Salinity Management

Salinity-Chloride Interactions
Effects on Yield

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Avocado yields are decreased by chloride toxicity and soil salinity throughout California orchards but there is little information on the extent to which different rootstocks can be used to improve tree performance under saline conditions. This research has been aimed at the development of a production function model that can be used to predict the impacts of irrigation water chloride content and salinity (EC) on avocado yields. The model further evaluates the effects of different soil chemical and physical properties, water chemistry, and rootstocks on the accumulation of chloride in the leaf tissue. Data have been collected from 10 orchards that span the major avocado production areas from San Diego to San Luis Obispo. Our modeling approach involves the use of an artificial neural network (ANN) program that enables us to separate out complex interactions that cannot be detected using traditional statistical procedures. The long term goal of this research is to develop a smart program that growers can access via the internet to predict how different water qualities and soil properties will affect their yields. This will also provide guidance on the best rootstocks for different irrigation water qualities, and estimates of yield losses and gains under different management scenarios.

In this last year of our five year project, we were successful in obtaining a large number of fruit yield data for the trees in our survey. Harvests from individual orchards were generally moderate, and after elimination of nonbearing or very low bearing trees, some 200 individuals were used in the final data set, representing the full north-south range for avocado production. In this last annual report, we provide our results on use of the ANN modeling approach for predicting fruit yields in relation to irrigation water salinity, leaf chloride, soil pH, and rootstock. The output from the 2011 ANN model confirms the major predictions of the first year's model; ie., that chloride and salinity strongly affect avocado yields independently, and via interactions between these variables that differ for each of the rootstocks. The model further predicts that soil pH is a major factor influencing salinity and chloride damage, suggesting that treatments aimed at long term lowering soil pH from 7.5 to 6.5 might be beneficial. This and several other hypotheses generated from the ANN model results remain to be investigated. The results of this research suggest that long term, multiyear data combined with the power of ANN time series analysis might eventually provide a useful decision support tool for growers.

As we have proposed in a new proposal addressing this subject, we would like to build on the data base for the trees and orchards we have been monitoring this past five years. Thus we have continued the leaf and soil sample collection for fall 2011 to provide continuity in the data set if our proposal is selected for funding. At the time, we have collected all of the leaf and soil samples from our orchards. These samples are now being analyzed by Fruit Growers Laboratory, and the data that are being returned are being organized and analyzed following the same procedures that we used for the past three years. With five or six years more data, we may also be able to examine whether there are any predictive relationships between alternate bearing and factors such as salinity, chloride, soil type, rootstock, and plant nutritional status.

Along with our salinity research supported by the CAC, we have also been conducting related research co-funded by the Kearney Foundation of Science that is investigating the ecology of indigenous plant growth promoting bacteria in the rhizosphere of avocado. These so called PGPR bacteria are present in all soils, but the relationship between their population density in the soil and their effects on root growth promotion are not yet known. We are examining PGPR that affect hormone production on the roots. This process of root elongation is moderated by auxin and ethylene, but the latter gas hormone ethylene can accumulate to high concentrations under stress conditions and inhibit root growth. Many PGPR bacteria carry gene that encode an enzyme called ACC deaminase, which suppresses the production of stress ethylene in the plant rhizosphere. By lowering the production of ethylene with these bacterial inoculants, it may be possible to improve root growth and water use efficiency under saline conditions. The salinity project supported by the CAC has thus enabled us to carry out other complimentary research that may be of value to avocado growers.

In this last year's research that we have now submitted for publication, we identified culturable PGPR 3 different rootstocks in soils with varying soil salinity (0.91-3.90 dS m-1), which were selectively enriched on agar medium containing 1-aminocyclopropane-1-carboxylic acid (ACC) as a growth substrate. Of these we selected 20 bacteria isolates that were then identified by 16S rRNA gene sequence analysis. Characterization of their growth promoting traits included measurements of their ACC-deaminase activity, indole acetic acid (IAA) production, phosphate solubilization, and siderophore and cyanide production. The efficacy of selected isolates for plant growth promotion was then studied under axenic conditions using maize as a model plant. Results revealed that all the rootstocks supported high population densities of indigenous ACC-degrading rhizobacteria, ranging from 1.5×104 to 8.5×106, with the highest populations of PGPR occurring on fine roots and root tips. Dominant PGPR included species of *Pseudomonas*, *Bacillus* and *Variovorax*. All of the PGPR had different combinations of traits and activity levels. Populations of PGPR varied among the different rootstocks, and had different levels of activity in promoting maize growth under axenic conditions. Bacterial strains with high ACC-deaminase activity and/or having multiple characteristics were the most effective. The results of these studies suggest that management practices that affect ACC degrading bacterial populations may influence avocado tolerance to salinity stress conditions. This also suggest that soil organic matter amendments and mulches that promote PGPR populations would likely help to ameliorate salinity induced stress ethylene production. Further research is needed to confirm these hypotheses.

In addition to the midyear report that shows how the model works and the types of output that are generated, we have also presented our research at several venues including a grower meeting in at international meetings with other scientists working on the same topic but different crops in other countries. In Fall 2011 seminars were given by Crowley in China at the top agricultural universities in Beijing (China Agricultural University), at Nanjing Agricultural University, and at the UCR-CAS (Chinese National Academy of Sciences) Institute of Arid Land Ecology in Xinjiang China, where researchers are similarly are beginning to explore the use of neural network modeling approach for environmental and yield data analysis. Likewise, Crowley visited with Dr. Raul Ferreira at INIA in Santiago Chile, where their research group is examining the effects of poor soil aeration and soil saturation on ethylene production in grapes, and on tree growth and yields in avocado. Dr. Ferreira's research group has a very advanced crop production function model based on several years data and includes much tree physiological data on fruit yields. Their statistician has now licensed the same software Peltarion Synapse that we are using for our research. They are only now beginning to analyze their data using this approach, but it will be interesting to collaborate in figuring out the best ANN modeling approaches. There are many different ANN architectures that may likely give better predictive analysis than the standard feedforward network model used in our research to date. Our research has so fare been very well received and is at the forefront for development of production function models that examine salinity and chloride effects on crop yields. In 2011, Crowley gave a series of talks on this research at grower meetings in Santa Barbara, Ventura, and San Diego counties. Crowley also gave a second series of talks on fertilization of avocado at these same venues, but sponsored by Index Packing. The lecture series was video recorded and is available online. The Powerpoint presentation is also available at the Index site, and at Avocadosource.com.

In summary, this project has been largely successful in applying a new statistical modeling approach that enables us to examine the effects of salinity and chloride on avocado yields. Some delays and problems were encountered over the course of the project as there little or no yields at many of the orchards for three of the five year project. Alternate bearing also introduces a large amount of variation that shifts patterns as to which rootstocks are best for salinity tolerance. The three major clonal rootstocks, Duke 7, Dusa, and Toro Canyon all show better performance than Mexican rootstocks under saline conditions. Salinity and chloride strongly interact with more than additive effects in decreasing avocado yields. Both 2010 and 2011 year data showed that low EC (0.9 dS/m) irrigation water with high chloride is more damaging than high EC (1.5 dS/m) water at the same chloride level.

Based on the results of this five year project, we believe that our research clearly shows the utility of the ANN modeling approach that can be applied for predicting crop yields under different salinity conditions, and for predicting the extent to which this can be affected by different rootstocks. The model also suggest that there may be relationships with tree nutrient status (leaf analysis) and salinity that merit further study in field experiments with fertilizer treatments that might suppress chloride toxicity. Likewise, microbiological analysis of the soils suggest that PGPR are present at high population densities that may help avocado roots suppress the production of stress ethylene. Further research is needed to examine and optimize the effects of management practices on PGPR activity (eg., soil aeration, available organic carbon, pH, and rootstock).

Major results of the ANN model run for 2011.

As in last years model output, an independent ANN model based on the yield data for 200 trees in 2011 show that the avocado yields decrease in linear proportion to the levels of chloride that are contained in the leaf tissues (Figure 1). This year's model analysis shows a shift in the relative performance rankings of the clonal rootstocks, with yields on Duke 7 being superior even at elevated leaf chloride. Trees grafted on to Toro Canyon had yield decreases from 60 to 38 kg tree as leaf chloride increased from 0.2 to 0.8%, representing an ~40% yield decrease. Trees on Dusa showed little variation in yields across leaf chloride. As in the previous year, trees on Mexican rootstocks had the lowest overall yields which were strongly affected by salinity, decreasing 60% from 44 kg per tree at 0.2% Cl to 18 kg at 0.8% leaf Cl.

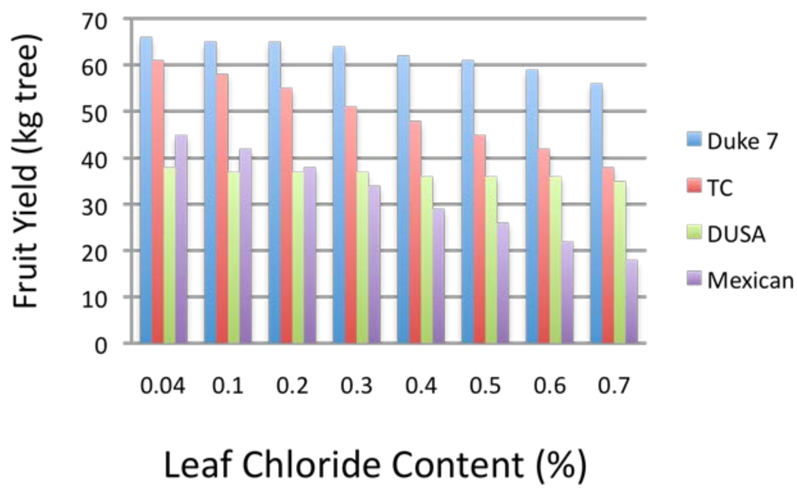

Figure 1. Relationship between leaf chloride content and predicted fruit yields for 10-15 year old Hass trees on different rootstocks.

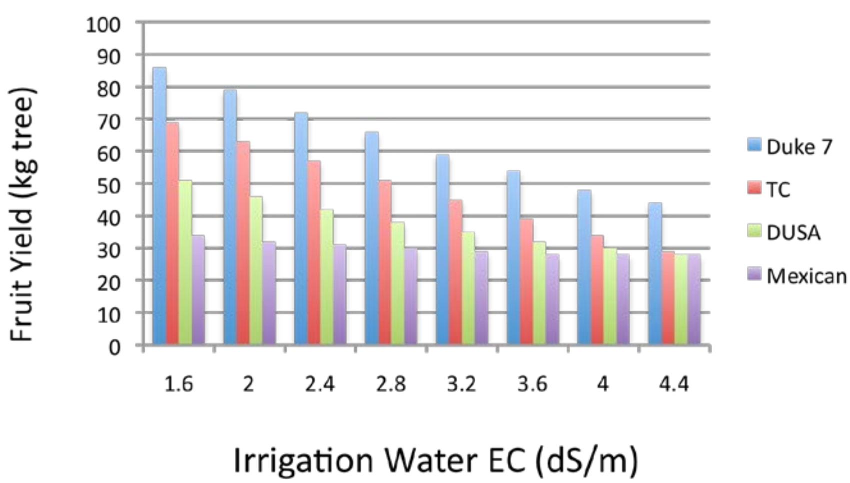

Figure 2. Relationship between fruit yield and irrigation water salinity for Hass avocado trees on Duke 7, Toro Canyon, Dusa, and Mexican rootstocks.

As with leaf chloride, irrigation water salinity is also predicted by the ANN model to cause a decrease in fruit yields, with the response varying for the different rootstocks (Figure 2). Duke 7 yields were decreased from 85 kg tree to 44 kg tree as irrigation water salinity increased from EC 1.6 to 4.4. Both Duke 7 and Toro Canyon were predicted to give better yields than Dusa and Mexican rootstocks at intermediate levels of salinity. The yields of trees on Mexican rootstocks were relatively nonaffected by salinity on its own. However, two way plots of salinity and chloride interactions show strong interactive effects in which high salinity exacerbates the effects of leaf chloride toxicity (Figure 3).

As shown in Figure 3, fruit yields were best on all rootstocks under conditions of low salinity and low leaf chloride contents. Correspondingly, yields were lowest on all rootstocks under conditions of high irrigation water salinity and high leaf chloride content. The rapid decrease in yields that occurs with increasing salinity is especially prevalent with the Toro Canyon and Mexican rootstocks and suggest a multiplicative (as opposed to a nonadditive) interactive effect. Recall that yields on Mexican rootstocks were barely affected by irrigation water salinity alone, but when combined with high chloride causes yield reductions. This is likely due to the increased water stress that occurs in soils irrigated with high EC water. When chloride has accumulated in the leaf tissues and the trees undergo water stress, they show the leaf burn scorch symptoms that are commonly associated with chloride toxicity.

Another interesting observation was the relationship between irrigation water chloride and pH on yields for irrigation water having different salinity content (EC 0.9 or EC 1.5 dS/m). In all cases, tree yields were inversely related to pH; ie., the lower the pH, the better the yields at any particular EC-Cl condition. This is shown in Figure 4 which was graphed for trees on Toro Canyon and Mexican rootstocks. At high EC levels, a low pH (6.5) offsets declines in fruit yields that occur for trees in soils having higher pH. At low EC levels, irrigation water chloride has a more severe effect on fruit yields than at high irrigation water salinity (EC 1.5). Under high EC conditions, lowering pH has a strong positive effect on yield. In groves with low EC water, pH has less of an effect. This suggest that acidifying treatments can offset the effects of high irrigation water chloride levels. This same observation was made in the 2010 model, and invites a field experiment to test whether this hypothesis is true, or whether there is simply a fluke correlation between pH and yields in chloride affected soils.

Figure 3. Relationship between irrigation water EC and leaf chloride content on predicted fruit yields of 10-12 year old Hass trees on Toro Canyon, Dusa, Duke 7, and Mexican rootstocks.

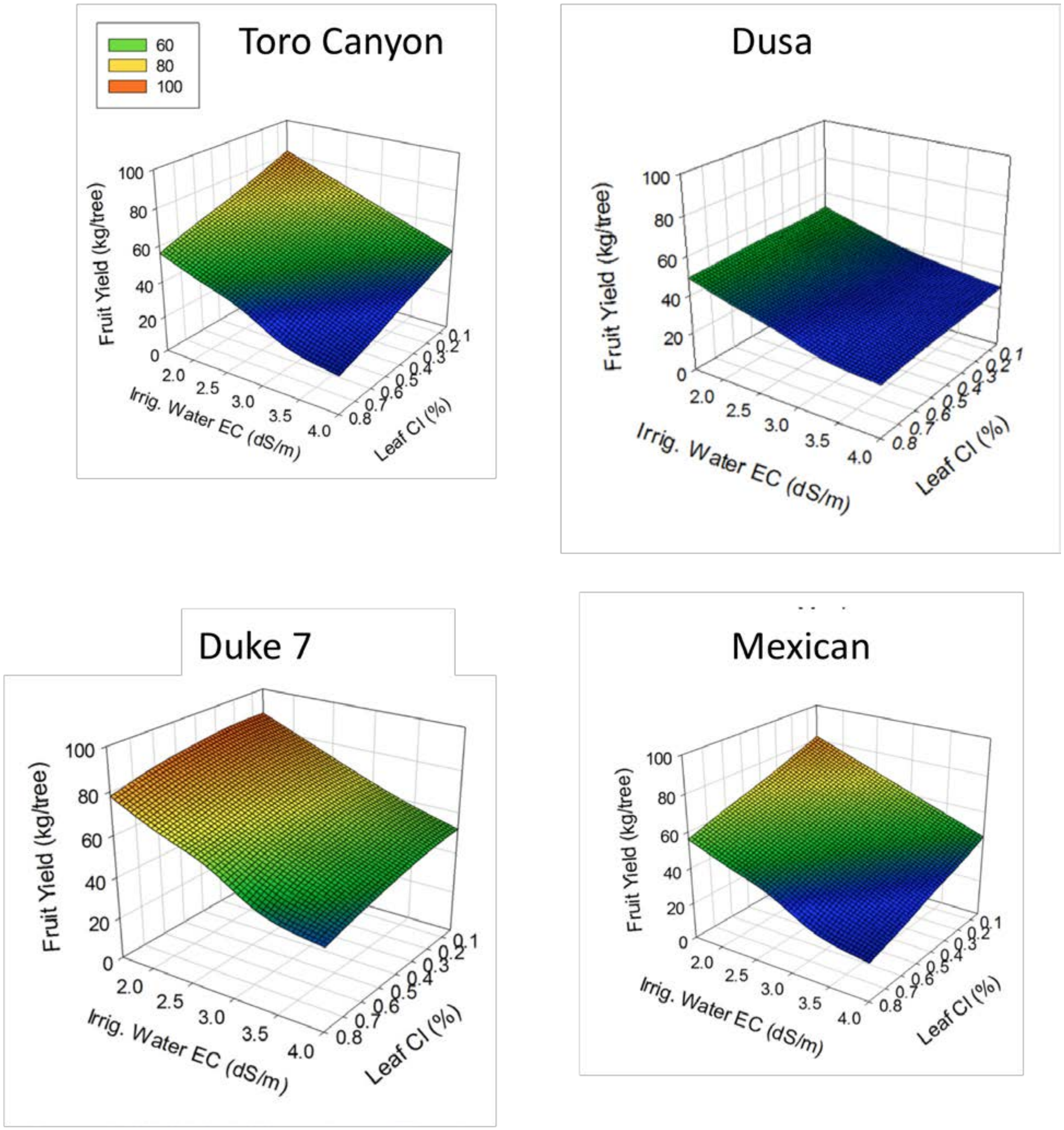

Figure 4. Relationship between irrigation water chloride and pH on fruit yields. Left hand column shows trees with high EC water (1.5 dS/m), right hand column trees with low EC water. Low EC water with a high pH is the most detrimental for yields.