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WATER USE BY AND SALINITY EFFECTS UPON TRICKLE IRRIGATED GRAPE PRODUCTION IN THE SOUTHERN BASIN AND RANGE PROVINCE OF NEW MEXICO

Technical Completion Report

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WATER USE BY AND SALINITY EFFECTS UPON TRICKLE IRRIGATED GRAPE PRODUCTION IN THE SOUTHERN BASIN AND RANGE PROVINCE OF NEW MEXICO

By

R. Scott Van Pelt
Graduate Research Assistant
Department of Agronomy and Horticulture
New Mexico State University

and

Peter J. Wierenga
Principal Investigator
Department of Soil and Water Science
University of Arizona

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DISCLAIMER

ABSTRACT

Irrigated agriculture in the Southwest depends upon the continued availability of good quality water. Recent increases in the cost of pumping have prompted many growers to consider planting high value crops such as wine grapes. Recent advances in irrigation technology, particularly trickle irrigation, may make production of quality fruit possible with ground water reserves of limited availability or poor quality. No regional guidelines exist to assist the potential grower in locating and establishing vineyards based on the water resources present. Field trials were conducted to provide information necessary for the formulation of such guidelines.

Cabernet Sauvignon grapes in a trickle irrigated commercial vineyard in southern New Mexico were irrigated with water of three salinities (350, 1000, and 1500 mg/l TDS). Grapes receiving the 350 mg/l water were irrigated with volumes representing 60, 80, 100, and 120 percent of predicted evapotranspiration. Consumptive use of water by the vines was estimated from lysimeter water balance data.

Our results indicate grapes may be produced with no more than 500 mm of water per year of which nearly half may be expected in the form of precipitation. Soil solution salinity levels in vine root zones were not found to be significantly greater than that of the applied irrigation water. Fruit production of acceptable quality was obtained from vines irrigated with water of all salinity levels tested.

Key words: salinity, trickle irrigation, consumptive use, grapes, fruit quality, field studies

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INTRODUCTION

The majority of agricultural production in the desert Southwest depends upon water for irrigation. The continued availability of water is of great concern to farmers in this region. Competition from municipal and industrial water users has increased in recent years, particularly in areas with surface water supplies. However, many agricultural areas are devoid of perennial surface water, and ground water must be used for irrigation. The continued use of the ground water reserves and the resultant lowering of the water table, coupled with recent increases in energy costs, threaten the economic viability of the traditional crops grown in this region. Faced with rapidly rising production costs, many producers have retired acreage and are no longer putting their ground water to beneficial use. Other producers are adapting to the new economic conditions by installing more efficient irrigation systems and planting crops of a higher cash value than traditional hay, fiber, and grain crops.

One high value crop recently planted in this region is wine grapes *Vitis vinifera* L. The climate and soils are favorable for high quality grape production. Many areas with the best climates for grape production are also areas with limited or saline water reserves. Recent advances in irrigation technology have made feasible the use of more limited water reserves for many soils and crops. The establishment of a vineyard is a costly investment that must be approached with caution. The existing water resources should be considered before planting, but there are currently no guidelines based on water resources for site selection and long-term production feasibility.

Related Research

Several literature searches have indicated relatively little information concerning the consumptive use of water by grapes or salinity effects upon wine grapes growing in a natural field. Information on these subjects varies greatly in terms of regional origin, methods of investigation, and selected cultivars. Salinity effects have been investigated to a greater extent, but rarely in field trials.

Measurements of the consumptive use of water by grapes have been estimated by a variety of methods. This variation of investigative procedures has resulted in water use estimates ranging from under one-half to nearly two meters per season. Estimates derived from volumes applied to flood irrigated plots (Nijjar and Chopra 1972; Nijjar and Sharma 1973) have tended toward the higher end of this range. Estimates derived by tensiometer-scheduled trickle irrigation volumes (Klein 1983; Peacock, Christensen, and Andris 1983; Bucks et. al. 1985) have tended toward the lower end of this range. Bravdo, Lavee, and Samish (1972) have investigated the water use by several one-year-old cultivars in lysimeters, a method we believe gives the most reliable estimates. Our water use estimates were derived from four large drainage type lysimeters located within a 320 acre vineyard.

The effects of irrigation and related water stresses upon the growth and productivity of wine grapes have been investigated to a greater extent. The emphasis of these investigations varies considerably in terms of the parameters measured. Several of the papers reviewed were primarily concerned with the effects of water stress upon vegetative growth (Kliewer, Freeman, and Hossom 1983; Nijjar and Sharma 1973; Sawaf, Adam, and Ansari 1981; Smart 1974; Smart, Turkington, and Evans 1974). Of the papers addressing the effects of water stress upon yield, two (Kliewer, Freeman, and Hossom 1983; Nijjar and Sharma 1973) emphasized the effects of the degree of stress, and one (Smart, Turkington, and Evans 1974) reported the effects of differential timing of the stress. Smart (1974) investigated the mechanisms through which water stress affects yields. The degree of water stress is influenced by irrigation scheduling and method of application. Conversion from furrow or basin flood irrigation to trickle irrigation results in more efficient use of the water applied (Bucks, Nakayama, and Warrick 1982; Goldberg, Gornat, and Rimon 1976; Sawaf, Adam, and Ansari 1981; Smart, Turkington, and Evans 1974). Research concerning the effects of this conversion upon vine performance have indicated no loss of productivity after conversion (Goldberg, Gornat, and Rimon 1976; Stevenson 1983). Kliewer, Freeman, and Hossom (1983) report that cultural practices such as pruning may affect the water use requirements of vines and such reduction in stress will be reflected in vine growth and yields.

Recent research has included investigations into the effects of irrigation and water stress upon fruit quality. The main emphasis of this research has been the effect of supplemental irrigations in regions previously not irrigated (Anonymous 1982; Freeman 1983; Freeman and Kliewer 1983). Quality characteristics studied by investigators include chemical properties of the fruit and fruit juice, must, such as sugars and acids (Freeman and Kliewer 1983; Freeman, Lee, and Turkington 1980; Nijjar and Chopra 1972; Nijjar and Sharma 1973; Smart, Turkington, and Evans 1974), and visual factors such as clarity and color development (Freeman 1983; Freeman and Kliewer 1983). Some research has indicated a trend of quality improvement associated with timing the water stress near the period of fruit softening and ripening, veraison (Anonymous 1982; Smart, Turkington, and Evans 1974).

The literature concerning the effects of salinity upon grapes is only slightly more extensive than that concerning water relations upon grapes. The general effects of salinity upon irrigated agriculture is well documented in several publications (Ayers and Westcot 1976; Shannon 1979; U.S. Department of Agriculture 1954). The effects of water quality upon vineyard establishment must be investigated in context of regional water resources. Well data from many representative basins and river valleys have been published (U.S. Geological Survey 1981; White et. al. 1981). From these water quality data, we determined the range of concentrations and the composition of saline water of interest to our investigation. These concentrations were, in general, lower than most of those investigated by other researchers, but the concentrations and composition of our experimental salt solutions were more representative of our region's water reserves than solutions previously utilized.

The literature concerning the effects of salinity upon the growth and productivity of grapes is in general agreement about the reduction of these measures with increasing salinity. The degree of reduction apparently varies with the type of growth medium. Two of the trials (Barlass and Skene 1981; Obbink and Alexander 1973) utilized aqueous cultures. Other trials utilized small volumes of soil or sand in containers irrigated with saline water (Al-Saidi 1980; Arbabzadeh-Jolfaee 1981;Bernstein, Ehlig, and Clark 1969; Divate and Pandey 1976, 1979, 1981; Downton 1977b, 1977c; Downton and Loveys 1978; Ehlig 1960; El-Gazzar, El-Azab, and Shehata 1979; Francois and Clark 1979; Gupta and Nauriyal 1973; Hawker and Walker 1978; Kamel et.al. 1977; Walker and Downton 1980). Of these papers, only two (Arbabzadeh-Jolfaee 1981; Downton 1977a) were found which dealt with the effects of saline water irrigation in a natural field setting. The main emphasis of many of the investigations was to index several different cultivars for salinity tolerance. Cultivars were found to differ greatly in their ability to tolerate salinity (Arbabzadeh-Jolfaee 1981; Barlass and Skene 1981; Bernstein, Ehlig and Clark 1969; Downton 1977a; Ehlig 1960; Francois and Clark 1979; Kamel et. al. 1977; Obbink and Alexander 1973). The factor apparently responsible for salinity tolerance is exclusion of chloride ions at the casparian strip in the root cortex. The more salt-tolerant cultivars have been recommended for use as rootstocks for more sensitive and often more commercially important cultivars.

Salinity is reported to affect the quality of wines negatively. This quality degradation has been studied by several investigators.

The results indicate quality degradation is due to ion imbalances in the fruit (Arbabzadeh-Jolfaee 1981; Downton 1977a, 1977c), and to the effects of salinity upon normal metabolic processes and the resultant accumulation of sugars and acids in acceptable balance (Arbabzadeh-Jolfaee 1981; Downton and Loveys 1978; Hawker and Walker 1978). Also, salinity effects upon wine quality has been documented as quite noticeable in sensory scores of wines from salt affected grapes (Arbabzadeh-Jolfaee 1981).

Objectives and Scope of Research

Little is known about water use requirements of wine grapes in southern New Mexico or west Texas. No research into grape water use has previously been conducted in this region. Water management strategies must be developed to maximize both the yield and quality of grapes produced in this region.

The quality of the water present also is of great concern to the producer. Many areas of the Southwest have water reserves with high levels of dissolved salts. While many of the traditional crops grown in this region are relatively tolerant of the salts, grapes and other perennial woody crops may be seriously injured. Guidelines exist for the feasibility of growing various crops dependent upon water quality, but these guidelines were developed for irrigation methods other than trickle. Growers in the Southwest need to know the effects of trickle-applied, low quality, irrigation water upon the growth, productivity, and quality of fruit produced. With such information, they may make appropriate management decisions about planting and irrigating new vineyards.

This research was conducted to answer some of the questions concerning irrigation management of grapes in the Southwest. We employed field trials using different irrigation strategies with three qualities of water in a trickle-irrigated vineyard. The vineyard was located in a closed basin representative of many potential grape-producing areas in the Southwest. The objectives of the investigation were:

1. To gather quantitative and qualitative information on the effects of saline water irrigation upon the growth of vines and the production and quality of fruit

2. To gather quantitative and qualitative information on the effects of various irrigation strategies upon the growth of vines and the production and quality of fruit

3. To gather quantitative and qualitative information on the effect of increased water stress during veraison on the growth of vines and the production and quality of fruit

4. To gather quantitative data on the consumptive use of water by wine grapes

5. To gather quantitative and qualitative information on the movement and accumulation of salts in the rootzone of trickle irrigated grapes

Very soon after the study began, vine diseases were found in our research plots. The diseases were investigated thoroughly by our team and other interested parties. These diseases are now apparently widespread throughout many vineyards in the Southwest. The diseases encountered were:

1. _Phymatotrichum_ _omnivorum_ also known as cotton root rot or Texas root rot. This is a fungal disease attacking the cortex of the root, and ultimately results in vine fatality if not treated. At this time, no universally accepted method of treatment exists.

2. _Agrobacterium_ _tumefaciens_ also known as crown gall. This is a bacterial disease that disrupts the vascular system of the vine and is also untreatable.

Both diseases have profound effects upon an infected vine's ability to extract and transport water through the soil-plant-atmospheric continuum. For this reason, the results obtained by our investigations may not be applicable to healthy vineyards. The patterns of disease created great variability in the responses of the vines in our treatment blocks. Vines planted in the lysimeters were apparently free of disease, but later may have been infected by inoculation from soil brought in during cultivation. Measured leaf area indices, defined as the surface area of the leaves divided by the surface area of the soil, never exceeded 0.2, further indicating a problem with vine vigor and vineyard establishment. The reader is encouraged to consider this situation when making decisions based upon the findings of this report.

MATERIALS AND METHODS

Site Description

The investigation was conducted in a trickle-irrigated commercial vineyard approximately five miles south of Deming, New Mexico. Normal cultivation, fertilization, vine training, and irrigation well maintenance were provided by the cooperating producer. The vineyard's location is approximately 1500 meters elevation above mean sea-level in a closed basin, which is very typical of many potential viticultural areas in the Southwest.

The soil throughout the research plots is a relatively uniform coarse loamy mixed Typic Torrifluvent. The surface 40 to 60 centimeters of the soil profile is composed of a sandy loam with clay contents of about ten per-cent. The second layer of the soil profile is composed of a fine loamy sand to a depth of 100 to 120 centimeters. The third layer is composed of a sandy loam to a depth of 160 to 180 centimeters, at which depth a buried clay loam is encountered. The soil is very young and exhibits less than two percent accumulation of calcium cabonate by weight in the soil's upper meter. Soluble chloride salts were notably absent in the surface meter of the soil profile.

The climate at the research site is classified as warm desert with a late summer maximum of rainfall. Throughout the year there is a great range in the temperatures between day and night. Percentage of possible light intensity hours is very high during the early part of the summer

(May-early July), air temperatures (^{o}F) are usually in the middle to upper nineties, and the air masses are very dry. From the middle of July until the end of September, circulation patterns bring moist air to the region. During this period, more than half the annual average rainfall may be expected, mainly in the form of afternoon thundershowers. Average annual precipitation for the Deming area is approximately eight inches per year. Mean temperature, solar radiation, and Hargreaves-Samani alfalfa reference crop evapotranspiration profiles (Hargreaves and Samani 1985) are presented in table 1.

Site Facilities and Instrumentation

Our investigations were conducted on two adjacent plots, each approximately one-half hectare in size (figure 1). Each plot was planted with 460 pairs of vines, 38 pairs on each of twelve trellises for each of the two varietal plots for a total of 920 vine pairs on twenty-four trellises. On plot one, Cabernet Sauvignon rooted cuttings were planted in May 1984. On plot two, Pinot Chardonnay rooted cuttings were planted in the same month. In July 1984, vines that failed to establish were replaced with transplants from the surrounding vineyard. The vine pairs were located at distances of 2.4 meters along the trellises and the trellises were spaced 3.3 meters apart. Disease forced the replanting of the Pinot Chardonnay vines with bench grafts of disease resistant rootstock. However, these bench grafts were destroyed by jackrabbits invading the vineyard from the surrounding desert. This report will only present data obtained from plot one, the plot planted with Cabernet Sauvignon.

TABLE 1

Average high and low temperature, extraterrestrial radiation (Ra), and potential evapotranspiration (ETo)of alfalfa reference crop as calculated by the Hargreaves-Samani method for Deming, New Mexico.

PERIOD	MAX TEMP (° F)	MIN TEMP (° F)	Ra ($mm\ d^{-1}$)	ETo ($mm\ d^{-1}$)
AP1-15	75.60	40.70	15.00	6.16
AP15-30	75.60	40.70	15.00	6.16
MY1-15	84.90	48.70	16.50	7.92
MY15-31	84.90	48.70	16.50	7.92
JN1-15	94.80	58.50	17.00	9.38
JN15-30	94.80	58.50	17.00	9.38
JL1-15	94.60	65.20	16.80	8.70
JL15-31	94.60	65.20	16.80	8.70
AU1-15	92.30	63.40	15.60	7.80
AU15-31	92.30	63.40	15.60	7.80
SP1-15	87.60	56.80	13.60	6.51
SP15-30	87.60	56.80	13.60	6.51
OC1-15	78.10	44.50	11.20	4.76
OCT15-31	78.10	44.50	11.20	4.76

The vines were irrigated with trickle irrigation emitters of the large-orifice, long-pass type set inline at a spacing of 80 cm. Individual emitters produced an average two liters per hour. The emitter lines were hung from the bottom wire of each trellis at a height of approximately 36 cm. above the ground. One emitter was centered over each vine pair and two additional emitters at 80 cm from the vine pair, one on each side. Each vine pair thus was supplied six liters of water during each hour of system operation. This system design supplied water to the vines in amounts adequate to meet consumptive use throughout the experiment.

Each trellis was segregated into nine sections (figure 1). The first section contained six vine pairs and each of the remaining eight sections contained four vine pairs. The whole plot was divided into three blocks perpendicular to the trellises. These blocks correspond to the treatment blocks discussed later. The twelve trellises were grouped by fours to form three lanes for irrigation treatment application within the plot. The three sections within each block multiplied by the three lanes resulted in nine treatment plots per block. Each treatment plot consisted of sixteen vine pairs arranged four to a trellis on four adjacent trellises (figure 2). The two central vine pairs on each of the two central trellises of each treatment plot served as the location for collection of growth and fruit data. These four vine pairs in each treatment plot were assumed to be free of the effect of adjacent treatments.

Nine water treatments were applied uniformly to each of these treatment plots. The treatments were designated as A-I and a summary of these treatments is presented in table 2. At the edge of each of the three blocks, water was supplied to the trickle lines by risers from nine 1-inch manifolds buried at a depth of eighteen inches. Where the water for one treatment plot passed over another treatment plot, polyethylene tubing without emitters was used.

Water for each of the nine water treatment manifolds was individually controlled by hydraulic water timers. The quantity of water delivered to the manifolds was measured with two 5/8-inch Rockwell water meters connected in series. The average of the two readings was assumed to be the amount delivered. The water pressure in the manifold system was regulated at 110 kPa. Flow rates for the individual manifolds varied by design in the range of 0.158 to 0.174 liters per second. The manifold system and trickle lines were flushed twice yearly to remove accumulated sediment.

The experiment utilized water of three different levels of total dissolved solids, TDS (table 2). The water quality level containing the lowest amount of dissolved solids (350 mg l^{-1} TDS) was obtained directly from the well and filter head belonging to the cooperator. The water then passed through buried pipe to the treatment control station. The increased salinity water treatments (1000 and 1500 mg l^{-1} TDS) were mixed and stored in 10,000 gallon railroad tankcars. The level of total dissolved solids was increased above the well water level by the

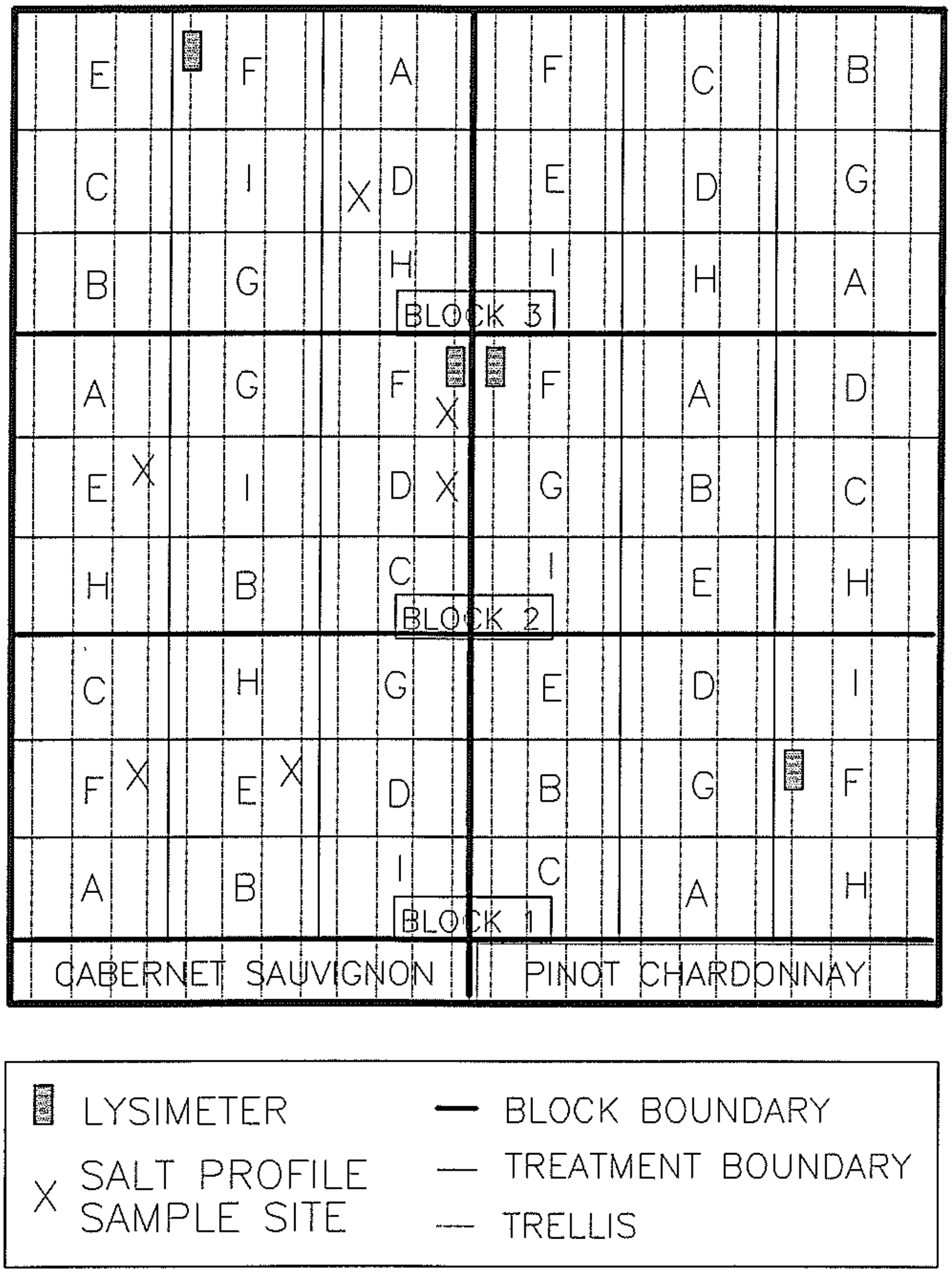


Fig. 1. Diagram of research site. Diagram not to scale.

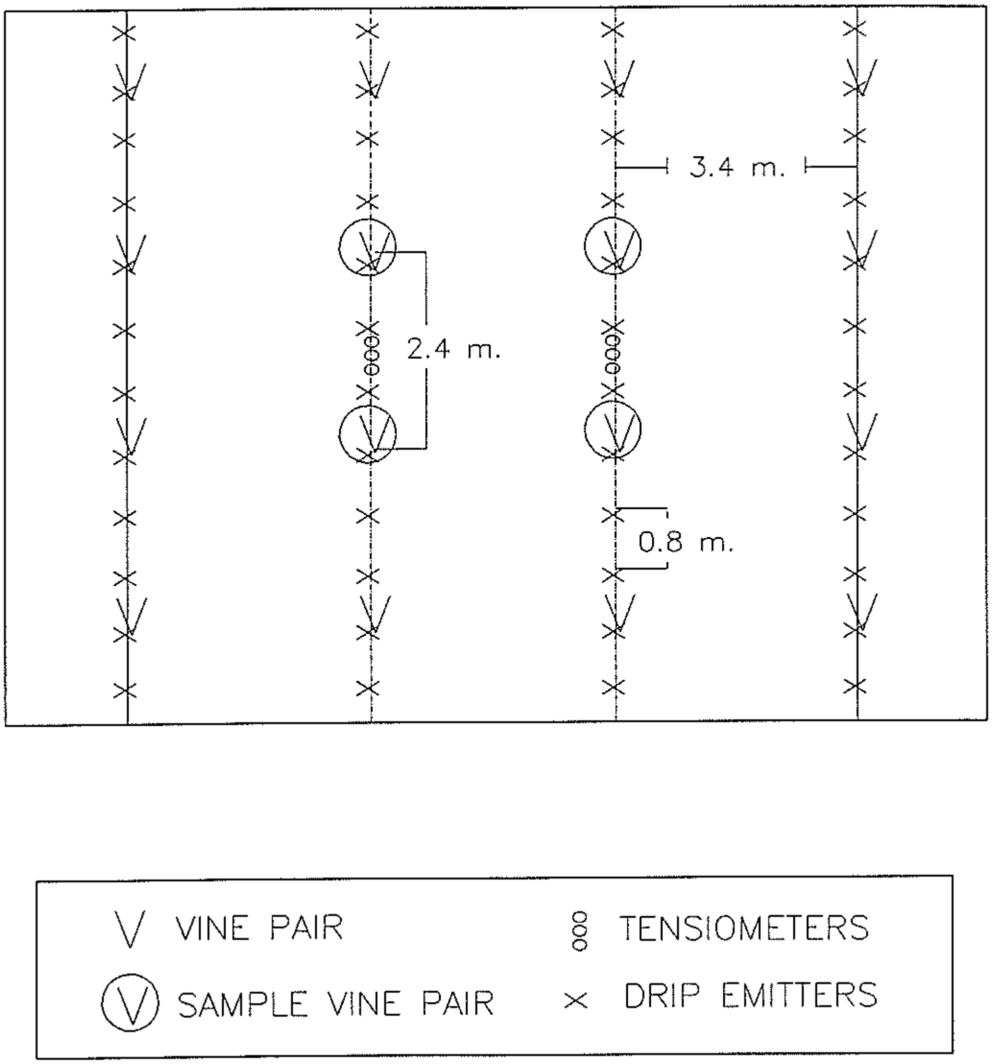


Fig. 2. Diagram of a typical treatment plot.

TABLE 2

Summary of irrigation treatments. WATER is the volume of water applied as a percentage of potential evapotranspiration (PET), TDS is dissolved solids in the irrigation water, EC is the electrical conductivity of the irrigation water, and Cl^- is the chloride content of the irrigation water. The symbol > used in the water application designation for the first three treatments indicates a reduction to the second percentage level at the time of veraison. Locations of the treatment plots are presented in fig. 1.

TREATMENT	WATER (% PET)	TDS (mg l^{-1})	EC (dS m^{-1})	Cl^- (mmol(-) l^{-1})
A	120>60	1500	2.34	10.94
B	120>60	1000	1.56	7.98
C	120>60	350	0.35	0.25
D	120	1500	2.34	10.94
E	120	1000	1.56	7.98
F	120	350	0.35	0.25
G	100	350	0.35	0.25
H	80	350	0.35	0.25
I	60	350	0.35	0.25

addition of an equal weighted mixture of sodium chloride and gypsum. Water from each of the reservoirs was pressurized with jet pumps, filtered, and delivered to the treatment control station via underground pipeline.

In each treatment plot, soil water potential was measured at three depths at two locations. The tensiometers were located equidistant from each of the two vine pairs on each trellis from which data were collected (figure 2). These tensiometers provided verification of our estimates of water use by the grapes and were monitored to insure against underestimating water use.

Consumptive water use by the grapes was estimated from water balance data obtained from large drainage type lysimeters (figure 3). The lysimeters were 1.5 meters wide, 2.4 meters long, and 1.2 meters deep. They were buried so the top of the lysimeter would be almost 1/2-meter below the soil surface. The lysimeter sides were extended upward to the soil surface with plastic sheeting. This depth of burial and plastic extension allowed the cooperator to cultivate as necessary. The two lysimeters per variety plot were located approximately half-way accross the plot from each other. At the interface between the variety plots, two lysimeters, one from each of the two variety plots, were located adjacent to each other.

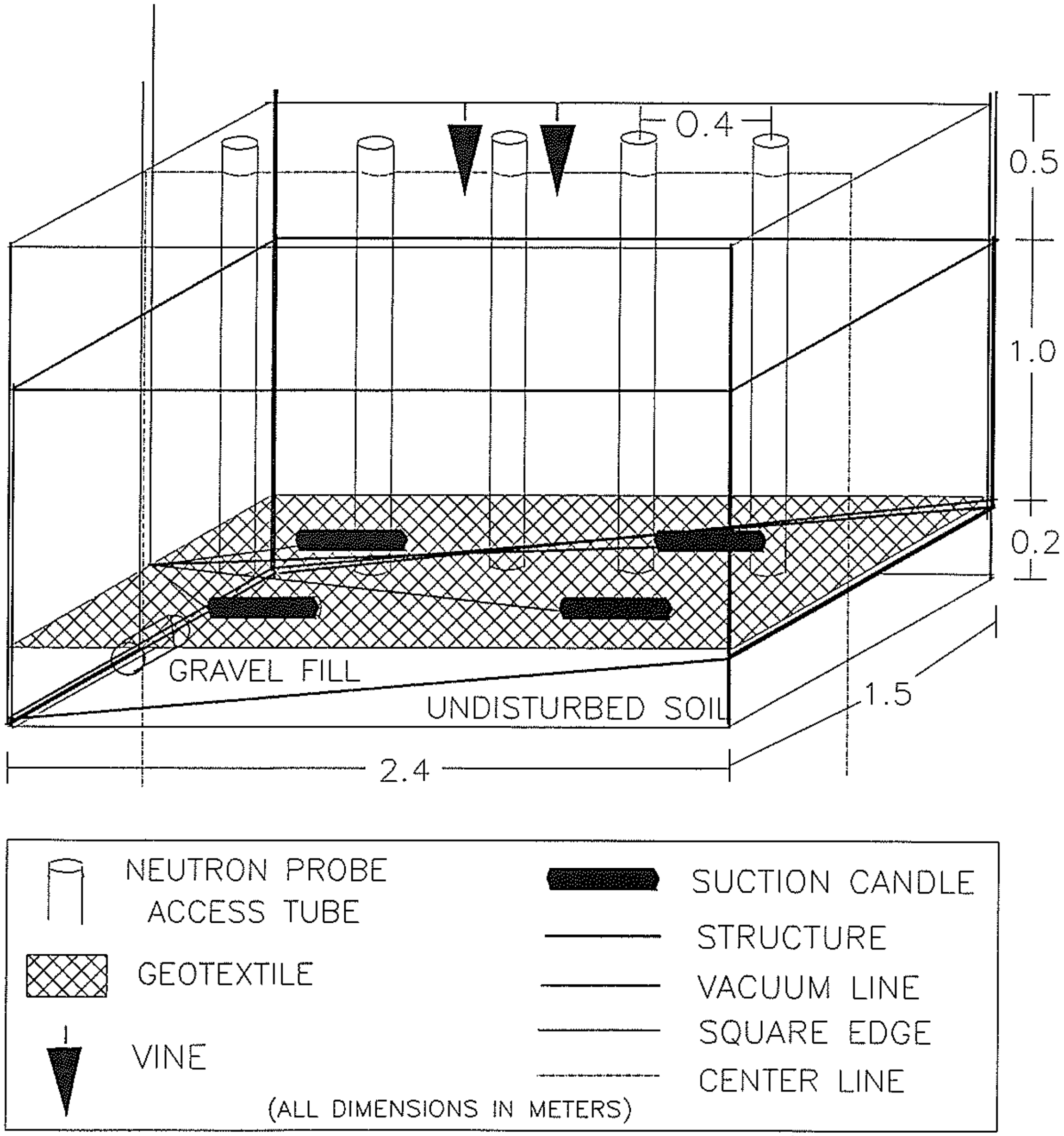


Fig. 3. Diagram of drainage lysimeter used to estimate vine consumptive use of water.

Treatment Application

Our research project encompassed two experiments with a total of nine treatments. One experiment investigated the effects of dissolved solids in irrigation water, the effects of reduced water application during veraison, and the interactions of these two factors upon the growth of the vines, the production of fruit, and the quality of the fruit. This experiment utilized treatments A through F outlined in table 2. The second experiment utilized only the low salinity water and investigated the effects of different water application levels upon the same growth and productivity parameters as in the first experiment. This experiment utilized treatments F through I outlined in table 2. The two experiments were connected by a common treatment F. This was also the treatment in which the lysimeters were located and consumptive use of water was estimated. The nine treatments were repeated three times, once in each of the three blocks (figure 1).

Treatments were initiated in July 1985 and continued through the growing season until August of that year. Irrigation was discontinued at that time to allow proper hardening of the vines for winter. Treatments were applied from April until August in 1986 and 1987 as well. Application of treatments was discontinued after the 1987 growing season due to poor results from the diseased vineyard.

Data Collection

Collection of treatment application data began with the initiation of treatments in July 1985 and continued until the treatments ended in

August 1987. Vine growth was estimated from the weight of prunings removed from sampled vines in each treatment plot after the 1985 and 1986 growing seasons. Fruit productivity data were collected in August 1986. Fruit quality data were collected in August 1986 and August 1987. Consumptive water use data were collected in all three growing seasons in which treatments were applied. Soil cores for salt accumulation analysis were collected at the end of treatment application in August 1987. For all field data collected, field location indices were used to identify samples in order to prevent biased sampling. Data collected from the vines were collected from the four vine pairs at the center of each treatment plot.

The effects of the treatments upon vine growth were estimated from the wood removed from each sampled vine during spring pruning in February, 1985 and 1986. The samples collected represented the growth of the vines during the previous growing season. The prunings from each vine were placed in individual paper sacks, labelled, and returned to New Mexico State University. At our laboratory, the samples were oven dried at 65 °C for fourteen days. The dried samples were then weighed and individual weights recorded.

Fruit production data was collected only during the 1986 growing season. In 1985, there was no fruit production and in 1987, fruit production was so variable that the expense of collection and analysis of production data was deemed not cost effective. For the 1987 growing season, one cluster was removed from each vine bearing fruit to be retained for fruit quality analysis. Notes were collected on vines that did or did not bear fruit. Treatment effects on fruit production were estimated from fruit harvested from the central four vine pairs in each treatment plot in 1986. Fruit was harvested into individually labelled sacks and taken to our laboratory where fruit production parameters could be more easily determined. The fruit harvested from each vine was weighed and the weights recorded. The number of clusters per bearing vine was observed and recorded. The rachi were removed from the fruit cluster, weighed, and recorded by vine. Ten berries were removed from each fruit sample in a treatment plot to determine mean berry weight for that treatment plot. The fruit from each treatment plot was then combined, crushed, and a sample of the fruit retained for quality analysis.

Fruit quality analysis was performed for fruit from the 1986 and 1987 growing seasons. Sugar content was measured by the refractomeric method. Titratable acidity and juice pH were measured with an autotitralizer utilizing 0.1 N NaOH to titrate a 15 ml sample of juice. Fruit chloride contents were measured potentiometrically on a Buchler chloridometer utilizing a 0.25 ml. juice sample (Adriano, Pratt, and Holtzclaw 1973). Data were recorded and tabulated for analysis.

Consumptive water use data were collected for all years in which treatments were applied. Four large drainage lysimeters were installed in the treatment using water with the lowest salt content, applied at the rate of 120 percent of predicted evapotranspiration. In order to estimate deep pecolation losses, water was removed from the bottom of the lysimeter at the end of the growing season. Inputs of irrigation water applied and rainfall received were carefully measured and recorded. Attempts to measure changes of soil moisture storage with a neutron probe were unsuccessful. Although the probe was carefully calibrated on-site, water appeared to move downward through the soil in a relatively narrow band. This limited path of post-irrigation water movement caused problems with soil moisture content measurement. The neutron probe may have had a larger sphere of influence relative to the path of downward moving water. Estimates of vine consumptive water use were, therefore, confined to seasonal totals. Tensiometers were employed to check assumptions of negligible change in stored moisture.

The movement and accumulation of soluble salts in the rootzone of the treatment vines were estimated from 2.5 centimeter diameter cores of soil removed from a three dimensional grid around two selected vines in each of three treatments representing the three water salt levels. The grids were centered on the vines sampled and extended to one side only of the trellis. Markers were placed on the surface of the soil at the base of the vine and at distances of 40 and 80 centimeters to either side of the vine along the trellis (figure 4). At each of these five locations along the trellis length, samples were also taken at distances of 30 and 60 centimeters from and perpendicular to the trellis. Thus, soil cores were collected from fifteen surface locations and at six depths from each of these locations for a total of 90 samples per vine.

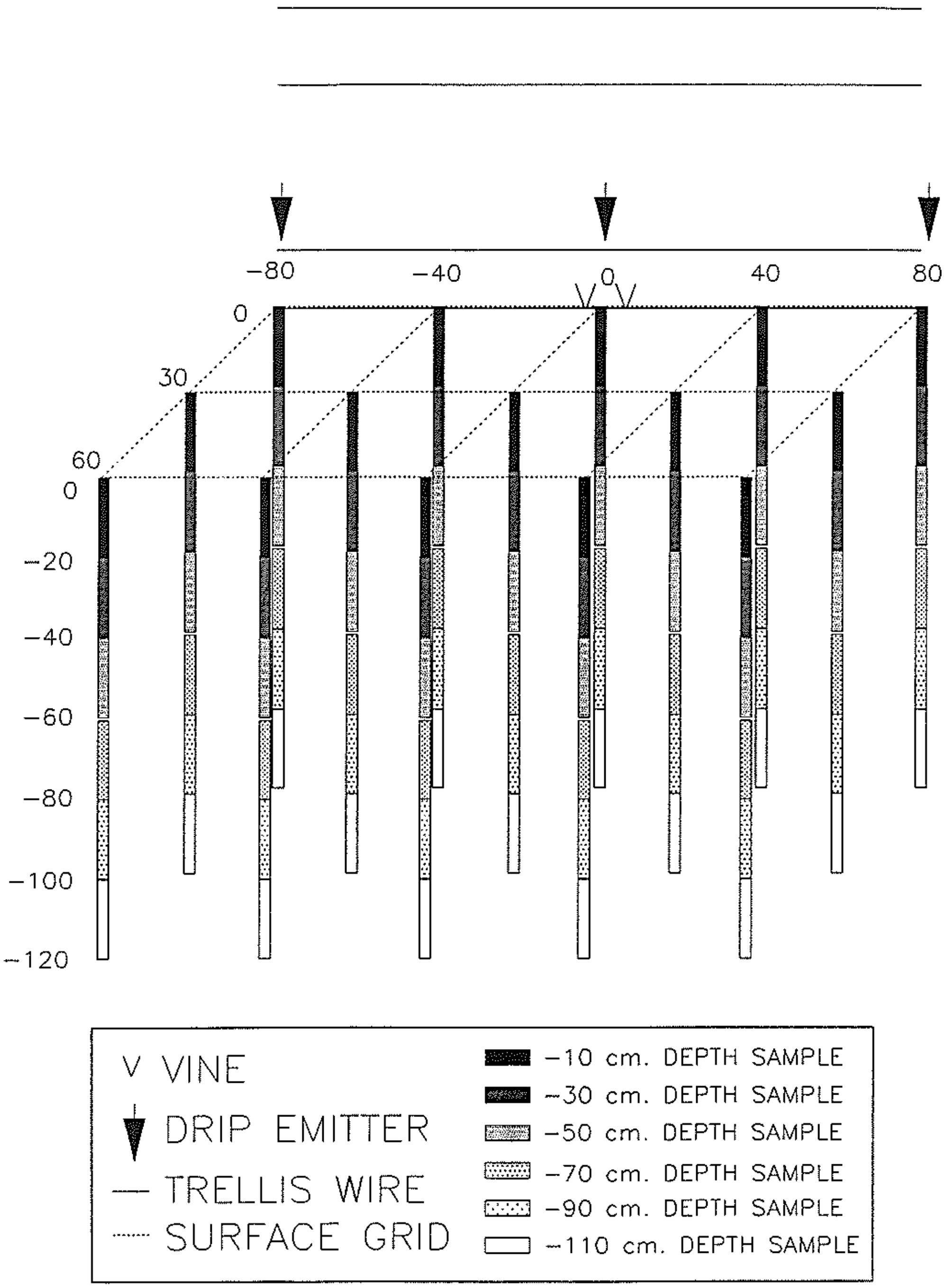


Fig. 4. Three dimensional diagram of soil salinity profile sample strategy within a typical sampling location.

Two vines from each of three treatments were sampled for a grand total of 540 soil samples.

The soil cores were collected and returned to our laboratory where they were oven dried at 65° C for 48 hours. This drying routine should not have changed the properties of the soluble salts and insured equal soil sample weights for the extraction procedure. Following drying, samples were crushed between wood blocks and passed through a 2 mm mesh sieve to remove sticks and rocks from the samples. Individual soil samples were weighed, placed in beakers, and a weight of water equal to twice the weight of soil was added to the beaker. Samples were stirred three times during the 48-hour equilibration period. Evaporation during this equilibration period was estimated from dummy beakers placed at random throughout the equilibrating samples. Equilibrated samples were then passed through #42 filter paper and the filtrate retained for analysis. Electrical conductivity measurements were performed on a solubility bridge. Chloride contents of the filtrate were measured potentiometrically on a Buchler chloridometer (Adriano, Pratt, and Holtzclaw 1973). Results from these analyses were adjusted for dilution effect to reflect the conditions in the soil solution held at -20 kPa soil water potential.

Data Analysis

For the statistical analysis of the effects of our treatments upon the growth, productivity, and fruit quality of the vines, averages were used from data collected at the four vines (two vine pairs) adjacent to each set of tensiometers. This allowed for two observations per treatment plot. The following response variables were utilized to test treatment effects upon the vines:

1. Growth of the vines - The weight of prunings collected from the sampled vines in the 1985 and 1986 growing seasons

2. Fruit yield of the vines - The total weight of fruit harvested, number of clusters per vine, mean berry weight, crush weight (total yield minus the weight of the woody portion of the harvest), number of berries per cluster, and the mean cluster weight for the sampled vines in the 1986 growing season

3. Fruit quality - fruit sugar measured in degrees Brix, must pH, titratable acidity measured in equivalent grams of tartaric acid per liter of must, fruit chloride content measured in mmol of chloride ion per liter of must, and the sugar to acid ratio of fruit collected in the 1986 and 1987 growing season

The effects of added salts upon the vine parameters were investigated along with the effects of increased water stress during veraison. This combination was analyzed as a 2 X 3 factorial with an analysis of variance and an orthogonal set of contrasts testing main and interaction effects. The block by treatment interaction terms generated in the analysis of variance tables were used for testing the treatment effect terms. Regressions of the vine parameters were run against the soil water potentials by water quality class and the differences in slope and intercept were tested with contrasts. Treatments A through F were utilized for these analyses.

The effects of irrigation strategy upon the vine parameters were analyzed with regression of the same response variables by the percentage of potential evapotranspiration and the mean seasonal soil tensions. Both linear and quadratic model terms were provided for the Statistical Analysis System (SAS) stepwise model fitting proceedure. Treatments F through I were utilized for this analysis. Regression by salinity class was used with treatments A through F to investigate the effects of soil moisture availability upon the vine parameters in these treatments with different qualities of water.

Consumptive use of water by the vines was estimated by totalling the irrigation depths and precipitation amounts within each growing season from 1985 to 1987 and subtracting the drainage obtained from the lysimeters from the total depth of inputs.

The movement and accumulation of tracer salts present in the irrigation water were analyzed graphically. The data for each sampling location was tabulated and sorted into families of planar regions through the soil profile in the following orientations:

1. Parallel to the soil surface (figure 5)

2. Perpendicular to the soil surface and parallel to the trellis (figure 6)
3. Perpendicular to the soil surface and to the trellis (figure 7)

These sorted data sets were interpolated geostatistically, Kriged, to provide 5 cm nodes and these Kriged data sets were plotted as contour plots. The ratio of the chloride ion concentration in the soil solution to that in the irrigation water was averaged across all four sample sites from treatments receiving water of increased salinities and similarly plotted. All families of planes were assumed to be symmetric about the vine pair. Values represented on these plots are the means of eight observations except for values in the plane and along the edges of the planes contacting the vine pair where values presented are the means of four observations.

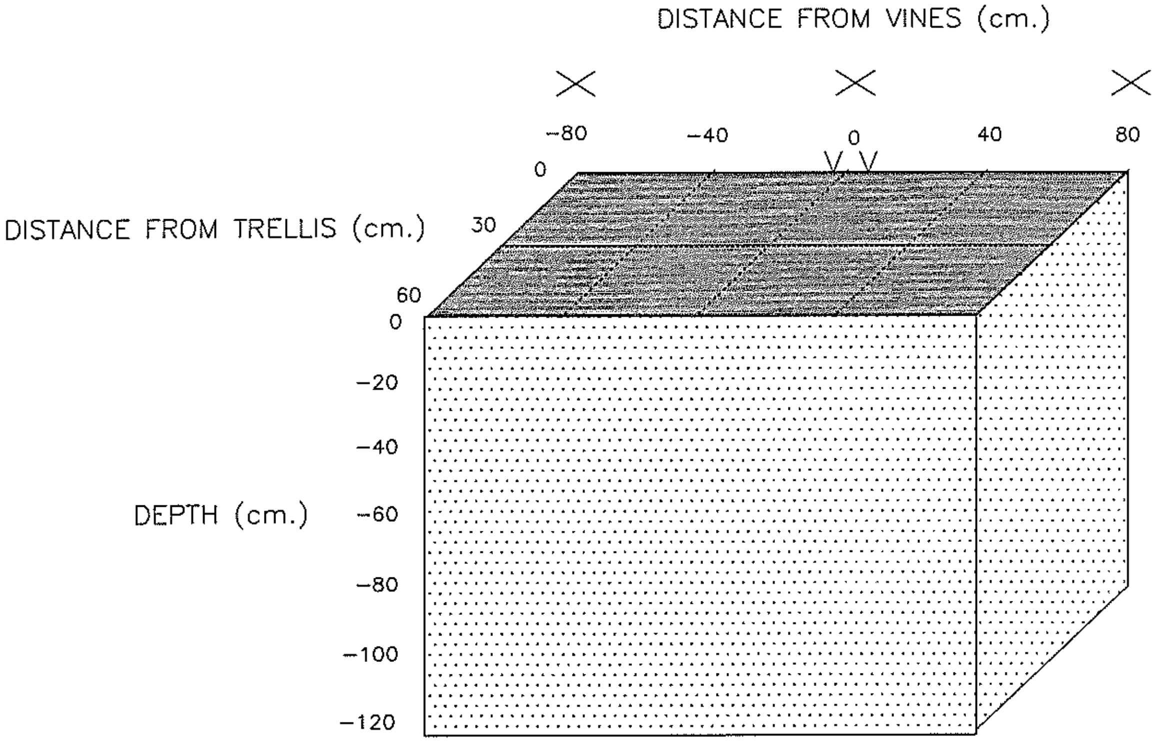


Fig. 5. Reference plane for graphic presentations of soil salinity profiles (figures 23, 26, and 29). Plane is parallel to the soil surface.

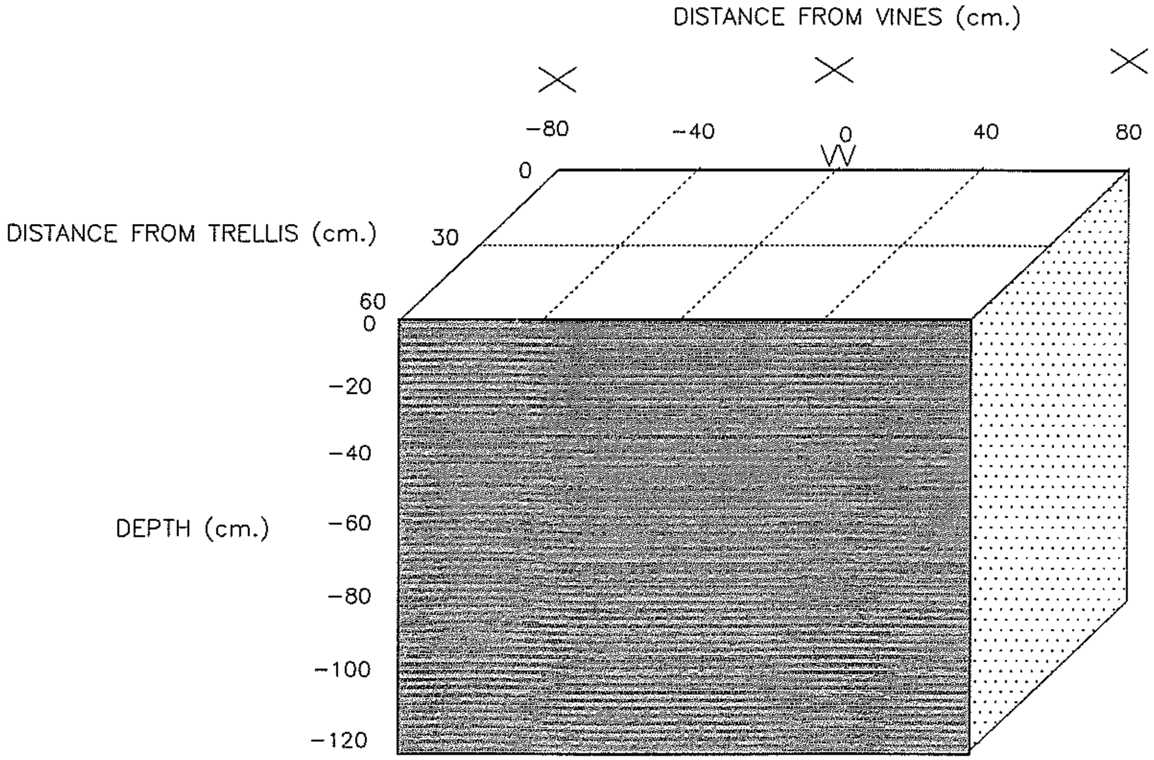


Fig. 6. Reference plane for graphic presentations of soil salinity profiles (figures 24, 27, and 30). Plane is perpendicular to the soil surface and parallel to the trellis system.

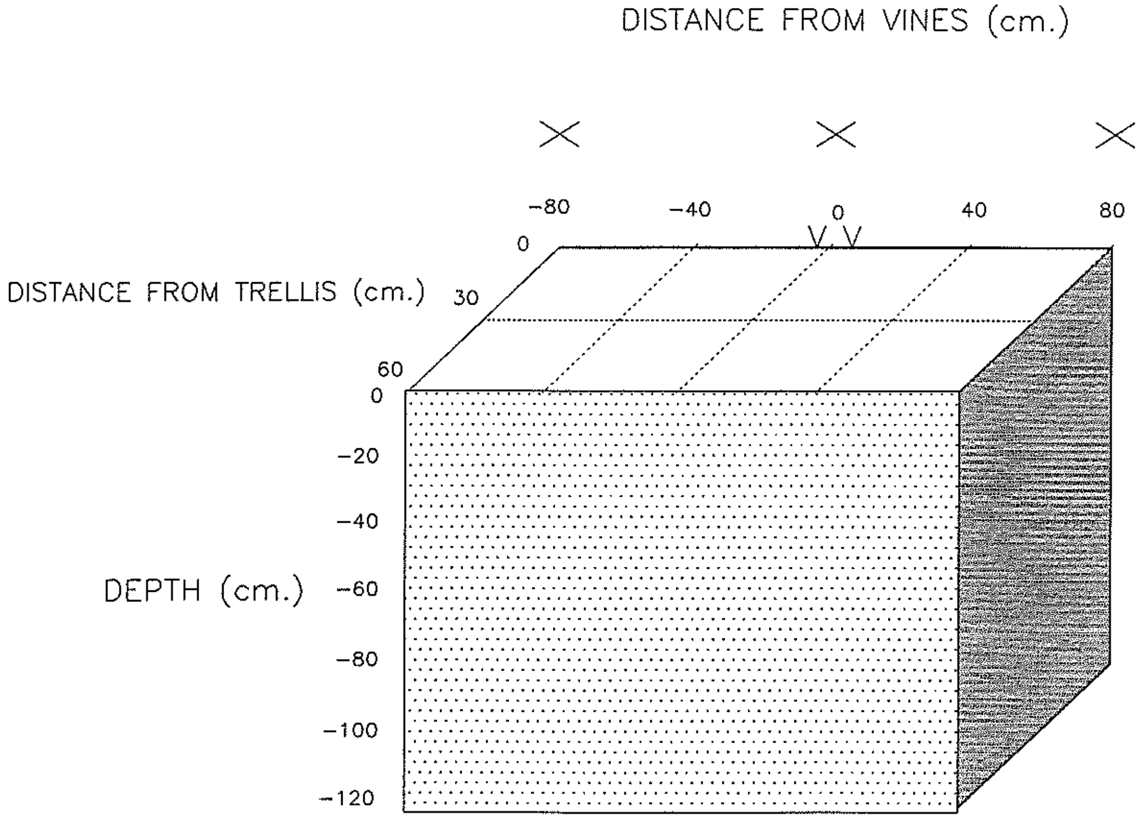


Fig. 7. Reference plane for graphic presentations of soil salinity profiles (figures 25, 28, and 31). Plane is perpendicular to the soil surface and perpendicular to the trellis system.

RESULTS AND DISCUSSION

The presence of two diseases in our research vineyard seriously compromised the validity of our results. Although significant treatment differences were found throughout the data analyses, these differences were rarely found to be significant in successive years. Many differences noted made no biological sense in the context of the experiment or were contrary to the body of literature existing on the subject in question. Means by block of data collected of vine growth in the 1985 growing season, vine growth in the 1986 growing season, fruit yield in the 1986 growing season, fruit quality in the 1986 growing season, and fruit quality in the 1987 growing season are presented in tables 3, 4, 5, 6, and 7 respectively. Graphic presentations of vine growth in the 1985 growing season, vine growth in the 1986 growing season, and fruit yield in the 1986 growing season are presented in figures 8, 9, and 10 respectively.

Salinity Effects

The effects of saline irrigation water on vine growth, productivity, and fruit quality are, according to the literature, deleterious. In 1985, vines in the 1500 mg l^{-1} treatments grew significantly more than vines in treatments utilizing water of lesser salinities (table 3, figure 8). We must conclude that these results are spurious since they are not supported by the findings of other researchers and, more importantly, similar results were not obtained in the following year. In the 1986 growing season, no significant salinity effects upon vine growth were noted (table 4, figure 9). Significant block effects, indicating differences in overall means between blocks, and significant block by treatment interactions, indicating different treatment treatment effects means between blocks, were present in 1986 analyses, indicating a nonrandomly distributed problem with the vines at the research site. No significant salinity effects upon fruit yield were noted (table 5, figure 10). However, fruit quality was shown to be significantly affected by the salinity of the irrigation water. In fruit must extracts made during the 1986 growing season, fruit chloride was found to be influenced by the interaction of salinity and veraison water stress levels (table 6). In the 1987 growing season, fruit must extracts showed a strong dependence of fruit chloride levels on irrigation water salinity levels (table 7).

Water Treatment Effects

The effects of irrigation strategy and veraison irrigation cutback upon vine parameters were more difficult to interpret (tables 3-7, figures 8-10). The disease problems present can be expected to cause moderate to severe water stress in the affected vines. These stress factors are difficult to quantify and thus difficult to separate from the effects of imposed soil moisture stress. In many cases, regression analysis of vine and fruit response variables against soil water potentials yielded slopes and intercepts indicating that optimal growth, production, and quality can be obtained at very negative soil water potentials. This is contrary to the findings of other researchers and is believed to have been caused by the limited ability of diseased vines to extract sufficient water from the soil water reservoir to draw soil moisture potentials below those of the soil at field capacity during irrigation intervals.

Irrigation strategy was not found to affect vine growth significantly (tables 3 and 4, figures 8 and 9). Regressions of vine growth against soil water potentials often indicated an inverse relationship between water availability and growth. These results did not seem to be influenced by the additional osmotic potential imposed by the salts in the increased salinity treatments.

Fruit yield and quality data were also apparently not greatly influenced by irrigation strategy. Yield and crush weight were found to be inversely proportional to the quantity of water applied (table 5, figure 10). Regressions of fruit yield response variables against soil water potentials almost always resulted in the fit of negative slopes. This again indicated an inverse relationship of fruit yield and soil water potential. In the 1986 growing season, no effects of irrigation strategy upon quality were found (Table 6). Regression of fruit sugar against soil water potentials indicated a highly significant positive relationship. Again, this result is contrary to results obtained elsewhere. Irrigation strategy was shown to affect significantly the acid to sugar ratio in fruit musts obtained during the 1987

TABLE 3

Mean weights of prunings taken from eight individual vines by treatment and block for the 1985 growing season. WATER is the water application based on the percentage of potential evapotranspiration estimated for treatment G, TDS is the total dissolved solids in the irrigation water applied to the vines, TENSION is the mean seasonal soil water potential for the same growing season, and PRUN WT is the mean weight of prunings.

TREATMNT	BLOCK	WATER (% PET)	TDS (mg/l)	TENSION (kPa)	PRUN WT (g)
A	1	120>60	1500	-25.49	123.75
A	2	120>60	1500	-28.29	108.55
A	3	120>60	1500	-17.94	105.88
B	1	120>60	1000	-19.57	98.29
B	2	120>60	1000	-25.23	109.01
B	3	120>60	1000	-19.32	96.37
C	1	120>60	350	-21.14	110.45
C	2	120>60	350	-20.92	67.30
C	3	120>60	350	-26.61	102.65
D	1	120	1500	-18.03	113.07
D	2	120	1500	-21.73	130.57
D	3	120	1500	-17.08	107.94
E	1	120	1000	-23.49	94.17
E	2	120	1000	-20.66	66.85
E	3	120	1000	-20.54	91.44
F	1	120	350	-24.23	96.35
F	2	120	350	-19.67	97.67
F	3	120	350	-17.77	100.90
G	1	100	350	-17.60	89.63
G	2	100	350	-28.77	121.16
G	3	100	350	-28.70	64.60
H	1	80	350	-17.98	92.42
H	2	80	350	-18.57	97.10
H	3	80	350	-16.72	54.86
I	1	60	350	-18.47	68.07
I	2	60	350	-25.92	100.43
I	3	60	350	-25.61	77.23

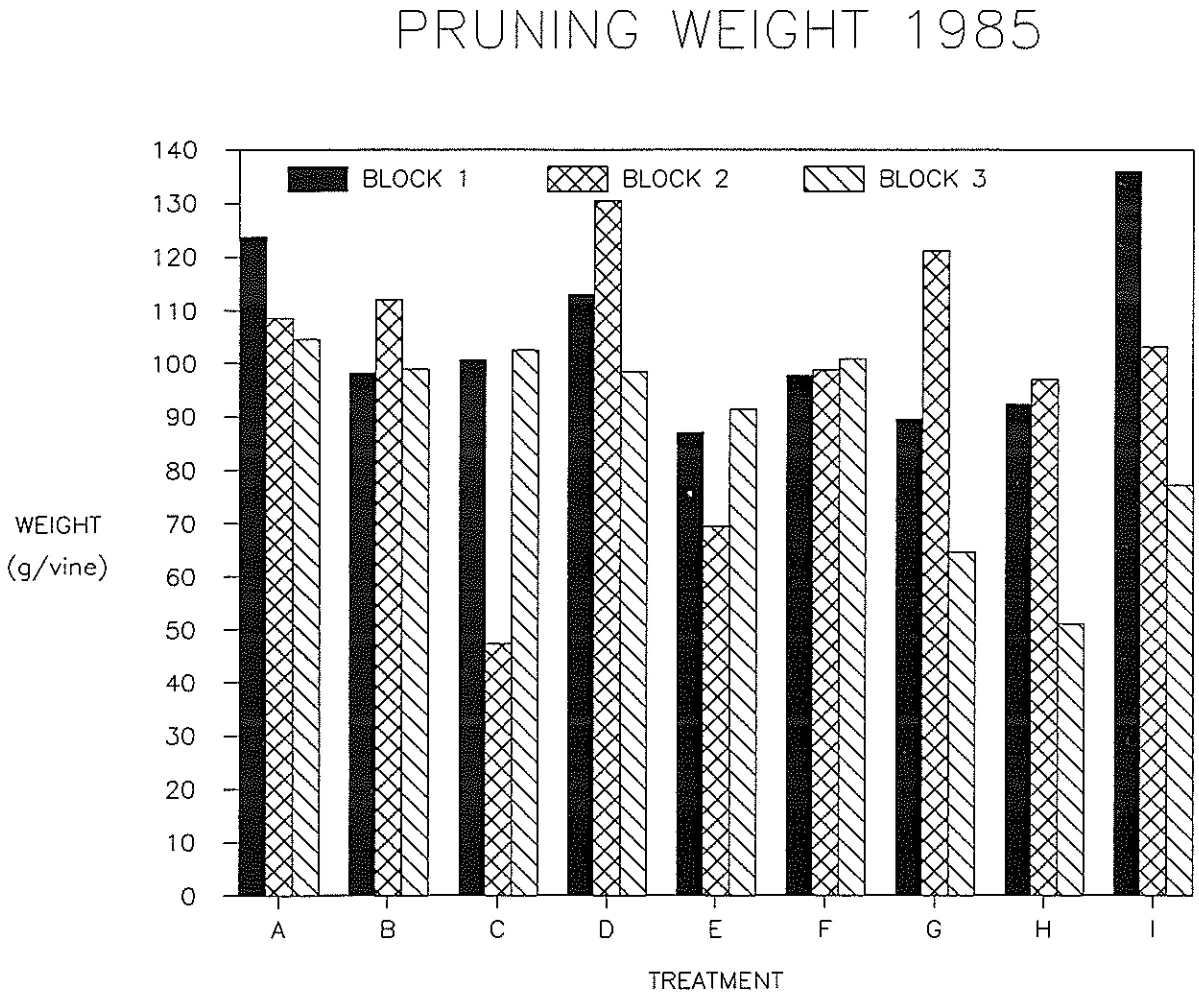


Fig. 8. Mean weight of prunings collected from vines after the 1985 growing season by treatment and block. Values presented represent the mean pruning weights of eight sampled vines (four vine pairs) in each treatment plot. Treatment specifications may be found in table 3.

TABLE 4

Mean weights of prunings taken from eight individual vines by treatment and block for the 1986 growing season. WATER is the water application based on the percentage of potential evapotranspiration estimated for treatment G, TDS is the total dissolved solids in the irrigation water applied to the vines, TENSION is the mean seasonal soil water potential for the same growing season, and PRUN WT is the mean weight of prunings.

TREATMNT	BLOCK	WATER (% PET)	TDS (mg/l)	TENSION (kPa)	PRUN WT (g)
A	1	120>60	1500	-25.22	255.61
A	2	120>60	1500	-21.64	114.30
A	3	120>60	1500	-28.86	309.30
B	1	120>60	1000	-26.61	339.91
B	2	120>60	1000	-22.21	355.68
B	3	120>60	1000	-14.89	60.08
C	1	120>60	350	-20.65	220.30
C	2	120>60	350	-25.77	227.19
C	3	120>60	350	-15.43	109.64
D	1	120	1500	-14.93	198.50
D	2	120	1500	-21.28	111.85
D	3	120	1500	-11.64	90.91
E	1	120	1000	-23.49	379.84
E	2	120	1000	-15.10	26.44
E	3	120	1000	-13.53	53.93
F	1	120	350	-22.99	261.48
F	2	120	350	-19.79	283.06
F	3	120	350	-20.68	209.51
G	1	100	350	-22.82	276.98
G	2	100	350	-29.52	278.78
G	3	100	350	-16.55	26.15
H	1	80	350	-23.01	273.30
H	2	80	350	-16.85	230.54
H	3	80	350	-25.21	70.39
I	1	60	350	-19.93	339.85
I	2	60	350	-21.64	158.71
I	3	60	350	-32.08	135.51

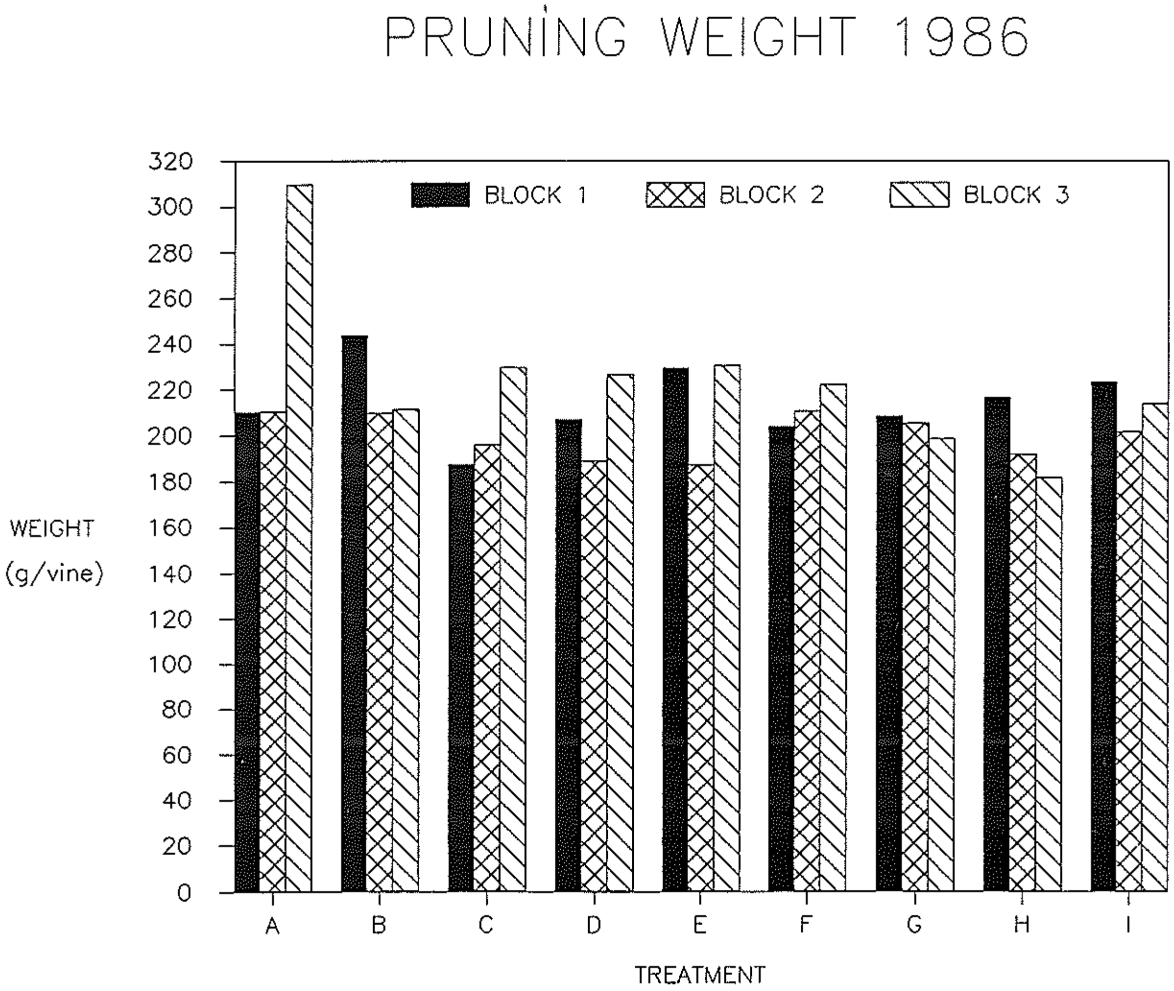


Fig. 9. Mean weight of prunings collected from vines after the 1986 growing season by treatment and block. Values presented represent the mean pruning weights of eight sampled vines (four vine pairs) in each treatment plot. Treatment specifications may be found in table 4.

TABLE 5

Fruit yield data for the 1986 growing season. Values represented are means of eight individual vines sampled by treatment and block. WATER is the water application based on the percentage of potential evapotranspiration estimated for treatment G, TDS is the total dissolved solids in the irrigation water applied to the vines, and VERN TEN is the mean soil water potential for the period of veraison. YIELD is the total weight of fruit clusters harvested per vine, CLUSTERS is the number of fruit clusters produced per vine, BER WT is the weight of individual berries (grapes), CRUSH WT is the weight of the de-stemmed fruit per vine, BERRIES is the total number of berries produced per vine, BER/CLUS is the number of berries per fruit cluster, and CLUST WT is the weight of the fruit clusters collected.

TREATMNT	BLOCK	WATER (% PET)	TDS (mg/l)	VERN TEN (kPa)	YIELD (kg/Ha)	CLUSTERS (#/vine)	BER WT (g)	CRUSH WT (kg/Ha)	BERRIES (#/vine)	BER/CLUS	CLUST WT (g)
A	1	120>60	1500	-25.23	28.30	1.38	0.90	29.59	13.36	2.23	2.00
A	2	120>60	1500	-21.64	48.25	0.92	1.05	40.11	15.51	6.57	6.90
A	3	120>60	1500	-28.86	497.93	7.38	0.89	461.62	210.06	17.77	15.87
B	1	120>60	1000	-26.61	102.27	1.25	1.02	99.57	39.68	8.52	8.69
B	2	120>60	1000	-22.21	236.41	2.63	1.00	219.95	89.19	11.72	11.75
B	3	120>60	1000	-14.89	28.67	0.63	0.79	27.95	14.44	10.84	8.53
C	1	120>60	350	-20.65	90.01	2.13	0.74	84.84	46.60	8.66	6.41
C	2	120>60	350	-25.77	330.53	5.25	1.07	310.30	118.25	16.05	17.13
C	3	120>60	350	-15.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D	1	120	1500	-14.93	354.15	4.00	0.96	334.44	141.03	17.82	17.17
D	2	120	1500	-21.28	428.93	3.25	1.15	407.65	143.85	18.05	20.80
D	3	120	1500	-11.64	452.70	5.63	0.98	184.90	76.38	13.18	12.97
E	1	120	1000	-23.49	593.15	7.25	1.17	569.12	198.30	20.25	23.62
E	2	120	1000	-15.10	39.30	0.88	0.73	38.07	21.20	8.05	5.88
E	3	120	1000	-13.53	97.14	2.00	0.87	94.22	44.15	8.76	7.60
F	1	120	350	-22.99	15.71	0.50	0.68	14.33	8.60	5.65	3.82
F	2	120	350	-19.79	663.95	5.13	1.36	628.62	187.55	14.08	19.18
F	3	120	350	-20.68	242.46	4.75	1.02	185.33	73.68	10.45	10.68
G	1	100	350	-22.82	311.10	4.50	0.67	293.97	178.36	22.07	14.79
G	2	100	350	-29.52	258.33	4.38	0.87	246.28	114.85	19.56	17.05
G	3	100	350	-16.55	35.06	0.88	0.67	31.43	18.94	12.72	8.58
H	1	80	350	-23.01	419.77	6.38	1.28	371.89	117.88	10.23	13.12
H	2	80	350	-16.85	110.05	1.58	1.01	105.72	42.76	14.23	14.30
H	3	80	350	-25.21	214.27	2.58	1.03	192.12	75.64	13.65	14.10
I	1	60	350	-19.93	525.89	5.96	1.05	500.12	193.25	19.34	20.34
I	2	60	350	-21.64	568.29	5.88	0.97	544.55	229.39	34.40	33.19
I	3	60	350	-32.08	509.53	5.50	0.95	483.76	207.73	22.92	21.70

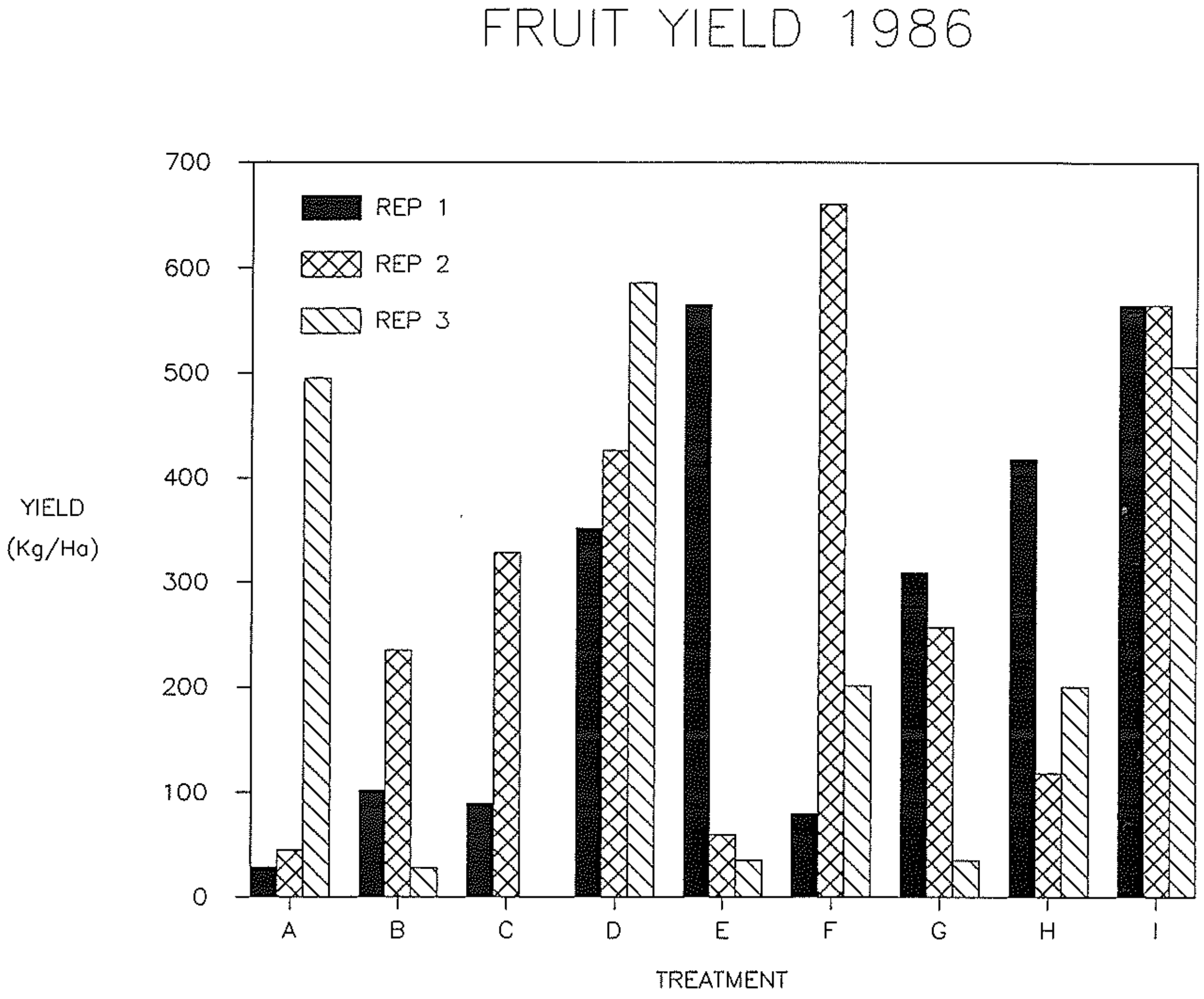


Fig. 10. Mean weight of fruit harvested from vines during the 1986 growing season by treatment and block. Values presented represent the mean fruit yields of eight sampled vines (four vine pairs) in each treatment plot. Treatment specifications may be found in table 5.

TABLE 6

Fruit quality data for the 1986 growing season presented by treatment and block. WATER is the water application based on the percentage of potential evapotranspiration estimated for treatment G, TDS is the total dissolved solids in the irrigation water applied to the vines, and TENSION is the mean soil water potential for the period of veraison, Cl is the chloride content of the irrigation water applied, SUGAR is the fermentable sugars present in the juice, pH is the pH of the juice, ACID is the titratable acidity of the juice expressed in equivalent weight of tartaric acid, RATIO is the ratio of fruit sugar to acid, and Cl is the chloride content of the fruit juice.

TRTMT	BLOCK	WATER (% PET)	TDS (mg/l)	TENSION (kPa)	Cl (mmol/l)	SUGAR (Dg BRIX)	pH	ACID (g/l)	RATIO	Cl (mmol/l)
A	1	120>60	1500	-25.2	10.94	20.50	3.24	10.62	1.93	1.148
A	2	120>60	1500	-21.6	10.94	17.00	3.49	4.17	4.08	1.176
A	3	120>60	1500	-28.9	10.94	20.25	3.36	7.51	2.70	2.092
B	1	120>60	1000	-26.6	7.98	20.50	3.52	4.60	4.46	1.592
B	2	120>60	1000	-22.2	7.98	18.00	3.11	4.51	3.99	1.352
B	3	120>60	1000	-14.9	7.98	21.25	3.55	4.29	4.95	6.228
C	1	120>60	350	-20.6	0.25	22.25	3.64	4.27	5.21	1.088
C	2	120>60	350	-25.8	0.25	21.25	3.47	4.89	4.35	1.968
C	3	120>60	350	-15.4	0.25	insufficient sample size				
D	1	120	1500	-14.9	10.94	20.75	3.01	8.46	2.45	1.652
D	2	120	1500	-21.3	10.94	17.25	2.75	13.88	1.24	5.304
D	3	120	1500	-11.6	10.94	21.75	3.03	8.34	2.61	4.156
E	1	120	1000	-23.5	7.98	18.00	2.97	9.49	1.90	1.44
E	2	120	1000	-15.1	7.98	17.00	3.32	4.36	3.90	2.916
E	3	120	1000	-13.5	7.98	23.75	3.63	4.29	5.54	5.168
F	1	120	350	-23.0	0.25	13.00	2.70	23.76	0.55	1.032
F	2	120	350	-19.8	0.25	18.75	3.06	4.36	4.30	1.396
F	3	120	350	-20.7	0.25	21.50	3.43	5.71	3.77	1.656
G	1	100	350	-22.8	0.25	19.75	3.37	5.21	3.79	1.584
G	2	100	350	-29.5	0.25	21.25	3.16	6.93	3.07	1.488
G	3	100	350	-16.6	0.25	23.25	3.30	3.92	5.93	2.06
H	1	80	350	-23.0	0.25	21.75	3.29	5.52	3.94	1.348
H	2	80	350	-16.9	0.25	19.25	3.23	5.72	3.37	1.696
H	3	80	350	-25.2	0.25	23.00	3.47	4.00	5.75	2.02
I	1	60	350	-19.9	0.25	20.00	3.10	6.56	3.05	1.344
I	2	60	350	-21.6	0.25	22.00	3.50	3.93	5.60	1.588
I	3	60	350	-32.1	0.25	22.00	3.45	6.55	3.36	1.42

TABLE 7

Fruit quality data for the 1987 growing season presented by treatment and block. WATER is the water application based on the percentage of potential evapotranspiration estimated for treatment G, TDS is the total dissolved solids in the irrigation water applied to the vines, and TENSION is the mean soil water potential for the period of veraison, Cl is the chloride content of the irrigation water applied, SUGAR is the fermentable sugars present in the juice, pH is the pH of the juice, ACID is the titratable acidity of the juice expressed in equivalent weight of tartaric acid, RATIO is the ratio of fruit sugar to acid, and Cl is the chloride content of the fruit juice.

TRTMT	BLOCK	WATER (% PET)	TDS (mg/l)	TENSION (kPa)	Cl (mmol/l)	SUGAR (Dg BRIX)	pH	ACID (g/l)	RATIO	Cl (mmol/l)
A	1	120>60	1500	-14.19	10.94	22.00	2.86	7.80	2.82	1.932
A	2	120>60	1500	-14.95	10.94	23.00	2.90	5.91	3.89	0.556
A	3	120>60	1500	-15.71	10.94	21.25	2.92	6.39	3.33	1.928
B	1	120>60	1000	-16.62	7.98	18.75	2.74	10.54	1.78	0.768
B	2	120>60	1000	-10.86	7.98	20.75	2.94	6.09	3.41	1.728
B	3	120>60	1000	-10.58	7.98	22.25	2.94	6.26	3.55	0.864
C	1	120>60	350	-40.21	0.25	22.50	2.89	6.86	3.28	0.452
C	2	120>60	350	-37.85	0.25	19.25	2.77	8.01	2.40	1.304
C	3	120>60	350	-32.18	0.25	21.75	2.96	5.41	4.02	0.532
D	1	120	1500	-11.56	10.94	20.50	2.89	6.59	3.11	1.824
D	2	120	1500	-13.75	10.94	21.00	2.93	6.26	3.35	3.308
D	3	120	1500	-9.46	10.94	20.75	2.94	6.18	3.36	3.272
E	1	120	1000	-13.95	7.98	19.50	2.78	8.25	2.36	0.884
E	2	120	1000	-9.71	7.98	21.50	2.82	6.73	3.19	0.800
E	3	120	1000	-9.83	7.98	22.50	3.00	5.85	3.85	0.960
F	1	120	350	-23.76	0.25	22.25	2.90	6.40	3.48	0.444
F	2	120	350	-25.41	0.25	22.00	2.84	6.64	3.31	1.868
F	3	120	350	-28.16	0.25	20.25	2.96	6.29	3.22	1.068
G	1	100	350	-21.78	0.25	21.25	2.92	6.69	3.18	1.052
G	2	100	350	-22.70	0.25	17.50	2.90	6.21	2.82	1.212
G	3	100	350	-18.62	0.25	19.00	2.97	5.96	3.19	1.168
H	1	80	350	-24.18	0.25	19.75	2.92	6.43	3.07	1.024
H	2	80	350	-11.98	0.25	22.00	2.83	7.45	2.95	0.600
H	3	80	350	-23.51	0.25	21.00	2.90	6.50	3.23	1.260
I	1	60	350	-12.32	0.25	20.75	2.91	6.96	2.98	0.972
I	2	60	350	-32.41	0.25	19.50	2.93	6.32	3.09	2.024
I	3	60	350	-29.06	0.25	18.00	2.89	6.28	2.87	0.932

growing season (table 7). During this same year, the regression analyses of fruit sugar and fruit titratable acidity against soil water potentials indicated that sugar increased and acid decreased linearly with soil water potential. These results were significant at very high probability levels, but were not consistent with the results normally obtained in similar studies.

Irrigation reduction during veraison apparently had little effect on the growth or the fruit yield of the vines. A slight, but insignificant trend was noticed for the vines in full irrigation treatments to yield more fruit than the vines in the reduced treatments (table 5, figure 10). Fruit quality did seem to be affected by temporary moisture stress to a slightly greater extent than growth and yield. In 1986, veraison moisture stress treatments yielded fruit with significantly higher pH, lower acid and lower acid to sugar ratio than vines receiving full irrigation quantities (table 6). Fruit chloride levels were found to be increased by the interaction of water stress and salinity levels (table 6). This same result was duplicated in 1987 (table 7). In both cases, the probability levels of significance were greater than 92%.

Consumptive Use of Water

Consumptive water use was estimated by the water balance method from data obtained from irrigation depth records of treatment F (120 % PET), precipitation records, and drainage water removal records for the drainage lysimeters located at our research site. Water was removed from the lysimeters at the end of the 1984 growing season indicating active drainage. During the 1985 growing season, 166 mm of irrigation were applied to the vines in the lysimeters through the irrigation system (figure 11) and an additional 198 mm were added by precipitation (figure 12). Less than 2 mm of water on the average were removed from the lysimeters at the end of the same season resulting in a net estimate of 364 mm lost to evapotranspiration (figure 13). The net water use estimates in the 1986 and 1987 growing seasons were 285 mm (figures 15-17) and 242 mm (figures 19-21) respectively.

The estimates for consumptive use of water by the vines in our research site were consistent with estimates made on-site by Dr. Kenneth Kunkel (personal communication 1988) utilizing the eddy correlation method. The estimates are slightly lower than those obtained by Bucks et.al. (1985) for Thompson Seedless vines in Arizona. The differences in climate and variety of grape could easily account for the differences noted. We were unable to obtain reliable estimates of water stored in the soil by use of a neutron probe. Soil water potential data for the 1985, 1986, and 1987 growing seasons are presented in figures 14, 18, and 22, respectively. The above consumptive use figures for southern New Mexico were calculated based on the assumption that no change of soil water storage occurred during the respective growing seasons. From these data, we are able to conclude that wine grapes use considerably less water than traditional crops grown in the Southwest.

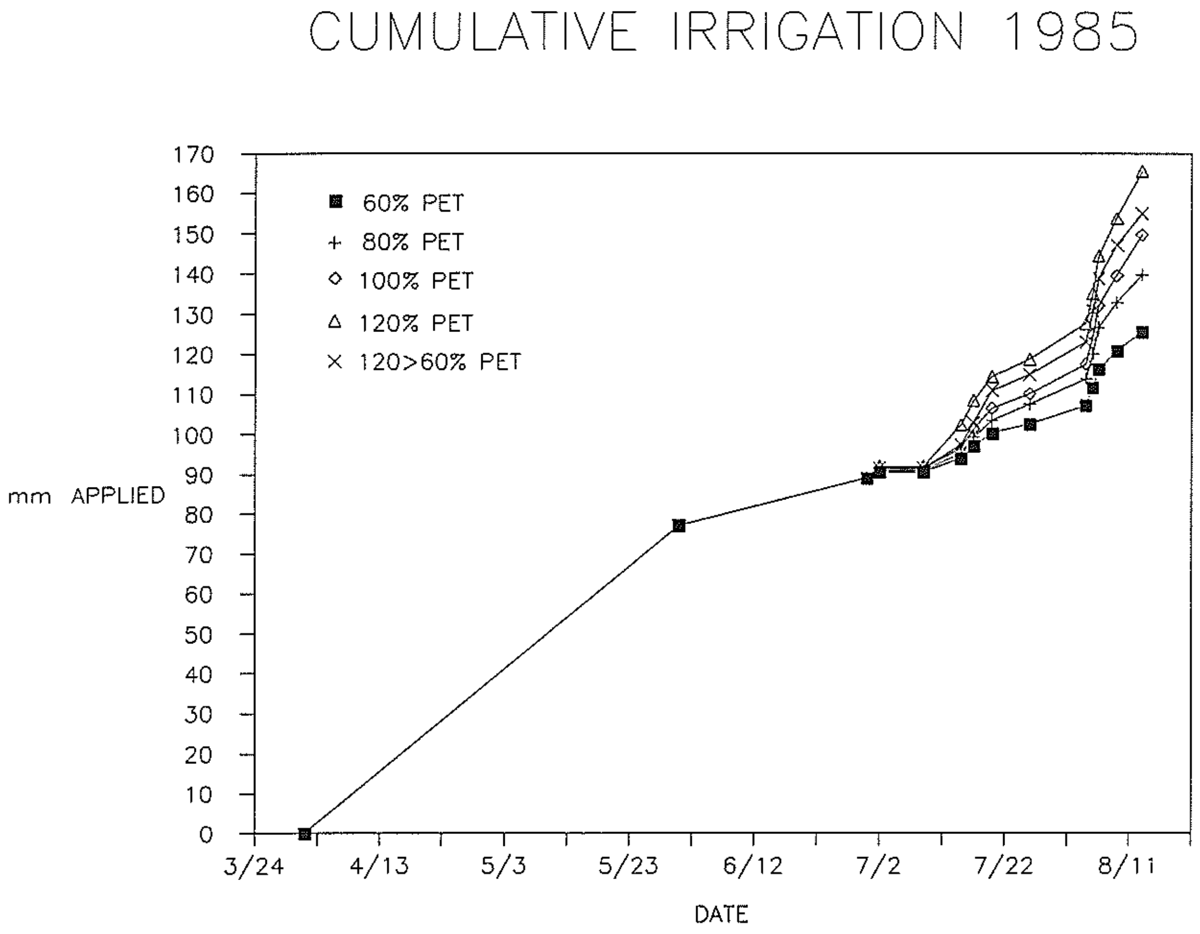


Fig. 11. Cumulative depths of irrigation water by percentage treatment levels delivered to vines during the 1985 growing season. The treatments were initiated in early July 1985.

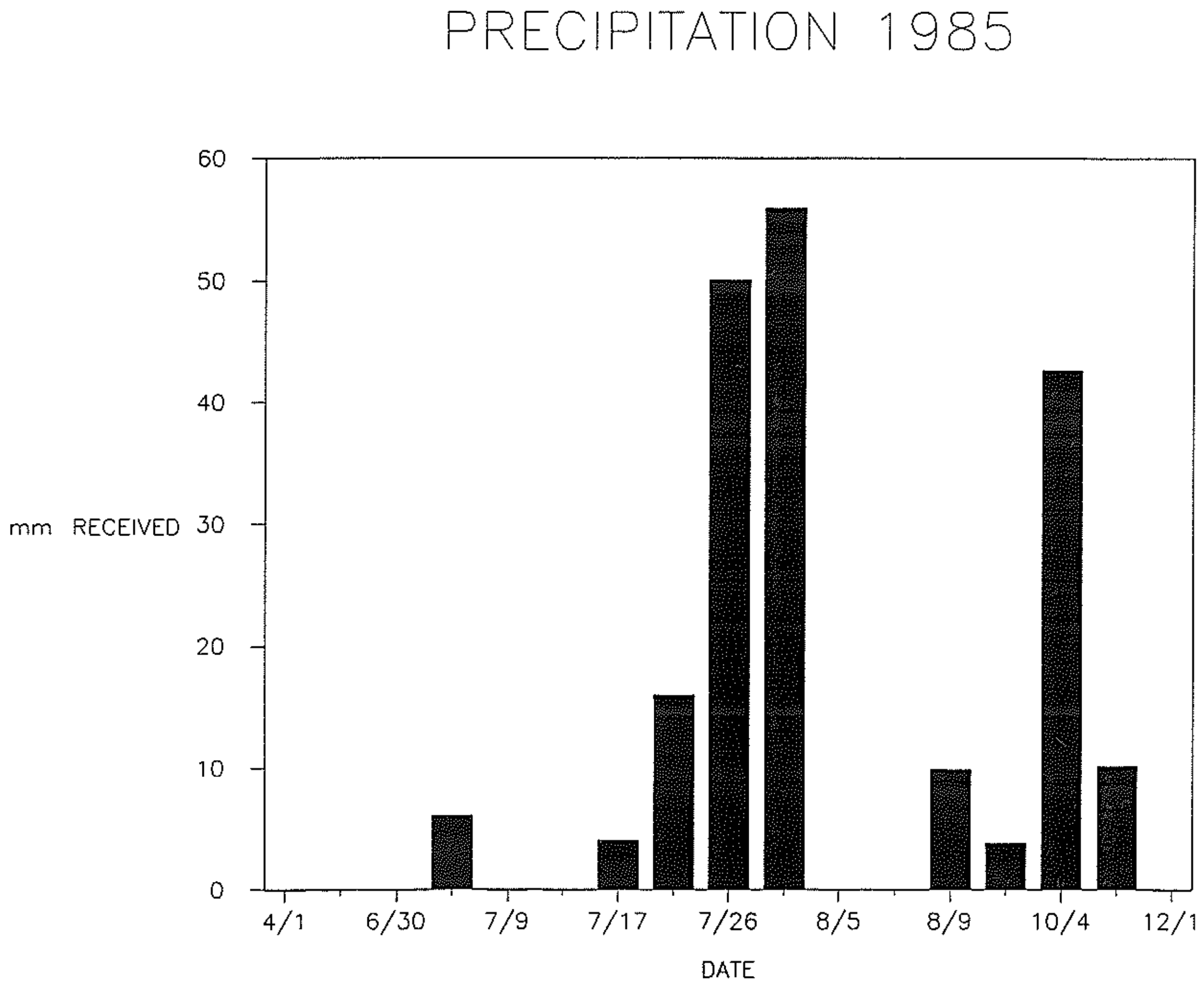


Fig. 12. Precipitation recorded on-site during the 1985 growing season.

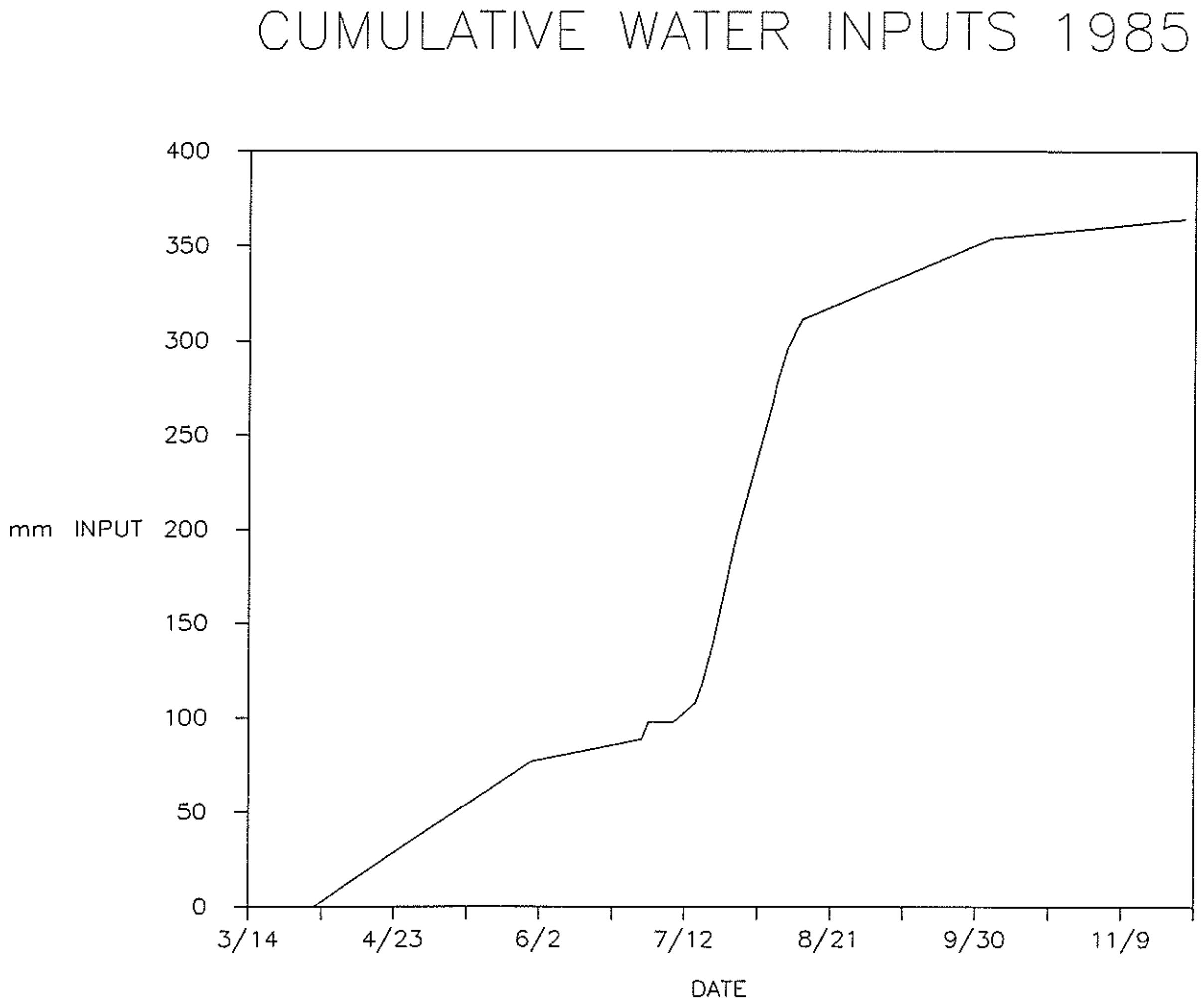


Fig. 13. Cumulative water inputs (irrigation + precipitation) for vines in lysimeters during the 1985 growing season.

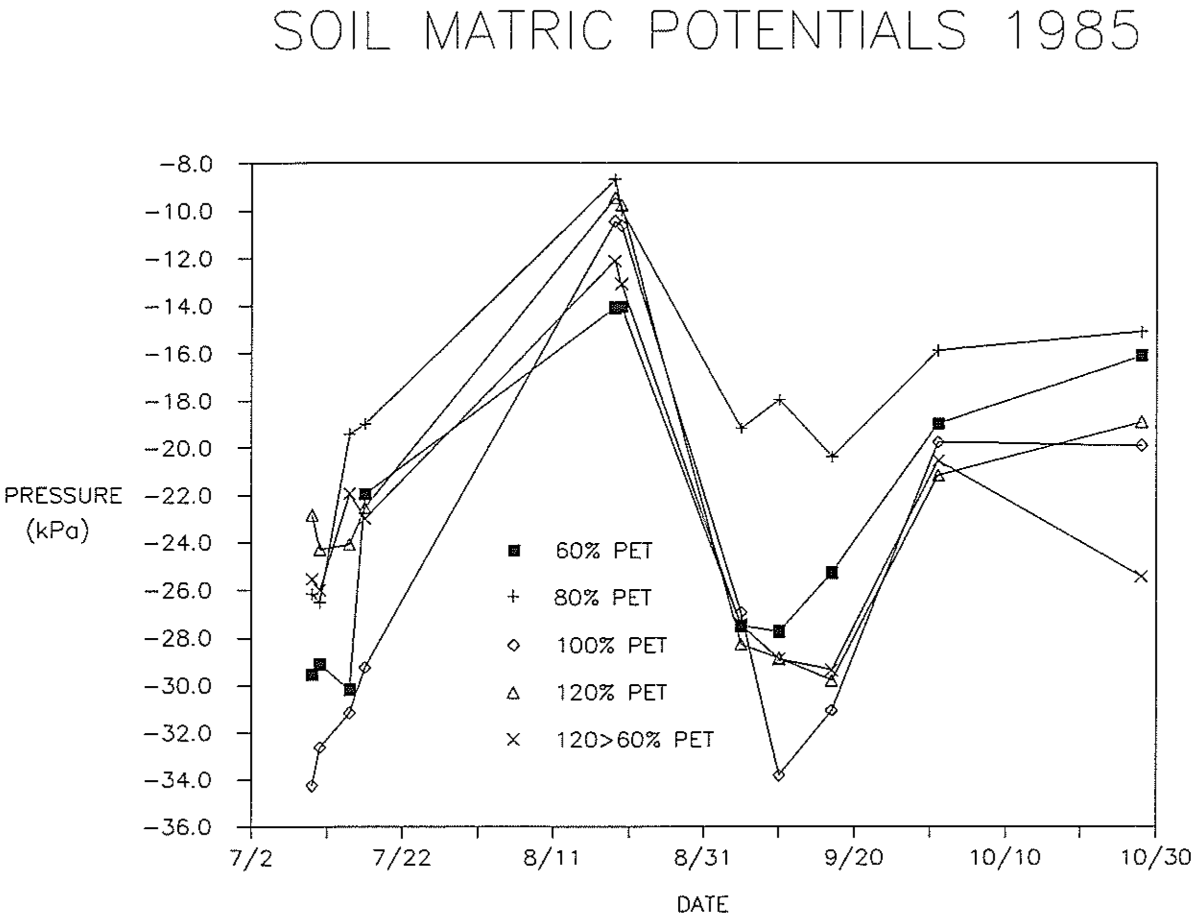


Fig. 14. Mean soil matric potentials by irrigation treatment percentage levels for the 1985 growing season.

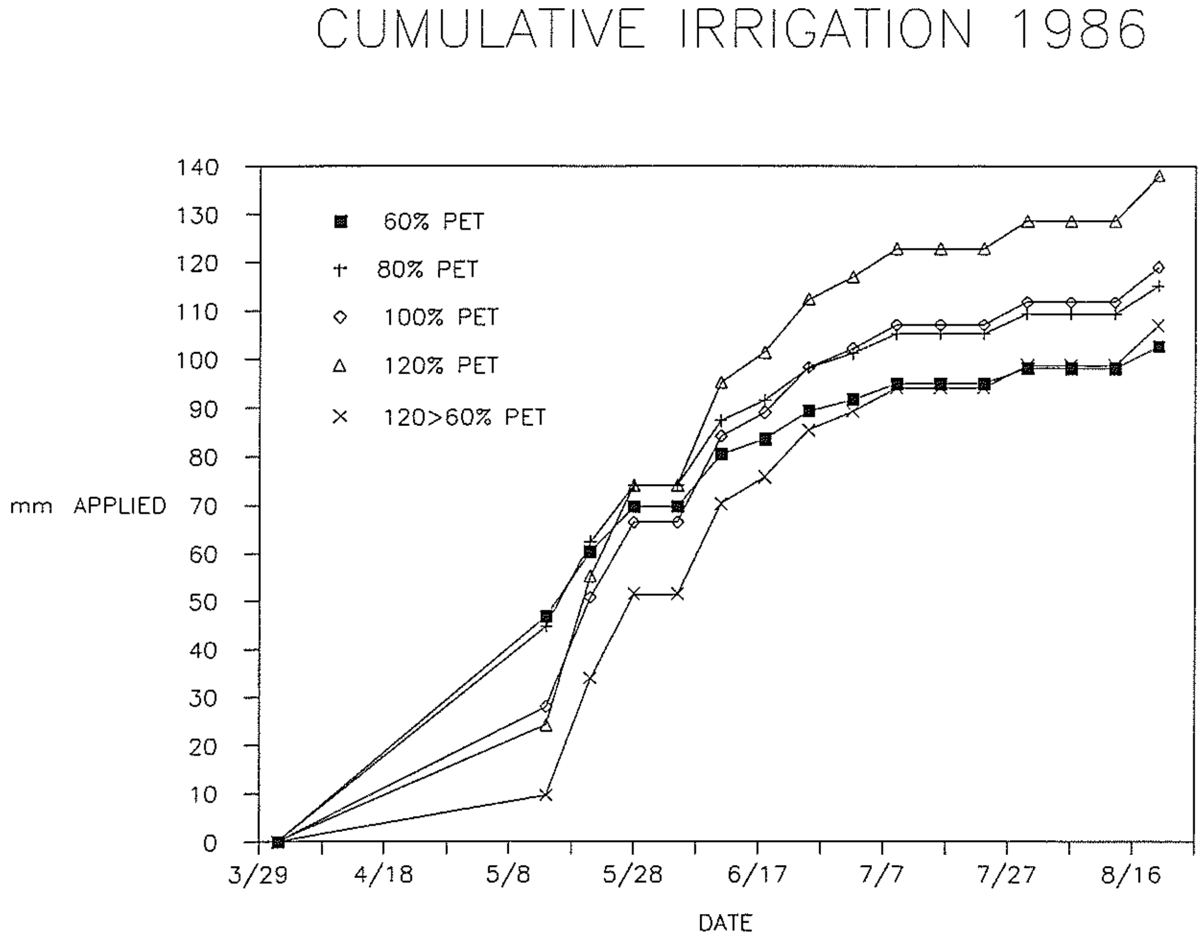


Fig. 15. Cumulative depths of irrigation water by percentage treatment levels delivered to vines during the 1986 growing season.

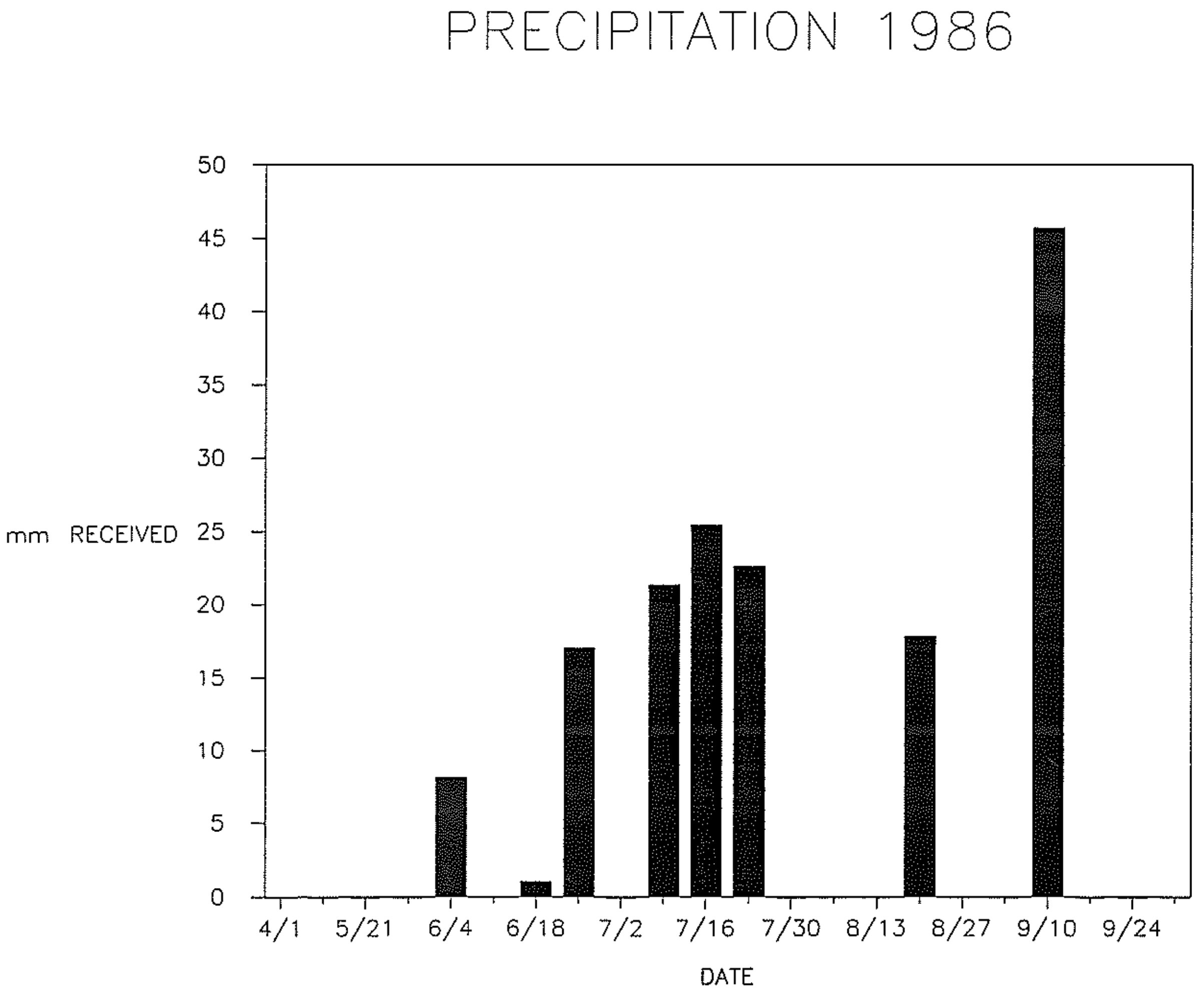


Fig. 16. Precipitation recorded on-site during the 1986 growing season.

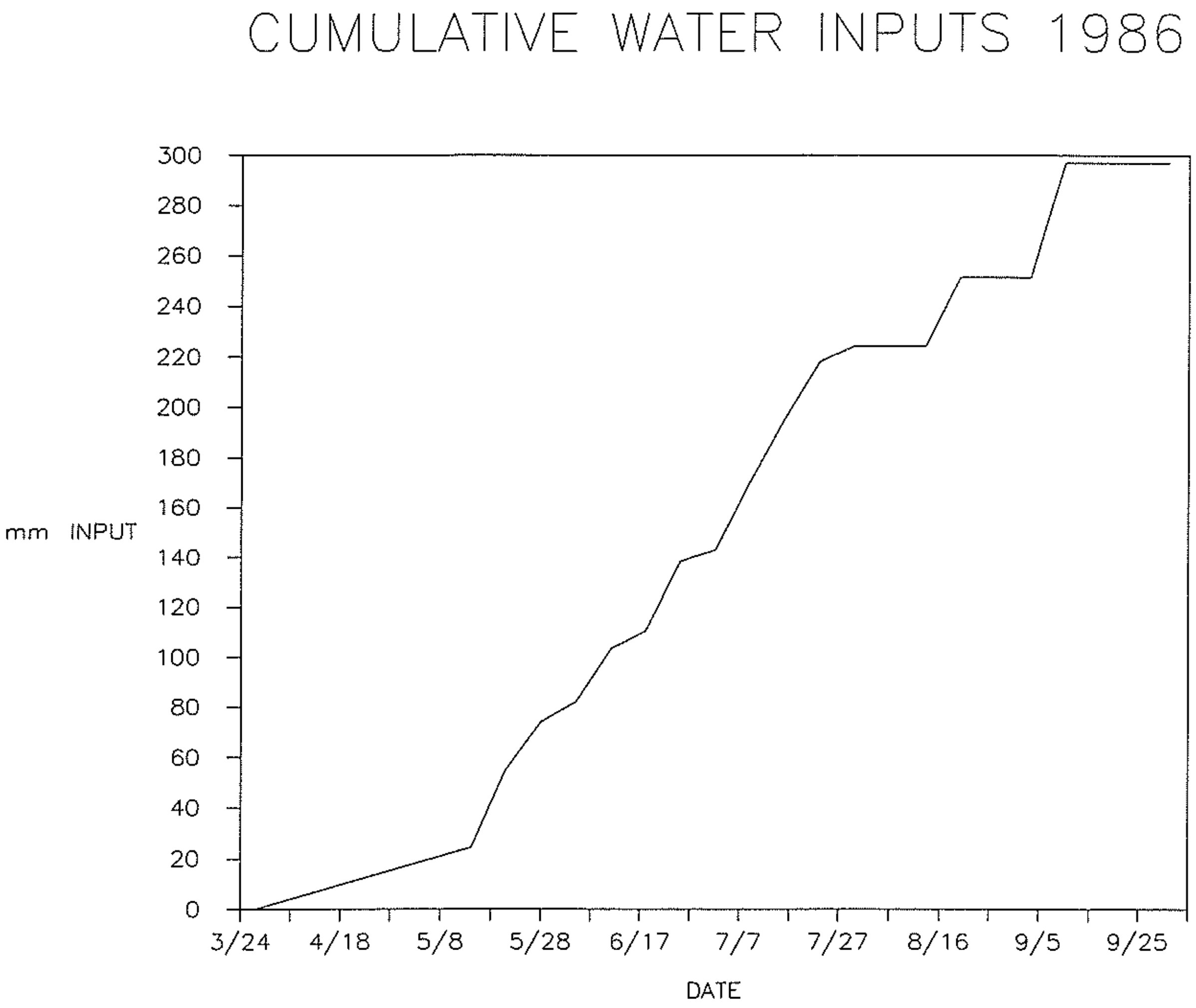


Fig. 17. Cumulative water inputs (irrigation + precipitation) for vines in lysimeters during the 1986 growing season.

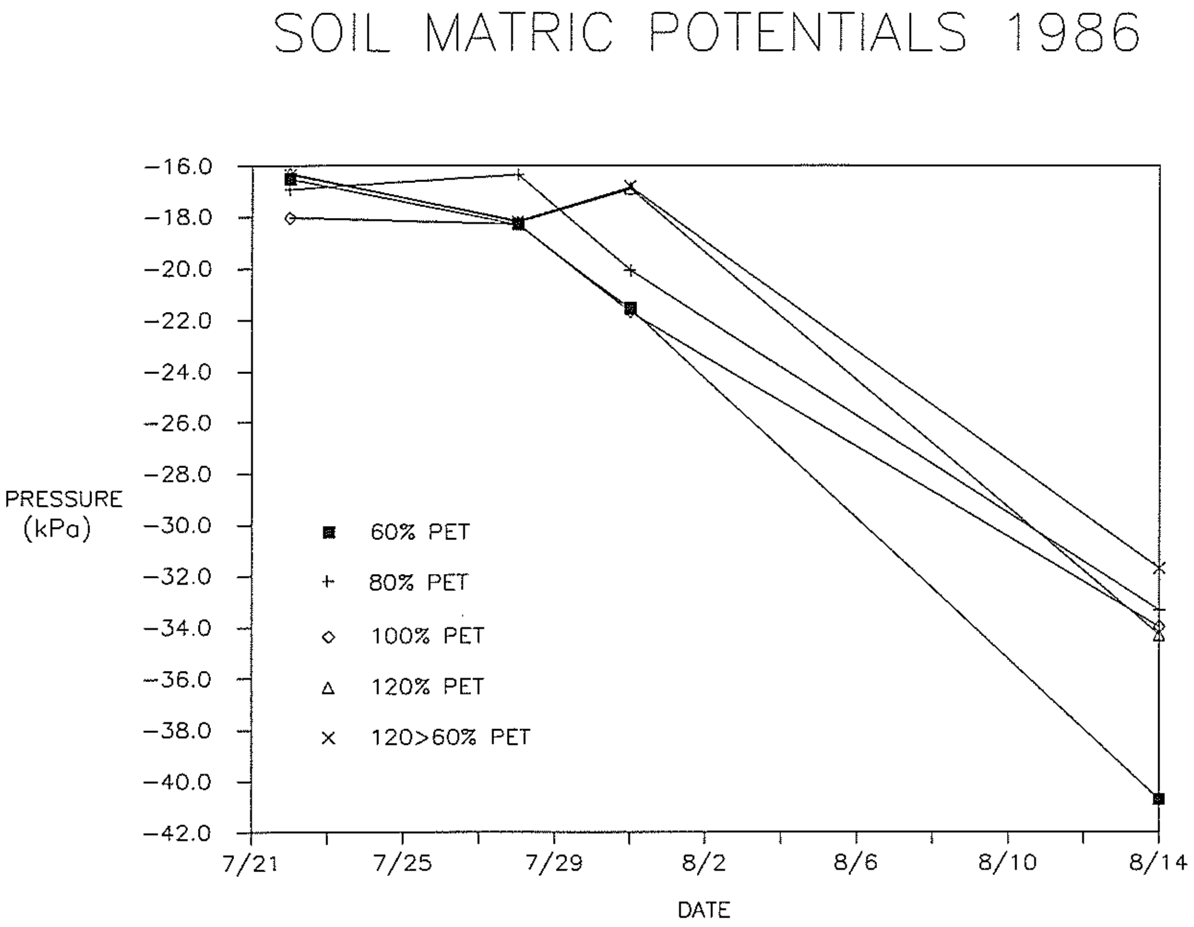


Fig. 18. Mean soil matric potentials by irrigation treatment percentage levels for the 1986 growing season.

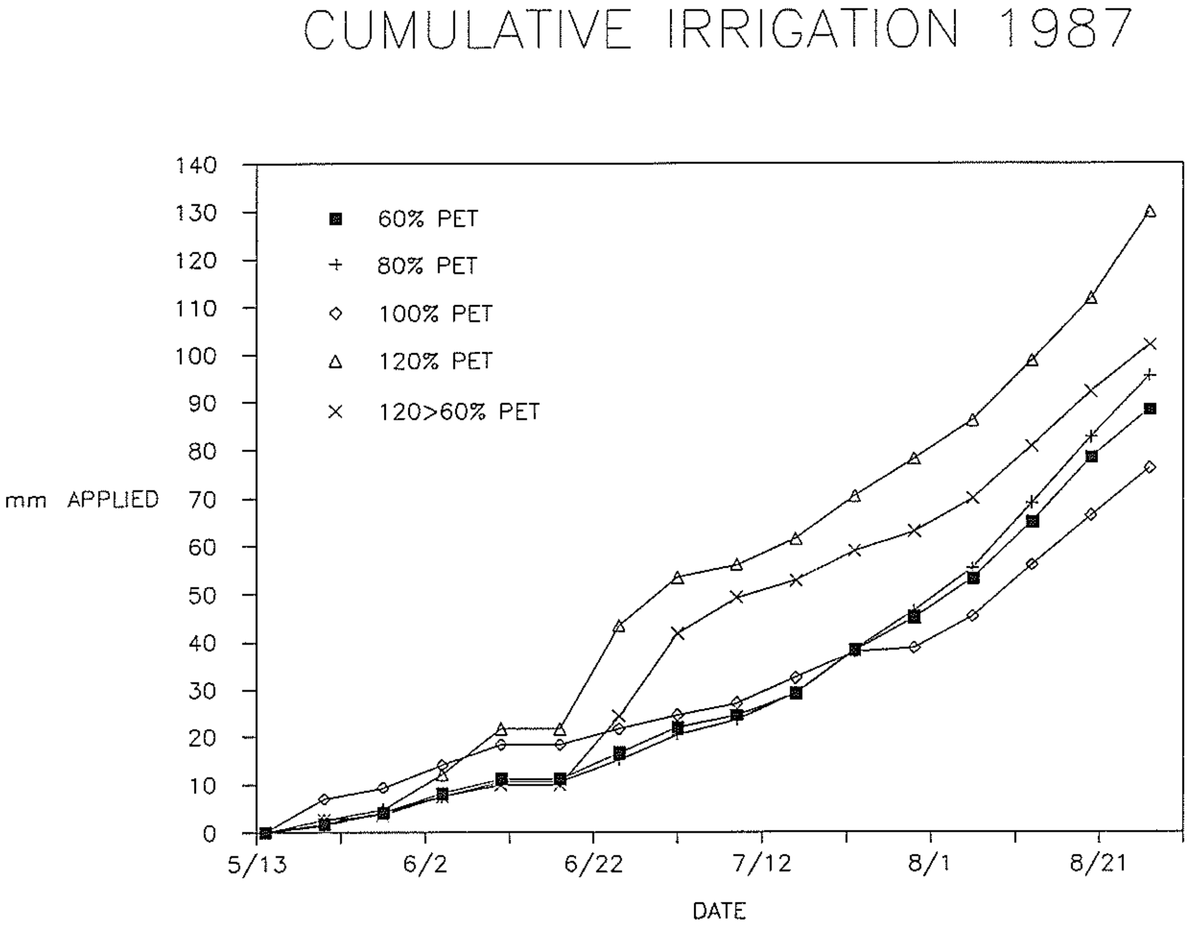


Fig. 19. Cumulative depths of irrigation water by percentage treatment levels delivered to vines during the 1987 growing season.

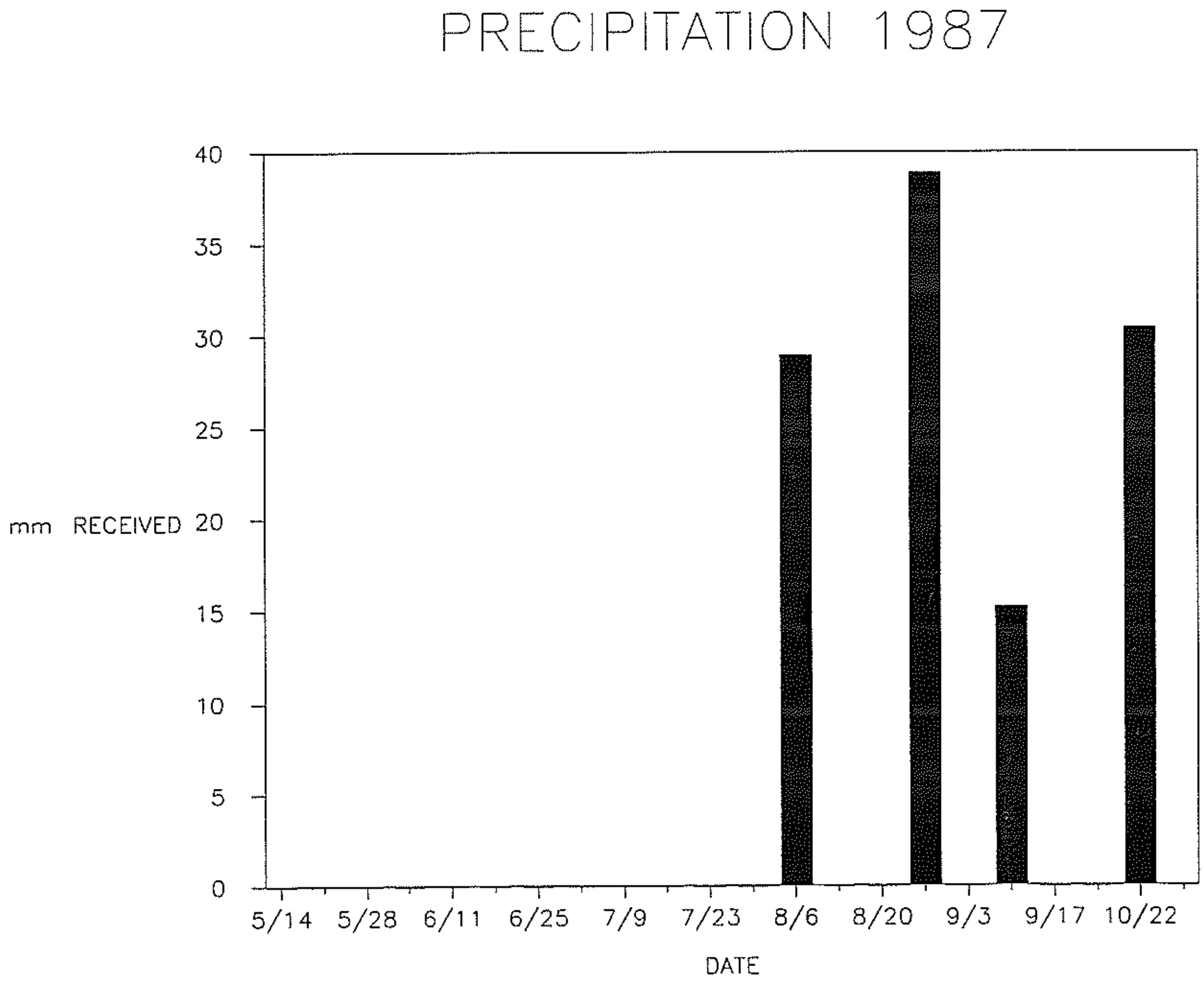


Fig. 20. Precipitation recorded on-site during the 1987 growing season.

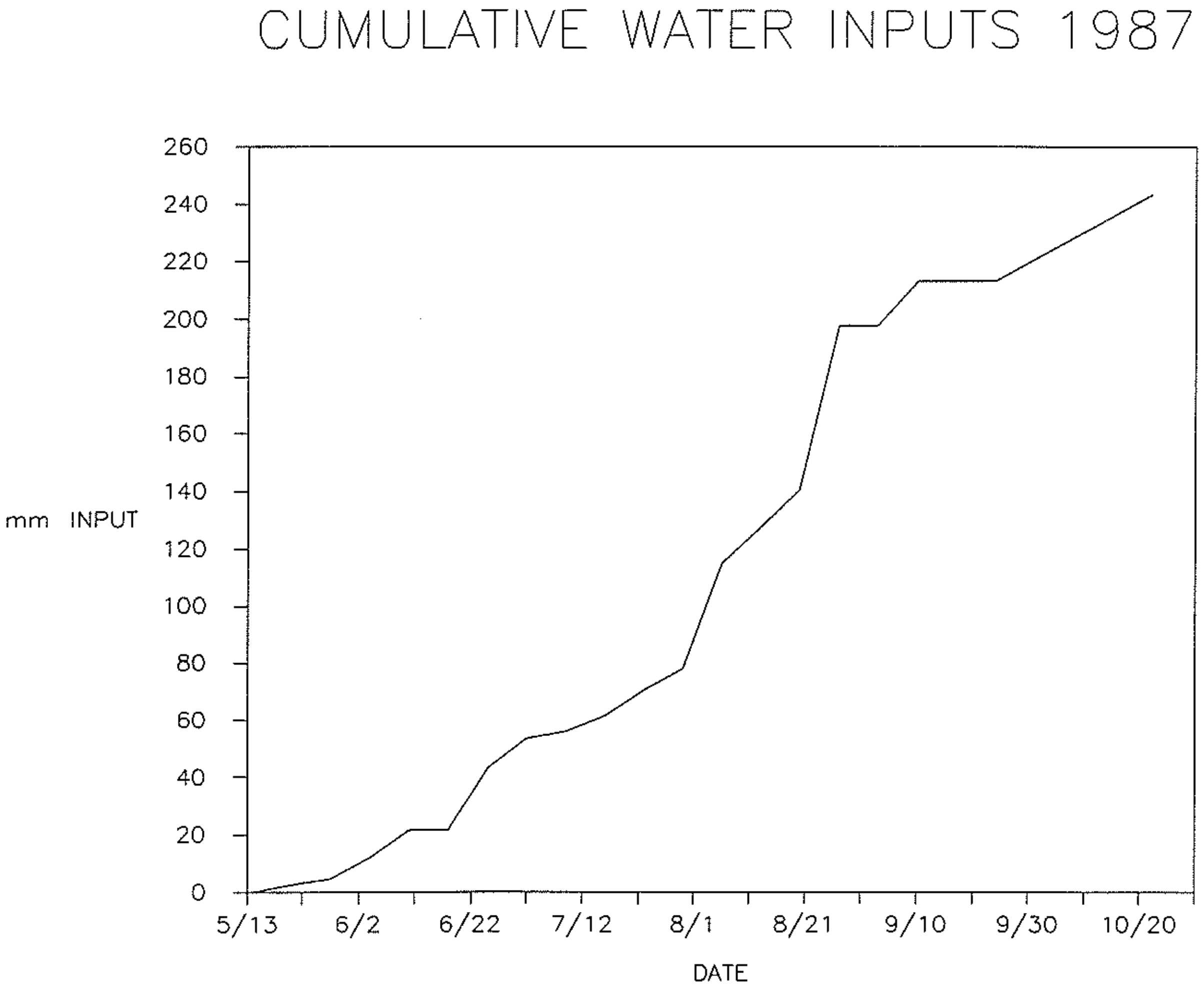


Fig. 21. Cumulative water inputs (irrigation + precipitation) for vines in lysimeters during the 1987 growing season.

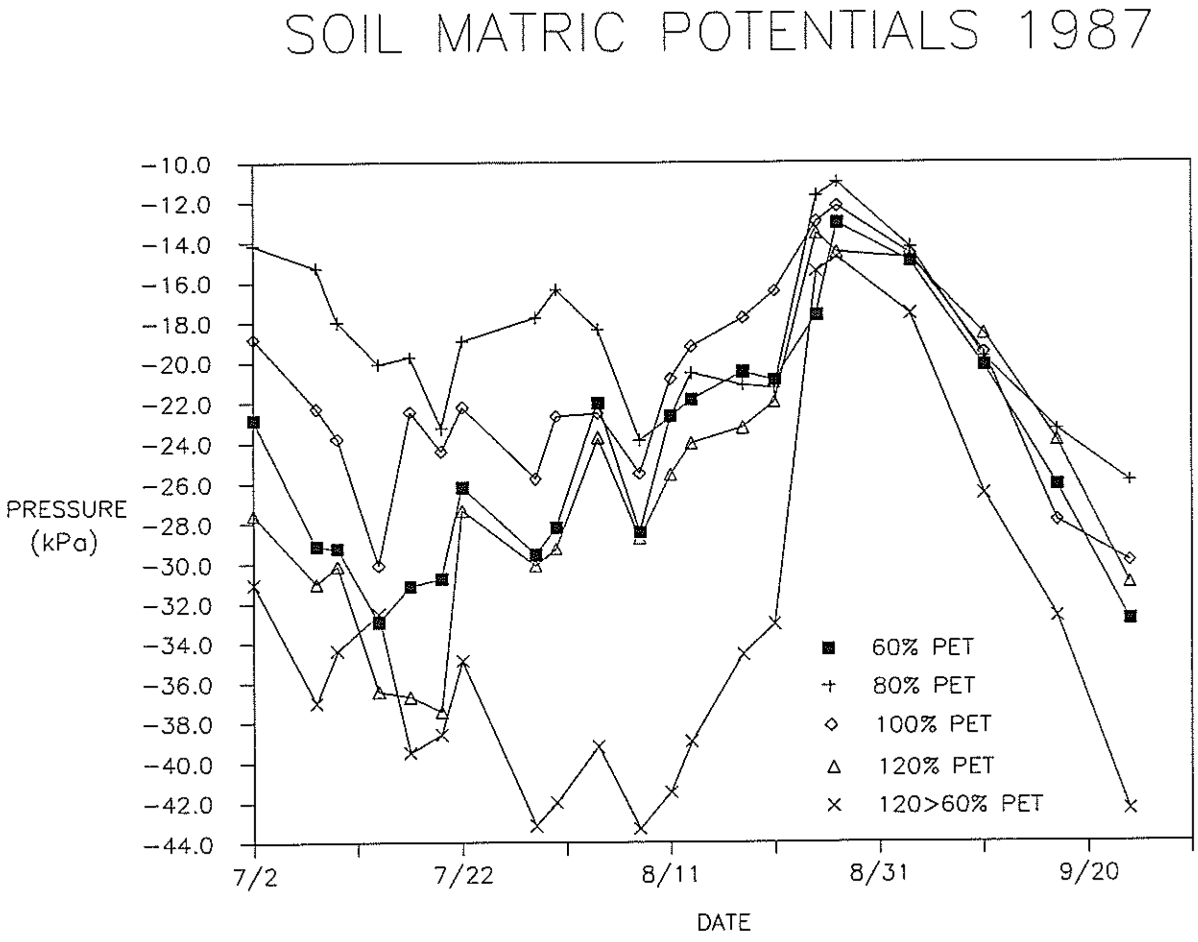


Fig. 22. Mean soil matric potentials by irrigation treatment percentage levels for the 1987 growing season.

Soil Salt Accumulation and Distribution

Soil salt profiles yielded very interesting results. The soils initially had low chloride contents and electrical conductivities. Increases in soil salts, especially those of chloride, were assumed to be due to the addition of irrigation water. Accumulations of irrigation-applied tracer salts varied greatly among locations and samples within any given location (table 8). In general, the patterns of salt accumulation indicated lateral water movement of soil water was very limited in the sandy loam soils present at our research site. Although the lateral wetting fronts converged in the soil under the trickle lines, they did not overlap sufficiently to effect uniform leaching along the line (figures 23-27). Similarly, the greatest variability of accumulated salt was observed at 30 cm distance from the trellis at points of irrigation water input. We interpret this greater variability to indicate that 30 cm was near the mean edge of the lateral wetting front. Only rarely was the soil electrical conductivity or chloride content significantly increased at a distance of 60 cm from the trellis (figures 24 and 27). Contour plots of soil electrical conductivity for a selected profile irrigated with water of 1500 mg l^{-1} TDS are presented in figures 24, 25, and 26. Contour plots of soil solution chloride concentration for the same profile are presented in figures 27, 28, and 29.

Although absolute electrical conductivities and chloride contents increased dramatically in soils after the application of treatments, the increase of these factors relative to those in the irrigation water

TABLE 8

Means and standard deviations of relative chloride concentration in the soil solution of increased salinity treatments. Values represented for distances 0 cm from the vine are the means of four observations and those for distances 40 and 80 cm from the vine are means of eight observations.

DISTANCE FROM: VINE (cm.)	TRELLIS (cm.)	DEPTH (cm.)	REL CONCENTRATION [Cl/Clo] MEAN	STD DEV
80	0	-10	0.44	0.28
80	0	-30	0.69	0.53
80	0	-50	0.61	0.56
80	0	-70	0.38	0.24
80	0	-90	0.35	0.42
80	0	-110	0.52	0.35
80	30	-10	0.39	0.19
80	30	-30	0.95	0.54
80	30	-50	0.78	0.27
80	30	-70	0.40	0.34
80	30	-90	0.43	0.26
80	30	-110	0.49	0.39
80	60	-10	0.45	0.40
80	60	-30	0.50	0.32
80	60	-50	0.45	0.32
80	60	-70	0.27	0.14
80	60	-90	0.33	0.26
80	60	-110	0.43	0.26
40	0	-10	0.41	0.27
40	0	-30	0.66	0.46
40	0	-50	0.82	0.78
40	0	-70	0.69	0.68
40	0	-90	0.72	0.59
40	0	-110	0.50	0.36
40	30	-10	0.49	0.44
40	30	-30	0.66	0.67
40	30	-50	0.65	0.41
40	30	-70	0.26	0.20
40	30	-90	0.37	0.19

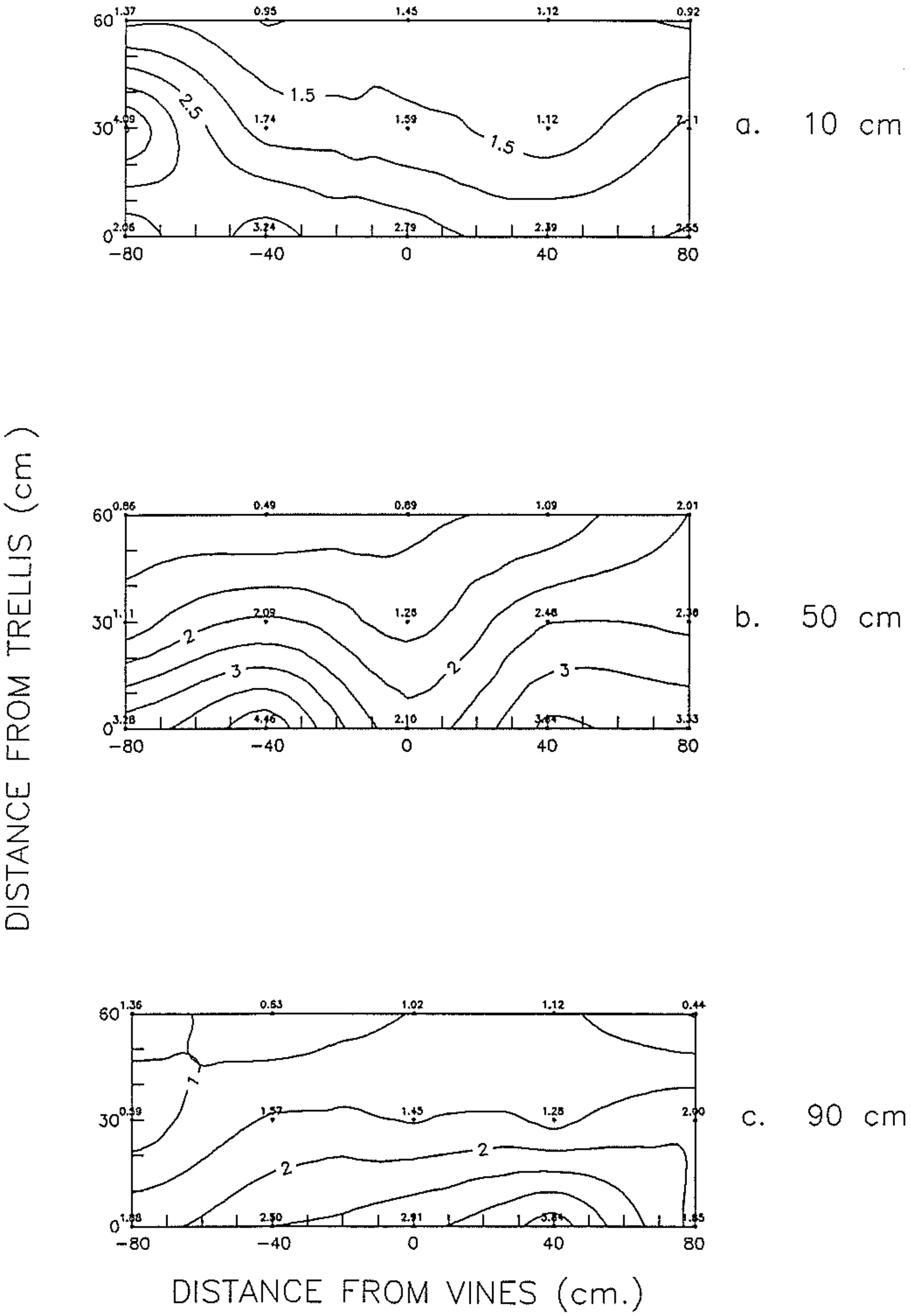
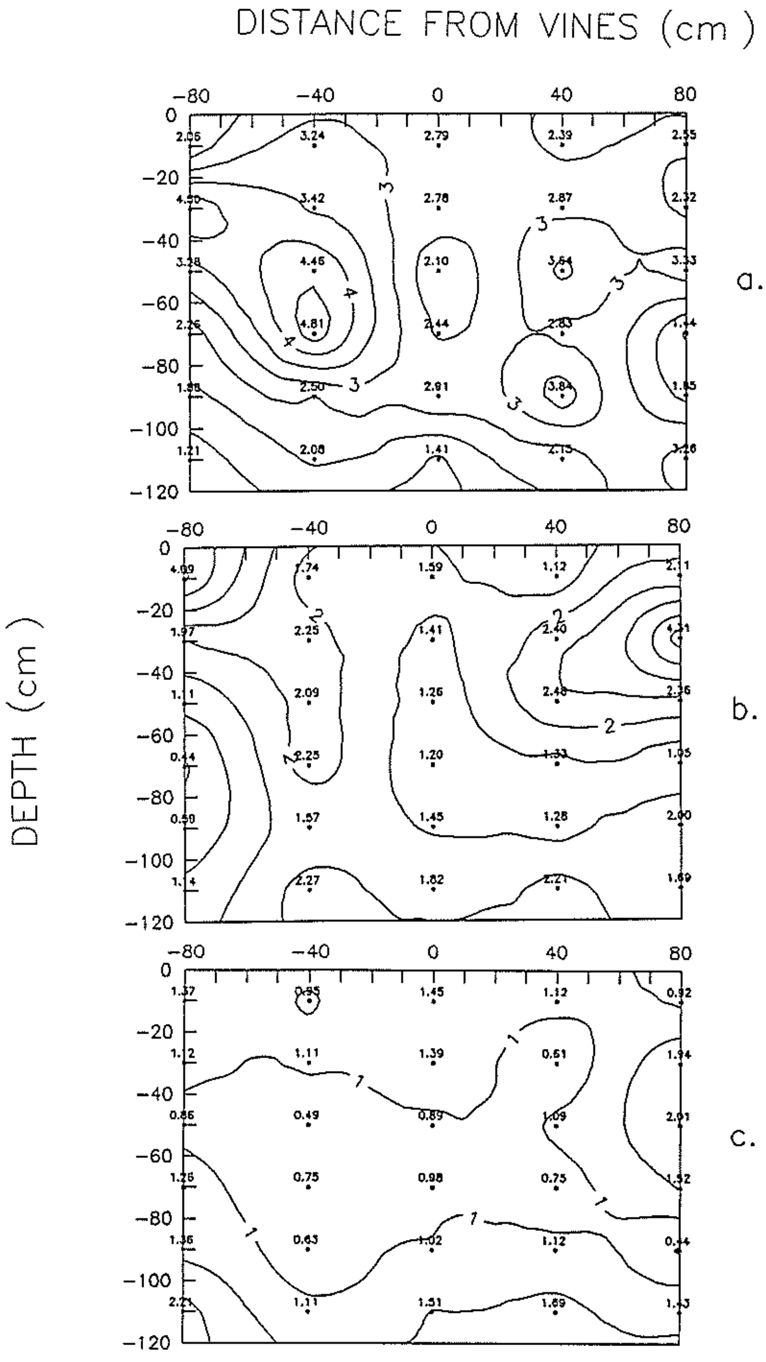


Fig. 23. Kriged contours of soil solution electrical conductivity in dS/m for treatment D (120% PET, 1500 mg/l TDS) location 1. Planes are parallel to the soil surface (figure 5). Depths of planes are given in the subtitles. Plumb lines from the vines contact point (0,0) in all three subfigures and plumb lines from the trickle emitters contact points (-80,0), (0,0), and (80,0) in all three subfigures.

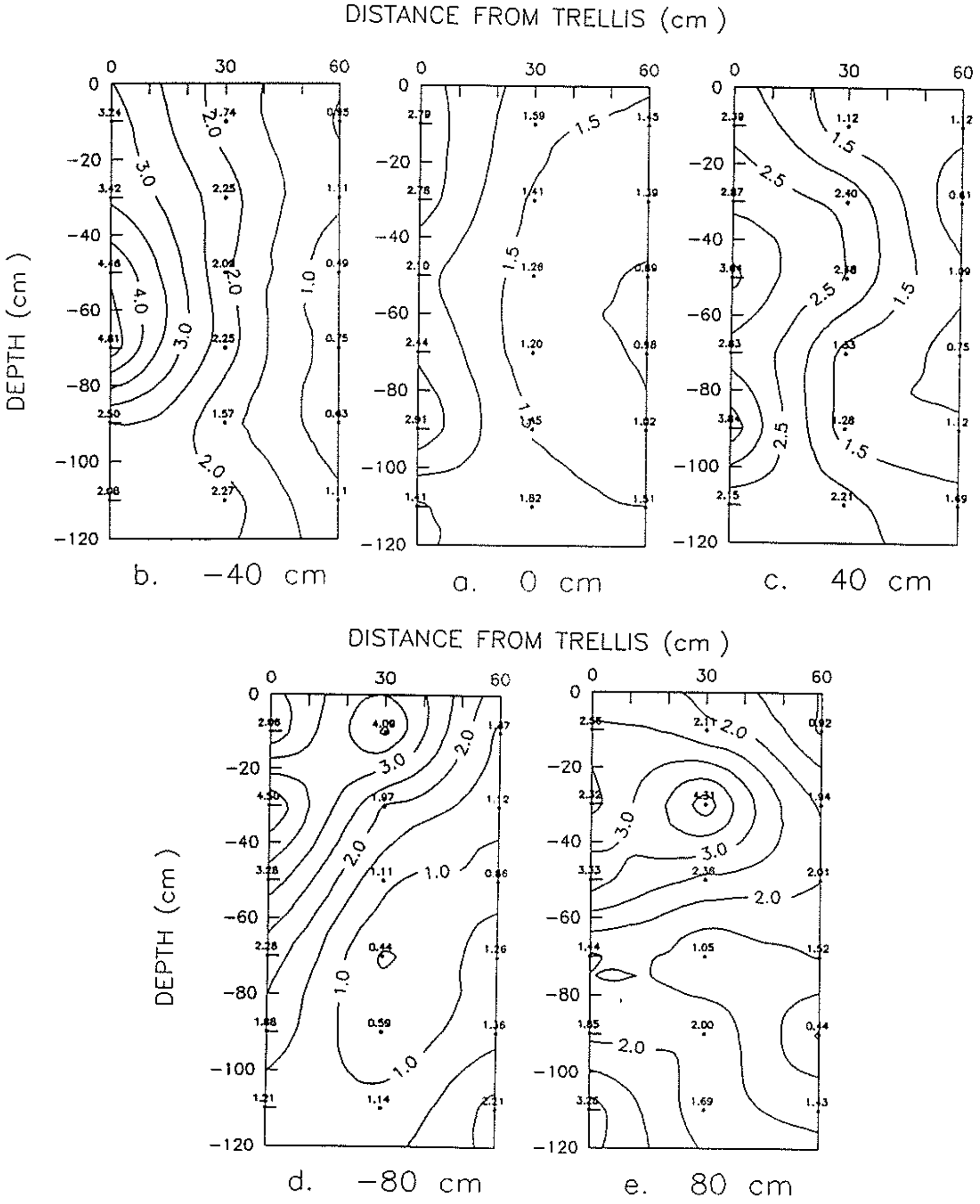


a. 0 cm

b. 30 cm

c. 60 cm

Fig. 24. Kriged contours of soil solution electrical conductivity in dS/m for treatment D (120% PET, 1500 mg/l TDS) location 1. Planes are perpendicular to the soil surface and parallel to the trellis system (figure 6). Distances of planes from the trellises are given in the subtitles. Vines are located at point (0,0) and trickle emitters are located at points (-80,0),(0,0), and (80,0) in subfigure a.



b. −40 cm a. 0 cm c. 40 cm

d. −80 cm e. 80 cm

Fig. 25. Kriged contours of soil solution electrical conductivity in dS/m for treatment D (120% PET, 1500 mg/l TDS) location 1. Planes are perpendicular to the soil surface and perpendicular to the trellis system (figure 7). Distance of the planes from the vines are given in the subtitles. Vines are located at point (0,0) in subfigure a. Trickle emitters are located at point (0,0) in subfigures a, d, and e.

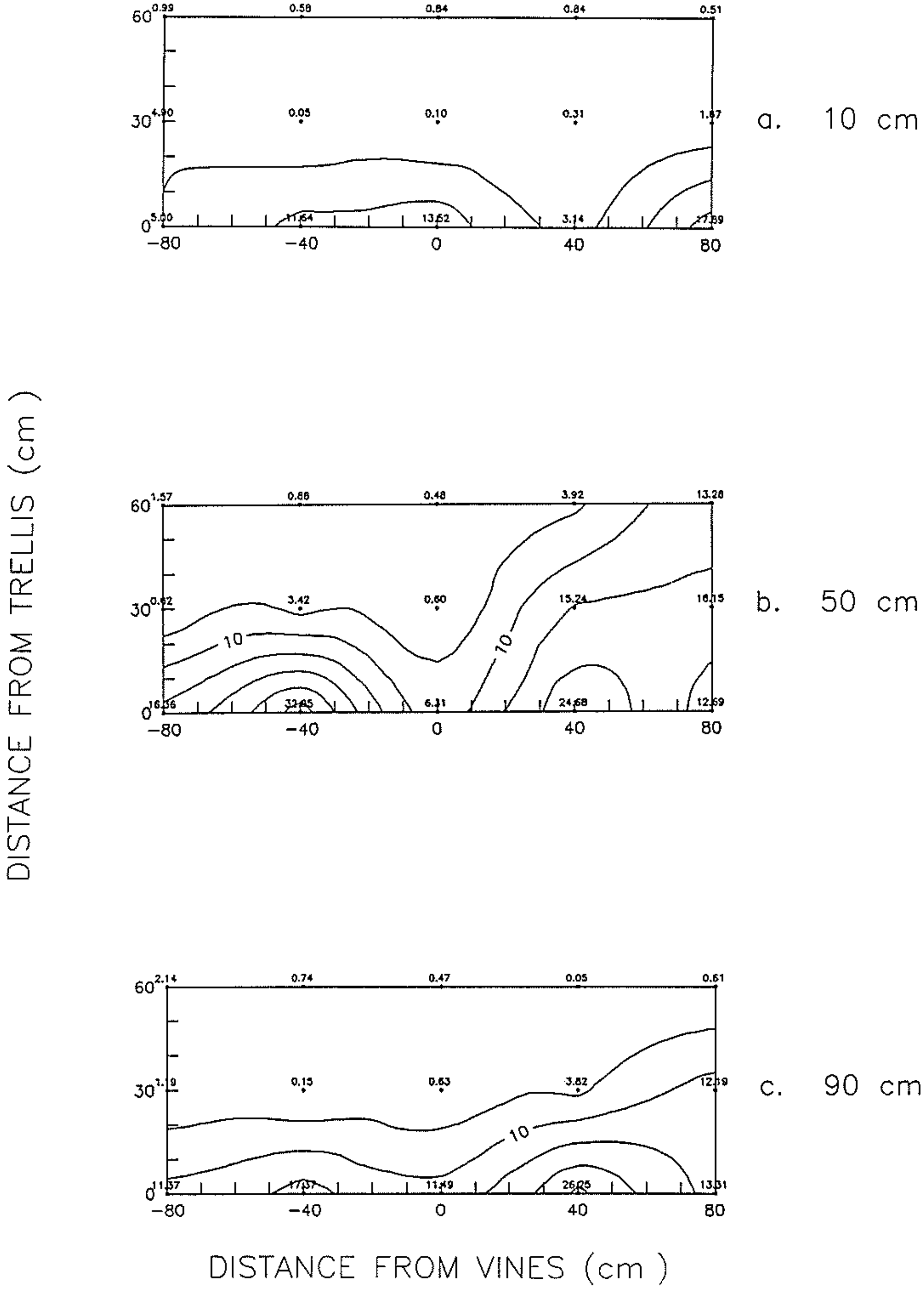


Fig. 26. Kriged contours of soil solution chloride concentration in mmol/l for treatment D (120% PET, 1500 mg/l TDS) location 1. Planes are parallel to the soil surface (figure 5). Depths of planes are given in the subtitles. Plumb lines from the vines contact point (0,0) in all three subfigures and plumb lines from the trickle emitters contact points (-80,0), (0,0), and (80,0) in all three subfigures.

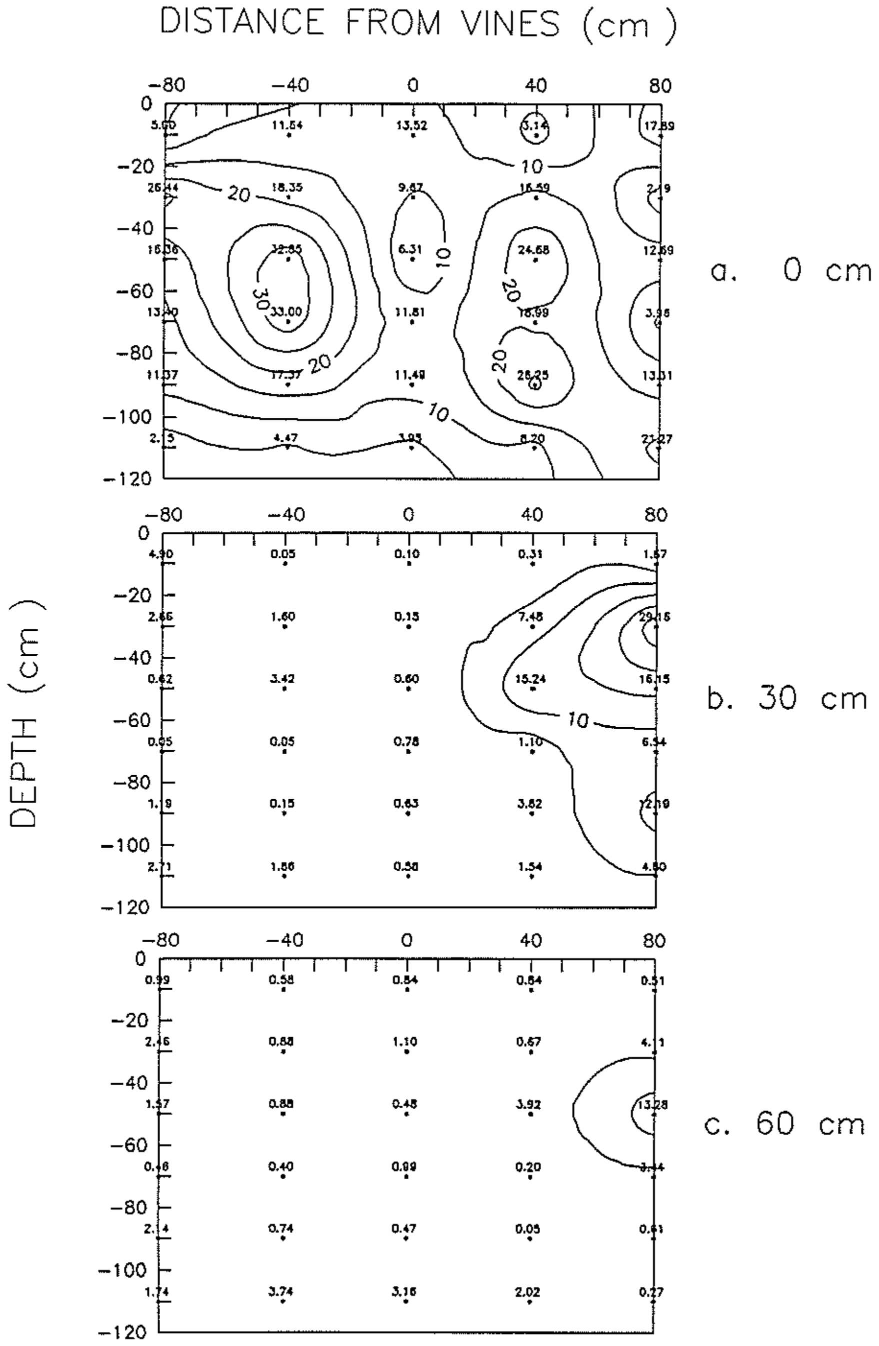


Fig. 27. Kriged contours of soil solution chloride concentration in mmol/l for treatment D (120% PET, 1500 mg/l TDS) location 1. Planes are perpendicular to the soil surface and parallel to the trellis system (figure 6). Distances of planes from the trellises are given in the subtitles. Vines are located at point (0,0) and trickle emitters are located at points (-80,0),(0,0), and (80,0) in subfigure a.

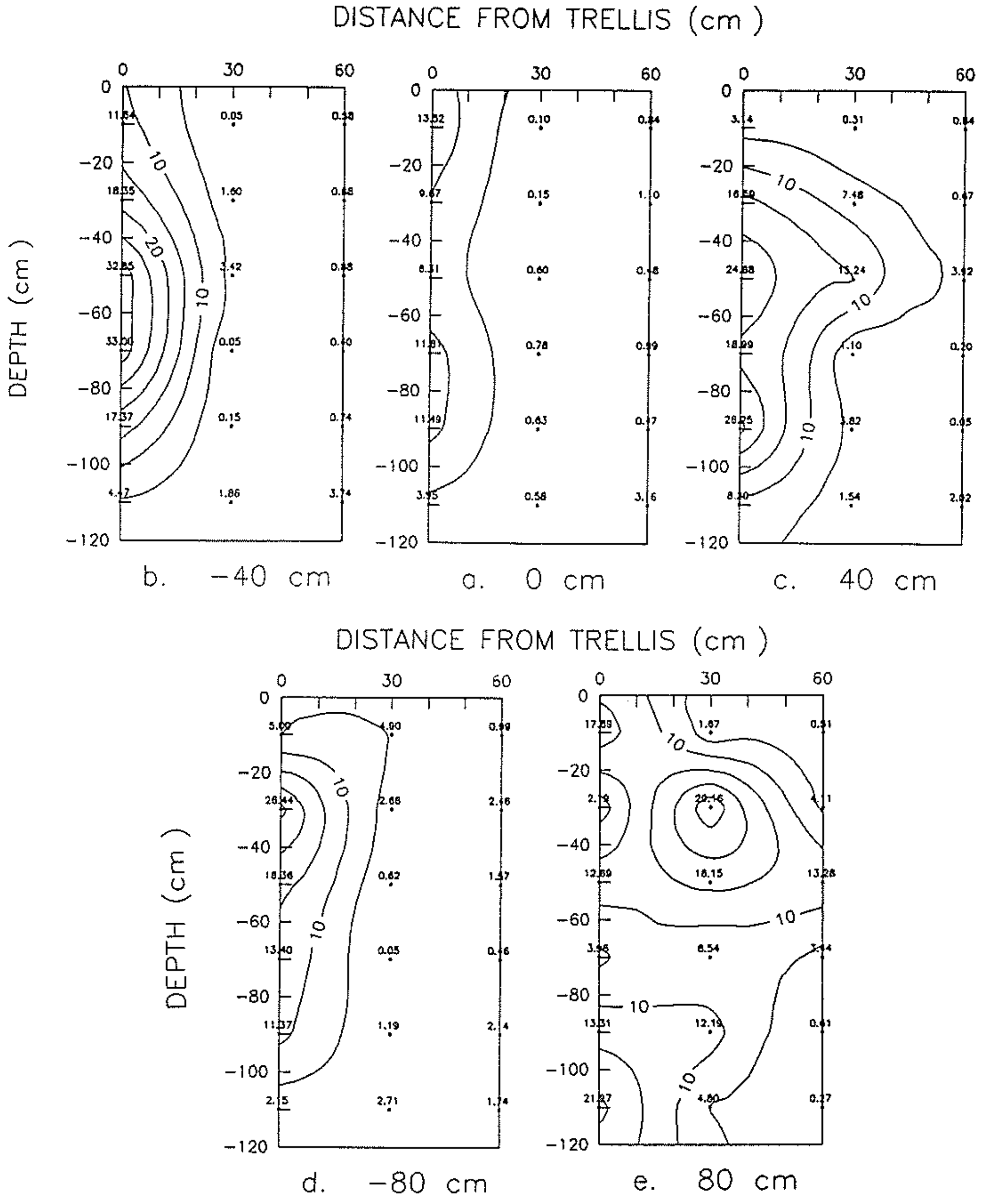
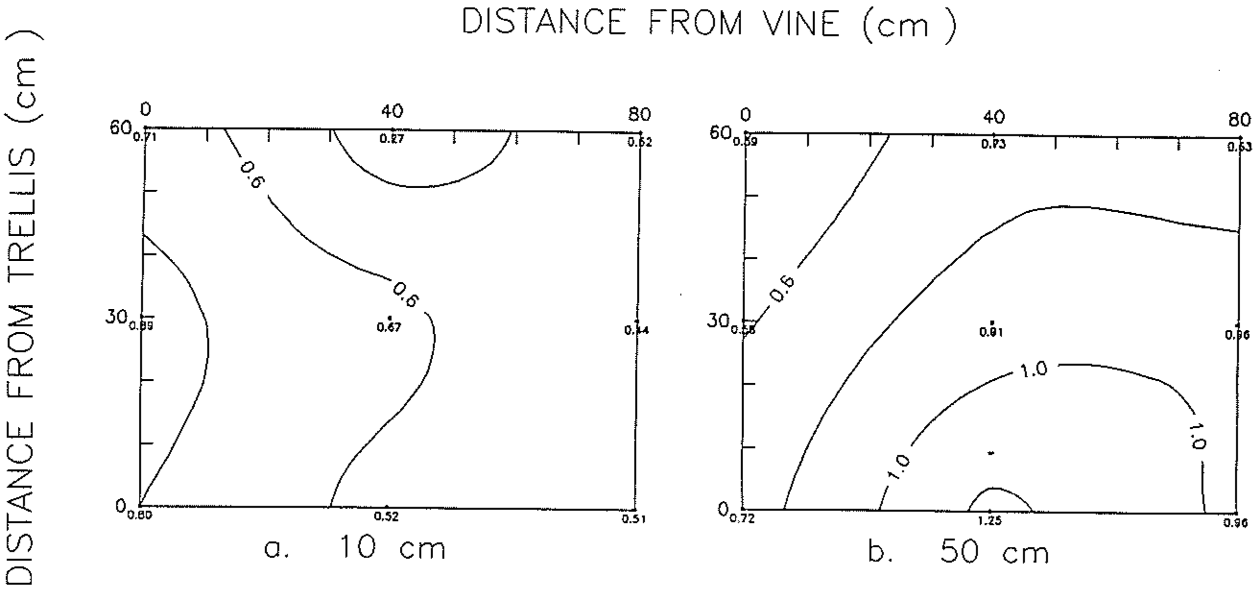


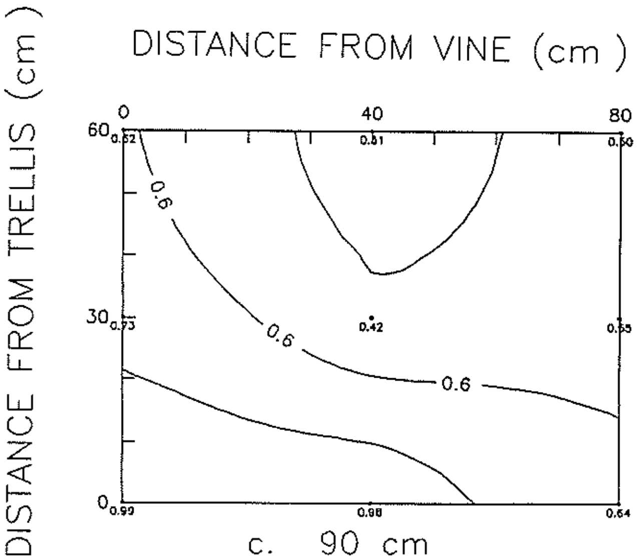
Fig. 28. Kriged contours of soil solution chloride concentration in mmol/l for treatment D (120% PET, 1500 mg/l TDS) location 1. Planes are perpendicular to the soil surface and perpendicular to the trellis system (figure 7). Distance of the planes from the vines are given in the subtitles. Vines are located at point (0,0) in subfigure a. Trickle emitters are located at point (0,0) in subfigures a, d, and e.

applied were not as great. Of 360 soil samples taken from the increased salinity treatments, only four showed a soil solution concentration greater than two times that of the irrigation water applied and only forty-eight others showed concentrations greater than that of the water applied. Many relative concentration values less than one were obtained from areas of active water transport below the trickle emitters. This phenomenon is attributed to the high proportion of precipitation to irrigation water necessary to meet consumptive use of water by the vines. Relative concentration values for sampled profiles irrigated with waters of increased salinities were averaged in order to plot the patterns of soil solution tracer salt concentration (figures 29, 30, and 31). Occasional great increases in soil electrical conductivity and chloride were noted in the samples taken from locations utilizing the 350 mg l^{-1} well water. These increases are believed to be due to a combination of surface soil moved during cultivation and random animal inputs. These profiles were not included in the data set utilized to generate figures 29, 30, and 31.



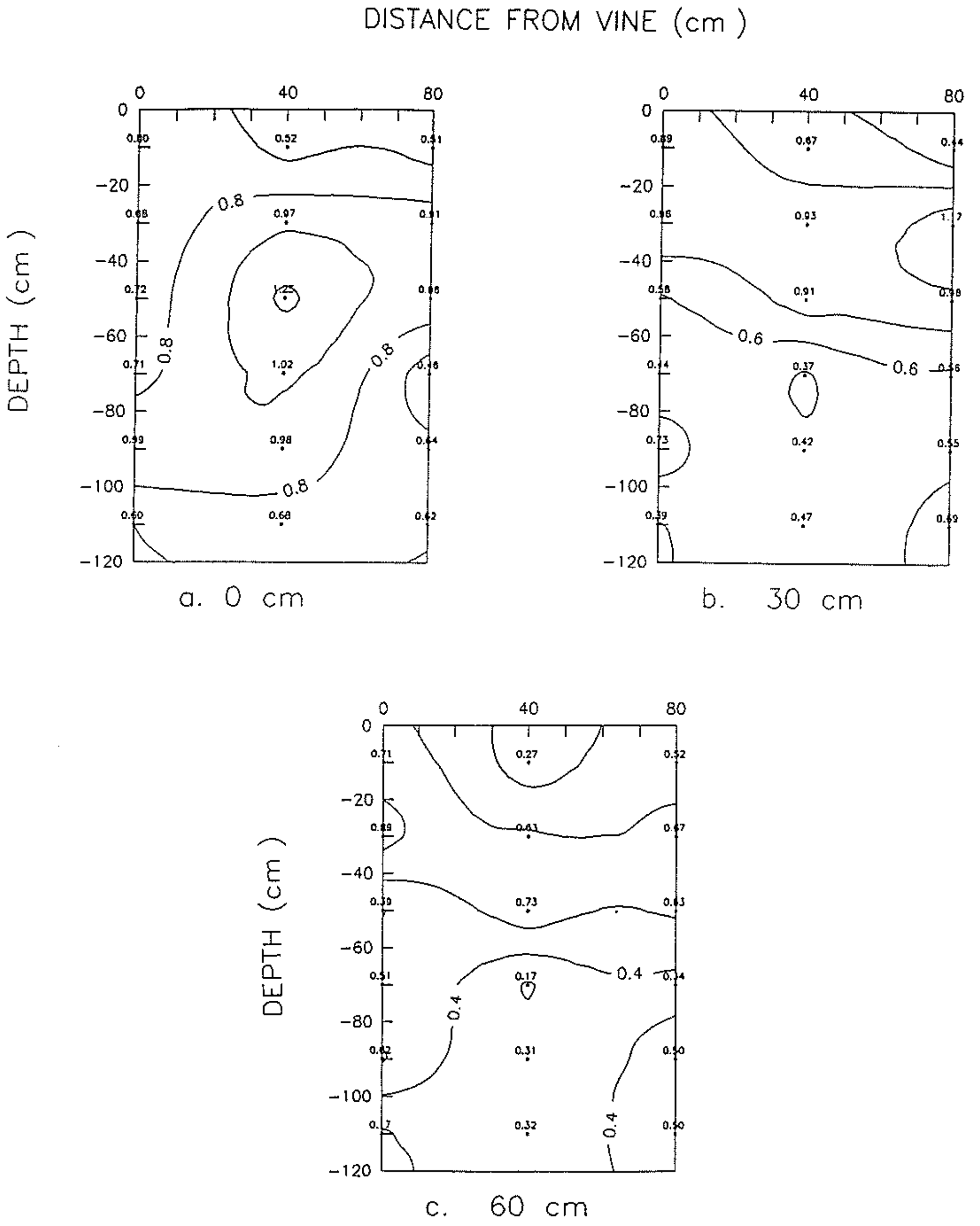
a. 10 cm

b. 50 cm



c. 90 cm

Fig. 29. Kriged contours of mean soil solution chloride concentration relative to the concentration in the irrigation water for all increased salinity treatments. Planes are parallel to the soil surface (figure 5). Depths of planes are given in the subtitles. Plumb lines from the vines contact point (0,0) in all three subfigures and plumb lines from the trickle emitters contact points (0,0) and (80,0) in all three subfigures.

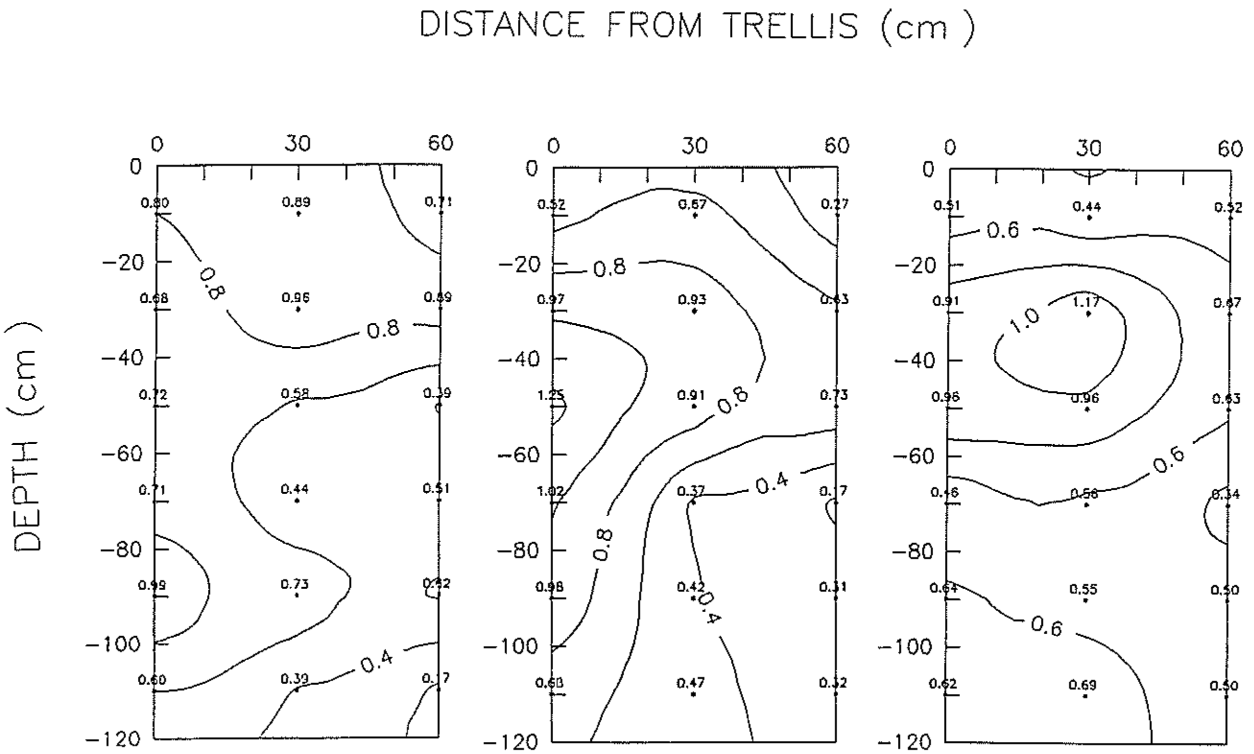


a. 0 cm

b. 30 cm

c. 60 cm

Fig. 30. Kriged contours of mean soil solution chloride concentration relative to the concentration in the irrigation water for all increased salinity treatments. Planes are perpendicular to the soil surface and parallel to the trellis system (figure 6). Distances of planes from the trellises are given in the subtitles. Vines are located at point (0,0) and trickle emitters are located at points (0,0) and (80,0) in subfigure a.



a. 0 cm b. 40 cm c. 80 cm

Fig. 31. Kriged contours of mean soil solution chloride concentration relative to the concentration in the irrigation water for all increased salinity treatments. Planes are perpendicular to the soil surface and perpendicular to the trellis system (figure 7). Distance of the planes from the vines are given in the subtitles. Vines are located at point (0,0) in subfigure a. Trickle emitters are located at point (0,0) in subfigures a and c.

PRINCIPAL FINDINGS AND CONCLUSIONS

The presence and severity of the diseases present in the research vineyard compromised most of our results. Under such circumstances, we must conclude that some of the significant results obtained may be due to random chance. The best example of this phenomenon is the higher growth from vines in the highest salinity treatments during the 1985 growing season. The tendency for negative growth and production functions with soil water potential as the input parameter further indicates that the diseases and their effects on the plants probably had a greater effect on the responses of the vines than did our treatment applications. Significant block effect and block by treatment interaction effects were noted in most of the analyses of variance conducted with data from this project. The large block by treatment interaction terms used to test main treatment effects made proof of significant main treatment effects difficult.

The only treatment effects we judge to be worthy of consideration are those pertaining to fruit quality. The increase of chloride in the fruit must with increasing chloride concentration in the irrigation water is an expected result. It should be noted, however, that the fruit chloride levels noted for even the 1500 mg l^{-1} TDS water treatments were below that generally found objectionable in wine.

The consumptive use estimates obtained from our investigation are also believed to be valid. The varieties used to determine vine consumptive use of water are lower in vigor and canopy surface area than many other commercial grape varieties. Based upon our findings and those of other researchers in our region (Bucks et al. 1985), it appears no more than 500 mm of water is necessary to produce wine grapes in the Southwest. Actual depths of irrigation water necessary to provide the appropriate depth to meet vine consumptive use will vary according to the type of irrigation system and management system used. We have also determined that water balances obtained by use of neutron probes may not be appropriate for widely spaced trickle irrigated crops.

The patterns of salt accumulation in the soil indicate that under proper irrigation management, salt accumulation is not expected to be a problem with trickle irrigated grape production in the Southwest. In sandy or sandy loam soils, we recommend emitter spacings of approximately 0.5 meter as the recommended maximum to insure uniform water and salt contents under the trickle lines. An increased emitter discharge rate of at least 1-gallon per hour is recommended to insure a larger effective rootzone for the vines and a larger soil water reservoir in such soils. The system utilized for our research did not create such a large zone of constant water availability and salt concentration. More work is needed on soils and soil hydraulic properties before trickle systems may be precisely matched to a particular soil type.

SUMMARY

A research project was initiated in Deming, New Mexico during the 1984 growing season to investigate the effects of trickle irrigation with different quantities and qualities of water upon grape production in the Southwest. Waters of three salinity levels were used in surplus irrigation treatments until veraison. At that time, half the vines receiving each of the representative salinity waters were stressed in order to investigate the effects of ripening period stress upon the growth of the vines, fruit yield, and fruit quality. The investigation into the effects of irrigation with different water quantities utilized irrigation treatments with the lowest salinity levels applied at the rate of 60%, 80%, 100%, and 120% of predicted evapotranspiration. The presence of two diseases was detected in our research plot in the 1985 growing season. The effects of the diseases influenced the vines to a greater degree than did the treatments. There were no significant treatment effects other than the effect of irrigation water salinity upon fruit chloride levels.

The consumptive use of water by wine grapes was estimated from water balance data obtained from large drainage lysimeters. Due to problems encountered with estimation of soil water storage with a neutron probe, only yearly estimates were obtained. From these data and the data of others, it was concluded that wine grapes planted on regular commercial spacings require less than 0.5 meter of water per year.

Salt accumulation profiles taken from three-dimensional grids about the root zone of selected vines indicate that under proper management, salt accumulation from trickle irrigated water is not a problem. The concentration of chloride in the soil solution rarely exceeded twice the concentration in the irrigation water. The consumptive water use requirements of grapevines are low enough that precipitation was more than one-half of the water required to produce a crop of wine grapes. The patterns of salt accumulation were examined to show patterns of water movement in the soil below the trickle emitters. From the distribution of salts, it was concluded that the wetting front moved only slightly beyond 30 cm from the trellis and did not overlap sufficiently to insure uniform leaching of salts along the trellis. These patterns indicate that in sandy soils, emitters should be placed closer together and/or have a higher water discharge rate to create a true line source of readily available water along the trellis rows.

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