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# Reclamation of Salt-affected High Boron Soils in Western Kern County

F. T. Bingham, A. W. Marsh, R. Branson,
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Two experiments were conducted in the west side of Kern County to evaluate and develop appropriate reclamation procedures for salt-affected high boron soils. The experiments consisted of sprinkler irrigation applied at two rates with straw, gypsum, and slip-plowing. The reclamation was primarily in response to depth of water percolating through the soil profile and that neither amendments nor slip-plowing facilitated reclamation. Soluble salts were reduced to safe levels throughout 5-foot soil profiles by application of about 5 acre-feet of water. Reduction of boron and exchangeable sodium to safe levels required approximately 15 acre-feet of water. No resalinization occurred upon fallowing leached soil profiles for 12 months.

THE AUTHORS:

F. T. Bingham is Professor of Soil Science and Chemist in the Experiment Station, Riverside

A. W. Marsh is Irrigation and Soils Specialist, Agricultural Extension Service, Riverside.

R. Branson is Soils and Water Specialist, Agricultural Extension Service, Riverside.

R. Mahler is Staff Research Associate, Department of Soil Science and Agricultural Engineering, Riverside.

G. Ferry, formerly Farm Advisor, Kern County, now County Director, Kings County.

*F. T. Bingham, A. W. Marsh, R. Branson, R. Mahler, and G. Ferry*

# Reclamation of Salt-Affected High Boron Soils in Western Kern County[1]

## INTRODUCTION

An unusually rapid conversion of rangeland into irrigated land is taking place in the southwestern portion of the San Joaquin Valley—western Kern County following introduction of irrigation water services to this area in 1968. Currently, 112,000 acres are under irrigation, practically all by sprinkler. Crop production costs are relatively high, due primarily to water costs and outlay for sprinkler irrigation systems; therefore, crop selections consist mainly of specialty crops with higher income-producing potential—citrus, deciduous fruits, and certain vegetable and field crops. This selection has, however, created additional problems and costs because of reclamation needs. Substantial acreages contain soils with excessive amounts of salts, sodium, and boron which present a serious hazard to the cultivation of all but the most tolerant crops (Bingham *et al.*, 1970; Committee, 1968*a*, 1968*b*). Although the need for reclamation is now generally recognized, no specific information based upon experience in this area, is available for developing appropriate reclamation procedures. Therefore, the present authors initiated in 1968 reclamation experiments in this area to evaluate techniques for leaching excess salts, sodium and boron with the prime objective of developing realistic reclamation procedure(s). The results of these experiments provide the basis for the present discussion of reclamation needs for west-side soils in the San Joaquin Valley.

## MATERIALS AND METHODS

### Reclamation sites

The experiments were conducted at two sites on a gently sloping alluvial fan 6 miles north of Blackwell's Corner and 2 miles west of Highway 33 (Sections 10 and 3, T26, R19E). Both were located on the Panoche soil; however, the soil at site II contains more clay and has a more distinct B horizon which somewhat impedes transmission of water through the profile. Figure 1 indicates the specific location of each site and its relation to the major soil bodies of the west side. At the time of setting up the two reclamation experiments, the site areas under investigation were in a natural, undisturbed state and had plant covers of grasses and forbs (fig. 2).

### Description of Soils

Panoche soil is found on broad confluent alluvial fans sloping gently eastward from the base of the Coast Range; it is the principal soil under develop-

[1] Submitted for publication April 27, 1971.

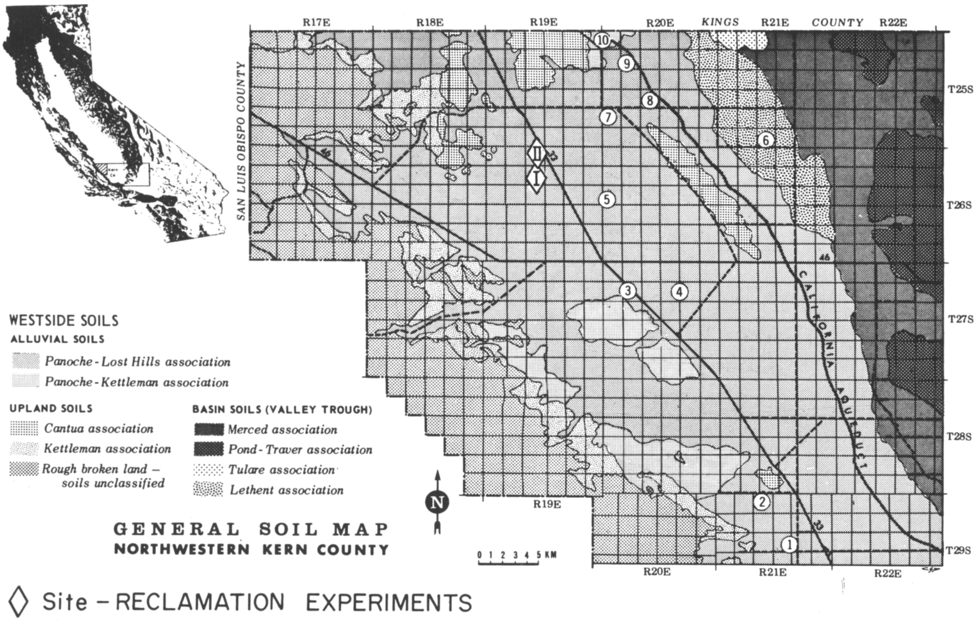


**Fig. 1. General soil map of west side soils in western Kern County showing location of the two reclamation experiments I and II, west of highway 33.** (After Huntington [Committee, 1968*a*].)

ment west of the California Aqueduct. This soil is calcareous throughout and has gypsum and other salts in the profile, especially in the subsoil. The two sites were selected after examining a number of soil bodies in the area with respect to water transmission characteristics, salinity, alkali, and boron content as well as availability of water and power for the irrigation system.

Table 1 indicates the general salinity-alkali and boron characteristics of Panoche soil in sites I and II. The data shown also include texture, $CaCO_3$- and $CaSO_4.2H_2O$-content, pH, and moisture content at saturation ($PW_{sp}$), with each having a mean value of 32 and 16 soil samples, respectively, for sites I and II. Additional description of these soils is contained in a recent report on the mineralogical-chemical properties of westside soils (Bingham *et al.*, 1970).

## Design of reclamation experiments

Table 2 shows treatments for each of the two sites used to observe the influence on reclamation of leaching by sprinkler irrigation at two application rates. Site I received amendments (in split-plot design), whereas site II received tillage management. All treatments were replicated four-fold.

Tillage treatment entailed slip-plowing (Robinson and Luthin, 1968) two furrows 8 inches apart to a 5-foot depth across one-half of each plot ($35 \times 17.5$ feet); the companion half of the plot was left bare. Amendments (straw and gypsum, site I) were lightly disced into the soil before leaching. Irrigation (leaching) was acomplished by using a low application rate and a solid-set sprinkler system consisting of four lateral lines spaced 35 feet apart, each connected to a header line. Lateral lines, header, and fittings were PVC (regid plastic, polyvinyl chloride). Sprinklers mounted on 18-inch plastic risers were spaced 35 feet apart on the lateral lines. Each leaching plot consisted of a $35 \times 35$-foot area

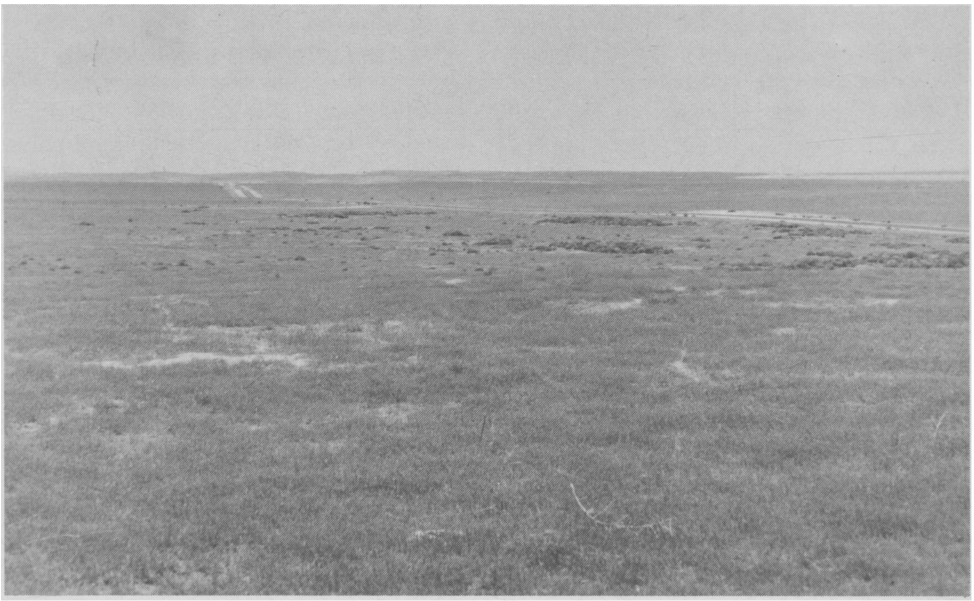

Fig. 2. Area in vicinity of reclamation experiments prior to development of irrigated agriculture. Approximately 120,000 acres of rangeland here have been converted into cropland.

TABLE 1

CHARACTERISTICS OF PANOCHE SOIL, SITES I AND II

| Reclamation site | Profile depth | Texture | $CaCO_3$ | $CaSO_4 \cdot 2H_2O$ | $PW_{sp}$ | $pH_{sp}$ | Saturation extract: $EC_e$ | SAR | Cl | $SO_4$ | $B_e$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *feet* | | | *per cent* | | | *mmho/cm* | | *me/l* | | *mg/l* |
| I................ | 0–1 | Loam | 3.3 | 0.01 | 32 | 7.7 | 0.9 | 3.7 | 1.6 | 2.7 | 0.6 |
| | 1–2 | Clay loam | 5.1 | 0.01 | 37 | 8.0 | 2.7 | 16.6 | 17.6 | 5.0 | 3.3 |
| | 2–3 | Clay loam | 2.8 | 0.10 | 42 | 7.9 | 9.1 | 19.5 | 23.8 | 50.0 | 8.9 |
| | 3–4 | Clay loam | 3.3 | 0.74 | 39 | 7.8 | 9.1 | 18.9 | 42.5 | 59.5 | 8.8 |
| | 4–5 | Loam | 3.5 | 0.45 | 33 | 7.8 | 8.9 | 17.2 | 37.8 | 60.2 | 7.3 |
| II............... | 0–1 | Clay loam | 3.9 | 0.01 | 41 | 7.8 | 1.6 | 6.6 | 2.0 | 10.2 | 1.3 |
| | 1–2 | Clay | 4.0 | 0.26 | 53 | 8.0 | 4.8 | 14.5 | 11.5 | 40.4 | 6.6 |
| | 2–3 | Clay | 3.4 | 1.10 | 55 | 7.7 | 12.7 | 19.9 | 66.4 | 61.7 | 10.3 |
| | 3–4 | Clay | 3.2 | 1.20 | 56 | 7.7 | 12.6 | 20.4 | 78.9 | 58.0 | 9.1 |
| | 4–5 | Clay | 3.4 | 1.00 | 51 | 7.7 | 11.0 | 18.7 | 57.4 | 62.3 | 8.5 |

TABLE 2

RECLAMATION TREATMENTS FOR SITES I AND II

| Whole plot sprinkler rate | Split plot soil treatment |
|---|---|
| | *site I—Panoche Loam* |
| 0.054 inch per hour................................ | Gypsum 0 and 5.0 tons per acre |
| | Barley straw 0 and 1.5 tons per acre |
| 0.089 inch per hour................................ | Combination |
| | *site II—Panoche Clay Loam* |
| 0.054 inch per hour................................ | Slip-plowing |
| 0.089 inch per hour................................ | No slip-plowing |

TABLE 3
COMPOSITION OF AQUEDUCT CANAL WATER, 1969 SEASON

| EC | Ca | Mg | Na | $HCO_3 + CO_3$ | $SO_4$ | Cl | SAR | B |
|---|---|---|---|---|---|---|---|---|
| *mmho/cm* | | | | *me/l* | | | | *mg/l* |
| 0.50 | 1.1 | 1.3 | 2.2 | 1.5 | 2.2 | 1.4 | 2.0 | 0.30 |

bounded by four similar sprinklers. Plot positions were randomly selected, and each was further subdivided by random selection for amendment or soil manipulation treatments.

Sprinklers were single nozzle, low-gallonage impact type. Two nozzles sizes ($\frac{1}{16}$- and $\frac{5}{64}$-inch) were used to obtain two application rates. At an operating pressure of 50 psi the average application rate over the 35- × 35-foot plot area for site I was, respectively, 0.054 and 0.089 of an inch per hour for the two treatments. With the operating schedule used this provided a daily irrigation of 0.65 and 1.07 of an inch for respective treatments. Average daily irrigation for site II was essentially the same.

Water was taken from a district pipe line that carried a continuous flow at low pressure from the California Aqueduct. The chemical analysis of the water (table 3) is typical of composition of water used in the two experiments. The water had a low salt and sodium hazard.

Pressure for sprinkler operation was provided by a motor-driven booster pump. A time clock, control panel, and electric valve automatically controlled the pump and water supply to the plots. Sprinkler operations were set for 12 continous hours nightly during the period of least wind (usually 8 p.m. to 8 a.m.). An aluminum main line carried water from the pump to the plots. A $\frac{1}{16}$-inch-mesh screen and a low-pressure shutoff valve were inserted in the last section of the aluminum line just before connecting to the header line at the plots to reduce sprinkler nozzle plugging, and to prevent drainage of the main line through sprinkler heads at the end of each irrigation.

Commercial dial-type tensiometers were installed in one plot at site II to provide measurements of soil suction throughout the 5-foot profile in relation to irrigation and slip-plowing treatment. These tensiometers were installed between slip-plow slots, in the middle of the slip-plow slot, and in the adjacent undisturbed native area.

Plots at site I were leached from June 11, 1968 to January 2, 1969, with approximately 9.1 and 13.8 feet of water for the two irrigation treatments. Soil samples were collected by 12-inch horizons to the 60-inch depth on 3-week intervals during the leaching operation. The plots at this site were subsequently fallowed until February 12, 1970, at which time they were sampled again to determine the extent of resalinization (including sodium and boron) during the fallow period.

Leaching operations began for site II, May 20, 1969, and were continued until December 23, 1969. Approximately 9.5- and 14.8-feet of irrigation water were applied. These plots were sampled by 12-inch increments to 60-inches at the 2nd, 5th, 9th, 14th and 20th week following initiation of leaching; all were resampled in March, 1970.

## Soil analysis

Soil samples were air-dried, crushed, and sieved through a 2-mm screen preparatory to examination in the laboratory. The initial set of samples (before leaching) were analyzed for $CaCO_3$, $CaSO_4.2H_2O$, and saturation extract components. The saturation extract was examined for electrical conductivity level ($EC_e$), SAR, C1, $SO_4$, $HCO_3$, $NO_3$, and soluble B using methods described by Bingham *et al.* (1970) in connection with the chemical-mineralogical characterization of west-side soils. Exchangeable sodium (ES) and cation-exchange capacities (CEC) were measured with the neutral *N* $NH_4Ac$ technique (Chapman and Pratt, 1961). Textural classifications were based upon the results of mechanical analysis using an improved hydrometer technique (Day, 1956).

# RESULTS AND DISCUSSION

## Leaching effects

Regression analysis of saturation extract data for soil samples collected during the leaching operations showed that neither amendments nor profile tillage had any significant effect on the progress and extent of leaching, but that irrigation rates and depths of water applied did. Therefore results obtained from the treated plots (gypsum, straw, and slip plowing) were combined into two irrigation treatments (0.054 and 0.089 of an inch per hour) to bring out the effect of variable rates of sprinkler irrigation on reclamation. Table 4 shows the salt-affected condition of the soil at site I prior to and after application of 13.8 feet of water. Table 5 gives similar information for site II. Both sets of data reflect extensive removal of salts, sodium, and boron from the 5-foot profile. As examples, the $EC_e$, SAR, and B analyses for site I were reduced from detrimental levels in the subsoil ($EC_e$, 9 mmho/per cm; SAR, 19; and B, 9 mg B/l), to levels safe for cultivation of a wide variety of crops. The $EC_e$ values were reduced to 2 mmho/per cm or lower, SAR to 3-4, and B to less than 1 mg B/l. The soil at site II is somewhat more developed, having a zone of clay accumulation in the subsoil (B horizon). Though reclamation was sufficiently complete with respect to cultivation of most crops, the $EC_e$ and B levels noted after the leaching operation (table 5) may be slightly excessive for tree crops.

Figures 3, 4, 5, 6, and 7 portray profile distribution patterns to 5-feet for $EC_e$, Cl, $SO_4$, B, and SAR in relation to depth of water applied and application rate for the two test sites. These figures reflect the progress of salt displacement and leaching out of the 5-foot profile. Differences in leaching rates are pronounced when comparing Cl and $EC_e$ with B and SAR. These differences are brought out more strikingly and quantitatively by plotting the average (weighted) salinity level for the 5-foot profile as a function of depth of water applied (fig. 8 and 9). The resultant data indicate the depth of water needed to reduce specific salt components (i.e., $EC_e$, SAR, and B) to a given level(s), and hence are helpful in determining the amount of leaching needed for a particular crop. For example, $EC_e$ values of 4 mmho/per cm or less are taken as the upper limit for salt-sensitive crops such as citrus and deciduous fruit trees. According to figures 8 and 9, about 5-feet of water properly applied by a sprinkler system would reduce $EC_e$ values throughout the top 5-feet of the soil to safe levels. There is evidence that plants can grow satisfactorily under conditions where part of the root system is salinized (Bingham and Garber, 1970), but as a safeguard the soil profile should be leached free of harmful salts to a depth just below root extension.

Chloride is frequently the principle anion in soil solutions. Tree crops are particularly sensitive to relatively low Cl concentrations provided the root system is completely exposed to this anion. According to Bernstein (1965, 1967), Fenn *et al.* (1970), and Bingham *et al.* (1968), a saturation extract concentration of 10 me Cl/l is indicative of excessive Cl for certain tree crops. Based

TABLE 4

SATURATION EXTRACT ANALYSIS OF PANOCHE LOAM AT RECLAMATION EXPERIMENT SITE I BEFORE AND AFTER RECLAMATION

| Profile depth (feet) | ECe (mmho/cm) | Ca + Mg* | Na* | $HCO_3$* | Cl* | $NO_3$* | $SO_4$* | SAR | B (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *natural condition* | | | | | |
| 0–1.......... | 0.9 | 4.7 | 5.7 | 4.2 | 1.6 | 0.1 | 2.7 | 3.7 | 0.6 |
| 1–2.......... | 2.7 | 3.9 | 23.2 | 2.8 | 17.6 | 0.3 | 5.0 | 16.6 | 3.3 |
| 2–3.......... | 9.1 | 23.8 | 67.4 | 1.5 | 23.8 | 0.5 | 50.0 | 19.5 | 8.9 |
| 3–4.......... | 9.1 | 31.7 | 75.2 | 1.3 | 42.5 | 0.9 | 59.5 | 18.9 | 8.8 |
| 4–5.......... | 8.9 | 34.7 | 71.6 | 1.2 | 37.8 | 1.2 | 60.2 | 17.2 | 7.3 |
| | | | | *reclaimed condition*† | | | | | |
| 0–1.......... | 0.8 | 5.9 | 3.3 | 3.0 | 0.8 | 0.1 | 4.5 | 1.9 | 0.4 |
| 1–2.......... | 0.7 | 4.3 | 3.6 | 2.1 | 0.9 | 0.1 | 4.5 | 2.5 | 0.4 |
| 2–3.......... | 0.9 | 4.8 | 5.1 | 2.1 | 0.8 | 0.1 | 6.2 | 3.3 | 0.5 |
| 3–4.......... | 1.8 | 13.4 | 9.2 | 1.7 | 0.8 | 0.1 | 20.0 | 3.6 | 0.6 |
| 4–5.......... | 2.1 | 17.6 | 8.7 | 1.6 | 1.0 | 0.1 | 23.5 | 2.9 | 0.8 |

* Expressed as me/l.
† Following a treatment of 13.8 feet of irrigation water at 0.089"/hr.

TABLE 5

SATURATION EXTRACT ANALYSIS OF PANOCHE CLAY LOAM AT RECLAMATION EXPERIMENT SITE II BEFORE AND AFTER RECLAMATION

| Profile depth (feet) | ECe (mmho/cm) | Ca + Mg* | Na* | $HCO_3$* | Cl* | $NO_3$* | $SO_4$* | SAR | B (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *natural condition* | | | | | |
| 0–1.......... | 1.6 | 6.0 | 11.5 | 3.9 | 2.0 | 0.3 | 10.2 | 6.6 | 1.3 |
| 1–2.......... | 4.8 | 15.5 | 40.4 | 2.7 | 11.5 | 0.2 | 40.4 | 14.5 | 6.6 |
| 2–3.......... | 12.7 | 41.7 | 90.7 | 1.3 | 66.4 | 0.6 | 61.7 | 19.9 | 10.3 |
| 3–4.......... | 12.6 | 46.6 | 98.3 | 1.2 | 78.9 | 1.2 | 58.0 | 20.4 | 9.1 |
| 4–5.......... | 11.0 | 42.1 | 85.6 | 1.3 | 57.4 | 1.1 | 62.3 | 18.7 | 8.5 |
| | | | | *reclaimed condition*† | | | | | |
| 0–1.......... | 0.9 | 5.0 | 3.6 | 3.8 | 0.9 | 0.1 | 3.9 | 2.3 | 0.5 |
| 1–2.......... | 1.0 | 3.9 | 5.1 | 3.3 | 0.9 | 0.1 | 4.8 | 3.7 | 0.9 |
| 2–3.......... | 2.9 | 22.6 | 10.2 | 2.5 | 0.8 | 0.1 | 29.6 | 3.0 | 1.5 |
| 3–4.......... | 3.7 | 28.4 | 14.3 | 2.0 | 0.8 | 0.1 | 39.9 | 3.8 | 1.9 |
| 4–5.......... | 3.9 | 29.0 | 16.0 | 1.9 | 0.8 | 0.1 | 42.2 | 4.2 | 2.3 |

* Expressed as me/l.
† Following a treatment of 14.8 feet of irrigation water at 0.089"/hr.

upon the Cl-leaching data in figures 8 and 9, 3 to 4 feet of water would suffice for reduction of Cl throughout the 5-foot profile to safe levels.

Ordinarily, little concern is expressed over $SO_4$ concentrations in soil solutions because field experience with a wide variety of plants indicates that plants are relatively tolerant of $SO_4$. These soils in the west side contain gypsum which tends to dissolve to a limited degree (30 to 50 me/l) with leaching. This phenomenon is beneficial to soils from the point of view of preventing dispersion and sealing of soils. However, gypsum can be solubilized and leached out of the profile, resulting in a soil solution low in $Ca^{++}$ and in electrolytes which might lead to a deterioration of soil structure. Hence, the question of gypsum loss is pertinent. Based upon soil analysis for $CaSO_4.2H_2O$ of sites I and II before and after leaching with 15 feet of water, 15 tons per acre and 26

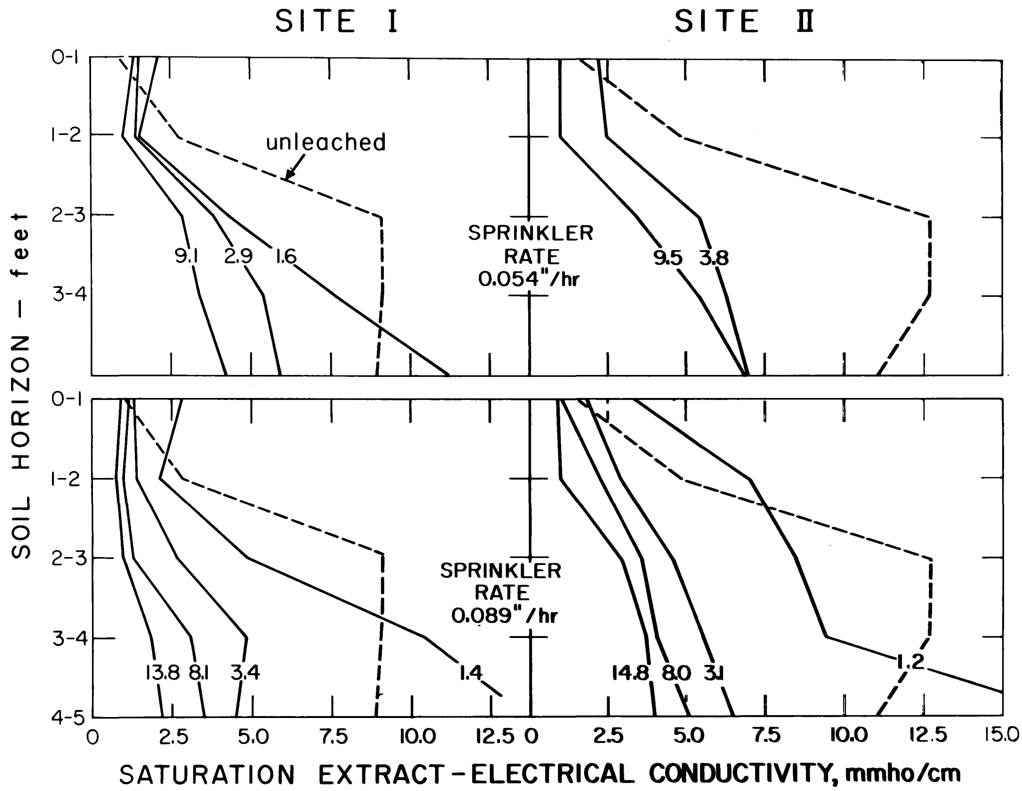


Fig. 3. Distribution of soluble salts (ECe) throughout soil profile for sites I and II in relation to sprinkler application rate and depth in feet of water applied.

tons per acre of $CaSO_4.2H_2O$, respectively, were leached out of the 5-foot profile. On an average basis, 1.4 tons per acre of $CaSO_4.2H_2O$ was leached out of the profile for each 12 inches of water applied. About one-half of the native gypsum was dissolved and leached out of the top 60 inches of the soil during leaching operations (14 feet of water). Hence, complete loss of gypsum from the 60-inch profile is essentially a matter of applying enough water, possibly 30 feet or so.

Boron at relatively low concentrations is injurious to plants, especially fruit trees; therefore, reclamation of west-side soils scheduled for orchard development should be carried out to reduce B in the saturation extract (comparable to that of the soil solution) to safe levels at approximately 1 mg B/l or lower. According to the B leaching relationship depicted in figures 8 and 9, substantial amounts of water are required for effective reclamation. These data indicate a need for 10 to 12 feet of water for leaching excessive B beyond the 5-foot soil depth.

Relatively low amounts of exchangeable sodium exert as detrimental effect on fruit trees (Bernstein, 1965) as well as on the physical structure of soils with predominantly montmorillonitic clay (McNeal *et al.*, 1968). These west-side soils usually have relatively low intake rates which decrease with increasing sodium. Therefore, reclamation should be managed so as to drop the SAR level of the saturation extract to as low as 5 which, according to figures 8 and 9, re-

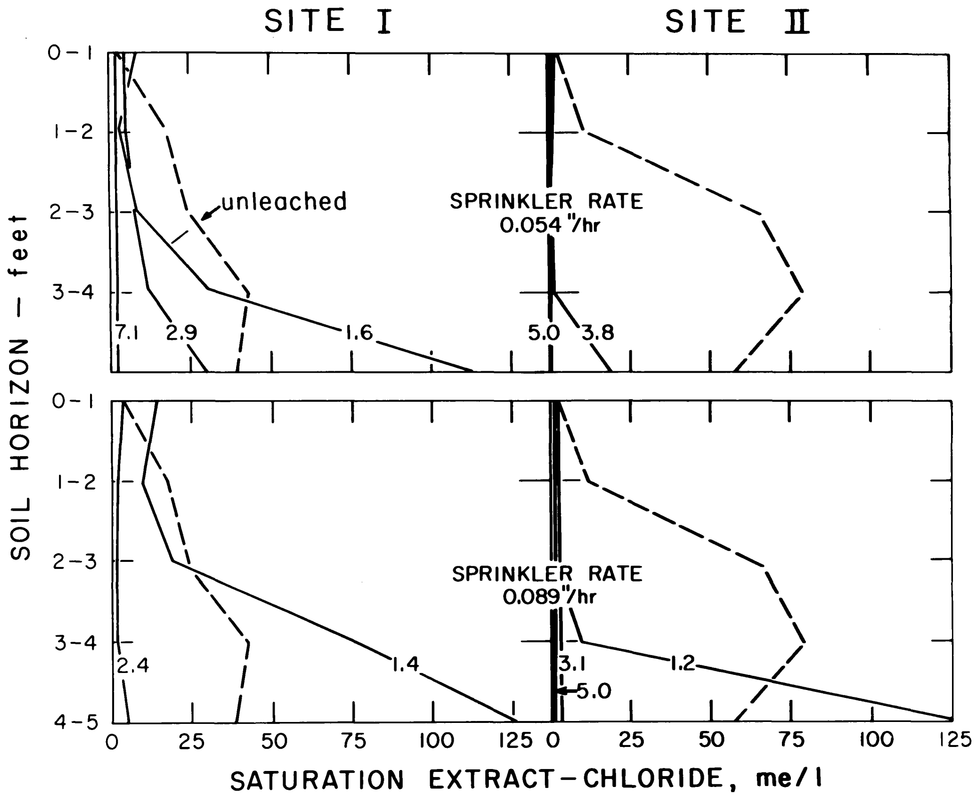


Fig. 4. Distribution of chloride throughout soil profile for sites I and II in relation to sprinkler application rate and depth in feet of water applied.

quires a water application of about 10 feet.

These figures show greater leaching efficiency for the higher application rate. The greater removal of salts per unit of water applied by the higher rate is to be expected because evaporation losses are a smaller fraction at the higher rate of application, provided intake capacity is not exceeded. At site I, where surface soil and vegetation was not disturbed, no runoff from sprinkling occurred. At site II, ponding was occasionally observed after 12 hours of irrigation—this soil had a more developed clay-pan horizon than site I and its surface soil and vegetation had been disturbed during the slip-plowing operation. Runoff from the plots was not observed except from one slip-plowed plot. Evidently, the higher application rate was at about the upper limit possible for the soil at site II. Judging from our experiences with these two experiments, an upper limit for application rates probably does not exceed a tenth of an inch an hour.

## Fallow effects

There is no question that salt-affected soils such as those at sites I and II can be leached free of excesses of salts, sodium, and boron, but there is some uncertainty regarding resalinization (including boron) once the leaching operation has been stopped. The data in table 6 are particularly significant because they show $EC_e$, SAR, and B levels immediately after the leaching operation and also after a 12-months fallow. No

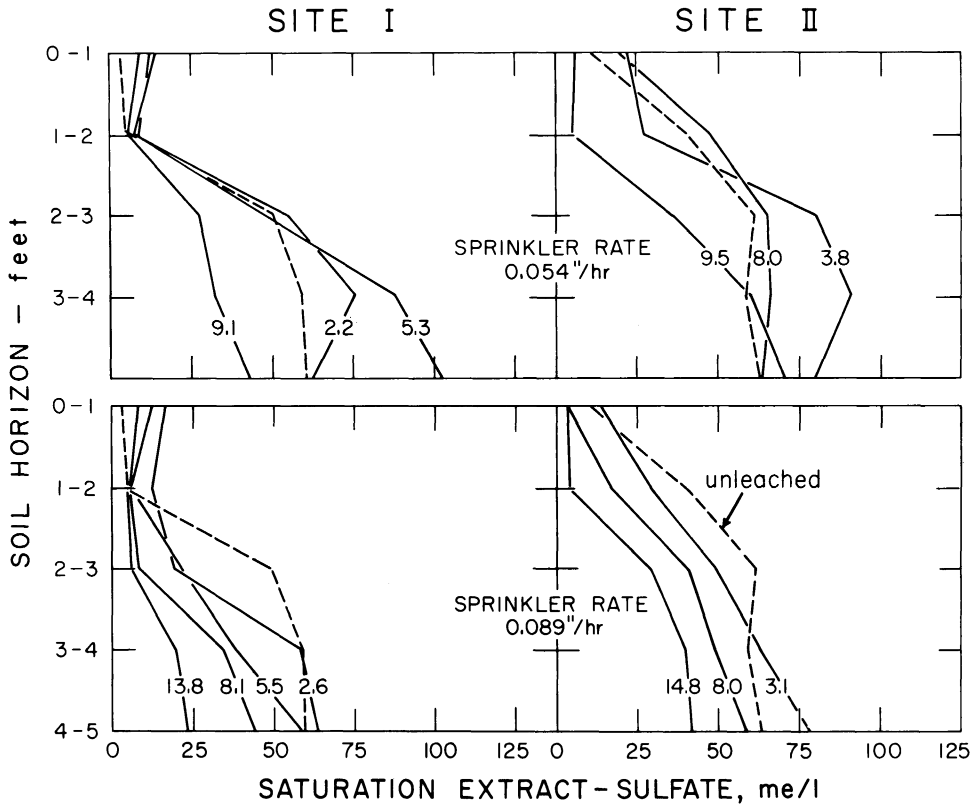


**Fig. 5.** Distribution of sulfate throughout soil profile for sites I and II in relation to sprinkler application rate and depth in feet of water applied.

build-up of consequence occurred during the fallow period. With continuous cultivation and periodic irrigations, similar results would be expected—that is, levels of $EC_e$, SAR, and B would probably continue to decrease.

## SAR-ESP relationships

Many soils have a direct relationship between SAR of the saturation extract and ESP. Although these west-side soils are calcareous, gypsiferous, clayey, and salt-affected, ESP can be predicted with a reasonable degree of accuracy from SAR data.

The SAR-ESP data for figure 10 were obtained from soil samples analyzed to determine actual ESP values and the SAR value of saturation extracts. This SAR value was used to calculate an ESP value by the procedure recommended by the staff of the United States Salinity Laboratory (1954):

$$ESP = \frac{100\ (-\ 0.0126 + 0.01475\ SAR)}{1 + (-\ 0.0126 + 0.01475\ SAR)}$$

ESP either calculated or measured agrees surprisingly well with the saturation extract SAR value shown in figure 10. This relationship is quite evident for site I.

## Soil suction relations

The extent to which a soil remains unsaturated during leaching is related to maximum leaching efficiency, and is especially important if an economic crop is to be grown during the final stages of

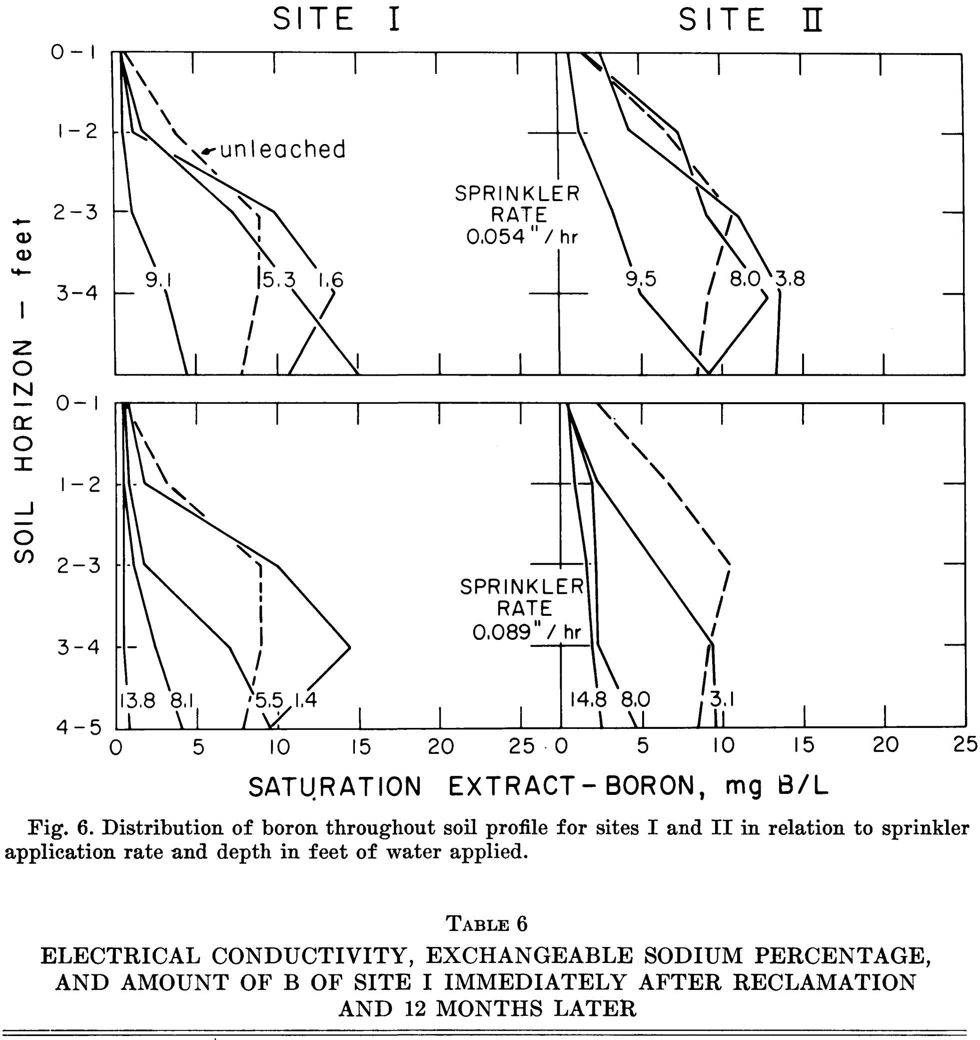


Fig. 6. Distribution of boron throughout soil profile for sites I and II in relation to sprinkler application rate and depth in feet of water applied.

TABLE 6

ELECTRICAL CONDUCTIVITY, EXCHANGEABLE SODIUM PERCENTAGE, AND AMOUNT OF B OF SITE I IMMEDIATELY AFTER RECLAMATION AND 12 MONTHS LATER

| Soil depth | Chemical analysis* | | | | | |
|---|---|---|---|---|---|---|
| | ECe | | ESP | | B | |
| | R | F | R | F | R | F |
| *feet* | *mmho/cm* | | | | *mg B/l* | |
| 0-1 | 0.8 | 1.0 | 1.5 | 2.0 | 0.4 | 0.5 |
| 1-2 | 0.7 | 0.7 | 2.7 | 2.5 | 0.4 | 0.5 |
| 2-3 | 0.9 | 0.9 | 4.1 | 5.9 | 0.5 | 0.7 |
| 3-4 | 1.8 | 2.0 | 4.5 | 4.5 | 0.6 | 0.9 |
| 4-5 | 2.1 | 2.5 | 4.9 | 2.2 | 0.8 | 1.0 |

* R and F represent soil analysis (composite of 4 profile samples) at time of completing reclamation, and after 12 months of fallow, respectively.

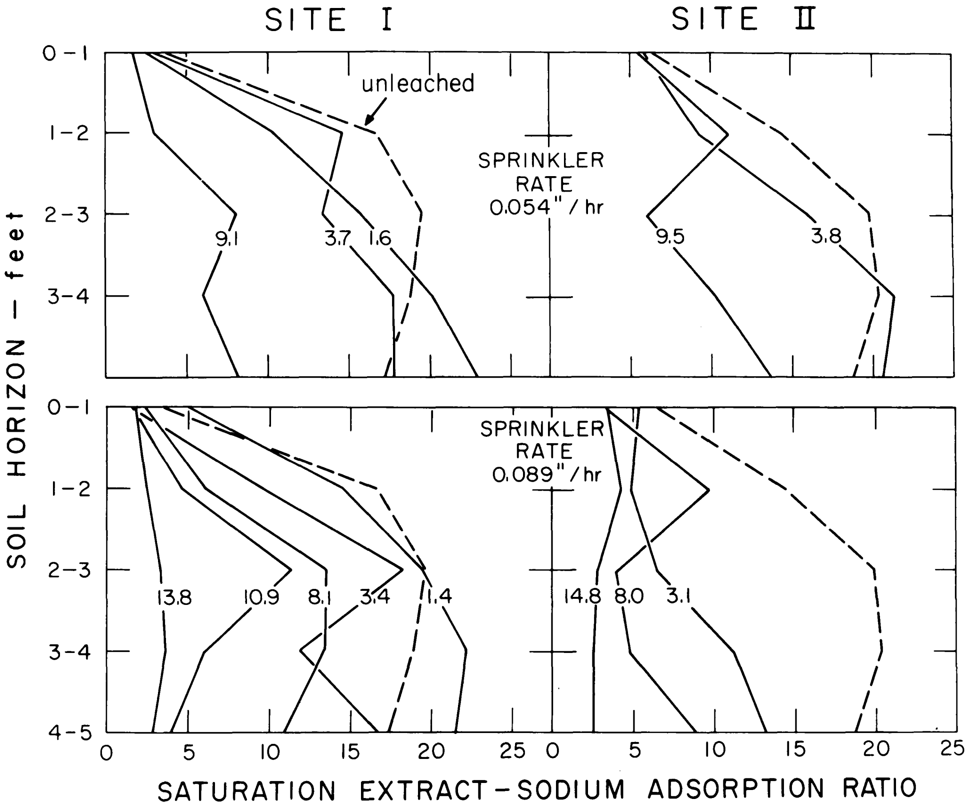


Fig. 7. Distribution of SAR values throughout soil profile for sites I and II in relation to sprinkler application rate and depth in feet of water applied.

reclamation. Tensiometers were installed (as previously described) on one of the plots of site II that received the higher application rate, and readings were taken weekly or more often when possible. Table 7 shows readings taken during a 6-week period in July and August. Because these readings are not corrected for depth, they represent negative hydraulic head with respect to the soil surface and provide information about water flow in the soil profile. Water flows toward larger numbers as indicated by the arrows in table 7. It is evident that an uninterrupted flow downward was maintained in treatment 2 where slip-plowing had opened textural layers in the profile that tended to impede water flow. Treatment 1 showed an impedance between 4 and 5 feet of depth, while treatment 3 showed an impedance generally between 3 and 4 feet. The impedance appeared to be about a foot deeper in treatment 1, possibly because of closer proximity of these tensiometers to the slip-plow slot.

Hydraulic head readings are a sensitive measure of water impedance and show it in these data even where saturation does not occur. To assess saturation in the soil, a subtraction of 3 cb per foot of depth was made from each figure in table 7; the result is a value of soil suction at the depth of measurement. Zero soil suction reveals a saturated soil; table 8 shows these data.

It is evident that saturated conditions seldom occur within the soil profile and

TABLE 7

TENSIOMETER READINGS AT SITE II

| Treatment* | Depth | July 18 | July 22 | July 23 | July 25 | July 29 | July 31 | Aug. 1 | Aug. 5 | Aug. 8 | Aug. 14 | Aug. 20 | Aug. 22 | Aug. 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tensiometer readings on various dates† | | | | | | | | | | | | |
| | | centibars | | | | | | | | | | | | |
| | 1′ | 7 | 7 | 6 | 7 | 17 | 12 | 5 | 5 | 11 | 5 | 6 | 12 | 20 |
| | 2′ | 9 | 7 | 9 | 7 | 16 | 15 | 12 | 10 | 11 | 6 | 9 | 12 | 17 |
| 1 | 3′ | 14 | 14 | 16 | 16 | 20 | 20 | 20 | 20 | 18 | 15 | 14 | 15 | 19 |
| | 4′ | 18 | 17 | 17 | 17 | 21 | 22 | 21 | 17 | 18 | 18 | 16 | 19 | 23 |
| | 5′ | 9 | 18 | 18 | 18 | 20 | 20 | 19 | 21 | 18 | 18 | 16 | 15 | 20 |
| | 1′ | 2 | 2 | 2 | 2 | 15 | 2 | 2 | 4 | 8 | 4 | 4 | 8 | 2 |
| | 2′ | 8 | 8 | 8 | 9 | 14 | 12 | 6 | 5 | 10 | 6 | 8 | 12 | 18 |
| 2 | 3′ | 14 | 14 | 14 | 13 | 18 | 17 | 11 | 12 | 16 | 12 | 12 | 17 | 22 |
| | 4′ | 16 | 14 | 14 | 15 | 20 | 21 | 20 | 17 | 17 | 14 | 15 | 18 | 22 |
| | 5′ | 0 | 15 | 16 | 18 | 23 | 22 | 22 | 20 | 20 | 19 | 16 | 19 | 22 |
| | 1′ | 8 | 1 | 7 | 6 | 20 | 9 | 4 | 5 | 13 | 6 | 8 | 15 | 51 |
| | 2′ | 15 | 11 | 11 | 10 | 18 | 19 | 11 | 10 | 15 | 10 | 10 | 14 | 21 |
| 3 | 3′ | 31 | 8 | 18 | 16 | 22 | 23 | 22 | 15 | 18 | 17 | 15 | 18 | 24 |
| | 4′ | 0 | 0 | 18 | 16 | 20 | 21 | 21 | 14 | 17 | 18 | 12 | 16 | 22 |
| | 5′ | 27 | 21 | 21 | 18 | 20 | 20 | 20 | 19 | 16 | 17 | 13 | 13 | 18 |

*Treatment 1: tensiometers located in area between slip-plow slots; treatment 2: tensiometers located in middle of slip-plow slot; treatment 3: tensiometers located in undisturbed native area.

†Vacuum gauge readings; not corrected for depth.

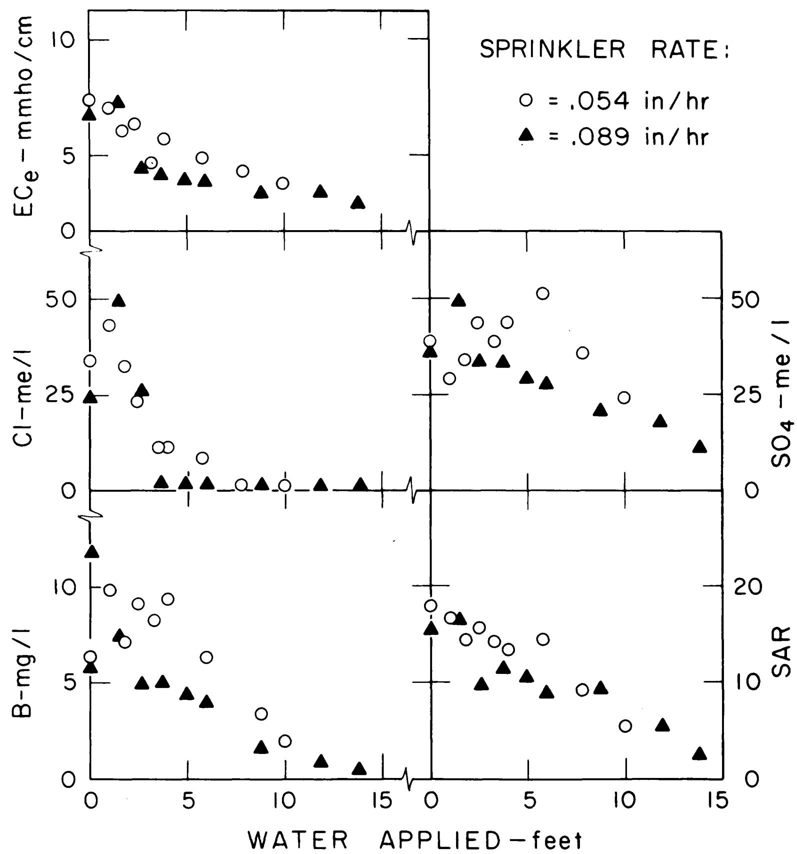


Fig. 8. Distribution of ECe, Cl, $SO_4$, B, and SAR throughout soil profile at site I in relation to depth of water applied at two rates.

TABLE 8

SOIL SUCTION AT THE TENSIOMETER CUP

| Treatment | Depth | Soil suction measured on various dates | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | July | | | | | | August | | | | | | |
| | | 18 | 22 | 23 | 25 | 29 | 31 | 1 | 5 | 8 | 14 | 20 | 22 | 28 |
| | | *centibars* | | | | | | | | | | | | |
| | 1′ | 4 | 4 | 3 | 4 | 14 | 9 | 2 | 2 | 8 | 2 | 3 | 9 | 27 |
| | 2′ | 3 | 1 | 3 | 1 | 10 | 9 | 6 | 4 | 5 | 0 | 3 | 6 | 11 |
| 1.................. | 3′ | 5 | 5 | 6 | 6 | 11 | 11 | 11 | 11 | 9 | 6 | 5 | 6 | 10 |
| | 4′ | 6 | 5 | 5 | 5 | 9 | 10 | 9 | 5 | 6 | 6 | 4 | 7 | 11 |
| | 5′ | 0 | 3 | 3 | 3 | 5 | 5 | 4 | 6 | 3 | 3 | 1 | 0 | 5 |
| | 1′ | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 1 | 5 | 1 | 1 | 5 | 0 |
| | 2′ | 2 | 2 | 2 | 3 | 8 | 6 | 0 | 0 | 4 | 0 | 2 | 6 | 12 |
| 2.................. | 3′ | 5 | 5 | 5 | 4 | 9 | 8 | 2 | 3 | 7 | 3 | 3 | 8 | 13 |
| | 4′ | 4 | 2 | 2 | 3 | 8 | 9 | 8 | 5 | 5 | 2 | 3 | 6 | 10 |
| | 5′ | — | 0 | 1 | 3 | 8 | 7 | 7 | 5 | 5 | 4 | 1 | 4 | 7 |
| | 1′ | 5 | 0 | 4 | 3 | 17 | 6 | 1 | 2 | 10 | 3 | 5 | 12 | 48 |
| | 2′ | 9 | 5 | 5 | 4 | 12 | 13 | 5 | 4 | 9 | 4 | 4 | 8 | 15 |
| 3.................. | 3′ | 22 | 0 | 9 | 7 | 13 | 14 | 13 | 6 | 9 | 8 | 6 | 9 | 15 |
| | 4′ | — | — | 6 | 4 | 8 | 9 | 9 | 2 | 5 | 6 | 0 | 4 | 10 |
| | 5′ | 12 | 6 | 6 | 3 | 5 | 5 | 5 | 4 | 1 | 2 | 0 | 0 | 3 |

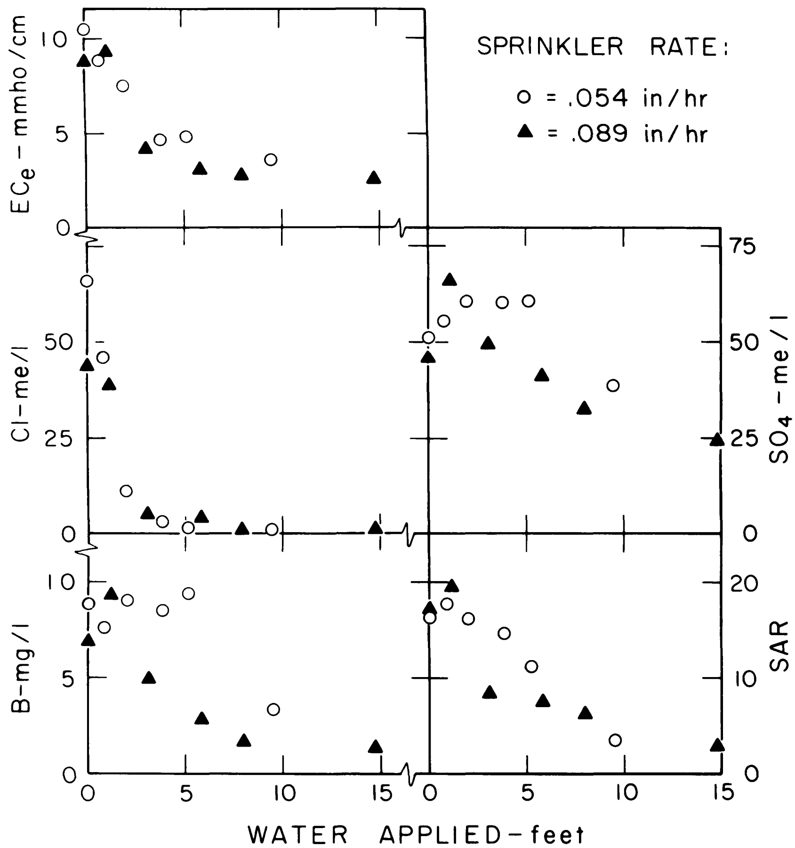


Fig. 9. Distribution of ECe, Cl, $SO_4$, B, and SAR throughout soil profile at site II in relation to depth of water applied at two rates.

economic crops probably could have been grown during this operation. An exception occurs in the surface foot of the slip-plow treatment, and to a minor degree in the second foot. This is the treatment that had the least impedance in the lower part of the profile, but the disturbance in the upper part by the slip-plow operation apparently had adverse effects on the soil structure and destroyed roots of native vegetation. Under the higher rate of sprinkling the soil in this condition puddled and retarded downward flow of water.

## DISCUSSION AND CONCLUSION

Although reclamation studies with saline-alkali soils have been carried out by many investigators, most of the studies did not include measurements of water used during leaching operations. Usually, the emphasis was placed on the role of various amendments. The study by Reeve *et al.* (1948) on reclamation of a saline-alkali soil in the Delta area of Utah contains observations on depth of water used. Amemiya *et al.* (1956) also reported water use for reclamation of a soil in western Utah. Both studies indicated that reclamation was possible with about 6 feet of water.

Perhaps the Reeves *et al.* (1955) pub-

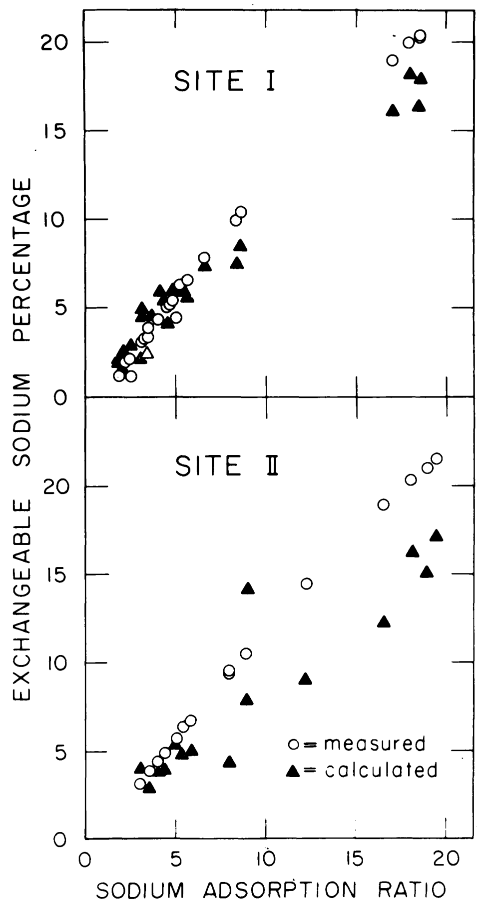


Fig. 10. ESP (calculated and measured) as a function of SAR value of saturation extract of soil samples from sites I and II.

lication on leaching a salt-effected, high boron soil in Coachella Valley is most pertinent to the present investigation. However, Reeves *et al.* used a basin-irrigation technique which differs markedly from irrigation with low-volume sprinklers. They concluded that reduction of $EC_e$ to safe levels was possible by leaching 12 inches of water per foot of soil; boron removal required about three times more water. Actually, these requirements are very similar to those observed in the present investigation. More recently, Meyer and Ayers (1968) reported a successful reduction of boron in almond orchard soil by leaching with about 2 feet of water. They also compared the boron-leaching effiiciencies, of flood and sprinkler techniques. No differences were noted—reclamation was primarily a question of depth of water applied. This conclusion appears to be identical to that for the west-side experiments.

Admittedly, 10 to 12 feet of water represents a substantial part of land development costs for the west-side area. Perhaps an alternative approach could be to cultivate shallow rooted, relatively tolerant crops for the first few seasons. Continuous cropping and irrigation would result in a progressive decrease in

$EC_e$, SAR, and B levels to levels safe for tree crops, at which time orchards could be set out.

Another possibility is to reclaim only the surface two feet or so, and then to set out trees. Leaching would be continued by irrigating frequently with a low-volume sprinkler system designed to wet the immediate area of the tree, perhaps out to 5 feet from the trunk—the irrigation distribution pattern could then be gradually expanded.

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## LITERATURE CITED

Amemiya, M., C. W. Robinson, and E. W. Cowley
1956. Reclamation of a saline-alkali soil in the upper Colorado River basin. Soil Sci. Soc. Amer. Proc. 30:423–26.

Bernstein, L.
1965. Salt tolerance of fruit crops. U.S.D.A. Inf. Bul. **292.**
1967. Quantitative assessment of irrigation water quality. Special Tech. Publ. No. **416**, Amer. Soc. for Testing and Materials 51–65.

Bingham, F. T., L. B. Fenn, and J. J. Oertli
1968. A sandculture study of chloride toxicity to mature avocado trees. Soil Sci. Soc. Amer. Proc. **32:**249–52.

Bingham, F. T., R. J. Arkley, N. T. Coleman, and G. R. Bradford
1970. Characteristics of high boron soils in western Kern County. Hilgardia **40**(7) :193–204.

Bingham, F. T., and M. J. Garber
1970. Zonal salinization of the root system with NaCl and boron in relation to growth and water uptake of corn plants. Soil Sci. Soc. Amer. Proc. **34:**122–26.

Chapman, H. D., and P. F. Pratt
1961. Methods of Analysis for Soils, Plants, and Waters. University of California, Division of Agricultural Sciences.

Committee, College of Agriculture and Environmental Sciences
1968*a*. Agricultural development of new lands, west side of San Joaquin Valley, lands, crops, and economics. Report No. **1** [multilith]. University of California, Davis.
1968*b*. Agricultural development of new lands, west side of San Joaquin Valley, lands, crops, and economics. Report No. **2** [multilith]. University of California, Davis.

Day, P. R.
1956. Report of the committee on physical analyses, 1954–55. Soil Sci. Soc. Amer. Proc. **20:** 167–69.

Fenn, L. B., J. J. Oertli, and F. T. Bingham
1970. Specific chloride injury in *Persea americana*. Soil Sci. Soc. Amer. Proc. **34:**617–20.

McNeal, B. L., D. A. Layfield, W. A. Norvell, and J. D. Rhoades
1968. Factors influencing hydraulic conductivity of soils in the presence of mixed-salt solutions. Soil Sci. Soc. Amer. Proc. **32**:187–90.

Meyer, J. L., and R. S. Ayers
1968. Boron leaching. Calif. Agr. **22**(9):6.

Reeve, R. C., L. E. Allison, and D. F. Peterson, Jr.
1948. Reclamation of saline-alkali soils by leaching—Delta area, Utah. Utah State University, Agr. Exp. Sta. Bul. **335.**

Reeve, R. C., A. F. Pillsbury, and L. V. Wilcox
1955. Reclamation of a saline and high boron soil in the Coachella Valley of California. Hilgardia **24**:69–91.

Robinson, F. E., and J. N. Luthin
1968. Slip-plowing in non-stratified clay. Calif. Agr. **22**(11):8–9.

Staff, United States Salinity Laboratory
1954. Diagnosis and improvement of saline and alkali soils. U.S.D.A. Handbook **60.**

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