Potential for Using Drainage Water for Irrigating Westside San Joaquin Valley Pistachios

Project Investigators:

Louise Ferguson
Office: (209) 646-6541, E-mail: louise@uckac.edu
Department of Pomology
University of California, Davis

Blake Sanden
Office: (661) 868-6218, E-mail: blsanden@ucdavis.edu
UC Cooperative Extension, Kern County

Steve Grattan
Office: (530) 752-1130, E-mail: srgrattan@ucdavis.edu
Department of Land, Air and Water Resources
University of California, Davis

Research Staff:

Heraclio C. Reyes, Laboratory Assistant III

ABSTRACT

A 1999 greenhouse rootstock salinity tolerance trial by our research group (Ferguson et al., 2002) and trials by others established salinity tolerances of, and the relative rankings among, various pistachio rootstocks. These greenhouse studies generally used unbudded, or in our 1999 study, budded seedlings, and measured growth in response to soil salinity. This long-term field trial was designed based upon the results of these earlier greenhouse studies. The major difference is that in this field trial individual tree marketable yield, the final product of growth, is used as the indicator of salinity tolerance. Growth by trunk circumference, tree nutrient status by leaf analysis, and tree water status by both pressure bomb and photosynthesis are also being measured. Water applied and water remaining in the soil are being monitored directly by flow-meter and neutron probe respectively. Ground evaporation and tree transpiration, tree water use, is calculated using the pistachio tree crop coefficient and local CIMIS station data. Pre and post season soil samples are analyzed to monitor soil salinity levels.

This trial was planted in 1989 and trees achieved full bearing in 1997. The four rootstocks being evaluated in this trial are *Pistacia integerrima*, Pioneer Gold I (PGI), *P. atlantica*, Atlantica, and two hybrids of these two species, *P. atlantica* X *P. integerrima*, known as Pioneer Gold II (PGII), and University of California Berkeley 1 (UCB1). The saline irrigation treatments began in 1994 and by 1997 produced salinity levels in the soil approaching or surpassing that of the respective irrigation water treatments. The yield data discussed in this report will focus on 1997 through 2001. The tree and soil water status data will focus on 1999 – 2001.

Yield results from 1997 through 2001 demonstrated that eight sequential seasons, 1994 through 2001, of irrigation with 8 dS/m (5,920 TDS) water produced no significant effect on the marketable yield of trees grown on all four rootstocks. Above 8 dS/m, at 12 dS/m (11,040 TDS) trees on all four rootstocks displayed consistent, but not always significant, decreases in yield, particularly in 2000 and 2001. Trees on UCB1 rootstocks had the most marked decreases annually averaging 35% less marketable crop than control trees when irrigated with 12 dS/m water. Trees on PGII and Atlantica rootstocks both had 12% annual average decreases in yield. Trees on PGI rootstocks had a 9% decrease in yield. These rankings differ with our earlier greenhouse study in that trees on PGI rootstocks demonstrated decreased growth when irrigation water salinity was above 8 dS/m and had significantly less growth than trees on UCB1 or Atlantica rootstocks when irrigation water was 16 dS/m.

As would be expected with the lack of effect on yield reported above, none of the trees, on any or rootstocks at any treatment level, were measurably stressed. Leaf water potentials, photosynthetic rate and stomatal conductance measurements were all within normal ranges for trees on all rootstocks at all treatment levels. Leaf nutrient levels are all within normal ranges with few exceptions.

Since 1999, despite the lack of statistically significant yield decrēases or differences in plant stress indictors, all irrigation salinity treatments have shown significantly less water use that the control (0.75 dS/m). This is consistent with our earlier greenhouse trial that demonstrated vegetative growth decreases in trees on all rootstocks when soil salinity levels were greater than 8 dS/m. Further, when annual circumference measurements are graphed it appears the highest salinity treatment is beginning to impact tree growth. All the above evidence indicates the salinity tolerance threshold of the pistachio rootstocks in this trial is about 8 dS/m.

KEYWORDS

Pistacia vera, cv. 'Kerman', P. integerrima, P. atlantica, P. atlantica X P. integerrima, rootstocks.

• • • • •

INTRODUCTION

Pistachios can be grown in microclimates with combinations of heat, and poor soil and water quality, not favorable to other tree crops. The lower West Side of the San Joaquin Valley, where surface irrigation water is expensive or poor quality if it is ground or reclaimed drainage water, is an example. If irrigation in this microclimate could be supplemented by using poor quality ground or drainage water, profitable production would be more possible. Or more importantly, as water supplies become less available to agriculture, reclaimed drainage water or poor quality ground water could be a regular source of irrigation water. Currently, unused ground water supplies in the Shafter area are reporting salinities of 5-6 dS/m. The decreased water allocations of the early 1990s are sure to be repeated as competition for California's better quality water supplies become more acute in future droughts. Some West Side districts are slated to receive 47% of their allocation in 2001. If the salinity tolerance of our current commercial pistachio rootstocks are known poor quality water can be used with confidence that growth and productivity will not be harmed.

Our 1999 greenhouse trial demonstrated pistachios are potentially among the most salt tolerant of the tree nut crops (Ferguson et al, 2002). However, measuring scion growth of two year old nonbearing, budded, seedling rootstocks for ten months and monitoring yield of mature bearing trees in a production orchard for nine years are completely different situations. This long-term field trial, with mature bearing trees, is an attempt to corroborate the salinity potential demonstrated in our earlier greenhouse trial. A long term field trial with bearing trees is particularly important as the effects of sustained salinity are slow to develop and subtle. Field trials like this one should be conducted until soil salinities cause statistically significant declines in growth and yield.

There are two ways saline irrigation can harm a plant. The first is by osmotic influences. The second is by specific – ion toxicities. Osmotic pressures manifest in slowed plant growth and productivity over a number of years. Specific ion toxicities manifest within a season. The former is more difficult to detect than the latter.

Osmotic effects are the more common way salts in irrigation water reduce plant growth and yield. Normally the concentration of solutes in root cells is higher than that in soil water. This allows water to move freely into the plant root. But, as the salinity of soil water increases, this difference in concentration between constituents in the soil water and those in the root lessens, initially making the soil water less available to the plant. To prevent salts in the soil from reducing the soil water available to the plant the plant cells must adjust osmotically. They must either accumulate salts, or synthesize organic compounds, generally sugars or organic acids, that raise the osmotic level of the plant root cells. This osmotic adjustment through the acquisition or synthesis of new cellular constituents allows the plant roots to compete more effectively for the available soil water. However, this synthesis process uses energy that would otherwise be used for plant growth and yield. The net result is a smaller plant that appears otherwise healthy. Some plants are more efficient at osmotic adjustment and are therefore more salinity tolerant. However, there are limits to a plant's ability to osmotically adjust.

The second way salts harm plants is specific ion toxicity. Specific-ion toxicities occur when chloride, boron or sodium ions in the soil water are absorbed by, and accumulate within, the plant, generally in stems or leaves. The most common manifestation of specific ion toxicity is marginal and tip leaf burn. Boron toxicity is an example of this. However, visible leaf symptoms do not necessarily result in compromised tree performance. Our 1999 greenhouse rootstock salinity trial demonstrated boron did not harm pistachio growth until it was above 1500 ppm in dried leaf tissue. However, boron commonly produces marginal leaf burn at much lower levels. This study also demonstrated sodium and chloride do not produce specific ion toxicity in 'Kerman' on any the rootstocks used in this field trial.

Our 1999 greenhouse trial demonstrated trees on PGI, Atlantica, and UCB-1 rootstocks tolerated irrigation with water up to 8dS/m. This trial also demonstrated Atlantica and UCB-1 rootstocks were equally tolerant, and significantly more tolerant, than the PGI rootstocks (Ferguson et al, 2002).

The objectives of this trial are:

1. Demonstrate at what soil salinity levels pistachio production declines.
2. Rank the relative salinity tolerance levels of the four pistachio rootstocks in this trial.
3. Determine if salts harm pistachio productivity through osmotic effects, by preventing water extraction from the soil or through specific ion damage.
4. To determine if greenhouse trials are an accurate predictor of field performance.

PROCEDURES

EXPERIMENTAL PLOT

This trial is located within a larger rootstock trial established by our research group in 1989 and maintained by Paramount Farms in Kern County, CA. Female trees were established with buds from one female tree, thus differences among trees should be the result of rootstock influence as all the scions are genetically identical. All female trees were the same distance from a male pollinator tree.

The soil type at this field site, located approximately 15 miles southwest of Kettleman City, CA, has been classified as a silty clay loam, mixed, thermic Typic Haplargid. Good commercial fertilization, pest, disease, pruning and harvest practices have been performed by ranch personnel since planting.

SALINE IRRIGATION

The unit, decisiemen per meter, dS/m, is a measure of the electrical conductivity, EC, of a solution. The units dS/m and milliho per centimeter, mmho/cm, are equal. EC in dS/m X (640-840) = TDS ppm. The range of salinities used in this experiment ranged from 0.75 to 12 dS/m, or 480 to 11,040 ppm TDS.

Four saline irrigation treatments with ECw values of 0.75, 4.0, 8.0 and 12.0 dS/m were randomly replicated four times across 20 rows within a 400 tree pistachio rootstock trial established at Paramount Farms, in Kern County, in 1989. The experiment was conducted on 64 female 'Kerman' trees. There were four replications of four salinity treatment levels applied to sets of four trees budded onto four different rootstocks: *P. atlantica* (Atl), *P. integerrima* (PGI), and *P. atlantica* X *P. integerrima* (PGII and UCB1); 4 X 4 X. 4 = 64 trees. Two high salt concentration nurse tanks, one at 0.27 lbs / gal sodium sulfate and the other at 0.13 lbs/gal calcium chloride, 0.33 lb/gal NaCl and 0.006 lb/gal Solubor (20.5% B) were used as salt water sources for creating saline treatments with a Na:Ca ratio of 5:1 and increasing B concentration of 1 ppm for each 1 dS/m increase in salinity. These ratios are representative of Westside drain waters. Salt treatments were injected from each high salt concentration nurse tank using an impeller pump into a manifold equipped with flowmeters and then at differential rates into four sets of irrigation lines pressurized at 22 psi with canal water to produce the desired salinity treatment levels as measured with a portable EC meter. One irrigation line, the control treatment which was California Aqueduct canal water, received no salt injection. Each of the four irrigation lines was equipped with water meters to measure seasonal irrigation delivery. Each of the four irrigation lines appeared as headers at each of the twenty rows of trees to provide source outlets for drip irrigation lines to achieve the appropriate salinity treatment replication. Existing irrigation lines were plugged and new 360° micro sprinklers, (14.4 gph) were installed four feet from trunks of treatment trees with the water outlet pattern being directed back towards the trunk. Irrigations were scheduled using normal year evapotranspiration data. Excessive saturation has been a problem on the 8 and 12 dS/m treatments so reduced flow microsprinklers (12.0 gph) were installed on these trees in 2001. This still provides a 20 – 40% leaching fraction.

WATER AND SOIL SALINITY MEASUREMENTS

Field samples of irrigation water were collected in 400 ml containers over the course of each irrigation in order to determine water quality. Individual tree soil samples were collected before the irrigation season in April and after the irrigation season in November of each growing season. Water and soil analysis were conducted using established laboratory procedures at the Division of Agriculture and Natural Resources Laboratory in Davis, CA.

HORTICULTURAL MEASUREMENTS

Individual annual trunk growth and yield were determined on all trees. Individual tree yield samples were commercially graded at the Paramount Farming Processing Facility. Annual individual tree leaf samples were collected for nutritional analysis at the same lab as above.

TREE WATER STATUS MEASUREMENT

Tree water status by midday, bagged leaf water potential was measured before each irrigation, when trees should be most stressed, and within 24 hours after irrigation. Tree water status was measured by bagging one leaf from the lower internal part of the canopy from each tree of four replications of each rootstock-saline irrigation treatment combination. Bags were constructed from black polyethylene and aluminum foil with the intent of excluding measured leaves from light and micrometeorological environments. Leaves were bagged at 0900 Pacific Standard Time, then removed three hours later for water potential determination using a Scholander type pressure vessel. All leaves were selected based upon similar age and canopy position.

PHOTOSYNTHETIC GAS EXCHANGE MEASUREMENTS

A Licor LI-6400 portable photosynthesis system was used to measure gas exchange of individual tree leaves annually in August. The reference CO2 was set at 400 ppm. The PAR (photosynthetically active radiation) level was 1500 microeinsteins. Sample relative humidity was maintained at 55% =/- 5%. The flow rate was maintained at 500 micromoles and adjusted as required. Sample leaves were mature, fully expanded, and selected for maximum sun exposure and height. The same sample leaves were used each time and measured at the end of the irrigation cycle, immediately prior to the next irrigation. Measurements were made between 0900 and 1500 hours. Photosynthesis measurements were initiated in 2000 and 2001 as a more discrimination indicator of tree water stress in addition to bagged leaf water potentials.

SITING OF NEUTRON PROBE ACCESS TUBES, REPLICATION AND MEASUREMENT OF SOIL WATER CONTENT

Using a measurement of the backscatter of thermalized (slowed) neutrons, the neutron probe determines soil water content of a volume of soil the size of a basketball. For this study, 2 inch PVC Class 125 pipe access tubes have been installed to allow for repeated measurements of soil water content from 0.5 to 5 feet in one-foot increments. As demonstrated in figure 1, from 1994 through the 2000 season, one neutron probe access tube per tree was installed to a depth of 5.5 feet on every tree in the trial in approximately the same location relative to the trunk and the opposing fanjet; about 4 feet east of the trunk, 4.5 feet west of the fanjet and 1.5 feet south of the hose. This placed the access tube in an area that represented average to slightly better than average application of irrigation water. This wetted area, and the subsurface redistribution of water, gave the tree an active root volume of about 50% of the entire orchard floor. This meant that a 1-inch irrigation over the whole orchard equaled about 2 inch around the site of the neutron probe tube. Likewise, neutron probe readings that show a 2-inch extraction of water between irrigations represented about 1 inch of tree water use as transpiration over the whole orchard.

However, the variability in spatial distribution of tree roots and the precipitation pattern of the fanjets can result in different rates of water application and subsequent tree uptake throughout the root zone of a given tree. For this study, to get the most comparative information possible across all treatments, we measured soil water content to maximize replication across the most trees instead of opting for complete ET estimates using many tubes on only a few trees. The assumption was that the location of the neutron probe tube represented an equal water application and extraction opportunity for each tree and provided a relative comparison suitable for statistical analysis. Therefore results reported through 2000 were generated from neutron probe data taken from 4 replications times 4 rootstocks times 4 levels of salinity; a total of 64 tubes as demonstrated in figure 1.

However, water extraction figures from 1999 through 2000 suggested we were not obtaining an accurate picture of water extraction from the soil. Consequently, for the 2001 season the number of neutron probe tubes was increased to four per tree and sited as demonstrated in figure 2. As previous years showed very little difference in water extraction among trees on the different rootstocks we dropped neutron probe monitoring on trees on the Atlantica and PGII rootstocks. The result was a doubled number of access tubes, 128, that concentrated our ET estimates on trees on PGI and UCB-1 rootstocks. Tubes were also installed to a depth of 6.33 feet to allow for water content measurements to 6 feet. This new tube placement was designed to monitor the locations that receive the most water, tube 1, T1. The areas that receive somewhat less, T2. The areas adjacent to the fanjet, a little bit of surface wetting and at the edge and the substantial subbing of water to the 1-3 foot depths, T3. And areas that receive no surface wetting and minimal subbing in the middle of the drive row, T4. This tube arrangement effectively monitored a much larger area of the root system laterally and vertically. This siting of neutron probe tubes compensated for both the irregular fanjet irrigation pattern and the highly variable subsurface water redistribution during and after irrigation. It also compensated for the irregular root distribution. The net result was a better estimate of soil water content.

A further field site modification was done in 2001. Direct soil water status measurements by neutron probe and tree transpiration calculations from 1997 through 2000 suggested trees at the 8 and 12 dS/m irrigation salinity levels were extracting and transpiring only a fraction of the

PHOTOSYNTHETIC GAS EXCHANGE MEASUREMENTS

A Licor LI-6400 portable photosynthesis system was used to measure gas exchange of individual tree leaves annually in August. The reference CO2 was set at 400 ppm. The PAR (photosynthetically active radiation) level was 1500 microeinsteins. Sample relative humidity was maintained at 55% =/- 5%. The flow rate was maintained at 500 micromoles and adjusted as required. Sample leaves were mature, fully expanded, and selected for maximum sun exposure and height. The same sample leaves were used each time and measured at the end of the irrigation cycle, immediately prior to the next irrigation. Measurements were made between 0900 and 1500 hours. Photosynthesis measurements were initiated in 2000 and 2001 as a more discrimination indicator of tree water stress in addition to bagged leaf water potentials.

SITING OF NEUTRON PROBE ACCESS TUBES, REPLICATION AND MEASUREMENT OF SOIL WATER CONTENT

Using a measurement of the backscatter of thermalized (slowed) neutrons, the neutron probe determines soil water content of a volume of soil the size of a basketball. For this study, 2 inch PVC Class 125 pipe access tubes have been installed to allow for repeated measurements of soil water content from 0.5 to 5 feet in one-foot increments. As demonstrated in figure 1, from 1994 through the 2000 season, one neutron probe access tube per tree was installed to a depth of 5.5 feet on every tree in the trial in approximately the same location relative to the trunk and the opposing fanjet; about 4 feet east of the trunk, 4.5 feet west of the fanjet and 1.5 feet south of the hose. This placed the access tube in an area that represented average to slightly better than average application of irrigation water. This wetted area, and the subsurface redistribution of water, gave the tree an active root volume of about 50% of the entire orchard floor. This meant that a 1-inch irrigation over the whole orchard equaled about 2 inch around the site of the neutron probe tube. Likewise, neutron probe readings that show a 2-inch extraction of water between irrigations represented about 1 inch of tree water use as transpiration over the whole orchard.

However, the variability in spatial distribution of tree roots and the precipitation pattern of the fanjets can result in different rates of water application and subsequent tree uptake throughout the root zone of a given tree. For this study, to get the most comparative information possible across all treatments, we measured soil water content to maximize replication across the most trees instead of opting for complete ET estimates using many tubes on only a few trees. The assumption was that the location of the neutron probe tube represented an equal water application and extraction opportunity for each tree and provided a relative comparison suitable for statistical analysis. Therefore results reported through 2000 were generated from neutron probe data taken from 4 replications times 4 rootstocks times 4 levels of salinity; a total of 64 tubes as demonstrated in figure 1.

However, water extraction figures from 1999 through 2000 suggested we were not obtaining an accurate picture of water extraction from the soil. Consequently, for the 2001 season the number of neutron probe tubes was increased to four per tree and sited as demonstrated in figure 2. As previous years showed very little difference in water extraction among trees on the different rootstocks we dropped neutron probe monitoring on trees on the Atlantica and PGII rootstocks. The result was a doubled number of access tubes, 128, that concentrated our ET estimates on trees on PGI and UCB-1 rootstocks. Tubes were also installed to a depth of 6.33 feet to allow for water content measurements to 6 feet. This new tube placement was designed to monitor the locations that receive the most water, tube 1, T1. The areas that receive somewhat less, T2. The areas adjacent to the fanjet, a little bit of surface wetting and at the edge and the substantial subbing of water to the 1-3 foot depths, T3. And areas that receive no surface wetting and minimal subbing in the middle of the drive row, T4. This tube arrangement effectively monitored a much larger area of the root system laterally and vertically. This siting of neutron probe tubes compensated for both the irregular fanjet irrigation pattern and the highly variable subsurface water redistribution during and after irrigation. It also compensated for the irregular root distribution. The net result was a better estimate of soil water content.

A further field site modification was done in 2001. Direct soil water status measurements by neutron probe and tree transpiration calculations from 1997 through 2000 suggested trees at the 8 and 12 dS/m irrigation salinity levels were extracting and transpiring only a fraction of the applied water. Roots were proliferating outside the wetted zone, obtaining fresh water outside the saline irrigation zone. To prevent this 0.006 inch thick plastic barriers were installed around all treatments to a depth of 1.5 m, fig.3. Trenching to sink the barriers cut many small roots in the top three feet of the profile, but this did not appear to adversely affect tree vigor during the 2001 season.

RESULTS AND DISCUSSION

The larger rootstock trial that contains this salinity trial was planted in 1989 and reached full bearing in 1998. The salinity treatments commenced in 1994. By 1998, when the trees were full bearing, the soil salinity levels, as measured by soil saturation extract, were reflective of the irrigation water salinity. As the tables 1, 2, and 3 below demonstrate, eight sequential seasons of irrigation with 0.75 through 8.0 dS/m water had no consistent significant effect on mature tree marketable yield. As Table 4 shows irrigation water at 12 dS/m produced decreases, generally insignificant, in marketable yield of trees on all four rootstocks. However, trees on UCB-1 rootstocks appeared to be most adversely affected. This contradicts our greenhouse trial in which Atlantica was the most saline tolerant rootstock followed by an almost equally tolerant UCB-1. PGI was the most saline sensitive rootstock.

Figure 4 graphically synthesizes the data given in the four tables above. This figure demonstrates the effect of salinity on average annual yield, 1997-2001, of individual trees, on all four rootstocks. This graph corroborates our greenhouse study demonstrating irrigation water up to 8 dS/m, which produces an average root zone salinity of 7.7 dS/m, has no effect on marketable yield of trees on any rootstock. However, and again consistent with our 1999 greenhouse trial, all four rootstocks produced statistically insignificant yields when irrigation water salinity was 12 dS/m and soil salinity averaged 9.8 dS/m.

EFFECT OF SALINE IRRIGATION ON GROWTH

Figures 5, 6, 7 and 8 graph the annual increase in rootstock growth of 'Kerman' trees on the four different rootstocks. Among the trees on PGII, Atlantica and UCB-1 rootstocks the trees irrigated with 12 dS/m water are displaying slightly slower growth, though not significant decreases in annual growth. As stated earlier, the effects of salinity are slow to develop. However, these small decreases in the rate of trunk growth suggest the sustained salinity in the root zone may be beginning to affect growth. If so, yield will eventually be impacted.

EFFECT OF SALINE IRRIGATION ON TREE NUTRIENT STATUS AND SPECIFIC ION TOXICITY

No differences in tree macronutrient or micronutrient status, including sodium, boron or chloride, have been observed. All leaf nutrient levels have remained within normal ranges throughout this trial. This is consistent with the results of our earlier greenhouse trial. The single exception is trees on PGI rootstocks have had consistently high levels of sodium when irrigated with 8 dS/m water.

No consistent, visible, specific ion tonicities have been observed. Our 1999 greenhouse trial demonstrated that if they did manifest they were a result of boron accumulation.

EFFECT OF SALINE IRRIGATION TREATMENTS ON SOIL WATER CONTENT, PLANT STRESS AND TREE WATER USE

The following discussions address the impact of salinity averaged over all rootstocks for 1999 through 2001. This provides 12 replicates of data for each salinity level for the factors being discussed: irrigation water applied, leaf water status, available amount of soil moisture, transpiration and rates of photosynthesis and stomatal conductance.

IRRIGATION APPLICATION; CIMIS ET AND APPLIED IRRIGATION

Irrigations during the season were scheduled using normal year CIMIS potential evapotranspiration (ET_0) multiplied by pistachio crop coefficients determined in a previous study by Goldhamer (1985). When the orchard was young and coverage of the orchard floor was about 50%, crop ET was further discounted to 95% of a mature orchard depending on age (Snyder, 1989). As the orchard matured this was adjusted upward. Irrigation was timed to match this demand with the same depth applied to all salinity treatments. Separate flowmeters record the application depth for each treatment. Figures 9a, b, and c show pistachio ET for the 1999 through 2001 seasons calculated using the real time CIMIS ET_0 at the Shafter Field Station multiplied by the appropriate crop coefficient for that time of year along with individual treatment irrigation depths. CIMIS ET_0 from the Shafter Field Station was used instead of Lost Hills or Dudley Ridge due to the quality of data and weather station siting. In general, application depths matched calculated ET fairly well. Total water application in the higher salinity treatments was less than the 0.75 dS/m control treatment; probably due to some precipitation of calcite around fanjet nozzles and declines in meter accuracy due to some marginal calcite precipitation in the meters. In 2001 water application in the 8 and 12 dS/m treatments were decreased to avoid soil saturation.

LEAF WATER STATUS MEASUREMENTS

Bagged leaf water potential is an indicator of overall trunk water potential. Midday bagged leaf water potentials for 1999 and 2001, leaf water potential were not done in 2000, indicated the trees were not under water stress as shown in figures 10 a and b. Figures 10 c and b, demonstrating percentage differences from the control among treatments and cumulative leaf water potentials through the season demonstrate increasing differences between the control and 12 dS/m irrigation treatments. This suggests tree water stress is developing at the 12 dS/m irrigation treatment level.

However, it is clear that leaf water potential measurements appear inadequate for estimating the very large differences that were found this season in actual tree transpiration (Figures 12 a, b and c).

It is also possible that the more negative soil water matric potential, the ability of the soil to hold water more tightly, caused by lower available soil water in the 0.75 dS/m treatment could cause a similar bagged leaf water potential resulting from the osmotic stress caused by the salt in the 8 and 12 dS/m treatments. But it is clear this method of measurement is inadequate for estimating the very large differences that were found in actual tree transpiration (Fig 13 a, b and c.).

EFFECT OF SALINE IRRIGATION TREATMENT ON PHOTOSYNTHETIC EFFICIENCY AND STOMATAL CONDUCTANCE

Because midday bagged leaf water potentials did not demonstrate any significant difference in tree water status, photosynthetic rate and gas exchange measurements, generally more accurate indicators of tree stress, were attempted. As with bagged midday leaf water potentials there were no significant differences within each rootstock or among the four salinity treatments. By these measurements in 2000 and 2001 the trees were not stressed. This is consistent with the appearance of leaves of trees on all four rootstocks at all four salinity levels, and with the results of bagged midday leaf water potential measurements.

SOIL WATER STATUS MEASUREMENTS

Figures 12a, b and c for 1999 through 2001 demonstrate major differences in root zone soil water content. Initially, in 1999, beginning in July the 12 dS/m treatment remained at or above field capacity for the entire season while the fresh water control treatment, 0.75 dS/m, declined to 40% after harvest. This pattern of soil water content was much more obvious in 2000 and 2001 with the 12 and 8 dS/m treatments beginning the season with strikingly higher soil water contents and maintaining this pattern throughout the season. This indicates that the depth of irrigation in the low salinity treatment was insufficient to meet all the ET demand for these trees; causing excessive extraction of available soil water. The maintenance of near 100% field capacity in the higher salinity treatments indicates the trees are extracting less water, and that leaching is occurring in these treatments.

TREE WATER USE

For the 1999 and 2000 seasons actual comparative treatment transpiration was calculated by measuring the soil water depletion in between irrigations. Since the wetted volume from the fanjets is only 50% of the entire orchard floor, net depletion of soil water in the area of the neutron probe tubes is then multiplied by 0.5 to estimate transpiration over the whole orchard floor. Thus, a 3 inch average depletion would mean 1.5 inches of transpiration. Water consumption in Figure 12 a and b is reported as transpiration and not evapotranspiration (ET) because the neutron probe is incapable of accurately measuring water content changes in the top three inches of soil; the zone from which most evaporative water loss will occur. This means that the depletion measured between irrigations is either extraction by the tree (transpiration), or leaching. Nearly all measurements of depletion for 1999 and 2000 seasons consisted solely of transpiration as we waited two to five days after irrigation before making the initial soil water content measurement, with the subsequent measurement immediately before the next irrigation. This technique woefully underrated the Actual ET. With the addition of plastic barriers and now four access tubes per tree to provide average water content for the whole orchard floor occupied by a given treatment, the 2001 measured ET is virtually the same as the calculated CIMIS ET.

This depletion measured by the neutron probe is multiplied by 0.5 and then divided by the actual CIMIS ET_0 for that same period. This calculated crop coefficient value (K_c) for each treatment is then multiplied by the CIMIS ET_0 during the following irrigation interval to estimate the treatment transpiration during that period. This provides a continuous cumulative estimate of crop transpiration over the season.

For the 2001 season the additional three additional probe tubes per tree gave a much better estimate of tree water extraction as well as the ability to estimate leaching. The data collected in 2001 demonstrated trees receiving the 0.75 control and 4 dS/m treatments transpired almost equal amounts of water. Trees receiving the 8 and 12 dS/m irrigation water transpired less water. This is a function of 20% less water being applied when 12 gph emitters were substituted for the 15 gph emitters in mid July to avoid marked soil saturation. Thus the two higher salinity treatments are producing an osmotic effect that is decreasing the water extraction ability of the trees on all rootstocks.

CONCLUSIONS

In summary, from 1994 through 2001 results indicate irrigation water salinity above 8 dS/m can, though not consistently or significantly, decrease yield of pistachios grown on all four rootstocks tested. Using marketable yield as an indicator of salinity tolerance, the rootstocks ranked as follows, from least to most saline tolerant; UCB-1, Atlantica, PGII and PGI. Trees on UCB-1 rootstocks were also the trees beginning to demonstrate a slightly decreased growth rate. Leaf macronutrient and micronutrient levels; including chloride, sodium and boron have remained, with few exceptions, within normal ranges. No consistent specific ion tonicities have been observed.

Not surprisingly, considering the lack of significant effects on tree growth, nutritional status or yield, the trees on all rootstocks also have normal leaf water status, photosynthetic rate and stomatal conductance. However, measurements of tree water application, extraction and use indicate salinities above 8 dS/m are deleteriously affecting the trees' ability to extract water at soil water salinities above 8 dS/m.

The results from this trial thus far strongly suggest osmotic pressure, and not specific ion toxicity, is the mechanism by which salinity harms pistachios.

All the results above, with the exception of rootstock salinity tolerance rankings, are consistent with our 1999 greenhouse rootstock salinity trial and those of others.

While the trees have demonstrated great tolerance through the eight years of this trial, these decreases must eventually manifest in decreased growth, and therefore yield. It is these limits that must be definitively known if drainage water is to be successfully integrated into future irrigation programs.

ACKNOWLEDGEMENTS

The authors wish to thank 'Goyo' Jacobo, Rick Cole, Kiko Garza, Joe Gonzales, Dennis Elam and Brenda Hansen of Paramount Farming Company for the generous contribution in time and service to this trial. We also gratefully acknowledge the support of California Pistachio Commission and the UC Westside Salinity/Drainage Task Force.

• • • • •

LITERATURE CITED

Ferguson, L., P.A. Poss, S.R. Grattan, C.M. Grieve, D. Want, C. Wilson, T.J. Donovan, and C. T. Chao. 2002. Pistachio rootstocks influence scion growth and ion relations under salinity and boron stress. J. Amer. Soc. Hort. Sci. 127(2): in press.

Goldhamer, D.A., R.K. Kjelgren, and R. Beede. 1985. Water use requirements of pistachio trees and response to water stress. Annual report, CA Pistachio Commission. Pp. 85-92.

Picchioni, G. A., A. Miyamoto, and J. B. Storey. 1999. Salt effects on growth and ion uptake of pistachio rootstock seedlings. J. Am Soc. Hort. Sci. 115:647-653.

Snyder, R.L., B.J. Lanini, D.A. Shaw, and W.O. Pruitt. 1989. Using reference evapotranspiration (ET_o) and crop coefficients to estimate crop evapotranspiration (ET_c) for trees and vines. Univ. CA Coop. Ext. Leaflet 21428.

Walker, R. R., E. Torokfalvy, and M. H. Behouboudian. 1987. Uptake and distribution of chloride, sodium and potassium ions and growth of salt treated pistachio plant. Austral. J. Agr. Res. 38:383-394.

• • • • •

Table 1. Individual tree yields, Kg of dry, inshell splits per tree, for trees receiving 0.75 dS/m irrigation water.

	Mean Root Zone Salinity as ECe (dS/m) for 0.75 dS/m irrigation water				
	2.1	**1.8**	**1.2**	**2.3**	**
Rootstock	**Yield (kg/tree)***				
	1997	**1998**	**1999**	**2000**	**2001**
Atlantica	6.0 a	8.4 a	0.2 a	13.6 a	7.0 a
PGI	7.6 a	11.9 a	1.7 a	14.8 a	9.9 a
PGII	6.5 b	10.8 a	0.3 a	14.0 a	8.7 a
UCB1	6.3 b	11.9 a	0.5 a	14.8 a	8.8 a

*Values for a specific rootstock for a given year followed by the same letter are not significantly different from the same rootstock at a different salinity level within that same year.
+12 dS/m irrigation was only applied for 1997 through 2000 seasons.
**Soil samples not yet analyzed.

Table 2. Effect of irrigation water salinity (dS/m)* and average root zone soil water extract. Water averaged over 1-4 ft depth (dS/m) on yield of trees on four pistachio rootstocks. The top line of the table is the irrigation water salinity. The line below is the salinity of the soil water extract that year.

	Salinity of Irrigation Water (ECw) 4.0 dS/m				
	Salinity of Soil (ECe) in dS/m				
	2.1	**5.3**	**5.4**	**6.2**	**
Rootstock	**Yield (kg/tree)***				
	1997	**1998**	**1999**	**2000**	**2001**
Atlantica	6.1 a	7.6 ab	0.5 a	13.3 a	7.6 a
PGI	8.6 a	9.0 b	3.4 a	12.4 a	10.1 a
PGII	7.8 a	10.9 a	0.4 a	13.1 a	9.5 a
UCB1	8.2 a	12.3 a	0.8 a	16.1 a	10.7 a

*Values for a specific rootstock for a given year followed by the same letter are not significantly different from the same rootstock at a different salinity level within that same year.
+12 dS/m irrigation was only applied for 1997 through 2000 seasons.
**Soil samples not yet analyzed.

Table 3. Effect of irrigation water salinity (dS/m)* and average root zone soil water extract. Water averaged over 1-4 ft depth (dS/m) on yield of trees on four pistachio rootstocks. The top line of the table is the salinity of the irrigation water. The next line is the salinity of the soil water extract that year.

	Salinity of Irrigation Water (ECw) 8.0 dS/m				
	Salinity of Soil (ECe) in dS/m				
	6.0	**6.9**	**8.5**	**9.5**	**
Rootstock	Yield (kg/tree)*				
	1997	**1998**	**1999**	**2000**	**2001**
Atlantica	6.5 a	8.3 a	0.7 a	11.3 a	8.5 a
PGI	8.1 a	10.8 b	2.3 a	10.6 a	8.5 a
PGII	8.1 a	10.8 a	1.2 a	15.3 a	10.1 a
UCB1	8.8 a	10.9 a	0.4 a	13.3 a	10.2 a

*Values for a specific rootstock for a given year followed by the same letter are not significantly different from the same rootstock at a different salinity level within that same year.
+12 dS/m irrigation was only applied for 1997 through 2000 seasons.
**Soil samples not yet analyzed.

Table 4. Effect of irrigation water salinity (dS/m)* and average root zone soil water extract. Water averaged over 1-4 ft depth (dS/m) on yield of trees on four pistachio rootstocks. The top line of the table is the salinity of the irrigation water. The next line is the salinity of the soil water extract that year.

	Salinity of Irrigation Water (ECw) 12.0+ dS/m				
	Salinity of Soil (ECe) dS/m				
	7.5	**10.3**	**11.5**	**10.0**	**
Rootstock	Yield (kg/tree)*				
	1997	**1998**	**1999**	**2000**	**2001**
Atlantica	5.2 b	6.9 b	0.7 a	10.5 a	7.51 a
PGI	7.7 a	10.3 b	0.7 a	13.0 a	10.1 a
PGII	6.7 b	9.0 b	1.2 a	11.4 a	7.2 a
UCB1	5.1 c	6.1 b	0.3 a	9.3 a	6.5 a

*Values for a specific rootstock for a given year followed by the same letter are not significantly different from the same rootstock at a different salinity level within that same year
+12 dS/m irrigation was only applied for 1997 through 2000 seasons.
**Soil samples not yet analyzed.

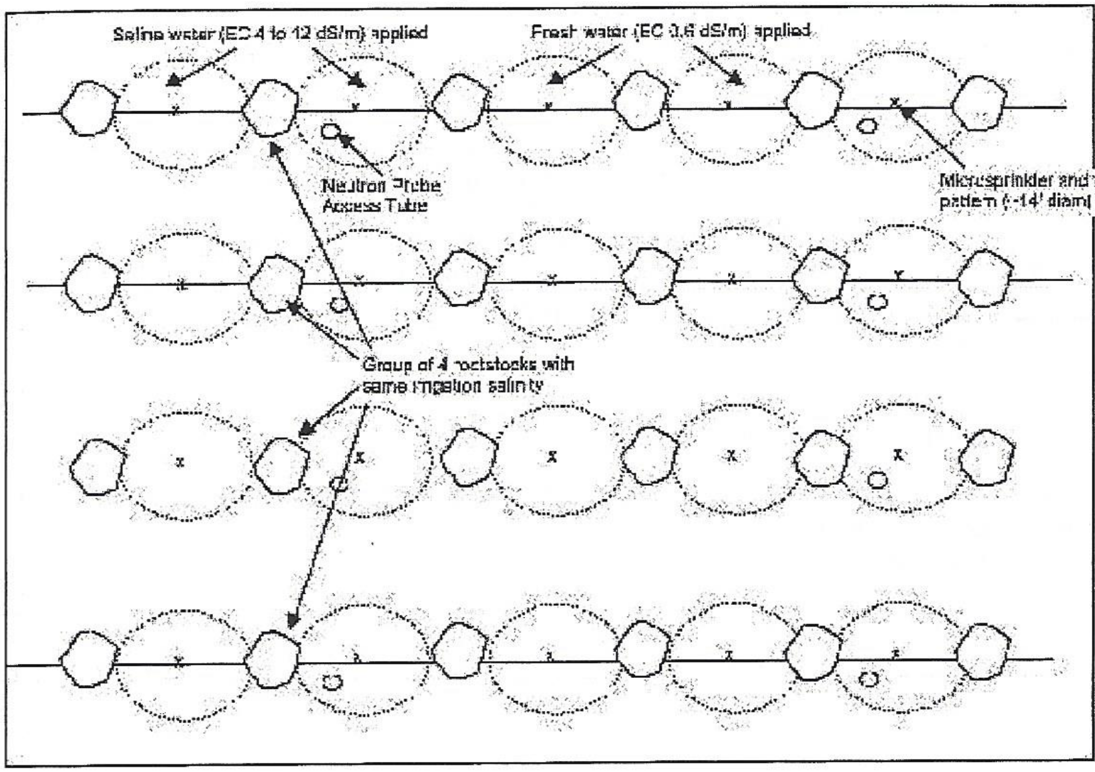

Figure 1. Neutron probe tube placement 1994 through 2000.

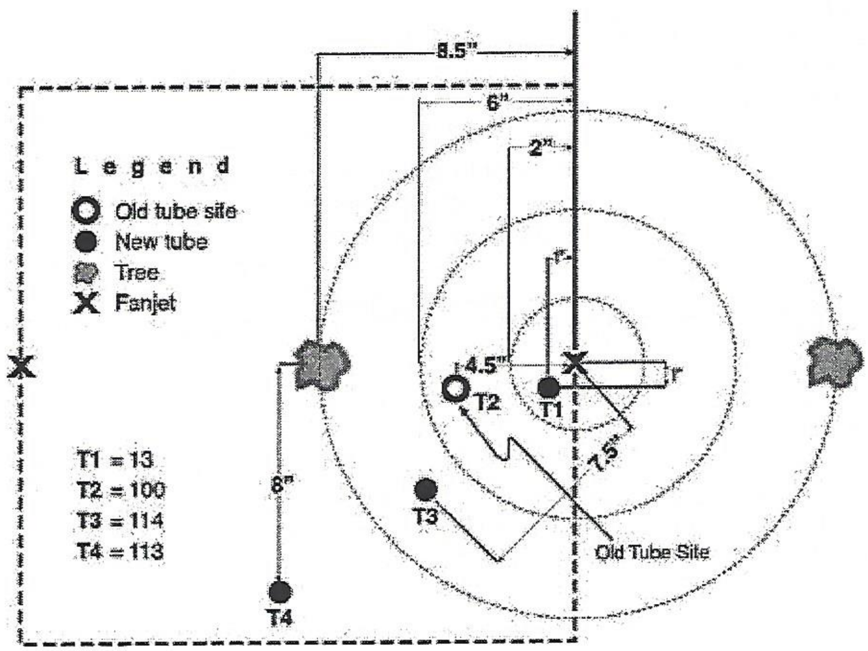

Figure 2. Neutron tube placement in 2001. Note that the number of tubes was increased to four per tree.

Figure 3. Barriers of 0.006 inch plastic were sunk to 1.5m depth around each irrigation treatment replication in March, 2001.

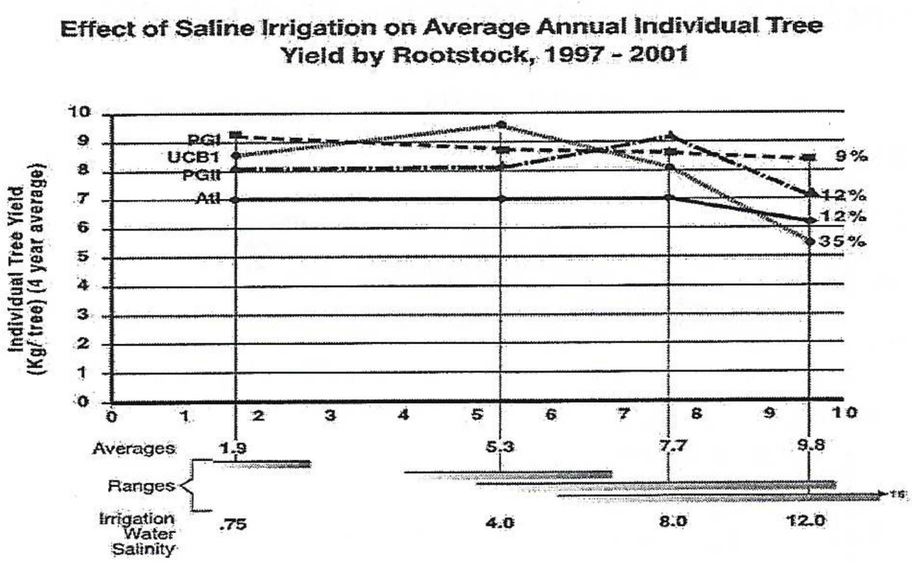

Figure 4. Effect of saline irrigation on per tree yield averaged over 5 seasons, 1997 through 2001. The horizontal axis, bottom, indicates irrigation water salinity, middle, the range of soil salinities produced in the soil, and, top, the root zone salinity averaged over five feet and five years, 1997 – 2001. Average individual tree yields did not decrease until irrigation water salinity was 12 dS/m and produced a root zone salinity of 9.8 dS/m. However, these percentage tree yield decreases versos the control treatment were not statistically significant, as they are an average calculated value.

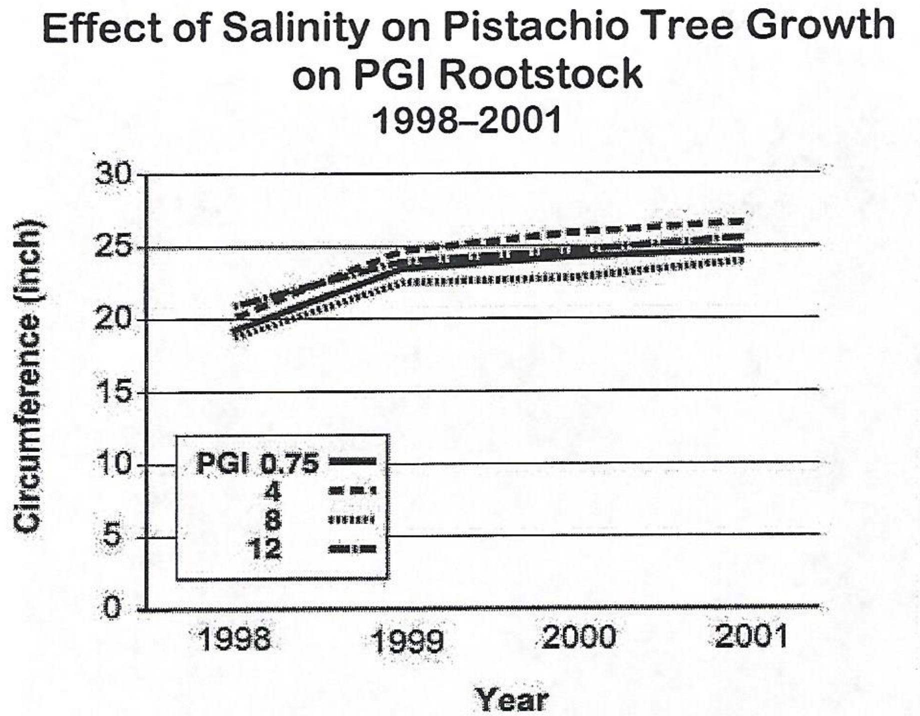

Figure 5. Effect salinity on annual trunk growth of trees on PGI rootstocks. There are no significant differences among treatments or rootstocks.

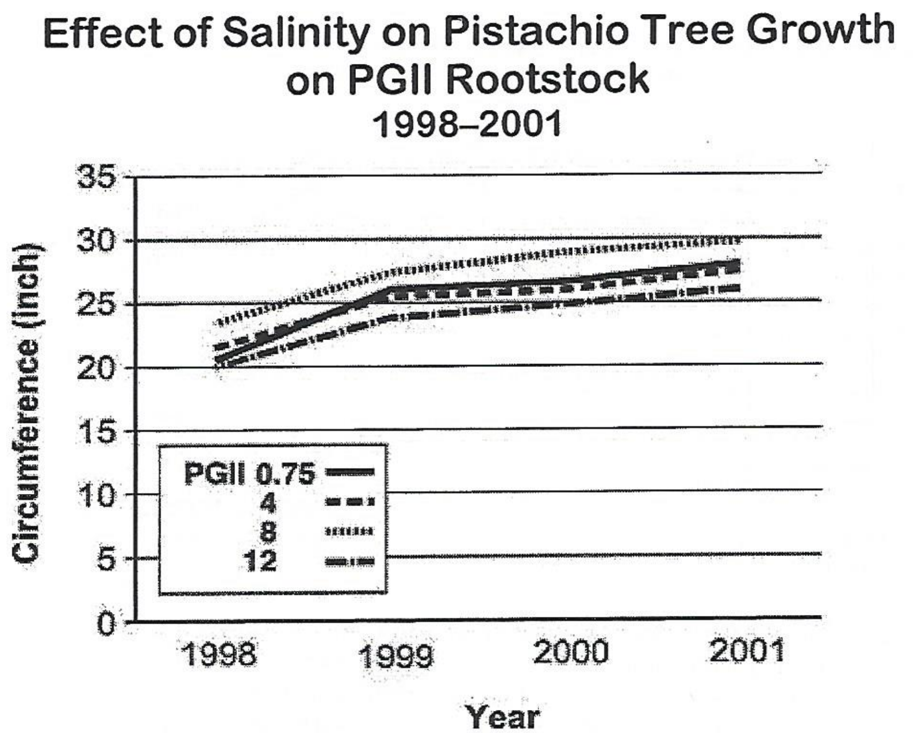

Figure 6. Effects of sustained salinity on trunk growth of trees on PGII rootstocks. There are no significant differences among treatments but the growth rate of trees receiving the 12 dS/m treatment is decreasing

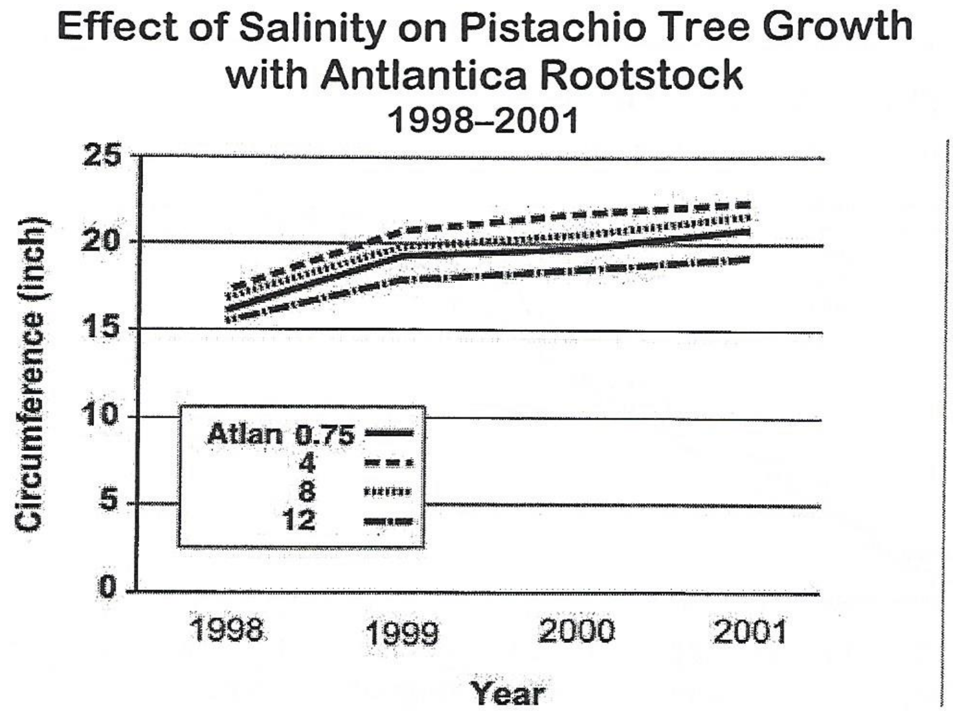

Figure 7. Effects of sustained salinity on trunk growth of trees on Atlantica rootstocks. There are no significant differences but the growth rate of trees receiving 12 dS/m water is decreasing.

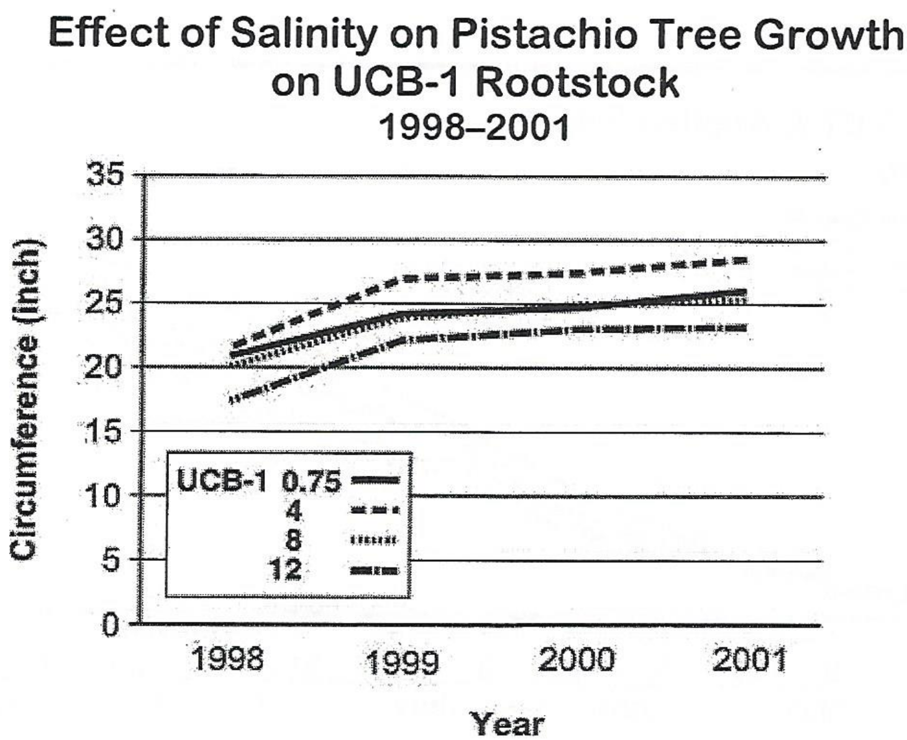

Figure 8. Effect of salinity on growth rate of trees on UCB1 rootstocks. There are no significant differences but the growth rate of trees receiving 12 dS/m water is decreasing.

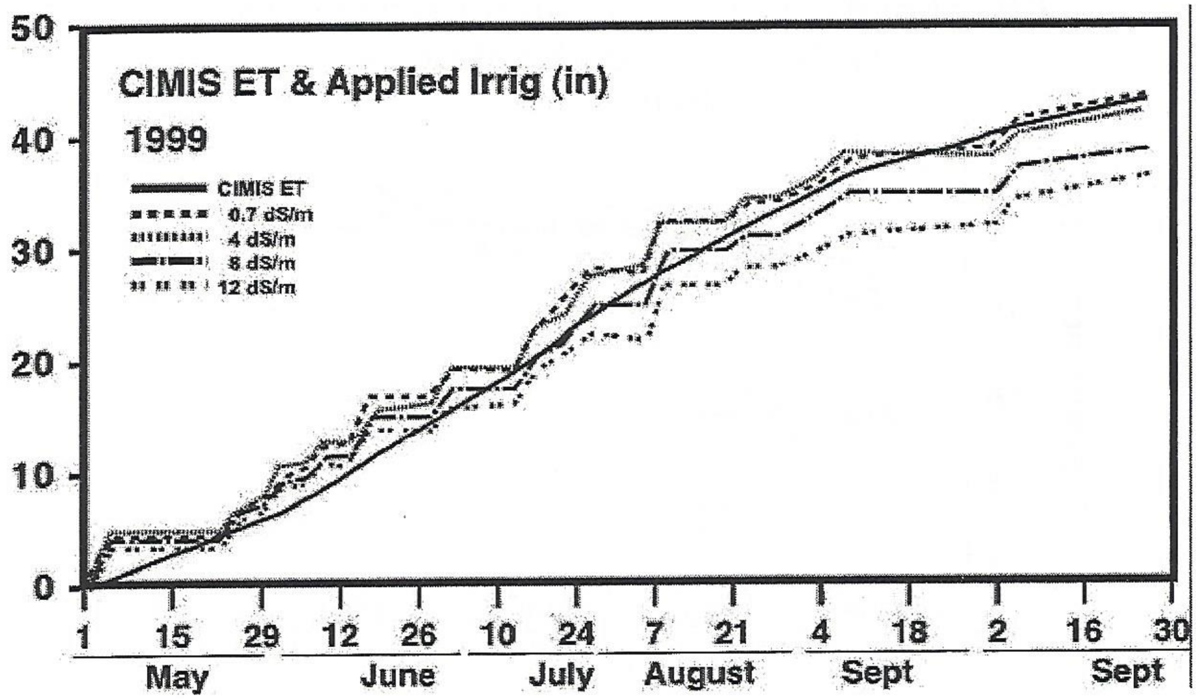

Figure 9a. Cumulative seasonal applied irrigation water to all treatments and calculated pistachio ET using 1999 CIMIS ET_0 as measured at the Shafter Field Station multiplied by crop coefficients described by Goldhamer (1987).

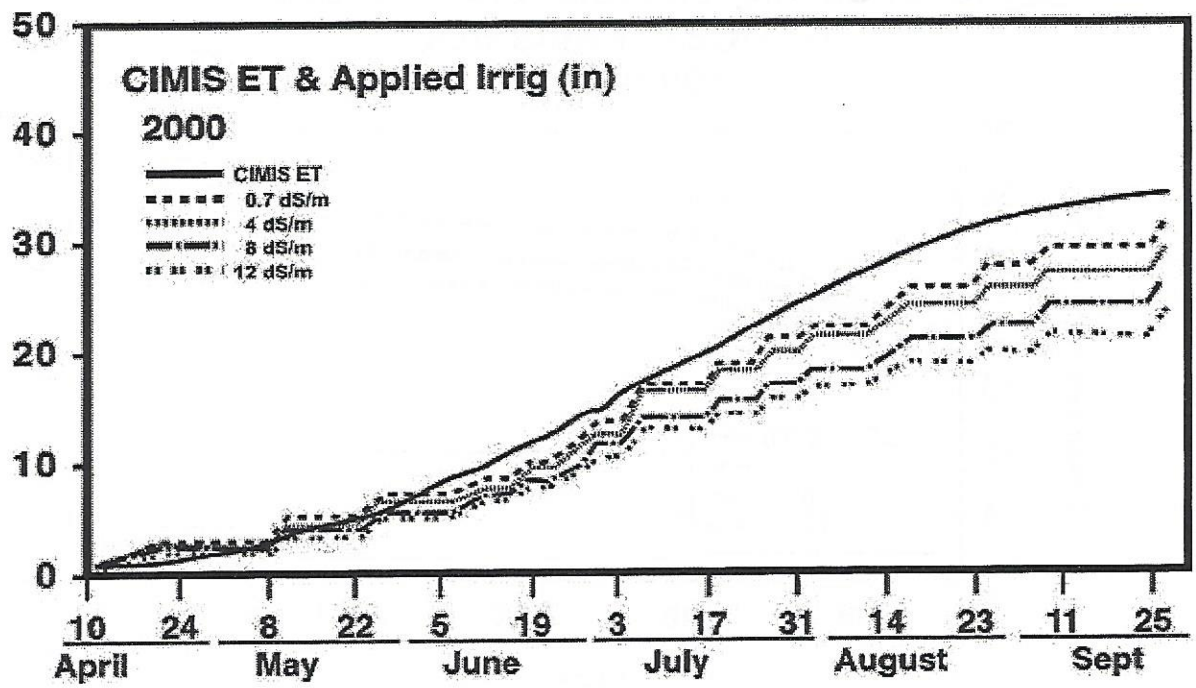

Figure 9b. Cumulative seasonal applied irrigation water to all treatments and calculated pistachio ET using 2000 CIMIS ET_0 as measured at the Shafter Field Station multiplied by crop coefficients described by Goldhamer (1987).

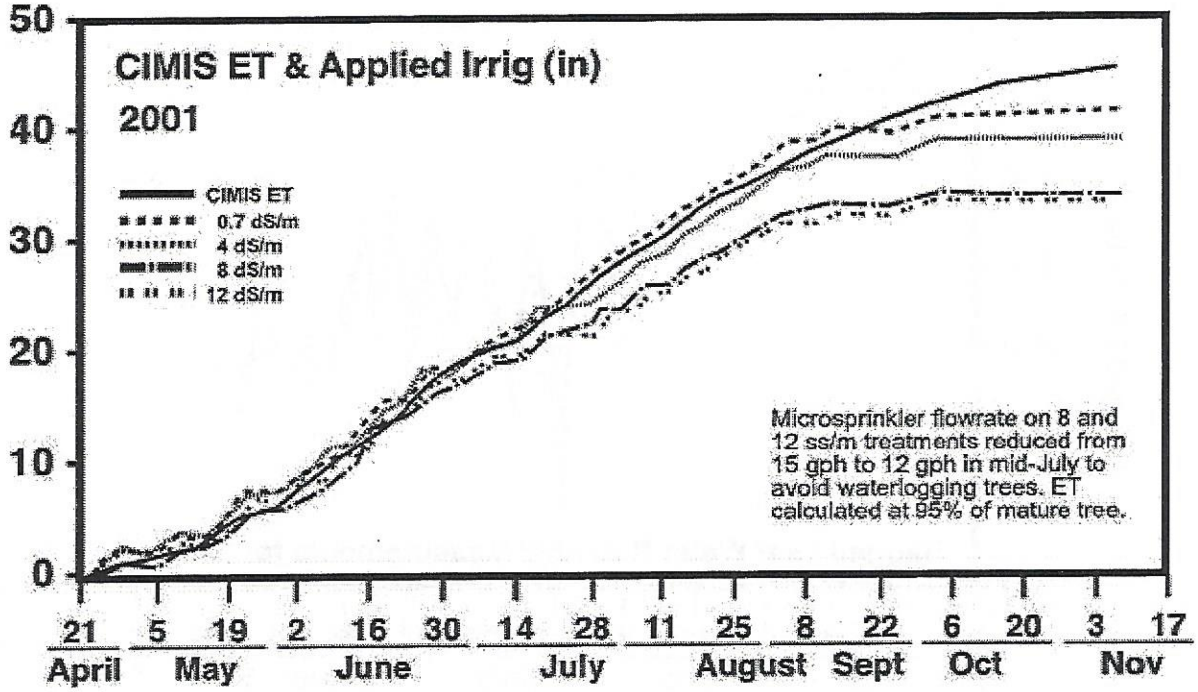

Figure 9c. Cumulative seasonal applied irrigation water to all treatments and calculated pistachio ET using 2001 CIMIS ET_0 as measured at the Shafter Field Station multiplied by crop coefficients described by Goldhamer (1987).

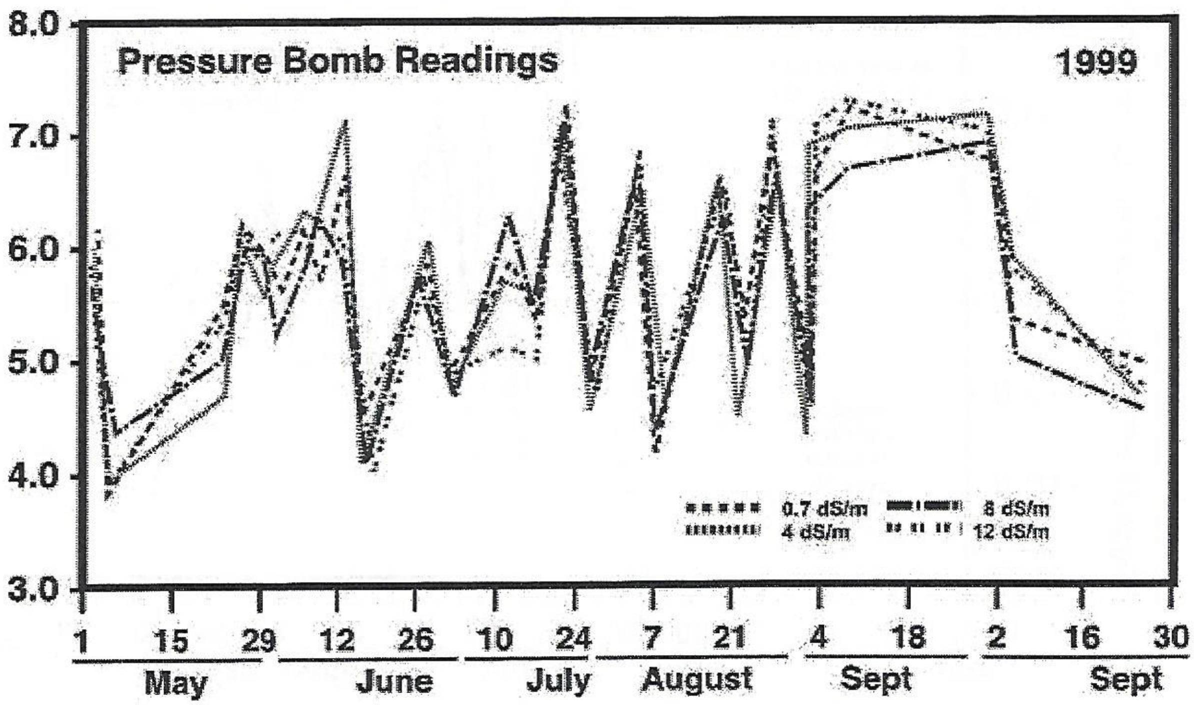

Figure 10a. Midday bagged leaf water potentials over season, 1999. No measurements were done in 2000.

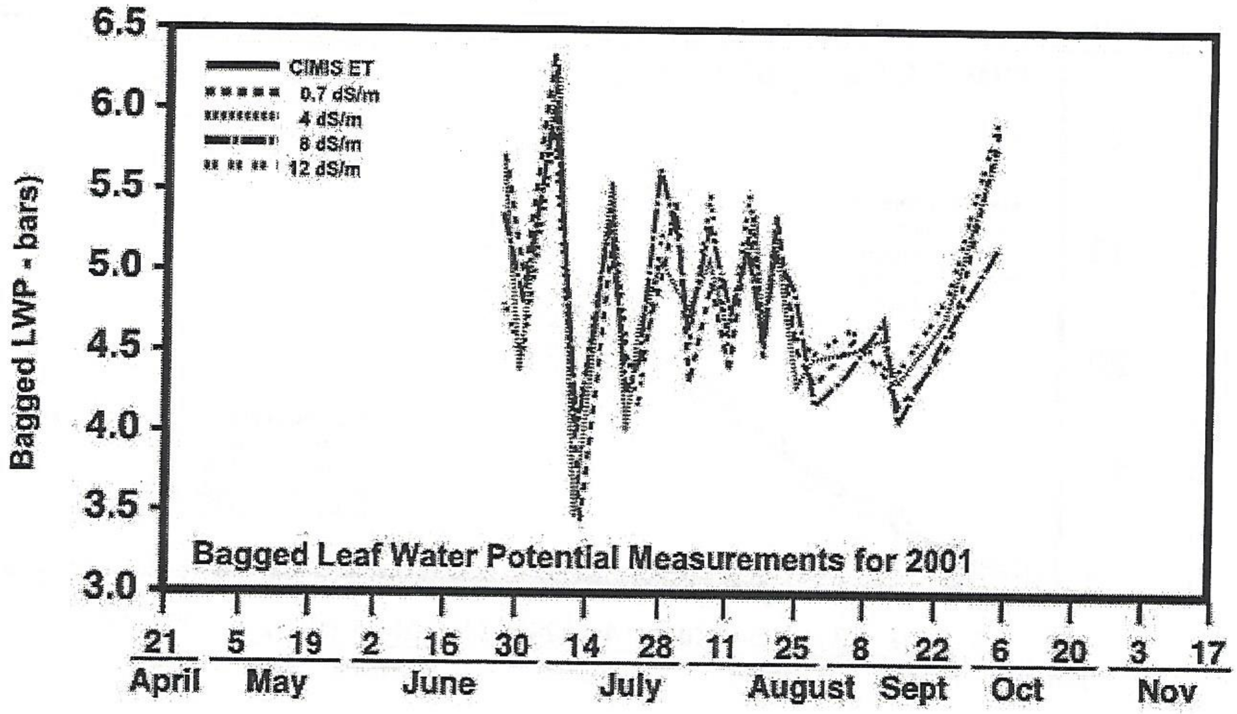

Figure 10b. Bagged midday leaf water potentials for 2001.

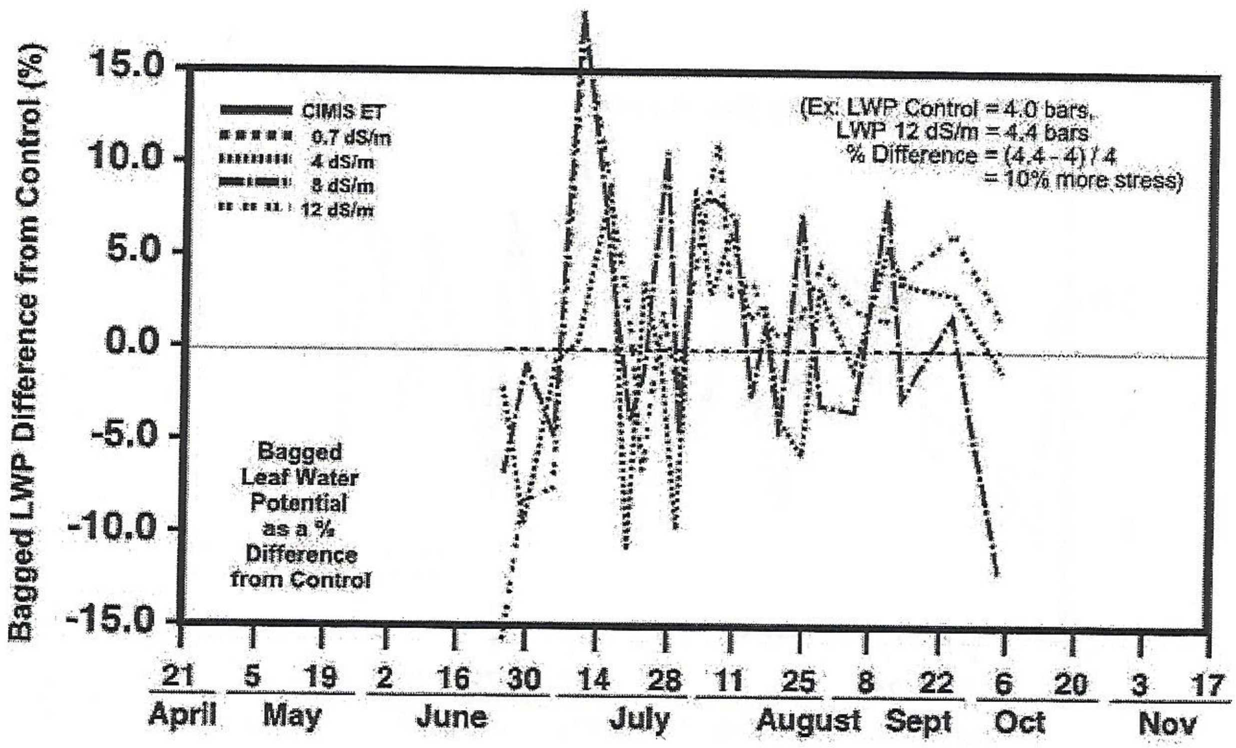

Figure 10c. Bagged midday leaf water potentials demonstrating percentage difference from the control among treatments.

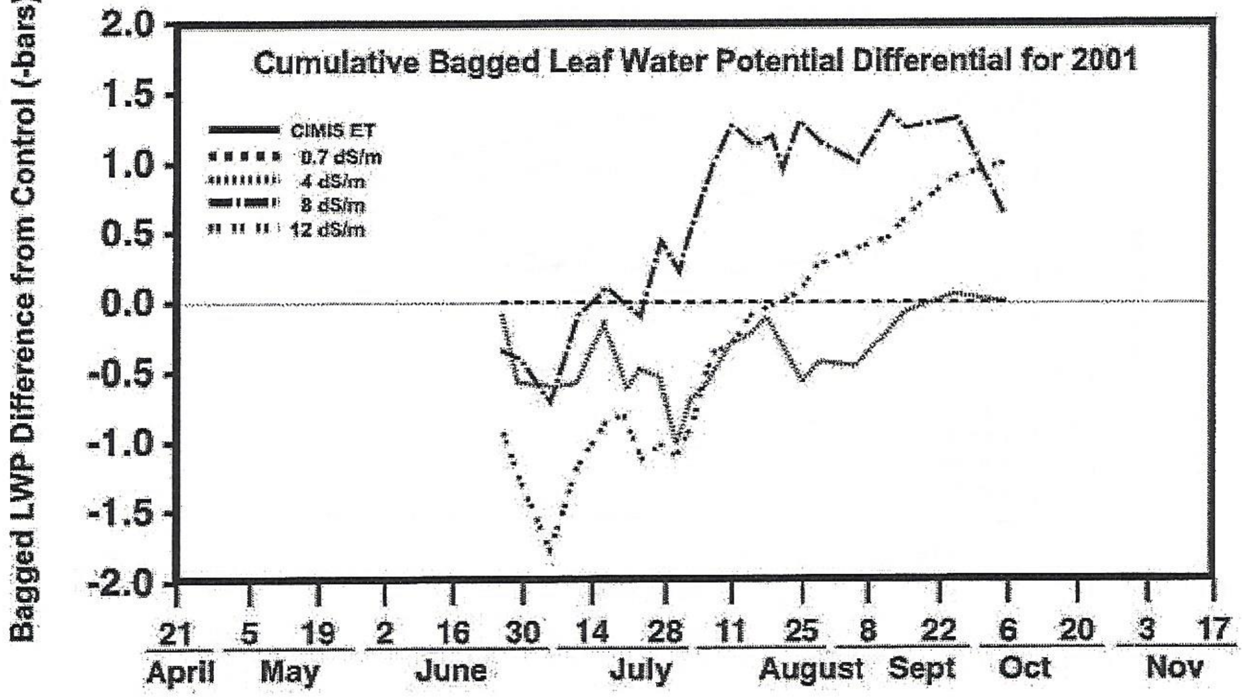

Figure 10d. Cumulative bagged midday leaf water potentials showing cumulative differential from control treatment.

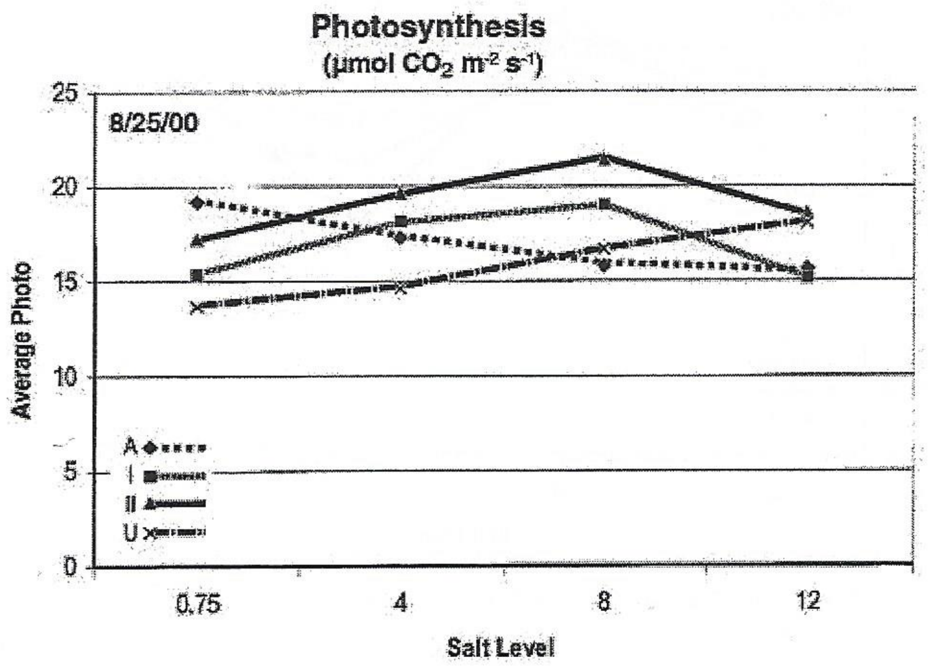

Figure 11a. Photosynthetic rate in August 2000, ten days before harvest.

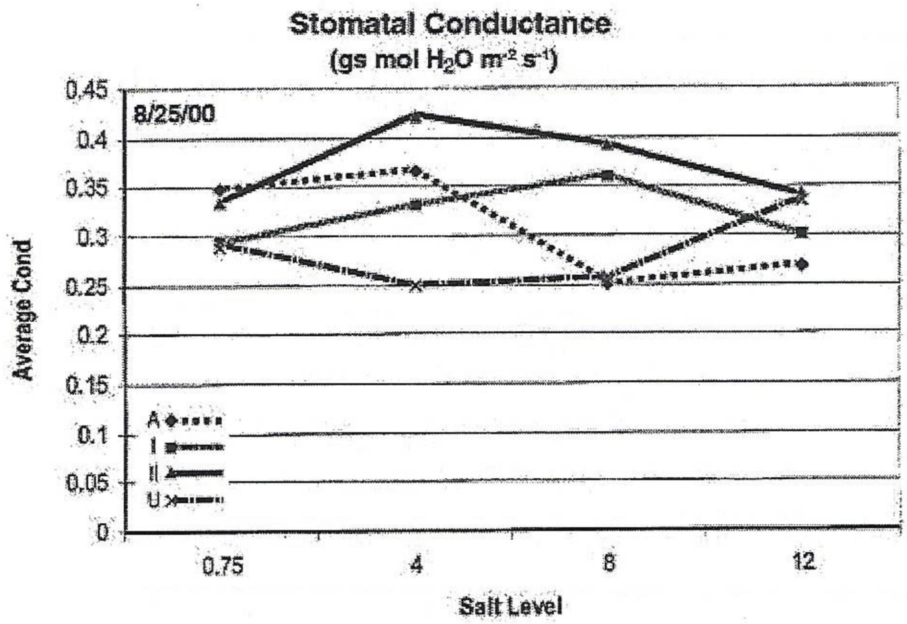

Figure 11b. Stomatal conductance rate in August 2000, ten days before harvest.

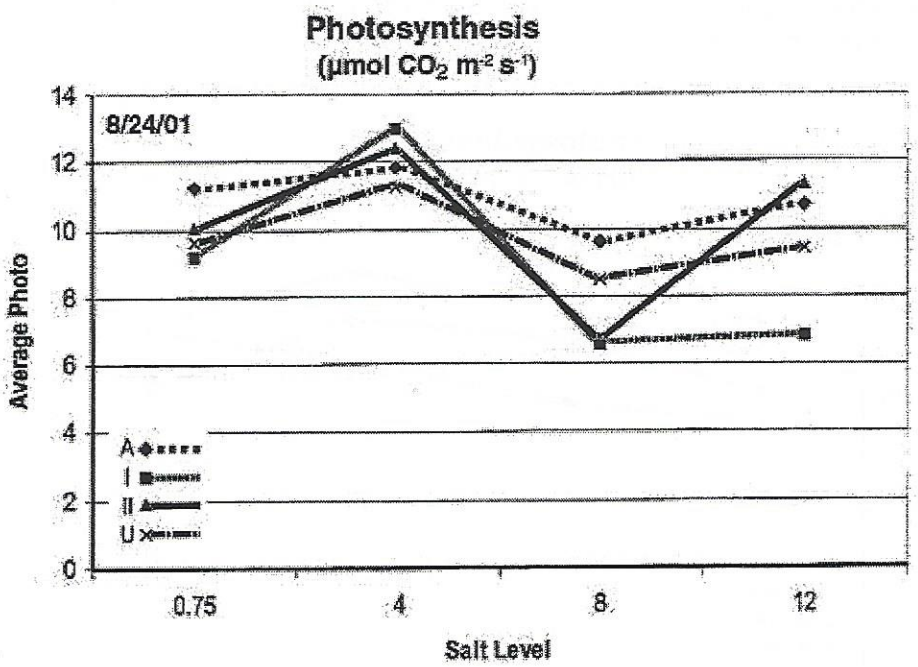

Figure 11c. Photosynthetic rate 2 weeks before harvest in August, 2001.

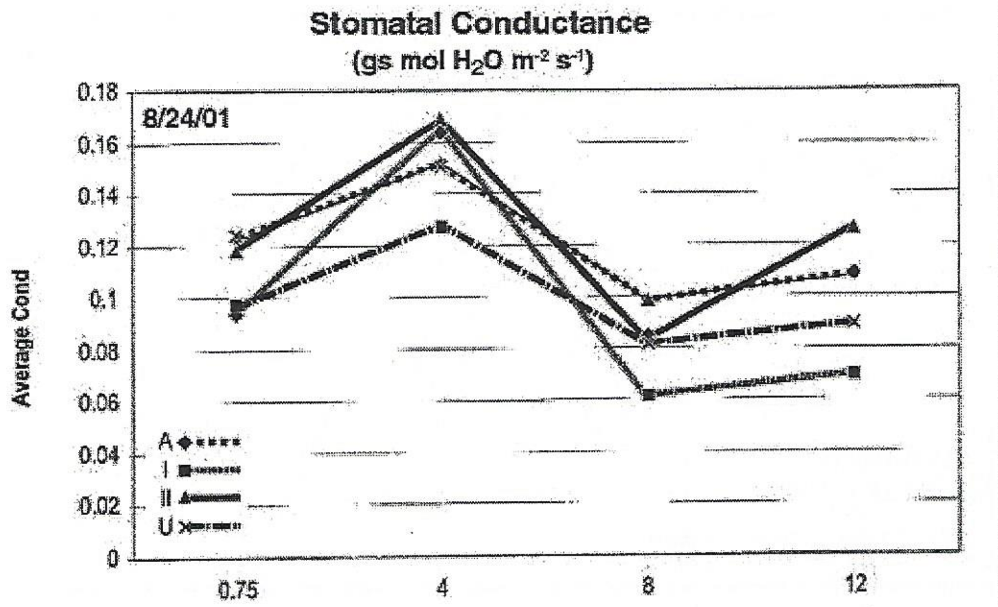

Figure 11d. Stomatal conductance rate measured 2 weeks before harvest in August, 2001.

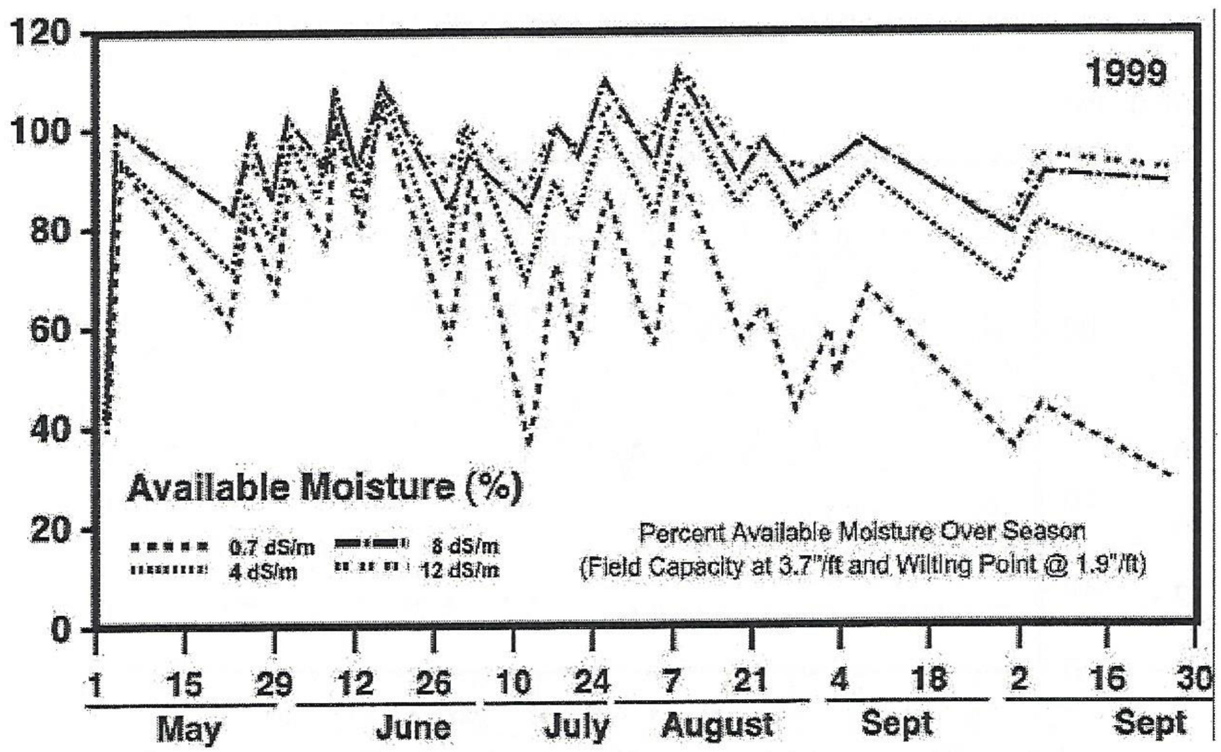

Figure 12a. Percent available water for all treatments from 0.2 to 5.2 foot depth. Calculated using field capacity at 3.7 in/ft, 18.5 inches total over 5 feet, and wilting point of 1.9 in/ft, 9.5 inches total over 5 feet. Total available water at 100% = 9.0 inches.

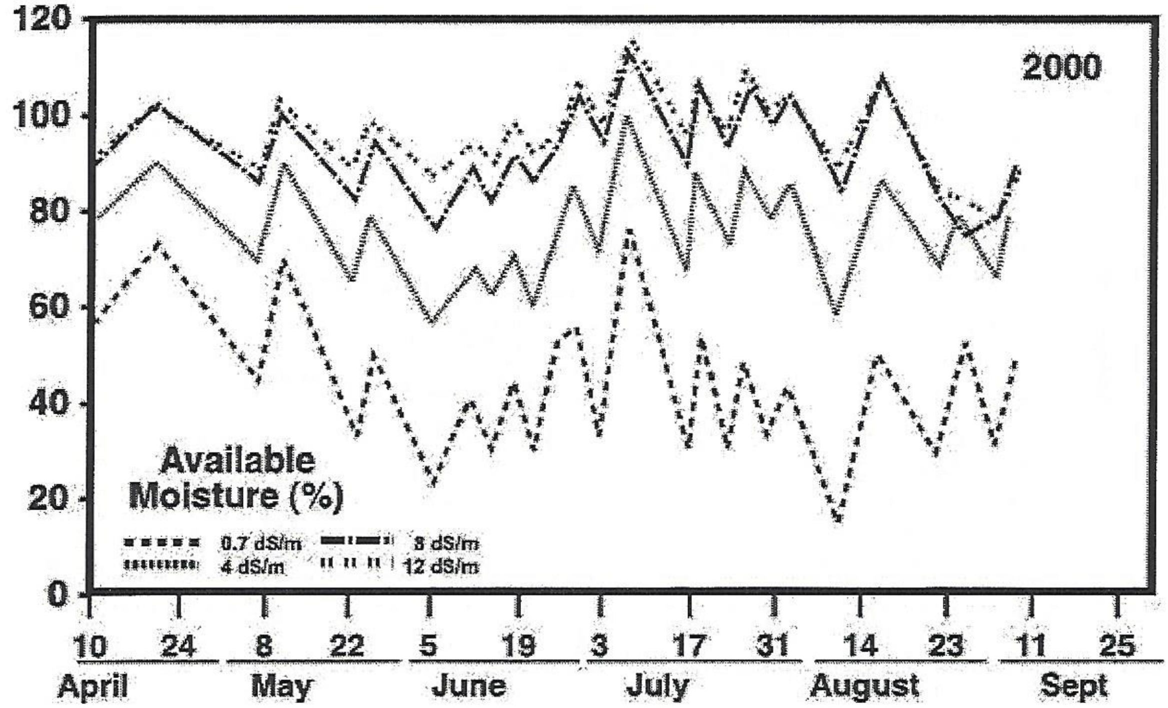

Figure 12b. Percent available water for all treatments from 0.2 to 5.2 foot depth. Calculated using field capacity at 3.7 in/ft, 18.5 inches total over 5 feet, and wilting point of 1.9 in/ft, 9.5 inches total over 5 feet. Total available water at 100% = 9.0 inches.

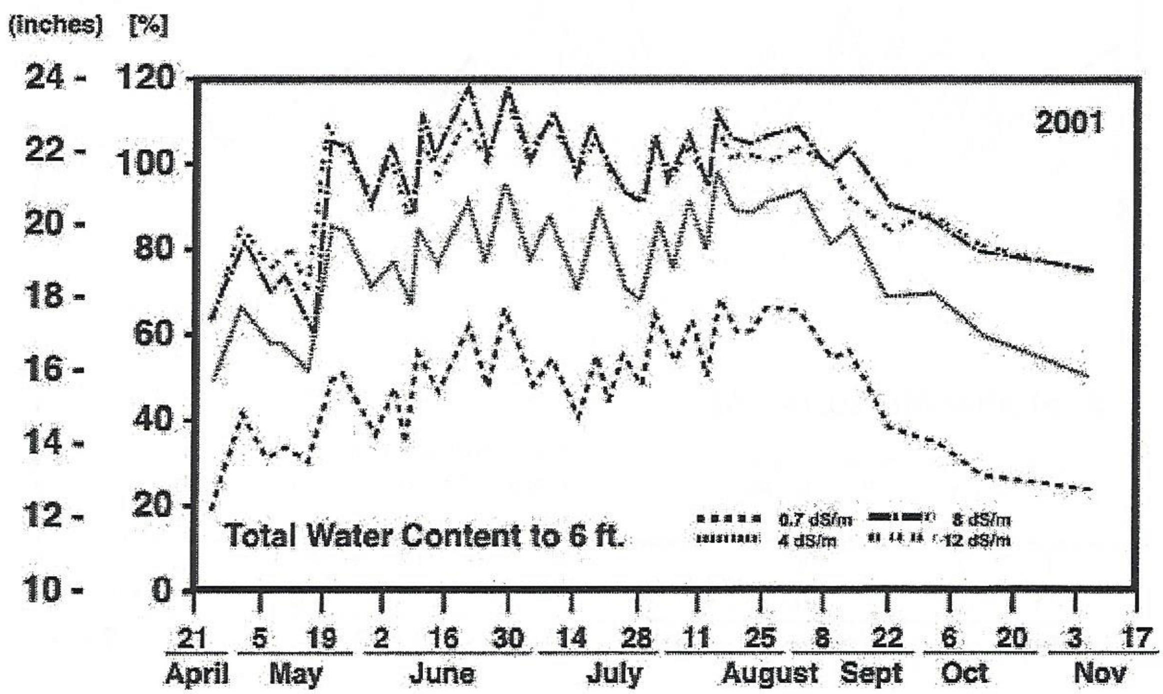

Figure 12c. Percent available water and total water content in inches for all treatments from 0.2 to 5.2 foot depth. Calculated using field capacity at 3.7in/ft, 18.5 inches total over 5 feet, and wilting point of 1.9 in/ft, 9.5 inches total over 5 feet. Total water available at 100% = 9.0 inches.