Evaluating Salinity in Irrigation Water

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Dissolved salts in irrigation water present numerous challenges to growers. Salts reduce the osmotic potential of water, increasing the energy that plants use to extract moisture from soil, and making them more susceptible to wilting. In addition to contributing to water stress, some constituents of salts such as sodium, chloride and boron, are toxic if they accumulate in the leaves and stem. High sodium levels can also reduce the rate that water infiltrates into soil. Soils irrigated with alkaline water (high bicarbonate) may have reduced availability of micronutrients such as iron, copper, manganese, and zinc. Lastly, salts can affect irrigation equipment by causing plugging of drip line emitters or by causing corrosion of metal fittings. All of these effects of salinity need to be considered when assessing the suitability of a water source for irrigation.

Various measurements are used to characterize the salinity of irrigation water. The main parameters tested are: 1. **Total dissolved solids** (TDS), a measure of the bulk salinity often determined indirectly by measuring electrical conductivity of the water 2. **Sodium adsorption ratio** (SAR), the ratio of sodium to the sum of calcium and magnesium, and 3. **Alkalinity,** a measure of the bicarbonate dissolved in the water (Table 1). TDS and EC are useful for evaluating the osmotic effects of salts on crop growth. SAR is useful for assessing if infiltration rates will be reduced or if sodium has the potential to build up in the soil. Measurements of alkalinity are used to assess if there is potential for calcium and magnesium carbonate to precipitate inside pipes and drip lines, or affect the pH of the soil. While these three measures of salinity can give a general assessment of the suitability of water for crop production, the principal cations and anions also need to be determined to know which types of salts are present in the water.

Salts dissolve into water to form pairs of positively (cation) and negatively (anion) charged ions. The main cations and anions in ground water, listed in Table 2, should be included in water tests. Although, iron and manganese are usually present at low concentrations, they should be also included in water tests because they can form oxides that clog drip emitters. Test results are usually expressed in units of parts per million (ppm) or milliequivalents per liter (meq/L). Parts per million is also the same unit as milligram per liter (mg/L). Conversion between ppm and meq/L is often necessary because thresholds for plant response may be expressed in either unit. The factors for converting from ppm or mg/L to meq/L are also listed in Table 2.

The questions to consider when evaluating a water test are:

1. Will the bulk salinity of the water reduce the yield of the crop?

Thresholds of salinity that cause yield loss are listed in Tables 3 and 4 for several fruit and vegetable crops. These thresholds should be used as rough guides, since actual values could vary significantly depending on climate, soil type, irrigation method, development stage of the crop, and the salt constituents. Crops often can tolerate higher levels of salinity if calcium, magnesium, sulfate, and/or bicarbonate represent a significant portion of the bulk salinity in the water. This is because calcium and magnesium tend to precipitate out of the soil solution as the soil dries. Plants can often tolerate higher salinity levels in climates with low evapotranspiration demands, such as near the coast. Also mature plants are usually more tolerant to salinity than seedlings.

2. Are concentrations of sodium, chloride, boron, or bicarbonate at levels that would be toxic to a crop?

Potential restrictions of water use due to specific ion toxicities are summarized in Table 5. Sodium, chloride and boron can accumulate in the stem and leaf tissues and build up to toxic levels. Tissues where the most water loss occurs will often show toxicity symptoms first. Short season crops, such as many vegetables, may not show toxicity symptoms to sodium and chloride while perennial crops may develop symptoms of toxicity after several seasons. Chloride toxicity often appears in leaves as interveinal chlorosis (yellowing) and marginal burning as the toxicity becomes more severe. Leaf burning can also be caused from absorption of these ions through the leaves during sprinkler irrigations. Try to avoid overhead sprinkling during periods of high evaporations, such as windy or hot conditions.

Sensitivity to boron varies greatly between crops. Perennial crops such as trees and vines are usually more prone to boron toxicity than vegetable crops. Boron toxicity symptoms include the yellowing of leaves and marginal burns. Tree crops may not show leaf symptoms but may have twig dieback or gum on the limbs and trunk.

3. Will the infiltration rate be reduced?

High levels of sodium in the water can cause soil particles (aggregates) to disperse and form crusts on the soil surface that impede the infiltration of water. Irrigation water with a high electrical conductivity will tend to have fewer problems with infiltration than a low EC water (Table 6). Also, a water source with high levels of bicarbonate may have less calcium available to counter act the dispersion effects of sodium. An adjusted SAR should be calculated when levels of bicarbonate are greater than 1 meq/L.

4. Are there salt constituents that would lead to the clogging of drip emitters or micro-sprinklers?

The potential for precipitates is of special concern for micro-irrigation systems (Table 7). Injection of fertilizers can sometimes cause precipitates to form that clog drip emitters. Calcium and magnesium carbonate precipitates may develop if the pH of the water is raised through the injection of alkali producing fertilizers, such as Aqua ammonia. Also, the injection of fertilizers containing calcium can cause precipitates to form in water that is high in bicarbonate. Phosphorus fertilizers can create precipitates in water that is high in calcium. Low concentrations of iron and manganese can oxidize and form precipitates capable of plugging drip emitters. Often injecting upstream of a well designed filter system and using the appropriate combination of fertilizers can avoid many potential plugging problems.

Conclusion

The quality of water needs to be evaluated in the context of the intended use. Testing water before designing a new drip system, purchasing or renting land, or switching to another vegetable crop may help you avoid potential production problems and wasting money. Although our office does not have the resources to test water for growers, I can help you interpret water test results from commercial laboratories. We also have a UC publication for sale in our office entitled "Agricultural Salinity and Drainage," that covers water testing and salinity management in more detail than can be addressed in this article.

Table 1. Major parameters for evaluating salinity in irrigation water.

Water Quality Measurement	Symbol	Formula[1]/Units	What it measures
Sodium Adsorption Ratio	SAR	$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$	ratio of the concentration of sodium to the sum of the concentration of calcium and magnesium in water
adjusted Sodium Adsorption Ratio	SAR_{adj}		same as SAR, but the calcium concentration is adjusted for the level of bicarbonate and EC of the water
Electrical Conductivity	EC_w	dS/m[2], mmhos/cm	measure of bulk salinity in water
Total Dissolved Solids	TDS	ppm[3], mg/L	measure of bulk salinity in water
pH	pH	$pH = -\log(H^+)$	concentration of protons (acidity) in water
Alkalinity		ppm or mg/L of $CaCO_3$	concentration of bicarbonate in water, usually expressed in equivalents of $CaCO_3$

1. SAR, SAR_{adj}, and pH are expressed without units

2. dS/m = deciSiemens per meter, mmhos/cm = millimhos per centimeter, 1 dS/m = 1 mmhos/cm

3. 1 ppm = 1 mg/L

Table 2. List of anions and cations commonly found in ground water.

Cation			Anion		
name	symbol	mg/meq[1]	name	symbol	mg/meq
Calcum	Ca^{2+}	20	Chloride	Cl^-	35
Magnesium	Mg^{2+}	12	Sulfate	SO_4^{2-}	48
Sodium	Na^+	23	Bicarbonate	HCO_3^-	61
Potassium	K^+	39	Carbonate	CO_3^{2-}	30
			Nitrate	NO_3^-	62
			Boron	B	--[2]

[1] conversion between mg/L and meq/L; (eg. 100 mg/L Ca = 100/20 = 5 meq/L)

[2] Boron can be in several anionic and neutral forms in water

Table 3. Tolerance of vegetables to salinity in soil and water, expressed as electrical conductivity.

Crop	100 % Yield Potential		90 % Yield Potential	
	EC_{soil}	EC_{water}	EC_{soil}	EC_{water}
	------------------------dS/m	--------------------------		
Squash, Zucchini	4.7	3.1	5.8	3.8
Beet, Red	4.0	2.7	5.1	3.4
Squash, Scallop	3.2	2.1	3.8	2.6
Broccoli	2.8	1.9	3.9	2.6
Tomato	2.5	1.7	3.5	2.3
Cucumber	2.5	1.7	3.3	2.2
Spinach	2.0	1.3	3.3	2.2
Celery	1.8	1.2	3.4	2.3
Cabbage	1.8	1.2	2.8	1.9
Potato	1.7	1.1	2.5	1.7
Corn, Sweet	1.7	1.1	2.5	1.7
Sweet Potato	1.5	1.0	2.4	1.6
Pepper	1.5	1.0	2.2	1.5
Lettuce	1.3	0.9	2.1	1.4
Radish	1.2	0.8	2.0	1.3
Onion	1.2	0.8	1.8	1.2
Carrot	1.0	0.7	1.7	1.1
Bean	1.0	0.7	1.5	1.0
Turnip	0.9	0.6	2.0	1.3

adapted from FAO Irrigation and Drainage Paper 29, 1985 pp. 31-33.

Table 4. Tolerance of fruit crops to salinity in soil and water, expressed as electrical conductivity.

Crop	100 % Yield Potential		90 % Yield Potential	
	EC_{soil}	EC_{water}	EC_{soil}	EC_{water}
	------------------------dS/m	--------------------------		
Grapefruit	1.8	1.2	2.4	1.6
Orange	1.7	1.1	2.3	1.6
Peach	1.7	1.1	2.2	1.5
Apricot	1.6	1.1	2.0	1.3
Grapefruit	1.5	1.0	2.5	1.7
Almond	1.5	1.0	2.0	1.4
Plum	1.5	1.0	2.1	1.4
Blackberry	1.5	1.0	2.0	1.3
Boysenberry	1.5	1.0	2.0	1.3
Strawberry	1.0	0.7	1.3	0.9

adapted from FAO Irrigation and Drainage Paper 29, 1985 pp. 31-33.

Table 5. General thresholds of specific ion toxicities for agricultural crops.

Specific Ion Toxicity	Units	Degree of Restriction on Use[1] No restriction	Slight to Moderate	Severe
Sodium (Na^+)		***------ Trees, Vines, and other Sensitive Crops -------***		
surface irrigation	mg/L	< 70	70 - 200	> 200
sprinkler irrigation	mg/L	< 70	> 70	
		-------------- Vegetables --------------------		
sprinkler irrigation	mg/L	< 115	115-460	> 460
Chloride (Cl^-)				
		------ Trees, Vines, and other Sensitive Crops -------		
surface irrigation	mg/L	< 140	140-350	> 350
sprinkler irrigation	mg/L	< 100	> 100	
		-------------- Vegetables --------------------		
sprinkler irrigation	mg/L	< 175	175-700	> 700
		-------------- All crops --------------------		
Boron (B)	mg/L	< 0.7	0.7-3	> 3
Bicarbonate (HCO_3^-)[1]	meq/L	< 1.5	1.5-7.5	>7.5

1. Adapted from FAO irrigation and drainage paper 29, 1985

2. sprinkler irrigation only

Table 6. Thresholds for potential water infiltration problems.

SAR	Degree of Restriction on Use[1] No restriction	Slight to Moderate	Severe
	------ EC of irrigation water (dS/m) -------		
0-3	> 0.7	0.7-0.2	<0.2
3-6	>1.2	1.2-0.3	<0.3
6-12	>*1.9*	1.9-0.5	<0.5
12-20	>2.9	2.9-1.3	<1.3
20-40	>5.0	5.0-2.9	<2.9

1. Adapted from FAO irrigation and drainage paper 29, 1985

Table 7. Thresholds for potential clogging in micro-irrigation systems.

		Degree of Restriction on Use[1]		
Potential Problem	**Units**	**None**	**Slight to Moderate**	**Severe**
Physical				
Suspended Solids	mg/L[2]	< 50	50-100	>100
Chemical				
pH		< 7.0	7.0-8.0	> 8.0
Dissolved Solids	mg/L	< 500	500-2000	>2000
Manganese	mg/L	< 0.1	0.1-1.5	>1.5
Iron	mg/L	< 0.1	0.1-1.5	>1.5

1. Adapted from FAO irrigation and drainage paper 29, 1985
2. 1 mg/L = 1 ppm