EXTENSION
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Fact sheet 21-08

Combatting Salinity: Evaluation of Tomato Rootstocks Under Mild and Severe Salt Stress

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Introduction

Thanks to its multiple uses; its nutritional characteristics; and pleasing attributes related to touch, taste, smell or feel, tomatoes are the second most important vegetable crop after potatoes in the United States for area planted and total production (USDA, 2020). Being a warm-season crop, tomatoes are grown by Nevada farmers during the summer in open fields, gardens and in protected environments (e.g., hoop houses). Growing vegetables in Nevada's climate can be challenging because of high evapotranspiration levels resulting from high summer daytime temperatures and low air relative humidity. In addition, salts tend to accumulate in soils from low-quality irrigation water sources and over-fertilization, resulting in impaired vegetable production and yields. Groundwater irrigation sources, in particular, can be high in salts in areas where geothermal waters and earthquake faults are common, such as in Nevada (Ayers & Westcot, 1985). Soil electrical conductivity (EC) is a measure of the salts accumulated in soil (USDA, 1999) and affects the productivity of salt-sensitive crops when it is higher than 2.0 decisiemens per meter (dS m^{-1}) (Shannon and Grieve, 1999). Most of Nevada's soils are characterized by an EC that is above this threshold (i.e., between 2.3 and 9.3 dS m^{-1}, see Figure 1). High soil EC tends to increase concentrations of sodium and chloride in the soil even over other salinizing ions such as calcium, and sodium is especially toxic to many plants (Grattan and Grieve, 1999). Moreover, soil salinity lowers the soil water potential, making it more difficult for the plant to take up water and impairing the availability of other nutrients.

Tomatoes are considered to be moderately sensitive to salt stress, and in soils with EC greater than 2.5 dS m^{-1},

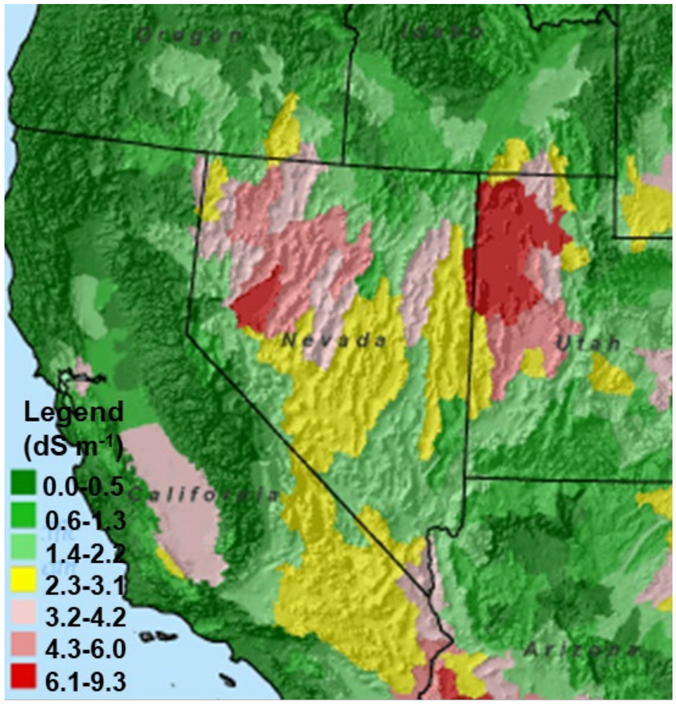

Figure 1. Map showing soil salinity in the state of Nevada. Source: Environmental Protection Agency, Environmental Monitoring and Assessment Program (EMAP) – West Metric Browser.

tomato yields are estimated to decrease about 10% per each additional EC unit (Saranga et al., 1991). The effects of salt stress on tomato crops depend on the concentration of salts, duration of stress exposure, and developmental stage of the tomato plant. Because salt stress impairs many different metabolic processes of the plant, breeding new tomato cultivars for salt tolerance is challenging (Cuartero et al., 2006), and a salt tolerant tomato variety has not been developed yet.

Grafting is an agronomic technique where the root system of one plant is physically joined or grafted to the shoot of another plant, through a graft union or grafting point. The resulting grafted plant begins to grow and maintain the characteristics of the root system of the first plant and of the shoot of the second plant. Grafting tomato elite cultivars with tomato rootstocks could be an effective tool to facilitate tomato production under conditions of high salt concentrations (Singh et al., 2020). Root traits from rootstocks can enhance the productivity of an elite or desired cultivar by facilitating water and nutrient uptake under salt stress (Venema et al., 2008). Moreover, it has been shown that grafted tomatoes improve salt tolerance through the capacity of the rootstock to limit the transport to the shoot of toxic salts such as sodium and chloride (Estañ et al., 2005).

This Extension publication reports the results of University of Nevada, Reno Experiment Station research that tested six different commercial tomato rootstocks and one commercial tomato cultivar for salt tolerance under low, moderate and severe salinity levels. We analyzed biomass production and partitioning for each genotype and each salinity level.

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Methods

Six commercial tomato rootstocks (Bowman, DRO141TX, Estamino, Maxifort, Spirit and Supernatural) were compared to one commercial tomato cultivar (BHN 589). The commercial cultivar was selected based on its use at University of Nevada, Reno Desert Farming Initiative and on a request from northern Nevada growers to examine this particular cultivar. Rootstocks were selected randomly from different developers, without prior information regarding salinity tolerance (Kleinhenz, 2017).

Plants were prepared for the experiment in the following steps:

1. Sterilization in aerated bleach (diluted to 3%) for 10 minutes and rinsed in aerated de-ionized water for 20 minutes.
2. Seeds were placed in Petri dishes with adequate moisture and left in a dark room at 26 degrees Celsius for five days to germinate.
3. Seeds with small radicles were transplanted into 72-cell trays with a 4:6 mixture of sand and seed starter, and then placed in a growth chamber with a photoperiod of 14 hours and temperature of 24.5-27 degrees Celsius for seedling emergence.
4. After two weeks, all seedlings were transplanted into square pots measuring 7cm wide by 23cm high, with a total volume of 960 ml (Stuewe and Sons, Inc., Ore. USA) filled with about 70g of fritted clay at the bottom and about 1,050g of sand on top.

The greenhouse temperature was set to 28 and 21 degrees Celsius during day and night, respectively. Three nutrient solutions (Hoagland) with different electrical conductivity (EC) levels were prepared as treatments (see Table 1): 1.5 dS m^{-1} (per liter: 0.9g Na_2SO_4 + 0.75g $CaCl_2$) as control, 6 dS m^{-1} (per liter: 3.6 g Na_2SO_4 + 3g $CaCl_2$) as mild salt stress, and 12 dS m^{-1} (per liter: 7.2g Na_2SO_4 + 6g $CaCl_2$) as severe salt stress. Each plant was subjected to one EC level for three to four weeks. At the end of the trial, shoot and roots were harvested and dried at 60 degrees Celsius for 48 hours. Shoot and root dry weights (DW) were recorded, and the root-to-shoot ratio calculated as DW_{Root}/DW_{Shoot}.

Table 1. Treatments applied to each group of plants during this experiment.

Treatment	Electrical Conductivity	Grams of NaCl per liter	Grams of $CaCl_2$ per liter
Control	~1.5 dS m^{-1}	0.90 g	0.75 g
Mild Salt Stress	~6 dS m^{-1}	3.60 g	3.00 g
Severe Salt Stress	~12 dS m^{-1}	7.20 g	6.00 g

We analyzed the data collected with the software R 3.6.3 (R Core Team, 2020), using the Analysis of Variance (ANOVA) method. The mean values for each parameter at different salinity treatments were compared within each rootstock. When the p-value was lees than 0.05, the results were considered statistically different.

Results

Our experimental research showed that, under both mild and severe salt stress, all six commercial rootstocks

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demonstrated higher vigor as compared to the one commercial cultivar (BHN589). Shoot dry weight (see Figure 2) was less affected than root dry weight (see Figure 3). Although increasing salinity levels in the soil decreased the shoot biomass of most rootstocks, all rootstocks still maintained higher shoot biomass than the BHN589. In addition, the highest decrease in shoot biomass was shown by BHN589 at 6 dS m^{-1}, with a 44% reduction. Shoot dry weight was also adversely affected in Supernatural and Maxifort at 6 dS m^{-1}, with about a 28% reduction in biomass. At 12 dS m^{-1}, all rootstocks showed a decrease in shoot biomass, except for Bowman and DRO-141. BHN589 showed less than half the shoot biomass compared to the rootstocks under mild and severe salt stress.

Root dry weight varied significantly among the evaluated tomato material, but rootstocks showed higher root biomass than BHN589 regardless of salinity level (see Figure 3). Root dry weight at 6 dS m^{-1} decreased in Estamino, Bowman and DRO-141 by 29%, 62% and 44% compared to 1.5 dS m^{-1}, respectively (Figure 3). At 12 dS m^{-1}, root dry weight was affected in Estamino, Spirit, Bowman and DRO-141, respectively by 55%, 34%, 62% and 60% reduction when compared to 1.5 dS m^{-1}. Interestingly, root dry weight was not affected by salinity treatment in BHN589 and the rootstocks Supernatural and Maxifort.

The root-to-shoot ratio (see Figure 4) was unchanged in the commercial cultivar BHN589 and the rootstocks Supernatural, Estamino and Spirit. Only three rootstocks, Maxifort, Bowman and DRO141, showed a change in biomass allocation, which decreased the root-to-shoot ratio under 6 dS m^{-1} and 12 dS m^{-1}.

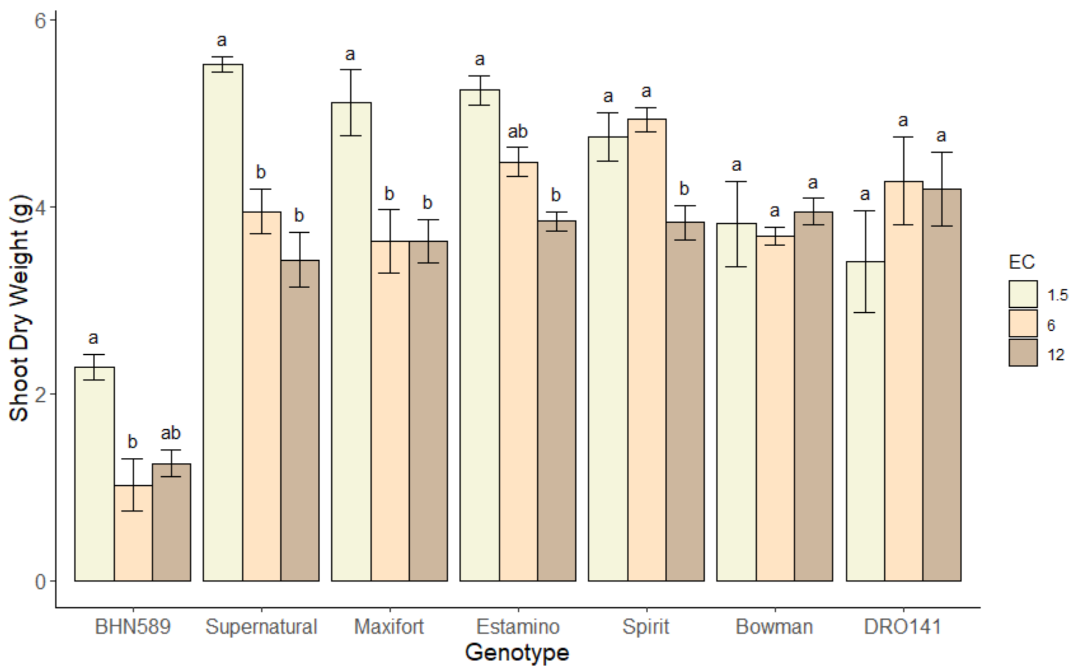

Figure 2. Shoot dry weight (g) of a commercial tomato cultivar (BHN589), commercial rootstocks (Bowman, DRO-141TX, Estamino, Maxifort, Spirit and Supernatural) under three salinity treatments (electrical conductivities (EC) of ~1.5, 6 and 12 dS m^{-1}). Values are mean ± standard error. Mean comparisons are within each rootstock, and different letters indicate that means are statistically different at p-value<0.05.

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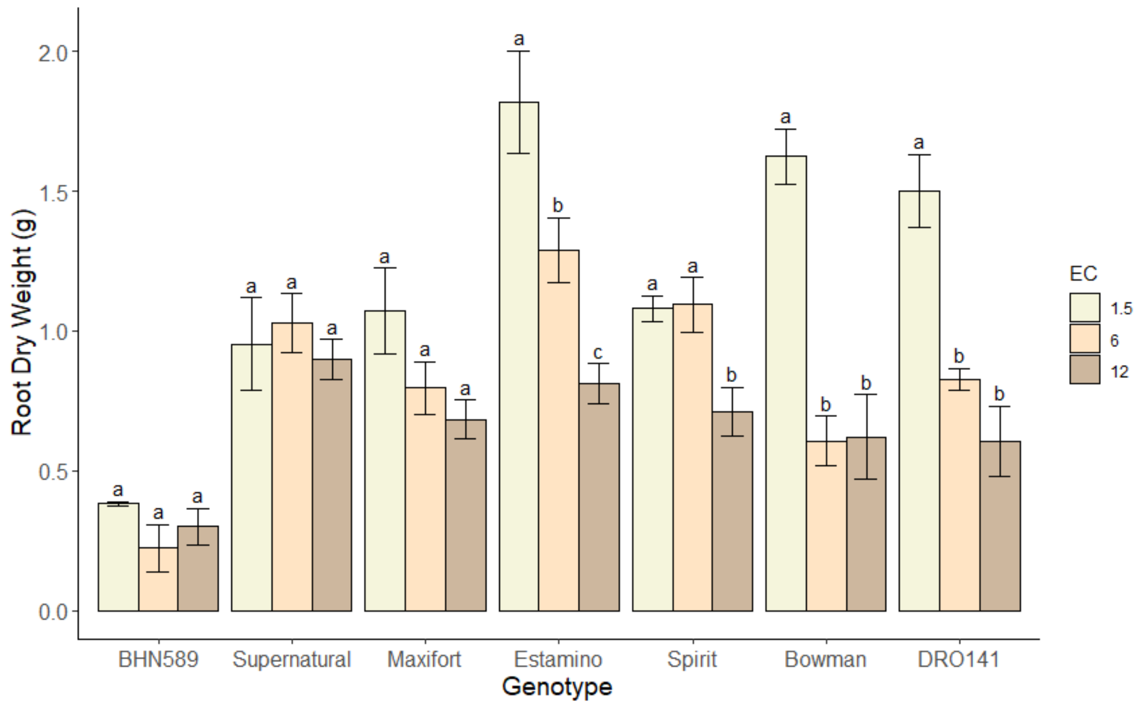

Figure 3. Root dry weight (g) of a commercial tomato cultivar (BHN589), commercial rootstocks (Bowman, DRO-141TX, Estamino, Maxifort, Spirit and Supernatural) under three salinity treatments (electrical conductivities (EC) of ~1.5, 6 and 12 dS m^{-1}). Values are mean ± standard error. Mean comparisons are within each rootstock, and different letters indicate that means are statistically different at p-value<0.05.

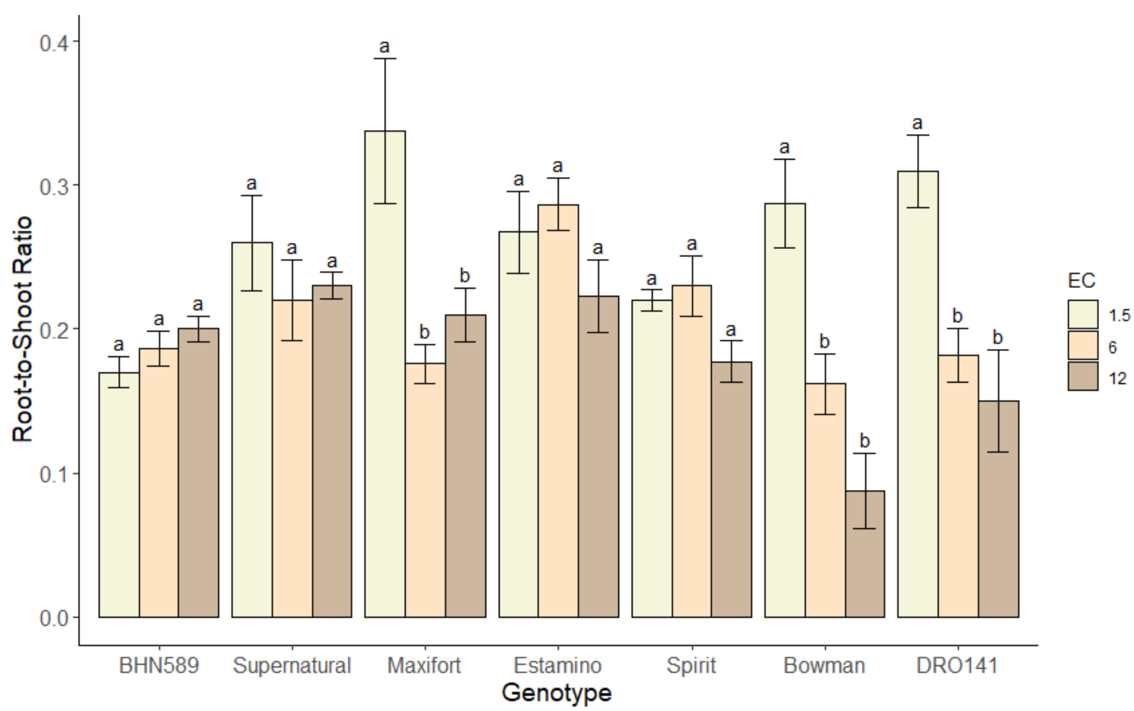

Figure 4. Root-to-shoot ratio of a commercial tomato cultivar (BHN589), commercial rootstocks (Bowman, DRO-141TX, Estamino, Maxifort, Spirit and Supernatural) under three salinity treatments (electrical conductivities (EC) of ~1.5, 6 and 12 dS m^{-1}). Values are mean ± standard error. Mean comparisons are within each rootstock, and different letters indicate that means are statistically different at p-value<0.05.

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Discussion

When compared to the six tomato commercial rootstocks (Bowman, DRO141TX, Estamino, Maxifort, Spirit and Supernatural), the commercial cultivar, BHN-589, showed the greatest reduction in shoot biomass under salt stress, with salt-stressed plants exhibiting less than half the shoot dry weight of unstressed plants. This result suggests that all six commercial rootstocks demonstrated increased vigor and capacity to accumulate more biomass under salt stress, as compared to BHN-589. For instance, the rootstocks Bowman and DRO-141 showed the highest shoot biomass under severe salt stress, indicating that they could be good candidates for salt-tolerant rootstocks.

Larger root systems can facilitate water and nutrient uptake, and all rootstocks had more root biomass than BHN589, even under a range of salinity treatments. Salt stress can limit root growth, and this may compromise the amount of shoot (including fruits) that can be supported by the roots. Although the *optimal* root-to-shoot biomass ratio remains unknown, our research suggests that shoot growth and maintenance could be supported with lower root biomass (i.e., lower root-to-shoot ratio), as demonstrated by the rootstocks Bowman and DRO-141, that maintain relatively high shoot biomass even when root biomass decreased significantly under high salinity. The root-to-shoot ratio for Bowman and DRO-141 was 0.09 and 0.15, respectively. Higher capacity for root water uptake per unit of root biomass can increase plant performance under salt stress. In addition, the development of barriers in the roots such as the Casparian band and the suberization of the exodermis restrict the flux of toxic ions, such as sodium, to the shoot. Roots have an active mechanism for exclusion and extrusion of ‘unwanted’ elements that can make it into the roots; yet this capacity can be overwhelmed and result in toxicity to plants. In this context, the response of root traits such as the capacity to regulate the water uptake (i.e., root hydraulic conductivity) and water use (e.g., transpiration) is important for salt tolerance. A recent study found that different rootstocks have differential root responses and can acclimate more readily to conditions of suboptimal soil temperatures (Bristow et al., 2021). These acclimation traits should be investigated in commercial tomato rootstocks under salt stress as well.

Conclusion

The use of rootstock grafting in horticulture is common in highly developed production systems around the world and becoming an increasingly important technique in U.S. vegetable production. The adoption of this practice has been slower than anticipated because of the expertise and infrastructure required for successful commercial-scale grafting. However, grafting can be an effective and ecologically sustainable tool to overcome a wide range of plant abiotic and biotic stresses.

Salt stress impairs many physiological and biochemical processes in a number of vegetable crops. For tomato growers, research increasingly indicates that the use of rootstocks can be a feasible alternative to combat this stress

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(Cuartero et al., 2006; Singh et al., 2017; Coban et al., 2020). This study shows that commercial tomato rootstocks vary in their response to salt stress in an early vegetative stage, and further evaluation of tomatoes grafted onto rootstocks and under Nevada's saline conditions is warranted to ultimately understand effects on yield. All rootstocks showed higher salt tolerance compared to the tomato commercial cultivar, with the most promising ones being Bowman and DRO-141.

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