# *AGRICULTURAL SALINITY AND DRAINAGE*

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# Electrical Conductivity

**By Blaine Hanson, Irrigation and Drainage Specialist**

Plants respond to the total dissolved solids (TDS) in the soil water that surrounds the roots. The soilwater TDS is influenced by irrigation practices, native salt in the soil, and by the TDS in the irrigation water. Assessing the salinity hazard of water on soil solution requires estimating the TDS. Since direct measurements of salt are not practical, a common way to estimate TDS is to measure the electrical conductivity (EC) of the water.

What causes "electrical conductivity" in water? When a salt dissolves in water, it separates into charged particles called ions. The charges are either negative or positive. When electrodes connected to a power source are placed in the water, positive ions move toward the negative electrode, while negative ions move to the positive electrode. This movement of ions causes the water to conduct electricity, and this electrical conductance is easily measured with an EC meter. The larger the salt concentration of the water, the larger its electrical conductivity.

## *Measuring Electrical Conductivity*

Electrical conductivity is normally expressed as millimhos per centimeter (mmhos/cm) or decisiemens per meter (dS/m). Millimhos per centimeter is an old measurement unit that has been replaced by the decisiemens per meter measure. The two measurement units are numerically equivalent. Sometimes electrical conductivity is expressed as micromhos per centimeter (µmhos/cm). Values of EC expressed in this unit can be converted to mmhos/cm or dS/m by dividing by 1000.

## *Types of Ions and Concentration Effects*

Several factors can affect the EC. First, some ions conduct electricity more readily than others. For example, for a concentration of 1,000 mg/l, the EC of a calcium sulfate solution is about 1.2 dS/m, while the EC of a sodium chloride solution is about 2 dS/m. Second, the EC increases as the concentration of salts increases, but the *rate* of increase decreases as the concentration increases. Doubling the salt concentration, therefore, does not necessarily double the EC, because as the concentration increases, neutral particles that do not contribute to the EC are formed. The percentage of neutral particles increases with concentration. This point is particularly important to remember when soil samples high in salts are diluted with distilled water in the laboratory before EC readings are made. Using this dilution factor to back-calculate the true salinity in the soil water can cause salinity to be over-predicted.

***Temperature Effects***

EC is also affected by temperature. For example, if the EC is 5dS/m at 25°C, it will be 5.5 dS/m at 30°C. The standard temperature for measuring EC is 25°C. Measurements made at other temperatures must be adjusted to the standard. Although many EC meters will automatically make this adjustment, the following equation can also be used:

$$EC_{25} = EC_t - 0.02 \times (T - 25) \times EC_t \qquad (1)$$

$EC_t$ = EC at temperature T of the sample (measured in centigrade units)

$EC_{25}$ = EC at 25 °C.

***Relationships Between TDS and EC***

Some common relationships for estimating TDS from EC measurements are:

*When EC is less than 5:*

$$\text{TDS (ppm)} = 640 \times \text{EC (dS/m)} \qquad (2)$$

$$\text{TDS (meq/l)} = 10 \times \text{EC (dS/m)} \qquad (3)$$

*When EC is more than 5:*

$$\text{TDS} = 800 \times \text{EC (dS/m)} \qquad (4)$$

For drainage waters of the San Joaquin Valley, however, the following relationships are more appropriate:

$$\text{TDS (ppm)} = 740 \times \text{EC (dS/m); EC less than 5 dS/m} \qquad (5)$$

$$\text{TDS (ppm)} = 840 \times \text{EC (dS/m); EC between 5 and 10 dS/m} \qquad (6)$$

$$\text{TDS (ppm)} = 920 \times \text{EC (dS/m); EC greater than 10 dS/m).} \qquad (7)$$

*Note: 1 dS/m = 1 mmho/cm and 1 ppm = 1 mg/L*

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Hanson, B.R. 1979. "Electrical Conductivity." *Soil and Water*, Fall 1979, No. 42.

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# *Measuring Soil Salinity*

***By Blaine Hanson, Irrigation and Drainage Specialist***

### *Saturated Paste*

The most common method of measuring soil salinity is to first obtain soil samples (200 to 300 grams of material) at the desired locations and depths, and then dry and grind the samples. The ground-up soil is then placed into a container, and distilled water is added until a saturated paste is made. This condition occurs when all the pores in the soil are filled with water and the soil paste glistens from light reflection. The solution of the saturated paste is removed from the paste using a vacuum extraction procedure. The electrical conductivity and chemical constituents are determined using the extracted solution. This EC measurement is frequently called the salinity of the saturation extract ($EC_e$).

The water content of the saturated paste is about twice that of the soil moisture content at field capacity. Thus, the EC of the in-situ soil solution is about twice that of the $EC_e$ because of the dilution effect. Therefore it is possible for $EC_e$ to be less than the EC of the irrigation water, particularly under high-frequency irrigation methods.

The $EC_e$ provides a way of assessing the soil salinity relative to guidelines on crop tolerance to salt. These guidelines, discussed in this manual, are based on $EC_e$. The saturation extract method also minimizes salt dissolution because less water is added to the soil sample compared to other dilution/extract methods.

### *Gypsiferous Soil*

The $EC_e$ of gypsiferous soil may be 1 to 3 dS/m higher than that of non-gypsiferous soil at the same soil water conductivity of the in-situ soil. Calcium sulfate precipitated in the soil is dissolved in preparing the saturated paste, which causes the higher $EC_e$.

### *Other Dilutions*

Some laboratories may use dilutions of 1:1, 1:2, 1:5, or 1:10 soil/water ratios. The EC is measured on the extracts of these solutions. Several problems exist using dilutions that differ from the saturation paste. First, the greater the dilution, the greater the deviation between the ion concentrations in the diluted solution and the soil solution under field conditions. These errors are caused by mineral dissolution, ion hydrolysis, and changes in exchangeable cation ratios. Soil samples containing excess gypsum will deviate the most because calcium and sulfate concentrations remain near-constant with sample dilution, while concentrations of the other ions decrease with dilution. Second, it may be difficult to interpret the meaning of the EC of diluted samples because guidelines describing crop response to salinity are based on $EC_e$. Thus, a saturated paste extract is always preferred for analyzing potential salinity problems.

### Saturation Percentage

It is recommended that the saturation percentage be determined when soil salinity is to be monitored over time. The saturation percentage (SP) is the ratio of the weight of the water added to the dry soil to the weight of the dry soil. Values of the SP may range between 20 and 30 percent for sandy soils, and 50 to 60 percent for clay soils. The saturation percentage can be used to evaluate the consistency in sample preparation over time. Saturation percentages of a given soil that vary considerably over time indicate that different dilutions were used in obtaining a saturated paste, and because of this, $EC_e$ may vary with time simply due to differences in sample preparation. These differences could result from differences in the skill of laboratory technicians in making a saturated paste. The SP can be used to correct for dilution effects with time by using a reference SP and $EC_e$ along with the following relationship:

$$ECe_t = SP_r \times ECe_r / SP_t$$

where $EC_{et}$ and $SP_t$ are the $EC_e$ and SP of a sample taken at some time, and $EC_{er}$ and $SP_r$ are a reference SP and $EC_e$. Caution should be used in making this adjustment for soils containing large amounts of gypsum. Also, if problems occur in obtaining consistent saturation percentages over time, then it may be best to use dilutions such as 1:1 or 1:2, recognizing their disadvantages.

### Soil Suction Probes

Another approach is to install soil suction probes at the desired depths. A vacuum is applied to the suction probe for a sufficient time, the solution accumulated in the probe is removed, and its salinity and chemical constituents are determined. This measurement will reflect the salinity of the in-situ soil water. However, this approach is time-consuming, and in a partially dry soil, obtaining a sufficient volume of solution may not be possible. The ceramic cups of the suction probes must be properly prepared before they are used or a potential for error may exist. Proper preparation includes flowing 0.1N HCl through the cup followed by a liberal volume of distilled water.

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Robbins, C. W. 1990. "Field and laboratory measurements." In: *Agricultural Salinity Assessment and Management*, ed. K.K. Tanji, American Society of Civil Engineering Manuals and Reports on Engineering Practice No. 71.

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# *How Plants Respond to Salts*

***By Stephen Grattan, Plant-Water Relations Specialist***

Although all agricultural soils and irrigation water contain salt, the amount and type of salts present depends on the makeup of both the soil and the irrigation water. A soil is not considered saline unless the salt concentration in the root zone is high enough to prevent optimum growth and yield.

Salts dissolved in the soil water can reduce crop growth and yield in two ways: by *osmotic* influences and by *specific-ion toxicities.*

### *Osmotic Effects*

Osmotic effects are the processes by which salts most commonly reduce crop growth and yield. Normally, the concentration of solutes in the root cell is higher than that in the soil water and this difference allows water to move freely into the plant root. But as the salinity of the soil water increases, the 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 water from reducing water availability to the plant, the plant cells must adjust osmotically — that is, they must either accumulate salts or synthesize organic compounds such as sugars and organic acids. These processes use energy that could otherwise be used for crop growth. The result is a smaller plant that appears healthy in all other respects. Some plants adjust more efficiently, or are more efficient at excluding salt, giving them greater tolerance to salinity.

### *Salt Tolerance in Halophytes*

Plants vary widely in their response to soil salinity. Some plants, called *halophytes,* actually grow better under high levels of soil salinity. These plants adjust osmotically to increased soil salinity largely by accumulating salts absorbed from the soil water. Salts accumulate in the root cells in response to the increased salinity of the soil water, thus maintaining water flow from the soil to the roots. The membranes of these plants are very specialized, allowing them to accumulate salts in plant cells without injury.

### *Salt Tolerance in Crop Plants*

Most crop plants are called *glycophytes.* They are a plant group that can be affected by even moderate soil salinity levels even though salt tolerance within this group varies widely. Most glycophytes also adjust osmotically to increased soil salinity, but by a process different from that of halophytes. Rather than accumulating salts, these plants must internally produce some of the chemicals (sugars and organic acids) necessary to increase the concentration of constituents in the root cell. This process requires more energy than that needed by halophytes, and crop growth and yield are therefore more suppressed.

### Specific-ion Toxicities

Salinity can also affect crop growth through the effect of chloride, boron, and sodium ions on plants by *specific-ion toxicities,* which occurs when these constituents in the soil water are absorbed by the roots and accumulate in the plant's stems or leaves. Often high concentrations of sodium and chloride are synonymous with high salinity levels. High sodium and chloride concentrations can be toxic to woody plants such as vines, avocado, citrus, and stone fruits. Boron is toxic to many crops at relatively low concentrations in the soil. Often the result of specific-ion toxicity is leaf burn, which occurs predominately on the tips and margins of the oldest leaves. Boron injury has also been observed in deciduous fruit and nut trees as "twig die back". This occurs in species where the boron absorbed by the plant can be mobilized via complexes with polyols. For more information see Brown and Shelp (1997).

Using saline water or water with high boron concentrations for sprinkler irrigation can also injure leaves. Like chloride and sodium, boron can be absorbed through the leaves and can injure the plant if it accumulates to toxic levels. The crop's susceptibility to injury depends on how quickly the leaves absorb these constituents, which is related to the plant's leaf characteristics and how frequently it is sprinkled rather than on the crop's tolerance to soil salinity. Plants with leaves that have long retention times, for example — such as vines and tree crops — may accumulate high levels of specific elements even when leaf absorption rates are low.

### Plant Growth Stage Influences Salinity Effects

Plant sensitivity to salinity also depends on the plant growth stage (i.e. germination, vegetative growth, or reproductive growth). Many crops such as cotton, tomato, corn, wheat, and sugar beets may be relatively sensitive to salt during early vegetative growth, but may increase in salt tolerance during the later stages. Other plants, on the other hand, may respond in an opposite manner. Research on this matter is limited, but if salinity during emergence and early vegetative growth is below levels that would reduce growth or yield, the crop will usually tolerate more salt at later growth stages than crop salt tolerance guidelines indicate.

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# *Crop Salt Tolerance*

***By Stephen Grattan, Plant-Water Relations Specialist and Blaine Hanson, Irrigation and Drainage Specialist***

The salt tolerance of a crop is the crop's ability to endure the effects of excess salt in the root zone. In reality, the salt tolerance of a plant is not an exact value, but depends upon many factors, such as salt type, climate, soil conditions and plant age.

Agriculturalists define salt tolerance more specifically as the extent to which the relative growth or yield of a crop is decreased when the crop is grown in a saline soil as compared to its growth or yield in a non-saline soil. Salt tolerance is best described by plotting relative crop yield at varying soil salinity levels. Most crops can tolerate soil salinity up to a given threshold. That is, the maximum salinity level at which yield is not reduced. Beyond this threshold value, yield declines in a more or less linear fashion as soil salinity increases. *Figure 1* on the following page shows the behavior of cotton and tomatoes in saline conditions. Cotton, which is relatively salt tolerant, has a threshold value of 7.7 dS/m, whereas tomatoes — which are more salt sensitive — have a value of 2.5 dS/m. Beyond the threshold values, cotton yields decline gradually as salinity increases, while tomato yields decline more rapidly.

### *Relationship Between Crop Yield and Soil Salinity*

The relationship between relative yield and soil salinity is usually described by the following equation:

$$Y = 100 - B\,(EC_e - A) \qquad (1)$$

where Y = relative yield or yield potential (%), A = threshold value (dS/m) or the maximum root zone salinity at which 100% yield occurs, B = slope of linear line (% reduction in relative yield per increase in soil salinity, dS/m), and $EC_e$ = average root zone soil salinity (dS/m).

Values of A and B for various crops are given in *Tables 2-6.* It should be emphasized that these values represent crop response under experimental conditions and that $EC_e$ reflects the average root zone salinity the crop encounters during most of the season after the crops have been well established under non-saline conditions. Values for woody crops reflect osmotic effects only, not specific ion toxicities, but are useful nonetheless since they serve as a guide to relative tolerance among crops.

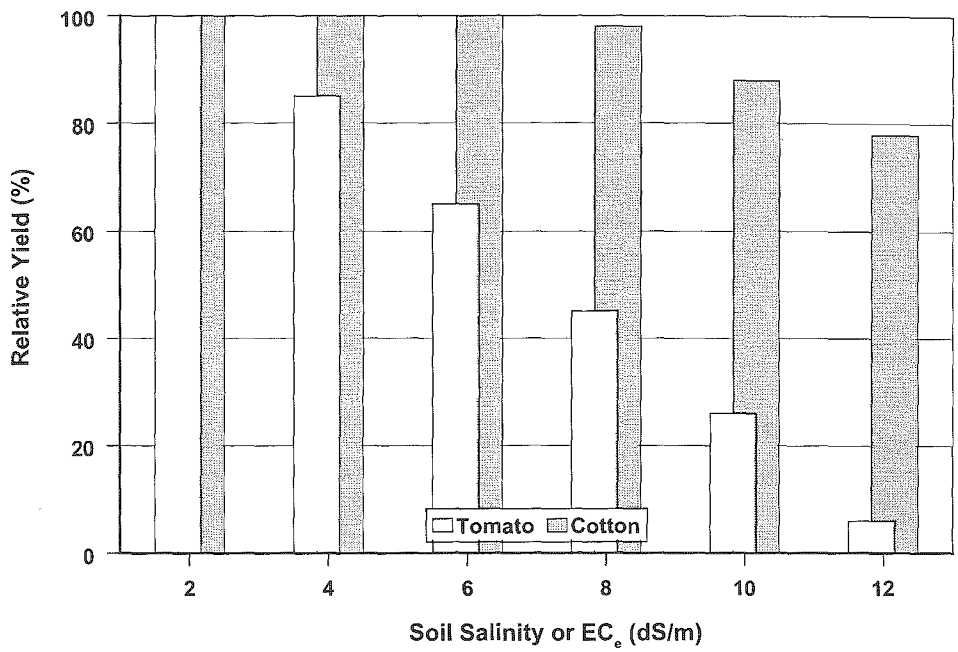


*Figure 1. Response of cotton and tomato to soil salinity.*

*Example:* Calculate the relative potential of tomatoes for an average root zone salinity of 4.0 dS/m. From *Table 4,* A = 2.5 and B = 9.9.

$$Y = 100 - B\,(EC_e - A) = 100 - 9.9\,(4 - 2.5) = 85$$

The relative yield of tomatoes is about 85% for an average root zone salinity of the saturated soil extract of 4 dS/m.

### Gypsiferous Water

Most of the $EC_e$ threshold and slope values were developed from studies that used non-gypsiferous, chloride-dominated waters and soils. The $EC_e$ threshold values in areas using gypsiferous irrigation water may be higher than those in *Tables 2-6*. Gypsum in the soil is dissolved in the saturation extract, thus increasing the EC of the extract compared to the $EC_e$ of a chloride solution. It has been suggested that plants grown in gypsiferous soils can tolerate an $EC_e$ of about 1-3 dS/m higher than those listed in the tables even though no data exits validating this. In reality, any adjustment will depend on the amount of gypsum in the soil and water.

### Climate

Climate can also affect crop tolerance to salt. Some crops such as bean, onion, and radish are more salt tolerant under conditions of high atmospheric humidity than under low atmospheric humidity. Others such as cotton are not affected by atmospheric humidity.

### *Other Crop-Yield Soil-Salinity Relationships*

Other methods have been proposed to describe salt-tolerance using non-linear relationships (e. g. Steppuhn et al, 2005). In general, all methods describe the data set quite well ($r^2 > 0.96$) even though the non-linear expressions have a slightly higher regression coefficient (i.e. > 0.97). Unfortunately, most non-linear expressions use a $EC_e$-50 or C50 value which is the soil salinity where yields are 50% of the maximum. Therefore, they provide confidence in predicting yield potential near 50%, but does not provide "yield threshold" estimates.

Nevertheless, since non-linear models fit the data better, it is likely that they have less error around the 90% yield potential estimate (Steppuhn, personal communication, 2005). However, the average rootzone salinity that relates to the 90% yield potential is more or less the same for most crops when predicted using the slope-threshold method or the Steppuhn and van Genuchten (2005) method. As such, either the Maas-Hoffman approach used by Ayers and Westcot (1985) or the non-linear expression could be used to determine $EC_e$ values that relate to a 90% yield potential.


***References***

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*Table 2. Salt tolerance of herbaceous crops — Fiber, grain and special crops.*

| *Crop* | *Threshold Salinity (A)* | *Slope (B)* | *Rating** |
|---|---|---|---|
| Barley | 8.0 | 5.0 | T |
| Bean, Common | 1.0 | 19.0 | S |
| Broad bean | 1.6 | 9.6 | MS |
| Canola | 10.4 | 13.5 | T |
| Corn | 1.7 | 12.0 | MS |
| Cotton | 7.7 | 5.2 | T |
| Cowpea | 4.9 | 12.0 | MT |
| Crambe | 2.0 | 6.5 | MS |
| Flax | 1.7 | 12.0 | MS |
| Guar | 8.8 | 17.0 | T |
| Kenaf | | | T |
| Millet, channel | | | T |
| Oat | | | T |
| Peanut | 3.2 | 29.0 | MS |
| Rice, paddy (field water)** | 1.9 | 9.1 | MS |
| Rye | 11.4 | 10.8 | T |
| Safflower | | | MT |
| Sesame | | | S |
| Sorghum | 6.8 | 16.0 | MT |
| Soybean | 5.0 | 20.0 | MT |
| Sugar beet | 7.0 | 5.9 | T |
| Sugarcane | 1.7 | 5.9 | MS |
| Sunflower | 4.8 | 5.0 | MT |
| Tricale | 6.1 | 2.5 | T |
| Wheat | 6.0 | 7.1 | MT |
| Wheat (semi-dwarf) | 8.6 | 3.0 | T |
| Wheat, durum | 5.9 | 3.8 | T |

*Table 3. Salt tolerance of herbaceous crops — Grasses and forage crops.*

| *Crop* | *Threshold* | *Salinity (A)* | *Slope (B)* |
|---|---|---|---|
| Alfalfa | 2.0 | 7.3 | MS |
| Alkali grass, nuttall | | | T |
| Alkali sacaton | | | T |
| Barley (forage) | 6.0 | 7.1 | MT |
| Bentgrass | | | MS |
| Bermuda grass | 6.9 | 6.4 | T |
| Bluestem, Angleton | | | MS |
| Brome, mountain | | | MT |
| Brome, smooth | | | MS |
| Buffelgrass | | | MS |
| Burnet | | | MS |
| Canary grass, reed | | | MT |
| Clover alsike | 1.5 | 12.0 | MS |
| Clover, Berseem | 1.5 | 5.7 | MS |
| Clover, Hubam | | | MT |
| Clover, ladino | 1.5 | 12.0 | MS |
| Clover, red | 1.5 | 12.0 | MS |
| Clover, strawberry | 1.5 | 12.0 | MS |
| Clover, sweet | | | MT |
| Clover, white Dutch | | | MS |
| Corn, forage | 1.8 | 7.4 | MS |
| Cowpea (forage) | 2.5 | 11.0 | MS |

**S = sensitive; MS = moderately sensitive; MT = moderately tolerant, T = tolerant*
***Grattan, S. R., L. Zeng, M. C. Shannon and S. R. Roberts. 2002. "Rice is more sensitive to salinity than previously thought." California Agriculture 56:189–195.*

*Table 3. Salt tolerance of herbaceous crops — Grasses and forage crops (continued)*

| *Crop* | *Threshold Salinity (A)* | *Slope (B)* | *Rating** |
|---|---|---|---|
| Dallis grass | | | MS |
| Dhaincha | | | MT |
| Fescue, tall | 3.9 | 5.3 | MT |
| Fescue, meadow | | | MT |
| Foxtail, meadow | 1.5 | 9.6 | MS |
| Glycine | | | MS |
| Grama, blue | | | MS |
| Guinea grass | | | MT |
| Harding grass | 4.6 | 7.6 | MT |
| Kallar grass | | | T |
| Kikuyagrass** | | | T |
| Love grass | 2.0 | 8.4 | MS |
| Milkvetch, cicer | | | MS |
| Millet, Foxtail | | | MS |
| Oatgrass, tall | | | MS |
| Oat (forage) | | | T |
| Orchard grass | 1.5 | 6.2 | MS |
| Panicgrass, blue | | | MT |
| Paspalum, Polo** | | | T |
| Paspalum, PJ299042** | | | MT |
| Rape | | | MT |
| Rescue grass | | | MT |
| Rhodes grass | | | MT |
| Rye (forage) | 7.6 | 4.9 | T |
| Ryegrass, Italian | | | MT |
| Ryegrass, perennial | 5.6 | 7.6 | MT |
| Salt grass, desert | | | T |
| Sesbania | 2.3 | 7.0 | MS |
| Sirato | | | MS |
| Sphaerophysa | 2.2 | 7.0 | MS |
| Sundan grass | 2.8 | 4.3 | MT |
| Timothy | | | MS |
| Trefoil, big | 2.3 | 19.0 | MS |
| Trefoil, narrowleaf bird's foot | 5.0 | 10.0 | MT |
| Trefoil, broadleaf bird's foot | | | MT |
| Vetch, common | 3.0 | 11.0 | MS |
| Wheat (forage) | 4.5 | 2.6 | MT |
| Wheat, durum (forage) | 2.1 | 2.5 | MT |
| Wheat grass, standard crested | 3.5 | 4.0 | MT |
| Wheat grass, fairway crested | 7.5 | 6.9 | T |
| Wheat grass, intermediate | | | MT |
| Wheat grass, slender | | | MT |
| Wheat grass, tall | 7.5 | 4.2 | T |
| Wheat grass, western | | | MT |
| Wild rye, Altai | | | T |
| Wild rye, beardless | 2.7 | 6.0 | MT |
| Wild rye, Canadian | | | MT |
| Wild rye, Russian | | | T |

**S = sensitive; MS = moderately sensitive; MT = moderately tolerant; T = tolerant*

*** Grattan, S. R., C. M. Grieve, J. A. Poss, P. H. Robinson, D. C. Suavez and S. E. Benes. 2004. "Evaluation of salt-tolerant forages for sequential water reuse systems." Agricultural Water Management. 70:109–120.*

*Table 4. Salt tolerance of herbaceous crops — Vegetables and fruit crops.*

| *Crop* | *Threshold Salinity (A)* | *Slope (B)* | *Rating** |
|---|---|---|---|
| Artichoke | 6.1 | 11.5 | MT |
| Asparagus | 4.1 | 2.0 | T |
| Bean, Common | 1.0 | 19.0 | S |
| Bean, Mung | 1.8 | 21.0 | S |
| Beet, red | 4.0 | 9.0 | MT |
| Broccoli | 2.8 | 9.2 | MS |
| Brussels sprouts | | | MS |
| Cabbage | 1.8 | 9.7 | MS |
| Carrot | 1.0 | 14.0 | S |
| Cauliflower | | | MS |
| Celery | 1.8 | 6.2 | MS |
| Corn, sweet | 1.7 | 12.0 | MS |
| Cowpea | 4.9 | 12.0 | MT |
| Cucumber | 2.5 | 13.0 | MS |
| Eggplant | 1.1 | 6.9 | MS |
| Garlic | 3.9 | 14.3 | MS |
| Kale | | | MS |
| Kohlrabi | | | MS |
| Lettuce | 1.3 | 13.0 | MS |
| Muskmelon | 1.0 | 8.4 | MS |
| Okra | | | S |
| Onion | 1.2 | 16.0 | S |
| Onion, Seed | 1.0 | 8.0 | MS |
| Parsnip | | | S |
| Pea | 3.4 | 10.6 | MS |
| Pepper | 1.5 | 14.0 | MS |
| Potato | 1.7 | 12.0 | MS |
| Purslane | 6.3 | 9.6 | MT |
| Pumpkin | | | MS |
| Radish | 1.2 | 13.0 | MS |
| Spinach | 2.0 | 7.6 | MS |
| Squash, scallop | 3.2 | 16.0 | MS |
| Squash, zucchini | 4.9 | 10.5 | MT |
| Strawberry | 1.0 | 33.0 | S |
| Sweet potato | 1.5 | 11.0 | MS |
| Tomato | 2.5 | 9.9 | MS |
| Tomato, cherry | 1.7 | 9.1 | MS |
| Turnip | 0.9 | 9.0 | MS |
| Turnip, greens | 3.3 | 4.3 | MT |
| Watermelon | | | MS |

**S = sensitive; MS = moderately sensitive; MT = moderately tolerant, T = tolerant*

*Table 5. Salt tolerance of woody crops.*

| Crop | Threshold Salinity (A) | Slope (B) | Rating* |
|---|---|---|---|
| Almond | 1.5 | 19.0 | S |
| Apple | | | S |
| Apricot | 1.6 | 24.0 | S |
| Avocado | | | S |
| Blackberry | 1.5 | 22.0 | S |
| Boysenberry | 1.5 | 22.0 | S |
| Castorbean | | | MS |
| Cherimoya | | | S |
| Cherry, sweet | | | S |
| Cherry, sand | | | S |
| Currant | | | S |
| Date palm | 4.0 | 3.6 | T |
| Fig | | | MT |
| Gooseberry | | | S |
| Grape | 1.5 | 9.6 | MS |
| Grapefruit | 1.2 | 13.5 | S |
| Guayule | 15.0 | 13.0 | T |
| Jojoba | | | T |
| Jujube | | | MT |
| Lemon | 1.5 | 12.8 | S |
| Lime | | | S |
| Loquat | | | S |
| Mango | | | S |
| Olive*** | 4.0 | 12.0 | MT |
| Orange | 1.3 | 13.1 | S |
| Papaya | | | MT |
| Passion fruit | | | S |
| Peach | 1.7 | 21.0 | S |
| Pear | | | S |
| Persimmon | | | S |
| Pineapple | | | MT |
| Pistacio**** | | | MT |
| Plum; Prune | 2.6 | 31.0 | MS |
| Pomegranate | | | MT |
| Pummelo | | | S |
| Raspberry | | | S |
| Rose apple | | | S |
| Sapote, white | | | S |
| Tangerine | | | S |

**S = sensitive; MS = moderately sensitive; MT = moderately tolerant, T = tolerant*

**** Araques, R., J. Puy and D. Isidora. 2004. "Vegetative growth response of young olive tress (Olea Enropaea L. cv. Arbeguina) to soil salinity and waterlogging." Plant Soil 258: 69-80.*

***** Ferguson, L., J. A. Poss, S.R. Grattan, C.M. Grieve, D. Wang, C. Wilson, T.J. Donovan and C.T. Chao. 2002. "Pistachio rootstocks influenct scion growth and ion relations under salinity and boron stress." J. Am. Soc. Hort. Sci. 127: 194-199.*

**Table 6. Salt tolerance of ornamental shrubs, trees and ground cover.**

| Crop | Maximum Salinity[1] | Crop | Maximum Salinity[1] |
|---|---|---|---|
| *very sensitive* | | *moderately tolerant* | |
| Star jasmine | 1-2 | Weeping bottlebrush | 6-8 |
| Pyrenees cotoneaster | 1-2 | Oleander | 6-8 |
| Oregon grape | 1-2 | European fan palm | 6-8 |
| Photinia | 1-2 | Blue dracaena | 6-8 |
| | | Spindle tree, cv. Grandiflora | 6-8 |
| *sensitive* | | Rosemary | 6-8 |
| Pineapple guava | 2-3 | Aleppo pine | 6-8 |
| Chinese holly, cv. Burford | 2-3 | Sweet gum | 6-8 |
| Rose, cv. Grenoble | 2-3 | | |
| Glossy abelia | 2-3 | *tolerant* | |
| Southern yew | 2-3 | Brush cherry | >8 |
| Tulip tree | 2-3 | Ceniza | >8 |
| Algerian ivy | 3-4 | Natal plum | >8 |
| Japanese pittosporum | 3-4 | Evergreen pear | >8 |
| Heavenly bamboo | 3-4 | Bougainvillea | >8 |
| Chinese hibiscus | 3-4 | Italian stone pine | >8 |
| Laurustinus, cv Robustum | 3-4 | | |
| Strawberry tree, cs. Compact | 3-4 | *very tolerant* | |
| Crape Myrtle | 3-4 | White iceplant | >10 |
| Eucalyptus (camaldulensis)***** | 3-4 | Rosea iceplant | >10 |
| | | Purple iceplant | >10 |
| *moderately sensitive* | | Croceum iceplant | >10 |
| Glossy privet | 4-6 | | |
| Yellow sage | 4-6 | | |
| Orchid tree | 4-6 | | |
| Southern Magnolia | 4-6 | | |
| Japanese boxwood | 4-6 | | |
| Xylosma | 4-6 | | |
| Japanese black pine | 4-6 | | |
| Indian hawthorn | 4-6 | | |
| Dodonaea, cv. atropurpurea | 4-6 | | |
| Oriental arborvitae | 4-6 | | |
| Thorny elaeagnus | 4-6 | | |
| Spreading juniper | 4-6 | | |
| Pyracantha, cv. Graberi | 4-6 | | |
| Cherry plum | | | |

*[1] Salinity levels exceeding the $EC_e$ (dS/m) value may cause leaf burn, leaf loss, or stunting.*
****** Grattan, S.R., M.C. Shennan, C.M. Grieve, J.A. Poss, D.L. Suarez, and L.E. Francois. 1996. Interactive effects of salinity and boron on the performance and water use of euclayptus. Acta Horticulturae 449: 607-613.*

# *Sodium and Chloride Toxicity in Crops*

**By Stephen Grattan, Plant-Water Relations Specialist**

Salinity can stunt plant growth by forcing the plant to work harder to extract water from the soil. Sodium and chloride, usually the major constituents in salt-affected soils, can cause additional damage to plants if they accumulate in the leaves to toxic concentrations. This can occur either by being absorbed through the roots and moving into the leaves or by being absorbed by the leaves directly from sprinkler irrigation.

Damage from sodium and chloride toxicity usually occurs only in tree and vine crops except where soil salinity is extremely high or when saline water is used for sprinkler irrigation. Under these conditions, non-woody annuals may also show leaf injury.

## *Sodium*

In most crops, most of the sodium absorbed by the plant remains in the roots and stems, away from leaves, but sodium, which is not an essential micronutrient, can injure woody plants (vines, citrus, avocado, stone fruits) if it accumulates in the leaves to toxic levels. Direct toxic effects, which includes leaf burn, scorch, and dead tissue along the outer edge of leaves, may take weeks, months, and in some cases, years, to appear. Although once concentrations reach toxic levels, damage may appear suddenly in response to hot, dry weather conditions. Symptoms are first evident in older leaves, starting at the tips and outer edge and then moving inward toward the midrib as injury progresses. Injury in avocado, citrus, and stone fruits can occur with soil-water concentrations as low as 5 meq/l but actual injury may be more dependent upon the amount of sodium in the soil solution relative to the amount of soluble calcium ($Ca^{2+}$). Damage can also result when sodium is absorbed by the leaves during sprinkler irrigation with concentrations as low as 3 meq/l.

Sodium can also affect crop growth indirectly by causing nutritional imbalances and by degrading the physical condition of the soil. High sodium levels can cause calcium, potassium, and magnesium deficiencies — and high sodium levels relative to calcium concentrations can severely reduce the rate at which water infiltrates the soil, which can affect the plant because of poor aeration (see "How Water Quality Affects Infiltration").

## *Chloride*

Chloride, an essential micronutrient, is not toxic to most nonwoody plants unless excessive concentrations accumulate in leaves. While many woody plants are susceptible to chloride toxicity, tolerance varies among varieties and rootstocks. Many chloride-sensitive plants are injured when chloride concentrations exceed 5 to 10 meq/l in the saturation extract, while nonsensitive plants can tolerate concentrations up to 30 meq/l. *Table 7* contains estimates of the maximum allowable chloride concentrations in saturation extracts and of irrigation water for various fruit-crop cultivars and rootstocks.

Chloride moves readily with the soil water, is taken up by the plant roots, translocates to the shoot, and accumulates in the leaves. Chloride injury usually begins with a chlorosis (yellowing) in the leaf tip and margins and progresses to leaf burn or drying of the tissue as injury becomes more acute. Chloride injury can also result from direct leaf absorption during overhead sprinkler irrigation with concentrations as low as 3 meq/l.

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*Table 7. Chloride-tolerance limits of some fruit-crop cultivars and rootstocks.*

| | *Soil $Cl_e$ meq/l | **Irrigation Water | |
|---|---|---|---|
| | | $Cl_i$ meq/l | $Cl_i$ (mg/l or ppm) |
| **Rootstocks** | | | |
| ***Avocado*** | | | |
| West Indian | 7.5 | 5 | 180 |
| Guatemalan | 6 | 4 | 140 |
| Mexican | 5 | 3 | 100 |
| ***Citrus*** | | | |
| Sunki mandarin grapefruit | 25 | 17 | 600 |
| Grapefruit | 25 | 17 | 600 |
| Cleopatra mandarin | 25 | 17 | 600 |
| Rangpur lime | 25 | 17 | 600 |
| Sampson tangelo | 15 | 10 | 350 |
| Rough lemon | 15 | 10 | 350 |
| sour orange | 15 | 10 | 350 |
| Ponkan mandarin | 15 | 10 | 350 |
| Citrumelo 4475 | 10 | 7 | 250 |
| Trifoliate orange | 10 | 7 | 250 |
| Cuban shaddock | 10 | 7 | 250 |
| Calamondin | 10 | 7 | 250 |
| Sweet orange | 10 | 7 | 250 |
| Savage citrange | 10 | 7 | 250 |
| Rusk citrange | 10 | 7 | 250 |
| Troyer citrange | 10 | 7 | 250 |
| ***Grape*** | | | |
| Salt Creek | 40 | 26 | 920 |
| Dog Ridge | 30 | 20 | 710 |
| ***Stone fruit*** | | | |
| Marianna | 25 | 17 | 600 |
| Lovell | 10 | 7 | 250 |
| Shalil | 10 | 7 | 250 |
| Yunnan | 7.5 | 5 | 180 |
| **Cultivars** | | | |
| ***Berries*** | | | |
| Boysenberry | 10 | 7 | 250 |
| Olallie blackberry | 10 | 7 | 250 |
| Indian Summer raspberry | 5 | 3 | 100 |
| ***Grape*** | | | |
| Thompson seedless | 20 | 13 | 460 |
| Perlette | 20 | 13 | 460 |
| Cardinal | 10 | 7 | 250 |
| Black rose | 10 | 7 | 250 |
| ***Strawberry*** | | | |
| Lassen | 7.5 | 5 | 180 |
| Shasta | 5 | 3 | 100 |

* *Chloride concentration of the saturation extract*

** *Chloride concentration of the irrigation water (assumes 15-20 percent leaching fraction)*