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Developing the Resource Potential of a Shallow Water Table

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# DEVELOPING THE RESOURCE POTENTIAL OF A
# SHALLOW WATER TABLE

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TECHNICAL COMPLETION REPORT

April 1984

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# TECHNICAL COMPLETION REPORT

April 1984

PROJECT TITLE: Developing the resource potential of a shallow water table.

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## ABSTRACT

Observations and estimates indicate that shallow water table encroachment affects increasingly large areas of agriculturally productive land in the central and western San Joaquin Valley. With current management techniques, the present drain and disposal facilities are inadequate to effectively handle the water volume that moves through soils and becomes a part of the shallow water system. In the presence of active plant roots, soil water is depleted in upper profile zones with the establishment of a potential gradient sufficient to effect upward capillary water movement in the presence of a shallow water table. A three-year study was done to evaluate the resource potential of shallow-perched water tables as a resource to meet crop evapotranspiration (ET) requirements.

Using water-budget and chloride-tracer techniques independently to measure shallow water table contributions to crop ET revealed that as much as 50 to 60 percent of crop ET could be met by the shallow water table. The amount of water contributed by the shallow water table was strongly

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conditioned by water table salinity and depth to the shallow water. Study results show the need for a total management system approach for effective utilization of the resource potential of shallow water tables in contrast to specific entities considered in isolation.

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Additional index words: Evapotranspiration, Water budget, Irrigation scheduling, Soil and water salinity, Plant water status.

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Irrigation and slowly permeable subsurface layers have resulted in substantial agricultural land with perched or shallow water tables in the west and low lying regions of the central San Joaquin Valley. As much as 100,000 hectares have a water table in or near the crop root zone. With continued encroachment as much as 400,000 hectares may require control of shallow water tables by the year 2000 (Water Conservation in California, 1976).

Subsurface drain installation is the traditional way to handle such problems and construction of a valley-wide master drain to convey drainage water out of the valley is recommended for the future. No such facility exists at present, and current drain water disposal practices consist of discharge into surface water channels and evaporation ponds. Quality of the shallow water varies considerably from place to place. However, large areas within the region have shallow water tables with a quality sufficiently good to have considerable agricultural resource value.

In the presence of active plant roots, water is depleted from the upper zones of the profile and a potential gradient is established that results in upward movement of water from a shallow water table. The magnitude of the capillary rise component represents the water resource that can be used conjunctively with irrigation to meet crop water requirements.

As water moves into the root zone and is evapotranspired by plants, dissolved solids present in the water are redeposited in the soil profile. Using this management technique requires close observation to maintain a salt balance consistent with maintaining high productivity.

Using the shallow water table as a crop production resource has several advantages that include reduced irrigation needs, lower production costs, use of potential drainage water without a drain and delivery system, moderation of water added to the shallow water table through deep percolation, and minimizing the quantity of salinized drain water requiring eventual disposal. The objective of this study was to determine the potential magnitude of the seasonal contribution of a shallow water table to the seasonal evapotranspiration of a crop consistent with maintaining acceptable salinity and/or toxic ion levels in the soil profile. Specific consideration was directed to determining the influence of: 1) in situ soil properties, especially those affecting water retention and conductance, 2) depth and quality of the shallow water table, and 3) rooting properties of the crops studies.

## LITERATURE REVIEW

Upper soil profile drying, in the presence of active plant roots and a shallow water table, develops a water potential gradient that allows water to move upward in the soil profile and be taken up by plant roots. This movement from a water table into an active plant root zone is recognized as an important resource in agriculture (Chaudhary et al., 1974; Follett et al., 1974; Hoorn, 1958; Wallender et al., 1979). However, successful use of a shallow water table depends on several factors that include: water table depth, the water retaining and transmitting properties of the soil, evapotranspiration demand, the distribution of the plant root system, and considerations for salinity and toxic ion effects. A main effect of a shallow water table on plant growth relates to soil aeration. Reduced aeration, associated with a very shallow water table, restricts root growth and the soil volume available for nutrient supply (Criddle and Kalisvaart, 1967; Hoorn, 1958; Meek et al., 1980). Conversely, a small amount of water would be expected from a relatively deep system where only a few roots reach the upper capillary fringe.

Subirrigation has been used in different climatic regimes of the world because of the benefit of capillary rise of water from a shallow water table. A system of controlled drainage to regulate water table depth as a subirrigation practice is used in certain areas of the Great Lakes states and in Florida (Criddle and Kalisvaart, 1967; Stuff and Dale, 1978). Subsurface irrigation is used successfully, although soil salinization is a potential hazard where excess salts are present in the soil and/or irrigation water (Campbell et al., 1960). Similarly, subirrigation is used extensively (about 65,000 ha) in peat soils of the Sacramento-San Joaquin Delta of California (Criddle and Kalisvaart, 1967).

Some quantitative _in situ_ measurements of shallow water table contributions are available. The contribution of a perched water table (WT) to the evapotranspiration (ET) demand of cotton was evaluated by Wallender et al. (1979) in field studies conducted in the San Joaquin Valley, California. A measured ET contribution of 36 cm represented about 60% of the total-season ET for cotton. Kite and Hanson (1984), working with irrigation scheduling of cotton (_Gossypium hirsutum_ L.) under saline high water tables, showed an average contribution of 22 percent of the crop ET derived from shallow ground water. Pressure chamber measurements of leaf water potential were useful for scheduling irrigation for cotton in the presence of a saline shallow water table. The additive effects of soil salinity and soil matric potential make this plant-based technique a useful alternative for irrigation scheduling under these conditions (Grimes and El Zik, 1982).

Stuff and Dale (1978) developed a water budget model for soils having shallow water tables in Indiana. Capillary rise past a 105 cm root zone boundary was estimated as the difference between estimated evapotranspiration (ET) and changes in soil moisture under corn (Zea mays L.). An average of 27 percent of the corn ET was supplied by capillary water in periods having little or no rainfall.

Though quantitative measurements of WT contributions to crop ET are somewhat limited, numerous reports show the beneficial effects of shallow water tables to crop production. For example, Campbell et al. (1960) found that alfalfa (Medicago sativa L.) produced nearly as much forage under arid conditions without irrigation as with 6 irrigations per year when the water table was 152 to 274 cm below the soil surface of a clay loam soil. However, soils either not irrigated or irrigated only once during the growing season experienced a pronounced salinization at depths below 75 cm.

On sandy soils, maximum yields of corn, sugar beet (Beta vulgaris L.) and alfalfa were obtained in the presence of a shallow water table without irrigation by Follett et al. (1974). Yields were consistently improved, relative to those without a water table, over a two-year period when the water table was as shallow as 69 cm early in the growing season. As initial depth to the water table increased to 193 cm, irrigation increased production of all crops with corn and sugar beets responding at an intermediate water table depth.

Chaudhary et al. (1974) showed that ground water of low salinity at a 60 to 90 cm depth can be an asset to wheat (Triticum aestivuum L.) production. When the salinity of ground water was high, a pronounced reduction in yield occurred and they found it necessary to maintain the water tables below 150 cm. It was also indicated that excess water must be drained from the root zone within three days of soil submergence to prevent yield losses. Henderson et al. (1968), working with the organic soils of the California Delta, found sugar beets to respond to higher moisture levels from sprinkling when the water table was 90 to 120 cm below the surface. This response phenomenon was due in part to an interaction with nutrition.

Water retaining and transmitting properties of the soil and the relative distribution of roots with depth form the main features of water uptake patterns (Gardner, 1964). van't Woudt (1956), in a study on the efficiency of subirrigation in heavy soils, observed that the rate of water extraction by roots tends to exceed moisture replenishment from the water table due to slow capillary movement. The rate of water movement to absorbing root surfaces further declined as the soil moisture content was depleted by the roots. Even with this situation, however, a substantial amount of water can be derived from a water table where active roots penetrate to close proximity. Stewart et al. (1980) studied the effect of depth of water table on growth of subterranean clover. The weights of the above-ground parts increased with an increase in the depth to water table. However, root growth was severely affected by very shallow water tables. The greatest root density with all treatments occurred at a height above the water table at which plant intake and upward movement of water from the water table were in equilibrium.

From studies on water conduction from shallow water tables for six soils of variable texture, Moore (1939) found that the texture of the soil affects the permeability by its influence on the size, number, and continuity of the interspaces. Massaud (1964) studied the effect of soil properties on the extent of capillary rise above the water table in a controlled environment. The upward moisture flow from the water table, as determined by chloride movement, was most closely related to the capillary conductivity of the soil, a parameter controlled primarily by the soil pore size distribution.

Mass transport of salts present in the capillary rise of perched water can result in substantial accumulation in the presence of active roots and limited leaching. Because of the potential for rapid salinization of soil, crop growth may suffer despite adequate moisture availability and aeration (Bingham and Garber, 1970).

Studies made on the effect of salts on plant growth have supported different concepts. The vertical distribution of salinity in a soil profile will vary over time in the presence of a shallow water table. In an extensive literature review on salt tolerance, Maas and Hoffman (1977) observed that salt tolerance data were frequently derived from field plot studies where salinity was maintained uniform with depth by irrigating with different saline waters at high leaching fractions. They also reported that crops in general tolerate salinity up to a threshold level above which yields decline approximately linearly as salt concentration increases. Best estimates of the threshold salinity level and yield decrease per unit salinity increase were presented for a large number of agricultural crops.

Shalhavet and Bernstein (1968) observed that plants respond to the mean salinity level of the root zone. As the salinity of the exposed zone increased, water uptake from the low salinity zone increased. Bingham and Garver (1970) and Lunin and Gallatin (1965) found that as much as two thirds of the plant root zone could be exposed to highly saline water with little effect on plant growth. However, Bernstein and Francois (1973) observed alfalfa to respond primarily to a weighted-mean salinity based on the amount of water absorbed at a given depth zone.

A greater reduction in the yield of wheat was found with shallow water tables, compared with deep water tables, as salinity of ground water increased in a study conducted by Chaudhary et al. (1974). Their results indicate that a critical depth of ground water for optimum crop production would vary in relation to its salinity.

Recently, Thomas (1980) studied the osmotic and specific ion effects due to salinity on the growth and ionic composition of cotton. Total soil water suction (TSWS), osmotic suction of the root zone (OS), plant height, and leaf mineral composition were periodically determined. The results showed that cotton stem elongation decreases with increasing TSWS, stopping completely as TSWS approached 12 bars. Growth suppression was found to be due to specific nutritional effects in addition to an osmotically induced water deficit.

The available literature reveals that the extent of capillary rise from a water table and its rate are governed by soil and plant factors, evapotranspiration demand, water table depth, and salinity characteristics. Capillary rise from saline ground water may cause salinization of the soil which affects plant growth. It is necessary to consider all aspects of a system when assessing the contribution of shallow water tables to crop ET requirements and salinity hazards associated with the conjunctive use of irrigation and capillary rise water from a shallow water table.

## MATERIALS AND METHODS

### Encroachment trends

Observation wells, to determine shallow water table depth, are maintained at one-mile intervals throughout much of the Westlands Water District in western San Joaquin Valley. This district, the largest in the state, extends from Kettleman City on the south to near Mendota as a northern boundary, a distance of approximately 62 miles. Its western boundary corresponds roughly to Interstate 5, and extends easterly about 15 miles. There are

244,175 hectares (603,350 acres) within the district. Contour maps showing depth to the shallow water table are prepared and published twice a year by the district.

The eastern boundary of the district lies near the lowest region of the valley along an east-west transect. Therefore, perched water tends to be closer to the surface at this point, generally becoming deeper in a westerly direction higher up on the alluvial fan outwash material of the coastal mountains. Because of the physiographic features and the availability of water table depth data for the district, this data base was used to assess shallow water table encroachment trends early in the study.

Prior to 1981, a planimeter was used on published maps to determine the area affected by water table depth increments of 0-1.5 m, 1.5-3.0 m, and 3-6.1 m at intervals starting in 1975. After 1981, this information was available on published maps.

A soil classification map was superimposed on the water table depth contours of April, 1980, and the area of several soil series affected by various water table increments was determined.

### Field study sites

Grower cooperators were involved in the study by selecting study locations that had site-to-site variability in soil physical and chemical properties, depth to perched or shallow water, and quality of shallow water. Four separate cooperator ranch locations were involved over the three-year (1981 through 1983) test period. All sites were untiled. Cotton (*Gossypium hirsutum* L.), alfalfa (*Medicago sativa* L.) harvested for seed, and barley (*Hordeum vulgare* L.) were grown to determine the contribution of shallow water to crop evapotranspiration. These crops were selected because of varying rooting characteristics and tolerance levels to salinity.

At each site (except for the unirrigated barley test), two irrigation intensities were replicated either three or four times to maintain statistical integrity of the tests. A T-1 treatment was designated as a "full" irrigation treatment in accord with the grower's normal irrigation practice. The T-2 treatment reduced the intensity of irrigations, but was designed to cause little or no yield loss.

Soil locations and classes of the various field locations are presented in Table 1. The Tulare soil represents the southern most location of the study. This is a valley basin soil associated with Tulare Lake bed sediments. When this soil dries, large cracks develop that are 2 to 5 cm across, and extend to depths of 30 to 60 cm. Some stratification is characteristic. The remaining four soils of Table 1 are found further north. The Merced soil is derived from mixed sedimentary and igneous rock alluvium of the basin floor. The Levis and Oxalis are basin rim soils derived from sedimentary rock alluvium at progressive higher elevations, respectively. Panoche soils, derived from sedimentary rock alluvium, occupy the highest position of the five soils on recent alluvial fans. Bulk density, textural properties, and water retention characteristics for the soils are given in Appendix Tables A, B, and C.

Table 1. Soil location, mapping units, pH, and textural properties of soils of the study sites.

| Ranch cooperator | Mapped soil class, location, and taxonomic classification | pH (0-30.5 cm) | Sand (>20 μm) | Silt (20-2 μm) | Clay (<2 μm) |
|---|---|---|---|---|---|
| Telles | Panoche loam<br>SE¼, Sec. 18, T.12S., R.12E.<br>fine-loamy, mixed (calcareous), thermic Typic Torriorthents | 7.68 | 26.8<br>(5.1)† | 37.0<br>(1.7) | 36.3<br>(3.6) |
| Pucheu | Levis silty clay<br>SE¼, Sec. 20, T.15S., R.15E.<br>fine, montmorillonitic, thermic, Typic Salorthids | 7.85 | 25.7<br>(1.6) | 32.5<br>(9.2) | 41.8<br>(9.4) |
| Gragnani | Oxalis silty clay<br>SE¼, Sec. 5, T.16S., R.15E.<br>fine, montmorillonitic, thermic Vertic Xerochrepts | 7.51 | 19.8<br>(2.0) | 40.7<br>(3.3) | 39.4<br>(3.6) |
| Stone | Merced clay loam<br>SW¼, Sec. 35, T.18S., R.19E.<br>fine, montmorillonitic, thermic Pachic Haploxerolls | 7.80 | 21.3<br>(11.8) | 28.6<br>(3.2) | 50.1<br>(14.4) |
| Newton | Tulare loam<br>NE¼, Sec. 30, T.20S., R.20E.<br>fine, montmorillonitic (calcareous), thermic Vertic Haplaquolls | 7.75 | 13.6<br>(6.5) | 36.0<br>(1.0) | 50.4<br>(6.0) |

† Numbers in parenthesis represent the standard deviation of depth intervals.

Water table contribution to crop ET

Two independent procedures were used to estimate the capillary rise (WT) component illustrated in Figure 1. The first procedure was a water budget analyses selected as a practical approach from our earlier experience with the technique (Wallender et al., 1979). The water budget relation, ET = SMD + 1W - PW + WT, was solved for WT (the water table contribution to season ET) as a function of crop ET (evapotranspiration) and SMD (soil moisture depletion). The relation was simplified by eliminating IW (irrigation water) and PW (deep percolation) parameters. This was possible by measuring SMD for a period following irrigation, after downward movement had become quite slow, to the day before the next irrigation was made.

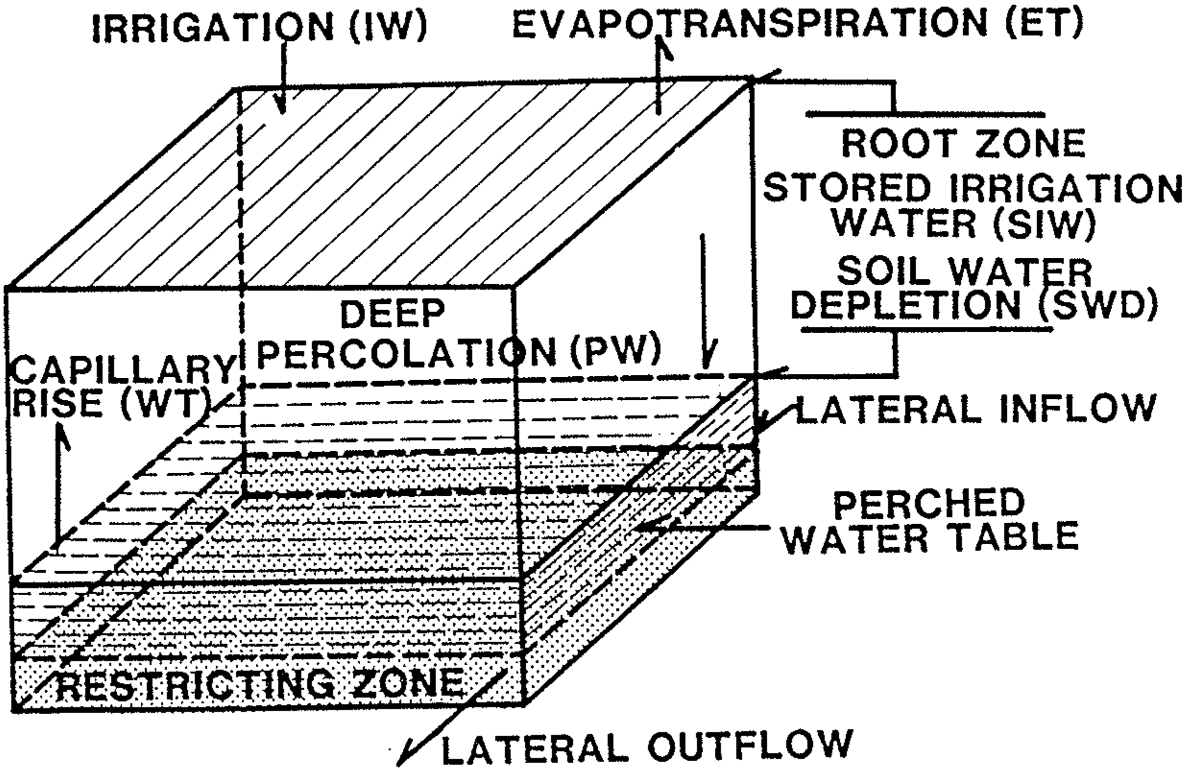

Figure 1. Components of an unconfined shallow water table in the presence of a growing crop.

Time periods unaccounted for were estimated by extrapolating average daily values of measured intervals forward and backward, each before and after measured interval to the mid-time interval of the unmeasured period. Crop ET was calculated as the product of daily estimates of potential ET from climatic stations in close proximity to the study and crop coefficients.

Typical crop coefficients (Kc) for cotton and alfalfa are illustrated, respectively, in Figures 2 and 3. Cotton Kc values represent a three-year average for a normal-early April planting at the U.C. West Side Field Station on Panoche clay loam (D.W. Grimes, unpublished data). For later

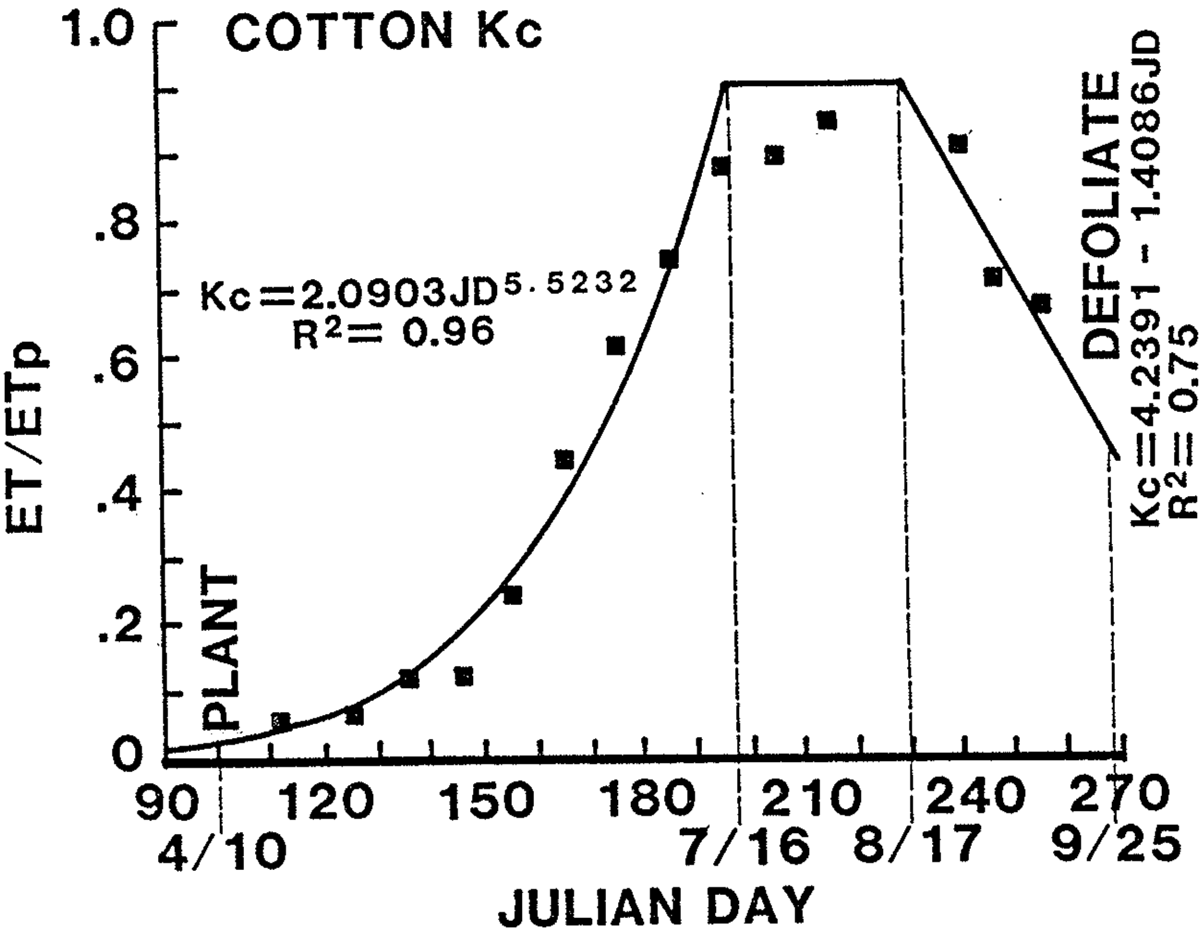

Figure 2. Crop coefficient values for cotton during the growing season in the San Joaquin Valley.

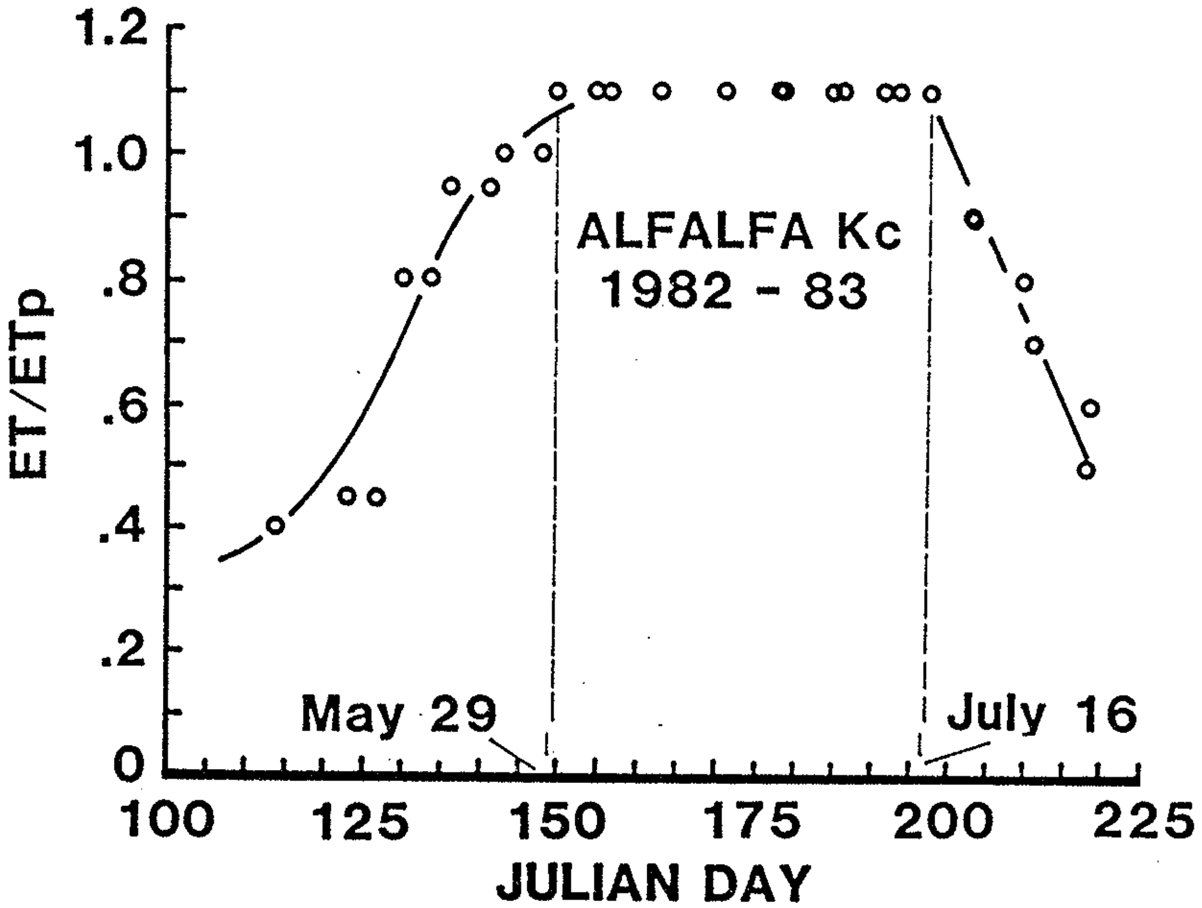

Figure 3. Crop coefficient values for seed alfalfa during the growing season in the San Joaquin Valley.

planting times, a modification was made in accordance with a procedure made available by the Fresno office of the U.S. Bureau of Reclamation. The alfalfa Kc curve was from unpublished data of D.W. Henderson. An end-of-season modification for alfalfa Kc's was made to accommodate water stress effects. The modification consisted of estimating the $ET/ET_p$ ratio just prior to dessication, and linearly exptrapolating Kc values to a time when water stress symptoms first visually appeared.

Potential ET, $ET_p$, was obtained from climatic weather stations at three different sites during the course of the study. Weather data for the Telles, Pucheu, and Gragnani ranch sites was obtained from a U.S. Bureau of Reclamation station located near Tranquility, a distance of 42, 16, and 19 km from the respective study sites. Three formulations were used at this station to predict potential ET; namely, the Jensen-Haise (Jensen and Haise, 1963) - alfalfa reference ($ET_p$), Penman (Penman, 1948) - grass reference ($ET_o$), and modified Penman (Dorrenbos and Pruitt, 1977) - alfalfa (California) reference ($ET_p$). These formulations were also used to calculate potential ET from climatic observations obtained by the USDA-ARS Water Management Laboratory weather station at the U.C. West Side Field Station. The West Side Field Station data were used to estimate crop ET for the Stone ranch location approximately 11 km away from the weather station site. In 1982, the West Side Field Station $ET_p$ was used for the Newton location (about 20 km away). However, in 1983, data were used (modified Penman) from a weather station established by the California Irrigation Management Information System (CIMIS) at the Newton site.

Soil moisture depletion was measured by volumetric water content determination made with a neutron probe at depths (30 cm increments below 30 cm) below the surface 15 cm of soil. To avoid surface effect errors with the neutron probe, volumetric water content was measured in the top 15 cm by multiplying gravimetric water content of this depth by bulk density. Two neutron probe access tube measurement sites were establised in each individual plot in close proximity to observation wells.

The mass flow of chloride present in soil water has been used successfully to trace water movement in other studies (Massaud, 1964; Richards et al., 1956; Verhoeven, 1950; Wallender et al., 1979). A second approach in this study, independent of the water budget analysis, used the chloride present in the shallow water table (Cg) to quantify WT for the growing season. The necessary information for determining $WT_d$ (cm) for each depth increment of the soil profile is initial ($C_o$) and final (C) chloride levels in meq/100 g soil, soil bulk density (BD, g $cm^{-3}$), depth of the interval (D, cm), and Cg. $WT_d$ is then calculated from:

$$WT_d = (C - C_o) \times BD \times D \times Cg^{-1} \times 1000 \text{ cm}^3 \text{ l}^{-1}$$

Average chloridometer determined Cl values were used that assume a traditional normal distribution; however, considerable evidence suggests a log-normal distribution may be more appropriate.

### Measurement sites

Two sampling and measurement sites were established in each individual plot of all locations. The sites were located approximately one-fourth of the total plot length distance from either end of the plots. At each site, neutron probe access tubes (sealed at the end to prevent water entry) and PVC-pipe water table-depth observation wells were installed. Volumetric soil water content was determined at intervals by positioning the neutron probe effective center of measurement at depths of 23, 46 and at 30.5 cm intervals thereafter to a point below the water table. The neutron probe was calibrated at each test site. Depth to water table was measured, at intervals throughout the growing season, by lowering a flexible tubing/tape-measure attachment (weighted at the end) until a bubbling noise was heard as air was blown through the tube. The observation wells also served as sampling ports to obtain water samples for analyses as the studies progressed.

Soil samples were collected, at either 15.2 or 30.5 cm-depth intervals, to a depth below the water table at the beginning and end of the growing season. Either two or three individual soil cores for depth intervals were collected, with a trailer-mounted hydraulic sampling machine, and composited for analysis. These samples were used for chloride analysis, mechanical analyses and bulk density for site characterization, and saturation extracts were obtained for $EC_e$ and specific ion analysis. Subsamples were obtained from the final sampling for root-length density analyses by the Newman (1966) procedure. In some instances, samples were collected with a Veihmeyer tube to conform to a time when maximum root length density would be expected (Grimes et al., 1975). Standard laboratory procedures were used to measure concentrations of $EC_e$, Na, Ca, Mg, and B of the saturation extracts.

### Xylem water potential

In the presence of a shallow water table, soil water measurements do not accurately reflect plant water status. To avoid excess stress in critical periods (Grimes et al., 1970), and because of the established reliability of pressure chamber measurements for cotton (Jordan, 1970) and established threshold values (Grimes and Yamada, 1982), this procedure was used for scheduling T-2 treatment irrigations of all cotton study sites.

### Cultural operations

Essentially all cultural operations, except for the scheduling of T-2 treatment irrigations, were at the discretion of the ranch cooperator. This included planting time, spraying operations, dessication of alfalfa in preparation for harvest, and harvesting operations.

For cotton, the cultivars Acala 'SJ-2' or 'SJ-5' were used at all locations (Pucheu, Telles, and Stone) and years. Planting was at a normal early-April date for the 1981 Pucheu ranch location, but was somewhat later at the Telles and Stone ranches. Planting was done April 25 and 29 for the 1982 and 1981 test years, respectively, at the Telles ranch. At the Stone ranch site, planting was done April 29 in 1982, but unseasonably cool-wet spring conditions in 1983 caused planting and

Table 2. Operational schedules for locations, crops, and years of the study.

| Location | Year | Plant | Treatment | Irrigation dates | Total no. | Defoliated/ dessication | Harvest |
|---|---|---|---|---|---|---|---|
| Cotton: | | | | | | | |
| Pucheu | 1981 | April 15 | T-1 | 6/11, 7/10, 7/27, 8/10, and 8/19 | 5 | Sept. 23 | Oct. 15 |
| | | | T-2 | 6/11, 7/15, 8/3, and 8/19 | 4 | | |
| Telles | 1981 | April 29 | T-1 | 6/8, 7/2, 7/22, and 8/6 | 4 | -- | Dec. 16 |
| | | | T-2 | 7/2, and 8/6 | 2 | | |
| Telles | 1982 | April 25 | T-1 | 6/10, 7/5, 7/21, 8/5, and 8/18 | 5 | -- | Nov. 26 |
| | | | T-2 | 6/10, 7/15, and 8/5 | 3 | | |
| Stone | 1982 | April 29 | T-1 | 5/28, 6/20, 7/20, 8/9, and 8/26 | 5 | Oct. 12 | Nov. 5 |
| | | | T-2 | 5/28, 6/20, 7/17, and 8/14 | 4 | | |
| Stone | 1983 | May 18 | T-1 | 6/23, 7/19, 8/5, 8/17, and 8/26 | 5 | -- | |
| | | | T-2 | 6/23, 7/19, 8/5, and 8/17 | 4 | | |
| Alfalfa: | | | | | | | |
| Gragnani | 1981 | -- | T-1 | 5/23, 6/25, 7/9, and 7/23 | 4 | Early-Sept. | Sept. 28 |
| | | | T-2 | 5/23, 6/25, and 7/9 | 3 | | |
| Newton | 1982 | Fall, 1981 | T-1 | 5/5, 6/9, and 7/1 | 3 | Early-Aug. | Aug. 19 |
| | | | T-2 | 5/5, and 6/17 | 2 | | |
| Newton | 1983 | Fall, 1981 | T-1 | 6/9, and 6/28 | 2 | Aug. 15 | Aug. 23 |
| | | | T-2 | 6/9, 6/24, and 7/8 | 3 | | |
| Barley: | | | | | | | |
| Stone | 1982-1983 | Nov. 1982 | - | plots not irrigated | - | -- | June 2 |

sprinkle-irrigating for emergence to be delayed until May 18. Defoliation and harvest was done at a normal time consistent with weather conditions at all sites and years.

Cotton plot size varied among locations with plot length conforming to the growers field length. This ranged from 335 m at the Stone site to 791 m at the Pucheu ranch. Plantings were in standard 1 m-wide rows at all sites with planting density within a desired range. Plot width varied from 18 m at the Pucheu site to 24 m at the Telles and Stone sites to conform to the equipment width of the grower.

All cotton tests were furrow irrigated; Table 2 gives the postplant irrigation dates. All locations were preplant irrigated sufficiently to provide some leaching fraction.

Cotton yields were measured by mechanically picking either 2 rows (Pucheu) or 4 rows (Telles and Stone) the entire plot length. Weights were determined by placing 4 individual wheel scales under cotton transportation trailers and determining weights as seed cotton from individual plots was dumped from picker to trailer. Subsamples, weighing about 2.7 kg, were collected from each plot for gin turnout determination at the USDA Cotton Research Station gin near Shafter, California. Fiber quality was determined at the fiber laboratory of that facility.

Alfalfa for seed production was grown in 1981 at the Gragnani ranch site and at the Newton ranch in 1982 and 1983; the cultivars 'Arc' and Germaine 'GS-100', respectively, were grown at the two sites. Plots at the Gragnani site were 12 m wide and 390 m long, with yields determined by machine harvesting 9 m wide strips the entire plot length. Plots were furrow irrigated at the Gragnani site.

A triangular field was used at the Newton location with harvested plot length varying from 193 m to 892 m. One m-wide rows were used at the Newton site and plots were 64 m wide; the harvested area was 14-m wide. A basin flood irrigation system was used at this location.

## RESULTS AND DISCUSSION

Using shallow or "perched" water conjunctively with surface irrigation as a resource in crop production has several advantages previously enumerated. However, a long-term approach to achieving the maximum advantage from this resource requires that consideration be given to all aspects of a total management system rather than to isolated variables treated individually. This study attempts this approach and we believe significant progress is made, but it must be recognized that much additional work remains to be accomplished.

### Water table depths and trends

Encroachment trends in the Westlands Irrigation District within the last decade are illustrated in Figure 4. Maps showing water table depth contours are published by the District twice each year, usually April and October. The late year inventory normally shows less land area affected by a water table in the 0 to 1.5 m depth range; values presented represent the early-season inventory. Higher water tables early in the year reflect winter rainfall and off-season irrigation to fully rewet the soil profile and leach accumulated salts to lower depths.

Since 1975, an additional 1.6 thousand hectares annually have a water table within six meters of the soil surface (Figure 4) with 1.1 thousand hectares of this increase reflected in a 1.5-m depth range. The magnitude of this increase is consistent with that predicted in an earlier report (Water Conservation in California, 1976).

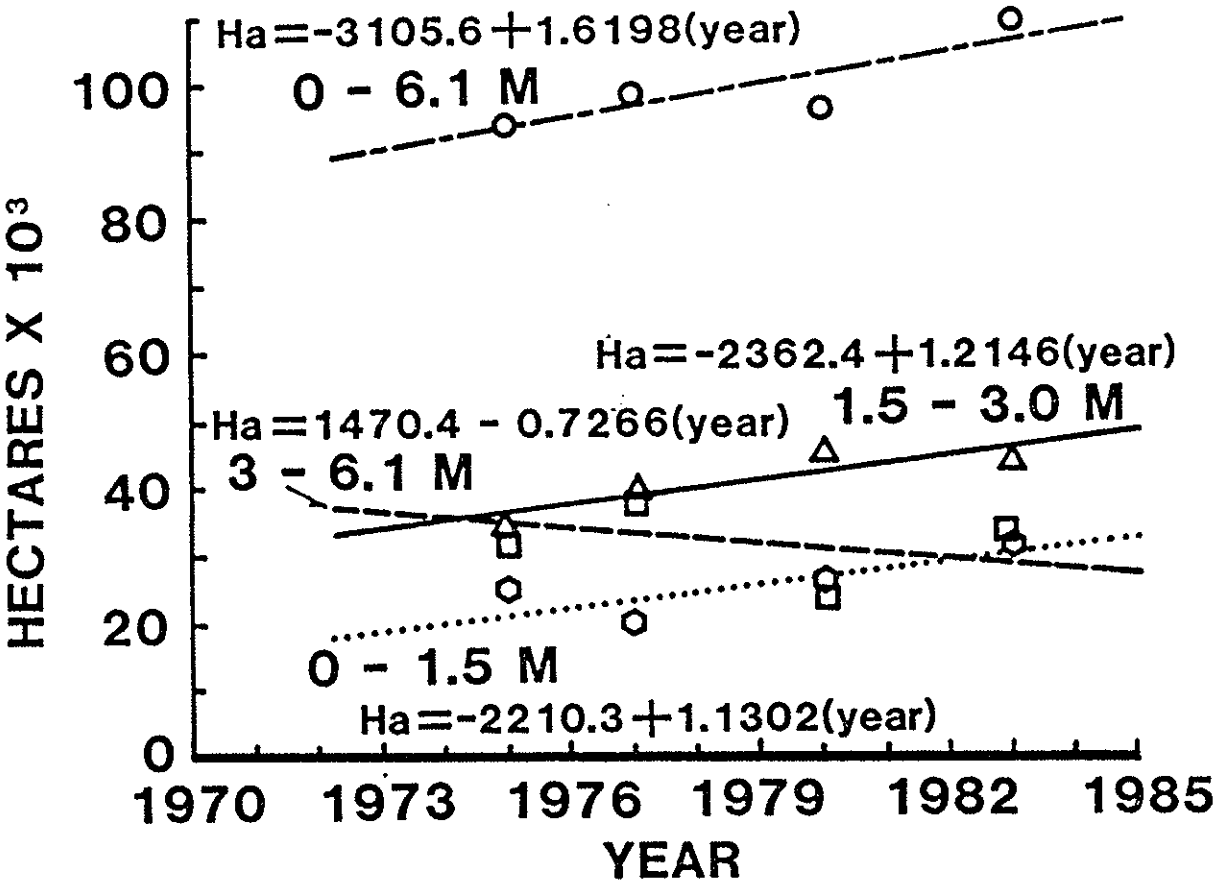

Figure 4. Land area influenced by a shallow water table at various depths for the Westlands Irrigation District data base.

To gain additional insight into the magnitude of the water table encroachment problem, a soil classification map was superimposed on the April, 1980 water table depth contour map of the Westlands Irrigation District and the areas were determined with a planimeter for various soil classes affected by a water table within 6 m of the soil surface (Table 3). As would be expected, the lowest elevation soils, occupying the basin (Merced) and basin rim (Oxalis) toposequence positions, were affected by shallow water most extensively. Though generally less productive than the Panoche

Table 3. Soil classes affected by shallow water tables in April, 1980.

| Water table[1/] depth, cm | Merced clay | Oxalis silty clay | Panoche clay loam | Panoche silty clay | Panoche loam | Panoche fine sandy loam | Panhill clay loan |
|---|---|---|---|---|---|---|---|
| | ha x $10^3$ | | | | | | |
| 0-1.52 | 0.65 | 21.86 | 1.45 | 1.16 | 0.68 | 0.54 | 0.21 |
| 1.52-3.05 | 0.35 | 29.99 | 4.67 | 4.05 | 3.40 | 2.67 | 0.35 |
| 3.05-6.10 | 0.13 | 14.33 | 3.39 | 2.37 | 2.22 | 2.42 | 0.09 |
| 0-6.10 | 1.13 | 66.18 | 9.51 | 7.57 | 6.30 | 5.63 | 0.65 |

[1/] Westlands Water District data base.

and Panhill series, these soils are cropped extensively to cotton, grain, and alfalfa. The potential crop loss through increased salinization and water table depths too shallow to manage, unless a drain system is installed, is considerable.

Water table depth trends for all locations and years of this study are shown in Figure 5A through 5D and Appendix Tables D through H. An increasing depth of water table, as the growing season progresses, is evident in all cases. The Telles (Panoche) site reflects a decrease in depth (Figure 5B) in June when the first post-plant irrigations are made. This is due to more water being added at this time than is needed to replenish that depleted through early season crop ET. With a relatively long length-of-run and furrow-water delivery system it is difficult or impossible to practically apply comparatively small amounts of irrigation water. Also, soil water intake rates tend to be much higher in early season and become progressively lower as the growing season progresses. Excess water is pulsed downward and contributes to the shallow water table. Irrigations in mid- and late-season tend to only replace crop ET water, or actually be less than soil water depletion.

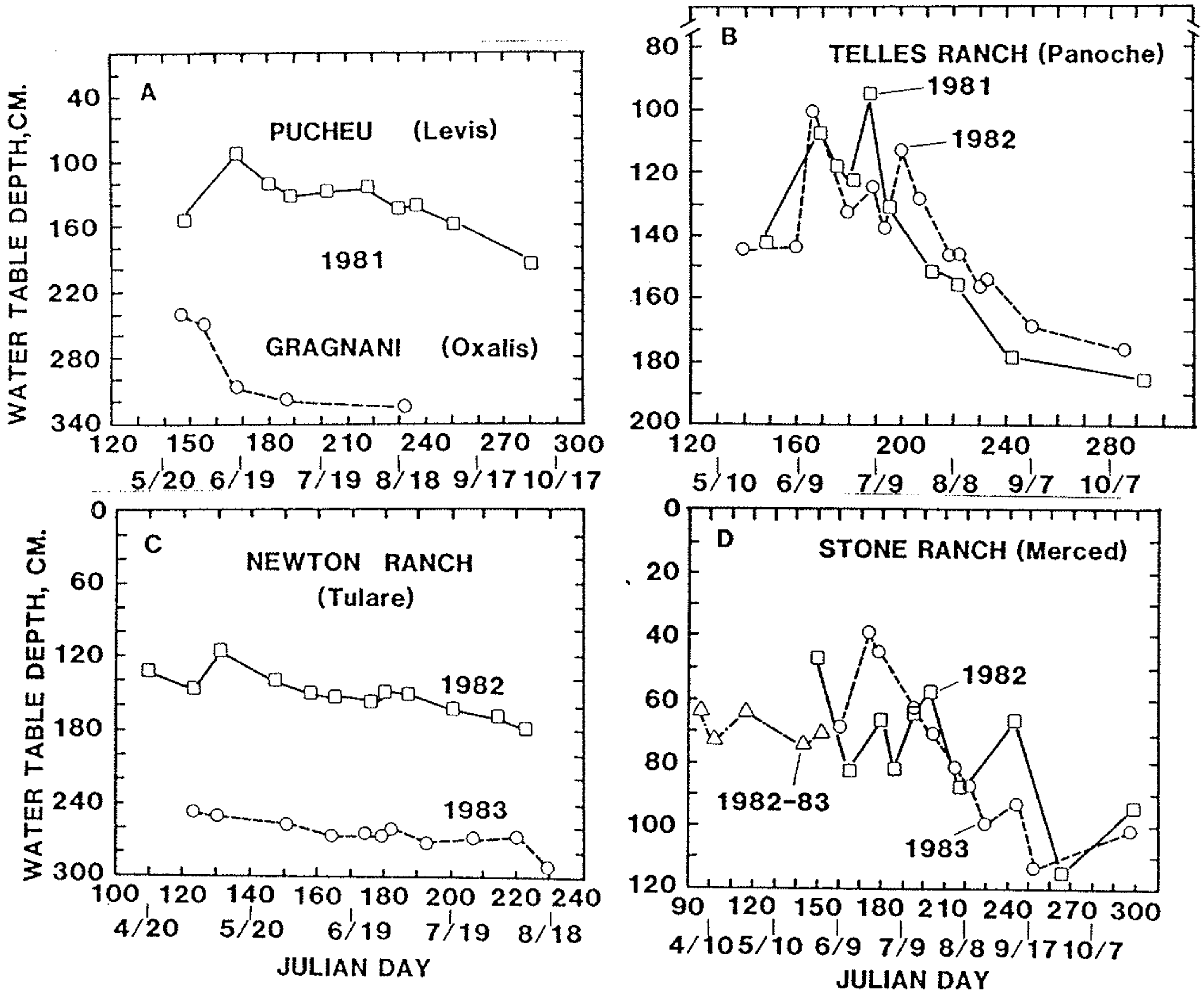

Figure 5. Seasonal changes in a shallow water table at: A) the Pucheu (Levis) cotton site and Gragnani (Oxalis) alfalfa site, B) the Telles (Panoche) cotton test, C) seed alfalfa at the Newton (Tulare) ranch, and D) cotton and barley at the Stone (Merced) site.

This trend is also evident at the Pucheu (Levis) site (Figure 5A), however, the Stone (Merced) location water was much shallower and fluctuating trend is evident throughout the growing season in 1982. The 1983 trend at the Stone site (Figure 5D) followed the more traditional decline after the early season irrigation. A fluctuating water table for the barley crop resulted from heavy winter and spring rains. Water table depths continue to decline after the last irrigation with maximum depths observed at the end of the growing season. This decline is due to a combination of lateral flow to lower water table elevations in contiguous regions and upward flow into the crop root zone and use as crop ET.

The Gragnani seed alfalfa test site (Figure 5A) shows only a declining water table with a maximum 320-cm depth observed at harvest in late August. Initial water table depth at the Newton seed alfalfa test location in 1982 (Figure 5C) was much shallower than the previous test location. The first growing season irrigation pulsed to the water table, but a generally declining trend was observed thereafter. After harvest in 1982 and through the winter and spring of 1983, limited irrigations were reflected in a continuing downward water table trend. This trend continued through the 1983 growing season with a maximum depth near 300 cm at harvest.

### Root length profiles

An understanding of the extent and density of a plant root system, as it occurs in the field, is essential for sound water management decisions. This is especially true when management includes the contribution of a shallow water table, in or near the root zone, to crop ET. Root length density profiles for cotton and alfalfa at the various study sites are presented in Figure 6 and 7.

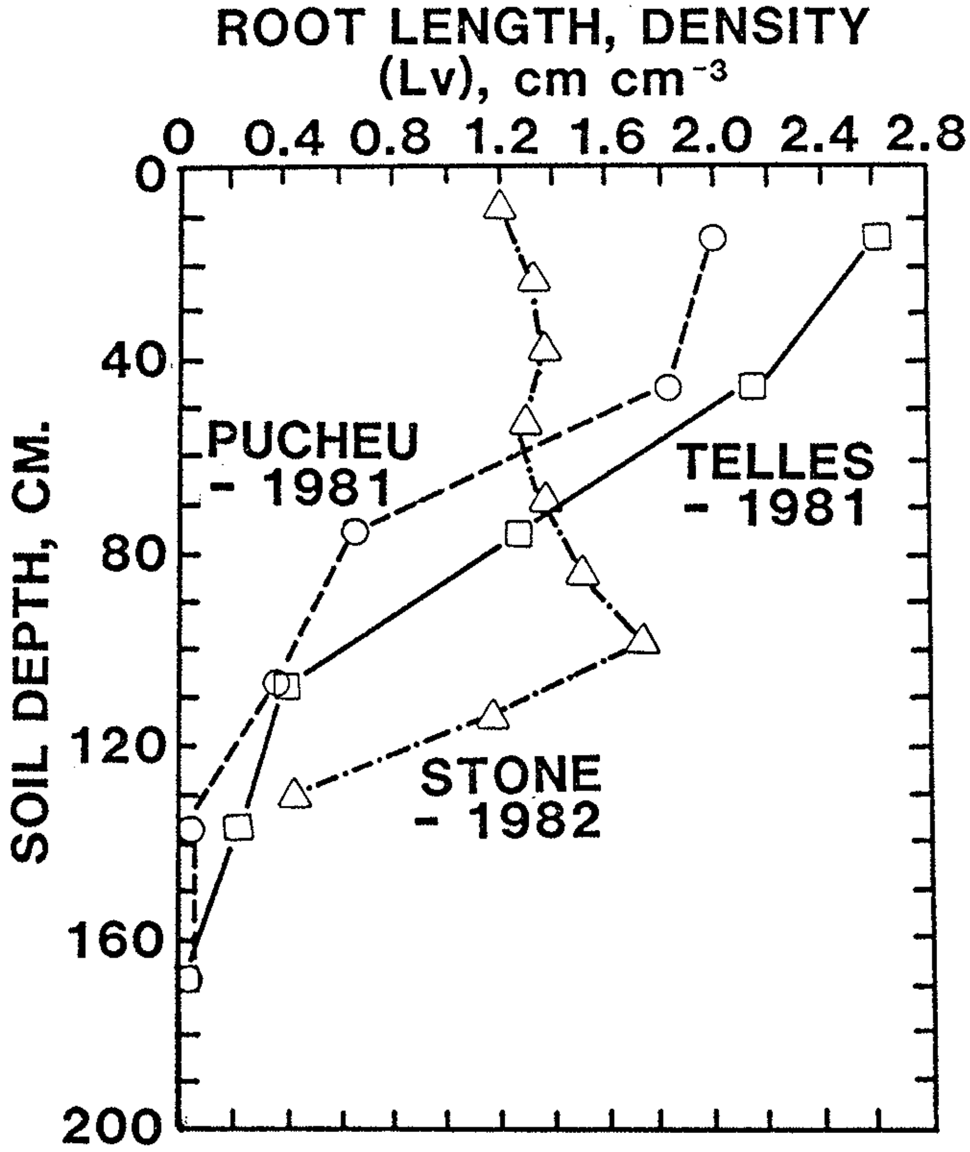

Figure 6. Cotton root length density at the Telles (Panoche), Pucheu (Levis), and Stone (Merced) locations.

Cotton root development differed at the three study locations (Figure 6) reflecting specific characteristics of each site. Cotton grown in a non-impeding soil will exhibit a root system most dense near the surface with root length density declining linearly with a few roots observed as deep as 2.5 m (Grimes et al, 1975; Grimes et al, 1982).

The Telles (Panoche) root length density profile declines with depth linearly to a depth of 110 cm with root length at this depth somewhat less than would be expected for an unimpeded expression. Appendix Table B shows soil bulk density values, at this and lower depths, to be sufficiently high to restrict root growth. An early season water table at about 100 cm may have been restrictive also. However, the water table declined to about 180 cm at season end. At any rate, the relation between root expression and water table depth at this site was adequate for a high WT contribution to crop ET.

Cotton root expression and depth to the water table during the season at the Pucheu site followed similar trends as was observed at the Telles location, but differed in that root length density was lower throughout the profile. This difference is attributed to much higher salinity levels at the Pucheu site.

The Stone (Merced) location exhibited a uniform cotton root-length-density profile to the water table depth with a marked reduction at that point. Visual examination of the samples on which root length density measurements were made revealed the presence of some roots persisting from a previous lettuce crop. This persistence is likely contributing to the apparent departure of cotton root development from the expected normal situation. Even so, cotton root development to the water table appears adequate for a substantial WT contribution to crop ET.

Alfalfa grown for a seed crop established a substantial root system throughout the soil matrix above the water table (Figure 7). At the Gragnani (Oxalis) location, root length density was at a maximum near the surface and declined linearly to the shallow water table. The fall-1981 seeding at the Newton (Tulare) test location did not establish a fully developed root system until the 1983 test year, however, with the shallower water table in 1982, the less dense root system did not appear to be a significant limiting factor. Severe cracking of the Tulare soil on drying may lead to a root continuity problem though no definitive observations of this aspect were developed in this study. Higher root-length-density values at shallow depths in 1983

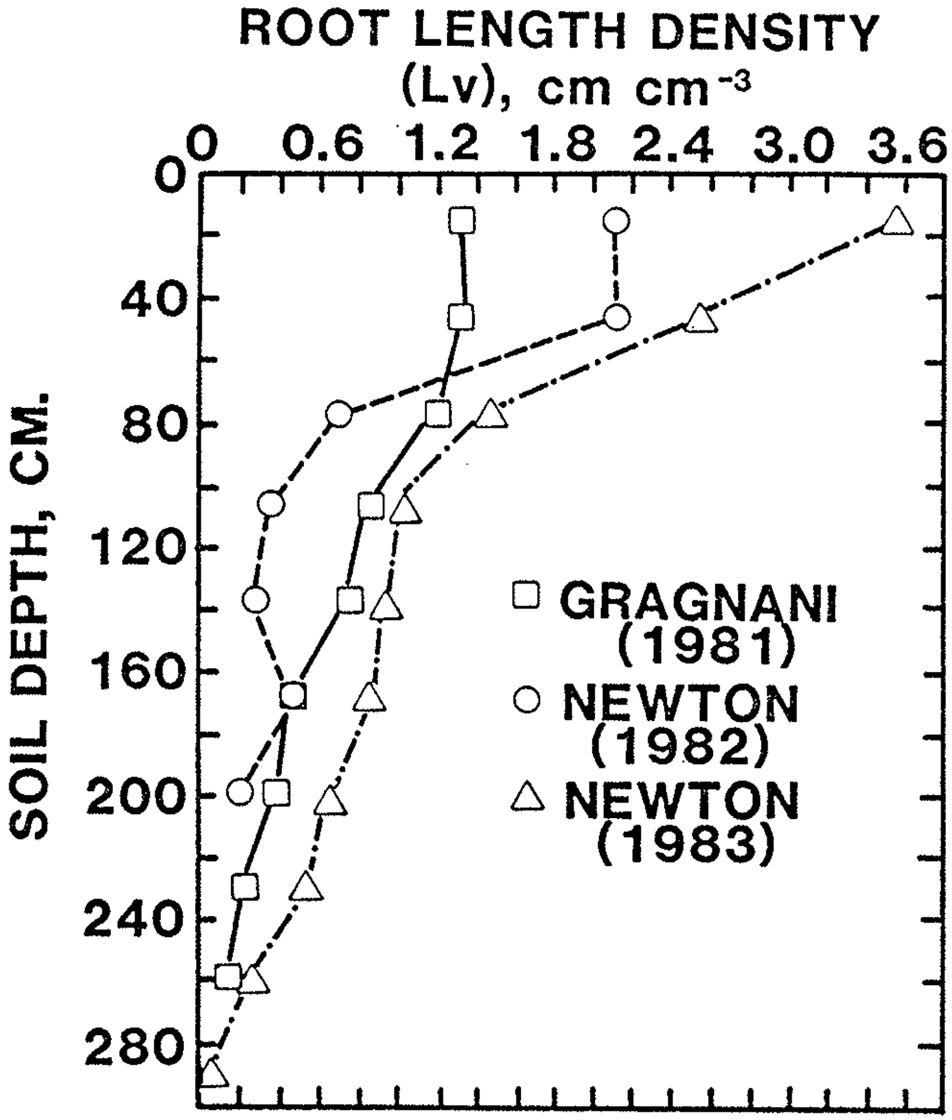

Figure 7. Alfalfa root length density at the Gragnani (Oxalis), and Newton (Tulare) study sites.

were consistent with those developed by container grown plants (Grimes et al, 1978).

Substantial differences in profile salinity were observed at the Telles and Pucheu locations. These differences were used to develop a regression model from field data to evaluate the potential restricting influence of salinity on root length density; the result is illustrated in Figure 8. The simple regression model accommodates inputs of soil depth (cm) and conductivity ($dSm^{-1}$) of the soil saturation extract ($EC_e$) and accounted for 93 percent of the variation observed in cotton root length density at the two sites. An increase of 10 $dSm^{-1}$ $EC_e$ reduced root length density by 0.34 cm $cm^{-3}$ throughout the entire profile. At lower depths, where rooting is less prolific, this reduction from increased salinity may be a substantial limitation.

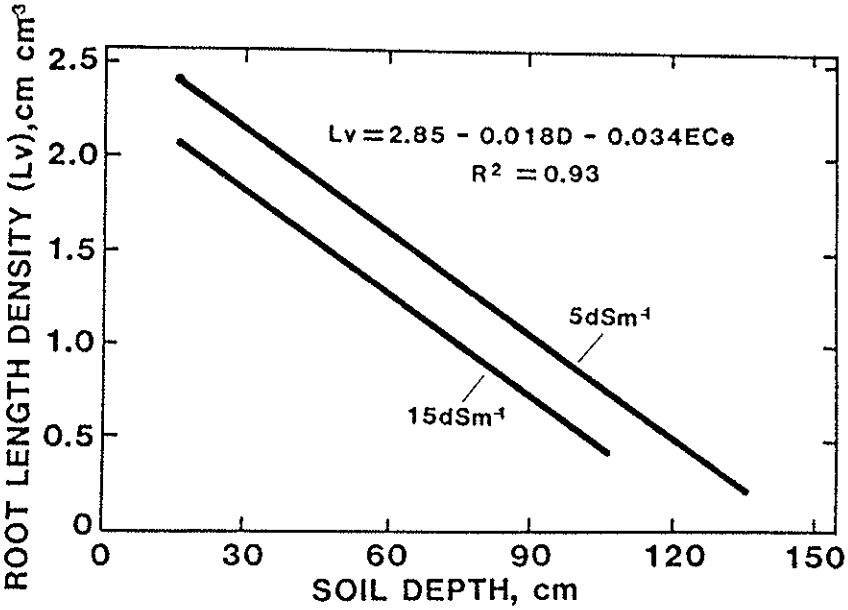

Figure 8. Salinity effects on cotton root length density.

Quality of shallow water table

Quality of the perched or shallow water is an important consideration when assessing the resource potential of this water source. Not only will the salt load present be expected to influence the magnitude of WT contribution to crop ET, but the deposition of salts upward in the soil profile must be stabilized with leaching for an effective long-term approach. Study site selection was based, in part, on obtaining a reasonable range in salt load among the various locations.

Table 4 presents water quality data for the shallow water table at all locations and years; considerable variability from site-to-site is observed. In fact, standard deviations of observed sample sites within a test location exhibit much variability as is indicated by the standard deviation of selected parameters. Of the cotton locations, Pucheu and Telles in 1981, Stone and Telles in 1982, and Stone in 1983, conductivity varies from a low of 4.97 $dSm^{-1}$ at the Telles site in 1982 to a 26.71 $dSm^{-1}$ high at the Pucheu location in 1981. Sodium, chloride, and boron levels were all quite high at the Pucheu test site. Water table conductivity at the Newton (Tulare) seed alfalfa location in 1982 was 12.7 $dSm^{-1}$ compared with a high, at the 1981 Gragnani (Oxalis) site, of 23.2 $dSm^{-1}$. The concentrations of specific ions such as sodium, chloride, and boron in the perched ground water showed similar trends. Only slight and negligible changes in ground water composition were observed as the growing season progressed.

Irrigation water analyses for the various locations are presented in Table 5. The Telles, Pucheu, and Gragnani sites were irrigated with water from the California aqueduct. Kings River water was used at the Stone and Newton sites. The salt load of these waters is low in all cases and they are ideal for maintaining, through a leaching fraction, a desired soil profile salt balance.

## Contribution of a shallow water table to crop ET (WT)

Though water tables near the surface are sometimes recognized as an asset, a comparatively small effort has been directed to quantifying the contribution of this resource to crop ET. However, several studies have demonstrated the qualitative nature of a shallow water table contribution; examples are the work of Follett et al. (1974) who modified irrigation schedules for

Table 4. Analyses of the shallow-perched water at various test locations for the three year study.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location (1981) | | | | | | | | | | | | | | |
| | Pucheu (Levis) | | | | | Telles (Panoche) | | | | | Gragnani (Oxalis) | | | | |
| | pH | EC, dSm$^{-1}$ | Na, meq/l | Cl, meq/l | B, ppm | pH | EC, dSm$^{-1}$ | Na, meq/l | Cl, meq/l | B, ppm | pH | EC, dSm$^{-1}$ | Na, meq/l | Cl, meq/l | B, ppm |
| Average | 8.0 | 26.71[1] | 342.6 | 51.1 | 25.5 | 8.0 | 5.22 | 38.1 | 24.0 | 9.1 | 7.4 | 23.20 | 131.5 | 29.3 | 5.8 |
| Standard dev. | | 9.74 | | 22.6 | | | 1.30 | | 7.7 | | | 4.52 | | 1.7 | 1.5 |
| | Location (1982) | | | | | | | | | | | | | | |
| | Stone (Merced) | | | | | Telles (Panoche) | | | | | Newton (Tulare) | | | | |
| Average | 8.0 | 8.12 | | 15.2 | | 7.8 | 4.97 | | 26.2 | | 7.9 | 12.70 | | 30.6 | |
| Standard dev. | | 2.45 | | 7.0 | | | 1.88 | | 10.4 | | | 5.08 | | 11.6 | |
| | Location (1983) | | | | | | | | | | | | | | |
| | Stone (Merced) barley | | | | | Stone (Merced) cotton | | | | | Newton (Tulare) | | | | |
| Average | 7.8 | 7.88 | | 15.6 | | 7.6 | 5.22 | | 12.2 | | 7.7 | 12.75 | | 21.8 | |
| Standard dev. | | 3.10 | | 7.4 | | | 1.82 | | 4.4 | | | 4.57 | | 8.0 | |

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[1] Values are the averages of all sample sites and from two to six sampling times during the growing season.

Table 5. Irrigation water analyses at the test locations.

| Location | pH | EC, $dSm^{-1}$ | Cl, meq/l |
|---|---|---|---|
| Telles (Panoche | 7.8 | 0.42 | 1.9 |
| Pucheu (Levis) | 7.8 | 0.37 | 2.0 |
| Gragnani (Oxalis) | 7.7 | 0.40 | 2.0 |
| Stone (Merced) | 8.0 | 0.40 | 1.7 |
| Newton (Tulare) | 7.8 | 0.28 | 0.4 |

corn, sugarbeets, and alfalfa in the presence of a water table and Chaudhary et al. (1974) who examined the effect of water table depth and salinity on wheat yields. Stuff and Dale (1978) used a water balance approach, similar to the procedure of this study, to measure the water table contribution at 27 percent of ET during periods with little or no precipitation. The capillary rise component increase with increased root zone moisture deficits and decreased with depth of the shallow water table below 100 cm. They developed an empirical model that predicted daily moisture status and changes in the corn crop root zone from inputs of pan evaporation, precipitation, soil moisture characteristics, corn silking date, and initial soil moisture conditions. Wallender et al. (1979) used chloride-tracer and water-budget techniques to estimate a capillary rise component of approximately 60 percent of the total season cotton crop ET when the water table was about 2 m below the surface. Namken et al. (1969) used a water balance approach in a series of lysimeters to measure a water table contribution as much as 60 percent of the total cotton water use.

A comparison of crop ET, determined from the three functions available for estimating potential ET at the Tranquility weather station, is made for seed alfalfa in Table 6 and for cotton in Table 7. The Jensen-Haise formulation does not contain a wind component and alfalfa crop ET is lower than that estimated by the Penman $ET_p$. The Penman $ET_o$ formulation gave slightly

Table 6. Water table contribution to the season ET of alfalfa as predicted using contrasting formulations for estimating potential ET.

| Equation type | Treatment | Crop ET,[2] cm | WT, cm | % of season ET |
|---|---|---|---|---|
| | | Gragnani (Oxalis) - 1981 | | |
| Jensen-Haise $ET_p$[1] | T-1 | 85.5 | 18.4 | 21.5 |
| | T-2 | 85.5 | 26.3 | 30.8 |
| Penman $ET_p$[1] | T-1 | 98.0 | 30.9 | 31.5 |
| | T-2 | 97.8 | 38.8 | 39.7 |
| Penman $ET_o$[1] (Historic) | T-1 | 107.6 | 40.5 | 37.6 |
| | T-2 | 107.3 | 48.3 | 45.0 |
| | | Newton (Tulare) - 1982 | | |
| Jensen-Haise $ET_p$ | T-1 | 65.0 | 9.3 | 14.3 |
| | T-2 | 65.0 | 17.7 | 27.2 |
| Penman $ET_p$ | T-1 | 71.4 | 14.7 | 20.6 |
| | T-2 | 71.4 | 22.9 | 32.1 |
| Penman $ET_o$ | T-1 | 73.5 | 16.4 | 22.3 |
| | T-2 | 73.5 | 24.8 | 33.7 |

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1/ The Jensen-Haise and Penman $ET_p$ (alfalfa cover) values were converted to $ET_o$ (grass cover) by the relation $ET_o = ET_p \times 0.85$ for the purpose of computing crop ET.

2/ Crop ET = $ET_o \times k_c$ where $k_c$ is the crop coefficient.

higher values for crop ET in 1981 at the Gragnani site (Table 6), but Penman formulations were about the same at the Newton location in 1982. Cotton crop ET, on the other hand, is essentially the same when determined with the Jensen-Haise or Penman $ET_p$ procedures (Table 7) and lower by the Penman $ET_o$ method. The different responses for cotton and alfalfa can probably be attributed to the condition that most cotton ET comes in July and August when

Table 7. Water table contribution to the season ET of cotton as predicted using contrasting formulations for estimating potential ET.

| | Treatment | Crop ET, cm | WT, cm | % of season ET |
|---|---|---|---|---|
| | | Telles (Panoche) - 1982 | | |
| Jensen-Haise $ET_p$[1/] | T-1 | 68.2 | 35.4 | 51.9 |
| | T-2 | 67.9 | 39.4 | 58.0 |
| Penman $ET_p$[1/] | T-1 | 69.5 | 37.2 | 53.5 |
| | T-2 | 70.2 | 41.9 | 59.7 |
| Penman $ET_o$[1/] | T-1 | 62.3 | 20.1 | 32.3 |
| | T-2 | 65.1 | 23.7 | 36.4 |
| | | Stone (Merced) - 1982 | | |
| Jensen-Haise $ET_p$ | T-1 | 57.2 | 15.7 | 27.4 |
| | T-2 | 60.0 | 19.5 | 32.5 |
| Penman $ET_p$ | T-1 | 62.3 | 20.1 | 32.3 |
| | T-2 | 65.1 | 23.7 | 36.4 |
| | | Stone (Merced) - 1983 | | |
| Jensen-Haise $ET_p$ | T-1 | 57.1 | 17.4 | 30.5 |
| | T-2 | 57.1 | 19.5 | 34.2 |
| Penman $ET_p$ | T-1 | 59.7 | 19.5 | 32.7 |
| | T-2 | 59.7 | 21.4 | 35.8 |

[1/] Crop ET = $ET_p$ x $k_e$ or $ET_o$ x $K_c$ where $K_c$ is the crop coefficient.

wind movement is minimal in the San Joaquin Valley. In contrast, alfalfa will use appreciable water in the spring and early summer months when wind movement is more of a determining factor. After examining these comparisons, we selected the Penman $ET_p$ procedure for presentation of alfalfa crop ET and the simpler Jensen-Haise $ET_p$ for cotton crop ET.

Water table contributions for each of the three study years are presented in Tables 8 through 10. The water-budget and chloride-tracer techniques, averaged over locations and treatments, give good agreement. In 1981 the average Wt contributions, as a percent of the season crop ET, was 33.2 by the water-budget procedure and 31.0 by the Cl-tracer method. In 1982 the same conparison was 37.1 and 42.4 percent, respectively, for the water-budget and Cl-tracer techniques.

Table 8. Water table contribution to crop ET at three locations in 1981.

| Parameter | Pucheu (Levis) T-1 | Pucheu (Levis) T-2 | Telles (Panoche) T-1 | Telles (Panoche) T-2 | Gragnani (Oxalis) T-1 | Gragnani (Oxalis) T-2 |
|---|---|---|---|---|---|---|
| | ---kg cotton lint per hectare--- | | | | Kg seed alfalfa per ha | |
| Yield | 1324a[1] | 1236b | 1502a | 1549a | 1318a | 1314a |
| | -----cm----- | | | | | |
| Crop ET | 68.0 | 68.0 | 70.3 | 70.3 | 98.0 | 97.8 |
| SWD | 51.3 | 51.9 | 45.6 | 38.9 | 67.1 | 59.0 |
| WT (water budget) | 16.7a | 16.1a | 24.7b | 31.4a | 30.9 | 38.8 |
| | -----%----- | | | | | |
| % of season ET | 24.6 | 23.7 | 35.1 | 44.7 | 31.5 | 39.7 |
| | -----cm----- | | | | | |
| WT (Cl tracer) | 14.5a | 13.0a | 31.7a | 36.3a | 19.5a | 25.3a |
| | -----%----- | | | | | |
| % of season ET | 21.3 | 19.1 | 45.1 | 51.6 | 21.3 | 27.6 |

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[1] Values for contrasting treatments at the same location not followed by the same letter differ at a 0.05 probability level according to Duncan's multiple range test.

Reducing the irrigation frequency (T-2) for cotton and alfalfa at the Telles and Gragnani locations resulted in significantly higher WT values with no loss in productivity (Table 8). One less irrigation at the Pucheu site caused a short term stress that lowered lint production by 88 kg per hectare. Water table depths at the Telles and Pucheu locations were nearly the same through the growing season, but differed in that the EC of the water table at the Pucheu site was much higher (26.7 dSm$^{-1}$) than that at the Telles location (5.22 dSm$^{-1}$).

Measured WT at the Telles and Stone cotton test sites in 1982 (Table 9) averaged 38.3 and 20.0 cm of water, respectively (56.3 and 34.0 percent). Water table depth at the Stone site (Fig. 5D) was much shallower (48 to 112 cm)

Table 9. Water table contribution to crop ET at three locations in 1982.

| Parameter | Telles (Panoche)<br>T-1 | <br>T-2 | Stone (Merced)<br>T-1 | <br>T-2 | Newton (Tulare)<br>T-1 | <br>T-2 |
|---|---|---|---|---|---|---|
| | ----kg cotton lint per hectare---- | | | | kg seed alfalfa/ha | |
| Yield | 1282a | 1196a | 1469a | 1480a | 777a | 594b |
| | ----cm---- | | | | | |
| Crop ET | 68.2 | 67.9 | 57.3 | 60.0 | 71.4 | 71.4 |
| SWD | 32.7 | 28.6 | 41.4 | 40.5 | 56.7 | 48.5 |
| WT (water budget) | 35.4b | 39.4a | 15.7 | 19.5 | 14.7a | 22.9a |
| | ----%---- | | | | | |
| % of season ET | 51.9 | 58.0 | 27.4 | 32.5 | 20.6 | 32.1 |
| | ----cm---- | | | | | |
| WT (Cl tracer) | 42.4a | 36.0a | 20.9a | 23.9a | 24.5a | 21.9a |
| | ----%---- | | | | | |
| % of season ET | 62.2 | 53.0 | 36.5 | 39.8 | 33.3 | 29.8 |

1/ Values for contrasting treatments at the same location not followed by the same letter differ at a 0.05 probability level according to Duncan's multiple range test.

and fluctuated during the season more than the Telles location (Fig. 5B). Salinity levels of the water table at the respective sites were 5.0 and 8.1 $dSm^{-1}$. Reduced irrigation frequency for cotton did not affect productivity at either location. The reduced irrigation of the T-2 treatment at the Stone site was the result of an earlier season-end irrigation cutoff.

Alfalfa at the Newton site in 1982 was the first production year following stand establishment the previous year. Seed yields were much lower than at the 1981 Gragnani site and were reduced by excessive stress imposed by the T-2 treatment. WT levels of 14.7 and 22.9 cm of water were measured for the T-1 and T-2 treatments, respectively, by the water-budget procedure and 24.5 and 21.9 cm by the Cl-tracer analysis. These values are lower than were observed the previous year at the Gragnani site even though water table depth was closer to the surface at the Newton site and EC of the Newton site water table was less. The Tulare soils at the Newton location undergo severe cracking on drying that may result in less root continuity and lower WT. WT values in 1983 (Table 10) at this location were of the same magnitude as was observed the previous year. The T-2 stress treatment lowered seed production by 14 percent in 1983, however, production levels were much more satisfactory following the first production year.

Cotton yield at the 1983 Stone location was not affected by one less irrigation (T-2) that represents an earlier irrigation cutoff than for the T-1 treatment. WT was essentially the same as observed in 1982.

The water table contribution to crop ET at various soil depth intervals by the Cl-tracer method is given in Table 11 for the 1981 sites. At the alfalfa location the greatest contribution was observed at the 213 to 244 cm-depth interval. By season end the water table had dropped to approximately

Table 10. Water table contribution to crop ET at the Stone and Newton locations in 1983.

| Parameter | Stone (Merced) (cotton) | | Stone (Merced) (barley) | Newton (Tulare) (alfalfa-seed) | |
|---|---|---|---|---|---|
| | kg per hectare | | | | |
| | T-1 | T-2 | not irrigated | T-1 | T-2 |
| Yield | 1072a | 1073a | 1184($s_x$ = 315)<br>n = 12 | 1607a | 1381b |
| | cm | | | | |
| Crop ET | 57.1 | 57.1 | 17.8 | 73.6 | 73.6 |
| SWD | 39.7 | 37.6 | 9.4 | 60.5 | 54.0 |
| WT (water budget) | 17.4 | 19.5 | 8.5 | 13.1a | 19.6a |
| | % | | | | |
| % of season ET | 30.5 | 34.3 | 47.8 | 17.8 | 26.6 |

1/ Values for contrasting treatments at the same location not followed by the same letter differ at a 0.05 probability level according to Duncan's multiple range test.

320 cm. Failure to sample to lower depths at the initial sampling precluded calculations of WT contributions at lower depths as the water table dropped later in the season. This accounts for the lower WT values by the Cl-tracer method (22.4 cm) than was determined by the water-budget technique (34.8 cm). At the Pucheu site the water table was as shallow as 90 cm following the first post-plant irrigation and declined to 190 cm at harvest. No WT was observed at the 90 - 120 cm depth interval for this saline water table and progressively higher WT values were found in increments closer to the surface. In contrast, the lower EC water table contribution at the Telles location was found at intermediate profile depths. This agrees with the observations of Wallender et al. (1979) for similar conditions.

Table 11. Water table contribution by depth intervals to crop evapotranspiration for 1981 study sites.

| Soil depth interval, cm | Gragnani (Oxalis) | | | Pucheu (Levis) | | | Telles (Panoche) | | |
|---|---|---|---|---|---|---|---|---|---|
| | T-1 | T-2 | $\bar{x}$ | T-1 | T-2 | $\bar{x}$ | T-1 | T-2 | $\bar{x}$ |
| | | | | | $WT_d$, cm | | | | |
| 0-30.5 | 1.1[1/] | 1.2 | 1.2 | 7.7 | 6.2 | 7.0 | 4.8 | 4.6 | 4.7 |
| 30.5-61.0 | 1.8 | 2.2 | 2.0 | 4.5 | 5.0 | 4.8 | 10.3 | 9.2 | 9.8 |
| 61.0-91.5 | 2.2 | 2.5 | 2.4 | 2.8 | 1.9 | 2.4 | 12.6 | 16.5 | 14.6 |
| 91.5-122.0 | 3.0 | 3.6 | 3.3 | - | - | - | 3.9 | 6.0 | 5.0 |
| 122.0-152.4 | 1.6 | 3.2 | 2.4 | | | | | | |
| 152.4-182.9 | 2.3 | 3.4 | 2.8 | | | | | | |
| 182.9-213.4 | 3.7 | 4.1 | 3.9 | | | | | | |
| 213.4-243.8 | 3.8 | 5.1 | 4.4 | | | | | | |
| $\Sigma WT_d$ = | 19.5 | 25.3 | 22.4 | 15.0 | 13.1 | 14.2 | 31.6 | 36.3 | 34.1 |

[1/] Each value is the average of eight analyses sites.

Cumulative WT levels as the season progressed were a direct reflection of cumulative ET curves for cotton in 1981 and 1982 (Figure 9). A general sigmoidal trend illustrates reduced ET rates in early and late season with maximum water use in July and August. In contrast, canopy development and water use by alfalfa occurs more rapidly in late spring and early summer. This is reflected in a linear cumulative WT function for the 1982 seed alfalfa crop (Figure 10). A declining water table at the site reduced the WT contribution in late season 1983 and an asymptotic cumulative WT function resulted.

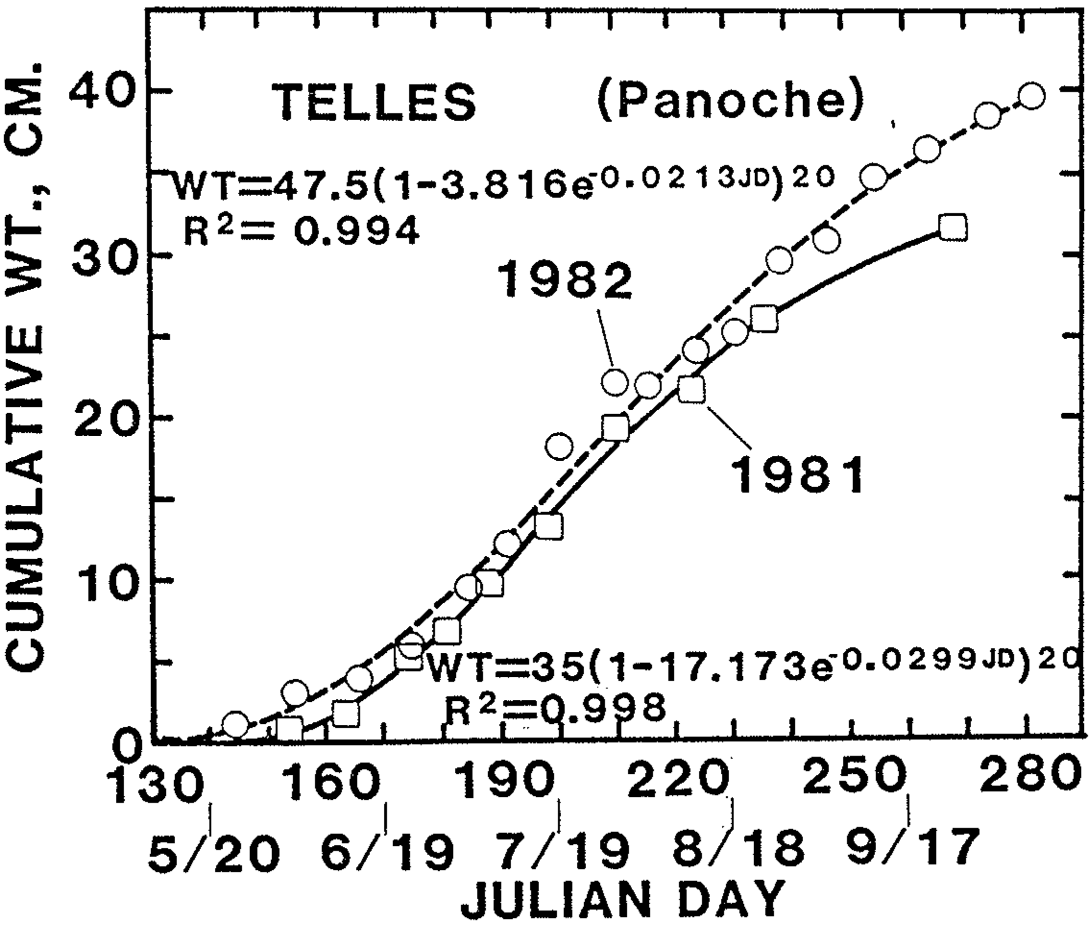

Figure 9. Cumulative water table contributions to cotton ET over a two year period.

An examination of WT season amounts show that the contribution is affected to a large degree by salinity level and depth of the water table. To gain additional insight of this relationship, WT values were converted to percent of total season crop ET for all crops, locations, years, and treatments of the three year study. The somewhat anomalous barley data were excluded. A multiple regression analysis was performed on the resulting 16 observations with water table depth and conductivity serving as independent parameters. A squared transformation of independent parameters was included as was an interaction term. The resulting empirical model accounted for almost 80 percent of the variation in WT values.

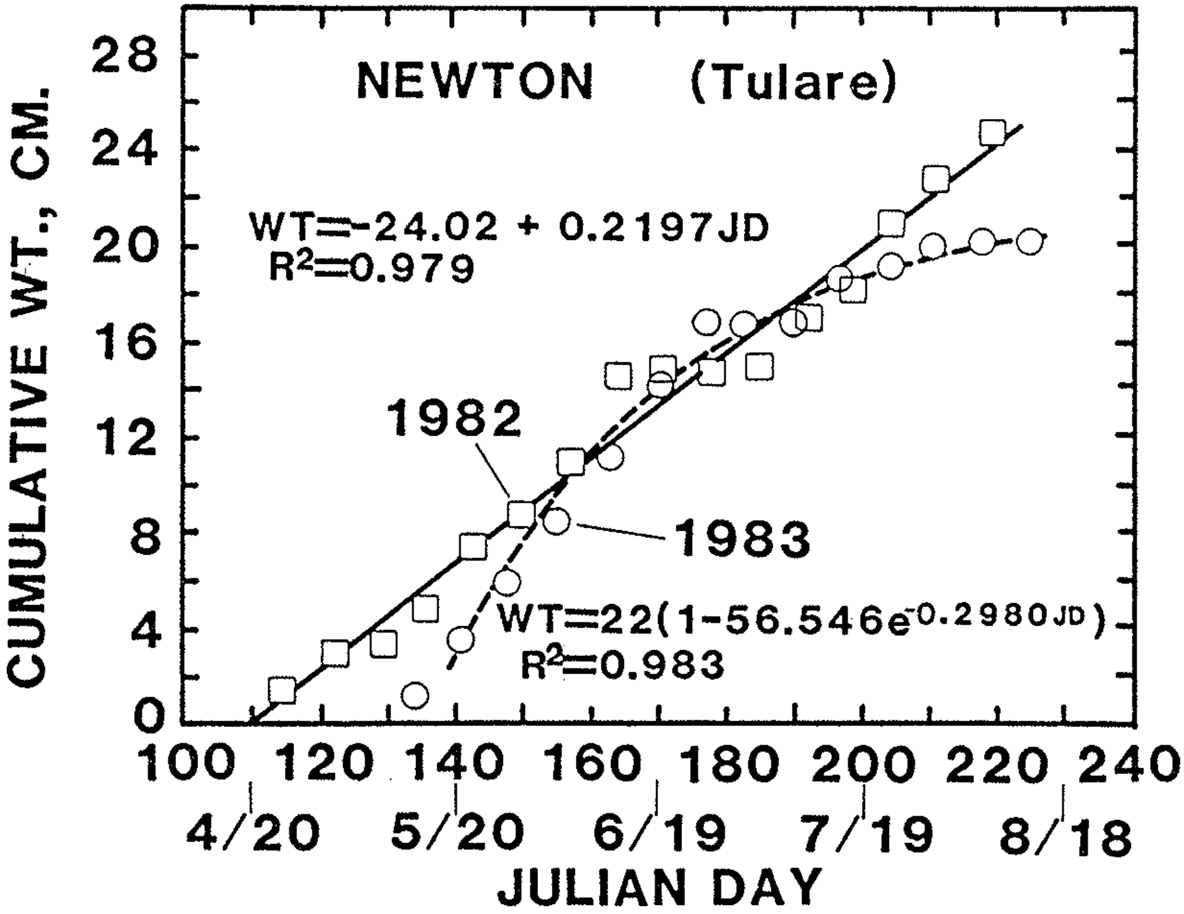

Figure 10. Cumulative water table contributions to seed alfalfa ET over a two year period.

Partial regression coefficients, t values, and a graphic plot are given in Figure 11. WT was reduced substantially by increased salinity. A maximum WT resulted with intermediate water table depths indicating detrimental effects of reduced aeration and effective root development volume with shallow water tables and limitations imposed by root length density - capillary conductivity relations with deeper water tables. The salinity-depth interaction resulted in a maximum WT observed at increasing profile depths as water table salinity increased.

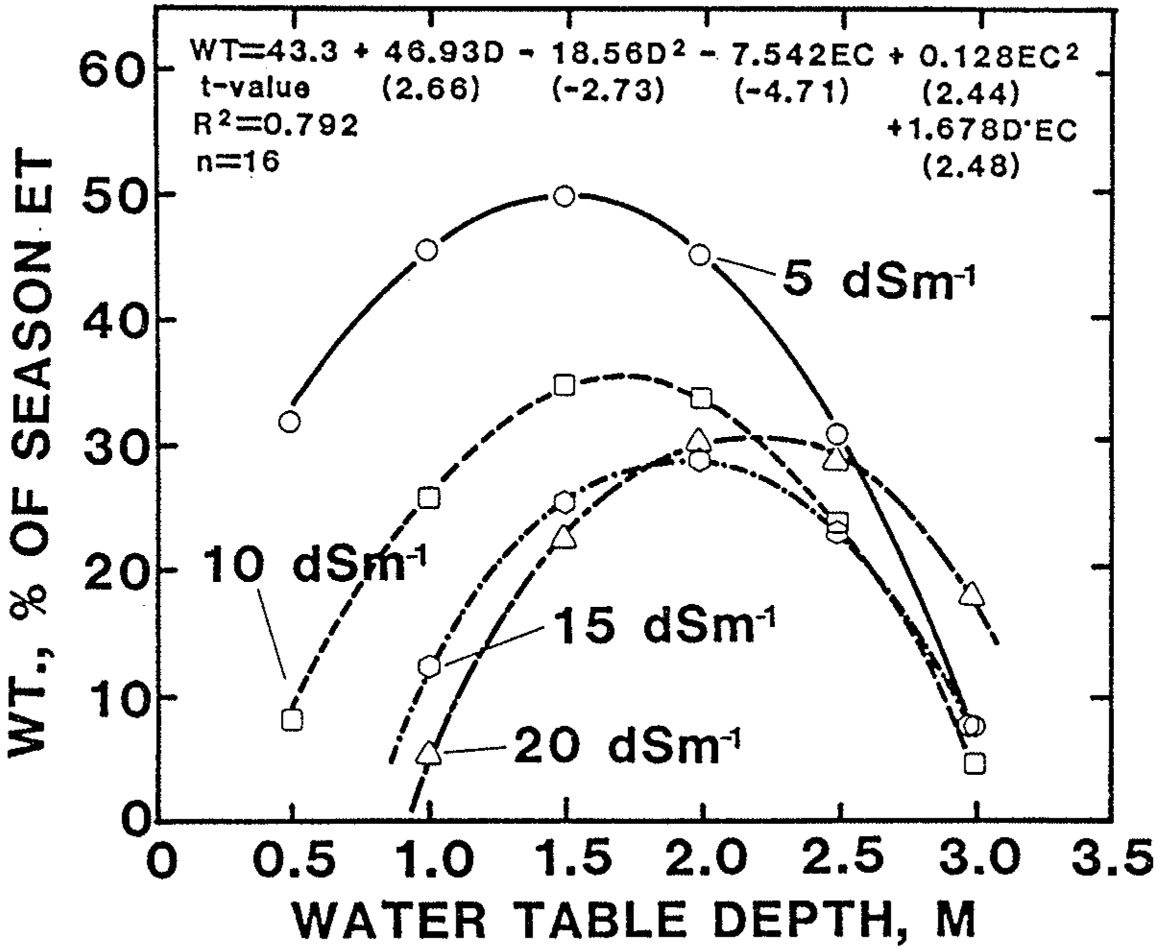

Figure 11. Regression model characterizing the water table contribution to crop ET as a function of water table depth and salinity level.

## Soil Salinity

Dissolved solids present in the shallow ground water move by mass flow upward in the soil profile and accumulate as ET progresses. Because of the potential for rapid salinization, crop growth may suffer even though soil moisture and aeration would otherwise be adequate (Bingham and Garber, 1970). Management of soil salinity becomes an important consideration when maximum use of a shallow water table is made for meeting crop ET requirements.

Seasonal changes in soil salinity profiles were observed at all study sites. Two year observations were possible with cotton at the Telles location (1981-1982) and seed alfalfa at the Newton site (1982-1983). The soil profile salt load was considerably greater at the end of the 1981 cotton growing season than at planting time (Figure 12); an expected result since close to half the season crop ET was derived from the shallow ground water. Winter rains and a heavy preplant irrigation before the 1982 crop served to reduce $EC_e$ values at all profile depths beck to the spring 1981 levels. Higher salinity levels were again observed after harvest in 1982 when utilization of the shallow water table to meet crop ET requirements was high during the growing season.

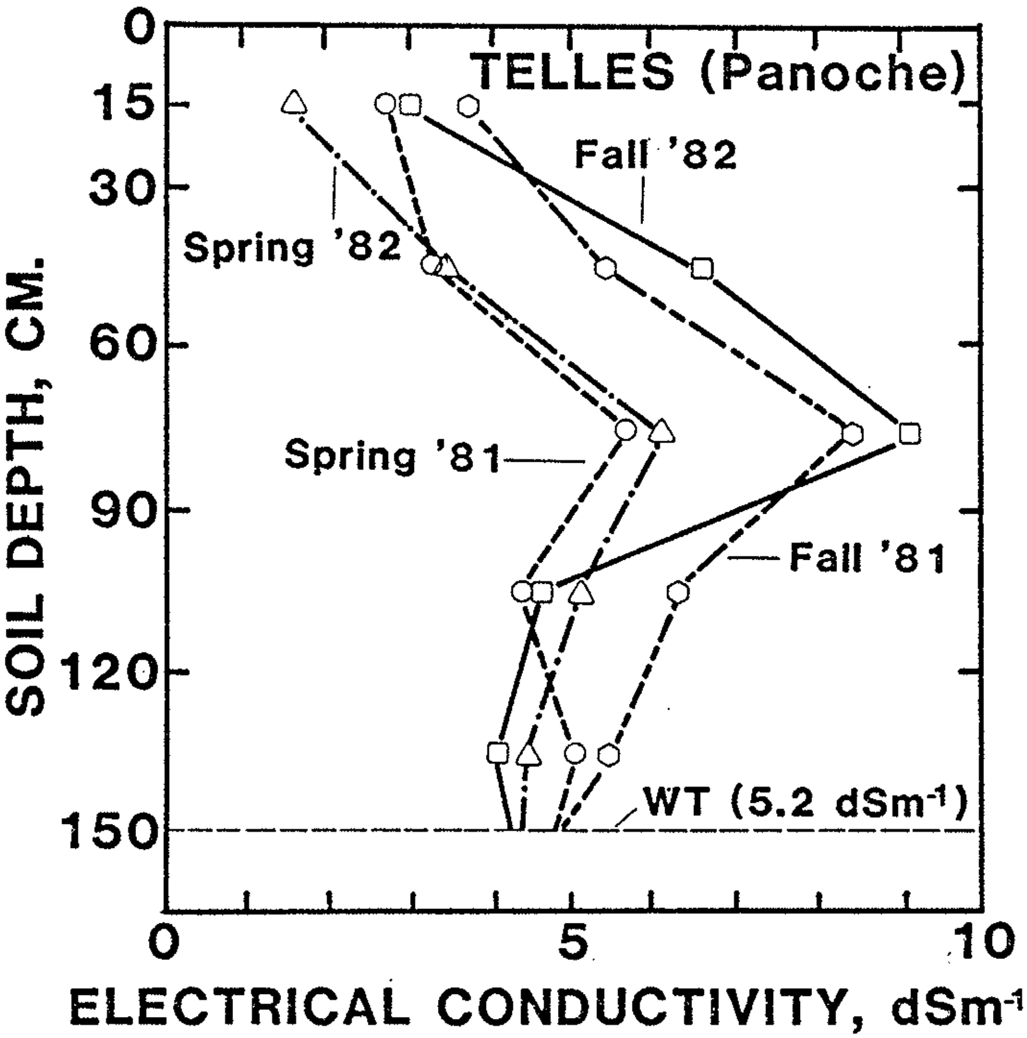

Figure 12. Salinity changes in the profile of the Telles cotton location over a two year period.

Overall profile salinity at the Newton seed alfalfa location (Figure 13) was higher than the Stone cotton site because of the more saline shallow water table. Conductivity of the saturation extract is essentially at the same level as the water table at both sites for approximately 50 percent of the soil profile immediately above the water table, but decreases rapidly closer to the surface reflecting low conductivity irrigation waters. Alfalfa site $EC_e$'s increased, above the lower spring 1982 level, by harvest in mid-August. No leaching irrigation was made prior to the beginning of the spring 1983

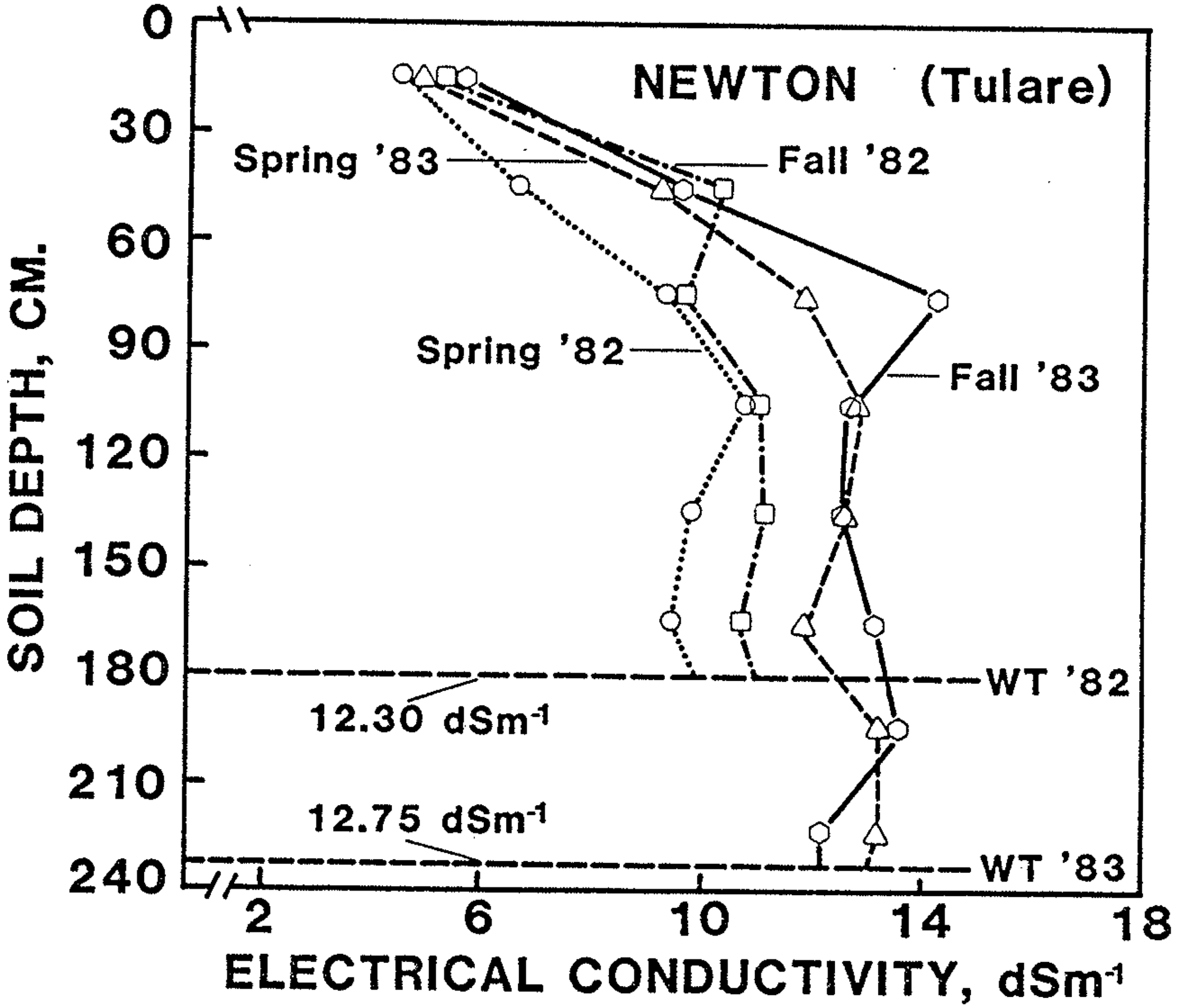

Figure 13. Salinity changes in the profile of the Newton seed alfalfa location over a two year period.

sampling and $EC_e$ values continued to increase. Irrigations during the 1983 growing season essentially replaced soil water depletion by the crop and profile salinity continued to increase until the final sampling in mid-August, 1983. This continued increase in $EC_e$ illustrates that sufficient water must be applied during some phase of the management pattern to keep salinity from building to yield limiting levels.

Table 12 illustrates a somewhat similar pattern over a cotton-barley cropping sequence at the Stone location. Rainfall amounts during the winter were abnormally heavy, and no irrigation was done during the barley growing season. Somewhat stable values are shown from fall to winter, but $EC_e$ values continued to increase during the spring and were highest following barley harvest. With this relatively shallow water table, $EC_e$ values throughout the profile were near that of the water table.

Contrasting soil salinity profiles for the Pucheu and Telles cotton sites are given in Table 13. Average salinity of the soil profile at the Pucheu site was close to three times that of the Telles location and

Table 12. Changes in soil salinity ($dSm^{-1}$) at Stone location (1982-83) during the growth of cotton and barley crops.

| Depth (cm) | Cotton | | Barley | |
|---|---|---|---|---|
| | Spring '82 | Fall '82 | Winter '83 | Summer '83 |
| | $dSm^{-1}$ | | | |
| 0-30.5 | 7.11 | 8.02 | 7.14 | 8.70 |
| 30.5-61.0 | 6.88 | 9.49 | 8.33 | 10.53 |
| 61.0-91.4 | 7.23 | 7.84 | 7.84 | 8.89 |
| 91.4-122.0 | 7.08 | 7.24 | 7.55 | 7.84 |

Table 13. Salinity ($EC_e$), osmotic suction (OS), and total soil water suction (TSWS) of the root zone at two cotton sites.

| SOIL DEPTH (cm) | TELLES | | | PUCHEU | | |
|---|---|---|---|---|---|---|
| | $EC_e$ | O.S.[1] | TSWS[2] | $EC_e$ | O.S. | TSWS |
| | $dSm^{-1}$ | ----bars---- | | $dSm^{-1}$ | ----bars----- | |
| 0 - 30.5 | 2.74 | 1.54 | 1.87 | 4.17 | 4.67 | 9.67 |
| 30.5 - 61.0 | 3.33 | 1.78 | 2.11 | 8.49 | 5.65 | 6.15 |
| 61.0 - 91.4 | 5.71 | 2.80 | 3.13 | 11.90 | 10.77 | 13.77 |
| 91.4 - 122.0 | 4.35 | 2.21 | 2.54 | 14.06 | 12.60 | 13.60 |
| 122.0 - 152.4 | 5.13 | 2.45 | 2.78 | 15.16 | 16.25 | 19.25 |

1/ OS = $W_s/W_f$ x 0.371 ($EC_e$ x $10^3$) where $W_s$ is soil water content at saturation and $W_f$ is the measured water content of the field soil.

2/ TSWS = O.S. + M.S. where MS is matric suction.

production averaged 245 kg of lint per ha less than at the Telles test site. This most probably was due to a higher salinity component. Osmotic and total soil water suctions were calculated by the technique presented by Thomas (1980), and are given in Table 13. A higher osmotic suction at the Pucheu site made more frequent irrigation mandator to avoid severe crop loss.

Irregular growth patterns were observed to some extent at all cotton test sites, but these were especially prevalent at the Telles location. Samples were collected that represented contrasting (tall and short) cotton growth patterns and analyzed for various components in an effort to determine the reason for the irregular growth; some results are given in Table 14. Below 30 cm, $EC_e$, sodium, and chloride levels were all much higher in growth restricting areas compared with contrasting growth sites that were closer to values obtained at the designated observation sites normal to our

Table 14. Analyses of soil saturation extracts from samples collected 10 August 1981 at variable growth sites in the Telles (Panoche) cotton field.

| | Plant Growth Group | | | | | |
|---|---|---|---|---|---|---|
| | tall | short | tall | short | tall | short |
| Soil depth, cm | $EC_e$, $dSm^{-1}$ | | Na, meq/l | | Cl, meq/l | |
| 0 - 30.5 | 3.81 | 2.70 | 14.1 | 18.5 | 12.2 | 11.1 |
| 30.5 - 61.0 | 5.88 | 8.51 | 32.6 | 65.2 | 9.0 | 41.2 |
| 61.0 - 91.4 | 3.33 | 8.89 | 28.3 | 79.3 | 9.7 | 26.2 |
| 91.4 - 122.0 | 3.33 | 8.90 | 27.2 | 79.3 | 9.2 | 25.4 |

experimental procedure. Such observations have been reported under saline conditions by a number of workers (Bingham and Garber, 1970; Lunin and Gallatin, 1965; Maas and Hoffman, 1977; Thomas, 1980).

These results suggest that a critical depth to a shallow ground water table will vary in relation to salinity and agree with the results of Chadhary (1974). Thomas (1980) observed that growth suppression of cotton was due to specific nutritional effects (cation balance) in addition to osmotically induced water deficits.

## Irrigation Scheduling

In the presence of a shallow water table that contributes to crop ET, traditional soil-based measurements do not accurately reflect whether water being supplied is at an optimum level. Also, osmotically induced stress, in the presence of high salinity, may not be properly assessed. Since the plant integrates its total environment, plant-based measurements of water status appear to more accurately reflect when irrigation is needed to replace evapotranspired water. Allowable critical plant water status values have been developed for cotton (Grimes and Yamada, 1982) and the technique of monitoring plant water status with a pressure chamber was used for all cotton locations during the course of this study.

Cotton leaf water potentials are shown in Figure 14 for contrasting treatments and locations. The T-2 treatment was allowed to decline to approximately -2.0 MPa before irrigation after the first post-plant irrigation. The first irrigation was scheduled at approximately -1.6 MPa. With the exception of the Pucheu and Stone locations, the T-1 treatment was irrigated before leaf water potential declined to that level.

The detrimental effect of excessive stress is illustrated by Figure 14B where leaf water potential of the T-2 treatment was inadvertently allowed to decline to -2.5 MPa before an irrigation was scheduled on JD 195. The rapid drop in leaf water potential occurred as a result of high profile salinity and an extremely saline shallow water table. This stress period lowered production by 88 kg of cotton lint per hectare.

Keeping too wet a regime may also reduce cotton lint yield. Additional undesirable effects of too frequent irrigations are associated with excessive vegetative growth and delayed crop maturity. The consistently lower micronaire values of the T-1 treatment shown in Table 15 illustrate the maturity delay of this treatment at various test locations. No other lint quality characteristic was influenced by irrigation frequency.

Cotton irrigation scheduling for the two treatments at the Stone location was essentially the same, except for the last or cut-off irrigation of the season. Cotton production for the early cut-off treatment (T-2) was either equal to or slightly higher than the later irrigation treatment.

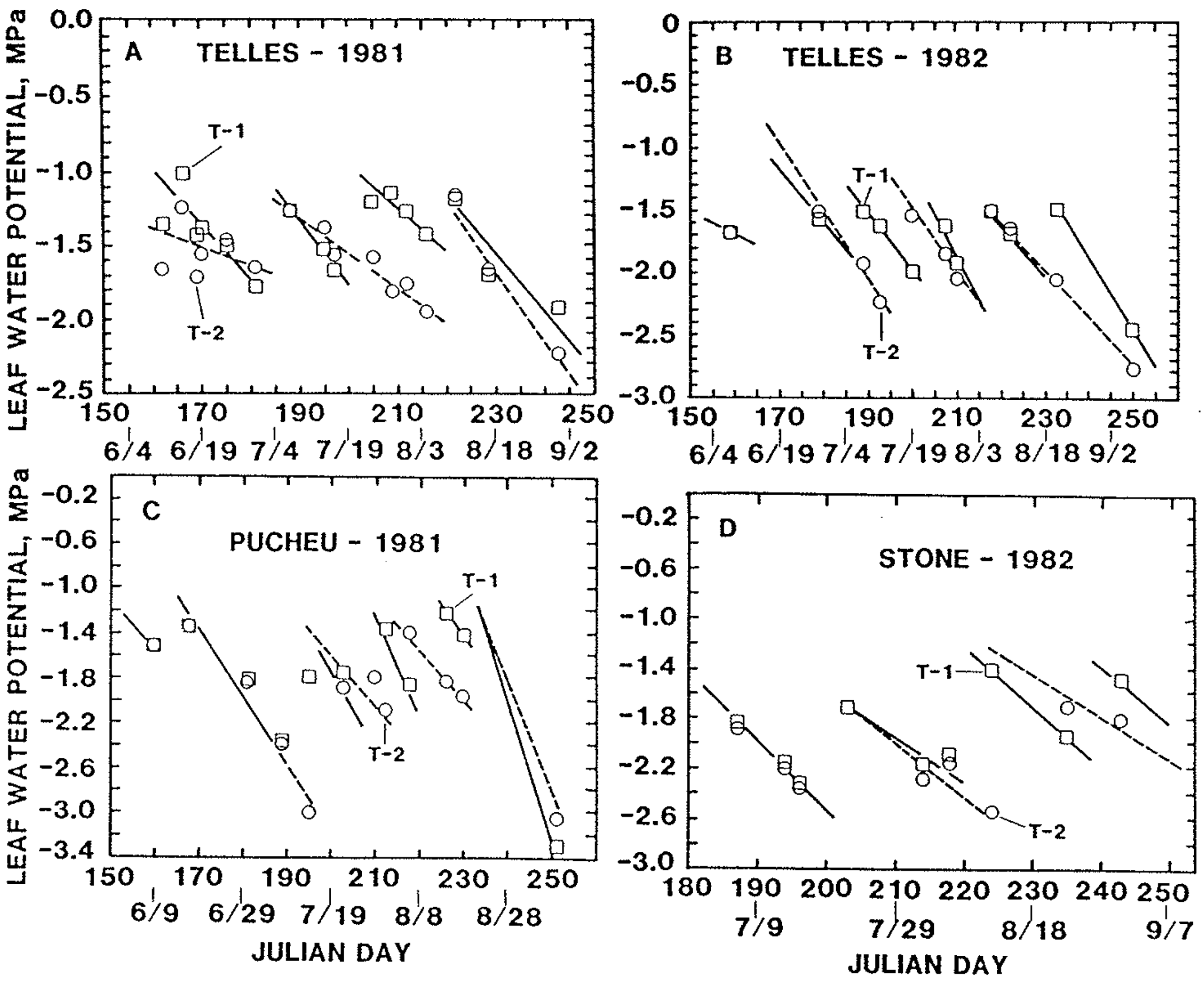

Figure 14. Leaf water potential for cotton during the growing season with contrasting irrigation schedules: A) Telles (Panoche)-1981, B) Telles (Panoche)-1982, C) Pucheu (Levis)-1981, and D) Stone (Merced)-1982.

Table 15. Quality characteristics of cotton lint during two years of testing.

| Treatment | Span length, cm 2.5% | 50% | Uniformity index, % | $T_1$, g/grex | $E_1$, % | Micronaire, curvilinear scale |
|---|---|---|---|---|---|---|
| Telles (Panoche) - 1981 | | | | | | |
| T-1 | 3.05a | 1.38a | 45.5a | 2.42a | 8.00a | 4.08a |
| T-2 | 3.04a | 1.36a | 44.7a | 2.42a | 7.92a | 4.44a |
| Pucheu (Levis) - 1981 | | | | | | |
| T-1 | 2.95a | 1.37a | 46.4a | 2.52a | 7.48a | 4.51a |
| T-2 | 2.95a | 1.37a | 46.4a | 2.48a | 7.40a | 4.62a |
| Stone (Merced) - 1982 | | | | | | |
| T-1 | 2.97a | 1.41a | 47.5a | 2.16a | 9.27a | 4.15a |
| T-2 | 2.97a | 1.40a | 47.1a | 2.24a | 9.12a | 4.27a |
| Telles (Panoche) - 1982 | | | | | | |
| T-1 | 2.95a | 1.39a | 47.1a | 2.32a | 9.10a | 4.05b |
| T-2 | 2.98a | 1.35a | 45.3a | 2.25a | 9.07a | 4.22a |

## CONCLUSIONS

Land areas influenced by shallow-perched water tables continue to increase in the central and western San Joaquin Valley with the present level of management. The results of this study demonstrate that improvement can be made that will effectively moderate the present encroachment rate if overall management includes taking advantage of the resource potential of the shallow water to meet part of crop ET requirements.

Effective management of the shallow water resource requires monitoring of water table depth fluctuations, salinity level of the water table, and changes in soil profile salinity at periodic intervals. Since much variation in salinity of the perched water exists, a given management regime will best be tailored to individual regions where major changes in water table salinity, depth to shallow water, and soil profile characteristics will determine the magnitude of a water table contribution to crop requirements.

Using shallow water table capillary movement into the crop root zone can result in a rapid accumulation of salts in the profile. A potential gradient must be created by upper profile drying during the crop growing season to allow upward flow. Deposition of salts closer to the soil surface requires some leaching with good quality irrigation water (and rainfall) that is most effectively accomplished during the winter months when ET is low. Close monitoring of this irrigation is required to effectively move accumulated salts to lower profile depths while minimizing deep percolation that will add to the shallow water table.

Since the shallow water table, with a desired irrigation schedule, is contributing to crop ET, irrigation scheduling must be modified, from that where no shallow water exists, to optimize this contribution. Traditional methods of irrigating at allowable soil water depletion levels are most likely inappropriate in these situations. Procedures of irrigating based on plant observations are best suited, however, critical levels for plant based water status measurements are known only for a limited number of crop plants. Experience and visual observation of plant appearance can be used to an advantage where defined levels are unknown.

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# APPENDIX

## Appendix Table A

Particle size distribution of soils for the various sites of the three year study.

| Depth, cm | Sand<br>>20μm | Silt<br>20-2μm | Clay<br><2μm | Sand<br>>20μm | Silt<br>20-2μm | Clay<br><2μ | Sand<br>>20μm | Silt<br>20-2μm | Clay<br><2μm |
|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | | | | |
| | Pucheu (Levis) 1981 | | | Telles (Panoche) 1981/82 | | | Gragnani (Oxalis) 1981 | | |
| 0-30.5 | 26.4 | 27.3 | 46.3 | 22.9 | 38.4 | 38.7 | 19.8 | 35.0 | 45.2 |
| 30.5-61.0 | 24.9 | 28.8 | 46.3 | 22.0 | 37.3 | 40.7 | 22.1 | 41.6 | 36.3 |
| 61.0-91.4 | 24.2 | 26.8 | 49.0 | 25.3 | 38.1 | 36.6 | 22.6 | 40.4 | 37.0 |
| 91.4-122.0 | 27.2 | 47.0 | 25.8 | 29.7 | 36.2 | 34.1 | 18.5 | 44.8 | 36.7 |
| 122.0-152.4 | 23.2 | 24.5 | 52.3 | 34.1 | 34.3 | 31.6 | 18.6 | 42.4 | 39.0 |
| 152.4-182.9 | 18.0 | 41.2 | 40.8 | 28.8 | 40.0 | 31.2 | 17.6 | 40.3 | 42.1 |
| 182.9-213.4 | 15.8 | 39.1 | 45.1 | 32.3 | 45.2 | 24.5 | 9.0 | 67.4 | 23.6 |
| 213.4-243.8 | 13.2 | 52.9 | 33.9 | 33.5 | 40.1 | 26.4 | 12.8 | 75.2 | 12.0 |
| 243.8-274.3 | 13.5 | 57.4 | 33.4 | 42.2 | 34.1 | 23.7 | 21.1 | 61.6 | 17.3 |
| 274.3-304.8 | 8.5 | 70.6 | 20.9 | 46.6 | 37.2 | 16.2 | 23.5 | 50.5 | 26.0 |
| 304.8-335.3 | -- | -- | -- | -- | -- | -- | 22.1 | 50.6 | 26.9 |
| | Newton (Tulare) 1982/83 | | | Stone (Merced) 1982 | | | Stone (Merced) 1983 | | |
| 0-30.5 | 7.8 | 43.0 | 49.2 | 18.6 | 28.6 | 52.6 | 5.1 | 36.3 | 58.6 |
| 30.5-61.0 | 19.6 | 41.2 | 39.2 | 14.7 | 29.4 | 55.9 | 8.8 | 36.3 | 54.9 |
| 61.0-91.4 | 27.6 | 37.0 | 35.4 | 16.3 | 27.1 | 56.6 | 14.6 | 37.3 | 48.1 |
| 91.4-122.0 | 29.6 | 37.2 | 33.2 | 22.4 | 27.5 | 50.1 | 20.6 | 34.5 | 44.9 |
| 122.0-152.4 | 33.6 | 35.2 | 31.2 | 37.7 | 33.6 | 28.7 | 18.6 | 35.8 | 45.6 |
| 152.4-182.9 | 25.6 | 43.2 | 31.2 | 44.2 | 31.5 | 24.3 | 14.6 | 36.5 | 48.9 |
| 182.9-213.4 | 31.6 | 33.2 | 35.2 | 45.0 | 29.0 | 26.0 | 18.6 | 37.0 | 44.4 |

## Appendix Table B

Soil bulk densities for all sites of the three year study.

| Depth | Telles (Panoche) | Pucheu (Levis) | Gragnani (Oxalis) | Newton (Tulare) | Stone (Merced) (1982) | Stone (Merced) (1983) |
|---|---|---|---|---|---|---|
| | | | Soil bulk density, $gcm^{-3}$ | | | |
| 0-30.5 | 1.20(0.23)[1/] | 1.17(0.23) | 1.18(0.08) | 1.28(0.04) | 1.38(0.06) | 1.37(0.11) |
| 30.5-61.0 | 1.46(0.16) | 1.20(0.17) | 1.34(0.07) | 1.28(0.04) | 1.41(0.07) | 1.48(0.08) |
| 61.0-91.4 | 1.42(0.14) | 1.52(0.17) | 1.21(0.16) | 1.28(0.05) | 1.47(0.10) | 1.59(0.11) |
| 91.4-122.0 | 1.58(0.09) | 1.42(0.24) | 1.27(0.04) | 1.25(0.07) | 1.53(0.15) | 1.56(0.14) |
| 122.0-152.4 | 1.65(0.25) | 1.51(0.17) | 1.23(0.04) | 1.31(0.08) | 1.53(0.06) | 1.46(0.10) |
| 152.4-182.9 | 1.80(0.15) | 1.44(0.20) | 1.25(0.13) | 1.23(0.07) | 1.56(0.02) | -- |
| 182.9-213.4 | 1.71(0.33) | 1.61(0.29) | 1.28(0.13) | 1.11(0.11) | 1.60(0.19) | -- |
| 213.4-243.8 | 1.62(0.25) | 1.50(0.17) | 1.31(0.13) | -- | -- | -- |
| 243.8-274.3 | -- | 1.53(0.35) | 1.24(0.12) | -- | -- | -- |
| 274.3-304.8 | -- | 1.41(0.17) | 1.20(0.11) | -- | -- | -- |

---

[1/] Numbers in parenthesis are standard deviations of measurements from all observation sites.

## Appendix Table C

Water retention characteristics of soils at various sites of the three year study.

| Soil Depth (cm) | Pressure, bars | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1/10 | 1/3 | 2/3 | 1 | 3 | 5 | 10 | 15 |
| | $g\ g^{-1}$ x 100 | | | | | | | |
| **Gragnani (Oxalis) - 1981** | | | | | | | | |
| 0-30.5 | 48.20 | 37.92 | 33.51 | 29.58 | 25.21 | 25.20 | 23.16 | 21.99 |
| 30.5-61.0 | 45.35 | 38.00 | 34.69 | 29.01 | 25.68 | 24.58 | 23.04 | 20.53 |
| 61.0-91.4 | 44.13 | 37.39 | 34.09 | 27.90 | 24.90 | 23.91 | 21.21 | 19.13 |
| 91.4-122.0 | 52.78 | 42.89 | 39.65 | 36.78 | 29.10 | 27.26 | 21.79 | 22.18 |
| 122.0-152.4 | 58.42 | 44.61 | 38.93 | 34.69 | 29.15 | 26.91 | 23.40 | 21.27 |
| 152.4-182.9 | 59.26 | 41.50 | 36.81 | 32.11 | 27.37 | 24.68 | 20.89 | 20.09 |
| 182.9-213.4 | 58.40 | 48.50 | 43.90 | 34.77 | 33.01 | 30.18 | 26.85 | 26.65 |
| 213.4-243.8 | 48.57 | 46.44 | 42.48 | 37.10 | 31.67 | 29.01 | 29.18 | 25.63 |
| 243.8-274.3 | 36.56 | 42.11 | 40.76 | 33.86 | 28.61 | 25.55 | 24.16 | 22.61 |
| **Pucheu (Levis) - 1981** | | | | | | | | |
| 0-30.5 | | 32.31 | 27.77 | 25.85 | 21.74 | | 18.29 | 16.95 |
| 30.5-61.0 | | 36.94 | 32.16 | 30.02 | 24.35 | | 18.25 | 17.25 |
| 61.0-91.4 | | 39.73 | 33.94 | 33.18 | 26.33 | | 22.11 | 20.94 |
| 91.4-122.0 | | 39.86 | 34.58 | 31.58 | 25.09 | | 20.28 | 19.09 |
| 122.0-152.4 | | 42.78 | 39.11 | 35.61 | 27.54 | | 23.74 | 22.55 |
| 152.4-182.9 | | 44.82 | 40.56 | 37.49 | 28.40 | | 23.76 | 21.99 |
| 182.9-213.4 | | 44.51 | 41.43 | 37.02 | 28.92 | | 23.62 | 22.58 |
| 213.4-243.8 | | 47.72 | 43.48 | 40.50 | 31.29 | | 25.09 | 23.62 |
| 243.8-274.3 | | 49.11 | 44.72 | 41.51 | 31.45 | | 26.49 | 24.24 |
| 274.3-304.8 | | 48.19 | 40.60 | 38.34 | 30.43 | | 24.16 | 22.89 |
| **Telles (Panoche) - 1981** | | | | | | | | |
| 0-30.5 | | 26.33 | 23.37 | 21.64 | 18.79 | 15.29 | 14.04 | 13.24 |
| 30.5-61.0 | | 26.40 | 24.56 | 23.06 | 19.61 | 15.84 | 14.27 | 13.38 |
| 61.0-91.4 | | 25.87 | 24.57 | 22.57 | 18.78 | 16.27 | 14.11 | 12.61 |
| 91.4-122.0 | | 24.66 | 23.15 | 20.55 | 16.97 | 14.98 | 12.22 | 12.27 |
| 122.0-152.4 | | 22.20 | 20.06 | 18.35 | 14.59 | 13.68 | 10.53 | 10.20 |
| 152.4-182.9 | | 22.44 | 20.05 | 17.19 | 14.62 | 11.90 | 10.02 | 9.56 |
| 182.9-213.4 | | 21.21 | 18.10 | 15.78 | 12.10 | 10.76 | 8.28 | 8.27 |
| 213.4-243.8 | | 20.75 | 18.07 | 15.87 | 12.64 | 11.27 | 8.85 | 8.11 |
| 243.8-274.3 | | 19.11 | 15.72 | 14.08 | 10.98 | 9.90 | 7.60 | 7.07 |
| 274.3-304.8 | | 14.25 | 12.51 | 10.32 | 8.03 | 6.53 | 5.61 | 5.25 |
| **Newton (Tulare) - 1982/83** | | | | | | | | |
| 0-30.5 | | 44.75 | 41.04 | 38.64 | 31.71 | | 25.27 | 24.52 |
| 30.5-61.0 | | 46.24 | 42.49 | 39.24 | 32.97 | | 25.67 | 24.81 |
| 61.0-91.4 | | 45.53 | 42.79 | 41.31 | 35.03 | | 28.90 | 24.94 |
| 91.4-122.0 | | 49.39 | 45.90 | 43.80 | 36.83 | | 28.67 | 27.69 |
| 122.0-152.4 | | 50.18 | 46.69 | 43.62 | 36.62 | | 28.18 | 26.86 |
| 152.4-182.9 | | 53.14 | 48.74 | 43.56 | 39.11 | | 30.78 | 28.74 |
| 182.9-213.4 | | 61.98 | 57.31 | 55.10 | 44.90 | | 31.23 | 29.65 |

Appendix Table C (cont.)

| Soil Depth (cm) | Pressure, bars | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1/10 | 1/3 | 2/3 | 1 | 3 | 5 | 10 | 15 |
| | g g$^{-1}$ x 100 | | | | | | | |
| Stone (Merced) - 1982 | | | | | | | | |
| 0-30.5 | | 45.85 | 36.77 | 33.71 | 29.33 | 28.83 | 20.69 | 23.20 |
| 30.5-61.0 | | 46.25 | 37.11 | 33.92 | 29.78 | 27.87 | 23.43 | 22.23 |
| 61.0-91.4 | | 45.94 | 37.22 | 34.43 | 29.66 | 27.23 | 22.47 | 23.12 |
| 91.4-122.0 | | 42.66 | 39.87 | 32.84 | 34.98 | 22.78 | 22.44 | 20.46 |
| 122.0-152.4 | | 39.75 | 35.21 | 30.90 | 23.60 | 19.93 | 19.58 | 19.21 |
| 152.4-182.9 | | 34.99 | 31.98 | 24.98 | 21.11 | 14.60 | 14.79 | 14.43 |
| 182.9-213.4 | | 35.45 | 25.43 | 18.57 | 15.63 | 22.20 | 11.31 | 11.27 |
| Stone (Merced) - 1983 | | | | | | | | |
| 0-30.5 | | 31.77 | | 22.87 | 17.59 | 18.77 | 18.02 | 17.34 |
| 30.5-61.0 | | 32.79 | | 22.54 | 20.45 | 18.04 | 16.70 | 16.69 |
| 61.0-91.4 | | 30.77 | | 20.47 | 18.52 | 15.22 | 14.41 | 15.01 |
| 91.4-122.0 | | 30.60 | | 19.57 | 20.55 | 15.87 | 14.10 | 15.83 |
| 122.0-152.4 | | 34.29 | | 21.09 | 19.58 | 17.13 | 15.06 | 14.43 |
| 152.4-182.9 | | 38.75 | | 24.96 | 17.41 | 18.56 | 16.10 | 12.30 |
| 182.9-213.4 | | 35.46 | | 24.85 | 22.05 | 17.40 | 16.63 | 15.82 |

## Appendix Table D

Changes in the water table depth (cm) at three locations in 1981.

| Date | W.T. depth, cm | Date | W.T. depth, cm | Date | W.T. depth, cm |
|---|---|---|---|---|---|
| Telles (Panoche) | | Pucheu (Levis) | | Gragnani (Oxalis) | |
| 5/28 | 142.0[1] | 5/28 | 152.9 | 5/26 | 240.7 |
| 6/18 | 107.4 | 6/17 | 92.4 | 6/4 | 248.9 |
| 6/24 | 117.6 | 6/30 | 121.0 | 6/17 | 307.4 |
| 7/1 | 122.4 | 7/8 | 131.4 | 7/6 | 318.0 |
| 7/7 | 94.7 | 7/22 | 126.5 | 8/20 | 325.1 |
| 7/14 | 130.8 | 8/6 | 125.2 | | |
| 7/31 | 151.4 | 8/18 | 142.9 | | |
| 8/10 | 155.4 | 8/24 | 139.1 | | |
| 8/31 | 178.1 | 9/8 | 158.4 | | |
| 10/20 | 185.2 | 10/7 | 193.8 | | |

[1] Values are an average of eight measurement sites.

## Appendix Table E

Fluctuations in water table depth at the Newton location, 1982.

| Date Mon/Day | Water Table Depth | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 101W | 102W | 201W | 202W | 301W | 302W | 101E | 102E | 201E | 202E | 301E | Ave. |
| | | | | | | cm | | | | | | |
| Apr. 19 | 91.4 | 180.3 | 111.8 | 137.2 | 160.0 | 177.8 | 108.0 | 108.0 | 81.3 | 134.6 | 162.6 | 132.1 |
| May 3<br>→ | 111.8 | 170.2 | 132.1 | 147.3 | 167.6 | 175.3 | 124.5 | 127.0 | 147.3 | 134.6 | 165.1 | 145.7 |
| May 11 | | 99.1 | 111.8 | 114.3 | 132.1 | 137.2 | 106.7 | 111.8 | 104.1 | 99.1 | 147.3 | 116.3 |
| May 27 | 121.9 | 121.9 | 132.1 | 147.3 | 162.6 | 167.6 | 132.1 | 129.5 | 127.0 | 132.1 | 157.5 | 139.2 |
| June 7<br>→ | 132.1 | 132.1 | 144.8 | 160.0 | 170.2 | 177.8 | 139.7 | 141.0 | 137.2 | 142.2 | 165.1 | 149.3 |
| June 14<br>→ | 134.6 | 134.6 | 144.8 | 157.5 | 170.2 | 175.3 | 144.8 | 144.8 | 142.2 | 147.3 | 172.7 | 151.7 |
| June 21 | 130.0 | 133.0 | 145.0 | 156.0 | 169.0 | 171.0 | 145.0 | 145.0 | 141.0 | 147.0 | 171.0 | 150.3 |
| June 25 | 139.7 | 141.0 | 149.8 | 156.2 | 165.1 | 175.3 | 149.8 | 152.4 | 152.4 | 154.9 | 180.3 | 156.1 |
| June 29<br>→ | 134.6 | 134.6 | 139.7 | 147.3 | 157.5 | 162.6 | 144.8 | 144.8 | 144.8 | 149.9 | 177.8 | 148.9 |
| July 6 | 132.1 | 132.1 | 139.7 | 147.3 | 160.0 | 167.6 | 147.3 | 147.3 | 144.8 | 152.4 | 177.8 | 149.8 |
| July 20 | 147.3 | 147.3 | 152.4 | 160.0 | 172.7 | 177.8 | 157.5 | 157.5 | 154.9 | 162.6 | 195.6 | 162.3 |
| Aug. 2 | 152.4 | 152.4 | 152.4 | 165.1 | 182.9 | 190.5 | 160.0 | 157.5 | 157.5 | 167.6 | 210.8 | 168.1 |
| Aug. 11 | 162.6 | 160.0 | 170.2 | 177.8 | 190.5 | 205.7 | 167.6 | 167.6 | 162.6 | 175.3 | 218.4 | 178.0 |

→ = Irrigation

Average W.T. of the crop season = 149.8 cm ≈ 4.92 ft.

## Appendix Table F

Changes in water table at the Stone location, 1983 Barley.

| Date | Water table depth (cm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 101E | 102E | 201E | 202E | 301E | 302E | 401E | 402E | 301W | 302W | 401W | 402W | Ave. |
| 4/5 | 81.3 | 68.6 | 66.0 | 61.0 | 61.0 | 43.2 | 61.0 | 61.0 | -- | -- | -- | -- | 62.9 |
| 4/12 | 88.9 | 69.8 | 71.1 | 69.8 | 68.6 | 72.4 | 66.0 | 66.0 | 66.0 | 71.1 | 76.2 | 78.7 | 72.0 |
| 4/27 | 83.8 | 73.7 | 66.0 | 64.8 | 63.5 | 66.0 | 58.4 | 53.3 | 61.0 | 61.0 | 58.4 | 58.4 | 64.0 |
| 5/23 | 81.3 | 73.7 | 69.8 | 73.7 | 76.2 | 83.8 | 77.5 | 76.2 | 63.5 | 69.9 | 73.7 | 71.1 | 74.2 |
| 6/1 | 78.7 | 71.1 | 68.6 | 66.0 | 66.0 | 76.2 | 73.7 | 68.6 | 66.0 | 66.0 | 68.6 | 68.6 | 69.8 |
| | | | | | | | | | | | | Ave. = | 68.6 |

Seasonal water table depth = 2.3 ft.

## Appendix Table G

Changes in perched water table depth at the Stone location, 1983 Cotton.

| Date | Plot No. | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mon/Day | 101W | 102W | 201W | 202W | 301W | 302W | 401W | 402W | 402E | 401E | 302E | 301E | 202E | 201E | 102E | 101E | Ave. | $s_x$ |
| | Inches | | | | | | | | | | | | | | | | | |
| 6/10<br>→ | 25.0 | 26.0 | 25.0 | 29.0 | 22.0 | 25.0 | 19.0 | 32.0 | 25.0 | 34.0 | 33.0 | 31.0 | 28.0 | 26.0 | 27.0 | 26.0 | 27.1<br>(68.7) | 4.0 |
| 6/23 | 10.0 | -- | 12.0 | 13.0 | 13.0 | 15.0 | -- | 12.0 | 19.0 | -- | 23.0 | -- | 18.0 | -- | -- | -- | 15.0<br>(38.1cm) | 4.2 |
| 6/28 | 12.0 | 12.0 | 14.0 | 15.0 | 16.0 | 17.0 | 17.0 | 17.0 | 24.0 | 22.0 | 24.0 | 22.0 | 18.0 | 18.0 | 18.0 | 16.0 | 17.6<br>(44.8cm) | 3.7 |
| 7/15<br>→ | 17.0 | 20.0 | 22.0 | 20.0 | 21.0 | 21.0 | 21.0 | 21.0 | 31.0 | 31.0 | 32.0 | 30.0 | 28.0 | 27.0 | 26.0 | 26.0 | 24.6<br>(62.5cm) | 4.8 |
| 7/23 | 21.5 | 24.0 | 24.5 | 23.0 | 23.5 | 22.5 | 24.0 | 24.0 | 33.0 | 33.5 | 34.0 | 33.0 | 31.0 | 30.5 | 29.5 | 29.0 | 27.5<br>(69.9cm) | 4.5 |
| 8/3<br>→ | 24.0 | 27.0 | 29.0 | 27.0 | 28.0 | 28.0 | 27.0 | 26.0 | 40.0 | 38.0 | 37.0 | 39.0 | 36.0 | 34.0 | 34.0 | 33.0 | 31.7<br>(80.5cm) | 5.3 |
| 8/10 | 26.5 | 30.5 | 31.0 | 30.0 | 30.0 | 30.0 | 29.5 | 30.0 | 40.5 | 40.0 | 41.0 | 40.0 | 38.0 | 38.0 | 37.0 | 35.0 | 34.2<br>(86.8cm) | 4.0 |
| 8/17<br>→ | 31.5 | 33.0 | 37.0 | 35.0 | 36.0 | 37.0 | 34.0 | 34.0 | 46.0 | 45.0 | 47.0 | 44.0 | 43.0 | 43.0 | 40.0 | 40.0 | 39.1<br>(99.3cm) | 5.1 |
| 9/1 | 28.0 | 31.0 | 33.0 | 32.0 | 32.5 | 33.0 | 31.0 | 31.0 | 43.0 | 42.0 | 44.0 | 42.0 | 40.0 | 41.0 | 41.0 | 39.0 | 36.5<br>(92.6cm) | 5.1 |
| 9/9 | 36.0 | 39.0 | 41.0 | 40.0 | 41.0 | 42.0 | 39.0 | 39.0 | 52.0 | 52.0 | 54.0 | 52.0 | 49.0 | 49.0 | -- | -- | 44.6<br>(113.4cm) | 6.3 |
| 10/25 | 27.0 | 29.0 | 34.0 | 34.0 | 37.0 | 39.0 | 38.0 | 37.0 | 48.5 | 47.0 | 49.0 | 47.0 | 42.0 | 44.0 | 42.0 | 41.0 | 39.7<br>(100.9cm) | 6.6 |

| Date | 6/10 | 6/23 | 6/28 | 7/15 | 7/23 | 8/3 | 8/10 | 8/17 | 9/1 | 9/9 | 10/25 | Ave. | $s_x$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WT (cm) | 68.7 | 38.1 | 44.8 | 62.5 | 69.9 | 80.5 | 86.8 | 99.3 | 92.6 | 113.4 | 100.9 | 78.0 | 23.7 |

→ Indicates on irrigation interval.

## Appendix Table H

Seasonal water table depths at the Newton location, 1983.

| Date | Water Table Depth (cm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 101N | 102N | 201N | 202N | 301N | 302 | 101S | 102S | 201S | 202S | 301S | Ave. | $s_x$ |
| → | | | | | | | | | | | | | |
| May 3 | -- | 241.3 | 254.0 | 259.1 | 246.4 | 223.5 | 228.6 | 254.0 | 254.0 | 254.0 | -- | 246.1 | 12.54 |
| May 10 | 269.2 | 259.1 | 254.0 | 251.5 | 231.1 | 218.4 | 233.7 | 248.9 | 254.0 | 259.1 | 269.2 | 249.8 | 16.00 |
| May 31 | 256.5 | 264.2 | 261.6 | 254.0 | 261.6 | 231.1 | 259.1 | 256.5 | 243.8 | 251.5 | 276.8 | 256.1 | 11.68 |
| → | | | | | | | | | | | | | |
| June 13 | 284.5 | 284.5 | 276.9 | 276.9 | 281.9 | 259.1 | 228.6 | 274.3 | 259.1 | 251.5 | 241.3 | 265.3 | 18.85 |
| June 23 | 279.4 | 279.4 | 274.3 | 266.7 | 274.3 | 248.9 | 248.9 | 264.2 | 259.1 | 274.3 | 223.5 | 263.0 | 17.06 |
| → | | | | | | | | | | | | | |
| June 28 | 279.4 | 274.3 | 269.2 | 284.5 | 276.9 | 251.5 | 281.9 | 261.6 | 243.8 | 248.9 | 261.6 | 266.7 | 14.15 |
| → | | | | | | | | | | | | | |
| July 1 | 274.3 | 274.3 | 271.8 | 269.2 | 266.7 | 251.5 | 279.4 | 259.1 | 238.8 | 236.2 | 231.1 | 259.3 | 17.24 |
| → | | | | | | | | | | | | | |
| July 12 | 276.9 | 289.6 | 284.5 | 294.6 | 284.5 | 256.5 | 279.4 | 259.1 | 243.8 | 264.2 | 248.9 | 271.1 | 17.32 |
| July 26 | 274.3 | 271.8 | 271.8 | 266.7 | 266.7 | 281.9 | 281.9 | 261.6 | 238.8 | 259.1 | 266.7 | 267.4 | 11.95 |
| August 8 | 276.9 | 269.2 | 276.9 | 269.2 | 264.2 | 248.9 | 281.9 | 254.0 | 236.2 | 261.6 | 279.4 | 265.3 | 14.25 |
| August 17 | 292.1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 292.1 | 292.1 | 0.00 |
| | | | | | | | | | | | $\bar{x}$ | 263.8 | 12.12 |

Seasonal water table depth = 8.6 ft.

→ Indicates on irrigation interval.