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Environmental Protection Technology Series

MINIMIZING SALT IN RETURN FLOW THROUGH IRRIGATION MANAGEMENT

Robert S. Kerr Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Ada, Oklahoma 74820

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MINIMIZING SALT IN RETURN FLOW THROUGH IRRIGATION MANAGEMENT

Interim Report

by

U.S. Salinity Laboratory Staff
Agricultural Research Service
U.S. Department of Agriculture
Riverside, California 92502

Interagency Project No. EPA-IAG-D4-0370

Project Officer

James P. Law, Jr.
Source Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C. Galegar

William C. Galegar
Director
Robert S. Kerr Environmental
Research Laboratory

PREFACE

Maintaining or improving water quality is a prime objective for the United States and an issue of considerable importance worldwide. In arid areas where food production depends on irrigated agriculture, the relation between irrigation and water quality is often dominant.

The Colorado River exemplifies the complexity of problems encountered in a highly developed major river basin. Technological solutions are sought for problems created by increasing salinity as use of the River's water continues to intensify -- problems of economics, resource conservation, and international comity across a wide spectrum of user interests.

The U.S. Salinity Laboratory is concerned with all aspects of salinity as it affects agricultural production and with the effects of agricultural operations on water quality.

This report deals with a study to evaluate the potential of modifying irrigation management to obtain higher irrigation water use efficiency and thus reduce the adverse effects of irrigation on water quality degradation. Application of this concept must always be carefully related to the specific situation. At the site chosen for these studies, the Wellton-Mohawk Division of the Gila Project in Arizona, any reduction in return flow achieved through irrigation management would result in an equal reduction in drainage water volume to be desalted by a planned desalination complex.

Jan van Schilfgaarde
Director
U.S. Salinity Laboratory

ABSTRACT

Two field experiments are being conducted in southwestern Arizona to investigate the potential of reducing the salt load in irrigation return flow by decreased leaching. Three leaching treatments of 5, 10, and 20%, replicated nine times for citrus and five times for alfalfa, were established and compared with conventional flood irrigation management.

Three years' results on citrus indicate that leaching percentages of 8, 11, and 22 were achieved, compared to 47% on the border flood check. The best estimate of the annual evapotranspiration of citrus is 1400 mm. To date, reduced leaching has not adversely affected fruit quantity or quality. If leaching were reduced to 20%, the volume of drainage from the 3000 ha of citrus in the district would be decreased 43.7×10^6 m^3/yr and the salt load would be cut by 45,500 Mg/yr.

Leaching percentages of about 3, 5, and 10 have been obtained in the alfalfa after 19 months. The level-basin flood check received the same amount of water as the high leaching treatment. Results indicate that the sprinkled plots were underirrigated and that the annual evapotranspiration for alfalfa is about 2000 mm. Yields from the sprinkled plots have been 16% less than those on the flooded field because of underirrigation, weed problems, and soil compaction. Even with reseeding and less frequent irrigation, it is unlikely that substantial improvement is possible over the low leaching obtained on the level-basin flood check.

This interim report was submitted in fulfillment of Interagency Agreement No. EPA-IAG-D4-0370 by the U.S. Salinity Laboratory, USDA-ARS, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from December 5, 1973 through December 4, 1976. The agreement has been extended through December 1978, at which time the final results will be reported.

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SELECTED ABBREVIATIONS AND CONVERSIONS

Symbol	Meaning	Equivalent
m	meter	3.3 feet
ha	hectare	2.47 acres
ℓ	liter	0.26 gallons
kg	kilogram	2.205 lbs
Mg	megagram	tonne, 2205 lbs
s	second	
kPa	kilopascal	0.01 bar, 0.15 lb per square inch
kW	kilowatt	1.34 horsepower
mmole	millimole	10^{-3} gram-formula weight
ℓ/s	liters per second	15.8 gallons per minute
mg/ℓ	milligrams per liter	1 part per million
S/m	Siemens per meter	10 millimhos per centimeter
meq/ℓ	milliequivalents per liter	
C_{Cl}	chloride concentration in meq/ℓ	
Cl_{dw}	chloride concentration of drainage water	
Cl_{iw}	chloride concentration of irrigation water	
EC_e	electrical conductivity of saturation extract	
ET	evapotranspiration	
LF	leaching fraction	
S	standard deviation	
SAR	sodium-adsorption ratio	
TA	total acid	
TDS	total dissolved solids	

ACKNOWLEDGMENTS

The work reported here could not have been carried out without the ready cooperation of a number of individuals and organizations.

Mr. C. V. Spencer, President, Spencer and Spencer, Inc., managers of the Desert Valencia Ranch, made available the orchard where the citrus experiment is conducted and has assisted in numerous ways. His support and expertise have been invaluable to the success of the work and his continuing enthusiasm is infectious.

Similarly, Mr. W. M. Wootton, Manager of the Snyder Ranch, provided the land for the alfalfa experiment, and arranged for land preparation, seeding, spraying, and harvesting. Without his continuing advice and support, the work could not have been done.

The Wellton-Mohawk Irrigation and Drainage District has cooperated fully in making special arrangements for water supply and power. Its cooperation is greatly appreciated.

Conducting large-scale field experiments 260 miles from home base is a difficult undertaking. Besides the cooperation acknowledged above, due credit must be given to Mr. Robert Ingvalson, Soil Scientist, ARS, who has provided competent leadership to the small group stationed at Tacna, Arizona, for the daily operation of the project.

SECTION 1

INTRODUCTION

The salt load of the Colorado River is a major national problem. Unless corrective actions are taken, the present average salt concentration of about 850 mg/ℓ in the lower reaches of the river may increase to about 1200 mg/ℓ by the year 2000 (Bessler and Maletic, 1975). Such an increase would have serious economic consequences for the seven states adjoining the river and for the Republic of Mexico. Drainage from irrigated agriculture has been identified by the U.S. Environmental Protection Agency (1971) as the major controllable source of salinity in the Colorado River. Thus, it appears that irrigated agriculture must bear a large part of the burden of reversing the trend of increasing salinity. Salinity problems, however, are by no means restricted to the Colorado River.

Research at the U.S. Salinity Laboratory indicates that in many instances the salt in drain water from irrigated agriculture can be reduced (van Schilfgaarde et al., 1974). The key new finding is that if crops are irrigated so that water of low salinity is available in the upper portion of the root zone, the soil solution in the lower portion of the root zone can be permitted to concentrate considerably more than had previously been thought possible without decreasing yields (Bernstein and Francois, 1973). If these same results hold true under field conditions, the leaching requirement of most crops grown with Colorado River water could be reduced below 10%. Less leaching would result in reduced irrigation diversions and lower drainage rates. In turn, low leaching would reduce soil mineral dissolution and enhance precipitation of gypsum and lime, thereby reducing the salt load of the drain waters (Rhoades et al., 1974). Where the groundwater is saline or the aquifer provides a source of salt, a reduction in drainage will reduce the salt load returned to a stream. Furthermore, the smaller volume of drainage water may make alternative means of disposal feasible.

Achieving uniformly low leaching requires an irrigation system capable of overcoming the inherently nonuniform infiltration characteristics of most fields. For nonuniform fields, the infiltration rate must be controlled by the irrigation system rather than by the soil. This may be accomplished by applying water uniformly at a rate sufficiently low to avoid surface ponding and in amounts sufficiently small to avoid saturating the soil profile. Frequent irrigation also provides a continuous supply of low-salinity water in the upper root zone. Limited experience indicates that uniformity of infiltration approaching 95% can be achieved with some well-designed irrigation systems. Even with such systems, programming irrigation to achieve as little as 5% leaching offers some challenges. Clearly, irrigation based on evapotranspiration measurements alone is not feasible because a 1% error in estimating evapotranspiration causes a 20% change in leaching if the leaching target is 5%. Precise irrigation management in salt-affected soils requires knowledge of drain-water flux, measured directly or inferred from soil salinity and irrigation volume (Oster et al., 1976).

Although a reduction in leaching well below levels generally recommended appears theoretically feasible, the principles and components necessary for its achievement have been demonstrated only on a small scale. To evaluate its potential for alleviating the salinity problem of a major river basin, field studies were designed to provide key information spanning the range of conditions found in the Colorado River Basin. One field study, consisting of two experiments, has been started in the Wellton-Mohawk Irrigation and Drainage District of southwestern Arizona (Fig. 1); its irrigation water quality, climate, cropping pattern, and range of soil properties complement another field study in progress in the Grand Valley of Colorado.[1] The first experiment was installed in December 1973 with citrus on coarse-textured mesa soil, and the second was started in September 1974 with alfalfa on medium-textured valley soil.

The primary objective of these field studies is to determine the feasibility of reducing the salt output in drain water by reduced leaching while maintaining crop yield. This objective is to be accomplished by utilizing (1) uniform and frequent irrigations, (2) recent concepts of crop salt tolerance, and (3) recent models of salt losses by precipitation and of salt gains from mineral weathering. Additional objectives are (1) to determine the components of the water and salt balance quantitatively under minimum leaching, and (2) to determine the requirements for irrigation systems to achieve low leaching under field conditions.

This constitutes an interim report of results obtained to date and should, therefore, not be considered conclusive. Field data collection and analyses will continue for 2 years. At that time, the final conclusions and recommendations will be reported. The additional time is required for several years of data collection after the soil salinity profiles have reached equilibrium.

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[1]1974 and 1975 annual progress reports on "Alleviation of salt load in irrigation water return flow of the Upper Colorado River Basin" prepared by E. G. Kruse for the Bureau of Reclamation under Contract No. 14-06-40-0-5942.

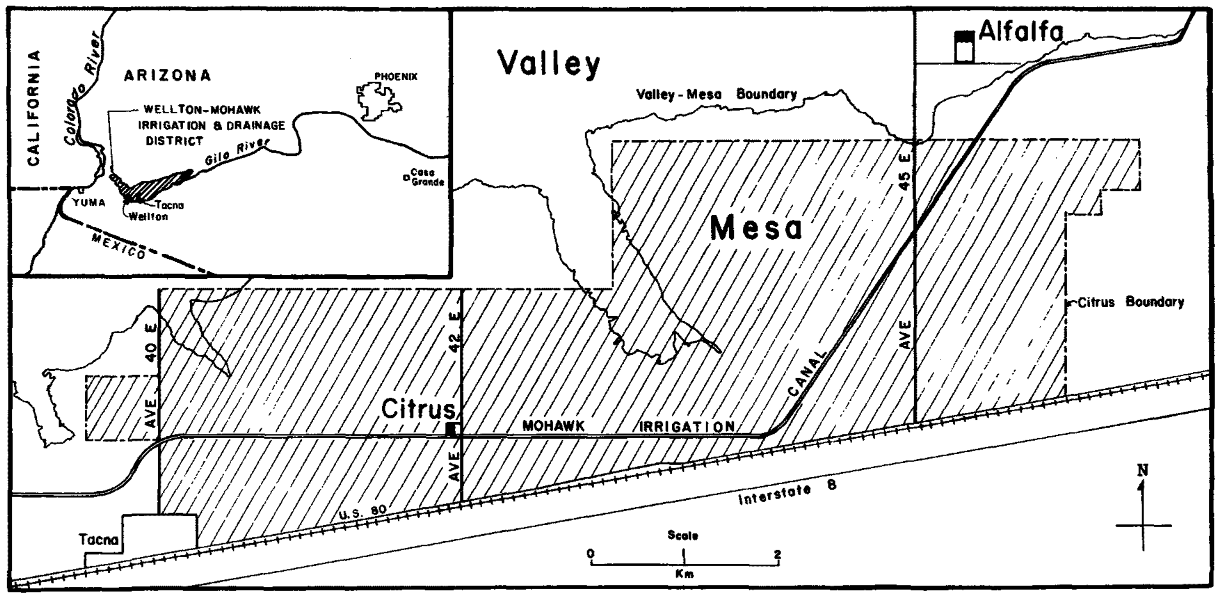

Figure 1. Location of citrus and alfalfa minimum leaching experiments in southwestern Arizona.

SECTION 2

SUMMARY AND CONCLUSIONS

To investigate the potential of reducing the salt load in return flow from irrigated areas by reduced leaching, two field projects were established near Tacna, Arizona in the Wellton-Mohawk Irrigation and Drainage District. Colorado River water with about 944 mg/ℓ total dissolved solids was used for irrigation.

In one project, trickle irrigation was used to control the amount of water applied to each tree in a mature Valencia orange orchard located on Dateland fine sandy loam. Three treatments, replicated nine times, intended to apply 5, 10, and 20% leaching water, were established and compared with conventional border flood irrigation. Three years' results indicate that the actual leaching percentages obtained were 8, 11, and 22, compared to 47 on the border flood check. The best estimate for annual evapotranspiration is 1400 mm. To date, no differences have been observed in the quantity or quality of fruit among treatments, or between treatments and the check plots. Soil salinity has increased as anticipated.

If the citrus yields can be maintained over time, the data may be used to project, for the 3000 ha of citrus now grown in the Wellton-Mohawk Irrigation and Drainage District, that decreasing the leaching percentage from 47 to 20 would reduce drainage water by 43.7×10^6 m^3/yr and salt load of this drainage water 45,500 Mg/yr. The short-term effect of this management change, however, could be substantially greater. Since the drainage water currently pumped out of the District has a concentration of about 3000 mg/ℓ, the reduction in salt load would initially be 130,000 Mg/yr.

In the other project, controlled low leaching rates were evaluated on alfalfa grown in Indio fine sandy loam soil. About 2 ha of an 8-ha field was divided into 15 plots, providing 5 replications of 3 treatments. The treatments imposed were expected to result in 5, 10, and 20% leaching. A moving boom-spray irrigation system that applied 6 mm of water each pass was used. The remainder of the field was irrigated by level-basin flooding. The actual leaching percentages obtained to date were lower than those planned, and were probably about 3, 5, and 10. The flooded field received the same amount of water as the 20% treatment.

The high frequency of irrigation caused continuously wet soil surface conditions that increased weed growth and, combined with the heavy harvesting equipment, reduced the alfalfa stand. Alfalfa yields on the sprinkled plots were about 16% less than those on the flooded field.

Analyses of leachate volumes and concentrations, *in situ* salinity sensor readings, and records of water applied provide reasonably consistent results. They imply that the sprinkled plots were underirrigated, and that the flooded field obtained some of its water from the rather shallow water table. The annual ET for alfalfa at the site probably is about 2000 mm. The salinity profiles have developed rather slowly and probably haven't reached equilibrium. The salinity is substantially lower in the flooded field than in the sprinkled plots.

Reseeding of the alfalfa and redesign of the irrigation system so that fewer passes are required are expected to resolve the management difficulties encountered. It is unlikely, however, that the low leaching obtained on the flooded field can be substantially decreased further.

SECTION 3

CITRUS

EXPERIMENTAL PROCEDURE

Experimental Design

The citrus experiment, located 3 km east of Tacna, Arizona, on the Desert Valencia Ranch, consists of nearly 2 ha of trees centered within a 4-ha block planted in the fall of 1963. The experiment is surrounded by similar-age trees, except on the south, where it is bordered by the Mohawk Irrigation Canal. The 4-ha block was chosen based on its history of high yield and the experimental site was located within the block on the basis of the uniformity of tree trunk circumference. The Valencia orange trees (*Citrus sinensis* L.) are Campbell Nucellar budwood grafted on Rough Lemon root stock. Tree spacing is 4.9 by 6.7 m. The experimental design is illustrated in Fig. 2. The randomized block experiment consists of three treatments of 5, 10, and 20% leaching. Each treatment consists of nine replications of nine trees each in three- by three-tree plots. Based on the analysis of Jones, Embleton, and Cree (1957), this experimental design should permit the statistical detection of 12% yield differences at the 5% level of significance. The experiment is separated from the remainder of the grove by border trees irrigated to achieve 20% leaching.

Soil Properties

Three soil profiles within the experimental site were examined by Soil Conservation Service personnel for characterization and description of the soil morphological properties. A soil description from samples taken by the SCS near the center of the experiment is given in Table A-1 of the Appendix. The soil is classified as Dateland fine sandy loam (Typic Haplargid, coarse-loamy, mixed, hyperthermic) and is representative of the soils where citrus is grown in the district. The soil is calcareous throughout, well drained, and moderately permeable. It is underlain with sand beginning at a depth of 1.5 to 2.0 m and continuing to at least a depth of 4 m. Over 300 soil samples were taken in plots L7, M8, and H6 during December 1973 for chemical analysis and characterization of initial soil conditions. Sampling traverses were made under the tree canopies in the four major compass directions. Samples were collected along each traverse at distances of 1.0, 1.4, 1.8, 2.1, 2.4, and 3.0 m from the tree trunk and at depth intervals of 0 to 0.15, 0.15 to 0.30, 0.3 to 0.6, 0.6 to 0.9, and 0.9 to 1.2 m. The samples were mixed and sieved, then analyzed for cation-exchange capacity, exchangeable sodium, sodium-adsorption ratio, saturation percentage, field-water

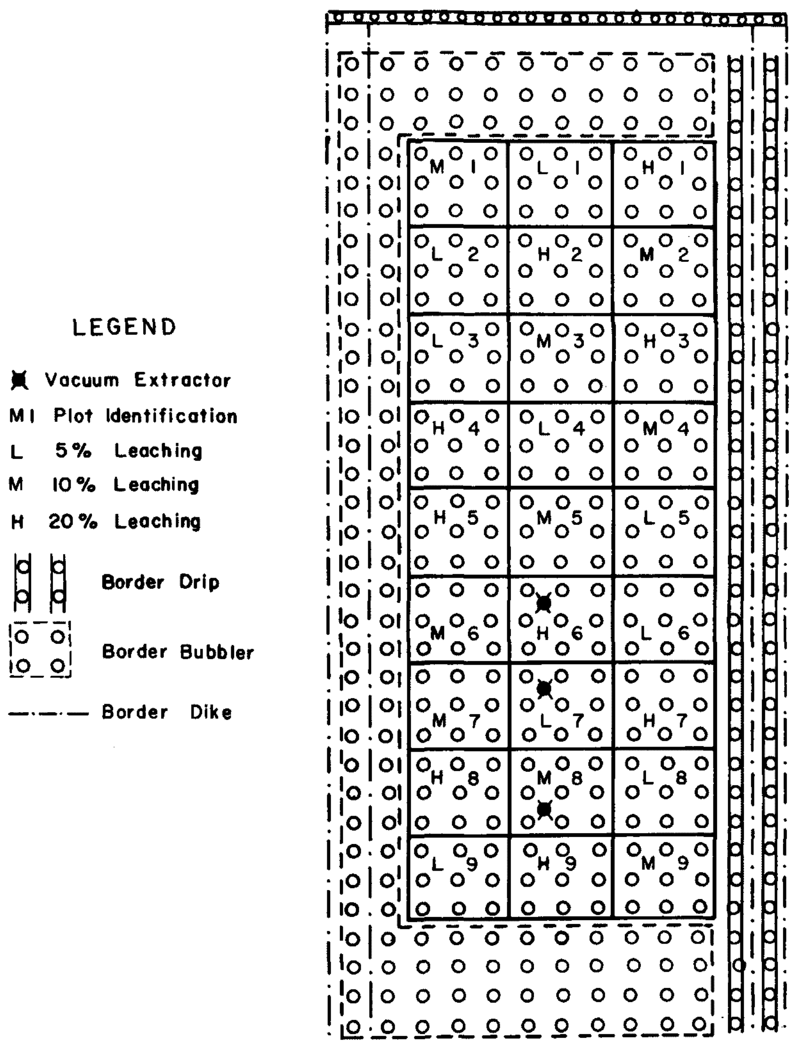

Figure 2. Design of minimum leaching experiment on mature Valencia orange trees in southwestern Arizona.

content, electrical conductivity, pH, and the following soluble constituents in saturation extracts: calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and nitrate. A similar number of samples will be taken at the conclusion of the experiment.

The relationship between hydraulic conductivity and matric potential for Dateland fine sandy loam soil was determined in a temperature-controlled laboratory from three 0.9-m-deep, undisturbed soil columns taken in the winter of 1973. Water was applied to the top of the sealed columns by a constant flow device while a vacuum pump was used to maintain a constant suction on the drainage collection chamber of each column. Miniature tensiometers, spaced 0.1 m apart along the length of the columns, were used to measure soil matric potential. The columns were operated for about 9 months. Each time steady state was reached at preset inflow rates, soil matric potentials were recorded and the hydraulic conductivity was calculated at each tensiometer depth.

Irrigation

The irrigation water is diverted from the Colorado River at Imperial Dam and delivered to the district in open, concrete-lined canals. The typical concentration of total dissolved solids in the Mohawk Canal during 1975 was 944 mg/ℓ and the major salt constituents and their concentrations were Ca, 4.5; Mg, 2.7; Na, 6.8; HCO_3, 2.8; SO_4, 7.7; and Cl, 3.5 meq/ℓ[2]. Irrigation water for the experiment is pumped directly from the Mohawk Canal, passed through commercial sand and screen filters, and delivered in buried, plastic mains to each plot at a pressure of about 350 kPa. The filters provide effective filtration of foreign material down to 75 micrometers in size. The 11-kW centrifugal irrigation pump can deliver 16 ℓ/s.

The frequency of irrigation and volume of water applied is controlled by programmable time clocks which operate the pump and automatic irrigation controls at each plot. Initially, the time clock for the experimental plots was programmed to operate the pump for 30 min three (winter) to six (summer) times every day. During the summer of 1976, the pump operation time was decreased to 15 minutes and the maximum number of irrigations per day was doubled. These changes were made to prevent surface ponding under some trees. A flow control valve at each tree delivers 32 ml/s to each tree whenever a plot is irrigated. This irrigation volume is equivalent to a uniform application of 0.9 mm over the entire surface area for a 15-minute irrigation period. The volume of water applied to each plot of nine trees is measured by two water meters placed in series to insure accurate, fail-

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[2]The 944 mg/liter reported is the sum of the analytically determined dissolved solutes. The equivalent concentration in terms of total dissolved solids is 857 mg/liter. For this conversion of soluble to residue constituents, it was assumed that all constituents would result in anhydrous salts upon evaporation and that all bicarbonate in solution would exist as carbonate in the residue. The bicarbonate in solution was divided by 2.03 to determine its equivalent weight as carbonate in the residue.

safe measurements. Each of the 243 experimental trees is irrigated with a 35-m spiral of dual-chamber, drip-irrigation tubing as shown in Figs. 3 and 4. The tubing has 0.5-mm-diameter outlets every 0.3 m along its length. This design was chosen to enhance uniform water application under each tree.

The border trees are irrigated by a second programmable time clock that operates the pump and automatic irrigation controls for 45 minutes as many as two (winter) to four (summer) times daily during times when the experimental plots are not being irrigated. The two border rows along the west side of the experiment and trees bordering the experiment on the north and south are irrigated by bubblers (see Fig. 4) filling small basins formed under each tree. The water delivery rate of each bubbler is controlled at 63 ml/s by a flow control valve. The two border rows along the east side of the experiment and the closely spaced trees on the north edge of the block are irrigated from capillary tubes (1.7 mm ID) inserted inside 25-mm-diameter polyethylene pipe (see Fig. 4). The pipe was laid on the soil surface about 1 m out from the trunk on both sides of the trees. The capillary tube outlets are spaced 0.7 m apart, giving 14 emitters per tree. Flow control valves in each pipeline deliver an average of 32 ml/s to each tree.

Instrumentation

Each plot is irrigated automatically based on the readings of four tensiometers installed at the 0.3-m depth and located 60 degrees apart 1.5 m radially out from the trunk of the center tree of each plot (Fig. 3). To sense soil matric potential, a light-emitting diode and a phototransistor are placed directly opposite each other on the manometer columns of the tensiometers (Austin and Rawlins, 1977). As the soil dries, rising mercury in the manometer column interrupts the light beam from the diode. This electrically opens a water valve to irrigate the plot whenever the pump is operated. To help overcome variability and to guard against tensiometer failure, the electrical signal to open the valve must come from any two of the four tensiometers. Irrigation frequency is controlled by the location (setpoint) of the phototransistor on the manometer column. Lowering the setpoint raises the soil matric potential and increases leaching; raising the setpoint decreases leaching.

Salinity sensors (Richards, 1966; Oster and Willardson, 1971) and additional tensiometers in two spatial distributions were installed beneath the center tree of each plot. For three of the nine replications for each leaching treatment, four sets of salinity sensors and two sets of tensiometers were installed along one radial (see Fig. 3). All the tensiometers and the salinity sensors at 0.15-, 0.30-, and 0.45-m depths were installed initially, and those at 0.60- and 0.90-m depths were installed in June 1974. Initially, the salinity sensors were installed at relatively shallow soil depths because of the expected time lag in salinity buildup with depth and the need for responsive salinity feedback to control irrigation. During October and November 1974, the soil salinity at 0.90 m began to increase. In addition, the soil salinity at the 0.15-m depth equaled or exceeded that at 0.30 m and also tended to fluctuate more rapidly than at 0.30 m. Because the leaching percentage and soil salinity at the bottom of the root zone are of primary interest, the sensors buried at a depth of 0.15 m were

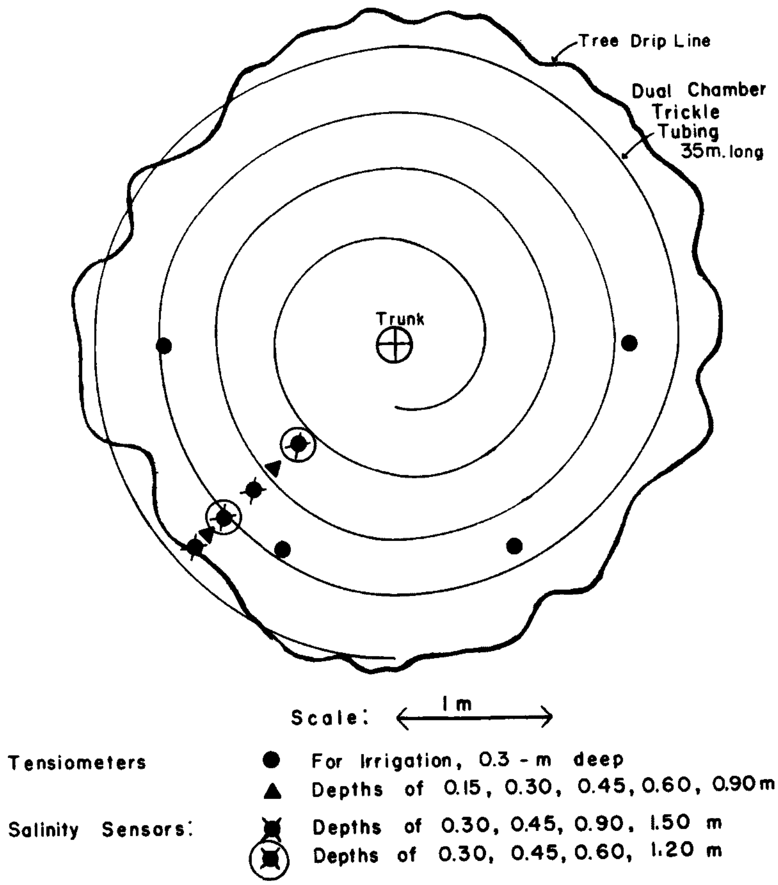

Figure 3. Illustration of instrumentation under center tree of three of the nine replications for each leaching treatment. The remaining replications have two sets of salinity sensors and one set of tensiometers.

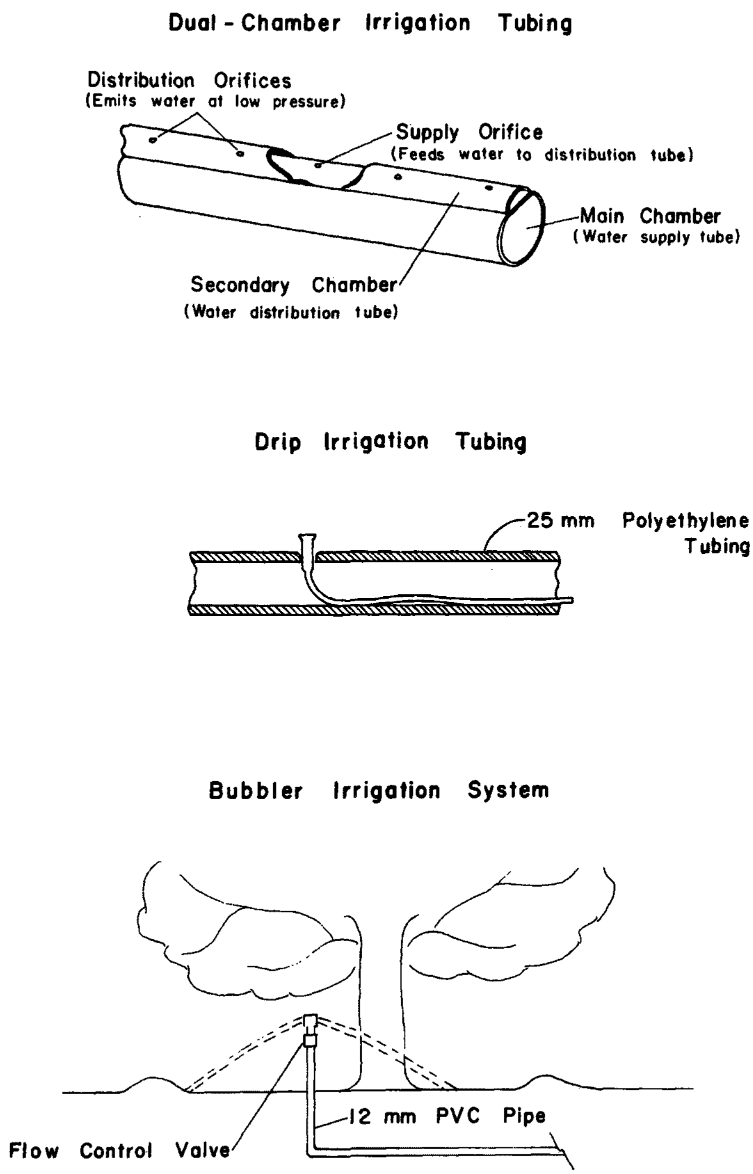

Figure 4. Sketch of dual-chamber, bubbler, and drip irrigation systems.

reinstalled at depths of either 1.2 or 1.5 m in March 1975. The present depth pattern of salinity sensors for these three replications is four sensors at depths of 0.3 and 0.45 m and two at depths of 0.6, 0.9, 1.2, and 1.5 m. For the remaining six replications, only two sets of salinity sensors and one set of tensiometers were installed. The salinity sensors, at depths of 0.30 and 0.45 m, were located 1.25 and 1.65 m out from the trunk on the same radial line and the tensiometers, at the depths given in Fig. 3, were installed midway between the salt sensor sets. The salinity sensors and tensiometers are read twice weekly.

To obtain detailed information on the instantaneous water flow pattern under a citrus tree, 84 tensiometers were installed under the center tree of plot H4 in March 1975. The tensiometers, identical to those installed in December 1973, were installed at depths ranging from 0.3 to 1.8 m and at 0.6-m intervals on three radial lines out from the tree trunk; one radial line was in the tree row, one was perpendicular to the row, and the third was diagonal.

Four vacuum extractors were installed in one replication of each of the three leaching treatments to measure the leaching rate and the chemical composition of the soil solution below the undisturbed root zone (Duke and Haise, 1973). Within a treatment, extractors are directed toward the center of four different trees from a common manhole. A diagram of the extractor is given in Fig. 5; note location in Fig. 2. Each extractor consists of three independent sheet-metal troughs (0.15 m wide by 0.20 m high by 0.61 m long). The extractors were installed in a rectangular tunnel formed by first augering a horizontal hole at a soil depth of 1.2 m and then forcing a rectangular shaper into the hole. Each extractor contained two lines of ceramic tubes 12 mm in diameter and was filled with soil removed in forming the tunnel. The extractors were raised against the smooth ceiling of the tunnel by inflating a butyl rubber air pillow. Soil solution is collected in a small sample bottle in each extractor drain line just ahead of a large collection bottle held under partial vacuum. With sufficient flow, the contents of the small sample bottles are continually replaced by fresh soil water, providing samples in equilibrium with the partial pressure of the soil CO_2. The vacuum is adjusted so that two tensiometers over the center of the extractor read the same as two tensiometers about 0.3 m away from the extractor at the same depth (see inset in Fig. 5). With uniform soil matric potential near their tops, the extractors should intercept the flux representative of their cross-sectional area without causing convergence or divergence of flow.

Soil Chloride Distribution

Soil samples are taken annually to determine the chloride distributions under selected trees. The chloride data are useful in locating the depth of the root zone and indicating water uptake and salinity distributions, and providing complementary data to the salinity sensor readings. The water uptake distribution is required in reassessing the anticipated soil salinity at shallow depths for feedback in controlling irrigation. The maximum chloride concentrations, which are indicative of the lower boundary of the root zone, provide an estimate of leaching fraction. The chloride distri-

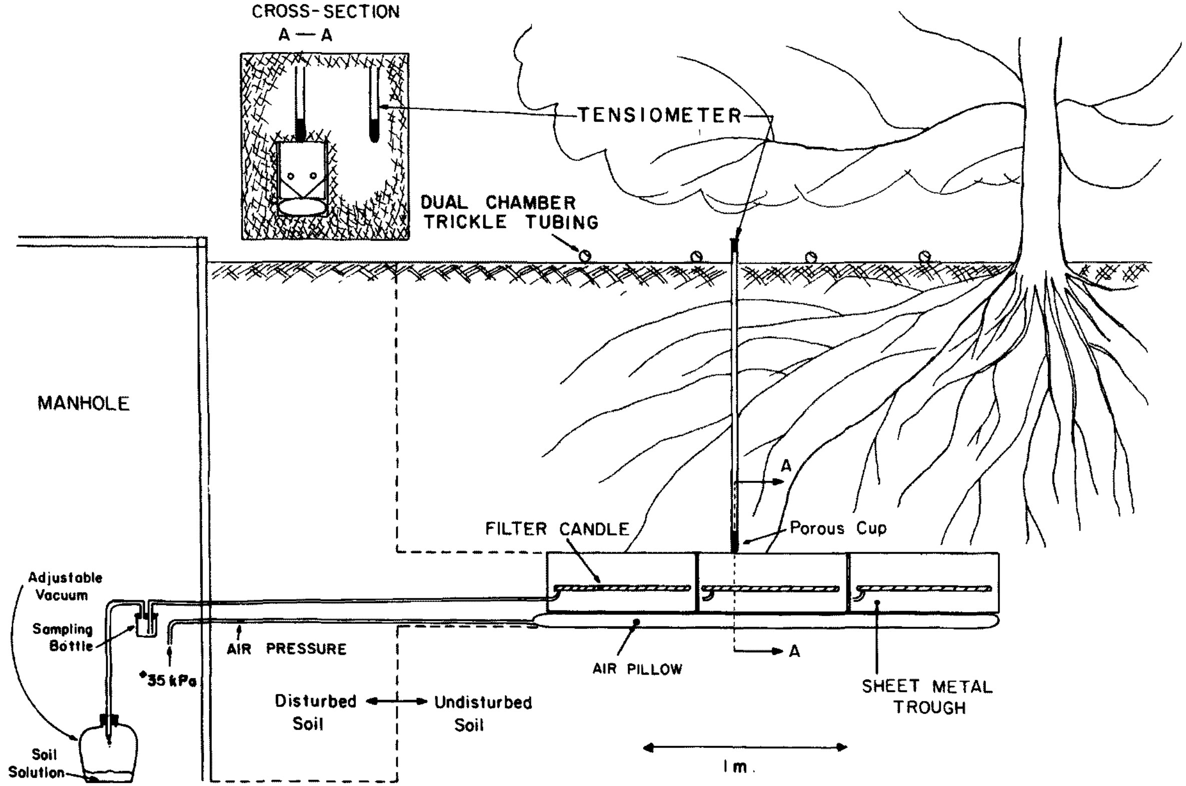

Figure 5. Schematic of vacuum extractor installation.

bution data, in conjunction with the amounts of applied water and the chloride concentration in the leachates, provide another technique of estimating evapotranspiration. The chloride data also provide a measure of the variability of soil salinity.

In December 1974, the average chloride distribution with soil depth was determined by sampling beneath three trees in three of the 20% (H3, H4, and H6) and three of the 5% (L3, L5, and L7) leaching plots. The sampling sites were about 1.2 m from the tree trunk at three randomly selected locations around each tree. The soil samples were divided in 50-mm increments to a depth of 100 mm and in 100-mm increments between 100 and 1800 mm. The areas beneath the center trees of plots H4 and L7 were also sampled in February 1975 and March 1976. The sampling pattern for 1975 and 1976 is illustrated in Fig. 6. The chloride concentrations were expressed in milliequivalents per liter at field water content at the time of sampling.

Irrigation Management

The ultimate objective of the experiment requires that leaching at the bottom of the root zone be controlled precisely. Since routine measurements of water flux below the root zone are not feasible, our management scheme was to control the salinity at the bottom of the root zone at a level corresponding to that predicted for the imposed leaching fraction. Because of the lag between changes in water application and corresponding changes in soil salinity with depth, the irrigation system is controlled directly by the irrigation tensiometers described previously. Irrigation is applied whenever the soil matric potential as measured by these tensiometers decreases below a predetermined setpoint. Control of matric potential can assure adequate water for plant growth, but it will not assure a prescribed leaching percentage, because the relationship between hydraulic conductivity and matric potential is too variable and because the depth of rooting, and thus the percentage of water lost at the tensiometer depth, is not known, and in any case, may vary. Thus, a salinity measure is needed as feedback to the irrigation control. To overcome the long lag between water application and soil salinity changes at depth, salinity sensor readings at the 0.3-m soil depth are used as feedback.

The initial values of soil salinity at the 0.3-m soil depth used for control were estimated from salinity distributions calculated by means of the soil water composition model of Oster and Rhoades (1975). These distributions depend on the chemical composition of the irrigation water, the partial pressure of CO_2 in the soil, and the water uptake pattern of the crop, as well as the leaching percentage. Using the water uptake data for citrus reported by Erie, French, and Harris (1965) and a typical Colorado River water composition, we calculated the target distributions given in Fig. 7 for February 1974. These calculations indicated target salinities of 0.18, 0.20, and 0.22 S/m for the 20, 10, and 5% leaching treatments at the 0.3-m depth, with corresponding values at the bottom of the root zone of 0.5, 0.9, and 1.3 S/m, respectively. The tensiometer setpoints were chosen initially on the basis of best judgment. Decisions on adjustment of the tensiometer setpoints for each plot were made based on biweekly evaluation of the soil salinity, the soil matric potential profile, and the amount of irrigation

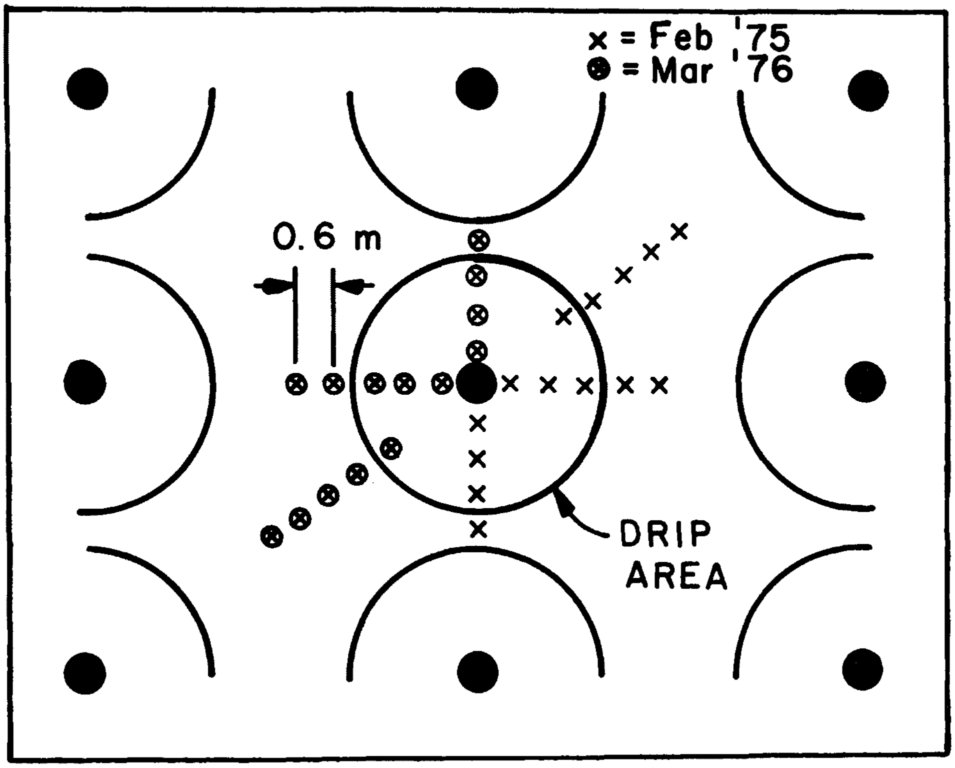

Figure 6. Sampling pattern for soil chloride determinations beneath the center tree of plots L7 and H4 in 1975 and 1976.

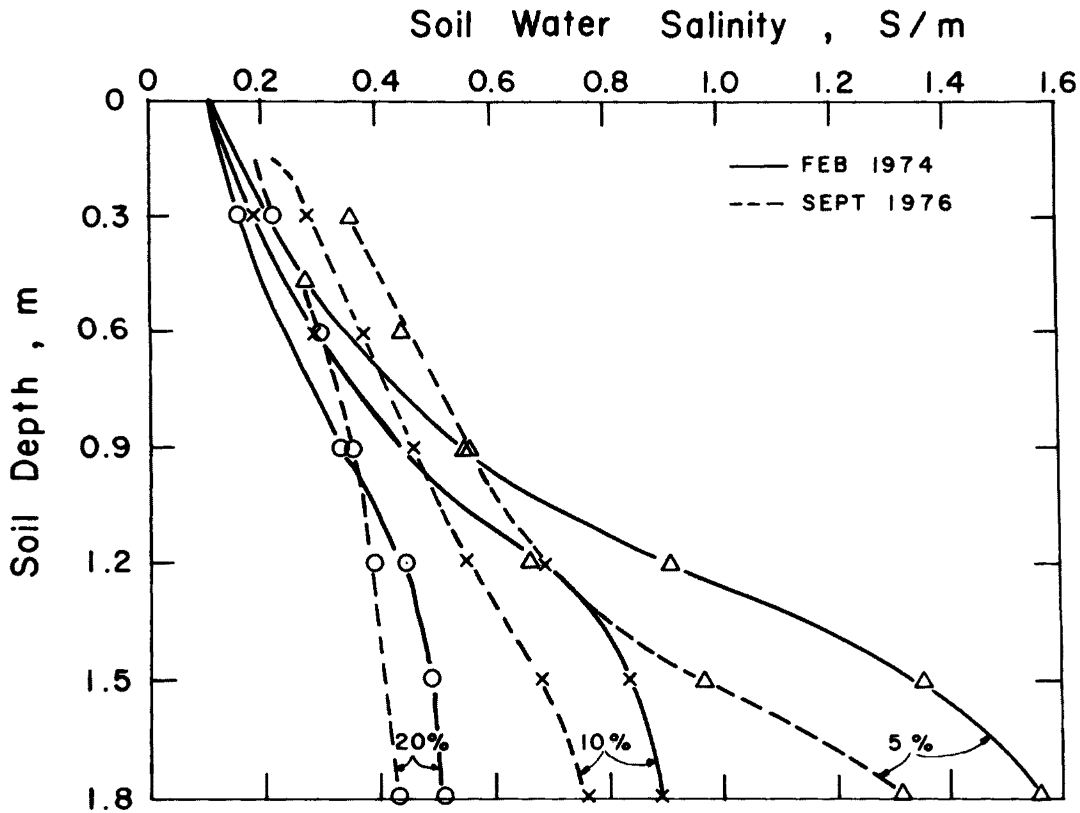

Figure 7. Computed values of electrical conductivity with soil depth for Valencia orange trees irrigated with Colorado River water at 5, 10, and 20% leaching.

water applied. As knowledge was gained from soil chloride distribution, leachate volumes and salt concentrations from the vacuum extractors, soil salinity deeper in the profile, and the partial pressure of CO_2 in the soil, the target salinity levels at the 0.3-m soil depth were also changed. Table 1 lists the projected salinity values used as feedback in controlling irrigation. The current projected soil salinity distributions as a function of leaching are also given in Fig. 7.

TABLE 1. ALTERATIONS OF THE PROJECTED ELECTRICAL CONDUCTIVITY OF THE SOIL WATER (S/m) AT THE 0.3-m DEPTH TO ACHIEVE THE DESIRED LEACHING IN THE CITRUS EXPERIMENT

Date	Leaching Treatment		
	5%	10%	20%
Dec. 1973	0.22	0.20	0.18
Aug. 1974	0.34	0.29	0.24
Jan. 1975	0.29	0.26	0.21
Mar. 1975	0.28	0.25	0.22
Sep. 1976	0.36	0.29	0.22

Four irrigation tensiometers were also installed under one tree for each of the two borders. Since the water application geometry for the borders is different from that of the experimental plots, the tensiometer setpoints are adjusted so that the same amount of water is applied to the borders as the average application for the 20% leaching treatment. Salinity sensors are not used as feedback to control irrigation for the borders.

Check Plots

The citrus grove on the ranch is irrigated by border flooding; a border consists of 6 rows of 35 trees each, a total area of 0.7 ha, surrounded by earthen dikes. A typical border irrigation consists of a 150-mm-deep application over the entire area within the border. The water is applied to each border in about 45 minutes through six sliding gates in the concrete wall of the irrigation lateral. Such a border was selected for comparison in the 4-ha block of trees immediately north of the experiment. Soil matric potential is monitored under three separate trees with tensiometers as described above. Because of the high leaching percentage, the soil salinity level is very low and is monitored periodically from soil samples. For yield and quality comparison, 27 trees from the center of three rows in the middle of the border are harvested individually. Water applied is measured with a concrete, critical-flow flume (Replogle, 1977) installed in the irrigation lateral and elapsed-time devices installed on the irrigation outlets. Water flow in the lateral can be calculated to within about 2% from the known flume geometry and by continuously recording water elevation at the entrance relative to the flume floor at its throat.

One border of flood-irrigated trees just east of our experiment within the same 4-ha block is fertilized by foliar application, as are the experimental trees, rather than through the irrigation water as is done throughout the grove. This border is also used for yield comparisons with the experimental trees.

Yield and Fruit Quality

The fruit from all the experimental trees, the two rows of border trees parallel with the experimental trees on the east and west, and three rows of trees from both the flood- and fertilizer-check plots are harvested by individual tree in April of each year and weighed. The number of fruit per tree is determined by counting the number of fruit in one field box from each tree and calculating the total number from the average weight per fruit.

Just before harvest, four fruit are picked from each experimental tree for quality analysis. Three samples of 12 fruit each are also picked from the borders and the flood- and fertilizer-check plots. Measures of fruit quality include: fruit length and width, rind color and texture, and ring size. Ring size is equivalent to the average number of fruit contained in a standard-size shipping carton. After the fruit analyses, the juice is extracted and analyzed. Juice analyses include total soluble solids, total acid, and percent juice.

Tree Growth and Leaf Analysis

A simple measure of tree growth often used in citrus research is trunk enlargement with time. Although the trees are over 10 yrs old, they are not fully mature, and trunk circumference is measured annually.

Leaf samples were taken initially in March 1974, and yearly in September thereafter, to evaluate nutritional status and detect possible toxic levels of chloride and sodium. Each sample consists of 72 leaves obtained by sampling eight leaves from each of the nine trees per plot. Leaves that represent average foliar conditions are taken from the ends of nonfruiting terminal branches at two heights on four sides of each tree. Leaf samples are handled, cleaned, and prepared for analysis according to established procedures (Reisenauer, 1976). The leaf samples are analyzed for 13 mineral elements.

Agronomic Practices

Except for fertilization, all crop management operations such as frost protection, pruning, and insect and weed control are performed by the ranch to match those given the surrounding groves. The experimental trees are fertilized with foliar sprays of urea and microelement chelates. Foliar application was chosen to permit uniform fertilizer applications to each tree while differential water applications were made, to minimize nitrate discharge in the leachate, to avoid further salt additions to the irrigation water, and to minimize the amount of fertilizer required. Timed applications of nitrogen as low-biuret urea are applied to each tree six times each spring at a rate of 115 g N per tree per application. Chelates of iron, zinc, and manganese are also applied with some nitrogen applications at the rates of 1.0, 1.0, and 0.5 g per tree per year, respectively.

Soil Air

With frequent irrigations to maintain the soil matric potential near -10 kPa, soil aeration may be a problem, particularly in heavy soils. Even though no aeration problems were expected in the sandy loam soil of the citrus experiment, soil oxygen concentrations were measured during both the winter and summer of 1975, in cooperation with Dr. Burl Meek of the Imperial Valley Conservation Research Center in Brawley, California, with polarigraphic probes installed at the 0.45-m soil depth and about 1.5 m radially from the tree trunk. Because the carbon dioxide concentrations in the soil-air phase will affect the chemical composition of the salt load of the drainage waters, soil-air samples were obtained by attaching evacuated plastic bags to porous aeration stones buried in the soil and the carbon dioxide content was determined by using an infrared gas analyzer.

RESULTS

Soil Properties

Analyses of the initial soil samples, summarized in Table 2, show that soil salinity was generally low at the beginning of the experiment, but a few moderately salinized zones of apparently restricted permeability were found. Chloride concentrations in the soil samples and distributions in the soil profile suggest that past flood irrigation management has resulted in a leaching percentage of about 40 at the 1.2-m soil depth. A few profiles showed evidence of leaching as low as 8%; these profiles correspond to areas with relatively high clay contents near the soil surface.

The relationship between hydraulic conductivity and matric potential for Dateland fine sandy loam soil is given in Fig. 8. These data were obtained from three 0.9-m-deep undisturbed soil columns taken in the fall of 1973. The horizontal lines in the figure indicate the variability in each measured point.

Water Use

The average depth of water applied daily for the three leaching treatments is given in Fig. 9 by months for the period of February 1974 to September 1976. The rate of application on the flood check plot is given from January 1975 to September 1976. These water application rates are the sum of irrigation and rainfall and are calculated for the total area allocated each tree, 32.7 m^2. The average number of liters applied daily to each tree in a given treatment may be calculated by multiplying the depth given in Fig. 9 by 32.7.

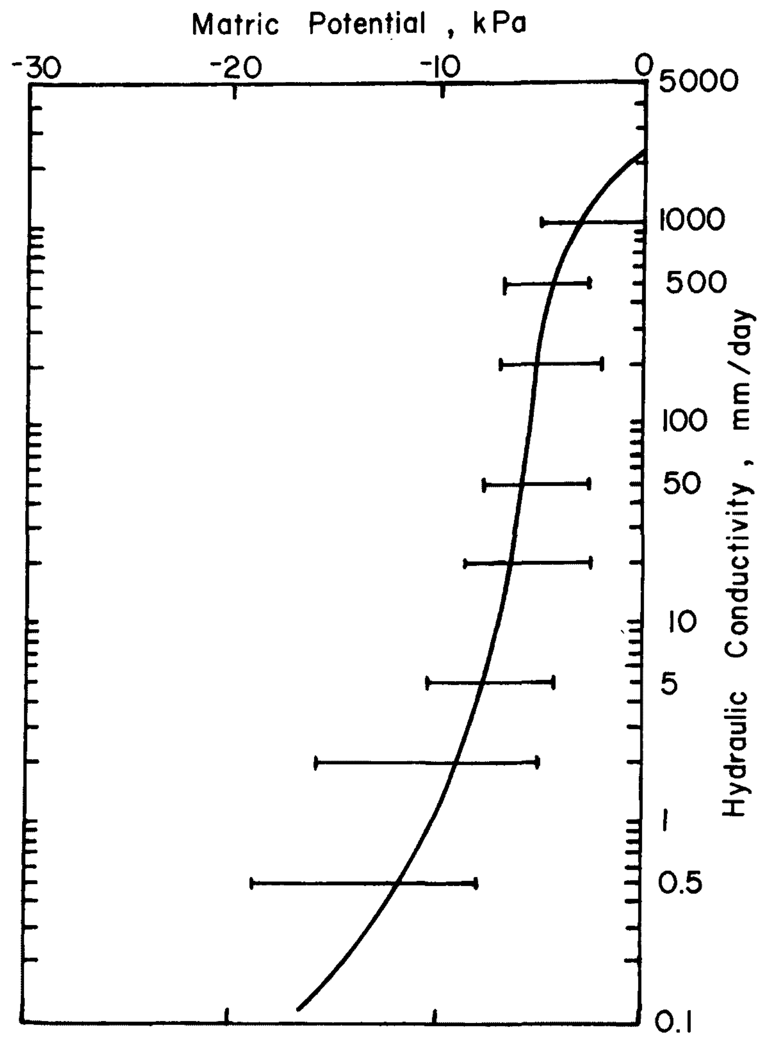

Figure 8. Relationship between soil matric potential and hydraulic conductivity for Dateland fine sandy loam soil.

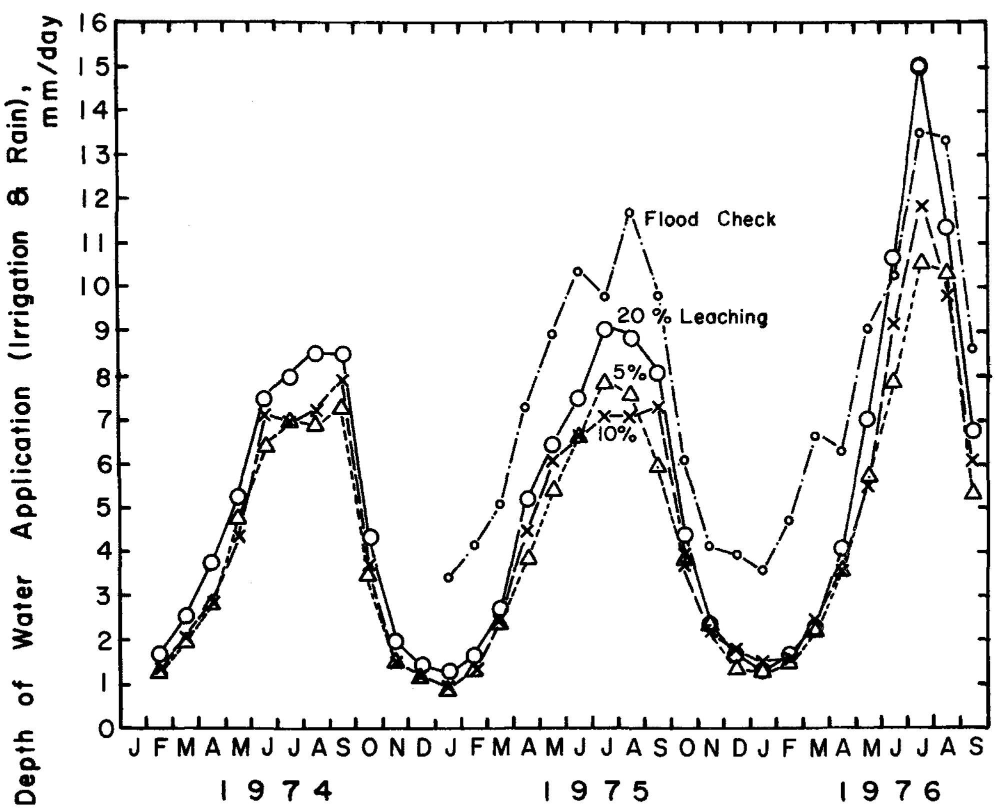

Figure 9. Average daily water application for the three leaching treatments and the flood check by month from February 1974 to September 1976.

TABLE 2. REPRESENTATIVE SOIL PROPERTIES OF DATELAND FINE SANDY LOAM SOIL

Property	Unit	Typical Values	Range
Cation-exchange capacity	meq/100g	9 - 13	2.5 - 23
Exchangeable-sodium percentage	%	3 - 4	3 - 13
Sodium-adsorption ratio	-	3 - 4	3 - 10
Saturation percentage	%	25 - 30	19 - 50
Field water content	g/g	11 - 12	4 - 22
EC_e	S/m@25°C	0.13- 0.15	1 - 6
pH	-	7.4	6.4 - 8.3
Soluble* calcium	meq/l	3 - 4	1.6 - 23
" magnesium	"	2	0.7 - 11
" sodium	"	5 - 7	3 - 37
" potassium	"	0.2	tr - 0.6
" bicarbonate	"	2	0.8 - 4.6
" sulfate	"	5 - 6	2.3 - 56
" chloride	"	2 - 3	0.9 - 28
" nitrate	"	0.6	0.2 - 6.2

*Soluble in saturation extract.

The annual water application amounts for the three leaching treatments are given in Table 3, along with those for the two borders and the flood check plot. For comparison, annual pan evaporation and rainfall are also given in Table 3. The evaporation pan occupies the area normally taken by a citrus tree in a grove about 0.4 km from the experiment. Pan evaporation values from an open area about 5 km from the grove are given in the alfalfa section. Pan evaporation from the citrus grove has been about 85% of that from an open area.

Water was withheld in the beginning to increase the soil salinity to the projected levels for the three leaching treatments; thus, the total amount of water applied in 1974 was no doubt too low to be typical. On the other hand, based on the relationship between pan evaporation and calculated evapotranspiration shown in Fig. 10, we realized that our irrigation management scheme lagged changes in pan evaporation. Thus, in the summer of 1976, we attempted to anticipate pan evaporation; unfortunately, we overcompensated and applied too much water in the summer of 1976. As a consequence, either the water application data for 1975 or the 3-year average is used as our current estimate of the water requirements for the three leaching treatments. Our attempts to achieve 20% leaching on the two borders, based on the average amount applied to the 20% leaching treatment, were successful. About 50% more water was applied to the flood check plot than to our experimental trees.

Evapotranspiration (ET) for these trees can be estimated by multiplying the depth of water applied by 0.95, 0.90, and 0.80 to account for the desired leaching percentages of 5, 10, and 20. This estimate of ET does not account for failing to achieve the desired leaching percentage or for

TABLE 3. ANNUAL IRRIGATION, RAINFALL, AND PAN EVAPORATION FOR VALENCIA ORANGE TREES

Year	Depth of water applied* (mm)						Rain-fall mm	Pan Evapo-ration mm	Cal-culated ET (mm)
	Leaching Treatment			Borders		Flood Check			
	5%	10%	20%	Bubbler	Drip				
1974	1401	1450	1685	1651	1818	--	105	1838	1325
1975	1498	1560	1802	1942	1912	2582	84	1732	1450
1976†	1675	1725	1975	2049	1704	2750	90	1650	1550
Average	1525	1578	1821	1881	1811	2666	93	1740	1440

*Irrigation plus rainfall.
†Data estimated for October, November, and December.

changes in soil water storage. The actual ET for each leaching treatment should be the same, unless growth or stomatal aperture is influenced by these small differences in leaching. ET has been assumed to be independent of the leaching treatments imposed, because data presented below indicate no significant differences in trunk circumference. The annual estimates of ET presented in Table 3 show the 3-year average as 1440 mm.

As an independent check of the ET estimate based on water applied, ET was computed by the modified Penman equation (Doorenbos and Pruitt, 1975) and the Jensen-Haise equation (Jensen, 1973). The potential ET calculated from these two equations was multiplied by a crop coefficient, varying from 0.5 in winter to 0.6 in summer, to obtain ET. The results of these computations of ET are given in Table 4 as average daily ET rates by month. Also listed in the table are the estimates of ET calculated from water application and the consumptive use of mature Navel orange trees near Phoenix, Arizona, published by Erie, French, and Harris (1965). ET calculated by the modified Penman equation agrees well with the ET calculated in our experiments.

The average annual ET based on the modified Penman and Jensen-Haise equations are 1421 and 1342 mm, respectively, compared to 1440 mm based on water applied. The data of Erie et al. (1965) were consistently lower, with the average annual ET being 1000 mm.

The average daily ET based on water applied and computed by month was compared to the average daily rate of pan evaporation in the grove in Fig. 10. As expected, the shapes of the curves are similar, but the calculated ET lags pan evaporation throughout. This lag is no doubt caused by a lag in the irrigation management. Based on these data, the pan factor (ratio of ET to pan evaporation) is 0.84.

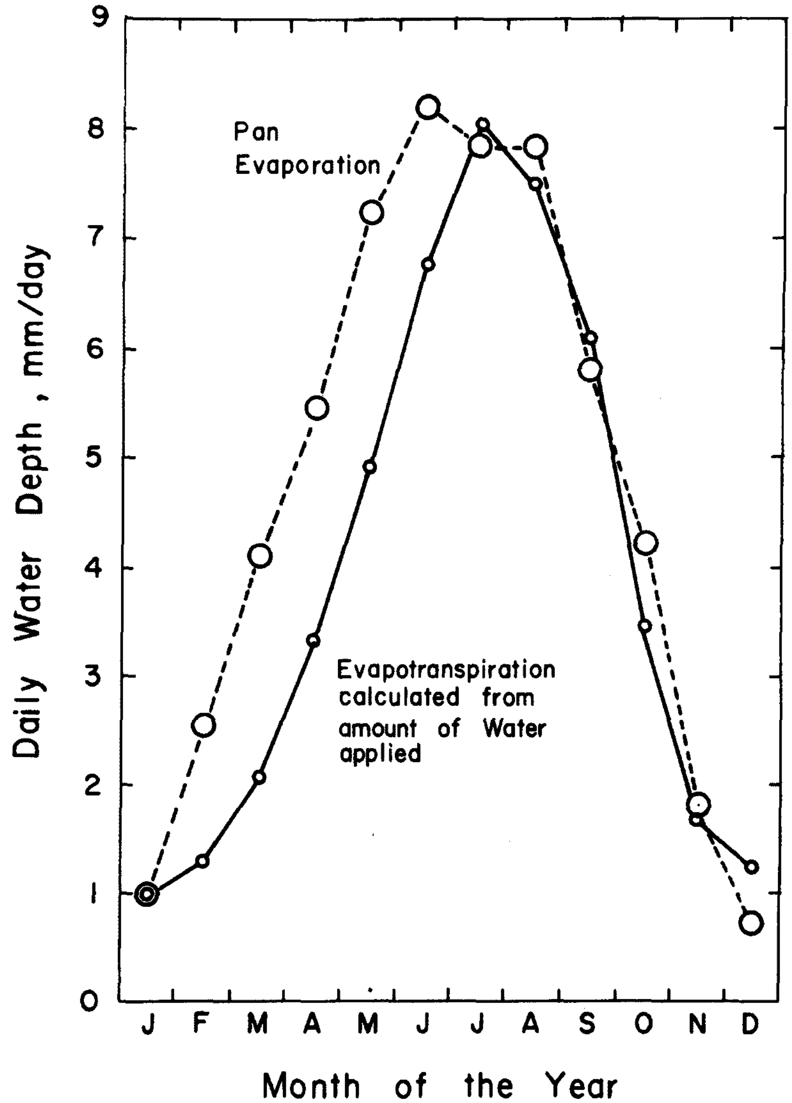

Figure 10. Comparison of the daily rate of pan evaporation and evapotranspiration estimated from the amount of water applied for Valencia orange trees in southwestern Arizona. Data averaged by month from January 1974 to September 1976.

TABLE 4. COMPARISON OF VARIOUS ESTIMATES OF EVAPOTRANSPIRATION OF VALENCIA ORANGE TREES IN SOUTHWESTERN ARIZONA

Month	Erie* et al.	Modified Penman†				Jensen-Haise§				Calculated from expt.			
		1974	1975	1976	Avg.	1974	1975	1976	Avg.	1974	1975	1976	Avg.
	mm/day	mm/day				mm/day				mm/day			
Jan	1.1	1.2	1.5	1.1	1.3	1.2	1.2	1.1	1.2	0.9	0.9	1.2	1.0
Feb	1.6	2.3	2.1	2.0	2.1	1.8	1.6	1.7	1.7	1.3	1.3	1.4	1.3
Mar	1.8	3.2	3.1	3.3	3.2	2.9	2.5	2.8	2.7	1.9	2.2	2.0	2.0
Apr	2.4	4.4	3.9	4.2	4.2	3.9	3.4	3.7	3.7	2.8	4.0	3.3	3.4
May	2.9	5.5	5.4	5.4	5.4	5.1	4.9	4.9	5.0	4.2	5.2	5.3	4.9
Jun	3.9	6.6	6.5	6.4	6.5	6.4	6.2	6.3	6.3	6.2	6.1	8.1	6.8
Jul	4.3	6.2	6.8	6.3	6.4	6.0	6.5	6.2	6.2	6.4	7.0	10.8	8.1
Aug	4.3	6.2	6.5	5.8	6.2	6.2	6.4	5.8	6.1	6.6	6.9	9.0	7.5
Sep	3.9	5.2	4.8	-	5.0	5.0	4.9	-	5.0	6.9	6.2	5.3	6.1
Oct	2.9	3.2	3.3	-	3.2	3.1	3.2	-	3.2	3.4	3.5	-	3.4
Nov	2.1	1.8	2.0	-	1.9	1.8	1.8	-	1.8	1.4	1.9	-	1.6
Dec	1.1	1.4	1.1	-	1.2	1.1	1.1	-	1.1	1.1	1.4	-	1.2
Yearly total (mm)	1000	1438	1434	-	1421	1357	1334	-	1342	1325	1450	-	1440

*Data taken from Erie et al. (1965).

†Calculated by modified Penman equation described by Doorenbos and Pruitt (1975). Data based on meteorological information taken by the Irrigation Management Service of the U.S. Bureau of Reclamation, Wellton, Arizona.

§Calculated by the Jensen-Haise equation described by Jensen (1973).

Soil Salinity

The time course of average soil salinity measured with salinity sensors is given in Fig. 11 for the three leaching treatments. (Salinity data for the 0.6- and 1.2-m soil depths are not given to simplify the figure.) Initial soil-salinity levels were about equal to the salinity of the irrigation water, 0.13 S/m, because of previous overirrigation. Beginning in February 1974, soil salinity increased with time until quasi-stable values were attained at the 0.3- to 0.45-m soil depth by July (5 months) and at the 0.9-m depth by January 1975 (11 months). Since March 1975, changes in soil salinity have undergone two complete cycles. The cyclic pattern is evident to a soil depth of 0.9 m and the cycle covers about 1 year. During the first half of the year, the trees are underirrigated and soil salinity increases; during the last half of the year they are overirrigated and salinity decreases. Although cyclic, the differences in salinity among leaching treatments are as expected, with 5% leaching being the most saline and 20% leaching the least.

Fig. 12 compares time-averaged soil salinity as a function of soil depth for the two time intervals of January 1974 to July 1975 and July 1975 to July 1976, the initial soil-salinity distribution, and the projected soil-salinity distribution at equilibirum from the model of Oster and Rhoades (1975). In general, soil salinity has increased with time at all soil depths and leaching percentages. The soil-salinity distribution is nearly equal to or exceeds the projected salinity values for all three leaching treatments to a depth of 1.5 m, except below the 1.2-m depth in the 5% leaching treatment.

Soil Matric Potential

The tensiometer readings serve primarily as a check on the irrigation management. Of course, the readings also give the soil matric potential profiles for the different leaching treatments. The average profiles for the three leaching treatments during 1974 and 1975 are given in Fig. 13. As anticipated, the soil matric potentials were very high near the soil surface, with essentially no differences among treatments. With depth, significant differences among treatments did appear and at a depth of 0.9 m, the soil matric potential averaged -24 kPa for 5% leaching and -14 kPa for 20%.

Soil matric potential was not held steady throughout the year and the changes that occur can be assessed from Appendix Figs. A-1 through A-9, which show the potential distribution below the center tree in plot H4 at nine different times as determined from 84 tensiometers. The data are presented as total head, using the 0.3-m depth as a reference. On January 22, 1976, the plot was irrigated on the basis of a tensiometer setpoint of -9.0 kPa at a depth of 0.3 m. This setpoint more or less fixes the heads at the 0.3-m depth. The hydraulic gradient varied from around 2 between depths of 0.3 and 0.6 m under the wetted area, to 3 farther from the trunk at the same depth interval, to less than unity at deeper depths. The setpoint was changed to -8.5 kPa on February 24. On March 23, 1976, the total head was everywhere lower than it was in January. At deep depths, the gradients

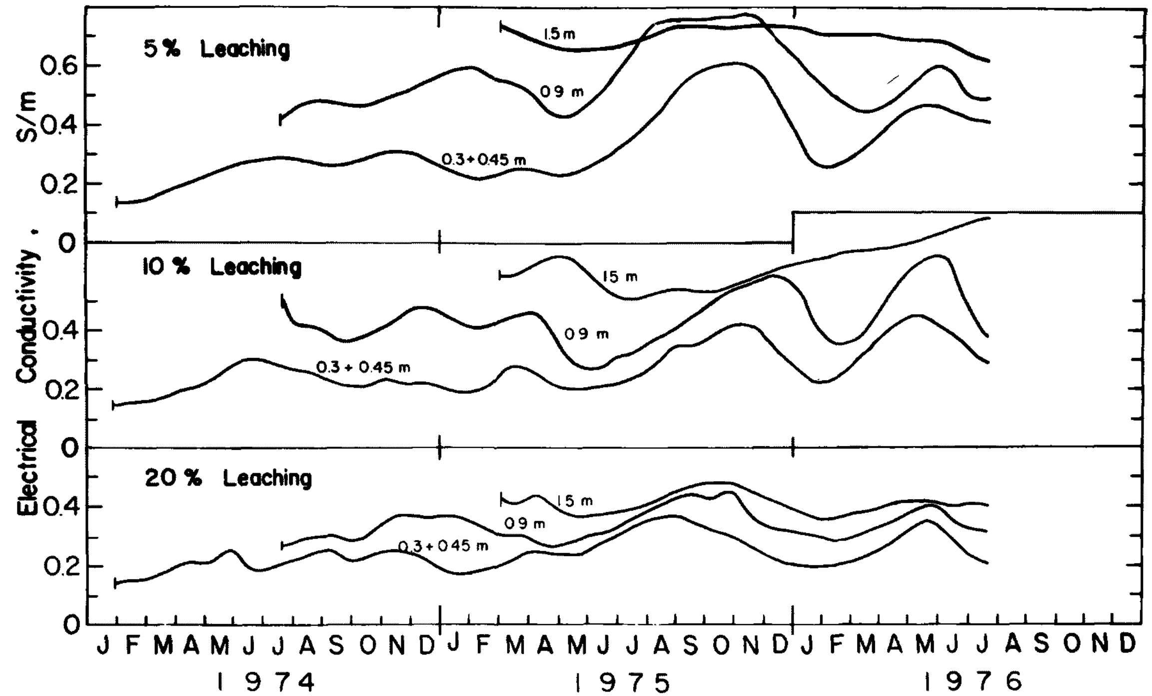

Figure 11. Salinity trends with time for the three leaching treatments of the citrus experiment at various soil depths.

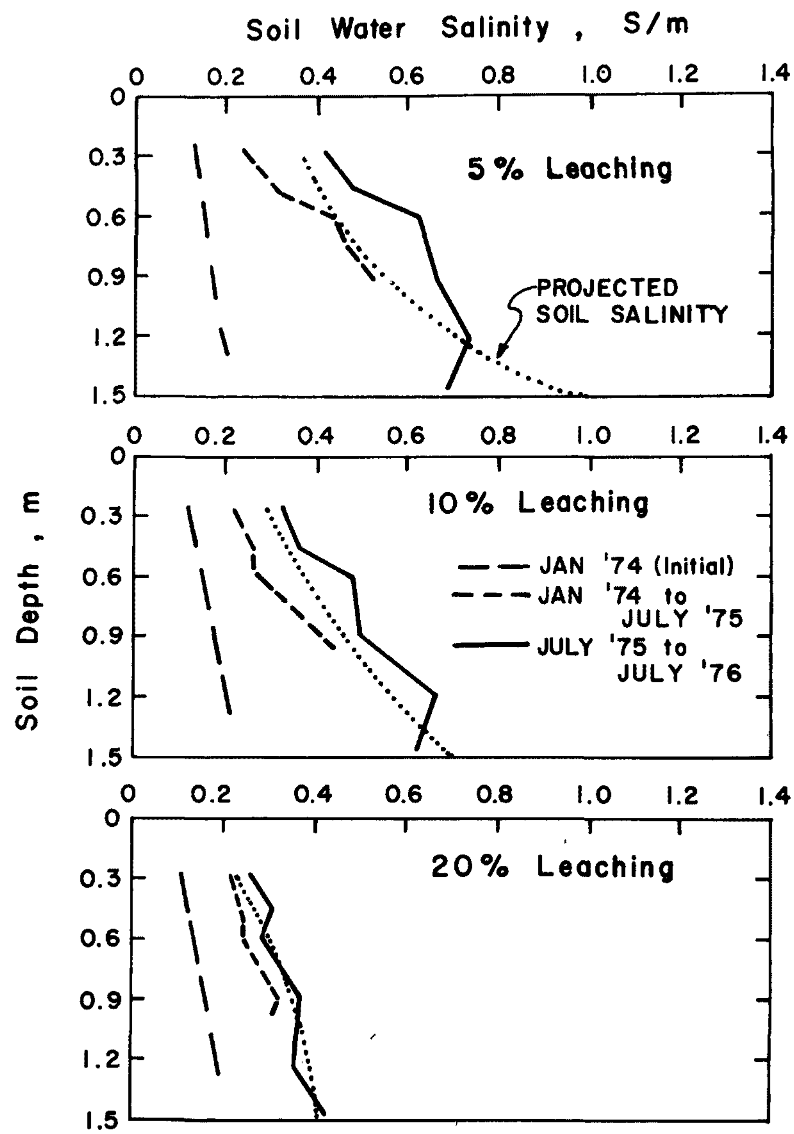

Figure 12. Time-averaged soil salinity distributions with soil depth for the initial, two intermediate time periods, and the projected final conditions.

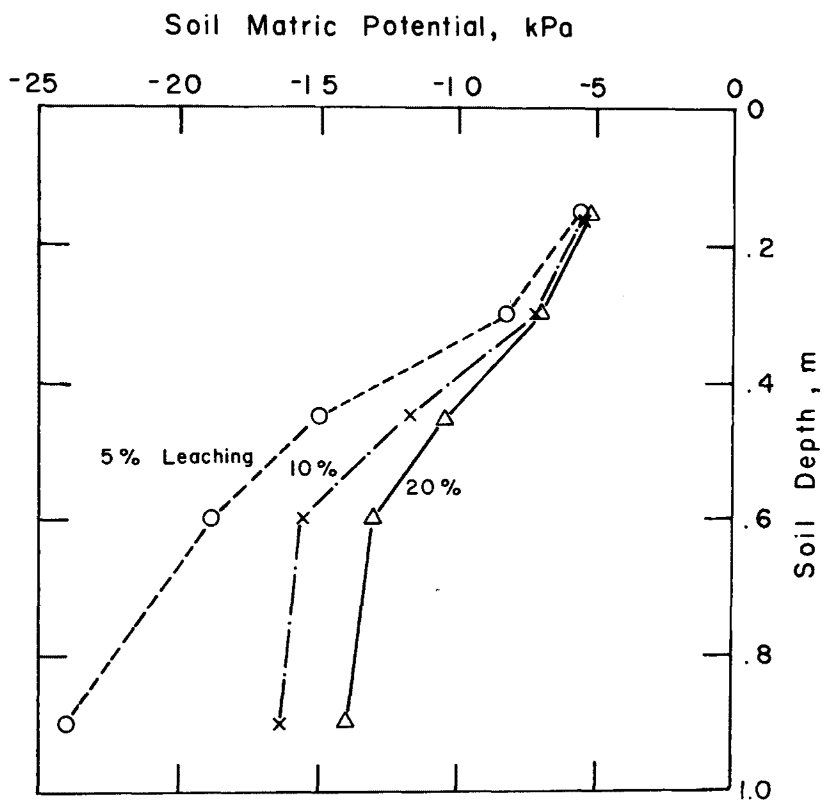

Figure 13. Average soil matric potential profiles for the three leaching treatments in the citrus during 1974 and 1975.

were near unity. Early in April, the soil salinity began to rise sharply. On April 28, 1976, the setpoint was still -8.5 kPa, and the total heads were lower than a month earlier. During April, the ET increased sharply and, accordingly, the profile should have been permitted to become wetter. This was not achieved until after the middle of May when the setpoint was lowered to -6.5 kPa. On August 24, 1976, the setpoint was -5.5 kPa. The profile was everywhere wetter than it was during the winter and spring and the hydraulic gradients ranged from 1.5 between depths of 0.3 and 0.6 m, to near unity at deeper depths.

From 0930 hrs on August 24, 1976 until 2040 hrs on August 29, 1976, the tree was not irrigated. All tensiometers were read twice daily. By the morning of August 28, soil drying had caused the -20-kPa contour to shift upward slightly and the region with total heads between -15 and -20 kPa to increase substantially. Everywhere the total head was smaller than -10 kPa. By the evening of August 29, the -20-kPa contour had moved up a little further and the region with total heads between -15 and -20 kPa had decreased at the expense of a region with total heads below -20 kPa in the 0.3- to 0.6-m depth interval. In the afternoon of September 1, 1976, 3 days after the irrigation had again been turned on, the -20-kPa contour was closer to the soil surface than it was on August 28; the region with total heads between -15 and -20 kPa was very small; and the region with total heads smaller than -20 kPa near the soil surface had disappeared entirely, except for large distances from the tree on the diagonal radial. At that time, the gradients in the 0.3- to 0.6-m-depth interval were very large, while at deeper depths, there was nearly hydrostatic equilibrium. The distributions on September 4 and 9, 1976, illustrate the return to the potential distribution prevailing before the water was turned off. The time course of the total head distribution during the period August 24 to September 1 strongly suggests that there is little root activity below the 0.6-m depth.

Soil Chloride Distribution

After 1 yr, chloride concentrations were highest in the plots that received the least amount of water, i.e., the 5% leaching plots. The chloride concentration was maximum in the 0.9- to 1.2-m soil-depth interval, indicating this was the lower boundary of the root zone. This conclusion was considered suspect because only 11 months had elapsed since the start of the experiment. Composite cross sections of the chloride distribution with soil depth along the three lines sampled in both 1975 and 1976 are shown in Fig. 14 for 5 and 20% leaching. (Individual cross sections are given in Appendix Figs. A-10 and A-11.) An overview of the distributions for both years clearly shows the highest concentrations in both treatments were beyond the tree canopy. The chloride concentrations were higher for 5% leaching than for 20% and increased during the time between the sampling dates in both treatments. Lateral water movement and water loss beyond the tree canopy are also obvious from the figures.

The chloride distribution for plot L7 indicates that the bottom of the root zone is saucer shaped. At a distance of 3.3 m from the tree, the concentration is maximum at a depth of 1.1 m as compared to depths of 1.2

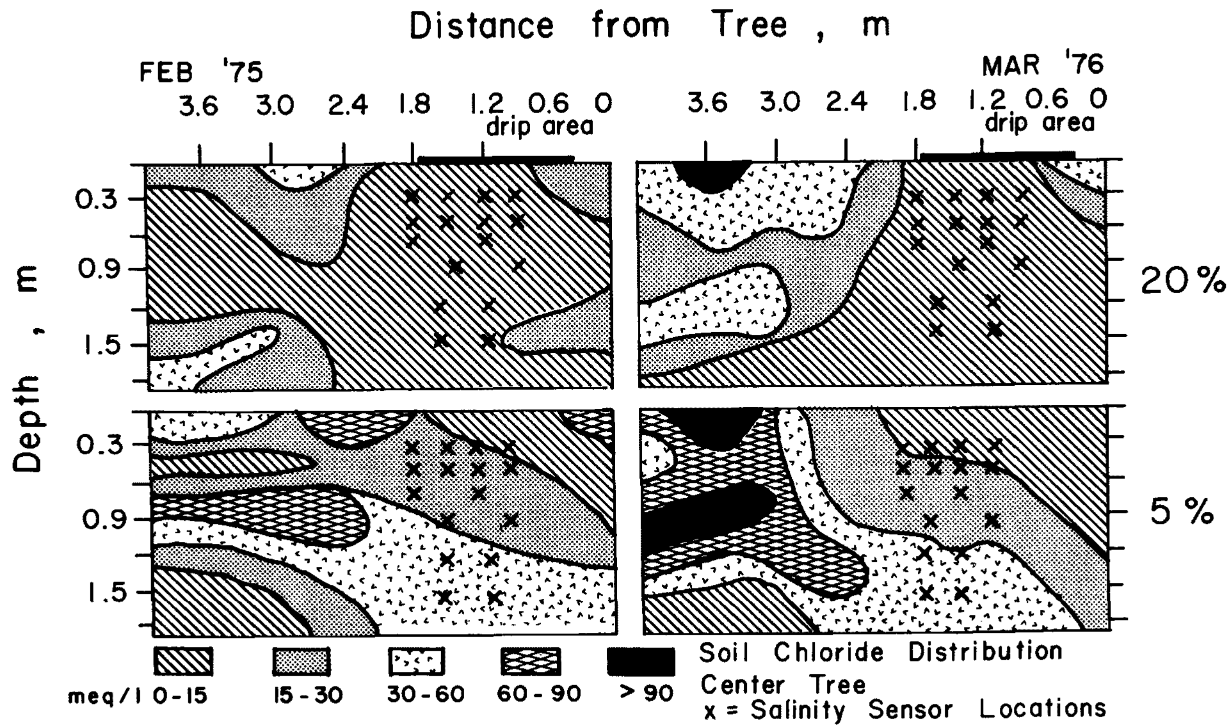

Figure 14. Composite cross sections of soil chloride distribution under the center tree of a 5% (L7) and 20% (H4) leaching plot after 1 and 2 years.

and 1.8 m at distances of 3.0 and 0.6 m away from the tree. The calculated leaching percentages at the bottom of the root zone for plots H4 and L7 are given in Table 5. The calculated evapotranspiration for plots H4 and L7 is 1211 and 1246 mm, respectively, from calculations based on the weighted average leaching of 30 and 6% and water applications of 1730 and 1340 mm.

An assessment was made of the nature of variability in soil chlorides, and, by inference, soil salinity. A log transformation of the chloride concentrations increased the number of significant sources of variation (depths, depths x leaching percentage, depths x trees, and leaching treatments) in an analysis of variance. It reduced the coefficient of variation of the measurement error from 56% for untransformed data to 16%. The data were also classified into 11 arrays from a total of 681 observations, for which the arithmetic means were not significantly different at the 5% level. The standard deviation was independent of the mean based on log-transformed chloride concentrations (Table 6), which was not true for untransformed data. Figure 15 shows the frequency distribution of the 681 observations in terms of the variable

$$(C_{Cl} - \overline{C}_{Cl})/S \tag{1}$$

where $\overline{C}_{Cl}$ represents the mean chloride concentration of the group and S represents its standard deviation. The log-transformed data are more nearly normally distributed. This result is not considered to be unusual by statisticians, since it is characteristic of dependent variables (C_{Cl}) that are inversely related to the independent variable (leaching percentage).

The distribution of water lost from a soil root zone is determined by surface evaporation, root uptake, and leaching fraction. With saline irrigation water, the fraction of water lost as a function of soil depth can be calculated based on knowledge of the leaching fraction (LF), the chloride concentration of the irrigation water (Cl_{iw} = 3.3 meq/ℓ), and the chloride concentration of soil water at a given depth (Cl_{sw}), since chloride does not precipitate and negligible quantities are taken up by plant roots. Thus, the relative water lost (RWL) can be calculated from

$$RWL = [1 - (Cl_{iw})/(Cl_{sw})]/(1 - LF). \tag{2}$$

The term (1 - LF) is the fraction of the irrigation water that is lost in the total root zone and ($1 - Cl_{iw}/Cl_{sw}$) is the fraction of the irrigation water lost in the root zone above a given soil depth. At a soil depth where LF = Cl_{iw}/Cl_{sw}, root water uptake has ceased.

The mean chloride concentrations and relative water loss as functions of soil depth are given in Table 7 for plots H4 and L7. The Cl concentrations are the means of the seven sites beneath the tree canopy sampled in March 1976. The leaching percentages for plots H4 and L7 are 30 and 6, respectively. The water loss distribution is similar for both trees, but this may have been caused by less stable soil salinity levels in plot L7 than in H4. Transients in soil salinity during the 12 months before soil sampling

TABLE 5. LEACHING PERCENTAGES FOR TWO PLOTS OF THE CITRUS EXPERIMENT AS CALCULATED FROM THE CHLORIDE CONCENTRATIONS IN THE SOIL AND THE IRRIGATION WATER

Distance from tree (m)	Plot area represented (m^2)	Calculated leaching percentage Plot H4	Plot H7
0 - 0.9	2.54	29	14
0.9 - 2.0	10.02	37	7
2.0 - 2.9	11.45	39	5
2.9 - 3.3	8.69	11	4
Weighted average	---	30	6

TABLE 6. MEAN AND STANDARD DEVIATIONS (S) OF <u>IN SITU</u> CHLORIDE CONCENTRATIONS FOR ORIGINAL AND ℓn TRANSFORMED DATA

Array	Number of samples	Not transformed		Transformed	
		Mean	S	Mean	S
		meq/ℓ		ℓn(meq/ℓ)	
A2	81	6.0	2.3	1.73	.34
B2	108	8.9	5.0	2.07	.45
A11	42	9.3	4.3	2.14	.40
D	177	10.6	5.0	2.26	.45
C2	108	11.3	6.1	2.29	.24
B13	36	13.9	5.7	2.56	.38
C111	57	14.6	7.1	2.58	.45
B121	30	30.6	8.7	3.38	.27
C112	15	31.4	10.2	3.40	.33
B112	15	35.5	14.6	3.49	.41
B111	12	55.7	20.8	3.93	.47

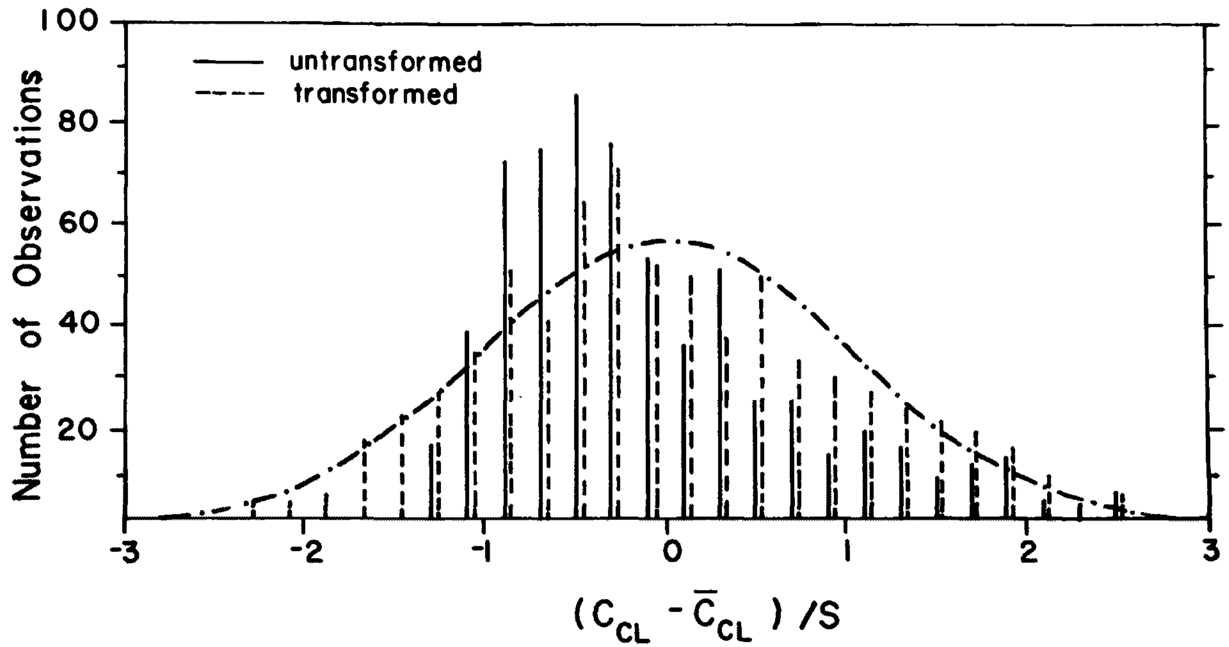

Figure 15. Frequency distribution of the ratio of the difference between individual chloride measurements and the mean to standard deviation.

TABLE 7. CHLORIDE CONCENTRATION AND WATER LOSS DISTRIBUTION UNDER CENTER TREES OF 5 AND 20% LEACHING TREATMENT PLOTS

Soil depth	Plot H4 (20%) Cl concentration	Plot H4 (20%) Accumulated RWL*	Plot L7 (5%) Cl concentration	Plot L7 (5%) Accumulated RWL*	Average Accumulated RWL*
m	meq/ℓ		meq/ℓ		
0.3	6.0	0.64	12.0	0.77	0.70
0.6	8.3	0.86	14.5	0.83	0.84
0.9	9.4	0.93	18.0	0.88	0.90
1.2	10.2	0.97	23.0	0.92	0.94
1.5	10.6	0.98	33.0	0.97	0.98
1.8	--	--	45.0	1.00	--

*Relative water loss.

were greater for plot L7 than H4. A general rise in soil salinity in plot L7, which ended about 3 months before sampling, was followed by a drop in salinity, particularly at the 0.3- to 0.9-m soil depth, until about 1 month before sampling. Salinity transients in plot H4 were very small. Thus, the lower accumulated relative water loss for plot L7 in the 0.6- to 1.2-m depth may reflect the drop in salinity at that depth before sampling. Regardless, the relative water loss data indicate that two-thirds of the water is lost above a soil depth of 0.3 m and that 90% is lost above a depth of 0.9 m. This water loss distribution was used to retarget soil salinity values for irrigation feedback (see Fig. 12) from the salinity sensors and to determine the intermediate response of soil salinity to the different leaching treatments.

Response of Salinity Distribution to Changes in Leaching Fraction

Assuming one-dimensional vertical flow, the time-averaged velocity of a parcel of water within the root zone is given by

$$v = \theta v/\theta = \{I - E - T \int_o^z \beta dz\}/\theta \qquad (3)$$

where v is the velocity of the parcel of water, θ is the volumetric water content (i.e., θv is the volumetric flux), I is the irrigation rate, E is the rate of evaporation from the soil surface, T is the rate of transpiration for the volumetric rate of uptake by plant roots. The product of T and the integral of β from 0 to z represents the cumulative rate of uptake above depth z. The progress of a parcel of water along its path can be calculated by introducing the expression for v given by equation (3) into

$$t - t_o = \int_o^z v^{-1}\, dz \qquad (4)$$

where t_0 is the time at which the parcel was introduced at the soil surface. Use of equations (3) and (4) requires knowledge of I, E, T, β and θ. If I, E, and T are given, the leaching fraction $L = (I - E - T)/I$ is of course given by implication. Figure 16 shows calculated travel times assuming $I = 7$ mm/day, $\theta = 0.15$, and $L = 0.05$, 0.1, and 0.2. Based on distributions of chloride, the evapotranspiration was assumed to be distributed as follows:

Soil Depth, z m	ET %	Soil Depth, z m	ET %
0 to 0.3	70	0.9 to 1.2	4
0.3 to 0.6	10	1.2 to 1.5	2
0.6 to 0.9	8	1.5 to 1.8	1

The sum of the percentages just given is 95%. The remaining 5% represents an allowance for the fact that the leaching fractions are averages for an entire tree, whereas the chloride profiles are measured under the tree canopy where the leaching fraction is relatively large. The time for a parcel of water to reach 0.9 m ranges from 1 to 2 months and to reach 1.8 m from 3 to 7 months. In an earlier theoretical study, the distribution of the uptake was assumed to be given by

$$\beta = \delta^{-1} \exp(-z/\delta), \tag{5}$$

where δ can be interpreted as a characteristic length for the rooting depth. In Figure 16, depth-time trajectories for $\theta = 0.15$, $E = 0$, $L = 0.05$, 0.1, and 0.2, and $\delta = 0.2$ and 0.4 m are shown. The results for $\delta = 0.4$ m agree quite well with the travel times based on the uptake distribution determined from the chloride profiles.

The travel times indicated above must be regarded as minimum estimates. Farther away from the trunk, the leaching fraction will be smaller. Measured salinity distributions indicate a continual buildup during the second year of the experiment.

Vacuum Extractor Volumes and Concentrations

Volume of Leachates--

The vacuum extractors were installed in December 1973 in soil that was relatively wet from previous flood irrigations. Accordingly, some extract was obtained initially. With the conversion to the new irrigation regime, and the withholding of irrigation water to increase soil salinity, the roots dried out the soil at the depth of the extractors and this stored water was not immediately replenished with water from the surface. As a result, the tensiometers near the extractors went off-scale and drainage stopped. In the late spring of 1974, the soil water content increased, the soil matric potential measured by the tensiometers came back on scale and many of the extractors started to flow. The 10 and 20% leaching treatments started to drain before the 5% treatment, as expected. Most of the problems with leaks in the ceramic tubes were solved. Of the total 36 extractor segments, three

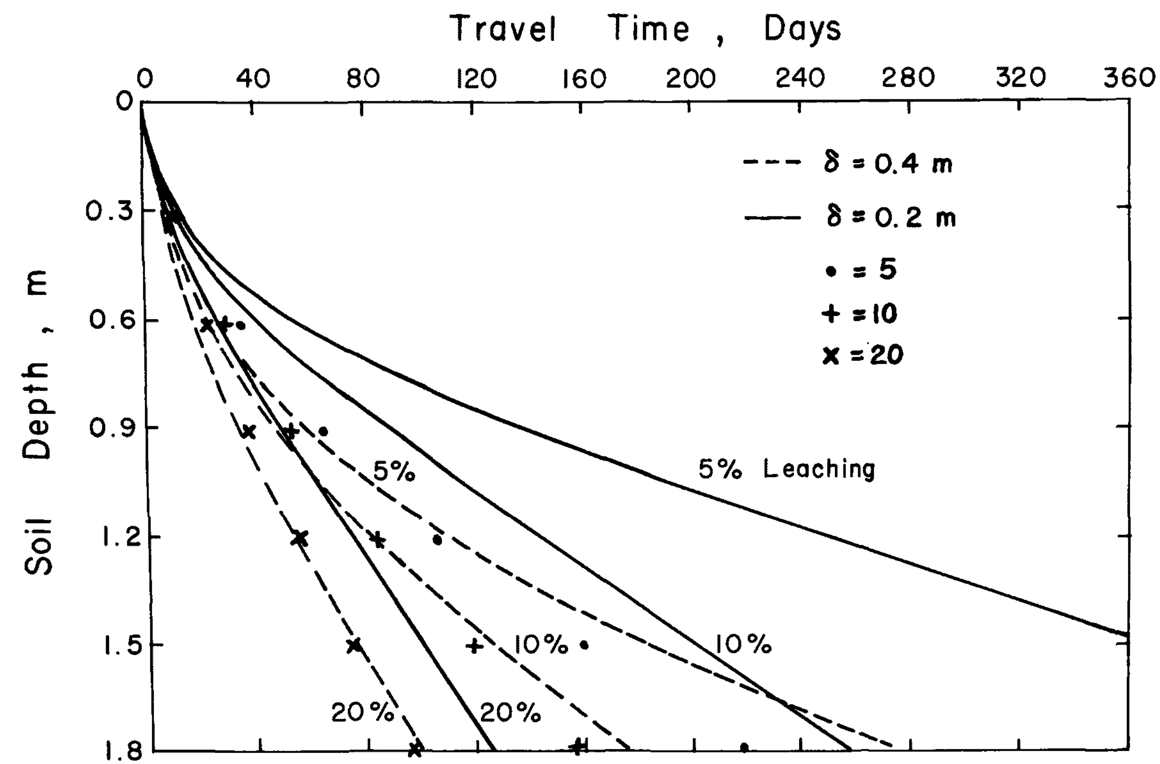

Figure 16. Chloride-derived and calculated travel time for a parcel of water to pass through the soil profile as a function of leaching fraction and rooting depth.

are nonfunctional, and two in plot M8 and seven in plot L7 drain very infrequently or not at all.

Table 8 gives a summary of the cumulative drainage volumes and leaching percentages calculated from the beginning of the experiment in January 1974, and the EC of the leachates for the best segment and the average of all working segments for each of the three treatments. The cumulative leaching percentages of the best segments as of August 4, 1976 were 4.5, 5.9, and 3.6%, compared to the target values of 5, 10, and 20%, respectively. The average values were much lower at 1.3, 2.2, and 1.7%, respectively. The three extractor segments under the southwest tree of L7 had yielded almost the same drainage volume as the maximum yielding segments of each of plot H6 and plot M8, and much more than those under the remaining three trees of these treatments. All tensiometers near the extractors read essentially the same. Therefore, most, if not all, extractors are not functioning properly, rather than being in dry soil. Since it is unlikely that the extractors would drain too much, one could take the highest yielding segment as normative for each treatment. The leaching percentages shown in Table 8 are lower than those obtained more recently, because of the influence of the initial period when the extractors were not draining. The leaching percentages from August 1974 to August 1975, and from August 1975 to August 1976, of the highest yielding segment are 3.9 and 6.5%, 8.1 and 6.9%, and 4.3 and 2.9%, for the 5, 10, and 20% leaching treatments, respectively. The 2-yr average for the 5% treatment is on target, that for the 10% treatment is 25% below target, and that for the 20% treatment is 82% below the target value. These values are not corrected for the fact that the leaching percentages are based on irrigation volumes as expressed in depth over the total surface area. Actually, water layers 2.27 times as deep were applied over approximately 44% of the total soil surface. Therefore, should no appreciable divergence of flow occur above the depth of the extractors (1.2 m) into the dry soil between trees, the leaching percentages would actually be only 44% of the values noted above. On the other hand, should the flow diverge out to the centerline between trees such that the downward flow at the extractor depth had become uniform, the leaching percentages would be correct as presented. The tensiometers in plot H4 indicate that at the depth of the extractors the flow is still generally downward over an area extending somewhat beyond the radius of the extractors, whereas flow is outward or even upward at the extractor depth in a center strip between the tree rows. The downward flow region is largest during the wetter summer season. The extractor tensiometers on plot H6 measured nearly the same total head as those on plot H4 at the same depth. This suggests that the flow fields around the extractors are similar to those measured in plot H4. Thus, there may be little divergence of flow above the depth of the extractors and the leaching percentages cited above probably should be reduced to about half their values.

The tensiometers installed with the extractors to monitor and regulate the suction in the filter candles of the extractors are very insensitive to the suction in the filter candles, and read generally the same within the expected experimental error. Thus, no efforts have been made to adjust the suction in the extractors to balance the readings between those tensiometers directly over the extractor and those in the adjacent undisturbed soil.

TABLE 8. CUMULATIVE DRAINAGE AND LEACHING PERCENTAGE SINCE JANUARY 1974 AND EC OF LEACHATES FOR THE VACUUM EXTRACTORS IN THE THREE LEACHING TREATMENTS IN THE CITRUS EXPERIMENT

Date	Best Segment			Average of all Draining Segments		
	Cumulative leachate	Cumulative leaching	EC	Cumulative leachate	Cumulative leaching	Weighted av. EC leachate
	mm	%	S/m	mm	%	S/m
			5% Leaching			
04-01-74	1.9	1.1	--	0.2	0.1	--
07-02-74	7.9	1.5	0.32	1.2	0.2	0.28
09-27-74	22.5	2.1	--	4.3	0.4	--
11-11-74	35.2	2.9	0.50	7.6	0.6	0.52
02-05-75	39.8	3.1	0.41	9.1	0.7	0.37
05-21-75	52.5	3.4	0.39	11.8	0.8	0.61
08-08-75	59.2	3.0	0.38	13.8	0.7	0.61
10-06-75	70.2	3.0	0.44	16.9	0.7	0.71
03-12-76	105.5	4.1	--	26.4	1.0	--
04-24-76	115.4	4.3	--	31.2	1.2	--
06-28-76	131.2	4.2	--	37.6	1.2	--
08-04-76	155.9	4.5	--	46.7	1.3	--
			10% Leaching			
04-01-74	0.5	0.5	0.35	0.2	0.2	0.26
07-02-74	1.7	0.3	0.27	1.7	0.3	0.38
09-27-74	19.4	1.6	--	12.3	1.0	0.73
11-11-74	30.4	2.3	0.46	15.8	1.2	0.58
02-05-75	38.8	2.7	0.55	18.1	1.3	0.52
05-21-75	59.3	3.3	0.41	24.0	1.3	0.65
08-08-75	128.1	5.2	0.32	44.3	1.8	0.71
01-15-76	166.3	5.5	0.38	59.3	2.0	0.62
04-24-76	173.0	5.4	--	62.5	1.9	--
06-28-76	186.5	5.0	--	69.1	1.9	--
08-04-76	246.5	5.9	--	89.3	2.2	--
			20% Leaching			
04-01-74	7.2	7.3	0.27	1.7	1.7	0.27
07-02-74	7.3	1.2	0.32	2.5	0.4	0.31
09-27-74	60.7	4.3	--	21.1	1.5	0.48
11-11-74	68.5	4.5	0.26	24.7	1.6	0.41
02-05-75	80.2	4.8	0.29	30.9	1.8	0.37
05-21-75	97.9	4.8	0.27	38.1	1.9	0.36
08-08-75	108.8	4.2	0.25	44.5	1.7	0.35
12-16-75	128.8	3.9	--	57.1	1.7	0.47
04-24-76	143.8	4.0	--	64.5	1.8	--
06-28-76	154.1	3.7	--	70.9	1.7	--
08-04-76	171.3	3.6	--	80.2	1.7	--

Composition of Leachates--

Complete salinity analyses of the drainage waters collected by the extractors are being carried out to ascertain the amounts and compositions of salt loss by deep percolation resulting from our irrigation management. To date, 213 samples have been analyzed. Average drainage water compositions by treatment and standard error of mean values for June 1976 samples are given in Table 9. Compositions with time are compared in Table 10.

These data show that the salt levels in the drainage waters have increased with time and reflect the differences in leaching treatments. The average total salinities by treatment in June 1976 were (in meq/liter): 113 (plot L7), 75 (plot M8), and 49 (plot H6). The chloride concentrations were (in meq/liter): 56 (plot L7), 24 (plot M8), and 13 (plot H6), which corresponded to apparent leaching fractions, Cl_{iw}/Cl_{dw}, of 0.06, 0.15, and 0.27, respectively. Analogous data in 1974 resulted in leaching fraction estimates of greater than 0.33 for past management. These apparent leaching fractions represent the degree to which the water percolating past the 1.2-m soil depth below the irrigated area of the trees has been concentrated by evapotranspiration. Since some soil water is currently also flowing into the inter-row soil regions, the overall LF's may be less than those suggested by these apparent values. To determine if the shallow drainage waters sampled are truly representative of the waters that pass into the ground water, we need to collect and analyze soil-water samples from deeper depths, both under the trees and in the inter-row regions.

The compositions of the drainage waters in June 1976 had not equaled those expected for steady-state conditions. The expected composition of the drainage water as a function of leaching fraction is given in Table 11. Compared to these compositions, the waters in June were high in calcium and low in magnesium, sodium, sulfate, and SAR for all treatments. This probably resulted from the fact that sodium and magnesium were still being adsorbed by the exchange complex and calcium was being displaced to solution. Exchange equilibrium had not been achieved. This is reasonable, considering the short time the experiment has been underway.

Yield and Fruit Quality

The average yields per tree for the three leaching treatments are presented in Table 12, along with the average yield for the border and check-plot trees. The average yield per tree for each replication of the experiment and for each row of the border and check-plot trees is given in Appendix Table A-2. Analysis of variance showed no significant differences in yield among leaching treatments for each of the 3 yrs. This lack of significant yield differences among leaching treatments, however, was not unexpected, since significant yield differences did not appear in an irrigation water quality trial on orange trees until the fourth year in a study by Bingham et al. (1974). Yields from the borders and check plots were not significantly different from the experimental trees and they were more variable. Yields in 1975 and 1976 were consistently larger from the fertilizer-check plot and the drip border than from the leaching treatments. Historically, the east side of the grove, where the drip border and fertilizer check plot are located, has out-yielded the west side.

TABLE 9. AVERAGE DRAINAGE WATER COMPOSITIONS FROM THE VACUUM EXTRACTORS FOR THE CITRUS EXPERIMENT IN JUNE 1976

Plot no.	Leaching treatment	EC*	Ca	Mg	Na	K	Sum of cations	HCO_3	SO_4	Cl	NO_3	SiO_2	SAR†	$\frac{Cl_{iw}}{Cl_{dw}}$§
		S/m	← meq/ℓ								→	mg/ℓ		
L7	5%	0.86	54.9	22.0	35.5	0.39	112.8	6.2	48.5	55.6	2.6	35.2	6.3	.06
		(0.09)¶	(9.5)	(3.1)	(4.1)	(.03)	(11.6)	(0.6)	(4.9)	(13.4)	(0.8)	(2.5)	(0.9)	
M8	10%	0.58	27.2	14.2	33.2	0.52	75.2	8.2	42.8	24.3	1.1	33.4	7.4	.15
		(0.06)	(3.0)	(1.9)	(3.7)	(.04)	(7.8)	(0.6)	(5.3)	(3.5)	(0.2)	(2.2)	(0.6)	
H6	20%	0.39	21.0	8.8	18.9	0.29	48.9	8.6	27.0	13.1	0.7	35.8	5.1	.27
		(0.02)	(2.0)	(0.6)	(1.3)	(.02)	(2.6)	(0.7)	(1.9)	(1.3)	(0.1)	(3.2)	(0.5)	

*Electrical conductivity at 25°C.

†SAR = $Na/\sqrt{(Ca + Mg)/2}$, where solutes are in meq/liter.

§Ratio of Cl concentration (meq/liter) in irrigation water (iw) to drainage water (dw).

¶Standard error of mean.

TABLE 10. COMPOSITION OF DRAINAGE WATERS FROM SELECTED VACUUM EXTRACTORS IN THE CITRUS EXPERIMENT AS A FUNCTION OF TIME

Leaching treatment	Extractor No.	Date	Ca	Mg	Na	K	Sum of cations	HCO_3	SO_4	Cl	NO_3	SiO_2	EC*	SAR†
%			← meq/ℓ								→	mg/ℓ	S/m	
5(L7)	B-1	07-73	9.2	5.5	10.3	0.2	25.1	7.5	9.4	7.6	0.6	95	0.23	3.8
		02-75	17.2	9.8	15.9	0.3	43.3	7.4	18.7	17.3	1.3	73	0.37	4.3
		06-76	79.3	27.6	23.9	0.3	131.0	4.9	44.1	82.0	3.2	24	1.01	3.3
10(M8)	B-1	04-74	9.7	6.1	10.4	0.3	26.5	6.8	11.0	9.2	0.3	77	0.24	3.7
		06-75	21.0	12.4	26.1	0.4	60.0	10.5	35.2	12.7	1.2	22	0.45	6.4
		06-76	37.4	21.1	29.5	0.6	88.7	8.9	46.4	31.2	2.0	25	0.66	5.5
20(H6)	B-1	08-74	22.2	11.0	16.0	0.3	49.4	5.8	24.0	17.1	1.4	81	0.41	3.9
		08-75	34.2	15.0	14.3	0.2	63.8	6.4	33.7	22.8	0.7	61	0.47	2.9
		06-76	29.6	10.7	20.5	0.3	61.1	7.1	35.1	18.6	0.8	38	0.47	4.6

*Electrical conductivity at 25°C.

†SAR = $Na/\sqrt{(Ca - Mg)/2}$, where solutes are in meq/liter.

TABLE 11. PREDICTED DRAINAGE WATER COMPOSITIONS FOR CITRUS TREATMENTS*

Leaching fraction	Ca	Mg	Na	Sum of cations	HCO_3	SO_4	Cl	EC†	SAR§
	← meq/ℓ →							S/m	
.03	23.7	90.0	227.0	340.0	8.5	215.0	117.0	2.46	30.1
.05	24.9	54.0	136.0	215.0	6.9	138.0	70.0	1.68	21.7
.10	22.8	27.0	68.0	118.0	5.8	77.0	35.0	1.00	13.6
.15	17.2	18.0	45.3	80.6	5.9	51.3	23.3	0.69	10.8
.20	14.4	13.5	34.0	61.9	5.9	38.5	17.5	0.53	9.1
.30	11.6	9.0	22.7	43.2	5.9	25.7	11.7	0.37	7.1
.40	10.1	6.7	17.0	33.9	5.9	19.2	8.7	0.29	5.9

*Assuming the partial pressure of CO_2 is 0.015 and the irrigation water composition (in meq/liter) is Ca (4.5), Mg (2.7), Na (6.8), Cl (3.5), HCO_3 (2.8), and SO_4 (7.7).

†Electrical conductivity at 25°C.

§$SAR = Na/\sqrt{(Ca + Mg)/2}$, where solutes are in meq/liter.

TABLE 12. AVERAGE ANNUAL VALENCIA ORANGE YIELD (kg/tree) FOR THE MINIMUM LEACHING TREATMENTS AND THE BORDER- AND CHECK-PLOT TREES

Year	Leaching treatment			Border trees		Check plots		Weighted
	5%	10%	20%	Bubbler	Drip	Flood	Fert.	average
1974	116	126	122	123	113	--*	--*	120
1975	143	148	147	141	165	121	179	149
1976	74	70	71	77	88	98	105	83

*Trees were not individually harvested.

The yields reported here and the historical yield record of the grove indicate an alternate year pattern in fruit bearing. This yield pattern for Valencia orange is well documented (Parker and Batchelder, 1932; Bingham et al., 1974). Thus, although the yields of 1976 were discouragingly low, they were not unexpected.

The average number of fruit harvested per tree is summarized in Table 13. The number of fruit harvested each year agrees well with the weight of fruit harvested, but the variation among years for the number of fruit is even larger than variation among weights. The numbers of fruit per kg each year were 4.5, 5.2, and 4.2 for 1974, 1975, and 1976, respectively, indicating smaller fruit for the higher yields.

TABLE 13. AVERAGE NUMBER OF VALENCIA ORANGE FRUIT HARVESTED PER TREE FOR THE MINIMUM LEACHING TREATMENTS AND THE BORDER- AND CHECK-PLOT TREES

Year	Leaching treatment			Border trees		Check plots		Weighted
	5%	10%	20%	Bubbler	Drip	Flood	Fert.	average
1974	522	558	559	551	479	--	--	537
1975	788	798	781	706	871	519	939	770
1976	329	299	309	314	349	426	406	349

The average annual value of each measure of fruit quality is presented in Table 14. None of the fruit quality measurements differed significantly among the leaching treatments in any year. The fruit-size data support the results from the number of fruit per kg in that the heavier yield in 1975 resulted from smaller fruit (larger ring size, shorter, and narrower than in 1974 and 1976). There were few differences among the leaching treatments, borders, and check-plots. In 1974, the fruit from the drip border were consistently larger than the fruit from the other treatments. Fruit from the bubbler-border and the flood-check plots were larger than the fruit from the remaining treatments in 1975. No consistent differences were noted in rind color. The orange rind was consistently rougher in 1976 than in either 1974 or 1975 for all treatments, and in 1975, the fruit from the drip border were smoother and the fruit from the flood-check plot were rougher than from the remaining treatments.

TABLE 14. VALENCIA ORANGE FRUIT QUALITY FOR 1974, 1975, AND 1976 HARVESTS

Measure of fruit quality	Year	Leaching treatments 5%	Leaching treatments 10%	Leaching treatments 20%	Border trees Bubbler	Border trees Drip	Check plots Flood	Check plots Fertilizer	Weighted Average
Ring Size*	1974	70	68	69	72	64	75	--	69
	1975	82	81	79	75	86	68	81	79
	1976	70	68	71	65	63	70	66	68
Rind Color†	1974	10.3	10.3	10.3	10.2	10.1	10.4	--	10.2
	1975	10.4	10.4	10.4	10.4	10.3	10.4	10.4	10.4
	1976	10.4	10.3	10.3	10.5	10.3	10.4	10.3	10.4
Rind Texture§	1974	3.3	3.3	3.3	3.2	3.5	3.3	--	3.3
	1975	3.2	3.3	3.3	3.4	2.9	3.8	3.3	3.3
	1976	4.1	4.2	4.2	4.3	4.2	4.2	4.3	4.2
Fruit Length, mm	1974	80	81	81	81	84	78	--	81
	1975	77	78	78	81	78	84	78	79
	1976	84	85	84	88	86	84	85	85
Fruit Width, mm	1974	74	75	74	74	77	72	--	74
	1975	72	72	73	75	71	77	72	73
	1976	76	77	76	77	79	76	76	77

*Ring size is equivalent to the average number of fruit to a standard size shipping carton.

†Rind color is denoted by a numerical scale from 3 (dark green) to 13 (orange-red).

§Rind texture is evaluated on a numerical scale from 1 (smooth) to 6 (very rough).

Results of the annual juice analyses are given in Table 15. The fruit were harvested purposely at a lower TDS/TA ratio in 1975 and 1976 than in 1974. As orange fruit ripens, the TDS/TA ratio increases because TDS decreases slower than does TA. The legal minimum ratio for sale of oranges is eight. Juice quality measurements did not differ significantly among leaching treatments in any year. Fruit were not as ripe from the flood-check plot as from the other treatments, as is evident from a lower TDS/TA ratio and a lower percent juice.

Leaf Analyses

Leaf samples, taken in September 1974 and 1975 for evaluating the nutritional status of the trees, were analyzed for 13 mineral elements. The 1975 analytical results for the experimental, border, and check plots are summarized in Table 16. The 1974 results are given in Table A-3. The nutritional status of the trees was reasonably uniform among all plots and all nutrient elements except boron were within or near optimum levels. Leaf boron concentrations were unexpectedly high and will require careful monitoring in the future. Analyses of the soil and irrigation water did not indicate either as the boron source. Sodium and chloride, which can accumulate to toxic levels, were well within acceptable limits. However, Cl levels seem to be increasing in the low leaching treatments.

Except for some chlorosis observed in the spring on new growth and attributed to seasonal deficiencies in Fe and Mn, the trees appeared in good health. Leaf samples were taken again in October 1976 for continued evaluation of tree nutrition and the fertilizer program.

Trunk Circumference

Trunk circumferences were measured in September 1973, July 1974, August 1975, and July 1976. In 1974, a nail was driven into each trunk to locate permanently the measurement elevation. The average annual increases in trunk circumference for the leaching treatments, the borders and the check plots are given in Table 17. The annual measurements of circumference, averaged by replication for the leaching treatments and by row for the borders and check plots, are given in Table A-4.

There have been no significant differences in trunk circumferences among leaching treatments. Analysis of variance showed, however, that the mean trunk circumferences for all three leaching treatments have enlarged significantly each year with the exception of the 5% leaching treatment during the initial year. The mean trunk circumference of the experimental trees increased less than 2.5% the first year, but more than 5% during each of the last 2 yrs. Although less consistent than the experimental trees, the border trees have made similar growth. Measurements were not taken every year on the check-plot trees, so comparisons cannot be made. However, they seem to be growing as rapidly as the experimental trees, although they are smaller and more variable in size.

TABLE 15. VALENCIA ORANGE JUICE QUALITY FOR 1974, 1975, AND 1976 HARVESTS

Measure of juice quality	Year	Leaching treatments			Border trees		Check plots		Weighted average
		5%	10%	20%	Bubbler	Drip	Flood	Fertilizer	
Total dissolved solids, %*	1974	9.7	9.8	9.8	10.0	9.1	10.0	--	9.8
	1975	10.3	10.1	10.0	10.0	10.1	10.0	10.1	10.1
	1976	9.9	9.9	9.8	9.8	9.7	10.2	9.7	9.9
Total acid, %†	1974	0.90	0.89	0.90	0.89	0.83	0.93	--	0.89
	1975	1.03	1.01	1.00	0.97	1.00	1.04	1.02	1.01
	1976	0.99	0.99	0.98	0.94	0.93	1.10	0.97	0.99
Ratio, TDS/TA	1974	10.8	11.0	10.9	11.2	11.0	10.7	--	10.9
	1975	10.0	10.0	10.0	10.3	10.1	9.6	9.9	10.0
	1976	10.0	10.0	10.0	10.5	10.3	9.2	10.0	10.0
Percent juice	1974	44.3	44.1	44.6	44.3	42.5	41.8	--	43.6
	1975	43.7	43.2	42.7	43.1	43.9	39.3	43.3	42.9
	1976	41.4	40.9	40.6	38.4	41.8	36.6	41.6	40.2
Extractable TDS, %§	1974	3.65	3.67	3.72	3.77	3.29	3.55	--	3.62
	1975	3.83	3.71	3.63	3.66	3.77	3.34	3.72	3.66
	1976	3.45	3.40	3.40	3.10	3.45	3.20	3.45	3.36

*Total dissolved solids (TDS) are determined with a Brix hydrometer or refractometer. Total dissolved solids in orange juice consist mainly of sucrose, fructose, and citric acid, together with potassium, calcium, magnesium, and sodium salts. Traces of glycosides are also present.

†Total acid refers to the titratable acidity and is determined volumetrically by the amount of standard alkali necessary to neutralize the acid in a known amount of juice. The acid in orange juice consists mainly of citric acid with small amounts of malic, tartaric, and succinic acids.

§The juice plant can extract only about 85% as much juice as can the laboratory. Thus, the grower is paid on the basis of 85% of the total dissolved solids per fruit weight measured in the laboratory. To convert from % (given above) to lbs. of solids per ton of fruit, multiply by 20.

TABLE 16. MINERAL COMPOSITION OF VALENCIA ORANGE LEAVES SAMPLED SEPTEMBER 1975

Element	(unit)	Optimum range	Leaching treatments			Border trees		Check plots	
			5%	10%	20%	Bubbler	Drip	Flood	Fertilizer
N	%	2.2-2.7	2.9	2.8	2.8	2.7	2.8	2.5	3.1
P	mmole/100 g	4-6	4.1	4.1	4.2	4.2	4.4	3.6	3.9
K	meq/100 g	25-45	31	30	32	32	31	34	31
Ca	" "	150-250	224	224	221	234	227	236	210
Mg	" "	17-50	23	23	22	23	21	22	19
Na	" "	2.5-6.5	1.6	1.7	1.6	1.6	1.8	0.6	1.7
Cl	" "	<4.2	3.4	3.0	1.8	1.9	2.2	0.6	1.2
S	" "	12-19	20	20	20	20	20	21	20
B	µg/g	25-150	208	212	206	182	182	195	211
Fe	"	60-150	56	58	58	56	62	61	65
Mn	"	20-100	26	26	28	31	25	22	25
Zn	"	25-100	28	27	27	28	27	17	21
Cu	"	4-10	9	9	9	10	9	10	8

TABLE 17. AVERAGE ANNUAL INCREASE IN THE TRUNK CIRCUMFERENCE (mm) OF VALENCIA ORANGE TREES FOR THE MINIMUM LEACHING EXPERIMENT IN SOUTHWESTERN ARIZONA

Growth period	Leaching treatment 5%	10%	20%	Border trees Bubbler	Drip	Check plots Flood	Fertilizer
1973-74	10 ns†	15*	16*	13	22	--	--
1974-75	34**	33**	35**	40	28	43	--
1975-76	36**	37**	38**	25	38	22	24

†Results of the analysis of variance comparing the nine replication means; * and ** denote statistical significance at the 5 and 1% levels, respectively.

Soil Air

Soil Oxygen--

The soil oxygen results are summarized in Table 18. Soil oxygen concentrations above 10% are considered adequate for most crops. No measurements were below 10% in the citrus experiment, not even in the flood check 1 day after an irrigation. Thus, poor soil aeration is not expected to be a problem with trickle irrigation of citrus on these coarse-textured soils.

TABLE 18. COMPARISON OF THE PERCENT SOIL OXYGEN AT THE 0.45-m SOIL DEPTH AND 1.5 m OUT FROM THE VALENCIA ORANGE TREE TRUNK FOR SEVERAL IRRIGATION TREATMENTS

Date	Leaching Treatments 5%	20%	Border Trees Bubbler	Drip	Flood Check
Feb. 1975	17.4	20.1	19.8	20.4	20.2
June & July 1975	18.1	14.8	18.2	18.5	20.2

Soil Carbon Dioxide--

The carbon dioxide concentrations in the soil air (Table 19) are affected by time of year, but not by soil depth. They are higher during the summer months (May-October) than in January because of increased root and microbial respiration and increased soil-water content. The former results in greater rates of carbon dioxide production and the latter increases the resistance to carbon dioxide exchange with the atmosphere.

TABLE 19. AVERAGE PERCENT CARBON DIOXIDE IN SOIL AIR UNDER MATURE CITRUS TREES AS A FUNCTION OF TIME AND SOIL DEPTH

Soil Depth (m)	Oct 1975	Jan 1976	Mar 1976	May 1976
0.3	2.8	0.4	1.7	2.5
0.6	3.0	0.4	1.5	3.2
0.9	3.0	0.6	1.7	2.4
1.2	3.0	0.6	1.5	2.6

DISCUSSION

Our experience thus far suggests, but does not establish with certainty, that citrus can be irrigated with leaching percentages of 20 or less without decreasing production. Available data indicate that dynamic equilibrium was approached in 1975, so that evapotranspiration can be reasonably estimated. Unless the trees respond physiologically after a longer time - a possibility that cannot be overlooked - the data also permit estimates of the effect of changing irrigation management on drainage volumes and salt loading in the drainage waters.

Evapotranspiration

Based on the results presented, evapotranspiration (ET) for citrus can be estimated by several techniques. First, ET can be calculated by subtracting the amount of leaching from the depth of irrigation and rainfall (I). This assumes the desired leaching is achieved, an assumption that is reasonable in view of the carefully controlled differentials and the internal consistency of the data. A second approach is to calculate the leaching percentage from the ratio of the chloride concentration in the irrigation water (Cl_{iw}) to that at the bottom of the root zone (Cl_{dw}) as measured from soil samples or vacuum extractor leachates for individual plots; ET is then determined as $ET = I[1 - (Cl_{iw}/Cl_{dw})]$. The response time of soil salinity to decreased leaching was slower than anticipated, but since 1975 steady state has been achieved basically so that chloride concentrations at the bottom of the root zone should be representative of the leaching treatments. A third technique is to calculate ET from meteorological data. A fourth method would be to use the drainage volume as measured in the vacuum extractors. However, this last method will not be used, because the volumes collected have been small and inconsistent.[3] Here we compare the three estimates of ET with each other and with published values.

[3] We believe that the ceilings of the extractor tunnels were smeared during formation. Some extractors will be removed for examination early in 1977.

TABLE 20. ESTIMATE OF CITRUS EVAPOTRANSPIRATION (ET) BASED ON CHLORIDE CONCENTRATION FROM VACUUM EXTRACTORS OR SOIL SAMPLING

Plot	Date Cl sampled	Source of sample	Water applied during previous year	Leaching fraction	Annual ET
			mm	Cl_{iw}/Cl_{dw}	mm
H4	Mar 1976	soil sample	1730	0.30	1211
L7	" "	" "	1340	0.06	1260
H6	Jun 1976	vacuum extractor	2066	0.22	1611
M8	" "	" "	1706	0.12	1501
L7	" "	" "	1456	0.05	1383
				Average	1390

The estimate of ET based on water application and the desired leaching during the past 3 yrs is 1434 mm. The estimate of ET determined from those plots where chloride concentrations were measured is 1390 mm (see Table 20). These data are based on chloride concentrations from soil samples taken in March 1976 for plots H4 and L7 and upon chloride concentrations measured in extractor leachates in June 1976 for plots H6, M8, and L7. The leaching percentages based upon leachate composition were reduced 17% to correct for the effect of vacuum extractor location with respect to average chloride concentrations found from soil samples. The modified Penman and the Jensen-Haise equations, based on meteorological data, led to annual ET estimates of 1421 and 1342 mm, respectively.

The three estimates of ET closely agree and substantiate an annual value of 1400 mm. The resulting leaching percentages for the three leaching treatments from January 1974 to September 1976, based on this ET and the amounts of water applied, are 8, 11, and 22. Likewise, the leaching percentage for the flood check is 47.

Erie et al. (1965) published an estimate of 1000 mm for Navel oranges at Phoenix, Arizona; this value is significantly lower than ours. A likely explanation for the difference is that water use from the top 150 mm of soil was not taken into account in the evaluation reported by Erie et al. (Jensen, M. E., personal communication, 1975).

Salt Load Reduction

To estimate the effect of changing irrigation management of citrus on the contribution to the drainage volume and its salt load from the Wellton-Mohawk project, one may make the following assumptions: (1) annual ET is 1400 mm; (2) salt concentration of the irrigation water (S_{iw}) is 944 mg/ℓ (see footnote #2, p. 8); (3) present water delivery to the 3000 ha of citrus (A) is 3200 mm/yr (I_p); and (4) the salt concentration of the groundwater pumped at present averages 3000 mg/ℓ (S_{gw}). We will further assume no decrease in irrigation application efficiency below that of the experiment.

The annual reduction in the volume of drainage water resulting from a LF of 0.2 would be

$$\Delta V = A\{I_p - [ET/(1 - LF)]\}$$
$$= 3000\ [3200 - (1400/0.80)]$$
$$= 4.35 \times 10^7\ m^3/yr$$
$$= 35{,}000\ \text{acre-feet/yr.}$$

Assuming no effective salt precipitation, the reduction in salt load of the drainage water leaving the root zone would be

$$\Delta\ \text{salt load} = S_{iw}\ \Delta V$$
$$= 41{,}000\ Mg/yr$$
$$= 45{,}000\ \text{tons/yr.}$$

Accounting for lime precipitation (Oster and Rhoades, 1975), the salt load would be reduced an additional 11%, or

$$\Delta\ \text{salt load} = 45{,}500\ Mg/yr.$$

The actual amount of salt exported in the Wellton-Mohawk drains, presumably the feed water to the proposed desalting complex, would depend on changes in groundwater composition with time. During the next several years, the groundwater quality should not change significantly. Thus, the effect of changing citrus irrigation management on the quantity of salt exported would be a reduction of 3000 mg/ℓ $\times$ (4.35×10^7 m^3/yr) or 130,000 Mg/yr. These estimates may be compared with a current annual drainage volume of approximately 26×10^7 m^3/yr containing 780,000 Mg/yr of salt.

SECTION 4

ALFALFA

EXPERIMENTAL PROCEDURE

Experimental Design

The alfalfa experiment is located 13 km northeast of Tacna, Arizona, on the Snyder Ranch in the flood plain of the Gila River. The experimental site is the northern quarter of an 8-ha field that had been previously cropped to alfalfa and flood irrigated. Within 400 m of the south end of the field, the topography rises more than 15 m to a mesa where citrus is grown. A drainage well for water table control is adjacent to the southwest corner of the field. The experimental site was instrumented and the irrigation system installed during September 1974. After cultivation, alfalfa (*Medicago sativa* L., cv. Hayden) was planted in early October. All crop management practices, such as cultivating, planting, harvesting, and pest and weed control, are performed by Snyder Ranch personnel.

The experimental design, shown in Fig. 17, consists of 5, 10, and 20% leaching treatments, each replicated five times. Each plot is 12.2 m wide and 104 m long. The remainder of the 8-ha field is irrigated by the rancher using level-basin flooding.

Soil Properties

Soil Conservation Service personnel examined several soil profiles within the experimental site and classified the soil as Indio fine sandy loam (Typic Torrifluvent, coarse-silty, mixed, hyperthermic). The soil description prepared by the SCS for one of the soil profiles is given in TABLE B-1 of the appendix. The soil is calcareous, moderately alkaline, well drained, and representative of the valley soils in the district. The soil profile texture grades from very fine sandy loam to silt loam at a depth of 0.3 m, and to silty clay loam at a depth of 0.8 m.

Following the first harvest in February 1975, 303 soil samples were collected to characterize initial soil conditions and determine the soil salinity distribution resulting from previous irrigation management. Six locations were sampled in each of the six instrumented plots. These 36 locations were sampled by 0.3-m increments, 21 to a depth of 1.5 m and 15 to a depth of 2.4 m. Twelve locations were sampled in the level-basin, flood-irrigated check, six to a depth of 1.5 m and six to 2.4 m. All of the samples were subjected to the same analyses as those collected in the citrus

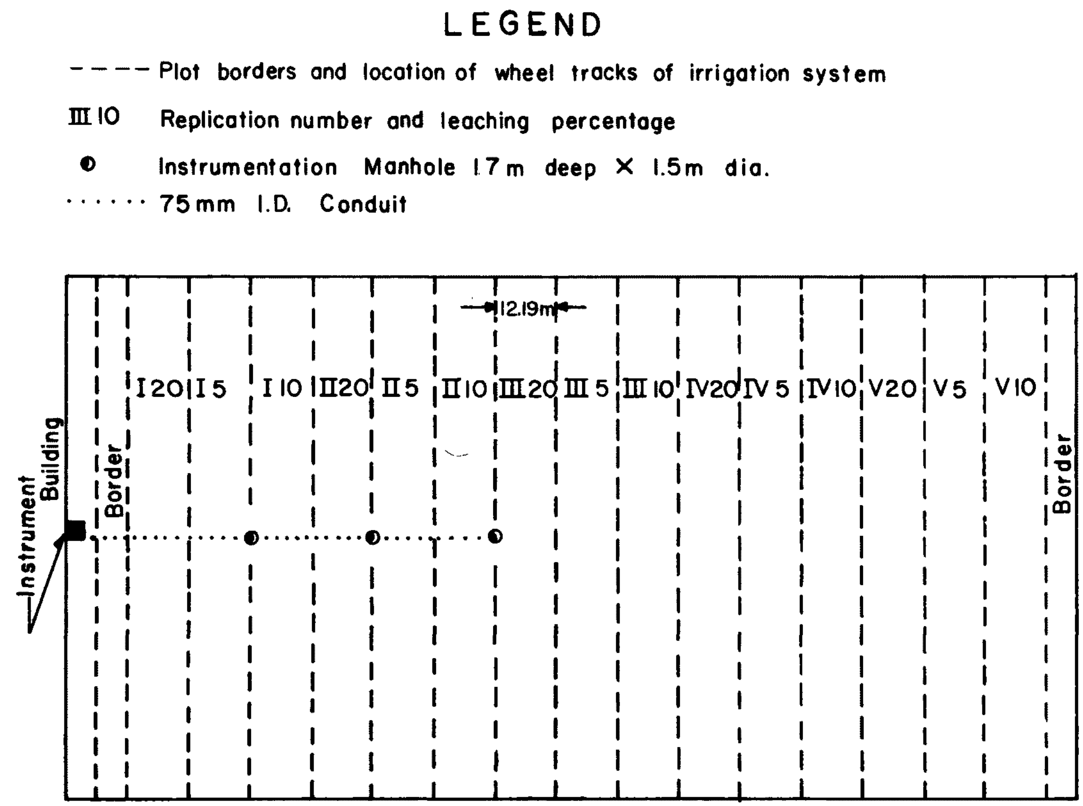

Figure 17. Design of minimum leaching experiment for alfalfa in southwestern Arizona.

experiment. As in the citrus, the relationship between hydraulic conductivity and matric potential was determined in the laboratory on three undisturbed soil columns, each 0.9 m deep, taken in the fall of 1974.

Irrigation

The irrigation water, pump, and filter system are identical to those used for the citrus. Water is applied with an electrically driven, lateral-move irrigation system 195 m long, with wheel towers spaced 12.2 m apart (see Fig. 18). The irrigation system was operated with impact sprinklers spaced at 12.2-m intervals along the main line for the first month after planting. On Nov. 8, 1974, after the crop was well established, the spray system shown in Fig. 18 was installed and differential irrigation treatments were initiated. During the first month of operation, several adjustments in alignment of the system were required to keep it running in the same tracks. Problems also arose from water running into the wheel tracks, causing the system to mire down. By filling the tracks with sand and by shielding spray nozzles near the wheels, these problems have been overcome. The irrigation system has operated trouble-free for over a year.

Differential irrigation treatments are achieved by regulating the pressure in each section of submain with a throttle valve. By periodically adjusting the pressure, based on water meter readings, the average differences in accumulated water application between the three treatments have been within 0.2% of those desired. Uniformity of water distribution within plots is also good. The standard deviation of water delivery rate from individual spray nozzles was about 2%, and the standard deviation of water delivery between 2.4-m-wide sections of a plot (irrigated with four spray nozzles) was within 1%. By selectively interchanging up to one-sixth of the nozzles, the differences in water delivery rate between 2.4-m-wide sections of any plot were reduced to less than 0.1%. This is well within the required uniformity and is possibly the most uniform field irrigation system in existence.

As in the citrus experiment, the water for each plot is measured by two water meters in series. The water is distributed through 20 nozzles (Fig. 18), which, at a pressure of 70 kPa, deliver 30 ml/sec each. At a ground speed of 30 m/hr, the irrigation system applies 6 mm each pass. Thus, the number of passes varies from one every few days in winter to a maximum of two per day in summer.

Instrumentation

Two replications of each leaching treatment were instrumented from three concrete manholes, each installed at the border between two plots as shown in Fig. 17. The manholes facilitate automatic data collection and minimize interference with farming operations. A conduit from the service building at the edge of the experimental plots to the manholes, shown in Figs. 17 and 19, contains electric cables for automatic data collection, pressure and vacuum pipes, and service wires. Two 1.5-m-long vacuum extractors, similar in design to those for the citrus, were installed at the 1.2-m depth in each of the six instrumented plots.

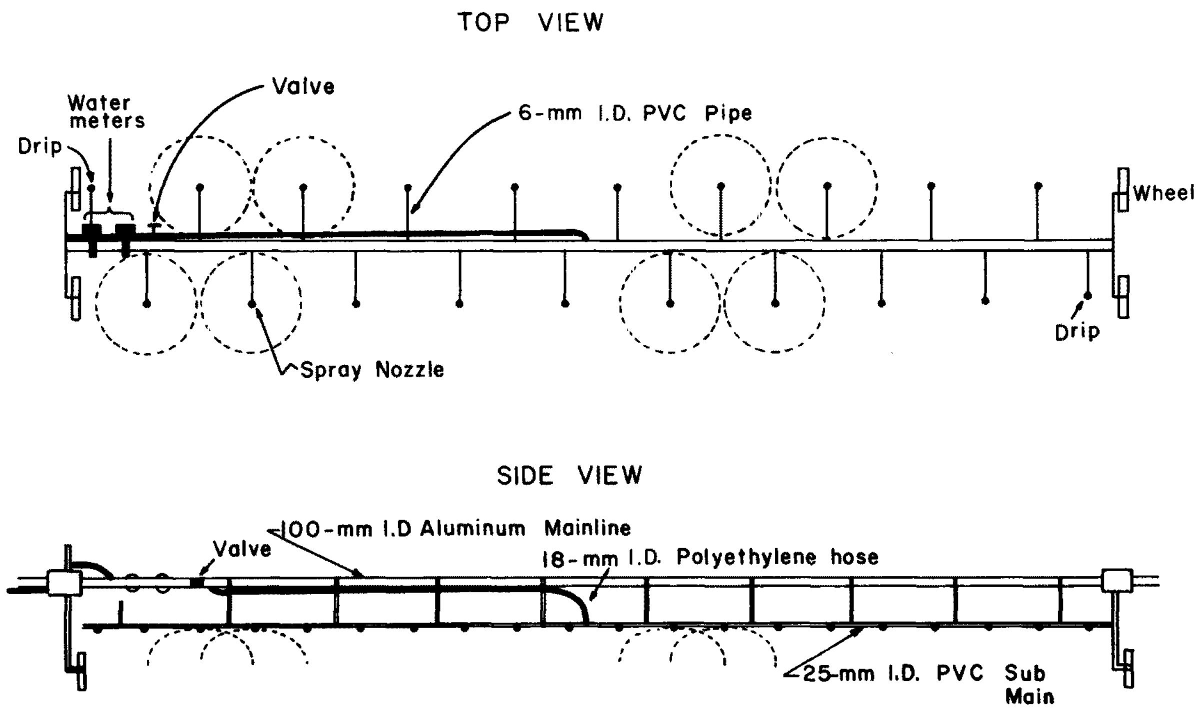

Figure 18. Spray system for one section of the lateral-move irrigation system serving one replication.

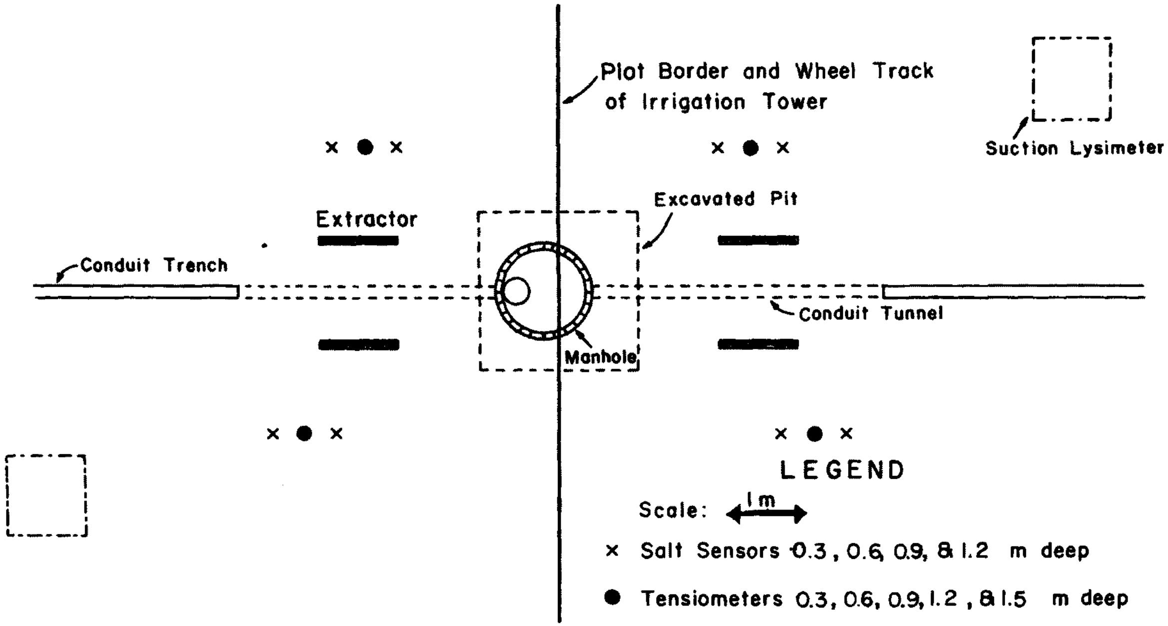

Figure 19. Location of instruments for two of the six plots instrumented in the alfalfa experiment.

Salinity sensors and tensiometers were installed as shown in Fig. 19. All the tensiometers installed in September 1974 had to be replaced because epoxy cement failed to seal the ceramic tensiometer cups to an acrylic adapter. New tensiometers were installed in February 1975. All sensor wires and tensiometer tubes leading to the manholes were buried at least 0.3 m below the soil surface.

Initially, the 40 tensiometers near each manhole (including 16 over the vacuum extractors) were connected to two switching boxes housing 24-position hydraulic scanning valves, each controlled by an electric stepping switch. The pressure within each tensiometer, as well as that of a standard and zero reference, was measured with a pressure transducer producing a voltage signal. These voltages were converted to soil hydraulic potentials by the data acquisition system. A calculator program was written to read the 120 tensiometers and references at any desired time interval. All tensiometers and associated tubing could be flushed and recharged automatically whenever it was necessary to eliminate air bubbles. The first automatic tensiometer data were obtained in March 1975. Measurements were continued through September, but were often interrupted or inaccurate because of problems with the scanning valves. After September, these valves became completely unsatisfactory and the entire automatic scanning system had to be discarded. Since March 1976, all tensiometers have been connected to mercury manometers that are located within the manholes and are read and recorded manually. The coaxial tubing for each tensiometer and a common shutoff device allow the tensiometers in a manhole to be flushed simultaneously. The tensiometers appear to be working satisfactorily.

Since January 1975, the salinity sensors have been read with the data acquisition system. Through a computer program, the unit activates the stepping switches, reads all 96 sensors in sequence, compensates the readings for soil temperature, and prints out the calculated soil water electrical conductivities on paper tape. Readings taken automatically are nearly identical to those read manually. It requires 20 minutes to read the sensors and produce the punched paper tape, which is then transmitted via teletype to Riverside for processing and analysis.

In addition to the vacuum extractors, a 1.2-m-deep suction lysimeter was installed in each of the six instrumented plots. These were formed by lining a 1.5-m-square hole with 250-μm-thick plastic film. A wooden frame, 0.3 m below the soil surface, serves as the top lip of the lysimeter. After backfilling with about 0.1 m of soil, ceramic tubes, identical to those used in the vacuum extractors, were installed in each lysimeter to extract the leachate. The lysimeters were then filled with disturbed soil and compacted by saturating with water.

Check Plot

A portion of the 8-ha field not within the experimental area serves as a check and is irrigated as a level basin from a single gate located in one corner of the field. During each irrigation, a depth of about 150 mm is applied at the rate of about 0.4 m^3/s. Irrigation volume is measured with a critical-flow flume identical to that used in the citrus experiment. Salinity sensors were installed at four depths (0.3, 0.6. 0.9, and 1.2 m) in six locations in the check plot.

Yield

The alfalfa is harvested by cutting with a windrower-conditioner and then cubed following customary procedures. Harvest dates are chosen by the ranch when the alfalfa is at approximately 50% bloom. The yield of each cutting is determined by weighing three samples from each replicate. The samples are taken from 26.8-m^2 areas in the north, center, and south sections of each plot from the first swath (4.4 m wide) made down the center of each plot. Nine similar samples are taken from the flood check at three locations in each of three windrows made in the east, center, and west sections of the field. Each sample is weighed and yields of air-dry alfalfa are calculated after measuring the water contents of representative subsamples.

RESULTS

Soil Properties

Only about three-fourths of the initial soil samples have been analyzed. A preliminary summary of the soil properties for Indio fine sandy loam is given in TABLE 21. It shows that the soil is nonsaline (EC_e less than 0.4 S/m) through most of the sampled profiles, indicating that this field has been well leached in the past. The chloride concentration in the lower depths is about 10 meq/liter in the saturation extract. Assuming a Cl concentration of 3.5 meq/liter in the irrigation water, this corresponds to a leaching percentage of about 35. Salt concentrations generally peak at a depth above 0.6 m, suggesting the effective root zone is relatively shallow or that water penetration is impeded by the textural break.

The relationship between hydraulic conductivity and matric potential for Indio fine sandy loam is given in Fig. 20. The length of the horizontal lines indicates the range of matric potential measured for a given hydraulic conductivity.

Water Use

The average daily rates of water application, rainfall included, are given in Fig. 21 for the three leaching treatments and the flood check from January 1975 to July 1976. Each data point in the summer is the daily average for an individual cutting, typically covering 4 to 6 weeks. Data points during the winter are the averages for about 2 months. The total depths of water applied over the 19 months shown in Fig. 21 were 3152, 3322, and 3613 mm for the 5, 10, and 20% leaching treatments, respectively, and 3598 mm for the flood check.

As with the citrus, the evapotranspiration rate (ET) can be estimated by subtracting the planned leaching depth from the actual depth of water

TABLE 21. REPRESENTATIVE SOIL PROPERTIES FOR THE SNYDER RANCH ALFALFA FIELD

Property	Unit	Depth (meter)	Typical values	Range
Cation-exchange-capacity	meq/100g	0 - 0.6	15	10 - 19
		> 0.6	28	25 - 35
Exchangeable-sodium-percentage	%	0 - 0.6	8	5 - 12
		> 0.6	10	5 - 30
Sodium-adsorption-ratio	-	0 - 0.6	6	5 - 8
		> 0.6	7	5 - 30
Saturation percentage	g/100g	0 - 0.6	40	30 - 45
		> 0.6	50	42 - 60
Field water content	g/100g	0 - 0.6	14	11 - 30
		> 0.6	28	23 - 36
pH		0 - 0.6	7.4	6.9 - 8.2
		> 0.6	7.5	7.0 - 7.8
EC_e	S/m at 25°C	0 - 0.3	0.25	0.15- 0.5
		> 0.3	0.35	0.17- 1.0
Soluble* calcium	meq/liter	0 - 0.3	5	3.8 - 26
		> 0.3	15	2 - 30
Soluble magnesium	"	0 - 0.3	3	3 - 16
		> 0.3	8	1 - 18
Soluble sodium	"	0 - 0.3	12	10 - 27
		> 0.3	20	10 - 60
Soluble potassium	"	0 - 0.3	0.3	0.1 - 0.7
		> 0.3	0.3	0.1 - 0.6
Soluble bicarbonate	"	0 - 0.3	2.3	1.9 - 4.0
		> 0.3	2.5	1.4 - 6.0
Soluble sulfate	"	0 - 0.3	16	8 - 30
		> 0.3	28	15 - 80
Soluble chloride	"	0 - 0.3	5	3 - 10
		> 0.3	10	5 - 30
Soluble nitrate	"	0 - 0.3	0.6	0.2 - 3
		> 0.3	0.3	0.1 - 1.7

*Soluble in saturation extract.

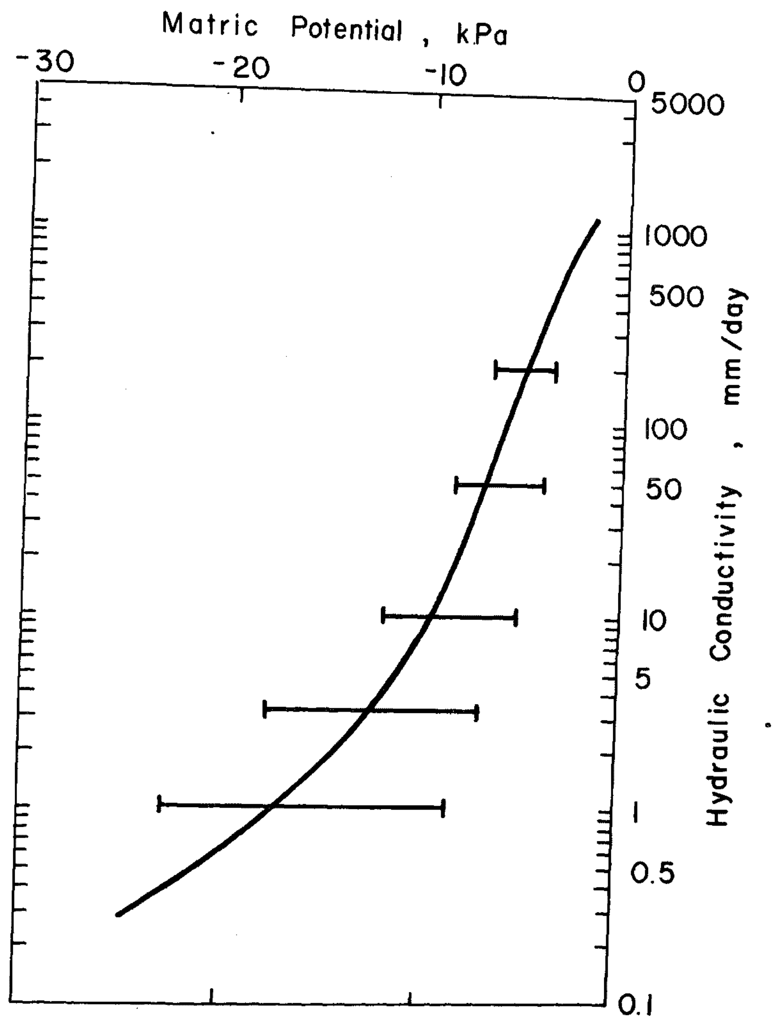

Figure 20. Relationship between soil matric potential and hydraulic conductivity for Indio fine sandy loam.

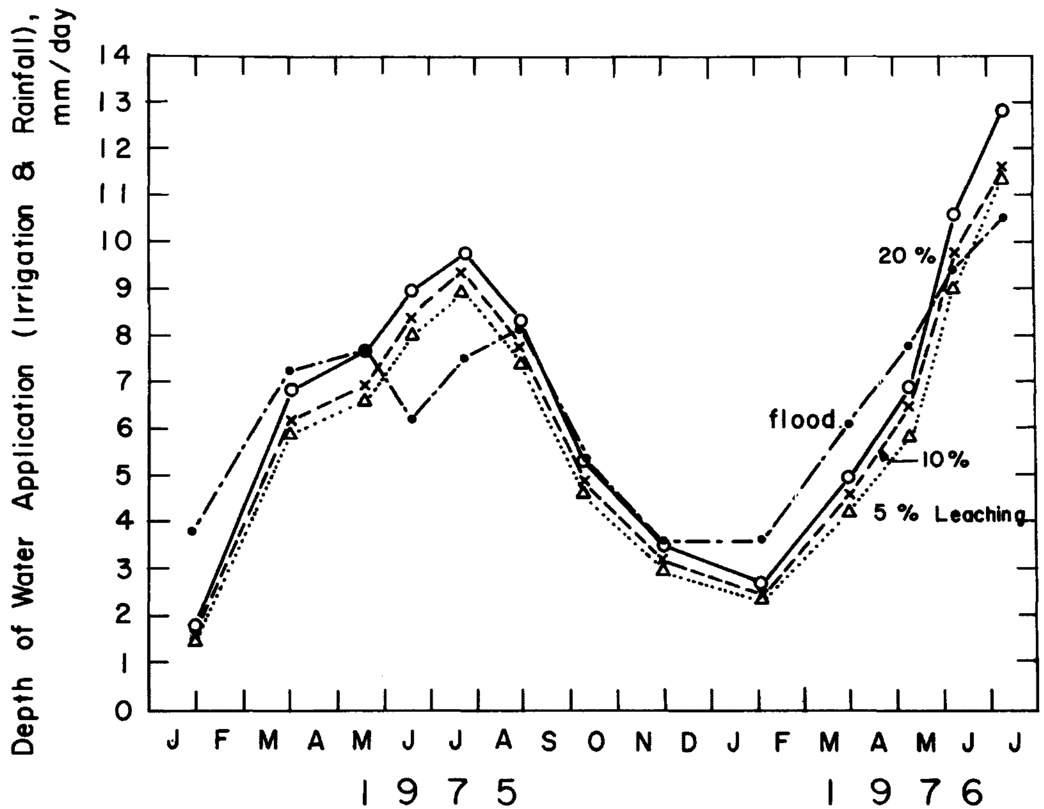

Figure 21. Total water application to the three leaching treatments and the flood check for the alfalfa experiment.

applied. This uncorrected daily evapotranspiration rate for alfalfa, computed monthly, is presented in Fig. 22. For comparison, the average daily rate of pan evaporation is also given. This evaporation pan is located in the valley about 15 km west of the alfalfa experiment. Based on these data, the pan factor (ratio of ET to pan evaporation) for alfalfa is 0.78. The average annual ET estimated from the data for 19 months is 1813 mm, and ET based on the year from July 1, 1975 to July 1, 1976 is 1740 mm.

As independent checks, the ET was also computed by the modified Penman equation (Doorenbos and Pruitt, 1975), and derived from measurements from a weighing lysimeter in the Imperial Valley of California, and from Erie et al. (1965). All the results are given in TABLE 22 as average daily ET rates by month. The three independent estimates of ET are from 4 to 21% higher than

TABLE 22. COMPARISON OF VARIOUS TECHNIQUES OF ESTIMATING EVAPOTRANSPIRATION OF ALFALFA IN SOUTHWESTERN ARIZONA

Month	Erie* et al.	Brawley† lysimeter	Modified Penman§ 1975	Modified Penman§ 1976	Modified Penman§ Avg.	Calculated from experiment 1975	Calculated from experiment 1976	Calculated from experiment Avg.
	mm/day							
Jan	—*	2.1	2.8	2.4	2.6	1.8	1.7	1.7
Feb	1.6	2.4	3.6	3.4	3.5	1.2	2.9	2.0
Mar	4.9	4.5	4.5	4.8	4.6	4.5	3.1	3.8
Apr	6.4	5.5	5.8	5.9	5.8	6.7	3.9	5.3
May	8.2	8.2	7.4	7.4	7.4	6.7	6.2	6.4
Jun	9.2	9.8	9.6	9.3	9.4	6.7	8.3	7.5
Jul	8.8	9.3	10.8	8.8	9.8	8.5	11.9	10.2
Aug	7.4	8.1	10.2	—	10.2	5.9	—	5.9
Sep	7.8	6.9	8.2	—	8.2	4.8	—	4.8
Oct	4.6	5.3	5.4	—	5.4	6.2	—	6.2
Nov	3.0	3.6	3.3	—	3.3	4.6	—	4.6
Dec	—	1.8	2.0	—	2.0	1.0	—	1.0
Yearly total, mm	1890	2060	2240	—	2201	1790	—	1813

*Data taken from Erie et al. (1965). No data given for January or December.

†Data from 1975 Annual Research Report of the Imperial Valley Conservation Research Center, ARS, Brawley, Calif. (See LeMert and Kaddah, 1977.)

§Calculated by modified Penman equation presented by Doorenbos and Pruitt (1975). Data based on meteorological information collected by the Irrigation Management Service of the U.S. Bureau of Reclamation, Wellton, Arizona.

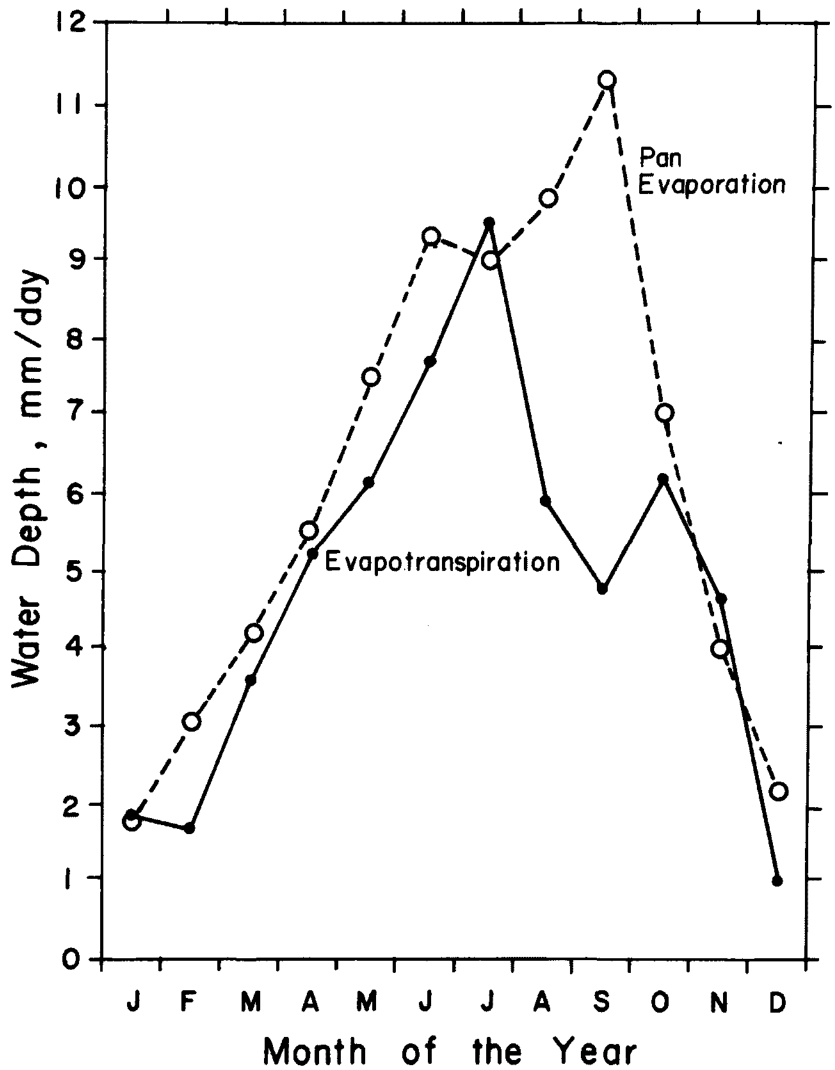

Figure 22. Comparison of the daily rates of pan evaporation and evapotranspiration estimated from the amount of water applied to alfalfa in southwestern Arizona. Average of data from January 1975 to July 1976.

the ET computed from the amount of water applied. Assuming that the actual ET for alfalfa is the average of all four measures, the resultant annual ET is 1991 mm. Corresponding leaching percentages for the 5, 10, and 20% leaching treatments are -3, 2, and 10; the flood check had 10% leaching. Data in later sections tend to confirm that the alfalfa was underirrigated.

Soil Salinity

Initial salinity sensor measurements taken in November 1974 averaged 0.79, 0.62, 0.68, and 0.73 S/m at the 0.3-, 0.6-, 0.9-, and 1.2-m depths, respectively. Due to operational difficulties with the irrigation system early in 1975, insufficient water was applied and salinity at the 0.3-m depth increased. By March, salinity at this depth started to decrease. This decrease has continued, although short-term cycles have occurred. The lowest level of salinity (about 0.4 S/m) was reached in January 1976. (See Fig. 23, and Figs. B-1 and B-2 of the appendix.) The salinity below 0.3 m was expected to increase initially, reaching stable levels after time. Such increases did occur, with stable but high levels reached by January 1976. As shown in Fig. 24, the salinity profiles have changed from ones decreasing with depth during the first half of 1975 to ones increasing with depth during the second half of 1975. They changed little through the first half of 1976, except for a slight increase at 0.9 and 1.2 m. These increases at greater depths show the beginning of the profile shapes expected to develop, but no significant salinity difference among treatments has yet been observed. For example, in May 1976, soil salinity at the 1.2-m depth was about 1.1 S/m for all leaching treatments; for irrigation water having a salinity of 0.13 S/m, the resultant leaching percentage is 12.

For comparison, the salinity profile for the flood check is shown in Fig. 24, along with that for the 20% leaching treatment. The salinity increased uniformly with depth, was quite stable, and was 0.2 to 0.3 S/m lower than in any of the experimental treatments. Based on EC = 0.77 S/m at the 1.2-m depth, the apparent leaching percentage obtained on the check plot was 17%, indicating that 5% more leaching had occurred on the flood-irrigated check than on the sprinkled experimental plots.

Hydraulic Potential

Satisfactory tensiometric data were obtained automatically during a few periods in the spring and summer of 1975. For instance, hydraulic potential profiles for April 1, June 5, and September 15, 1975 are plotted in Fig. 25.[4] The data for the 10 and 20% leaching treatments were consistent, so the averages are plotted. The two 5% leaching plots differed widely, however, so separate plots are given. The reference for the hydraulic potential values is the soil surface. To obtain matric potentials, the depth must be added algebraically to the hydraulic potential.

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[4]Hydraulic head is defined as the sum of matric and gravitational potentials. If both are expressed as equivalent to the height of a column of water, hydraulic head is obtained by subtracting the depth from the matric potential read with a tensiometer.

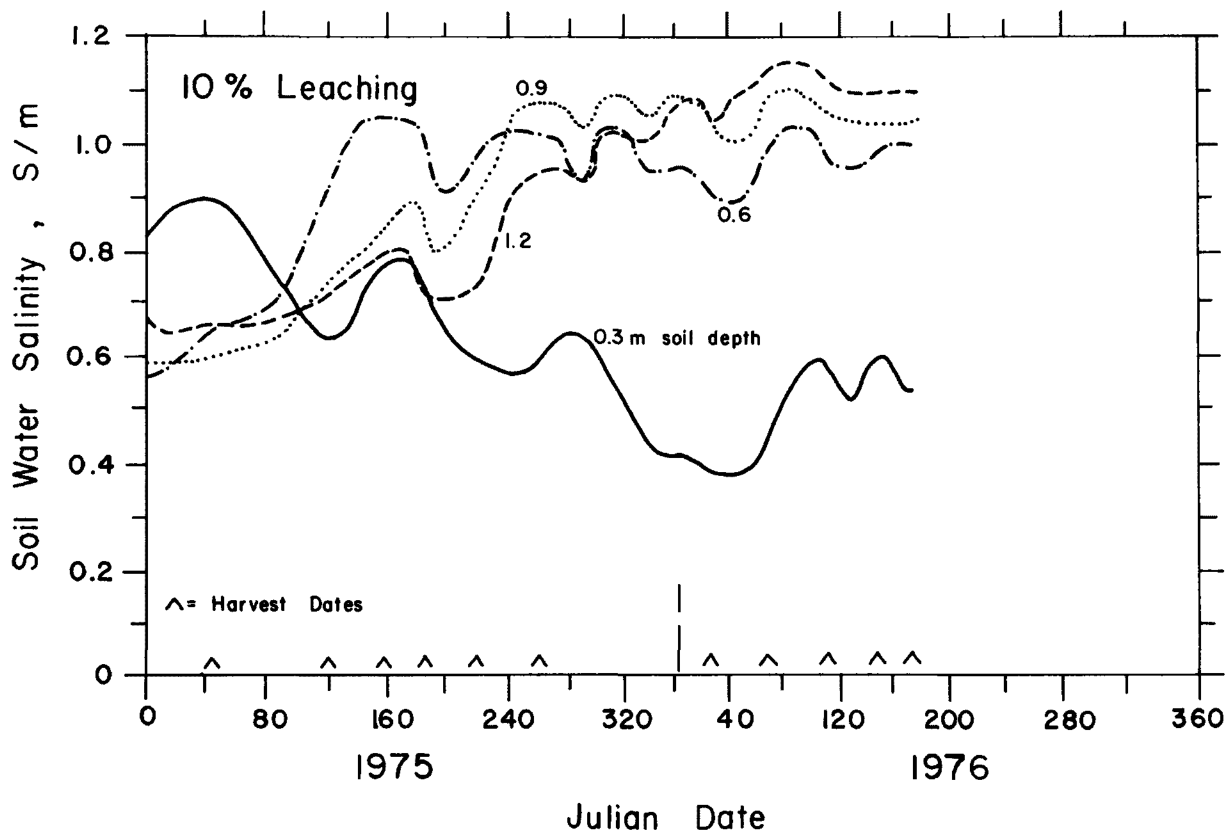

Figure 23. Salinity trends with time for the 10% leaching treatment of the alfalfa experiment at various soil depths.

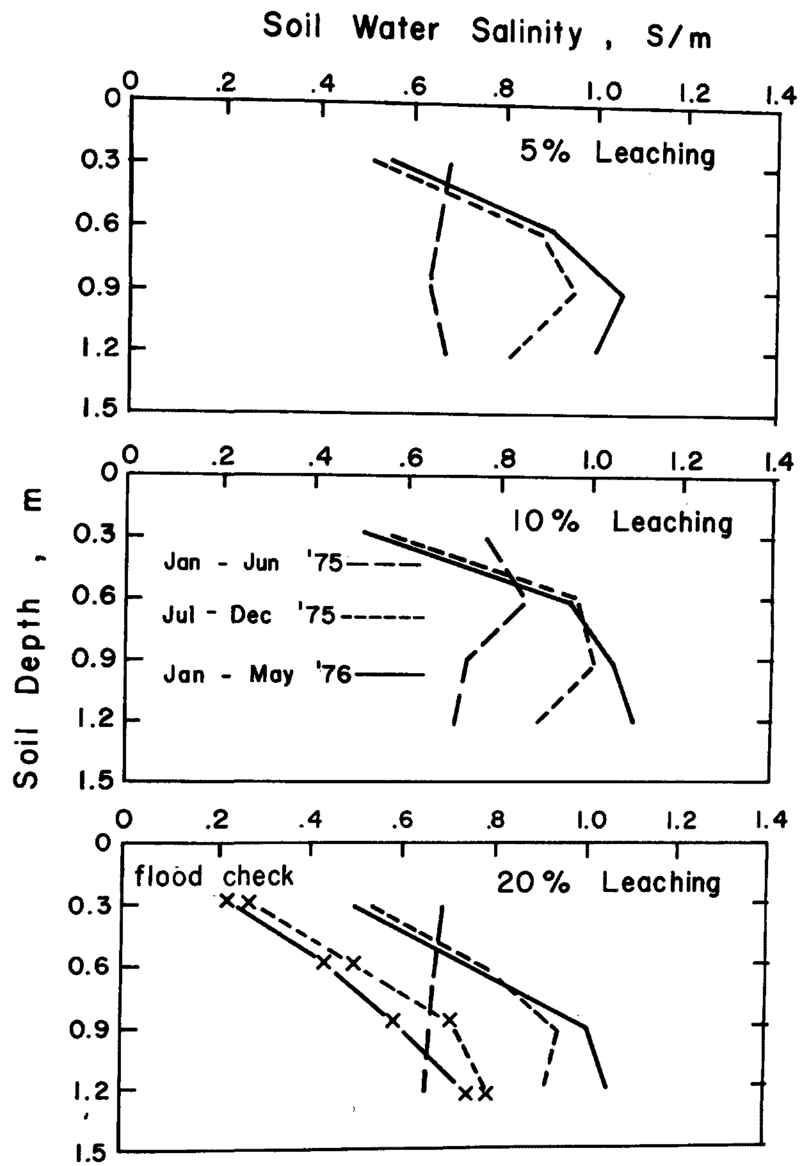

Figure 24. Time-averaged salinity distributions with depth for three leaching treatments and the flood-irrigation check of the alfalfa experiment.

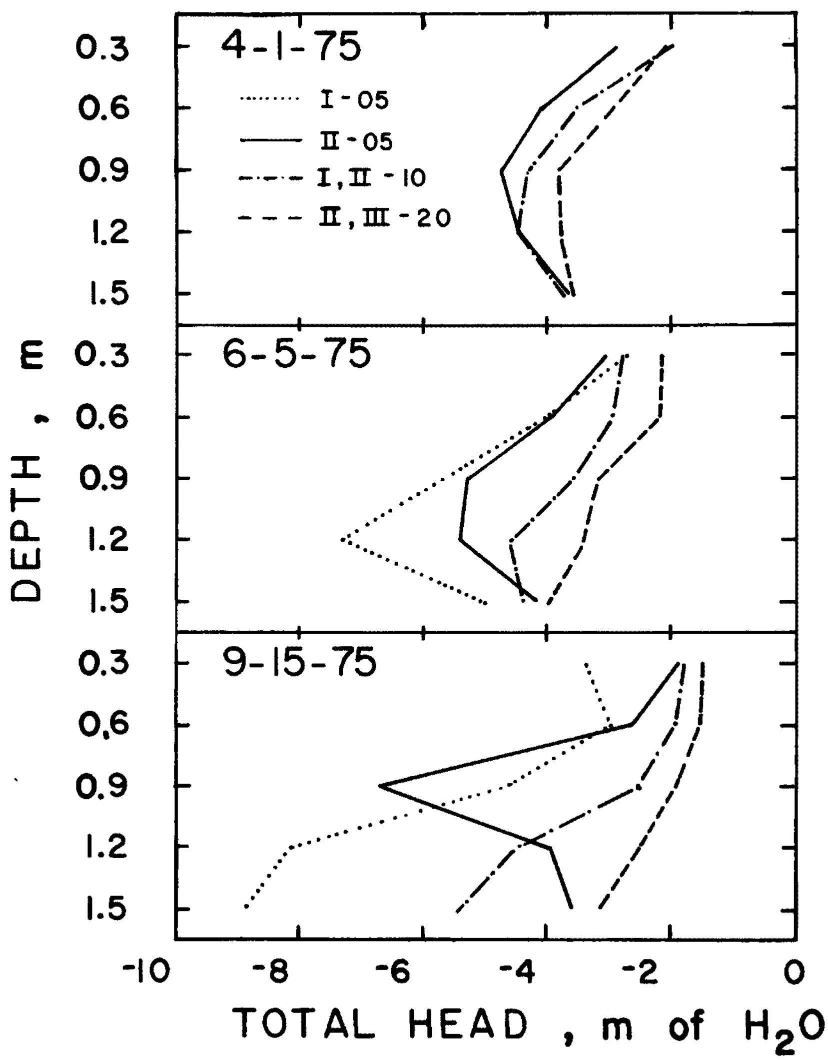

Figure 25. Hydraulic potential distribution for the three leaching treatments in the alfalfa at selected times during 1975.

On April 1, the three treatments had similar potential distributions, with relative values as expected from leaching differences. For all three treatments, upward gradients occurred in the bottom half of the soil profile. Data for the first replication of the 5% leaching treatment (I-05) are not available for this date because of equipment problems. By June 5, the profile for 20% leaching had become wetter down to the 1.2-m depth, resulting in downward water movement to a depth of at least 1.5 m. For 10% leaching, the wetting was not quite as deep, leaving an upward gradient at the bottom. In the II-05 replicate, the top half of the profile was unchanged while the bottom half was drier. I-05 was appreciably drier below 1 m than II-05. By September 15, the entire profile for 20% leaching had become still wetter; the profile for 10% leaching continued to wet down to 1.2 m, while drying at 1.5 m erased the upward gradient. The I-05 replicate was wetter at the 0.6- and 0.9-m levels but had become very dry below that depth, consistent with the leaching treatments. The II-05 replicate, however, had become wetter except for the 0.9-m depth, creating a large upward gradient in the bottom half of the profile. These data indicate that the soil profile of II-05 is supplied by water from the groundwater table, which prevents it from becoming as dry as I-05. On the other hand, the development of the hydraulic profiles in the 10 and 20% leaching treatments suggests that the upward gradients on April 1 are the result of drying from the top down by root uptake, rather than upward movement of water from the groundwater table. The relative positions of the potentials on September 15 are entirely consistent with the presence or absence of drainage from the extractors and lysimeters at that time, as discussed elsewhere in the report.

The data obtained manually since March 1976 are more reliable. There are distinct differences within treatments, especially in I-05. Figure 26 gives hydraulic potential distributions for March 29, May 17, and July 13, 1976. On March 29, the north and south groups of tensiometers in I-05 gave similar readings and the average is plotted. As in 1975, II-05 exhibited an upward hydraulic potential gradient, which became more pronounced on May 17. On May 17, the hydraulic potentials in I-05 indicate that both sites were being influenced by the water table. Pronounced upward gradients also existed in I-05 on July 13. The potential distributions on July 13 represented a period of overirrigation that continued well beyond that date. All profiles have become much wetter from the top, erasing the upward gradient in II-05. The generally heavier irrigations in 1976 kept the profiles wetter than in 1975 and prevented, for instance, development of a dry layer at the 0.9-m depth in II-05 as in 1975 (Fig. 26).

Apparently, the 10 and 20% leaching treatments were generally wet enough to prevent upward water movement, at least above a depth of 1.5 m. The 5% leaching treatment, however, was sufficiently dry that groundwater moved upward. The magnitude of any upward fluxes cannot be derived from tensiometer data, but it seems to vary depending on local subsoil conditions and fluctuations in depth to groundwater.

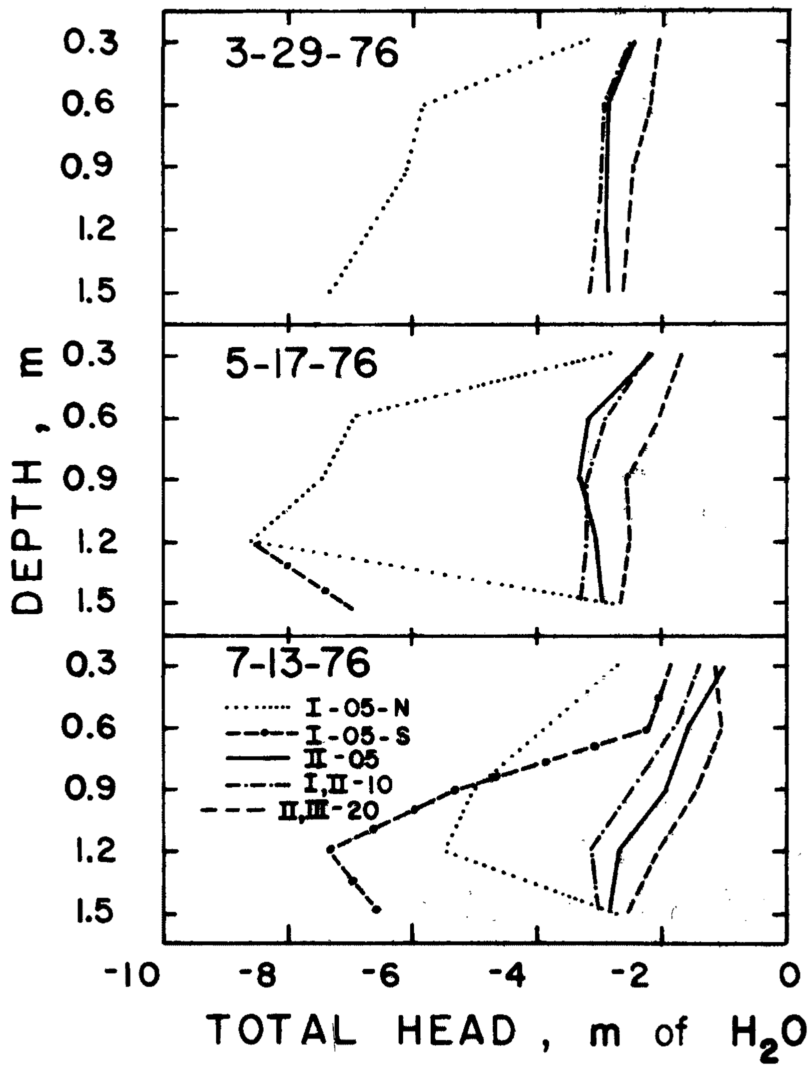

Figure 26. Hydraulic potential distribution for the three leaching treatments in the alfalfa at selected times during 1976.

Vacuum Extractors and Suction Lysimeters

Volume of Leachates--

The extractors appear to be working better in the alfalfa than in the citrus. Pairs of extractors of one replicate generally show good agreement. The same is true for replicates of the same leaching treatment. While only a few extractors produced some drainage during the summer of 1975, all except extractor I-05-N yielded leachate in the fall. Generally, the starting dates advanced and the amounts increased with increasing target leaching, as expected. Interestingly, outflow from all suction lysimeters started much later than from the corresponding extractors.

TABLE 23 shows the dates of first drainage after January 1, 1975, for each of the extractors and lysimeters, as well as the total amount of drainage until July 26, 1976. The only exceptions are Ext-III-20-N and Ext-III-20-S, which became defective after July 2, 1976, probably because of a pressure regulator failure, which allowed the pillow pressure to rise to over 300 kPa. The amounts of drainage for these two extractors, therefore, should not be compared directly with those of others. Instead, the leaching percentages should be compared, and they show excellent agreement.

Interpretation of the drainage from the extractors and lysimeters is complicated by seasonal fluctuations and interruptions of irrigation due to harvesting. With continuous leaching, higher ET in the summer dictates wetter soil and more drainage in the summer than in the winter. Nearly all extractors and lysimeters were working from December 26, 1975 till July 26, 1976. Since this covers approximately half a year from minimum ET to maximum ET, the comparison shown in the last two columns of TABLE 23 between replicates over this period appears valid. The measured leaching percentages during this period are about half the target values, except the extractors in II-05 which are slightly above target. This appears to be caused by upward flow from groundwater, as suggested by tensiometric data and other considerations discussed elsewhere. Generally, the agreement between a lysimeter and at least one of the corresponding extractors is good. So is the agreement between replicates of the same leaching treatment. The lower amount of drainage from Ext-III-20-N occurred primarily before December 26, 1975. After that, the extractor behaved similarly to the other three. The only extractor that does not appear to work well is II-10-S. The very low matric potentials in I-05 suggest that the small leaching volumes obtained for I-05-N are correct.

Figure 27 shows cumulative leaching percentage for selected extractors and lysimeters for all three leaching treatments. From TABLE 23, it can be seen that these are the higher yielding extractors. In November 1975, lysimeter II-20 started to yield appreciably more than extractors II-20-N and III-20-S, but since March 1976 the extractors have been draining at a higher rate. Only the cumulative leaching percentage of lysimeter II-20 from late January till the middle of April was above the leaching target. Similar data for the 10% leaching treatment show that lysimeter I-10 started yielding drainage about 2 1/2 months later than extractor I-10-S, and virtually stopped in April, just when the total amounts of drainage had become about equal. The extractor continued to yield drainage through the summer. The leaching percentages are about the same at the end of July 1976, because they are based on different amounts of irrigation. Again, only the lysimeter exceeded the target leaching from November till May.

The extractors in II-05 behaved nearly identically (Fig. 27). They started to drain regularly in October 1975, and have done so ever since, mostly at a leaching percentage above the target value. In contrast, the extractors in I-05 yielded far less and behaved qualitatively more like those in the higher leaching treatments. The lysimeter in II-05 started to drain late in December 1975 and was above target till early May 1975, but has not yielded much since. Appendix Figs. B-3, B-4, and B-5 give the

TABLE 23. DRAINAGE FOR EACH VACUUM EXTRACTOR AND SUCTION LYSIMETER IN THE ALFALFA EXPERIMENT AFTER JANUARY 1, 1975 UNTIL JULY 26, 1976

Replication	Date first drainage	Total drainage to 07-26-76	Total drainage between 12-26-75 and 07-26-76	% leaching between 12-26-75 and 07-26-76
		mm	mm	
Ext-I-05-N	03-25-76	14.5	10.2	0.9
Ext-I-05-S	09-03-75	28.3	24.0	2.1
Lys-I-05	01-06-76	17.2	17.2	1.5
Ext-II-05-N	09-18-76	82.4	62.7	5.5
Ext-II-05-S	09-03-75	85.1	68.8	6.1
Lys-II-05	12-26-75	26.5	23.6	2.1
Ext-I-10-N	09-03-75	72.4	43.6	3.6
Ext-I-10-S	06-02-75	97.2	61.1	5.0
Lys-I-10	12-05-75	53.6	40.0	3.3
Ext-II-10-N	06-02-75	63.7	48.1	4.0
Ext-II-10-S	10-06-75	24.0	20.7	1.7
Lys-II-10	12-15-75	61.6	52.4	4.3
Ext-II-20-N	09-03-75	213.6	140.0	10.5
Ext-II-20-S	06-02-75	178.0	110.1	8.2
Lys-II-20	09-18-75	220.7	127.6	9.6
Ext-III-20-N	06-02-75	124.0*	87.9*	8.9*
Ext-III-20-S	06-02-75	167.5*	95.8*	9.7*
Lys-III-20	09-03-75	206.5	105.6	7.9

*Until July 2, 1976.

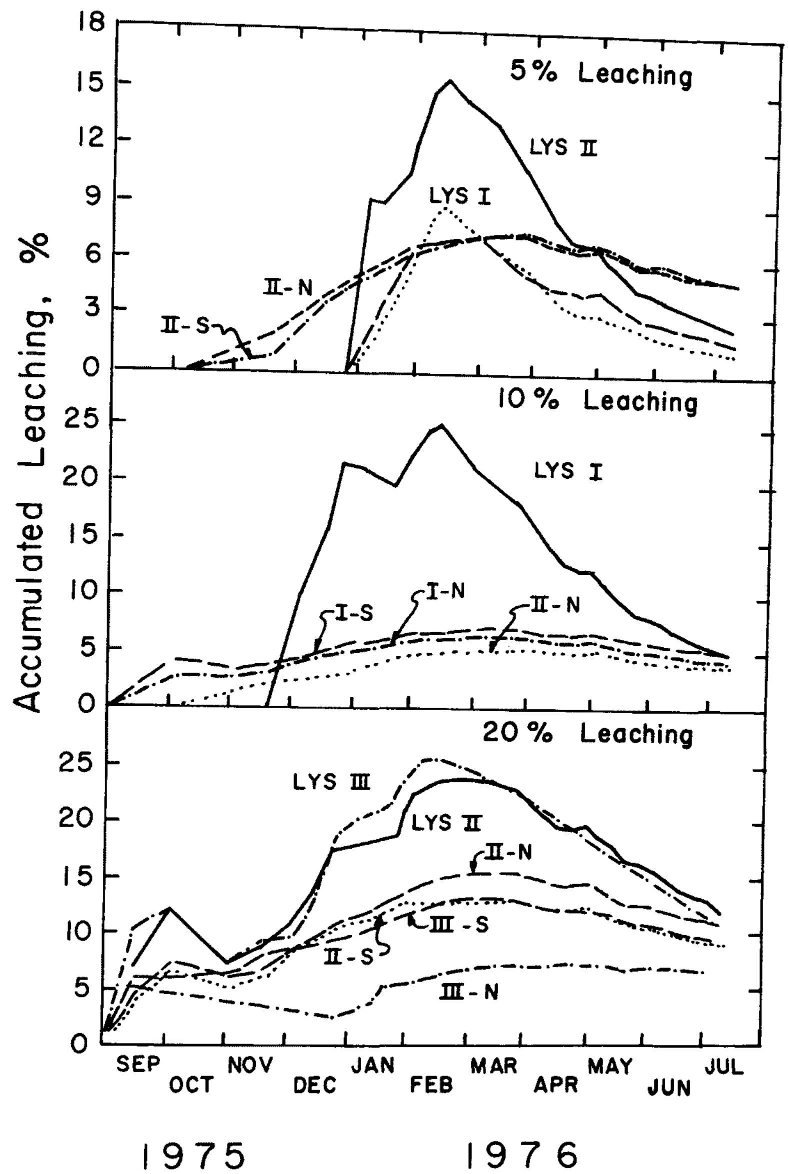

Figure 27. Accumulated leaching percentages based on leachate from vacuum extractors and suction lysimeters for the three alfalfa leaching treatments.

cumulative irrigation and drainage, as well as the cumulative drainage percentages of the various lysimeters and extractors, allowing a more detailed analysis.

With the exception of II-05, drainage per unit area from the lysimeters tended to be about the same as from the extractors, but it was faster over shorter time intervals. This suggests the suction in the ceramic tubes of the lysimeters was maintained too high. This could cause them to yield too much drainage compared with outside the lysimeters if the soil were dried out so much that it reduced the ET compared to the ET outside. There are no tensiometers in the lysimeters to check this. If wet, the lysimeters work under a negative feedback principle; if the ceramic tubes cannot handle the drainage flow passing by, the water will back up against the bottom of the lysimeters, which will wet up the soil around the tubes, increase the hydraulic conductivity, and increase the drainage rate. The situation with the extractors is different. If they cannot handle the drainage flow, the water will pass by without a chance to make up for it. If the suction in the ceramic tubes of the extractors is maintained too high, they could pull in too much flow. Actually, however, the suctions in the ceramic tubes of the extractors were regulated such that the tensiometers immediately above and adjacent to the extractors read about the same.

In view of the above consideration, it is likely that, if there is a discrepancy between the extractors and lysimeters, the latter will be high. There is one notable exception to this prediction: both extractors in II-05 yielded almost three times as much drainage per unit area as the lysimeter. Tensiometric data indicate this was the result of upward flow from the water table. For instance, Figs. 25 and 26 show an upward hydraulic potential gradient for the II-05 replicate. Of all replicates, only II-05 showed consistently upward gradients. Also, the total hydraulic potentials in II-05 were much higher than in I-05, about -1.5 m versus -5.0 m, and were even higher than in the 10% leaching treatments. Only during July 1976, when the field was overirrigated, was the hydraulic gradient reversed by wetting from above. The upward flow could not enter the lysimeter in II-05. Thus, the contrast between the sustained drainage of the extractors and the behavior of the lysimeter, which was more in line with that of the others, is entirely compatible with upward flow.

In summary, the extractors and lysimeters indicate that the alfalfa has been underirrigated at about half the values of each leaching target. The extractors in I-05 are affected by upward flow, and the suctions in the lysimeters should probably be lowered.

Composition of Leachates--

The waters collected by the extractors are analyzed to ascertain the amounts and compositions of the salt loss by deep percolation. To date, 137 samples have been analyzed. Compositions of drainage waters samples collected in April 1976 are given in TABLE 24. Comparisons of compositions with time are given in TABLE 25.

The salinity of the drainage water has increased with time. The earliest samples reflect previous management; the later samples show higher

TABLE 24. COMPOSITIONS OF DRAINAGE WATERS FOR ALFALFA FIELD, APRIL 1976

Extractor No.	pH	Ca	Mg	Na	K	Sum of cations	HCO_3	SO_4	Cl	NO_3	EC*	SAR†	Leaching fraction
		← meq/ℓ								→	S/m		Cl_{iw}/Cl_{dw}
5% Leaching													
I-5-N§	7.0	46.6	32.0	37.6	1.3	118	16.4	48.1	52.6	0.2	0.87	6.0	0.06
I-5-S	6.9	35.7	22.6	34.8	1.1	94	13.8	38.6	43.4	0.2	0.75	6.4	
II-5-N	6.7	32.2	44.0	140.0	0.9	217	25.0	137.0	56.6	0.2	1.46	23.0	
II-5-S	7.0	37.7	37.3	91.4	0.8	167	25.3	67.5	73.8	0.2	1.23	15.0	
10% Leaching													
I-10-N	6.9	54.0	41.8	81.0	0.9	178	19.5	81.7	75.8	0.4	1.24	12.0	0.06
I-10-S	7.4	47.1	40.8	121.0	1.0	210	23.7	113.0	77.8	0.3	1.43	18.0	
II-10-N	6.6	33.0	36.4	21.8	0.4	92	20.5	44.9	32.3	0.4	0.68	3.7	
II-10-S	6.8	43.4	34.2	32.7	0.6	111	22.1	52.4	40.0	0.2	0.79	5.2	
20% Leaching													
II-20-N	6.8	42.0	34.5	66.8	0.4	144	25.4	77.9	40.3	0.1	0.98	11.0	0.09
II-20-S	6.8	50.2	43.2	39.4	0.5	133	20.1	74.6	40.3	0.1	0.88	5.8	
III-20-N	6.4	34.4	20.7	26.4	0.5	82	21.7	35.9	23.5	0.1	0.60	5.0	
III-20-S	6.3	52.7	35.2	32.0	0.3	120	19.0	71.3	37.8	0.1	0.83	4.8	

*Electrical conductivity at 25°C.

†SAR = $Na/\sqrt{[(Ca + Mg)/2]}$, where solutes are in meq/liter.

§I-5-N denotes the extractor in the north position of the first replication in the 5% leaching treatment.

TABLE 25. CHANGES IN COMPOSITIONS OF DRAINAGE WATERS OF ALFALFA FIELD WITH TIME

Extractor No.	Date	Ca	Mg	Na	K	Sum of cations	HCO_3	SO_4	Cl	NO_3	SiO_2	EC*	SAR†
%		← meq/ℓ								→	mg/ℓ	S/m	
I-5-S§	12-74	33.5	17.1	27.5	0.9	79.0	10.6	38.7	25.1	2.0	56	0.59	5.5
	04-76	35.7	22.6	34.8	1.1	94.3	13.8	38.6	43.4	0.2	48	0.75	6.4
II-5-N	12-74	29.1	23.0	62.7	0.6	115.0	12.6	75.4	28.1	0.4	67	0.83	12.0
	04-76	32.2	44.0	140.0	0.9	217.0	25.0	137.0	56.6	0.2	38	1.46	23.0
I-10-S	12-74	32.5	21.0	43.1	0.6	97.2	12.2	54.1	32.2	2.3	55	0.74	8.3
	06-75	61.4	46.4	81.0	1.0	190.0	20.2	97.8	69.6	0.7	57	1.23	11.0
	04-76	47.1	40.8	121.0	1.0	210.0	23.7	113.0	77.8	0.3	37	1.43	18.0
II-10-N	12-74	14.4	14.9	18.2	0.3	47.8	15.0	19.6	11.1	0.4	58	0.38	4.8
	06-75	11.4	17.7	18.5	0.3	47.9	14.2	23.3	11.4	0.2	57	0.37	4.8
	04-76	33.0	36.7	23.0	0.4	93.1	20.5	44.9	32.3	0.1	37	0.68	3.9
II-20-S	12-74	20.8	17.0	22.3	0.3	60.3	11.5	35.0	14.1	0.3	61	0.46	5.1
	06-75	26.8	22.7	24.9	0.4	74.7	18.0	43.7	15.3	0.3	66	0.54	5.0
	04-76	50.2	43.2	39.4	0.5	133.0	20.1	74.6	40.3	0.1	43	0.88	5.8
III-20-S	12-74	20.8	11.1	22.8	0.4	55.1	11.0	28.7	14.6	0.8	23	0.42	5.7
	06-75	25.4	14.7	23.4	0.4	64.0	18.0	30.9	15.9	0.3	48	0.48	5.2
	04-76	53.8	35.8	33.2	0.5	123.0	18.9	71.3	37.8	0.1	43	0.83	5.0

*Electrical conductivity at 25°C.

†$SAR = Na/\sqrt{[(Ca + Mg)/2]}$, where solutes are in meq/liter.

§I-5-S denotes the extractor in the south position of the first replication in the 5% leaching treatment.

values because the imposed treatments result in lower leaching fractions. While in all cases the concentrations have increased, the present compositions are not well related to treatments, nor are replicates very similar. Drainage waters collected from extractors I-10 are higher in all major salt constituents than waters collected from extractors I-05. Waters collected from extractors II-10 are much lower in salts than their replicates (I-10) or the waters collected from extractors II-20. Nevertheless, the average leaching percentages for the three treatments given in TABLE 24 tend to support the leachate volume data shown in Fig. 27. By April 1976, the accumulated leaching percentages on a drainage volume basis were 7, 10, and 16 for the 5, 10, and 20% leaching treatments.

Predicted drainage water compositions as a function of leaching are given in TABLE 26. The present compositions do not yet correspond well with the predicted values. For a given chloride concentration, the present concentrations of magnesium, sodium, and sulfate are lower than expected, and calcium is higher. Insufficient time has elapsed since the experiment was initiated to attain steady state; continuing exchange reactions account for the departure in composition from predicted levels, including EC.

Yield

The yields for the three leaching treatments and the flood check are given for each replication in TABLES 27 and 28 for 1975 and 1976, respectively. Total yields for 1975 were 17.9, 17.6, and 17.6 Mg/ha for the 5, 10, and 20% leaching treatments, respectively. Likewise, yields for 1976 were 16.4, 15.8, and 15.9 Mg/ha for 5, 10, and 20%. The yield data indicate no significant differences among the leaching treatments. Total yields for 1976 were lower than for 1975 because fewer cuttings were taken, although yields by cutting were consistently higher in 1976. As expected, the yields of all treatments gradually increased with each cutting until early summer as the density of the alfalfa stand increased during the spring each year and then decreased during late summer.

Encroachment of grass and other weeds has plagued the experiment, and the flood check has had consistently higher yields except in midsummer when the flood check was probably underirrigated. Annual flood-check yields were 21.3 and 18.6 Mg/ha for 1975 and 1976, respectively -- 20 and 16% larger than the average experimental yields. After the sixth cutting in 1975, parts of the experimental area were cultivated lightly and reseeded in an attempt to eliminate weeds. This accounts for the discrepancy in cutting dates and resultant yields for the seventh cutting in 1975 (see TABLE 27). After the fifth cutting in 1976, the alfalfa was completely removed from the field to eliminate weeds. The field was allowed to dry throughout August and September to kill the grass and then was cultivated 0.2 m deep and leveled with a laser plane. The field was replanted the first of October.

Leaf Analysis

Alfalfa shoots were sampled in September 1975 to evaluate plant nutrient status. Samples were taken before the sixth harvest from five locations randomly selected along the length of each experimental plot and along three

TABLE 26. PREDICTED DRAINAGE WATER COMPOSITIONS FOR THE ALFALFA TREATMENTS*

Leaching fraction	Ca	Mg	Na	Sum of cations	HCO_3	SO_4	Cl	EC†	SAR§
	← -----	-----	-----	meq/ℓ	-----	-----	----- →	S/m	
.03	24.8	90.0	227.0	341.0	18.6	206.0	117.0	2.51	29.9
.05	26.2	54.0	136.0	216.0	15.0	131.0	70.0	1.68	21.5
.10	28.4	27.0	68.0	123.0	11.8	76.6	35.0	0.98	12.9
.15	22.9	18.0	45.3	86.2	11.6	51.3	23.3	0.72	10.0
.20	19.9	13.5	34.0	67.4	11.4	38.5	17.5	0.56	8.3
.30	16.8	9.0	22.7	48.5	11.1	25.7	11.7	0.39	6.3
.40	15.2	6.7	17.0	39.0	11.0	19.2	8.7	0.32	5.1

*Assuming the partial pressure of CO_2 is 0.080 and the irrigation water composition is, in meq/ℓ: Ca 4.5, Mg 2.7, Na 6.8, Cl 3.5, HCO_3 2.8, and SO_4 7.7.

†Electrical conductivity at 25°C.

§SAR = Na/√[(Ca + Mg)/2], where solutes are in meq/liter.

TABLE 27. ALFALFA YIELD (Mg/ha)* FOR EACH REPLICATION OF THE LEACHING TREATMENTS AND FOR THREE LOCATIONS WITHIN THE FLOOD CHECK FOR THE 1975 SEASON

Leaching treatment	Replication 1	2	3	4	5	Average yield
		1st Cutting -- 02-24-75				
5%	1.0	1.1	1.0	1.5	1.2	1.2
10%	1.1	0.9	1.2	1.4	1.1	1.2
20%	0.9	1.0	1.2	1.3	0.9	1.0
Flood	2.2	2.1	2.4			2.3
		2nd Cutting -- 04-30-75				
5%	2.6	2.2	2.3	2.0	2.1	2.2
10%	2.3	2.3	2.2	1.9	1.7	2.1
20%	2.9	2.2	1.9	2.2	2.0	2.2
Flood	2.7	2.5	2.3			2.5
		3rd Cutting -- 06-04-75				
5%	3.0	2.8	2.9	2.8	3.3	2.9
10%	3.1	2.7	2.8	2.7	2.6	2.8
20%	3.1	3.0	2.6	2.8	2.6	2.8
Flood	3.5	4.0	3.8			3.8
		4th Cutting -- 07-04-75				
5%	3.3	3.3	3.0	3.2	3.2	3.2
10%	3.6	3.4	3.3	3.1	3.4	3.3
20%	3.4	3.5	3.2	3.0	3.1	3.2
Flood	3.6	3.2	3.8			3.5
		5th Cutting -- 08-11-75				
5%	3.6	3.4	3.2	3.9	4.0	3.6
10%	3.3	3.5	3.6	3.1	3.8	3.4
20%	3.9	3.4	3.3	3.8	3.7	3.6
Flood	3.5	3.5	2.8			3.3
		6th Cutting -- 09-17-75				
5%	3.8	3.1	3.0	3.0	3.0	3.2
10%	3.2	3.2	3.3	3.3	2.9	3.2
20%	2.9	--	3.0	3.4	3.2	3.1
Flood	3.3	3.3	3.3			3.3
	7th Cutting -- flood cut 11-24-75 -- experiment cut 01-27-76					
5%	1.7	1.6	1.5	1.8	1.3	1.6
10%	2.0	1.5	1.7	1.8	0.7	1.6
20%	1.8	1.7	1.8	1.8	1.6	1.7
Flood	2.7	2.5	2.6			2.6

*Note: 1 Mg/ha = 0.466 ton/acre.

TABLE 28. ALFALFA YIELD (Mg/ha)* FOR EACH REPLICATION OF THE LEACHING TREATMENTS AND FOR THREE LOCATIONS WITHIN THE FLOOD CHECK FOR THE FIRST FIVE CUTTINGS OF 1976

Leaching treatment	Replication 1	2	3	4	5	Average yield
			1st Cutting -- 03-09-76			
5%	1.5	1.5	1.5	1.3	1.1	1.4
10%	1.5	1.8	1.3	1.2	1.0	1.4
20%	1.5	1.7	1.3	1.2	1.1	1.4
Flood	2.6	2.4	2.3			2.4
			2nd Cutting -- 04-23-76			
5%	3.7	3.3	3.7	3.2	3.7	3.5
10%	3.3	3.6	3.3	3.3	3.2	3.3
20%	3.5	3.5	3.2	3.4	3.3	3.4
Flood	4.2	4.0	4.1			4.1
			3rd Cutting -- 05-26-76			
5%	4.1	3.9	4.0	4.0	3.8	3.9
10%	3.6	3.8	4.1	3.4	3.6	3.7
20%	4.2	3.4	3.8	3.6	3.6	3.7
Flood	4.3	3.8	4.8			4.3
			4th Cutting -- 06-23-76			
5%	4.0	3.4	3.8	3.5	3.6	3.7
10%	3.9	3.8	3.9	3.6	3.2	3.6
20%	3.5	3.7	3.4	3.6	3.5	3.5
Flood	4.4	3.9	3.7			4.0
			5th Cutting -- 07-30-76			
5%	4.3	3.8	3.7	3.8	3.7	3.9
10%	3.9	4.4	3.9	4.3	2.7	3.8
20%	4.3	4.4	3.7	3.9	3.1	3.9
Flood	3.8	3.6	3.8			3.8

*Note: 1 Mg/ha = 0.446 ton/acre.

lengths within the flood check. Each sample consisted of approximately 200 g fresh weight of plants, cut about 0.05 m above the soil. The samples were washed, oven-dried, and analyzed for 13 mineral elements (TABLE 29). Compared with published tissue analyses used to evaluate nutrient status (Soil Testing and Plant Analysis, Part II, p. 79, Soil Sci. Soc. Amer., 1967), Ca levels appear low; Na and S are somewhat high. All other elements are within normal concentration ranges. The Na analyses indicate that foliar absorption may be responsible for the high Na levels in the experimental treatments, but, surprisingly, Replicate 5 in each leaching treatment had significantly lower Na levels than the other replications. Besides Na, significant, but small, differences in mineral contents between the flood check and experimental plants were present for K, Ca, and Cl.

TABLE 29. MINERAL COMPOSITION OF ALFALFA

Element	(unit)	Leaching Treatment 5%	10%	20%	Flood check
N	(%)	3.2	3.2	3.2	3.2
P	mmoles/100g	7.6	7.6	7.9	8.0
K	meq/100g	68	69	68	82
Ca	"	67	66	65	73
Mg	"	25	24	25	23
Na	"	25*	24*	27*	6
Cl	"	35	34	33	25
S	"	30	29	29	27
B	µg/g	66	62	64	65
Fe	"	90	90	87	85
Mn	"	25	23	25	27
Zn	"	26	23	22	26
Cu	"	13	13	13	13

*Average of replicates 1-4; Replicate 5 in all treatments was significantly lower (average 10 meq/100 g).

Water Table

During the installation of the manholes in September 1974, the water table was within 2 m of the soil surface. This was caused, in part, by the drainage well at the south end of the field being shut off for repairs. Nevertheless, the area has a history of shallow water tables and information on the depth to the water table is of concern when attempting a water balance with a deep-rooted crop. Thus, six observation wells (lined with a 5-m-long section of perforated plastic pipe) were drilled along the periphery of the experiment. One well was installed near each of the four corners of the leaching experiment field, and one at about the midpoint of each side of the field. Depth to water table below ground elevation is given in TABLE 30. To date, the depths to the water table have ranged from 2.0 to 3.5 m. From observations during drilling, a sand stratum seems to be present at the depths where water is found.

TABLE 30. DEPTH TO WATER TABLE IN ALFALFA EXPERIMENT (m)

Date	Position*					
	NW	NE	CW	CE	SW	SE
05-21-75	2.6	2.5	>5	2.9	>5.0	2.9
08-08-75	3.3	>5.0	3.2	2.9	>5.0	>5.0
09-18-75	3.1	>5.0	3.1	2.9	2.6	3.1
10-31-75	2.9	2.5	3.0	2.9	2.8	2.7
12-05-75	2.7	2.5	2.9	2.6	2.9	2.9
01-06-76	--	2.7	3.5	2.8	2.9	2.5
02-05-76	>5.0	>5.0	3.5	2.8	2.7	2.7
03-05-76	2.5	>5.0	3.1	2.9	3.1	2.5
04-05-76	2.3	>5.0	3.1	2.9	3.0	2.5
05-05-76	2.0	>5.0	2.8	2.6	2.7	2.5
06-08-76	2.3	>5.0	2.8	2.9	2.8	2.2
07-16-76	2.0	>5.0	>5.0	2.8	2.8	2.2
08-20-76	2.4	>5.0	3.0	2.7	>5.0	2.2

*CW refers to center of field on the west, CE to center of field on the east; the remaining locations correspond roughly to field corners, i.e., (NW) northwest, (NE) northeast; (SW) southwest, and (SE) southeast.

Soil Air

Soil Oxygen--

In conjunction with the soil oxygen measurements in the citrus experiment, Dr. Burl Meek (ARS, Brawley, Calif.) made similar measurements in the alfalfa at a soil depth of 0.45 m in two of the five replications in each of the three leaching treatments and at several locations in the flood check. Measurements were made for several days in succession three different times the first half of 1975. TABLE 31 shows the average soil oxygen content for each treatment.

In March, when the average irrigation rate was about 5 mm/day in the experimental plots, the soil oxygen content was well above 10%. During April 1975, about 10 mm/day of irrigation water was being applied to decrease the soil salinity to the desired level after some operational problems with the irrigation system. Soil oxygen levels during this period were well below 10% for the 20% leaching treatment and near 10% for 10% leaching. Visual

TABLE 31. PERCENT SOIL OXYGEN AT THE 0.45-m SOIL DEPTH IN THE ALFALFA EXPERIMENT

Date	Leaching treatment			Flood check
	5%	10%	20%	
March 1975	17.5	18.6	18.2	14.1
April 1975	16.0	10.5	5.8	11.1
June 1975	17.1	16.3	14.0	--

effects of low soil oxygen were apparent in some plots. The alfalfa in replication 3 of the 20% leaching treatment was yellowish green, whereas the plants in replication 2 appeared normal. Oxygen for replication 3 averaged 2.4%; the average for replication 2 was 12.0%. Similarly, the 10% leaching plot of replication 2 had a soil oxygen content of 5.9% and the alfalfa had a light-yellow tint, while replication 1 appeared normal with an oxygen content of 13.9%. Because of the drastic decrease in soil oxygen, the irrigation rate was reduced, thus extending the period needed to decrease the soil salinity. In June, the average irrigation rate was about 9 mm/day, but since ET was also high, soil oxygen was well above 10%.

Soil Carbon Dioxide--

Carbon dioxide concentration in soil air varies with time of year and soil depth as shown in TABLE 32. The values for alfalfa are about two to four times greater than the concentrations obtained in the citrus (see TABLE 19). The higher values for alfalfa are reasonable because the entire soil surface is irrigated, whereas only about one-half the area is irrigated in the orange grove. The soil in the alfalfa field is also finer textured. Both factors tend to reduce gaseous exchange between the soil and atmosphere in the alfalfa. The carbon dioxide concentrations in the flood check are similar to those in the leaching plots. Note that the carbon dioxide concentrations are highest immediately after a flood irrigation, which corresponds to the time the soil is wettest.

The amount of salt in the drainage water depends on leaching fraction and the carbon dioxide in the soil air. As leaching decreases, however, the influence of carbon dioxide on the salt load decreases for Colorado River water (Oster and Rhoades, 1975). For leaching fractions of 0.2 and 0.1 and with 10% carbon dioxide in the soil air, as under alfalfa, the respective predicted salt loads are 4.6 and 8.1 kg of salt per m^3 of drainage water. Comparable numbers for 3% carbon dioxide, as in the citrus, are 4.2 and 7.8 kg/m^3. The decrease is a direct result of the decreased solubility of lime with decreased carbon dixoide level. The relative reduction is 9 and 4% for leaching fractions of 0.2 and 0.1. At leaching fractions $\leq$0.1, the salt that can be dissolved in the drainage water resulting from irrigation with Colorado River water also depends on the solubility of gypsum. Decreases in the solubility of lime result in increased solubility of gypsum and vice versa.

TABLE 32. AVERAGE PERCENT CARBON DIOXIDE IN SOIL AIR UNDER ALFALFA AS A FUNCTION OF SOIL DEPTH

Soil depth	Leaching Experiment			
	Oct 75	Jan 76	Apr 76	Jul 76
meter				
0.3	2.3	4.0	5.5	4.2
0.6	4.7	5.3	6.1	9.3
0.9	7.7	6.5	7.8	9.7
1.2	8.5	7.2	8.2	10.1

Soil depth	Flood Check				
	Sep 75	Jan 76	Apr 76	August 1976	
	18*	16*	21*	4*	7*
meter					
0.3	2.2	1.7	4.1	6.8	3.7
0.6	5.4	4.2	6.9	9.4	7.3
0.9	7.1	5.0	9.7	11.6	9.7
1.2	7.9	5.7	9.3	12.1	10.6
1.5	8.9	6.8	9.6	12.6	12.1

*Days after irrigation.

DISCUSSION

The results presented for alfalfa are highly tentative and several additional years of experimentation are required for substantiation. It appears that a high irrigation efficiency can be attained with the level-basin, flood-irrigation technique. It does not appear that irrigation efficiency can be improved significantly for alfalfa by a change in irrigation method because of its deep rooting nature. Leaching percentage for the flood check was about 10%.

Evapotranspiration

Following the procedure used for the citrus, ET can be estimated by correcting the depth of irrigation and rainfall by the design leaching fractions, by calculations based on meteorological data, and by estimates based on the volumes or chloride concentrations of leachate from the vacuum extractors and suction lysimeters. These estimates of ET can also be compared with published values.

The estimate of annual ET based on water application and the desired leaching during the past 19 months is 1813 mm. Calculations from the modified Penman equation result in an annual ET estimate of 2201 mm. Erie et al. (1965) published a value of 1890 mm for alfalfa near Phoenix, Arizona, and lysimeter measurements at Brawley, California, indicate a yearly ET of 2060 mm.

Leaching percentages based on both volume (Fig. 27) and chloride concentration (TABLE 24) of leachates from the vacuum extractors and suction lysimeters indicate the sprinkled treatments were under-irrigated. If an annual ET of about 2000 mm were postulated, based on the estimates noted above, it would also indicate underirrigation.

Salinity Trends and Leachates

The salinity profiles developed slowly, as expected, and probably still have not reached equilibrium. The shapes of the profiles by mid-1976 indicated an apparent depth of rooting of 0.90 m for the 5% leaching treatment and a rooting depth in excess of 1.20 m for the other treatments. The flood check data indicate a probable rooting depth substantially deeper than alfalfa on the sprinkled treatments.

Based on the volumes of water extracted, leaching percentages for the three treatments are estimated to be about 3, 5, and 10%; based on composition of the leaching water, they are 6, 6, and 9%; based on the salt sensors, the leaching percentages at the 1.20-m depth for all three treatments are about 12%. One may conclude that the leaching fractions obtained to date were less than those planned; this observation is consistent with the water application data and the ET estimates.

Crop Yields

Yields from the leaching experiment have been consistently lower than those from the flood check. The frequent application of small amounts of water resulted in a high soil matric potential at shallow depth, which apparently stimulated weed growth. The high soil water content during harvest aggravated soil compaction by heavy equipment. Infiltration rates were low, again causing an unfavorable soil surface condition. Early in the experimental period, an excess of herbicides was applied accidentally to the plots. All these factors combined resulted in a rather poor alfalfa stand, compared to that on the flood check. Whatever the reason, the time-averaged *in situ* salinity in the 0- to 1.20-m root zone for the period July 1975 to May 1976 was about 0.5 S/m for the flood check compared to 0.8 S/m for the three experimental treatments. The yield depression expected from this difference (Maas and Hoffman, 1977) is 12%; the actual reduction observed (33.5 vs. 39.9 Mg for the first 12 cuttings) was about 16%.

Overview

The data suggest, but do not definitely establish, that the experimental plots were underirrigated more than was the flood check, notwithstanding comparable application rates. Quite possibly, the flood check used water from the water table, further confounding the water-use picture. This would explain, in part, the substantial difference in the salt profiles (Fig. 24) for identical water application rates. It is also possible that higher evaporation from the exposed soil surface following each cutting decreased the water available for leaching in the sprinkled treatments. Plainly, it has been difficult, with the irrigation system used, to obtain water infiltration rates consistent with projected needs.

The alfalfa was reseeded in the fall of 1976 and the irrigation system has been modified by installing larger capacity nozzles. It is expected that somewhat less frequent, but larger, irrigation applications will simplify the management and permit the soil to dry more before each cutting, thereby overcoming the severe weed and soil compaction problems associated with an excessively wet soil surface.

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TABLE A-1. DESCRIPTION OF SOIL AT THE CITRUS EXPERIMENTAL SITE PROVIDED BY THE SOIL CONSERVATION SERVICE

Date: September 27, 1973. Area: Yuma County, Arizona; Lower Gila River Area - 649.
Description by: R.L.A.
Classification: Typic Haplargid, coarse-loamy, mixed, hyperthermic.
Location: Between 21st & 22nd tree west of road & between 19th and 20th tree north of road in East Block No. 220D16, Sec. 20, R. 16 W., T. 8 S.
Vegetation: Valencia oranges. Climate: Arid. Parent Material: Old alluvium. Physiography: Mesa. Relief: A-nearly level. Elevation: 325 feet. Slope: Less than 1%. Aspect: North. Erosion: None to slight. Permeability: Moderate. Drainage: Well. Ground Water: Deep. Moisture: Moist to depth described. Root distribution: Normal.
Additional Notes: Coarse gravel found in a sand matrix from 144 to 206 in. (Dateland fine sandy loam.)

HORIZON	DESCRIPTION
Ap	0-6 inches (0-15 cm), brown (10YR 5/3) fine sandy loam, dark brown (10YR 4/3) moist; massive structure; soft, very friable, slightly sticky, nonplastic; many fine and very fine roots, many fine and very fine tubular pores; slightly effervescent; moderately alkaline (pH 8.2); abrupt smooth boundary.
B2t	6-17 inches (15-43 cm), light yellowish brown (10YR 6/4) fine sandy loam, dark yellowish brown (10YR 4/4) moist; massive structure; soft to slightly hard, very friable, sticky, slightly plastic; common fine and very fine and very few medium roots, common fine and very fine tubular pores; few thin clay bridges; strongly effervescent; moderately alkaline (pH 8.2), clear smooth boundary.
B3t	17-27 inches (43-69 cm), light yellowish brown (10YR 6/4) fine sandy loam, dark yellowish brown (10YR 4/4) moist; massive structure; soft, very friable, sticky, slightly plastic; very few medium and common fine and very fine roots, many fine and very fine tubular pores; few thin clay bridges; strongly effervescent, fine, irregularly shaped, pinkish white soft masses of lime (2% by volume); moderately alkaline (pH 8.2), clear smooth boundary.
C1ca	27-54 inches (69-137 cm), pale brown (10YR 6/3) loam, dark brown (10YR 4/3) moist; massive structure; soft, very friable, slightly sticky, slightly plastic; very few medium and coarse and common fine and very fine roots, common fine and very fine tubular pores; violently ef-

HORIZON	DESCRIPTION
	fervescent, fine and medium, irregularly shaped, pinkish white soft masses of lime (25% by volume); moderately alkaline (pH 8.2) clear wavy boundary.
C2	54-57 inches (137-145 cm), pale brown (10YR 6/3) fine sandy loam, dark brown (10YR 4/3) moist; massive structure; soft, very friable, slightly sticky, nonplastic; common very fine and few fine roots, many fine and very fine tubular pores; strongly effervescent, fine irregularly shaped concretions of lime (<1% by volume); moderately alkaline (pH 8.2), clear wavy boundary.
IIC3	57-74 (145-188 cm), pale brown (10YR 6/3) sand, brown (10YR 5/3) moist; massive structure; loose, very friable, nonsticky, nonplastic; very few very fine roots, many interstitial pores; noneffervescent, moderately alkaline (pH 8.2); cleary wavy boundary.
IIC4	74-84 inches (188-214 cm) pale brown (10YR 6/3) sand, dark brown (10YR 4/3) moist, massive structure; loose, very friable, nonsticky, nonplastic; many interstitial pores; 15% gravel (by volume), noneffervescent, moderately alkaline (pH 8.2), clear wavy boundary.
IIC5	84-94 inches (214-239 cm), pale brown (10YR 6/3) sand, dark grayish brown (10YR 4/2) moist; massive structure; loose, very friable, nonsticky, nonplastic, many interstitial pores; noneffervescent, moderately alkaline (pH 8.2).

TABLE A-2. AVERAGE ANNUAL VALENCIA ORANGE YIELD (kg/tree) BY REPLICATION FOR THE MINIMUM LEACHING EXPERIMENT AND THE BORDER- AND CHECK-PLOT TREES IN SOUTHWESTERN ARIZONA

Year	Treatment Replication									Treatment
	1	2	3	4	5	6	7	8	9	average
					5% Leaching					
1974	124	124	132	138	105	110	108	105	98	116
1975	124	135	130	154	149	149	152	149	143	143
1976	63	45	70	68	81	86	70	97	83	73
					10% Leaching					
1974	132	139	137	122	129	125	124	117	108	126
1975	106	131	160	150	165	149	165	159	141	148
1976	48	62	61	57	69	79	68	81	107	70
					20% Leaching					
1974	143	138	123	117	106	112	122	119	117	122
1975	128	170	155	132	134	152	166	138	147	147
1976	75	58	60	59	68	62	88	80	90	71

Year	Bubbler Border			Drip Border		
	West row	East row	Average	West row	East row	Average
1974	127	118	122	108	116	112
1975	140	142	141	160	170	165
1976	76	76	76	84	91	88

Year	Flood Check				Fertilizer Check			
	West row	Center row	East row	Average	West row	Center row	East row	Average
1974	--	--	--	--	--	--	--	--
1975	116	131	115	121	171	186	177	178
1976	88	103	103	98	100	112	104	105

TABLE A-3. VALENCIA ORANGE LEAF ANALYSIS SUMMARY FOR SEPTEMBER 1974

Element	(conc.)	Optimum Range	Leaching Treatments			Border Trees		Fertilizer check plot	Evaluation
			5%	10%	20%	Bubbler	Drip		
N	%	2.2-2.7	2.61	2.77	2.77	2.64	2.64	2.44	OK
P	mmole/100 g	4-6	3.95	3.82	4.02	3.82	4.12	3.85	OK
K	meq/100 g	25-45	25.1	24.4	25.8	26.2	25.9	29.8	OK
Ca	" "	150-250	236	241	237	243	245	246	OK
Mg	" "	17-50	19.3	19.3	19.4	19.7	17.4	20.4	OK
Na	" "	2.5-6.5	1.8	1.9	1.9	1.8	1.9	0.9	OK
Cl	" "	<4.2	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	OK
S	" "	12-19	19.3	19.2	20.0	20.7	19.5	20.8	OK
B	μg/g	25-150	194	199	203	199	179	186	HIGH
Fe	"	60-150	61	56	58	65	66	58	OK
Mn	"	20-100	26	27	27	33	31	21	OK
Zn	"	25-100	25	26	25	22	20	21	OK
Cu	"	4-10	11	11	11	10	12	10	OK

TABLE A-4. ANNUAL MEASUREMENTS OF VALENCIA ORANGE TREE TRUNK CIRCUMFERENCE (mm) AVERAGED BY REPLICATION FOR THE MINIMUM LEACHING EXPERIMENT IN SOUTHWESTERN ARIZONA

Year	Treatment Replication									Treatment average
	1	2	3	4	5	6	7	8	9	
					5% Leaching					
1973	551	574	564	566	589	582	587	579	566	573
1974	544	579	582	584	610	589	587	592	579	583
1975	576	614	610	616	635	621	646	623	608	617
1976	630	651	661	651	665	652	671	655	642	653
					10% Leaching					
1973	556	564	574	577	559	577	587	589	556	571
1974	582	579	577	599	566	599	599	605	572	586
1975	622	604	612	633	599	632	631	637	604	619
1976	651	653	652	666	635	670	668	670	637	656
					20% Leaching					
1973	572	566	582	538	561	574	574	556	556	564
1974	587	579	589	554	574	582	599	574	584	580
1975	620	616	630	590	610	613	639	604	614	615
1976	653	658	666	631	646	658	673	638	653	653

Year	Bubbler Border			Drip Border		
	West row	East row	Average	West row	East row	Average
1973	561	561	561	564	592	578
1974	574	574	574	594	607	600
1975	614	614	614	623	633	628
1976	638	640	639	660	673	666

Year	Flood Check			Fertilizer Check			
	West row	East row	Average	West row	Center row	East row	Average
1973	—	—	—	550	—	544	547
1974	536	513	524	—	—	—	—
1975	578	556	567	604	606	595	602
1976	596	582	589	618	631	628	626

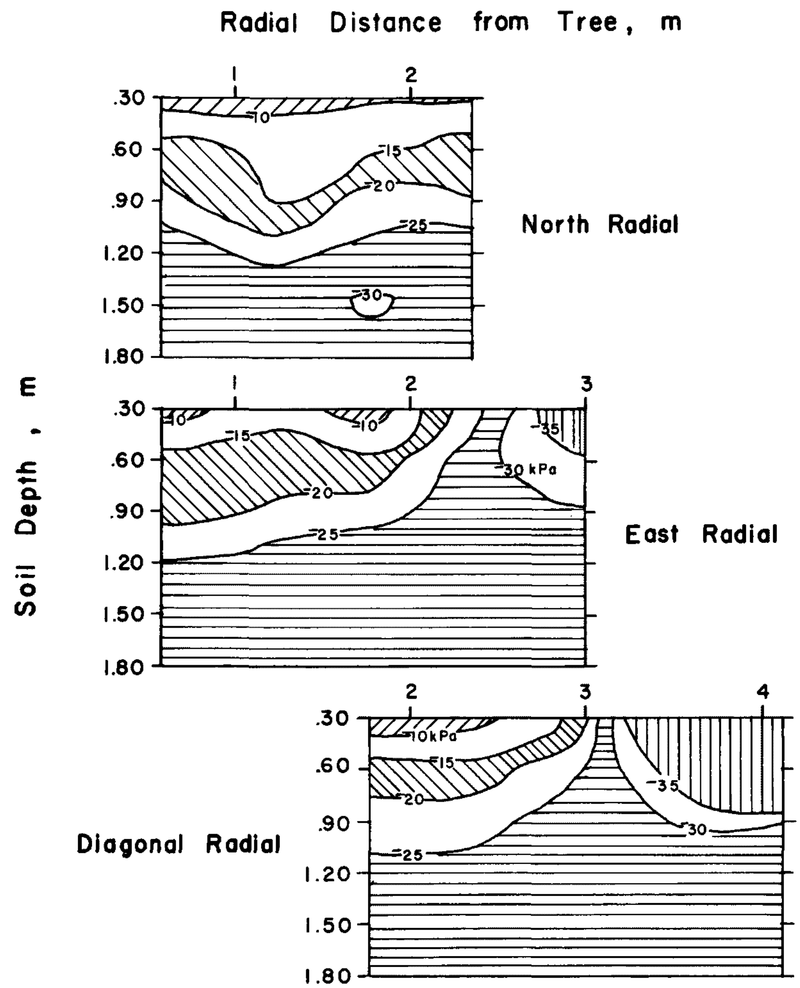

Figure A-1. Distribution of total head under the center citrus tree of plot H4 on January 22, 1976.

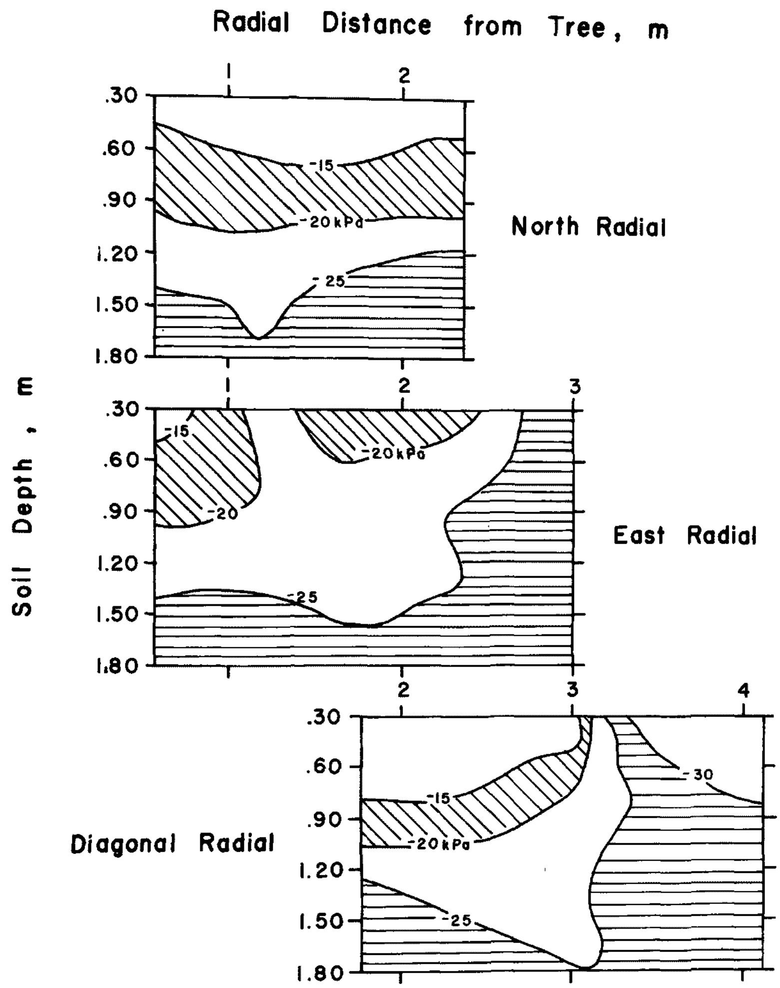

Figure A-2. Distribution of total head under the center citrus tree of plot H4 on March 23, 1976.

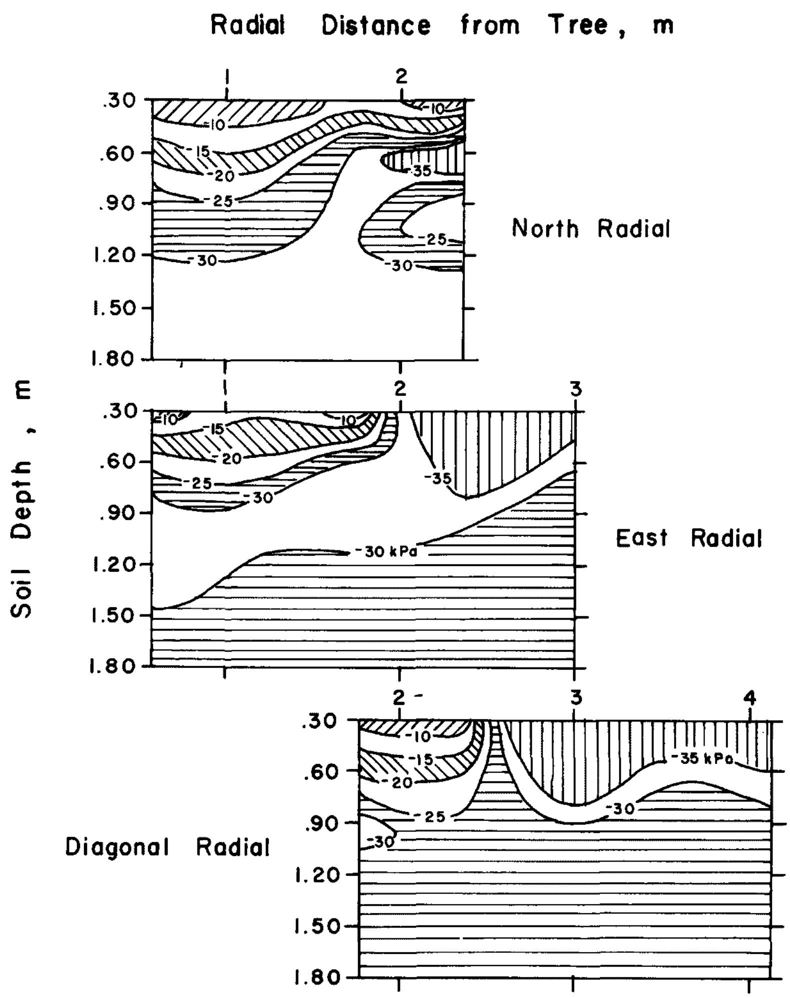

Figure A-3. Distribution of total head under the center citrus tree of plot H4 on April 28, 1976.

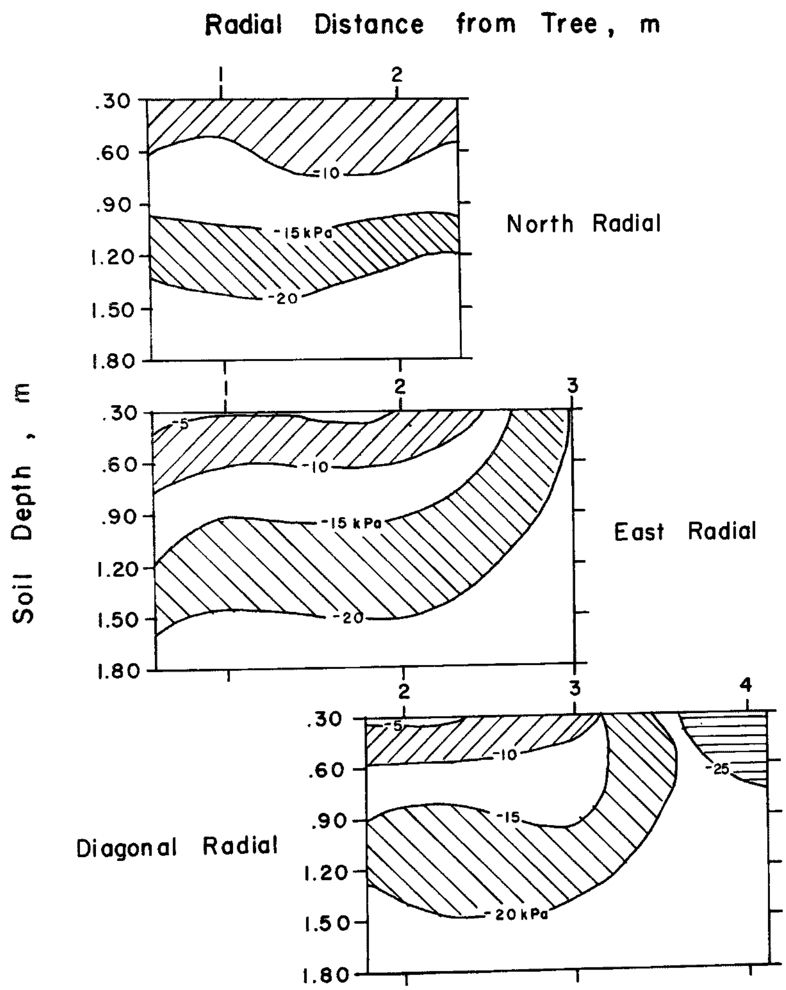

Figure A-4. Distribution of total head under the center citrus tree of plot H4 on August 24, 1976.

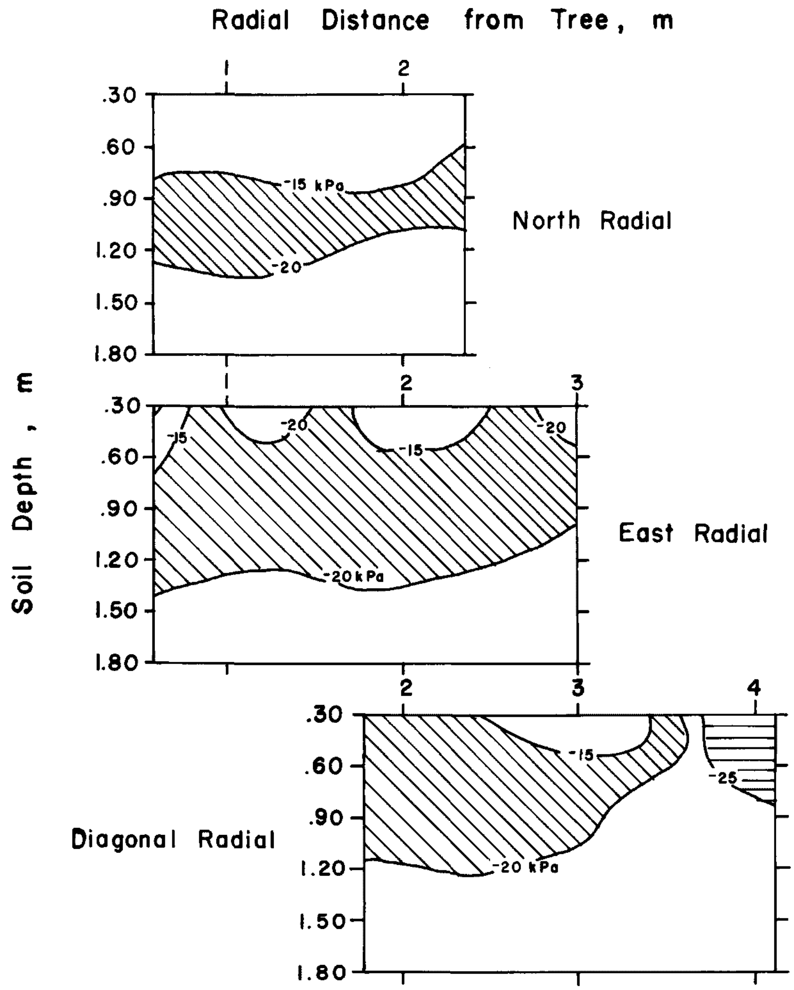

Figure A-5. Distribution of total head under the center citrus tree of plot H4 in the morning on August 28, 1976.

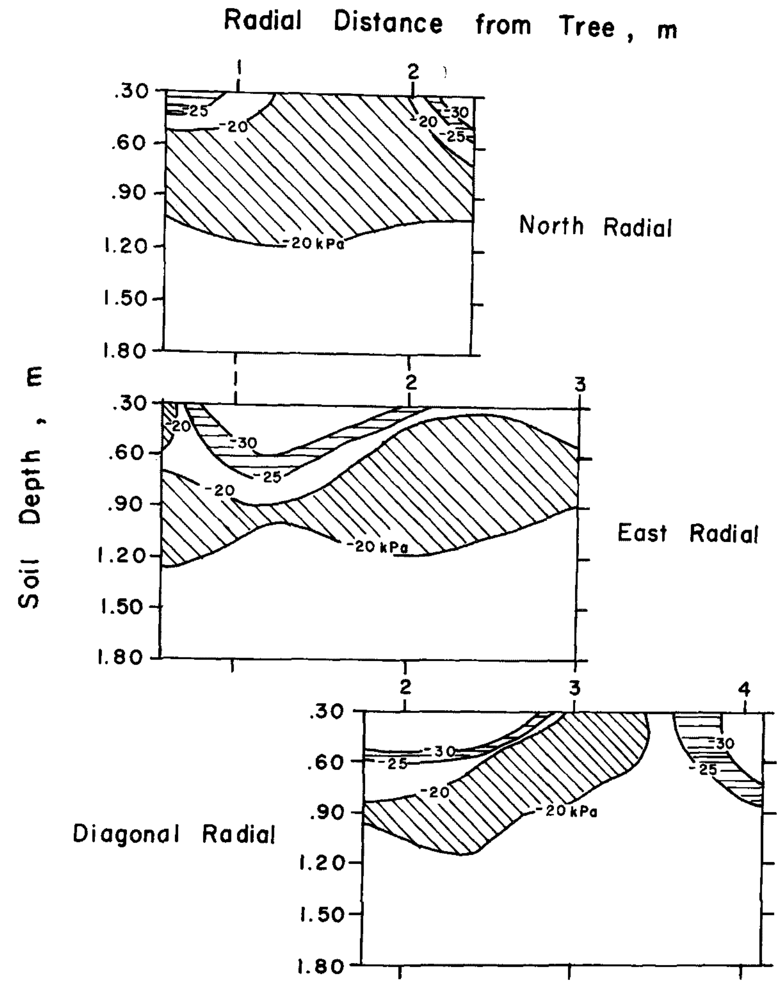

Figure A-6. Distribution of total head under the center citrus tree of plot H4 in the evening on August 29, 1976.

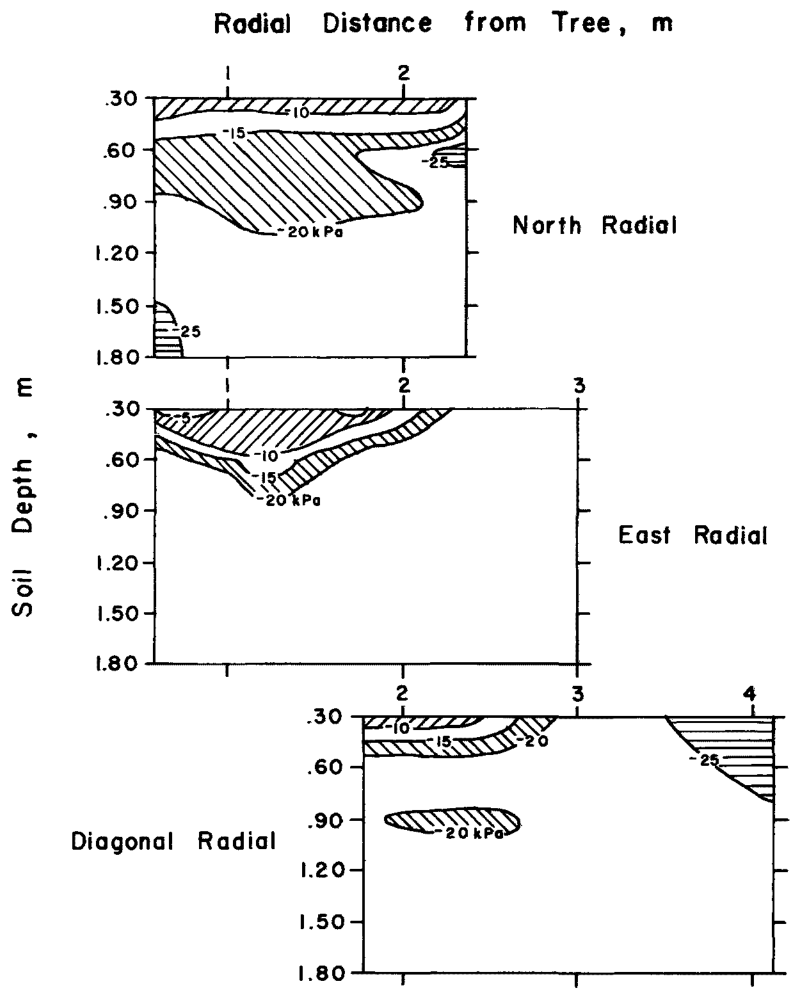

Figure A-7. Distribution of total head under the center citrus tree of plot H4 in the afternoon on September 1, 1976.

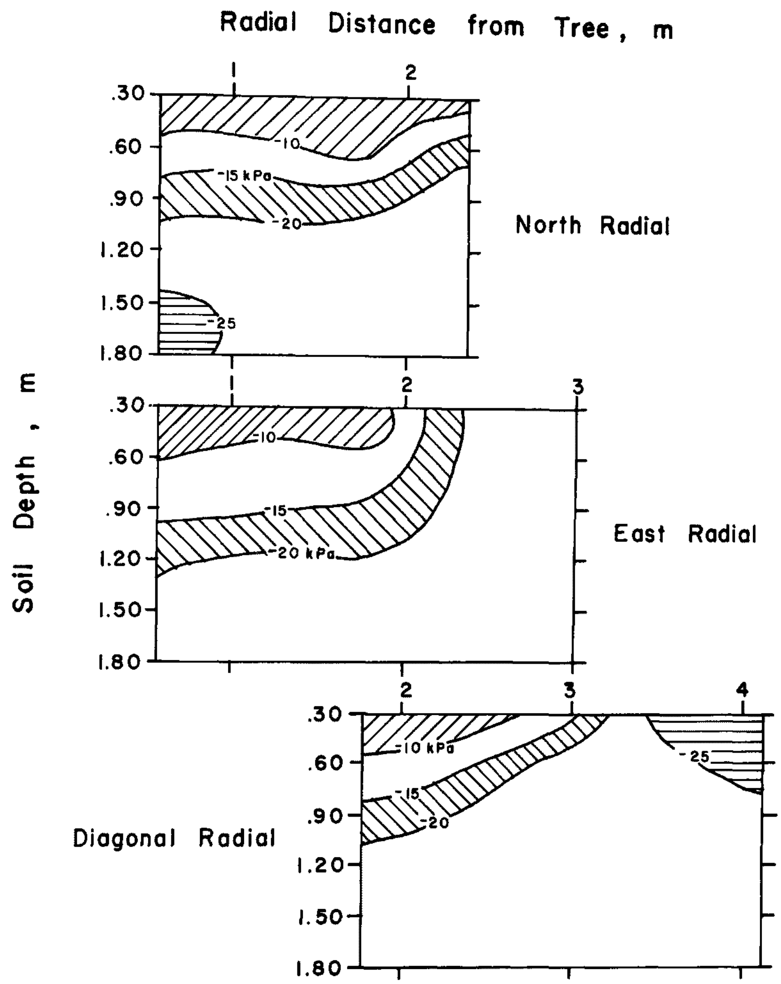

Figure A-8. Distribution of total head under the center citrus tree of plot H4 on September 4, 1976.

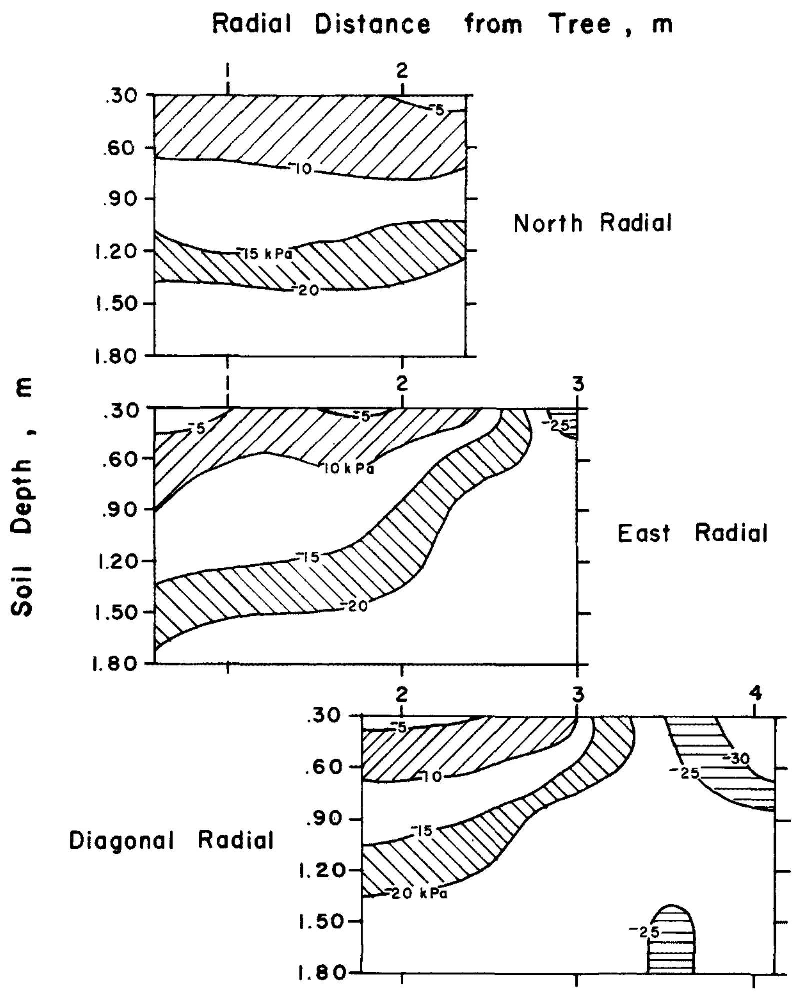

Figure A-9. Distribution of total head under the center citrus tree of plot H4 on September 9, 1976.

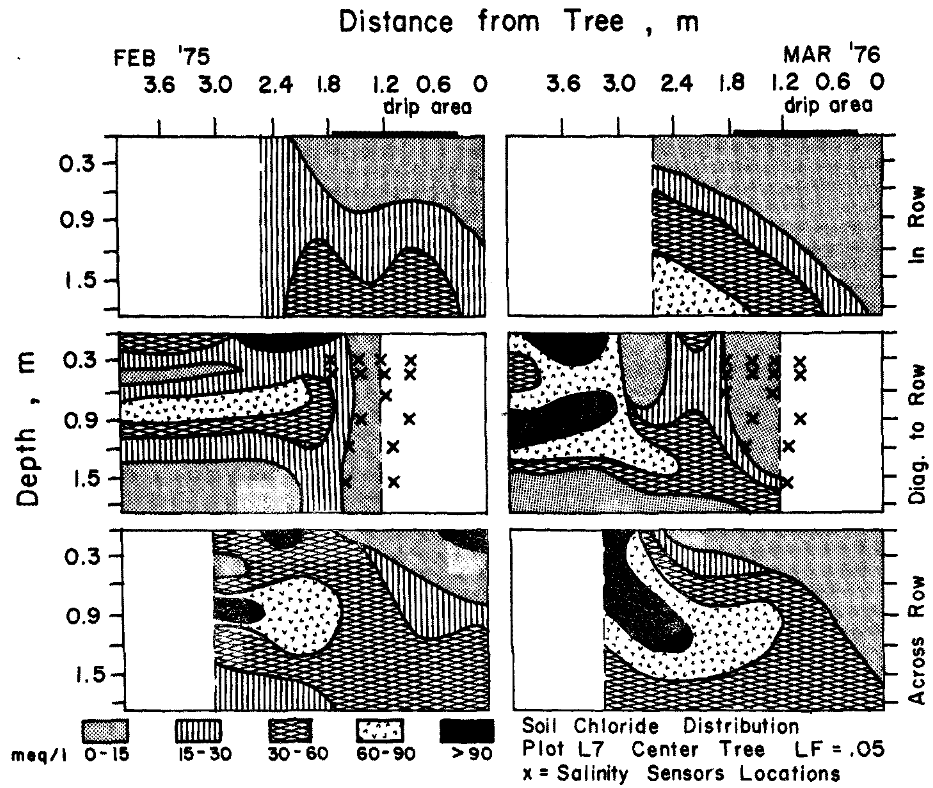

Figure A-10. Cross section of soil chloride distribution under the center tree of a 5% (L7) leaching plot after 1 and 2 years.

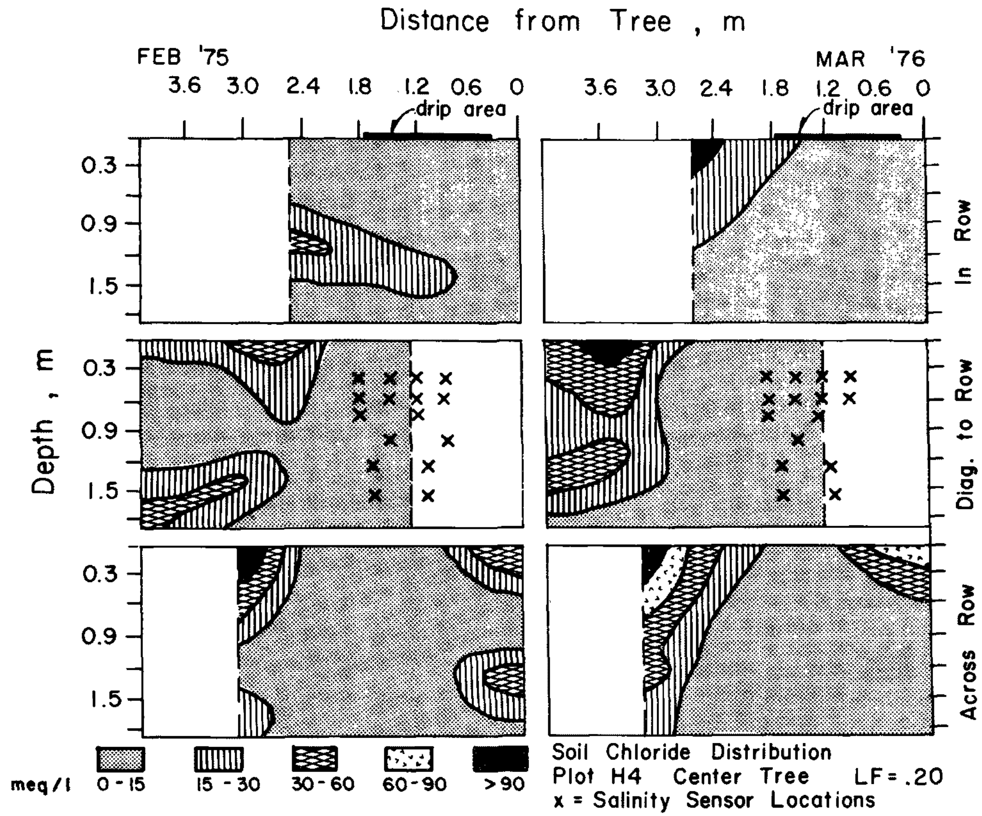

Figure A-11. Cross section of soil chloride distribution under the center tree of a 20% (H4) leaching plot after 1 and 2 years.

TABLE B-1. DESCRIPTION OF SOIL AT THE ALFALFA EXPERIMENTAL SITE PROVIDED BY THE SOIL CONSERVATION SERVICE

Date: September 10, 1974. Area: Yuma County, Arizona.
Description by: E. Chamberlin and J. White.
Classification: Typic Torrifluvent, coarse-silty, mixed, calcareous, hyperthermic.
Location: 800'E, 900'S. of NW corner section 12, T. 8.S., R.16.W. of G. & S.R. B. L. & M.
Vegetation: Fallow. Climate: 2-4 inches precipitation, mean annual air temp. 70-75°F. Parent Material: Gila River alluvium. Topography: Level. Elevation: 288'. Drainage: Well-drained.
Additional Notes: Indio very fine sandy loam (color for dry soil unless otherwise noted)

HORIZON	DESCRIPTION
Ap	0-13 inches (0-33 cm); light brown (7.5YR 6/4) very fine sandy loam, brown (7.5YR 4/4) moist; weak granular structure; soft, very friable, nonsticky, nonplastic; common medium and fine roots; common medium tubular and many fine interstitial roots; slightly effervescent; moderately alkaline (pH 8.2); abrupt smooth boundary.
C1	13-21 inches (33-53 cm) light brown (7.5YR 6/4) silt loam, brown (7.5YR 4/4) moist; weak very fine platy structure; slightly hard, very friable, slightly sticky, slightly plastic, few medium and many fine roots; common tubular and many very fine interstitial pores; slightly effervescent; moderately alkaline (pH 8.2); abrupt smooth boundary.
C2	21-33 inches (53-84 cm); light brown (7.5YR 6/4) silt loam, brown (7.5YR 4/4) moist; massive; slightly hard, very friable, slightly sticky, slightly plastic; few medium and fine roots; few tubular and many very fine interstitial pores; strongly effervescent; moderately alkaline (pH 8.5); clear smooth boundary.
C3	33-45 inches (84-114 cm); light brown (7.5YR 6/4) silty clay loam; brown (7.5YR 4/4) moist; massive; hard, friable, sticky, slightly plastic; few tubular and many very fine interstitial pores; strongly effervescent; moderately alkaline (pH 8.4); clear smooth boundary.
C4	45-72 inches (114-182 cm); light brown (7.5YR 6/4) silty clay loam, brown (7.5YR 4/4) moist; massive; slightly hard, friable, sticky, plastic, few tubular and many very fine interstitial pores; strongly effervescent; strongly alkaline (pH 8.8).

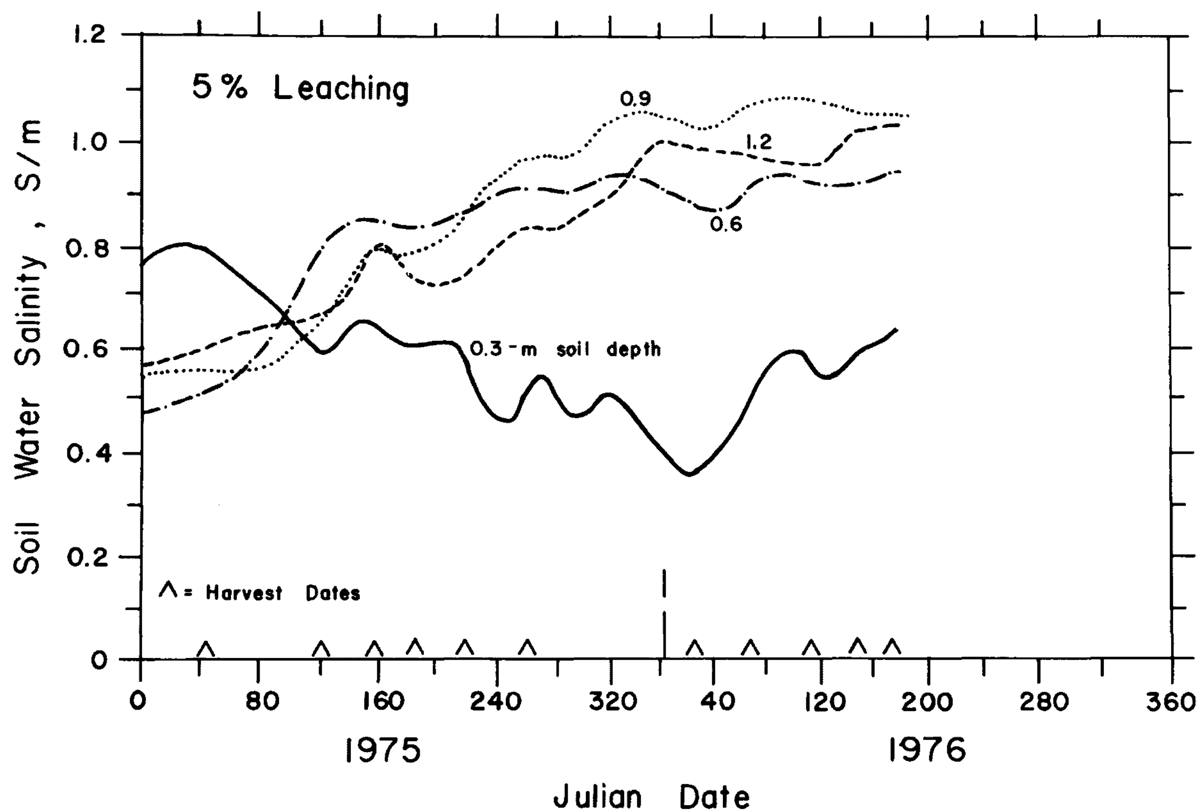

Figure B-1. Salinity trends with time for the 5% leaching treatment of the alfalfa experiment.

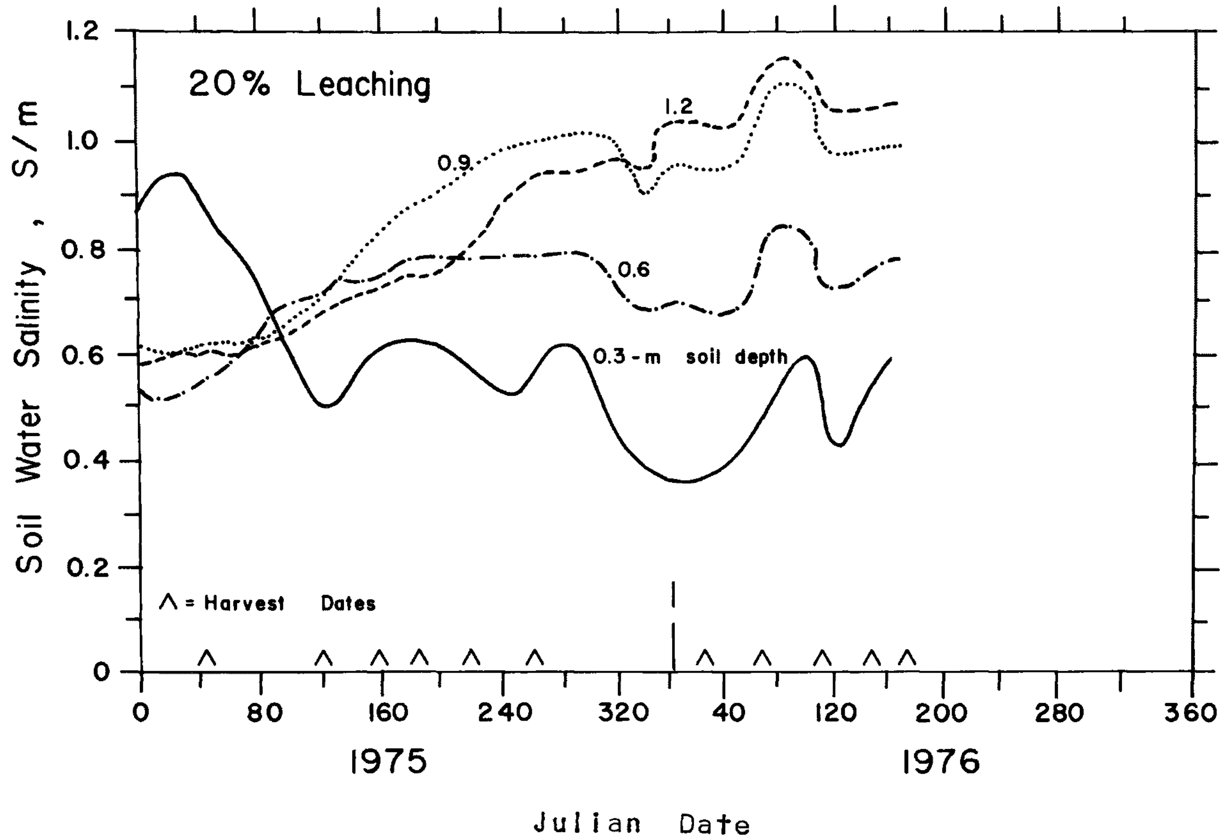

Figure B-2. Salinity trends with time for the 20% leaching treatment of the alfalfa experiment.

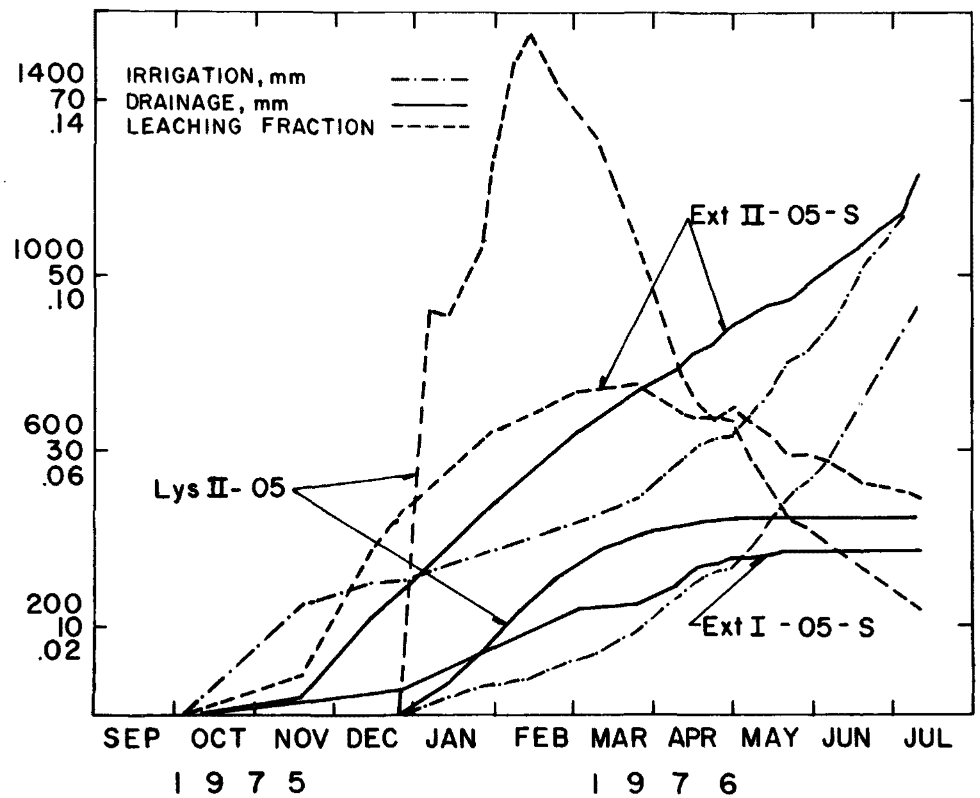

Figure B-3. Accumulated values for irrigation, drainage, and leaching fraction for the 5% alfalfa leaching treatment.

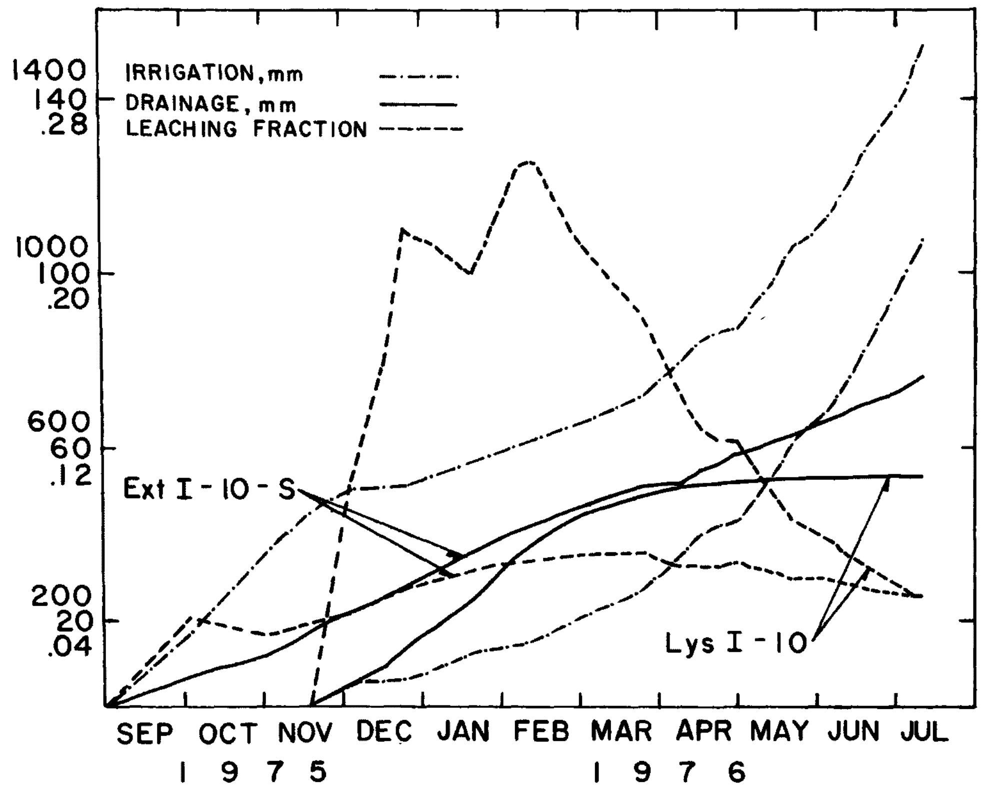

Figure B-4. Accumulated values for irrigation, drainage, and leaching fraction for the 10% alfalfa leaching treatment.

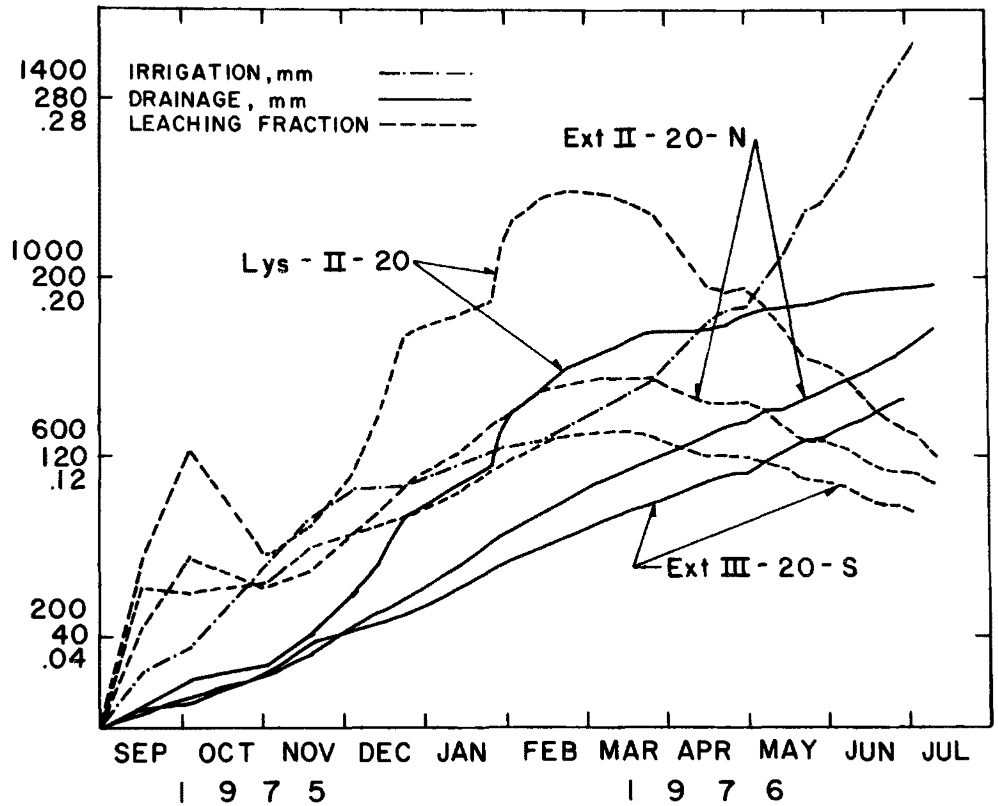

Figure B-5. Accumulated values for irrigation, drainage, and leaching fraction for the 20% alfalfa leaching treatment.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-134	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE MINIMIZING SALT IN RETURN FLOW THROUGH IRRIGATION MANAGEMENT		5. REPORT DATE July 1977 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) U.S. Salinity Laboratory Staff		8. PERFORMING ORGANIZATION REPORT NO. U.S. Salinity Lab. Publ. #613
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Salinity Laboratory, Agricultural Research Service, USDA, Post Office Box 672, Riverside, California 92502		10. PROGRAM ELEMENT NO. 1HB617
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15. SUPPLEMENTARY NOTES

16. ABSTRACT Two field experiments are being conducted in southwestern Arizona to investigate the potential of reducing the salt load in irrigation return flow by decreased leaching. Three leaching treatments of 5, 10, and 20%, replicated nine times for citrus and five times for alfalfa, were established and compared with conventional flood irrigation management. Results on citrus indicate that leaching percentages of 8, 11, and 22 were achieved, compared to 47% on the border flood check. The best estimate of the annual evapotranspiration of citrus is 1400 mm. Reduced leaching has not adversely affected fruit quantity or quality. If leaching were reduced to 20%, the volume of drainage from the 3000 ha of citrus in the district would be decreased 43.7 x 10^6 m^3/yr and the salt load would be cut by 45,500 Mg/yr. Leaching percentages of about 3, 5, and 10 have been obtained in the alfalfa. The level-basin flood check received the same amount of water as the high leaching treatment. Results indicate that the sprinkled plots were underirrigated and that the annual evapotranspiration for alfalfa is about 2000 mm. Yields from the sprinkled plots have been 16% less than those on the flooded field because of underirrigation, weed problems, and soil compaction. Even with reseeding and less frequent irrigation, it is unlikely that substantial improvement is possible over the low leaching obtained on the level-basin flood check.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Irrigation, salinity, leaching, water quality, desalting, efficiency	Colorado River Basin, salinity control, water use, Gila Project, Wellton-Mohawk Division,	02C

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