underline{\xi}_o) = \max_{\underline{d}} \Omega_k(\underline{d}|\underline{\xi}_o)$$

The task of the program is to choose for each year k a vector $\underline{d}_k^*(\underline{\xi}_o)$ of optimal strategies for each possible value of the initial soil salinity vector $\underline{\xi}_o$.

The dependence of the immediate profit on the leaching-irrigation strategy is via salinity damage to crop yield on the one hand, and water cost on the other. The immediate return function is specified as:

$$(2.7) \qquad f(\underline{d}|\underline{\xi}_o) = \sum_{j=1}^{2} f(\underline{d}|\xi_o^j)$$

$$= \sum_{j=1}^{2} [(P_j - c_j)y_j(d_j, \xi_o^j) - c_w \cdot w(d_j) - FC_j]$$

where:

P_j - price per ton of fruit from grove $j(j=1,2)$;

$y(d_j, \xi_o^j)$ - yield (in tons per hectare) from grove j for initial soil salinity ξ_o^j and strategy d_j;

c_j - cost per ton dependent on yield;

c_w - cost of water per m³;

$w(d_j)$ - total amount of water for leaching and irrigation specified by d_j;

FC_j - fixed costs for grove j.

The physical functions expressing the effect of strategy i on the yields are discussed in Appendix A.

The above model has been designed for the analysis of optimal irrigation of perennial crops (or crop rotations) with saline water, with the emphasis being laid on the monitoring of soil salinity of the plots. The model involves two state variables; it can be somewhat extended in terms of additional state variables at the cost of giving up accuracy in their definitions. However the substitutability between the number of state variables and the accuracy in their definitions is limited.

A Quasi Empirical Analysis

Assume that the farm under consideration grows 16.6 hectares of tangerines, 13.1 hectares of avocados and 460 hectares of field crops (mainly cotton). The annual water quota is 1.8 million m³, with a salinity of 15.0 meq Cl/l (= 533 ppm). For each grove there is only one summer irrigation strategy available; 9000 m^3 per hectare for tangerines and 10,000 m^3 per hectare for avocados, namely 283,900 m^3 are allocated to summer irrigation of the groves.

The remaining water (1,516,100 m^3) is allocated to tentative salt leaching of the groves and the irrigation of the field crops. In the case of leaching-irrigation being justified, high quality water (5.6 meq Cl.l) might be allocated to the farm at the same price. There are three leaching strategies available for each grove, namely, 0, 1000 and 2000 m^3/ha respectively. The optimal profit from field crops using the remaining water in each case is illustrated by Table 2.1 for three leaching strategies.

The evaluation of the effect of irrigation leaching strategies on soil salinity and the yields of fruit groves is described in Appendix A.

Table 2.1 Income Derived from Field Crops as a Function of the Leaching Strategies of the Two Groves

Leaching Tangerine (m^3/ha)	Strategies Avocado (m^3/ha)	Field Crop Irrigation (m^3)	Field Crop Income(*) (IL)
0	2000	1,516,000	10,406,000
1000	0	1,499,500	10,084,700
1000	1000	1,486,400	9,744,780
1000	2000	1,473,300	9,371,300
2000	0	1,482,900	9,645,000
2000	1000	1,469,800	9,271,510
2000	2000	1,456,700	8,898,030

(*) At spring 1978 price level. One IL (Israel Lirah) = 6 US cents approx.

Production data for the groves are as follows :

	Tangerines	Avocados
Standard base yield (ton/ha)(*)	0.45	0.125
Price (IL/ton)(**)	6400	15,400
Skilled labor (days/ha)	30	30
Unskilled labor (days/ha)	28	30
Price of skilled labor (IL/day)	350	350
Price ofunskilled labor (IL/day)	150	150
Marketing costs (IL/ha)	9000	32,000
Price of water (IL/m^3)	1.5	1.5

Assume the following: (a) five discrete levels of rainfall: 250 mm., 300 mm., 350 mm., 400 mm., and 450 mm., with respective probabilities of 0.1, 0.2, 0.4, 0.2 and 0.1; (b) the possible salinity levels of the soil solution in spring are the integer values from 3 to 20; (c) the planning horizon is 25 years; (d) discounting rate of interest is 6% annually and (e) the initial soil salinity of 12 meq Cl/l in the tangerine grove and 16 meq Cl/l in the avocado grove in the spring of the first year (= the initial point of the planning horizon).

The results of the analysis suggest that the optimal policy for both groves is not to leach. The expected present value of the accumulated profit is IL 158 x 10^6 over the 25 year period.

The following are the initial soil salinity levels in the second spring:

Rainfall	250	300	350	400	450
Salinity in tangerines	15.21	14.35	23.53	12.74	11.99
Salinity in avocados	16.40	15.47	14.58	13.74	12.93

(*) With no loss due to salinity.

(**) At spring 1978 price level. One IL (Israeli Lirah) = 6 US cents approx.

(These salinity levels are rounded off to the nearest integer to enable the application of the dynamic programming algorithm, with discrete state variables).

In the spring of the second year the salinity levels ofthe groves are determined by the amount of rainfall. If, for example, there were 400 mm during the course of the winter, the opening state is 13 meq Cl/1 in the tangerines and 14 meq Cl/1 in the avocados. The optimal policy for the second year is again not to leach, and the expected total profit over the remaining 24 years is IL 155 x 10^6. The initial soil salinity level for the third spring may also be determined in this way.

For this particular example (and other situations which have been analyzed), it was found that no <u>matter how high the initial salinity levels of the groves</u>, the optimal policy was not to leach the soil in the spring, but rather to use all the water remaining for the field crops. Although it was assumed that the irrigation water was quite brackish (15 meq Cl/1) the reduction in the damage to the fruit groves induced by leaching was less, in monetary terms, than the increased monetary gain obtained by using water for irrigation of the field crops.

A detailed analysis of the immediate profit function shows, for example, that for an initial soil salinity of 16 meq Cl/1 in the avocado grove, increasing the leaching water from $0m^3$ to $1000m^3$ per hectare results in an increase of IL 29,443 in the immediate profit. If this is done in the first year, the increase in the expected stream of profits over the remaining 24 years in IL 23,756, so that the benefit from this strategy is IL 53,199. On the other hand, the alternative of increasing field crop irrigation from 1,503,000 m^3 to 1,516,100 m^3 results in an increase of IL 249,500 in income from the field crops. The cost/profit structure is apparently the reason for the nonprofitability of leaching operations.

It is important to emphasize that te above analysis has been performed with respect to: (a) Irrigation of fruit crops with a low quality water with salinity content of 15 meq Cl/l (= 533 ppm Cl); (b) A wide range of initial soil salinities (up to 30 meq Cl/l); (c) Leaching water with a relatively low salinity content of 5.6 meq Cl/l (= 200 ppm Cl); (d) Low up to moderate rainfall with a yearly mean of 350 mm and a 450 mm maximum; and (e) High income and salinity-sensitive fruit crops (avocado and tangerines). In view of the dominance of field crops (mainly cotton) irrigation over soil leaching in the above rather extreme case, the conclusions regarding non leaching as the preferred strategy can be considered as generally valid with respect to farms growing cotton as the marginal water user, and the conditions, now prevailing in the South and the Negev regions. This conclusion was further validated by several auxilliary analyses aimed at the evaluation of water contribution in leaching versus cotton irrigation (Appendix B).

Convergence of soil salinity to steady state

Scrutiny of the variations in the soil salinity over the years in the above analysis, as well as in numerous other simulations of the process of salt accumulation and leaching during irrigation with saline water, suggests that under conditions of continuous irrigation with water of same salinity, the salinity of the soil converges within 3-5 years to

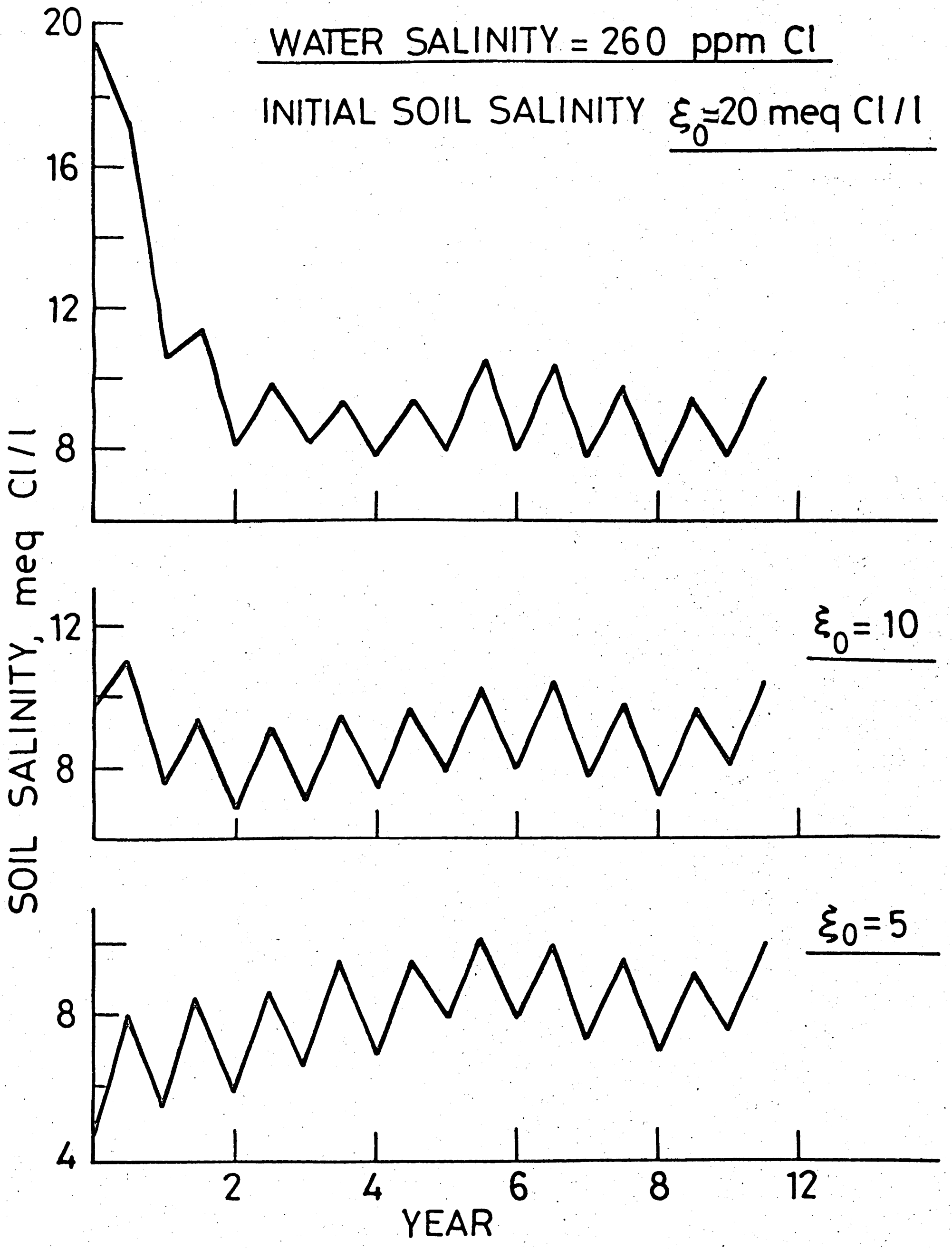


Fig. 2.2 Soil salinity under irrigation of fruit groves, subhumid region, medium-heavy soil, water salinity 260 ppm Cl.

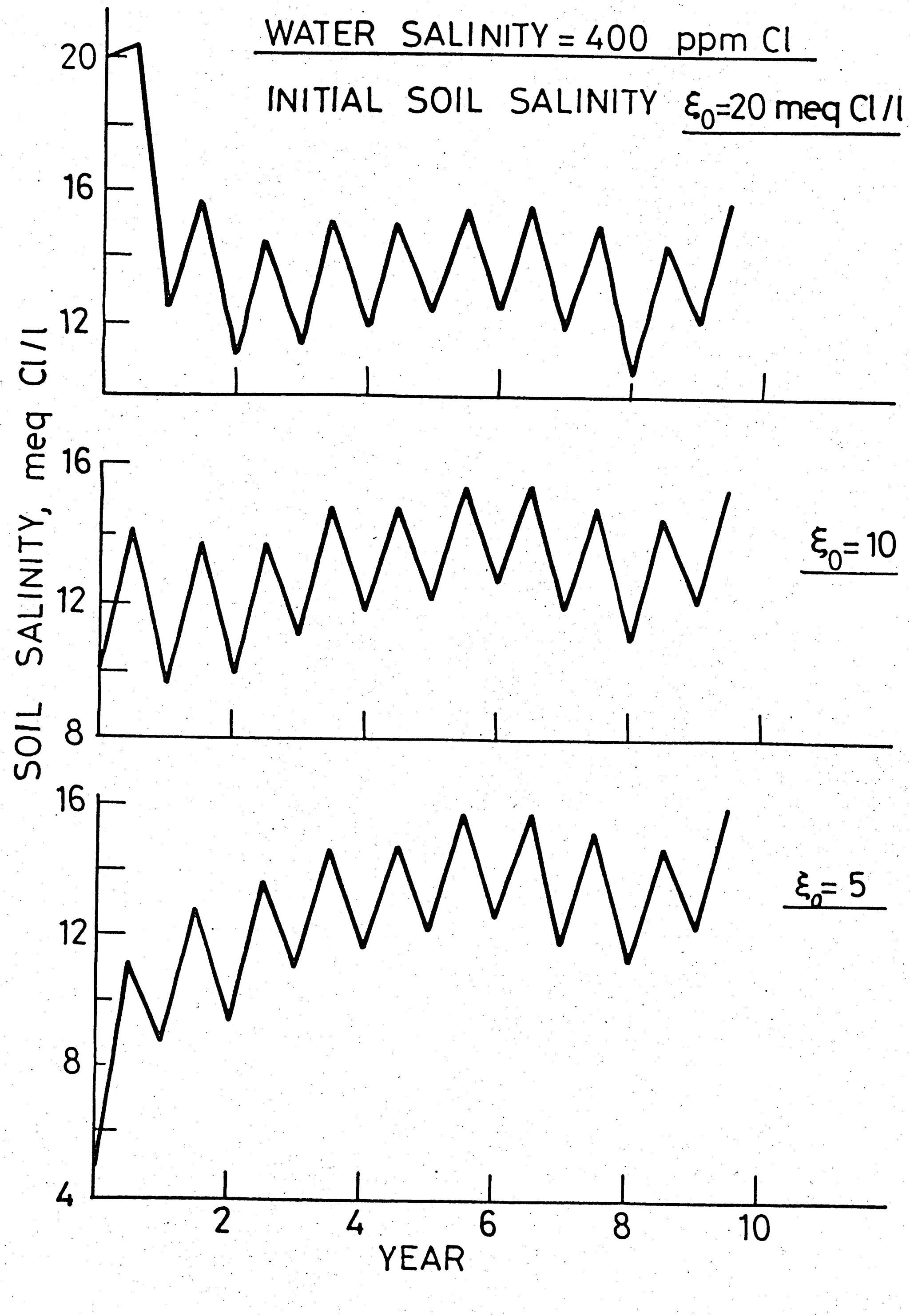


Fig 2.3 Soil salinity under irrigation of fruit groves, subhumid region, medium-heavy soil, water salinity 400 ppm Cl.

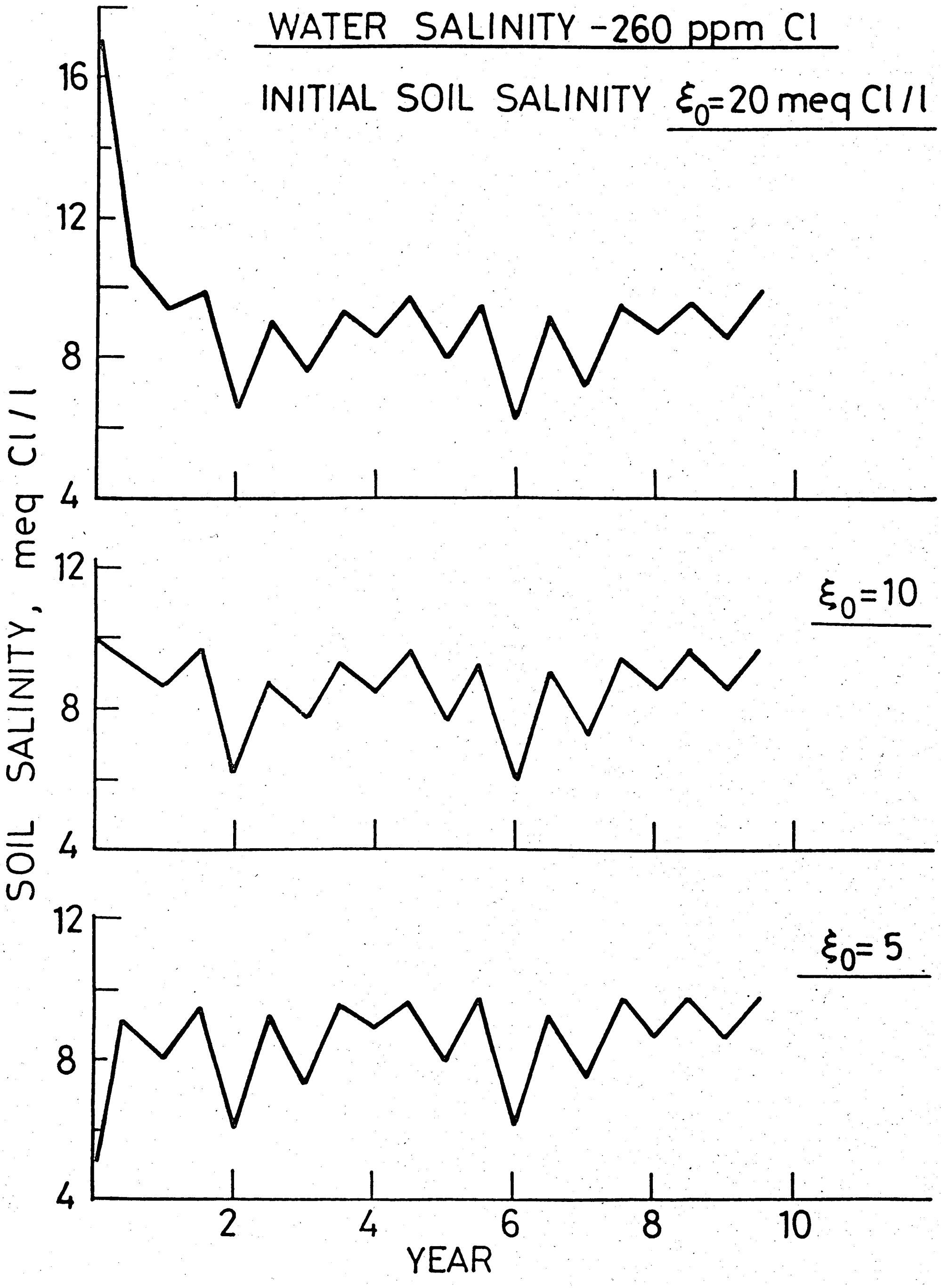


Fig. 2.4 Soil salinity under irrigation of fruit groves, semiarid region, light sandy soil, water salinity 260 ppm Cl.

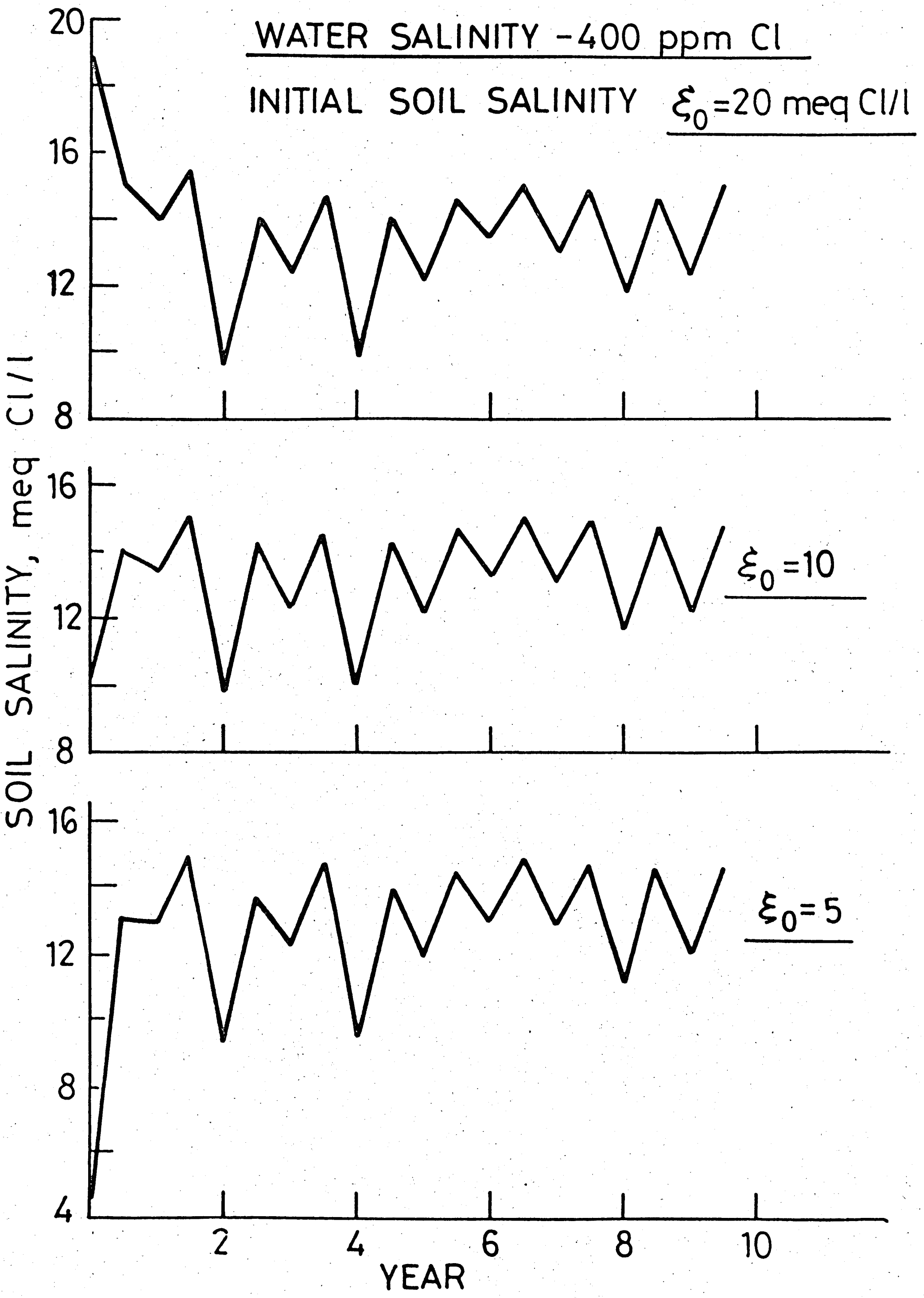


Fig. 2.5 Soil salinity under irrigation of fruit groves, semiarid region, light-sandy soil, water salinity 400 ppm Cl.

a steady state. The steady state is characterized by a given spring-fall average soil salinity level over the years, and between yearly fluctuations in the soil salinity, depending on the rainfall and soil properties. The level of the steady state average soil salinity depends on the salinity of the irrigation water, rainfall and soil properties. It does not depend on the initial soil salinity.

The convergence of soil salinity to a steady state in selected situations is illustrated by Figures 2.2-2.5. Scrutiny of the results of other simulations, not presented here, support the conclusion of this section.

Summary of Chapter Two

The chapter presents an approach to the analysis of optimal irrigation with saline water over time, involving salt leaching irrigations, whenever justified. The approach can be applied to farms with a limited number of plots on which crops sensitive to salinity are grown.

An application of the model to a quasi-empirical farm with two high income and salinity-sensitive fruit crops, under conditions of low-moderate rainfall, brackish irrigation water and low salinity water for leaching, suggests two major conclusions:

(1) Leaching is not justified. It is not competitive with the alternative use of water in the irrigation of cotton, under the prevailing technology and price structure. Since this conclusion was derived under somewhat extreme (hypothetical) conditions in favoring leaching it is valid with respect to the sample kibbutz farms in general, in which the justification of leaching is a priori weaker.(4

(4 See Chapter 3 for the details of the assumed conditions referred to in the study.

Furthermore, the no leaching conclusion is a priori valid with respect to the salinity sensitive field crops. This latter statement was later verified in a few analyses discussed in Chapter 3.

(2) Soil salinity converges in a few years to a steady state, characterized by a certain spring-fall average soil salinity over the years and between yearly fluctuations caused by the variations in rainfall.

In view of the above, no decisions responsive to soil salinity accumulation should be considered with respect to (the perennial) fruit crops and field crops not sensitive to salinity. The only adaptive - control - type decisions are a priori justified with respect to the acreage of field crops sensitive to salinity (e.g. carrots, onion). Since the total acreage per kibbutz of these latter crops is relatively small in comparison to the other ones (fruit groves, cotton and other non sensitive crops) it was decided to forgo the details of the between year fluctuations in the acreage of these crops in the empirical analysis, which follows. While the loss of accuracy is negligible, the considerable advantage of the approach is the applicability of a static analytical model, referring to a steady state and average soil salinity over a series of years.

Chapter 3

EMPIRICAL ANALYSIS OF KIBBUTZ FARMS

Generation of synthetic "observations" relating farm's income to water supply conditions

In view of the conclusions derived from the background analyses described in Chapter Two, a static linear programming model was applied to the determination of the long run optimal mix of crops and the optimal water allocation on the sample farms, with reference to steady state conditions. The sample of the kibbutz farms extends geographically from Lackish Region in the North to the Bessor Region in the south, with the annual rainfall in the area ranging from 200 to 500 mm,and soil types from medium heavy to sandy soils (Saturation percentage,SP, 66 and 29 respectively). The salinity of the water supplied to the kibbutzim from the National Water Carrier was 220-250 ppm Cl in recent years. The development and operation of the Dan reclaimed sewage project involves a planned rise in water salinity up to 260 ppm Cl. The long run trends in the supply demand relationships suggest a tendency towards increased salinity; however well below the 533 ppm Cl level used in the analysis of the hypothetical farm in Chapter Two.(5

The sample kibbutz farms grow fruit crops and field crops with most of the area of field crops being allocated to cotton which is insensitive to water salinity.

(5 Four of the sample kibbutzim operate their own wells, three of them highly saline (800-1200 ppm Cl). The highly saline wells were not included in the evaluation of the rates of substitution between "high" and "low" quality water.

The crops sensitive to salinity (mainly potatoes, carrots, onions) occupy relatively limited acreage. As previously mentioned, despite some yield losses accrued to the above salinity sensitive field crops, under no situation referred to in our study, salt leaching from the soil is justified. The issue of optimal water use on the farm reduces therefore to the allocation of the "good" and "low" quality water among the various crops.

One of the major policy decisions on the kibbutz farms is the position with respect to fruit crops most of which are sensitive to salinity. Three major scenarios were considered in our study:

(1) Reference to the acreage of the fruit crops as fixed. Note that in some situations (low water quality, low rainfall, heavy soil) the short run optimal economic decisions should be to eradicate some of the fruit groves. However, since fruit groves constitute a perennial activity, the short run decision is not necessarily the proper one, if expectations for improved profitability of the groves in the future prevail. Improved profitability could be the result of improved technology (cost reducing or yield raising), higher prices, due to reduced supply to local markets, increased demand on export markets, etc.

(2) Flexibility with respect to the acreage of fruit groves. This policy assumes that the short run optimal decisions are being executed and fruit groves which are not profitable in the short run will in reality be eradicated.

This policy is just the opposite of the previous one. Apparently a mix of the two policies is undertaken by the farmers at present and will be in the future.

(3) The last scenario is a hypothetical one and relates to a situation in which, by assumption the less profitable fruit groves have been substituted by more profitable and salinity sensitive fruit groves. It provides a framework for the following question: "What would have been the effect induced by the changes in water salinity if the fruit groves of the farms were all highly profitable and salinity sensitive?" While several fruit crops fall within this category (avocado, mango, tangerines, lemon, etc...) avocado was chosen to represent the prototype of the group. Note that the reference to a particular crop is immaterial; it is the prototype that counts (a discussion of major prototypes relevant to our study is given in a later section).

This senario will be referred to henceforth as "increased acreage of profitable and salinity sensitive fruit crops", or "Scenario 3".

Linear programming was applied to each farm in the sample aimed at the optimization of its system under varying water supply conditions. Towards this goal the following steps were undertaken with respect to each farm :

(a) Identification and quantification of the limited resources of the farm which have an impact on the selection of the crop mix and irrigation decisions, with emphasis on water supply.

(b) Evaluation of the alternatives for agricultural production (cropping alternatives and various irrigation regimes).

(c) Locally valid specification of input-output relationships in irrigation with saline water. (See Appendix C for details).

(d) Optimization of the system of the farm with the goal being the maximization of the farm's income subject to its water supply and other limited resources, given the technology and prices of inputs and outputs.

Stages (a) - (d) were repeated for different combinations of water quantity and quality as detailed in the following.

The linear programming model applied was to maximize f :

$$f = \underline{C}_1\underline{X}_1 + \underline{C}_2\underline{X}_2 + \underline{C}_3\underline{X}_3 \tag{3.1}$$

Subject to :

$$\begin{array}{lllll} A_1\underline{X}_1 & & & \leq & \underline{b}_1 \\ & A_2\underline{X}_2 & & \leq & \underline{b}_2 \\ D_1\underline{X}_1 & + D_2\underline{X}_2 & + D_3\underline{X}_3 & \leq & \underline{b}_3 \\ & \underline{X}_1 , \underline{X}_2 , \underline{X}_3 & & \leq & \underline{0} \end{array} \tag{3.2}$$

with:

$\underline{X}_1$, $\underline{X}_2$ = vectors representing activity levels of crops irrigated with "good" and "low" quality (saline) water, respectively;

$\underline{X}_3$ = vector of activity levels representing unirrigated crops;

$\underline{C}_1$,$\underline{C}_2$ = vectors representing net income coefficients per activity unit of crops irrigated with "good" and "low" quality water, respectively;

$\underline{C}_3$ = vector of income coefficients per activity unit of unirrigated crops;

$\underline{b}_1$,$\underline{b}_2$ = water restrictions of "good" and "low" quality, respectively;

A_1,A_2 = water input coefficients related to crops irrigated with "good" and "low" quality water, respectively;

$\underline{b}_3$ = vector of restriction levels other than water;

D_1,D_2,D_3= technological coefficients related to restrictions other than water.

The above model was solved by parametric programming with reference to various combinations of water quantity and quality (with the salinity of "low" quality water ranging between 260 ppm Cl and 400 ppm Cl) and three scenarios regarding fruit crop policy, previously discussed (see Appendix C for details). The optimal solution of each LP run provided a vector relating the farm's income with the quantity of "good" quality water (220 ppm Cl) and the quantity and salinity level of "low" quality water, under each of the policies considered for fruit crops.

Estimates of the marginal rate of substitution between "good" and "low" quality water

For each of the sample farms the relationship between the farm's income (value added), the quantity of good and low quality water and the policy with respect to fruit groves was estimated by fitting a function to the vectors of "observations" generated as previously described. A multiple regression technique was applied; note however that since the data were synthetically generated, this was not a conventional regression analysis in the statistical sense. The technique should be viewed rather as an application of a least square approach to fitting a curve to a given set of data, with no errors of observations and no stochastic properties in the estimated coefficients. Nevertheless the conventional measures of fit of the regressions, such as R^2, can be applied as useful indicators, but their modified meaning should be kept in mind.

The following variables were defined:

Y - income (=value added) of the farm (000 I.L., spring 1978 prices);[6]

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[6] One I.L. (Israel pound) = 6US cents.

GW - quantity of good quality water (220 ppm Cl) at the farm's disposal (000 m³).

BW - quantity of low quality water at the farm's disposal (000 m³).

CL - salinity index of the low quality water, formally defined as CL = (450 - C) with C being the Chloride concentration of the low quality water (ppm Cl). Cl represents the divergence from an upper bound of 450 ppm Cl.

V_1 - a dummy bivariate 0-1 variable attaining the value of 1 if the rigid acreage policy for fruit crops is applied, 0, otherwise.

V_2 and V_3 - bivariate variables defined as follows:

$$V_2 = \begin{array}{r|l} 1 & \text{if the flexible acreace policy with respect to fruit crops is applied;} \\ 0 & \text{otherwise.} \end{array}$$

$$V_3 = \begin{array}{r|l} 1 & \text{if "Scenario 3" with respect to fruit crops prevails;} \\ 0 & \text{otherwise.} \end{array}$$

The following specifications of the relationship between the income (Y) and the independent variables were applied :

$$(3.3) \qquad Y = b_1 \, GW + b_2 \, BW + b_3 \, BW \cdot CL + \sum_{i=1} c_i \, V_i$$

$$(3.4) \qquad Y = b_0 + b_1 \, GW + b_2 \, BW + b_3 \, BW \cdot CL$$

$$(3.5) \qquad Y = b_1 \, GW^{\alpha} + b_2 \, BW + b_3 \, BW \cdot CL + \sum_{i=1}^{3} c_i \, V_i$$

Regressions (3.3), (3.5) and (3.6) were estimated for each farm for the whole set of observations while regression (3.4) was estimated for selected subsets with a given V_i . The estimates of the regression coefficients for two selected kibbutzim are presented in Tables 3.1 and 3.2. In the last three columns of these tables the marginal value product (MVP) of good and low quality water is presented. The first column of the three presents the MVP of good water (220 ppm/Cl), the second column presents the range of the MVP values for the low quality water with salinity ranging from 400 ppm/Cl to 260 ppm/Cl,and the third column presents the MVP for the average low quality (320 ppm Cl). All R^2 values computed by the standard regression technique were higher than 0.95. However the interpretation of the R^2 values, in view of the fact that the data were artificially generated within a deterministic framework, should be recalled.

Scrutiny of Tables 3.1 and 3.2 suggests that the MVP estimated from regressions (3.3) and (3.5) are quite similar.a similar result was obtained for the other farms in the sample. As expected $c_1 < c_2 < c_3$; noteworthy is the difference between c_3 and the values of c_1 and c_2 ranging from 1.5 to 3 million I.L., with results in the same order of magnitude being obtained for the other sample farms.

Alternative regression specifications attempted, such as the Cobb-Douglas function; as well as several modifications of (3.3) and (3.5)involving the introduction of non linear terms did not yield improved results.

The above estimates relate to the total water supply to the sample kibbutz farms, with the quantity of water ranging from 70% to 130% of the currently allocated quota. However only a certain share of the farms' water is used in the irrigation of salinity sensitive crops. Table 3.3 indicates that the share of the total water supply allocated to the irrigation of

Table 3.1 Estimated Linear Regression Coefficients and MVP of Water for Two Selected Kibbutz Farms

Regression	Observations set	Regression coefficients							MVP IL/m³ *)		
		b_0	b_1	b_2	b_3	c_1	c_2	c_3	GW	BW	
										Range**)	Average&)
	Kibbutz A										
(3.3)	All observations (63)	-	.00445	.00400	1.68×10^{-6}	.078	.453	2.016	4.45	4.08-4.32	4.22
(3.4a)	Observations with $V_1 = 1$ (21 observations)	.0982	.00439	.00406	1.18×10^{-6}	-	-	-	4.39	4.12-4.28	4.21
(3.4b)	Observations with $V_2 = 1$ (21 observations)	.6118	.00422	.00400	7.95×10^{-7}	-	-	-	4.22	4.04-4.15	4.10
(3.4c)	Observations with $V_3 = 1$ (21 observations)	1.8380	.00476	.00392	3.07×10^{-6}	-	-	-	4.76	4.07-4.50	4.32
	Kibbutz B										
(3.3)	All observations	-	.00522	.00472	1.87×10^{-6}	-.684	.774	2.348	5.22	4.81-5.08	4.96
(3.4a)	Observations with $V_1 = 1$ (21 observations)	.7749	.00526	.00498	1.17×10^{-6}	-	-	-	5.26	5.06-5.21	5.14
(3.4b)	Observations with $V_2 = 2$ (21 observations)	.9614	.00497	.00463	1.62×10^{-6}	-	-	-	4.97	4.69-4.85	4.78
(3.4c)	Observations with $V_3 = 2$ (21 observations)	2.3248	.00536	.00451	3.37×10^{-6}	-	-	-	5.36	4.57-4.73	4.66

Footnotes:

*) At spring 1978 prices; one I.L. (Israel pound) = 6US cents.

**) With BW at its mean value, and water quality ranging from 400 to 260 ppm Cl.

&) With BW and water quality at their mean values.

Table 3.2 Estimated Non Linear Regression Coefficients and MVP of Water for Two Selected Kibbutz Farms

		Regression coefficient							MVP IL/m³ *)		
									GW+)	BW	
Regression	Observations set	b_1	α	b_2	b_3	c_1	c_2	c_3		Range**)	Average&)
(3.5	Kibbutz A-all observations (63)	.0067	.9383	.0039	1.68x10^{-6}	.1200	.4957	2.0582	4.45	3.98-4.22	4.12
(3.5)	Kibbutz B-all observations (63)	.00690	.9592	.00466	1.88x10^{-6}	-.6482	.8082	2.3836	5.25	4.75-5.02	4.90

Footnotes:

*) See footnotes to Table 3.1

**) See footnotes to Table 3.1

&) See footnotes to Table 3.1

+) With GW at its mean value.

Table 3.3 Share of Total Water Supply Allocated to Irrigation of Fruit Crops on Kibbutz Farms in the South and the Negev

Kibbutz No. & region	Fruit Crops Area ha.	Share of Water Allocated to Fruit Crops %
(1) South	26.3	14
(2) South	50.0	28
(3) South	56.7	31
(4) N.Negev	36.7	14
(5) N.Negev	51.6	35
(6) N.Negev	42.0	27
(7) N.Negev	92.5	41
(8) S.Negev	20.2	11
(9) S.Negev	38.9	20
(10) S.Negev	37.0	23
Average	44.7	25

Table 3.4 Estimated Regression Coefficient and MVP of Water for Two Selected Kibbutz Farms with Good Quality Water Restricted to 30% of the Total Quota

Regression	Observations set	b_1	b_2	b_3	c_1	c_2	c_3	MVP IL/m³ *)		
								GW	BW	
									Range **)	Average &)
(3.3)	Kibbutz A Good Quality Restricted to 30% of Water Quota (54 Observations)	.00470	.00392	$1.6\text{x}10^{-6}$	0.1396	0.5203	2.0489	4.70	4.00-4.22	4.13
(3.3)	Kibbutz B Good Quality Restricted to 30% of Water Quota (54 Observations)	.00541	.00466	$1.8\text{x}10^{-6}$	-.6328	.8327	2.3748	5.41	4.75-5.02	4.90

Footnotes:

*) See footnotes to Table 3.1

**) See footnotes to Table 3.1

&) See footnotes to Table 3.1

fruit crops on the sample farms falls within the range of 11 to 41% with the average being 25%. The other major crops sensitive to salinity are carrots, onion and potatoes; the acreage of these crops is rather limited and their water input per land unit area is about one half of that applied to fruit crops. Table 3.4 presents estimated regressions (3.3) for two selected farms with the observations restricted to those in which good quality water did not exceed 30% of the total quota. As expected the regression coefficients obtained for GW were higher than those corresponding to the complete observations sets (regression (3.3) in Table 3.1).

Regressions (3.3) - (3.5) were computed for the various observation subsets for the other kibbutzim in the sample and the estimates of the MVP's for good and low quality water were derived. These were later used to compute the marginal rate of substitution of low quality for good quality water, with constant income:

$$\frac{dBW}{dGW} = \frac{MVP_{GW}}{MVP_{BW}}$$

The marginal rates of substitution (MRS) between low quality and good quality water for the sample farms under conditions of fixed acreage of fruit groves (Scenario 1) are presented in Table 3.5; they were derived from the estimates of regressions (3.4a). Table 3.6 presents the estimates of MRS between low quality and good quality water derived from regressions (3.3), which refer to observations with good quality water restricted to 30% of the total quota.

Table 3.5 (column 6) indicates that the estimated MRS values for the <u>average water salinity of 320 ppm Cl</u> fall within the range not exceeding 1.09. (See column 5 for the MRS values for water salinity of 400 and 260 ppm Cl, respectively.) The MRS values derived from regressions (3.4b) (flexible fruit groves area, $V_2 = 1$) are very close to those presented in Table 3.5 and are not shown here. When the quantity of good quality water is restricted to 30% of the quota, and a mixed scenario with respect to fruit groves is assumed (V_1, V_2 and V_3 each equalling 1 in 1/3 of the cases) the MRS values rise considerably as shown by Table 3.6.

The MRS estimates presented in Tables 3.5 and 3.6 lead to similar results in terms of the compensating quantity of low quality water needed for maintaining the income unchanged. Consider a farm with a water quota Q; referring to the total quota and the overall mean MRS of 1.06 (Table 3.5) the compensating quantity will be $0.06\ Q$, while in reference to 30% of the quota and the overall mean MRS of 1.23 (Table 3.6) the compensating quantity is $0.23 \times 0.30 \times Q = 0.069\ Q$. It should be noted however, that the above refers to averages of the MRS values; for individual farms the results according to the computation of the two estimates may be quite divergent.

The estimated MRS values under assumed conditions of Scenario 3 are shown by Table 3.7. The overall mean of the MRS values is 1.16, higher by 10% than under conditions of Scenario 1.

An attempt to generalize and summarize the above results is not an easy task. While the individual farms differ considerably one from the other, generalizations are needed for policy decisions, and are expected by policy makers. Table 3.8 which presents the frequency distribution of the MRS values under Scenarios 1 and 3 can be referred to as a background for a summary. It should be noted however that the estimated MRS values were derived from analyses based on estimates and assumptions with respect to: (a) functions representing the physical relationships involved and the relevant parameter values; and (b) relative prices.

These are subject to variation, the magnitude of which is only partly objectively known. Due to this latter fact and in view of the complexity of the overall relationships, only a subjective evaluation of the results and their generalization may be attempted. Our subjective summary for water salinity approaching 300 ppm Cl is an MRS of 1.10 as a conservative measure and an MRS of 1.20 as a liberal one. Obviously, different readers will formulate their own generalizations; farmers to be affected by increased water salinity in the future will tend towards the higher MRS values.

It should be noted that the substitution of poor quality for good quality water is only one policy measure to compensate the farmers' income for increased salinity; numerous other policy options are open. Out of these, special mention should be made of the possibility of augmenting the supply of water to farms during the cotton irrigation season without changing the yearly quota. As is known cotton is not sensitive to salinity, and the bottlenecks in water supply on numerous kibbutz farms during the peak season of irrigation of cotton restrict its acreage.

Another comment refers to the potential of new irrigation technologies to reduce salinity-induced losses in citrus, avocado and other fruit crops. This potential is thus far not sufficiently known and debated by experts. Additional work is needed in order to evaluate it in quantitative terms.

The issue of the optimal compensation policy for increasing water salinity cannot be thouroughly discussed without reference to the long run trends in the farms' development and the effect of increased salinity on these trends. The results of the linear programming analyses point out that increased water salinity leads to eradication of fruit groves. In this context three categories of fruit crops can be distinguished:

a) Medium-high sensitivity to salinity and low profitability under conditions of spring 1978 (e.g. grapefruit).

Table 3.5 Marginal Productivity and Marginal Rates of Substitution between Low and Good Quality Water under Conditions of Fixed Acreage of Fruit Groves

Kibbutz No. & region +)	MVP IL/m^3 *)			MRS	
	GW	BW			
		Range **)	Average &)	Range **)	Average &)
(1)	(2)	(3)	(4)	(5)=(2)/(3)	(6)=(2)/(4)
1, S	4.39	4.12-4.28	4.21	1.07-1.03	1.04
2, S	3.64	3.31-3.60	3.42	1.10-1.01	1.06
3, S	4.10	3.66-3.85	3.75	1.12-1.06	1.09
4, NN	3.23	2.76-3.12	2.97	1.17-1.04	1.09
5, NN	5.26	5.06-5.21	5.14	1.04-1.01	1.02
6, NN	6.55	6.04-6.41	6.26	1.08-1.02	1.05
8, SN	3.03	2.65-2.89	2.79	1.14-1.05	1.09
9, SN	3.34	2.92-3.21	3.09	1.14-1.04	1.08
10, SN	6.70	6.11-6.55	6.29	1.10-1.02	1.06

Source: Estimates of regressions (3.4a).

Overall Mean = 1.06

Footnotes:

+) S = South; NN = North Negev; SN = South Negev.

*) At spring 1978 prices; one IL (Israel pound) = 6US cents.

**) With BW at its mean value and water quality ranging from 400 60 260 ppm Cl.

&) With BW and water quality at their mean values.

Table 3.6 Marginal Productivity and Marginal Rates of Substitution between Low and Good Quality Water with Reference to Observations in which Good Quality Wates is Restricted to 30% of the Total Quota

Kibbutz No. & region +)	MVP IL/m^3 *)			MRS	
	GW	BW			
		Range **)	Average &)	Range **)	Average &)
(1)	(2)	(3)	(4)	(5)=(2)/(3)	(6)=(2)/(4)
1, S	4.70	4.00-4.22	4.13	1.31-1.17	1.23
2, S	4.43	3.85-4.09	3.99	1.15-1.08	1.11
3, S	4.15	3.66-3.85	3.78	1.13-1.08	1.10
4, NN	4.57	2.62-2.99	2.83	1.74-1.53	1.61
5, NN	5.41	4.75-5.02	4.90	1.14-1.08	1.10
6, NN	6.41	5.68-6.08	5.88	1.13-1.05	1.09
7, NN	4.70	3.27-3.39	3.34	1.44-1.39	1.40
8, SN	3.37	2.59-2.88	2.75	1.30-1.17	1.23
9, SN	3.76	2.87-3.21	3.06	1.31-1.17	1.23
10, SN	7.12	5.99-6.37	6.21	1.19-1.12	1.15

Overall Mean = 1.23

Source: Estimates of regression (3.3) for the corresponding subset of observations.

Footnotes:

+) See footnotes to Table 3.5.

*) See footnotes to Table 3.5.

**) See footnotes to Table 3.5.

&) See footnotes to Table 3.5.

Table 3.7 Marginal Productivity and Marginal Rates of Substitution between Low and High Quality Water under Conditions of "Scenario 3" 1)

Kibbutz No. & region +)	MVP IL/m³ *)			MRS	
	GW	BW			
		Range **)	Average &)	Range **)	Average &)
1, S	4.76	4.07-4.50	4.32	1.17-1.06	1.10
2, S	5.76	5.14-5.46	5.28	1.12-1.05	1.09
3, S	4.43	3.69-3.96	3.84	1.20-1.12	1.15
4, NN	4.86	3.20-3.62	3.44	1.50-1.34	1.41
5, NN	5.36	4.57-4.73	4.66	1.17-1.13	1.15
6, NN	6.35	5.83-6.20	6.06	1.09-1.02	1.05
7, NN	4.84	3.54-4.39	4.15	1.36-1.10	1.17
8, SN	3.34	2.87-3.28	3.10	1.16-1.02	1.08
9, SN	3.92	2.99-3.06	3.03	1.31-1.28	1.29
10, SN	7.00	6.18-6.70	6.48	1.13-1.04	1.08

Overall Mean = 1.16

Footnotes:

1) See text for details of "Scenario 3".

+) See footnotes to Table 3.5 .

*) See footnotes to Table 3.5.

**) See footnotes to Table 3.5.

&) See footnotes to Table 3.5.

Table 3.8 Frequency Distribution and Means of the Estimated MRS Values under Selected Situation

Observations Set and Source	Salinity content of low quality water ppm Cl	MRS					
		≦ 1.05	1.06-1.10	1.11-1.20	1.20 <	Total	Median
		%					
All observations,	260	90	10	-	-	100	≦ 1.05
"Scenario 1"	320	30	70	-	-	100	1.06-1.10
(Table 3.5)*)	400	10	45	45	-	100	1.06-1.20
			40	50			
All observations,	260	50	10	20	20	100	≦ 1.10
"Scenario 3"*)	320	10	40	30	20	100	1.06-1.20
(Table 3.7)**)	400	-	-	70	30	100	1.11-1.20

Footnotes:

*) Note that the MRS values derived under conditions of "Scenario 2" are very close to those of "Scenario 1".

**) See text for the discussion of "Scenario 3".

b) High sensitivity to salinity and medium-low profitability (e.g. oranges, deciduous fruit crops).

c) High sensitivity to salinity and relatively high profitability (e.g. avocado, mango, tangerines).

Generally, fruit crops of category (a) and (b) are the first ones to be eradicated; in effect a trend of reduction in their acreage has been observed in recent years (due to low profitability) under the prevailing water salinities. On the other hand those of category (c) are the most persistent, in view of their high profitability.

The overall results indicate that a considerable reduction in the acreage of fruit crops will be justified, and compensated by a rise in the area of cotton.

Thus, the increased water salinity leads to a structural change - increased dependence on cotton, contrary to the sound management rules in favor of diversification, which guided the kibbutz farms in the past. A detailed evaluation of such structural change falls beyond the scope of our study; nevertheless the effect of increased water salinity in this direction should be emphasized.

This structural change <u>induced</u> or <u>augmented</u> by increased water salinity is perhaps the most important and negative effect of increased water salinity.

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Appendix A

The effect of irrigation-leaching strategies on soil salinity and yields of fruit groves.

From the salt balance equation in irrigation (Yaron and Olian, 1973), a transformation function is obtained:

$$\text{(A.1)} \qquad \hat{\xi} = \frac{Q \cdot C + \xi(V - \frac{\beta}{2} Q)}{(V + \frac{\beta}{2} Q)}$$

where:

$\hat{\xi}$ - soil salinity after irrigation, (meq.Cl/l);

Q - depth of irrigation water applied (mm);

C - chloride concentration in the irrigation water (meq.Cl/l);

ξ - soil salinity before irrigation (meq.Cl/l);

V - depth of water contained in the root zone (mm);

β - leaching parameter, denoting percentage of chloride leached below the root zone during irrigation.

Denote the parameters of strategy d^i by Q_L^i, C_L^i, Q_I^i, C_I^i, where Q_L^i, Q_I^i are the water quantities and C_L^i, C_I^i are the water salinities stipulated by d^i.

From (A.1) we obtain for either of the groves j (with grove index j omitted) :

$$\text{(A.2)} \qquad \hat{\xi}^i = \hat{\xi}^i(\xi_o, d^i) = \frac{Q_L^i \quad C_L^i + \xi_o (V - \frac{1}{2} \hat{\beta} \cdot Q_L^i)}{V + \frac{1}{2} \hat{\beta} \cdot Q_L^i}$$

(A.3) $$\hat{\hat{\xi}}^i = \hat{\hat{\xi}}^i\,(\xi_1\,,\,d^i) = \frac{Q_I^i \quad C_I^i + \hat{\xi}^i\,(V - \frac{1}{2}\,\hat{\hat{\beta}} \cdot Q_I^i)}{V + \frac{1}{2}\,\hat{\hat{\beta}} \cdot Q_I^i}$$

where:

$\hat{\xi}^i$ - soil salinity after spring leaching in grove by strategy d^i;

$\hat{\hat{\xi}}^i$ - soil salinity after summer irrigation in grove by strategy d^i;

$\hat{\beta}$ - spring leaching parameter;

$\hat{\hat{\beta}}$ - summer leaching parameter.

Salinity damage to yield is determined via the electroconductivity of the soil solution, assumed to be a function of two known parameters, A and B (Maas and Hoffman, 1977). Soil salinities $\hat{\xi}^i$, $\hat{\hat{\xi}}^i$ determine the value of the electroconductivity of the soil solution (EC_i) .

(A.4) $$EC_i = 0.62 + 0.137\,\frac{\hat{\xi}^i + \hat{\hat{\xi}}^i}{2}$$

Referring now separately to the two groves $(j = 1,2)$ and denoting by Y_0^j the base yield from grove j, in the absence of salinity damage, the actual yield is defined by :

(A.5) $$Y_j(d^i,\,\xi_o) = Y_0^j\,[1 - 0.01 \cdot B\{\max(0, EC_i^j - A)\}]\quad .$$

where EC_i^j is the electroconductivity of the soil solution in the j-th grove using strategy d^i .

The following numerical values were assumed:

(a) the parameters of the yield function for both fruit groves are $A = 1.3$ and $B = 30.0$;

(b) identical soil parameters for both groves (bulk density 1.5 and saturation percentage 39, giving $V = 526.5$);

(c) the leaching coefficients of the soil (β) for spring, summer and winter are 0.7 , 0.63 and 0.6 respectively.

Appendix B

Estimated returns to water allocated to salt leaching

Table B.1 presents estimated returns to salt leaching under selected conditions. As the table indicates the estimated values fall within the range between 0.6 - 1.7 I.L./m^3 at 1978 spring price level. These values are considerably lower than estimated returns to water allocated to irrigation of cotton, or the estimated MVP values of water on the sample kibbutz farms presented in Tables 3.5 - 3.7 in Chapter 3 in the text.

Table B.1 : Estimated returns to salt leaching under selected situations(1

Situation No.	Region and Climate	Soil type SP, %	Crop	Water quantity used in leaching, m^3/ha	Return to leaching I.L/m^3 (2
1	South	47	Avocado	1000	1.7
2	South	47	Avocado	1500	1.0
3	South	47	Citrus (Valencia)	1000	1.0
4	South	47	"	1500	0.6
5	Negev	30	Avocado	1000	1.6
6	Negev	30	Avocado	1500	1.1
7	Negev	30	Citrus (Valencia)	1000	0.8
8	Negev	30	"	1500	0.6

(1 At spring 1978 price level. One IL (Israel Lirah) = 6US cents approximately.

(2 In all situations a steady state was simulated; continuous irrigation with water containing 300 ppm cl, and leaching with water containing ppm cl were assumed.

Appendix C

Assumptions and data for the linear programming analysis

1. Water supply situations

The following water supply situations were considered:

1) Four levels of water salinity were included in the analysis:

   (a) 220 ppm/Cl - referred to as a "good" quality water, and

   (b) three levels of "low" quality water with:

   260 ppm/Cl, 300 ppm/Cl and 400 ppm/Cl, respectively.

2) Seven situations with respect to the shares of "good" and "low" quality water in the total water supply were distinguished, with 100% of the total water supply being equal to the annual water quota allotment to the farm effective in 1979. The seven combinations were:

Situation Code	% of good quality water	% of low quality water
1	100	0
2	0	70
3	10	90
5	30	70
6	0	100
9	30	100
10	0	130

The restrictions of water supply in the peak months were specified in accordance with the actual situation on each kibbutz.

Altogether with respect to each of the sample farms, the linear programming analysis referred to three salinity levels of the poor quality water, seven situations with respect to "good" and "low" quality shares in the water supply, and three policy scenarios regarding fruit groves, resulting in 63 combinations.

2. Input output coefficients

The input output relationships in irrigation with water of differing salinity levels under the agroclimatic conditions of sample farms (soil types and rainfall) were derived in two stages: (1) simulation of soil salinity accumulation and leaching till steady state is achieved, and (2) evaluation of the yield loss in response to the soil salinity (see Yaron et al. (1979, Hebrew) for details). Conventional sprinkler irrigation methods were assumed.

Regarding other inputs the prevailing technology and the corresponding input-output relationships were assumed.

Spring 1978 price level was referred to with one I.L. (Israel pound) = 6 US cents.

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