12 Assessing Water Quality

Water quality can affect the performance of the trickle irrigation system, influence the infiltration rate of the soil and the crop growth response. Trickle irrigation systems may be able to use water that is higher in salinity to irrigate crops than sprinkler systems can, providing that proper management and operation practices are used. This chapter provides information on water quality considerations for trickle systems.

12.1 Water Quality

Determining the water quality used by the trickle irrigation system is important for many reasons.

Irrigation System Considerations – Sediments, bacterial growths, algae and chemical precipitates can clog an emitter. A water analysis will help to identify potential problems that may persist. See Chapters 10 and 11 for information on treating organic and inorganic particles.

Soil Considerations – The composition of dissolved salts in the water supply may affect soil properties. Most irrigation waters contain some salts, but are only considered saline if the salt concentration is detrimental to the soil or crop. Fertilizers are also considered to be salts and can increase soil acidity and salinity. Trickle irrigation systems maintain a high soil moisture close to the emitter which push salts to the outer edges of the wetted area.

Deep percolation does not usually occur with a trickle irrigation system, therefore salts are not easily leached out of the soil at deeper depths. The system capacity must be large enough to provide the crop water requirement as well as a leaching requirement to maintain the soil salinity in the rooting zone within the crop tolerance range. Chapter 3 provides information on crop leaching requirement. Soil permeability can also deteriorate if water with a low salt content is applied to non-saline soils with a low sodium adsorption ratio (SAR). See Section 12.2 on soil salinity.

Crop Considerations – Use of saline water without adequate leaching could cause soil salinization reducing crop yield. While boron is essential to many crops, excess boron can be toxic. Many crops are also sensitive to excess chloride and nitrogen.

Other Considerations – Water pH helps to determine the types of dissolved solids that may be present in the water supply. Water pH also effects the availability of nutrients in the soil. Lowering the pH enhances the effectiveness of chlorination.

Water Analysis

Water samples should be taken from wells after the pump has been running for 15 minutes or more, from streams where the water is running and from the centre of reservoirs or dugouts if possible. For dugouts the water sample should be taken from below the surface.

Samples should be at least two litres in size and collected in clean plastic bottles that have been triple rinsed. The water should be analyzed within three hours after sampling or held at a temperature below 5˚C until analysis can be done. Water analysis should be done prior to the design of the trickle irrigation system and annually afterward for water supplies that vary significantly in chemical and sediment content.

A water quality analysis should include:

- Electrical Conductivity (EC) – measured in dS/m or mmho/cm as a measurement of total salinity or total dissolved solids
- pH – where 1 is very acidic, 7 is neutral and 14 is basic
- Cations including Calcium (Ca), Magnesium (Mg) and Sodium (Na) – meq/L
- Anions including Chloride (Cl), Sulfate (SO_4), Carbonate (CO_3) and Bicarbonate ($HC0_3$) – meq/L
- Iron (Fe), Manganese (Mn) and Hydrogen Sulfide (H_2S) – mg/L
- Sodium Adsorption Ratio (SAR) - measures the potential for sodium in the water to develop sodium sodicity, deterioration in soil permeability and toxicity to crops
- Suspended solids – mg/L
- Bacterial population – number per ml
- Nitrate nitrogen (NO_3-N) – mg/L

Chapter 11 provides further information on the Cations and Anions with respect to Calcium Carbonate precipitates. General water quality guidelines for trickle irrigation systems are shown in Table 12.1.

Table 12.1 Water Quality Guidelines for Trickle Irrigation Systems

Parameter	Severity Low	Medium	High
Clogging			
Suspended Solids - mg/L	< 50	50 - 100	> 100
pH	< 7.0	7.0 - 8.0	> 8.0
Manganese - mg/L	< 0.1	0.1 - 1.5	> 1.5
Iron - mg/L	< 0.2	0.2 - 1.5	> 1.5
Hydrogen Sulfide - mg/L	< 0.2	0.2 - 2.0	> 2.0
Bacteria - number / mL	< 10,000	10,000 - 50,000	> 50,000
Crop Sensitivity			
EC - mmho/cm	< 0.75	0.75 - 3.0	> 3.0
NO_3-N - mg/L	< 5	5 - 30	> 30
Ion Toxicity			
Boron - mg/L	< 0.5	0.5 - 2.0	2.0 - 10.0
Chloride - meq/L	< 4	4 - 10	> 10
- mg/L	< 142	142 - 355	> 355

From: Micro Irrigation Management and Maintenance, Farouk A. Hassan

The information in Tables 12.2 to 12.5 is taken from the Canadian Water Quality Guidelines. The tables have been altered to reflect information that pertains to crops irrigated with trickle irrigation systems only. These tables provide additional information on the water quality requirements for crop production.

Table 12.2 Summary - Guidelines for Irrigation Water Quality

Parameter	Guideline (mg/L) All soils[1]	Guideline (mg/L) Neutral to alkaline soils[2]
Major Ions		
Bicarbonate[3]	—	—
Chloride	100 - 700 (see Tables 12-3 and 12-4)	
Sodium	Soils: determine sodium absorption ratio. see Table 12-6 Crops: see Table 12-8	
Total dissolved solids (salinity)	500 - 3500 (may not protect some sensitive crops; see Table 12-9)	
Heavy Metals and Trace Ions[4]		
Aluminum	5.0	20.0
Arsenic	0.1	2.0
Beryllium	0.1	0.5
Boron	0.5 - 6.0 (see Table 12-5)	—
Cadmium	0.01	—
Chromium	0.1	—
Cobalt	0.05	5.0
Copper	0.2 (Sensitive crops)	5.0
	1.0 (Tolerant crops)	5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead[5]	0.2	2.0
Lithium	2.5	—
Manganese	0.2	10.0
Mercury[3]	—	—
Molybdenum	0.01	0.05
	0.05 (intermittent for acidic soils)	—
Nickel	0.2	2.0
Selenium	0.02	—
	0.05 (intermittent)	—
Uranium[5]	0.01	0.1
Vanadium	0.1	1.0
Zinc	1.0 (soil pH < 6.5)	—
	5.0 (soil pH > 6.5)	—
Biological Parameters		
Plant pathogens[3]	—	
Human and animal pathogens[5]	100 fecal coliforms per 100 mL; 1000 total coliforms per 100 mL	

[1] Assumes continuous irrigation unless otherwise noted.
[2] Maximum time of irrigation with water containing elevated concentrations of heavy metals and trace ions is 20 years on neutral to alkaline fine-textured soils.
[3] No guideline recommended at this time.
[4] Guidelines expressed as total concentrations.
[5] Tentative guideline.

Table 12.3 Chloride Tolerance of Fruit and Woody Crops by Root Uptake

Rootstocks	Cl in irrigation water (mg/L)	Cultivars	Cl in irrigation water (mg/L)
Grapes	710 - 960	Boysenberry Blackberry	250
Stone fruit (peaches, plums, etc.)	180 - 600	Raspberry	
		Grapes	230 - 460
		Strawberry	110 - 180

From: Westcot and Ayers 1984.

Table 12.4 Sodium or Chloride Concentrations in Irrigation Water Causing Foliar Damage

Sensitivity	Ion Concentrations (mg/L)		Affected Crops
	Cl	Na	
Sensitive	< 178	< 115	Almond, apricot, plum
Moderately sensitive	178 - 355	115 - 230	Grape, pepper, potato, tomato
Moderately tolerant	355 - 710	230 - 460	Alfalfa, barley, corn, cucumber
Tolerant	> 710	> 460	Cauliflower, cotton, safflower, sesame, sorghum, sugar beet, sunflower

From: Westcot and Ayers

Table 12.5 Relative Tolerance of Agricultural Crops to Boron

Tolerance[1]	Concentration of Boron in Soil Water[2] (mg/L)	Agricultural Crops
Very sensitive	< 0.5	Blackberry
Sensitive	0.5 - 1.0	Peach, cherry, plum, grape, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney bean, lima bean
Moderately sensitive	1.0 - 2.0	Red pepper, pea, carrot, radish, potato, cucumber
Moderately tolerant	2.0 - 4.0	Lettuce, cabbage, celery, turnip, Kentucky bluegrass, oat, corn, artichoke, tobacco, mustard, clover, squash, muskmelon
Tolerant	4.0 - 6.0	Sorghum, tomato, alfalfa, purple vetch, parsley, red beet, sugar beet
Very tolerant	6.0 - 15.0	Asparagus

[1] Tolerances will vary with climate, soil conditions and crop varieties; values are to be used only as a guideline.
[2] Maximum concentrations tolerated in irrigation water without reductions in yield or vegetative growth are approximately equal to soil water values or slightly less.

From: Westcot and Ayers 1984.

12.2 Salinity

Water salinity can affect both the soil and crop. While sodium is the element associated with salinity, the effects of sodium on the soil or crops is dependent on a number of factors.

Soil Effects

Excess sodium in irrigation water relative to calcium and magnesium or the total soluble salt content can adversely affect soil structure, reduce soil infiltration rates and permeability and reduce soil aeration. When the absorbed sodium exceeds 10-15% of the total cations a hard impermeable crust can form on the soil surface upon drying. Below the soil surface the permeability can be maintained because an increase in salinity from crop water uptake will usually be sufficient to offset the negative effects of exchangeable sodium. The Sodium Adsorption Ratio (SAR) is used to relate the effect of excess sodium to that of calcium and magnesium. The SAR is a measurement of the soil's capacity to adsorb exchangeable cations and is used as an index to evaluate the hazard of sodium in irrigation water on the soil's infiltration rate.

Equation 12.1

$$\text{SAR} = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where:

SAR = Sodium Adsorption Ratio
Na = Na ion in meq/L
Ca = Ca ion in meq/L
Mg = Mg ion in meq/L

Table 12.6 relates the SAR to the electrical conductivity (soluble salt content) of the water with respect to infiltration into the soil only. The ECw and SAR must be evaluated together.

Table 12.6 Guidelines on SAR for Irrigation Water Use

SAR	Restrictions on Water Use		
	None	Slight to Moderate	Severe
		(Electrical Conductivity (ECw) dS/m)	
< 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

From: Water Quality for Agriculture FAO

The SAR value calculated in Equation 12.1 is accurate for the sodium adsorption ratio of irrigation water in the upper root zone or close to the soil surface. For most irrigation waters with electrical conductivity's < 1.0 dS/m the effects of salt precipitation are insignificant in influencing soil water composition at leaching fractions of 0.2 or greater. However, if leaching fractions from irrigation are not significant (less than 0.1), precipitation of $CaCO_3$ may be significant, especially in the lower root zone. For sodic waters, an adjusted SAR_{adj} may be a better index in these situations. The SAR_{adj} is the same as Equation 12.1 except that the Ca concentration is an estimate of the concentration that will result in the soil solution upon equilibration of the soil and irrigation water. The SAR_{adj} should be determined from laboratory analysis. Table 12.7 provides water quality parameters using the SAR_{adj}.

Table 12.7 Sodium Evaluation Using SAR_{adj} for Trickle Systems

Parameter	Severity		
	Low	Medium	High
Ion Toxicity			
Sodium - SAR_{adj}	< 3.0	3.0 - 9.0	> 9.0
Soil Permeability			
EC - dS/m	> 0.5	0.2 - 0.5	< 0.2
SAR_{adj}	< 6.0	6.0 - 9.0	> 9.0

Crop Effects

Salinity effects on crops are more noticeable when plants are water stressed. Plants can tolerate higher levels of salinity under well watered conditions, such as high frequency irrigations provided by drip or trickle systems. The effects of high soil salinity's in the lower root zone can be minimized if sufficient low salinity water is applied to the upper root zone to satisfy the crop's water needs. This means the plant does not need to extract water from deeper saline part of the root zone.

Table 12.8 provides information on the toxicity of sodium to crops using SAR. Information on toxicity using SAR_{adj} is given in Table 12.7.

Table 12.8 Tolerance of Crops to Sodium

Tolerance	SAR of Irrigation Water	Crop	Conditions
Very sensitive	2 - 8	Deciduous fruits	Leaf tip burn, leaf scorch
Sensitive	8 - 18	Beans	Stunted growth
Moderately tolerant	18 - 46	Clover, oats, tall fescue	Stunted because of nutrition and soil structure
Tolerant	46 - 102	Wheat, lucerne, barley, tomatoes, beets, tall wheatgrass, crested wheatgrass	Stunted because of soil structure

From: Hart 1974.

Total Dissolved Solids (TDS) in water also causes soil salinity. The EC levels will indicate if salinity is a problem. Table 12.9 provides guidelines for various crops.

Table 12.9 Tolerance of Selected Crops to Total Dissolved Solid in Irrigation Water[1], as Determined by Research in California, USA

Degree of Tolerance	Fruits and Berries	Vegetables
Not Tolerant Ec_w< 0.7 TDS < 500	Strawberry Raspberry	Bean Carrot
Slightly Tolerant Ec_w< 1.2 TDS< 800	Boysenberry Currant Blackberry Gooseberry Plum Grape Apricot Peach Pear Cherry Apple	Onion Parsnip Radish Pea Pumpkin Lettuce Pepper Muskmelon Sweet potato Sweet corn Potato Celery Cabbage Kohlrabi Cauliflower
Moderately tolerant EC_w< 2.2 TDS < 1500		Spinach Cantaloupe Cucumber Tomato Squash Brussel sprout Broccoli Turnip
Tolerant EC_w < 3.6 TDS < 2500		Beet Zucchini
Very Tolerant EC_w < 5.0 TDS < 3500		Asparagus

[1] ***Assumptions and definitions:***

1. The crops within each "tolerant" grouping are listed from least to most tolerant. Actual tolerances will be modified by management, climate and soil conditions.
2. ECe means electrical conductivity of saturation extract (mS cm-1 or mmhos cm-1). ECw is the electrical conductivity of the irrigation water. ECsw is the electrical conductivity of the soil solution. ECsw = 3ECw for a leaching fraction of 0.15.
3. TDS means total dissolved solids in units of mg L -1. The conversion factor of 1 EC = 700 mg L-1 has been used to transpose data.
4. A leaching fraction of approximately 15% is maintained. The tolerance tables can be adjusted by increasing or decreasing the leaching fraction.
5. Soil texture ranges from sandy loam to clay with good internal drainage and no uncontrolled shallow water table.
6. Rainfall is low and does not play a significant role in meeting crop demands. The guidelines may be too restrictive for wetter areas.
7. Assume the use of gravity and sprinkler irrigation systems where water is applied infrequently as needed. The crop utilizes 50% or more of the stored available water before the next irrigation. Guidelines are too restrictive for frequent or drip irrigation systems.
8. Each irrigation leaches the upper root zone, and salt accumulation increases with depth. The crop responds to the average salinity in the root zone, and the salt content of the soil solution (ECsw) is about three times that of the irrigation water (ECw) because of evapotranspiration.

From: Kearney and Scofield 1936; Bernstein 1964, 1965, 1974; Bernstein *et al*. 1972; Ayers and Westcot 1976; Maas and Hoffman 1977; Francois 1981; Westcot and Ayers 1984; Maas 1985.

12.3 Trickle and Drip System Management for Salinity

As mentioned previously, trickle or drip irrigation systems offer some advantages with respect to using saline water. The effects of saline water or soils on crops are thereby reduced because the soil moisture levels are kept higher. The concern for the most part is for new transplants or crop germination. When a seedling is just planted, germinating or emerging from the ground it is very sensitive to salts. There is also a tendency for salt to accumulate near the soil surface, especially with buried drip systems. Sprinkler systems may initially be required to ensure good germination and leaching of the salts beyond the small root systems that are developing.

Drip or trickle systems can be used for germination in saline areas under the following conditions:

- The crop is tolerant to salt during emergence or germination. Salt sensitive crops such as lettuce may need sprinklers for proper germination. Deeper rooted crops such as tomatoes can be germinated with drip systems.
- There is effective rainfall of at least 15 cm during the early spring. The rainfall helps to leach salts to deeper depths in the soil.
- The emitter spacing is no further apart than 30 cm. Close emitter spacings allow the system to form a wetted front along the entire row thereby leaching salts out of the root zone.
- The depth of lateral burial does not exceed 20 cm for buried systems.
- The bed shape and seed placement can be important when germinating shallow vegetable seeds that are salt sensitive. Figure 12.1 provides an example bed shape and seed placement location developed at the Irrigation Training and Research Centre, at Cal-Poly in California. The intent is to have the salt accumulate above the indentation and away from the seed line.

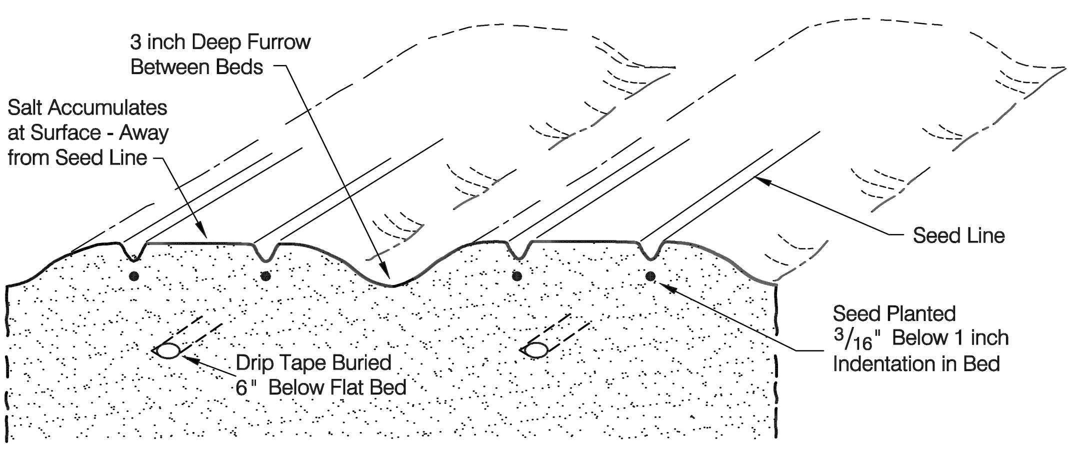

Figure 12.1 *Bed Shape for Germination of Shallow Planted Salt Tolerant Vegetables*

Management strategies that will assist in germination and saline control include:

- Surging or pulsing irrigation applications. The cycling of applications promotes upward and lateral water movement.
- Preparing a seed bed that has a firm side and top. To achieve good water movement for tape depths of less than 20 cm, soils structure is more important than soil texture. Coarser soils (sands) can often be worked into a finer seed bed and therefore offer better capillary water movement than finer soils which are prone to clods. However, for buried tape installations