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Factors Affecting Salt Tolerance in Fruit Crops—An Over View

HARPREET KAUR SAINI*[1], M. I. S. GILL[1] AND O. P. CHOUDHARY[2]

[1]Department of Horticulture, Department of Soil Science[2], Punjab Agricultural University
Ludhiana 141004, India
E-mail : tegisaini@yahoo.com
**Correspondance*

Abstract

Due to the rapid expansion of irrigated agriculture, efficient use of the limited water resources in arid and semi-arid regions is becoming more vital. The decreases in the quality of the water resources are also inevitable, so it is important that fruit growers continue to improve production practices and genetic varieties to deal with poor quality water to sustain production. However, water salinity is a major problem due to its negative influence on the yields of many fruit crops. The fruit plant response to salinity depends on several factors. Changing one or more of these factors may entirely give different results. To help fruit growers cope with salinity problems, researchers should not only understand the mode of action of salinity stress and the underlying mechanisms of salinity tolerance but also understand the major factors that can influence salt tolerance in different fruit crops. In this paper the factors affecting the salt tolerance are reviewed. The review summarizes the prevailing state of knowledge about the responses and tolerance of fruit trees to salinity.

Key words : Salt tolerance, Fruits, Citrus, Factors, Rootstock.

The capacity of a plant to endure the effects of excessive salts in the root zone is referred to as "Salt tolerance" of plants. The threshold salt concentrations tolerated by crops vary greatly (Table 1) from one fruit specie to another (1). Salinity is one of several abiotic stresses that limit plant growth in many arid and semi-arid regions of the world. About 40,000 ha of land in the world is salinized every year due to indiscriminate use of saline water (2) and about 20% of the world's irrigated land, suffers soil salinization (3). The salinity stress refers to the osmotic stress that restricits the availability of water stored in the soil. Irrigation with saline and sodic waters can deteriorate soil properties and adversely affect yields of different crops (4, 5). Saline soils and soils irrigated with saline waters contain excessive neutral salts mostly Cl^- and $SO_4^=$ of Na^+, Ca^{++} and Mg^{++}. Poor plant growth in saline environment results from high osmotic stress, low physiological availability of water, imbalancce of plant nutrients and direct toxic effects of individual ions (6).

The ability of the plant to tolerate salt is influenced by several factors such as growth stage of plants; rootstock; the nutritional level of plant; climate; chemical ion toxicity; and irrigation water quality.

Growth Stage

The growth stage of the plant is important when considering salt tolerance. Many plants are extremely sensitive to soil salinity during germination or in the early seedling stage. Most of the experiments have been conducted to evaluate salt tolerance only on mature plants only. The salinity of water and soil affects plant growth, directly or indirectly, partially or totally, during germination process and in various growth and development phases of the fruits plants including passion fruit (7, 8), mango (9, 10) and guava (11, 12). Therefore, the continuous use of such waters that offers moderate ($0.75 < EC_W < 3.0$ dS/m) and severe restriction ($EC_W > 3.0$ dS/m) due to salinity can accentuate toxic problems in plants and degrade the physical properties of soil. In these situations, the monitoring of water quality becomes important in terms of its effect on germination process, seedling production and establishment of majority of the plants (13). The increase of salt concentration reduces the water energy state of the soil, expressed by water and osmotic potential and thus plant have to spend more

Table 1. Salt sensitivity of fruit species related to growth parameters or leaf injuries (1).

Sensitive (Salt effects at EC= 1 m S/cm)	Almond, Apple, Apricot, Avocado, Banana, Blackberry, Cherimoya, Currants, Gooseberry, Grapefruit, Lemon, Lime, Loquat, Mandarin, Mango, Sweet Orange, Passionfruit, Peach, Pear, Persimmon, Pummelo, Raspberry, Sapota, Sweet Cherries, Walnut
Moderately sensitive (Salt effects at EC=3 m S/cm)	Pomegranate, Macadamia, Papaya, Pecan, Plum, Pistachio, Grape
Moderately tolerant (Salt effects at EC=6 m S/cm)	Pineapple, Fig, Guava, Coconut, Olive
Tolerant (Salt effects at EC=10 m S/cm)	Datepalm

energy for water absorption. During germination phase, this phenomenon promotes higher salt absorption by seeds which has a negative impact on germination process as reported by Mayer and Poljakoff-Mayber (14) and Santos (15). Ber is sensitive to salinity at germination stage but could withstand it with increase in age of seedlings (16).

The salinity effects on different phases of guava plants were evaluated (17, 18). They concluded that saline stress inhibited the plant growth during its vegetative cycle. Higher sensitivity however has been observed during germination. This observation diverges from that of Pereira (11) who reported that guava genotypes were more sensible to salinity during seedling formation phase than during germination phase.

Rootstocks

The rootstocks differ in their ability to extract water from saline soils and may influence the leaching pattern in the soil. For example, salinity stress increased N leaching in citrus (19). Since salinity reduces water use and transpiration differently in different rootstocks, rootstocks can actually modify soil salinity (20). It has been known for many years that citrus rootstocks differ in their ability to absorb the toxic ions, such as Cl^-, Na^+ and B, and then translocation to the canopy (21, 22). Because of the relative importance of Cl^- toxicity in citrus, salinity tolerance of rootstocks is most often based on the ability of the root system to limit the transport of Cl^- to the leaves. The rootstock tolerance to Cl^- may differ (Table 2), depending on the specific ions, effects of scion, conditions of incompatibility, and with disease status (viruses, viroids, root infactions, or pests).

Many citrus rootstocks with low growth vigor have good Cl^- exclusion characteristics, whereas some of the vigorous citrus rootstocks exhibit poor Cl^- tolerance (35). Since fast growing trees always use more water than slower-growing trees, leaves on high vigor trees would be exposed to relatively more concentrations of Cl^- in the transpiration stream from saline water than low-vigor trees. Thus, part of the mechanism underlying the accumulation of relatively low leaf Cl^- in some citrus rootstocks may be related to their low growth vigor (36). However, there are many exceptions to this rule; rangpur lime is a fast growing rootstock with good Cl^- and total salt tolerance and Volkameriana, another fast growing rootstock, exhibits some salt tolerance, at least as a young tree (37).

Nutrition Level of the Plant

The nutrition level of the soil (i.e. soil fertility) may affect the plant's response to salinity. Fertilization usually enhances plant's ability to tolerate high salt levels. However, fertilization beyond the plant's needs, does little to improve salt tolerance. Excessive fertilizer, involving soluble salts, may even sometimes aggravate the problem of soil salinity. The frequency of applying fertilizer also has a direct effect on the concentration of total salts in the soil solution. A fertilization program that uses frequent applications with relatively low concentrations of salts will normally result in lesser salinity stress than programs using only two or three applications per year. Likewise, relatively expensive controlled-release fertilizers or frequent fertigations are helpful in minimizing salt stress when using highly saline irrigation water.

Selecting nutrient sources that do not add potentially harmful ions to already high levels of salts in irrigation water can avoid compounding salinity problems. The KCl or $NaNO_3$ material adds more toxic ions (Cl^- and Na^+) salts to the soil solution. Repeated fertilizer application with sources like $(NH_4)_2SO_4$ can alter soil pH and cause soil nutrient imbalances. Specific ions can also add to potential nutrient imbalances in soil and trees. For example, Na^+ can displace K^+ and lead to K^+ deficiencies. The displacement of Ca^{2+} by Na^+ in the soil cation exchange complex can lead to decreased permeability and destroy soil structure. Such nutrient imbalances can compound drainage problems and aggravate the effects of salinity stress. Salinity problems can be minimized if concentrations of sufficient essential nutrients are maintained, especially those of K^+ and Ca^{2+}. Preliminary results suggest that continuous application of nitrates like KNO_3 under saline conditions can reduce Cl^- accumulation in scions grafted on susceptible rootstocks, and can increase yield in citrus (34, 37, 38—42). This effect might be due to competitive exclusion of Cl^- by NO^-_3 at the soil-root interface. In young trees, a dilution effect also occurs due to increase in growth.

There are marked differences in the salt index (the salt content per unit nurient) of particular formulations of fertilizer nutrients. Choosing nutrient sources with a relatively low salt index can reduce salinity problems in citrus (43). With highly saline irrigation water, fertilizer formulations should have low salt index. It may be necessary to increase the frequency of fertilizations, thereby making it possible to reduce the salt content of each application and aid in preventing excess salt accumulation in the root zone. The nutrient storage capacity of citrus trees tends to buffer the different seasonal demands for nutrients associated with specific growth demands. Leaf or fruit analysis should be used to detect excessive Na^+ and Cl^- concentrations, or deficient concentrations of essential elements caused by nutrient imbalances from salt stress.

Climatic Effect

The climate has much to do with a plant's ability to tolerate salts. High temperature, low humidity and high winds increase evaporation and make the plant more susceptible to salinity. High air humidity benefits salt sensitive crops more than salt-tolerant plants. High temperature in general reduces any plant's ability to tolerate salts.

There are direct interactions among soil salinity, leaf water relations, irradiance, leaf temperature, and atmospheric evaporative demand that are impossible to separate in the field. Physiological mechanisms underlying environmental interactions with salinity can only be studied in controlled environments. Such studies may provide insights into cultural practices or environmental conditions that can improve production under salinity stress.

Citrus leaves growing in full sun can experience temperatures that exceed air temperature by as much as 10 C (44). Leaf temperatures upto 45 C not only exceed optimum temperature for photosynthesis, but also lead to large vapour pressure differences (VPD) between leaves and air. Since stomata are sensitive to evaporative demand, a large VPD can reduce stomata conductance and net gas exchange. Treanspirational water use is also a function of VPD, and large VPDs can result in very low water use efficiency (WUE). Decreasing VPD by lowering leaf temperature or increasing humidity can increase stomatal conductance, net gas exchange and water use efficiency. Misting tree canopies with high-quality water may improve salinity tolerance and decrease accumulation of toxic ions as found in tomatoes (45). Since salinity stress is greater for sun-exposed than for shaded leaves, additional shade may enhance salinity tolerance. Artificial shade screens during the warmest season reduced citrus leaf temperature, improved WUE (46) and likely would decrease salt stress.

Chemical Ion Toxicity

The chemical ion toxicity affects plants that may be sensitive to specific individual ions. A part of the salt sensitivity in fruit crops is related to the specific toxic effects of accumulation of Cl^-, Na^+, B and other ions in leaves. These elements are transported by the transpiration stream and remain in the plant tissues after transpired water has evaporated. Under $NaCl^-$ salinity, fruit trees accumulate large amount of Cl^- in the leaves. Some species succeed in retaining Na^+ in the root tissue (salt excluders). An excessive uptake of Na^+ leads to lower leaf concentrations of both Ca^{2+} and K^+ in citrus (47). Ca^{2+}/Na^+ or K^-/Na^+ are known as an index of salt tolerance in fruit trees and field crops (48). In sensitive fruit trees under salt stress, Ca^{2+}/Na^+ or K^-/Na^+ ratios become less than 1 (49).

Chloride toxicity in woody species is generally

Table 2. Ranking of rootstock tolerance of Cl^- in different studies.

Susceptible	Medium	Tolerant	Scion	Max Cl^- range	Reference
Sweet lime	Sour orange		Sweet orange	500	22
Citron>Citrumelo> Rough lemon	Sweet orange>Sour orange	Cleopatra mandarin >Rangpur lime	Grapefruit	1800	23
	Sour orange	Cleopatra mandarin	Grapefruit	1200	24
Alemow>Carrizo citrange>Troyer citrange	Sweet lime>Sour Orange>Swingle citrumelo	Cleopatra mandarin> Rangpur lime>Sunki	Grapefruit	1200	25
Carrizo citrange	Cleopatra mandarin	Cleopatra mandarin	Seedlings	4690	26
Rough lemon>Trifoliate orange	Carrizo Citrange> Troyer citrange>Sweet orange	Rangpur lime>Cleopatra mandarin>Alemow	Seedlings	1775	27
Alemow	Sour Orange	Cleopatra mandarin	Lemon	1490	28
Rough lemon		Sour orange>Cleopatra mandarin	Grapefruit	680	29
Sour orange	Volkameriana	Alemow	Lemon	3550	30
Troyer citrange	Sour Orange>Citron	Cleopatra mandarin	Grapefruit	3400	31
Carrizo citrange= Troyer citrange	Rough Lemon	Volkameriana	Seedlings	1147	32
Sour organge	Cleopatra mandarin	Rangpur lime> Volkameriana	Seedlings	3000	33
Sour orange	Sunki × Beneke	Rangpur lime × Troyer citrange>Gau Tau> Cleopatra mandarin	Seedlings	1680	34
Troyer citrange	Sour Orange>Sunki × Beneke>Gau Tau	Volkameriana>Rangpur lime>Cleopatra mandarin	Grapefruit	880	34

more severe and observed in a wider range of species thant is Na^+ toxicity (50). Citrus is a good example. Since Cl^- ion is more toxic to citrus than Na^+, the concentration of Cl^- in water is an important parameter in deciding the suitability of water for citrus irrigation (51, 52). High amount of Cl^- can reduce leaf chlorophyll concentration (53), and cause bleaching or bronzing of sunlit leaves. Toxicity symptoms usually appear when leaf Cl levels reach 1% and Na levels reach 0.1—0.25% of leaf dry weight. Excessively high Na in leaves can be physiologically more determinable than excess Cl. Na^+ can be harmful through its effect on the absorption of other nutrients, especially K^+. Generally, plants grown under high salinity show K deficiency due to anatognistic effect of Na on K absorption (6). Changes in Na-K balance and their antagonism in grapevines under high salinity conditions were observed (54—56). Salinity increased Cl^- content in strawberry (57—59), ber (60) and accumulation of these ions causes toxicity resulting in necrosis and moulding in leaves.

In most situations, salinity problems are almost always caused by NaCl. The relatively greater importance of Cl^- than Na^+ is not unique to citrus. In stone fruits, Cl^- was found to be the main damaging ion, whereas Na^+ accumulated in leaves only after membranes had already been damaged by Cl^- (50). However, in situations where salinity is caused by non-Cl^- salts (mainly sulfates), Na^+ toxicity can appear. The impact of specific ions depends on the ability of rootstocks to restrict their transport to the scions.

Differences in Cl^- transport properties and tolerance of different rootstocks are apparent in lemon and Rangpur lime (61, 62). Thus, there is loss of chlorophyll affecting the chloroplast metabolism inhibiting the rates of photochemical reactions in plant leading to decreased growth (63).

However, higher concentrations of Cl and Na in leaf that corresponded with mortality suggest a breakdown in salt tolerance mechanism (64). Conversely, it was reported that the sequestration of these ions in roots, and the prevention of their transport to the shoot in the xylem, is a mechanism for salinity tolerance in grapevines (65—67).

Irrigation and Water Quality

Irrigation management can decrease the level of salts in the root zone of the crop. Permeability of the subsurface soils is important for management of salinity in soil profile. There is a correlation between moving sufficient salts downward beyond the rootzone and evapotranspiration bringing water and salts back towards the surface.

Salt concentrations in the soil solution can be monitored effectively with ceramic suction cups or soil salinity probes after proper calibration to approximate ECe (68). Monitoring of soil solution is important where saline conditions may result from intentional deficit irrigation (69) or from water-conserving irrigation scheduling based on soil moisture sensors (70) such as tensiometers or capacitance sensors (71). Salts in the root zone are dynamic and tend to change with climatic changes. For well drained soils, wetter periods tend to push salts down in the root zone, whereas drier periods bring salts nearer to the surface. In poorly drained soils, wetter periods tend to bring the water table closer to the surface. The salt moves with the water (upward) as the water table rises. Poorly drained soils usually have higher salinity in wetter periods than during a drier period. If these reasons are known, selection of crops for planting according to their salt tolerance can be used according to climate cycles and soil drainage classification.

Irrigation may add salt to the soil with the water. Ionic composition of irrigation water affects the level of salinity stress. The more soluble salts such as sodium chloride (NaCl), sodium sulfate (Na_2SO_4), sodium bicarbonate ($NaHCO_3$) and magnesium chloride ($MgCl_2$) cause more plant stress than less soluble salts such as calcium sulfate ($CaSO_4$), magnesium sulfate ($MgSO_4$), and calcium carbonate ($CaCO_3$). Therefore, some of these salts may need to be managed more carefully to prevent salinity build up in the root zone.

If natural leaching does not occur, leaching with irrigation water on better drained soils can help move salts downward, where these salts become less harmful to growing crops. The "leaching fraction" is defined as the amount of water pushed past the bottom of the root zone, divided by the total amount of water received into the soil. Unfortunately, the leaching fraction is very much controlled by the existing subsurface soils and geology, and finer textured soils are more difficult to manage for salts because the response time to leaching may span years compared to only weeks for coarse texture soils.

Micro irrigation, especially drip irrigation, results in a relatively small soil volume that is routinely wet and leached by irrigation water. This irrigation method has become common in arid areas and Mediterranean climates. Successful use of a drip system in citrus (42) depends on good water filtration and water treatment to prevent bacterial or mineral clogging. The utility of a drip system has beeen improved by fertigation in banana (72) and Nagpur mandarin (73).

Dripper improvement and chemical prevention of root penetration into the drippers make underground drip systems feasible in orchards. The advantage of this system over regular drip is that the water does not usually reach the surface, so it does not leave salts behind. This system is also advantageous when using reclaimed water that may be contaminated with harmful bacteria. Additionally, underground systems are less prone to damage from orchard operations and from pests like rodents or woodpeckers.

Conclusion

Based on the literature cited it has been found that salinity stress is a multifactor controlled trait. Thus to overcome salinity stress, we need to have indepth understanding of the factors such as growth stage, rootstocks, nutritional level of the plant, climatic effects, chemical ion toxicity, irrigation and water quality.

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