The Challenge of Salinity:

Hope for the Future with New Avocado Rootstocks

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California avocado growers face diminishing returns in areas where *Phytophthora* root rot and saline irrigation water predominate. To help find answers to this production issue, a research trial was planted at the University of California, Riverside (UCR) in 2011. The goal of this trial was to determine if there are root rot-resistant rootstocks that are also tolerant to salinity. The study was funded by the California Avocado Commission.

Background

Generally, salinity has a broad range of effects on plants, and therefore, there also are many different mechanisms for plants to tolerate this stress. Plants can reduce toxicity by reducing the accumulation of toxic ions in the leaf blades (sodium and chloride exclusion), and/or by increasing their ability to tolerate the salts that they have failed to exclude from the shoot, such as by compartmentation into vacuoles (tissue tolerance).

Salt tolerance of avocados is complicated because it is a salt sensitive species and ion toxicities (predominantly sodium and chloride) cause detrimental effects on growth and yield. For many fruit crops, damage to the plants can be related to the concentration of specific ions, e.g. chloride or sodium in the soil solution and/or plant leaves, rather than to the total soil salinity. A frequent toxicity problem is from chloride in the soil solution. If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. Avocados are especially susceptible to leaf injury caused by the toxic accumulation of sodium and chloride in the leaves. Enhancing varietal or rootstock salt tolerance gives farmers an opportunity to continue growing great quality avocados while using low quality water or planting in salt affected soils. For this reason, classification of fruit crops – with respect to specific salinity – according to varieties and rootstocks is important.

In 1992, Drs. Oster and Arpaia (UCR) and later Mickelbart and Arpaia (2002, 2007) showed that the tolerance level of Hass avocado was dependent on the rootstock used. Since Hass was the common scion, it was evident that the large variability in plant response was due to differences in the rootstock's ability to exclude sodium and chloride concentrations from accumulating in the leaves. The influence of chloride concentrations and other elements in the leaves was studied because California growers are faced with having to use irrigation water high in salts, especially high in sodium and chloride.

UCR Salinity Trial

For this trial, avocado rootstocks grafted with Hass were planted. Trees were irrigated with high quality irrigation water for 1.5 years before imposing the salt treatments. Selected rows were irrigated with water containing a blend of salts that mirror lower quality irrigation water in California. The salinity level was adjusted to electrical conductivity (EC) 1.5 dS m^{-1} with 175 mg

Table 1. Rootstocks evaluated for salinity tolerance.

University of California Riverside	Westfalia Technological Services
PP 4 (Zentmyer)	Dusa
PP 14 (Uzi)	R0.05
PP 24 (Steddom)	R0.06
PP 40	R0.07
PP 45	R0.16
Thomas	R0.17

L^{-1} chloride. Table 1 lists the rootstocks tested.

Prior to imposing the salinity treatment, soil samples were collected. In December 2013, as was expected, the two treatment plots were very similar in both EC and chloride concentration because there was no salt treatment being applied. For the duration of the trial, the trees in both salt and control rows were irrigated two to three times per week depending on the weather. The amount of water applied was determined using the irrigation calculator found at www.avocadosource.com. We used the avocado crop coefficient of 0.86 and a target leaching fraction of 10 percent in year one and 20 percent in years two and three. The extra irrigation amount was used to maintain the leaching fraction delivered with each irrigation. We increased the leaching fraction for year two based on the overall health of the trees in the fresh water treatment. We found that a 10 percent leaching fraction was not sufficient as we observed some salt damage at the 10 percent leaching fraction.

Salt treatments were gradually imposed from November 2013 to January 2014 in a step-wise manner to enable osmotic adjustment with the ultimate salt concentration of EC 1.5 (salt treated rows) and 0.67 dS m^{-1} (fresh water rows irrigated from the Gage Canal).

Leaf samples were collected in October 2013 (prior to salinization), 2014 and 2015. Samples were analyzed for calcium, magnesium, sodium, potassium, phosphorus, sulfur, chloride, iron, copper, manganese and zinc by inductively coupled plasma/optical emission spectrometry (ICP/OES). The mean chloride content of the leaves varied from 42 to 120 mmol kg^{-1} (dry weight) depending on the rootstock prior to salinization. This preliminary analysis showed that the rootstock variety expected to be more salt tolerant was either a chloride excluder or did not translocate chloride to the leaves, a trait that is expected for more salt tolerant plant varieties. From the preliminary leaf analysis we saw that R0.05 and Dusa were chloride excluders, which turned out to have some of the highest yields and highest survival rates.

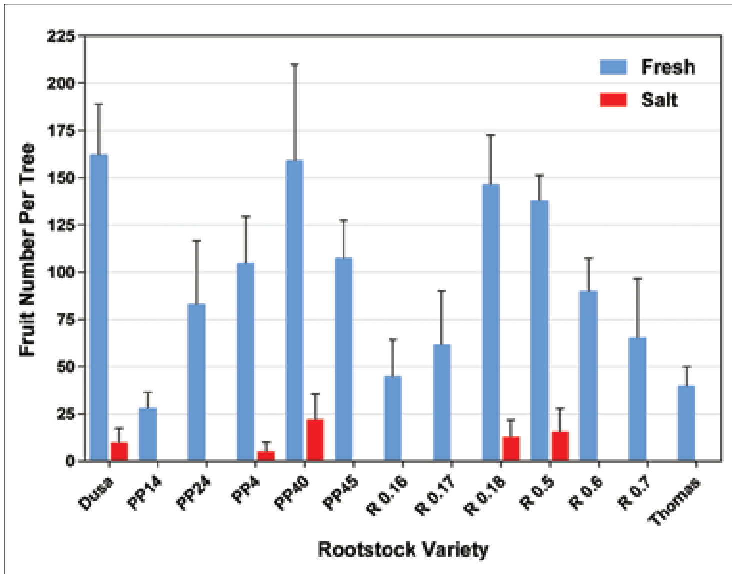
Leaf analysis proved to be a useful method to identify salt sensitive

Figure 1. R0.05 fresh water (left) and salt treated (right). Overall survival rate in salt treated row was 66.67 percent. Photo taken in 2015.

rootstocks such as R0.06, R0.07, PP14 and R0.17. Salt sensitive rootstocks had high chloride and sodium concentrations in the leaves and also were the least salt tolerant with 100 percent mortality in the salt treated rows irrigated with saline water for 23 months. The rootstocks R0.05, Dusa, PP40 and R0.18, accumulated the least amount of chloride in the leaves and were also the rootstocks that accumulated the lowest amount of chloride in the roots. This indicates that chloride exclusion is occurring at the root interface. This experiment shows, under field conditions, the influence of rootstock on the concentration of chloride and sodium and other elements in the leaves since rootstocks can impart salt tolerance to the scion of trees, usually by limiting the excessive accumulation of chloride and sodium from the scion. We observed 100 percent mortality after 20 months of salinization at EC 1.5 dS m^{-1} for the following rootstocks PP14, PP45, R0.06, R0.07, R0.16, and R0.17. The rootstocks that had the highest survival rate were PP40 and R0.05 both with a survival rate of 67 percent, followed by R0.18 with 63 percent and Dusa with 43 percent.

Fruit harvested in 2015 showed that there were significant differences in the number of fruit and weight of the fruit between treated and non-treated trees after one year of salt treatment. There also were significant differences in the number of fruit and weight of the fruit among the rootstock varieties in the control and salt-treated treatments. R0.05 and Dusa had the highest number of fruit and fruit weight in the control group; whereas, R0.05 and PP 40 had the highest number of fruit and fruit weight in the salt treatment. The number of fruit per tree ranged from 0 to 149, with an average of 18.8 fruit per tree. The total weight of fruit per tree ranged from 0 to 45.3 lb., and the average was 5.7 lb. per tree.

In 2016, after two years of salt treatment, there were significant dif-



ferences in the number of fruit and weight of the fruit between treated and non-treated trees. Additionally, within the fresh treatments there were significant differences among rootstocks with Dusa and PP40 having the highest number of fruit and fruit weight. However, within the salt treatment, there were no significant differences in the number of fruit or weight of the fruit among the rootstock varieties although PP 40 and R0.05 had the highest number of fruit and fruit weight under salinization. With the increasing length of the salt treatment, the fruiting capacity in the tolerant rootstocks significantly decreased. This may be due to the decrease of the photosynthesis rate, the growth of the tree or the ability to keep the fruits under the long-term salt stress.

In addition to leaf analysis, yield, leaf burn, tree height, canopy volume, trunk diameter and survival, we looked at physiological parameters to evaluate the influence of salt stress on the following rootstocks: Dusa, PP4, PP40 and R0.05 rootstocks. We found that salt stress significantly reduced the carbon assimilation rate in damaged leaves compared with leaves from control trees and healthy leaves from trees under salinity. In this trial, the damage was more severe in PP40 and least severe in R0.05. Salinity also affected water use efficiency (*WUE*) in avocado, by reducing its performance. WUE is a composite variable based on both photosynthetic capacity and the rate of water loss. PP40 had the highest transpiration rate (loss of water from the leaves) and the lowest WUE compared to Dusa and R0.05. Our findings showed that rootstocks affected the physiological performance of Hass avocado. Dusa and R0.05 were the most tolerant rootstocks under stress conditions.

Based on leaf analyses and the correlation of chloride in leaf tissue with tree survival data, we conclude that chloride accumulation in the leaves from both the control and salt treatments provided a good indicator of survival under the salt treatment or, in turn, salt tolerance. We also determined that sodium content in leaves was not a good marker for salt tolerance of avocado rootstock. There is a reduction in avocado yield at a chloride concentration of approximately 280 mmol kg^{-1} dry weight in the leaf tissue. In this experiment, the rootstocks that restricted chloride ion uptake and translocation to the mature fully expanded leaves were R0.05, PP40, R0.18 and Dusa, which also were the rootstocks that had minimal effect on growth and yield exhibiting the highest yield, highest trunk diameter and highest survival percentage.

Based on the currently available rootstocks that were evaluated in this study, Dusa had the highest salinity tolerance. Of rootstocks tested that are currently experimental, R0.05 and PP40 showed the most promise under these conditions. Further testing is needed to determine suitability in the various avocado production areas in California.

Preliminary conclusions:

- Fruit number, weight, and quality were negatively impacted by salinity
- Salt stress decreased the physiological performance of avocado 'Hass' independent of the rootstock
- Water and energy availability were directly impacted by salt stress
- Chlorophyll fluorescence indicated a trend that salinity reduced the photosynthetic energy conversion
- Differences in crop yield could not be explained by the photosynthetic capacity at the leaf level
- Selections such as R0.05 showed a promising increase in water use efficiency under saline conditions