Texas A&M AgriLife Extension
EB-1667 02/21

IRRIGATION WATER QUALITY STANDARDS AND SALINITY MANAGEMENT STRATEGIES

Guy Fipps*

Nearly all waters contain dissolved salts and trace elements, many of which result from the natural weathering of the earth's surface. In addition, drainage waters from irrigated lands and effluent (liquid waste) from city sewage and industrial wastewater can impact water quality. In most irrigation situations, the primary water quality concern is salinity levels since salts can affect both the soil structure and crop yield. However, a number of trace elements are found in water that can also limit its use for irrigation. Generally, "salt" is thought of as ordinary table salt (sodium chloride).

However, many types of salts exist and are commonly found in Texas waters (Table 1). Most salinity problems in agriculture result directly from the salts carried in the irrigation water. The process at work is illustrated in Figure 1, which shows a beaker of water containing a salt concentration of 1 percent. As water evaporates, the dissolved salts remain, resulting in a solution with a higher concentration of salt. The same process occurs in soils. Salts, as well as other dissolved substances, begin to accumulate as water evaporates from the surface and as crops withdraw water.

Table 1. Kinds of salts normally found in irrigation waters, with chemical symbols and approximate proportions of each salt *(Longenecker and Lyerly,1994).*[1]

Chemical name	Chemical symbol	Approximate proportion of total salt content
Sodium chloride	$NaCl$	Moderate to large
Sodium sulfate	Na_2SO_4	Moderate to large
Calcium chloride	$CaCl_2$	Moderate
Calcium sulfate (gypsum)	$CaSO_4\ 2H_2O$	Moderate to small
Magnesium chloride	$MgCl_2$	Moderate
Magnesium sulfate	$MgS0_4$	Moderate to small
Potassium chloride	KCl	Small
Potassium sulfate	K_2SO_4	Small
Sodium bicarbonate	$NaHCO_3$	Small
Calcium carbonate	$CaCO_3$	Very small
Sodium carbonate	Na_2CO_3	Trace to none
Borates	BO^{-3}	Trace to none
Nitrates	NO^{-3}	Small to none

[1] Waters vary greatly in amounts and kinds of dissolved salts. This water typifies many used for irrigation in Texas.

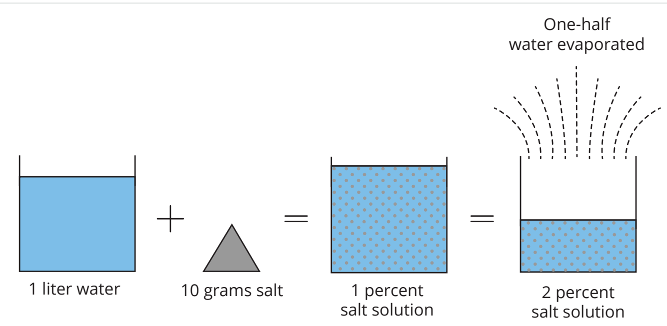

Figure 1. Effect of water evaporation on the concentration of salts in solution. A liter is 1.057 quarts. Ten grams is .035 ounces or about 1 teaspoonful.

WATER ANALYSIS: Units, Terms and Sampling

Numerous parameters are used to define irrigation water quality, to assess salinity hazards, and to determine appropriate management strategies. A complete water quality analysis will include the determination of:

1. The total concentration of soluble salts;
2. The relative proportion of sodium to the other cations;
3. The bicarbonate concentration as related to the concentration of calcium and magnesium; and
4. The concentrations of specific elements and compounds.

*Professor and Extension Agricultural Engineer (Irrigation and Water Management)

The amounts and combinations of these substances define the suitability of water for irrigation and the potential for plant toxicity. Table 2 defines common parameters for analyzing the suitability of water for irrigation and provides some useful conversions.

When taking water samples for laboratory analysis, keep in mind that water from the same source can vary in quality with time. Therefore, samples should be tested at intervals throughout the year—particularly during the potential irrigation period. The Soil and Water Testing Lab at Texas A&M University can do a complete salinity analysis of irrigation water and soil samples, and will provide a detailed computer printout on the interpretation of the results. Contact a county Extension agent for forms and information, or contact the lab at: (979) 845-4816.

Table 2. Terms, units, and useful conversions for understanding water quality analysis reports.

Symbol	Meaning	Units
Total salinity		
a. EC	Electric conductivity	mmhos/cm µmhos/cm dS/m
b. TDS	Total dissolved solids	mg/L ppm
Sodium Hazard		
a. SAR	Sodium adsorption ratio	—
b. ESP	Exchangeable sodium percentage	—

Determination	Symbol	Unit of measure	Atomic weight
Constituents			
(1) cations			
calcium	Ca	mol/m^3	40.1
magnesium	Mg	mol/m^3	24.3
sodium	Na	mol/m^3	23.0
potassium	K	mol/m^3	39.1
(2) anions			
bicarbonate		mol/m^3	61.0
sulphate		mol/m^3	96.1
chloride		mol/m^3	35.5
carbonate		mol/m^3	60.0
nitrate		mg/L	62.0
Trace Elements			
boron	B	mg/L	10.8

Conversions

1 dS/m = 1 mmhos/cm = 1000 µmhos/cm

1 mg/L = 1 ppm

TDS (mg/L) ≈ EC (dS/m) × 640 for EC < 5 dS/m

TDS (mg/L ≈ EC (dS/m) × 800 for EC > 5 dS/m

TDS (lbs./ac-ft.) ≈ TDS (mg/L) × 2.72

Concentration (ppm) = Concentration (mol/m^3) times the atomic weight Sum of cations/anions

(meq/L) ≈ EC (dS/m) × 10

Key

mg/L = milligrams per liter

ppm = parts per million

dS/m = deci Siemens per meter at 25°C

TWO TYPES OF SALT PROBLEMS

Two types of salt problems exist, which are very different: Those associated with the total salinity, and those associated with sodium. Soils may be affected only by salinity or by a combination of both salinity and sodium.

Salinity Hazard

Water with high salinity is toxic to plants and poses a ***salinity hazard.*** Soils with high levels of total salinity are called ***saline soils.*** High concentrations of salt in the soil can result in a "physiological" drought condition. Although the field may appear to have plenty of moisture, the plants wilt because the roots are unable to absorb the water. Water salinity is usually measured by the total dissolved solids (TDS) or the electric conductivity (EC). TDS is sometimes referred to as the total salinity and is measured or expressed in parts per million (ppm), or in the equivalent units of milligrams per liter (mg/L).

EC is actually a measurement of electric current and is reported in 1 of 3 possible units as given in Table 2. Subscripts are used with the symbol "EC" to identify the source of the sample. EC_{iw} is the electric conductivity of the irrigation water. EC_e is the electric conductivity of the soil as measured in a soil sample (e.g., saturated extract) taken from the root zone. EC_d is the soil salinity of the saturated extract taken from below the root zone. EC_d is used to determine the salinity of the drainage water, which leaches below the root zone.

Types of Salinity Problems				
Salinity hazard	affects →	Plants	can lead to →	Saline soil condition
Sodium	affects →	Soils	can lead to →	Sodic soil condition

Sodium Hazard

Irrigation water containing large amounts of sodium is of special concern, due to sodium's effects on the soil, which poses a ***sodium hazard.*** Sodium hazard is usually expressed in terms of SAR (or the sodium adsorption ratio). SAR is calculated from the ratio of sodium to calcium and magnesium. The latter two ions are important since they tend to counter the effects of sodium. For waters containing significant amounts of bicarbonate, the adjusted sodium adsorption ratio (SAR_{adj}) is sometimes used.

Continued use of water that has a high SAR leads to a breakdown in the physical structure of the soil. Sodium is adsorbed and becomes attached to soil particles. The soil then becomes hard and compact when dry and becomes increasingly impervious to water penetration. Fine textured soils, especially those high in clay are the most at risk of this occurrence. Certain amendments may be required to maintain soils under high SARs. Calcium and magnesium—

if present in the soil in large enough quantities—will counter the effects of the sodium and help maintain good soil properties. *Soluble sodium percent* (SSP) is also used to evaluate sodium hazard. SSP is defined as the ration of sodium in equivalents per million (EPM) to the total cation EPM multiplied by 100. A water with a SSP greater than 60 percent may result in sodium accumulations that will cause a breakdown in the soil's physical properties.

Ions, Trace Elements, and Other Problems

A number of other substances may be found in irrigation water and can cause toxic reactions in plants (Table 3). After sodium, chloride and boron are of most concern. In certain areas of Texas, boron concentrations are excessively high and render water unsuitable for irrigation. Boron can also accumulate in the soil.

Crops grown on soils having an imbalance of calcium and magnesium may also exhibit toxic symptoms.

Sulfate salts affect sensitive crops by limiting the uptake of calcium and increasing the adsorption of sodium and potassium, resulting in a disturbance in the cationic balance within the plant. The bicarbonate ion in soil solution harms the mineral nutrition of the plant through its effects on the uptake and metabolism of nutrients. High concentrations of potassium may introduce a magnesium deficiency and iron chlorosis. An imbalance of magnesium and potassium may be toxic, but the effects of both can be reduced by high calcium levels.

CLASSIFICATION OF IRRIGATION WATER

Several different measurements are used to classify the suitability of water for irrigation, including EC_{iw}, the total dissolved solids, and SAR. Some permissible limits for classes of irrigation water are given in Table 4. In Table 5, the sodium hazard of water is ranked from low to very high based on SAR values.

Table 3. Recommended limits for constituents in reclaimed water for irrigation *(adapted from Rowe and Abdel-Magid, 1995)*.

Constituent	Long-term use (mg/L)	Short-term use (mg/L)	Remarks
Aluminum (Al)	5.0	20	Can cause non-productivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic (As)	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium (Be)	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron (B)	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/L. Most grasses are relatively tolerant at 2.0 to 10 mg/L.
Cadmium (Cd)	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.
Chromium (Cr)	0.1	1.0	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt (Co)	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper (Cu)	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride (F–)	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron (Fe)	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead (Pb)	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium (Li)	2.5	2.5	Tolerated by most crops at up to 5 mg/L; mobile in soil. Toxic to citrus at low doses (recommended limit is 0.075 mg/L).
Manganese (Mg)	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/L in acid soils.
Molybdenum (Mo)	0.01	0.05	Non-toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel (Ni)	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium (Se)	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of added selenium.
Vanadium (V)	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc (Zn)	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.

Table 4. Permissible limits for classes of irrigation water.		
	Concentration, Total Dissolved Solids	
Classes of water	Electrical conductivity µmhos*	Gravimetric ppm
Class 1, Excellent	250	175
Class 2, Good	250–750	175–525
Class 3, Permissible[1]	750–2,000	525–1,400
Class 4, Doubtful[2]	2,000-3,000	1,400–2,100
Class 5, Unsuitable[2]	3,000	2,100

*Micromhos/cm at 25°C.
[1]Leaching needed if used
[2]Good drainage needed and sensitive plants will have difficulty obtaining stands

Table 5. The sodium hazard of water based on SAR Values.		
SAR values	Sodium hazard of water	Comments
1–10	Low	Use on sodium sensitive crops such as avocados must be cautioned.
10–18	Medium	Amendments (such as Gypsum) and leaching needed.
18–26	High	Generally unsuitable for continuous use.
>26	Very high	Generally unsuitable for use.

CLASSIFICATION OF SALT-AFFECTED SOILS

Both EC_e and SAR are commonly used to classify salt-affected soils (Table 6). ***Saline soils*** (resulting from salinity hazard) normally have a pH value below 8.5. They are also relatively low in sodium, and principally contain sodium, calcium, and magnesium chlorides and sulfates.

These compounds cause the white crust, which forms on the surface and the salt streaks along the furrows. The compounds that cause saline soils are very soluble in water. Therefore, leaching is usually effective in reclaiming these soils.

Sodic soils (resulting from sodium hazard) generally have a pH value between 8.5 and 10. These soils are called "black alkali soils" due to their darkened appearance and smooth, slick looking areas caused by the dispersed condition. In sodic soils, sodium has destroyed the permanent structure, which makes the soil impervious to water. Thus, leaching alone will not be effective unless the high salt dilution method or amendments are used.

Table 6. Classification of salt-affected soils based on analysis of saturation extracts *(adapted from James et al., 1982).*				
Criteria	Normal	Saline	Sodic	Saline-sodic
EC_e (mmhos/cm)	<4	>4	<4	>4
SAR	<13	<13	>13	>13

WATER QUALITY EFFECTS ON PLANTS AND CROP YIELD

Table 7 gives the expected yield reduction of some crops for various levels of ***soil salinity*** as measured by EC under normal growing conditions. Table 8 gives potential yield reduction due to ***water salinity*** levels. Generally, forage crops are the most resistant to salinity, followed by field crops, vegetable crops, and fruit crops, which are generally the most sensitive. For more on Salinity and Boron's effects on landscape and native plants in Texas, see Extension publication ECS-011.

Table 7. Soil salinity tolerance levels[1] for different crops *(adapted from Ayers and Westcot, 1976).*					
	Yield potential, EC_e				Maximum EC_e
Crop	100%	90%	75%	50%	
Field crops					
Barley[a]	8.0	10.0	13.0	18.0	28
Bean (field)	1.0	1.5	2.3	3.6	7
Broad bean	1.6	2.6	4.2	6.8	12
Corn	1.7	2.5	3.8	5.9	10
Cotton	7.7	9.6	13.0	17.0	27
Cowpea	1.3	2.0	3.1	4.9	9
Flax	1.7	2.5	3.8	5.9	10
Groundnut	3.2	3.5	4.1	4.9	7
Rice (paddy)	3.0	3.8	5.1	7.2	12
Safflower	5.3	6.2	7.6	9.9	15
Sesbania	2.3	3.7	5.9	9.4	17
Sorghum	4.0	5.1	7.2	11.0	18
Soybean	5.0	5.5	6.2	7.5	10
Sugar beet	7.0	8.7	11.0	15.0	24
Wheat[a]	6.0	7.4	9.5	13.0	20
Vegetable crops					
Bean	1.0	1.5	2.3	3.6	7
Beet[b]	4.0	5.1	6.8	9.6	15
Broccoli	2.8	3.9	5.5	8.2	14
Cabbage	1.8	2.8	4.4	7.0	12
Cantaloupe	2.2	3.6	5.7	9.1	16
Carrot	1.0	1.7	2.8	4.6	8
Cucumber	2.5	3.3	4.4	6.3	10
Lettuce	1.3	2.1	3.2	5.2	9
Onion	1.2	1.8	2.8	4.3	8
Pepper	1.5	2.2	3.3	5.1	9
Potato	1.7	2.5	3.8	5.9	10
Radish	1.2	2.0	3.1	5.0	9
Spinach	2.0	3.3	5.3	8.6	15
Sweet corn	1.7	2.5	3.8	5.9	10
Sweet potato	1.5	2.4	3.8	6.0	11
Tomato	2.5	3.5	5.0	7.6	13
Forage crops					
Alfalfa	2.0	3.4	5.4	8.8	16
Barley hay[a]	6.0	7.4	9.5	13.0	20

continued on next page

Table 7 *continued*

Crop	Yield potential, EC_e				Maximum EC_e
	100%	90%	75%	50%	
Forage crops *continued*					
Bermudagrass	6.9	8.5	10.8	14.7	23
Clover, Berseem	1.5	3.2	5.9	10.3	19
Corn (forage)	1.8	3.2	5.2	8.6	16
Harding grass	4.6	5.9	7.9	11.1	18
Orchard grass	1.5	3.1	5.5	9.6	18
Perennial rye	5.6	6.9	8.9	12.2	19
Sudan grass	2.8	5.1	8.6	14.4	26
Tall fescue	3.9	5.8	8.61	3.3	23
Tall wheat grass	7.5	9.9	13.3	19.4	32
Trefoil, big	2.3	2.8	3.6	4.9	8
Trefoil, small	5.0	6.0	7.5	10.0	15
Wheat grass	7.5	9.0	11.0	15.0	22
Fruit crops					
Almond	1.5	2.0	2.8	4.1	7
Apple, Pear	1.7	2.3	3.3	4.8	8
Apricot	1.6	2.0	2.6	3.7	6
Avocado	1.3	1.8	2.5	3.7	6
Date palm	4.0	6.8	10.9	17.9	32
Fig, Olive, Pomegranate	2.7	3.8	5.5	8.4	14
Grape	1.5	2.5	4.1	6.7	12
Grapefruit	1.8	2.4	3.4	4.9	8
Lemon	1.7	2.3	3.3	4.8	8
Orange	1.7	2.3	3.2	4.8	8
Peach	1.7	2.2	2.9	4.1	7
Plum	1.5	2.1	2.9	4.3	7
Strawberry	1.0	1.3	1.8	2.5	4
Walnut	1.7	2.3	3.3	4.8	8

[1]Based on the electrical conductivity of the saturated extract taken from a root zone soil sample (EC_e) measured in mmhos/cm.

[a]During germination and seedling stage EC_e should not exceed 4 to 5 mmhos/cm except for certain semi-dwarf varieties.

[b]During germination EC_e should not exceed 3 mmhos/cm.

Table 8. Irrigation water salinity tolerances[1] for different crops
(adapted from Ayers and Westcot, 1976).

Crop	Yield potential, EC_{iw}			
	100%	90%	75%	50%
Field crops				
Barley	5.0	6.7	8.7	12.0
Bean (field)	0.7	1.0	1.5	2.4
Broad bean	1.1	1.8	2.0	4.5
Corn	1.1	1.7	2.5	3.9
Cotton	5.1	6.4	8.4	12.0
Cowpea	0.9	1.3	2.1	3.2
Flax	1.1	1.7	2.5	3.9
Groundnut	2.1	2.4	2.7	3.3
Rice (paddy)	2.0	2.6	3.4	4.8
Safflower	3.5	4.1	5.0	6.6
Sesbania	1.5	2.5	3.9	6.3
Sorghum	2.7	3.4	4.8	7.2
Soybean	3.3	3.7	4.2	5.0
Sugar beet	4.7	5.8	7.5	10.0
Wheat	4.0	4.9	6.4	8.7
Vegetable crops				
Bean	0.7	1.0	1.5	2.4
Beet[b]	2.7	3.4	4.5	6.4
Broccoli	1.9	2.6	3.7	5.5
Cabbage	1.2	1.9	2.9	4.6
Cantaloupe	1.5	2.4	3.8	6.1
Carrot	0.7	1.1	1.9	3.1
Cucumber	1.7	2.2	2.9	4.2
Lettuce	0.9	1.4	2.1	3.4
Onion	0.8	1.2	1.8	2.9
Pepper	1.0	1.5	2.2	3.4
Potato	1.1	1.7	2.5	3.9
Radish	0.8	1.3	2.1	3.4
Spinach	1.3	2.2	3.5	5.7
Sweet corn	1.1	1.7	2.5	3.9
Sweet potato	1.0	1.6	2.5	4.0
Tomato	1.7	2.3	3.4	5.0
Forage crops				
Alfalfa	1.3	2.2	3.6	5.9
Barley hay	4.0	4.9	6.3	8.7
Bermudagrass	4.6	5.7	7.2	9.8
Clover, Berseem	1.0	2.1	3.9	6.8
Corn (forage)	1.2	2.1	3.5	5.7
Harding grass	3.1	3.9	5.3	7.4
Orchard grass	1.0	2.1	3.7	6.4
Perennial rye	3.7	4.6	5.9	8.1
Sudan grass	1.9	3.4	5.7	9.6
Tall fescue	2.6	3.9	5.7	8.9
Tall wheat grass	5.0	6.6	9.0	13.0
Trefoil, big	1.5	1.9	2.4	3.3
Trefoil, small	3.3	4.0	5.0	6.7
Wheat grass	5.0	6.0	7.4	9.8

continued on next page

Table 8 *continued*

Crop	Yield potential, EC_{iw}			
	100%	90%	75%	50%
Fruit crops				
Almond	1.0	1.4	1.9	2.7
Apple, Pear	1.0	1.6	2.2	3.2
Apricot	1.1	1.3	1.8	2.5
Avocado	0.9	1.2	1.7	2.4
Date palm	2.7	4.5	7.3	12.0
Fig, Olive, Pomegranate	1.8	2.6	3.7	5.6
Grape	1.0	1.7	2.7	4.5
Grapefruit	1.2	1.6	2.2	3.3
Lemon	1.1	1.6	2.2	3.2
Orange	1.1	1.6	2.2	3.2
Peach	1.1	1.4	1.9	2.7
Plum	1.0	1.4	1.9	2.8
Strawberry	0.7	0.9	1.2	1.7
Walnut	1.1	1.6	2.2	3.2

[1]Based on the electrical conductivity of the irrigation water (EC_{iw}) measured in mmhos/cm.

Table 9 lists the ***chloride tolerance*** of a number of agricultural crops. ***Boron*** is a major concern in some areas. While a necessary nutrient, high boron levels cause plant toxicity, and concentrations should not exceed those given in Table 10. Some information is available on the susceptibility of crops to ***foliar injury*** from spray irrigation with water containing sodium and chloride (Table 11). The tolerance of crops-to-sodium as measured by the exchangeable sodium percentage (ESP) is given in Table 12.

Table 9. Chloride tolerance of agricultural crops. Listed in order of tolerance *(adapted from Ranji. 1990).*[a]

Crop	Maximum Cl^- concentration[b] without loss in yield	
	mol/m³	ppm
Strawberry	10	350
Bean	10	350
Onion	10	350
Carrot	10	350
Radish	10	350
Lettuce	10	350
Turnip	10	350
Rice, paddy[c]	30[d]	1,050
Pepper	15	525
Clover, strawberry	15	525
Clover, red	15	525
Clover, alsike	15	525
Clover, ladino	15	525
Corn	15	525
Flax	15	525
Potato	15	525
Sweet potato	15	525
Broad bean	15	525
Cabbage	15	525
Foxtail, meadow	15	525
Celery	15	525
Clover, Berseem	15	525
Orchardgrass	15	525
Sugarcane	15	525
Trefoil, big	20	700
Lovegrass	20	700
Spinach	20	700
Alfalfa	20	700
Sesbania[c]	20	700
Cucumber	25	875
Tomato	25	875
Broccoli	25	875
Squash, scallop	30	1,050
Vetch, common	30	1,050
Wild rye, beardless	30	1,050
Sudan grass	30	1,050
Wheat grass, standard crested	35	1,225
Beet, red[c]	40	1,400
Fescue, tall	40	1,400
Squash, zucchini	45	1,575
Harding grass	45	1,575
Cowpea	50	1,750
Trefoil, narrow-leaf bird's foot	50	1,750
Ryegrass, perennial	55	1,925
Wheat, Durum	55	1,925
Barley (forage)[c]	60	2,100
Wheat[c]	60	2,100
Sorghum	70	2,450
Bermudagrass	70	2,450
Sugar beet[c]	70	2,450
Wheat grass, fairway crested	75	2,625
Cotton	75	1,625
Wheat grass, tall	75	2,625
Barley[c]	80	2,800

[a]These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending upon climate, soil conditions and cultural practices.

[b]Cl^- concentrations in saturated-soil extracts sampled in the rootzone.

[c]Less tolerant during emergence and seedling stage.

[d]Values for paddy rice refer to the Cl^- concentration in the soil water during the flooded growing conditions.

Table 10. Limits of boron in irrigation water *(adapted from Rowe and Abdel-Magid, 1995)*.

A. Permissible Limits (Boron in parts per million)

Class of water	Crop group		
	Sensitive	Semi-tolerant	Tolerant
Excellent	<0.33	<0.67	<1.00
Good	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
Permissible	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	>1.25	>2.5	>3.75

B. Crop groups of boron tolerance (in each plant group, the first names are considered as being more tolerant; the last names, more sensitive).

Sensitive (1.0 mg/L of Boron)		Semi-tolerant (2.0 mg/L of Boron)		Tolerant (4.0 mg/L of Boron)	
Pecan	Kadoka fig	Sunflower (native)	Barley	Athel (*Tamarix aphylla*)	Garden beet
Walnut (Black, Persian, or English)	Persimmon	Potato	Wheat	Asparagus	Alfalfa
Jerusalem artichoke	Cherry	Cotton (acala and pima)	Corn	Palm (*Phoenix canariensis*)	Gladiolus
Navy bean	Peach	Tomato	Milo	Date palm (*P. dactylifera*)	Broad bean
American elm	Apricot	Sweet pea	Oat	Sugar beet	Onion
Plum	Thornless blackberry	Radish	Zinnia	Mangel	Turnip
Pear	Orange	Field pea	Pumpkin		Cabbage
Apple	Avocado	Ragged Robin rose	Bell pepper		Lettuce
Grape (Sultania and Malaga)	Grapefruit	Olive	Sweet potato		Carrot
	Lemon		Lima bean		
(0.3 mg/L of Boron)		(1.0 mg/L of boron)		(2.0 mg/L of boron)	

Table 11. Relative susceptibility of crops to foliar injury from saline sprinkling waters *(Tanji, 1990)*.

Na or Cl concentration (mol/m^3) causing foliar injury[a]			
<5	5–10	10–20	>20
Almond	Grape	Alfalfa	Cauliflower
Apricot	Pepper	Barley	Cotton
Citrus	Potato	Corn	Sugar beet
Plum	Tomato	Cucumber	Sunflower
		Safflower	
		Sesame	
		Sorghum	

[a]Foliar injury is influenced by cultural and environmental conditions. These data are presented only as general guidelines for daytime sprinkling.

Table 12. Tolerance of Various Crops to Exchangeable-Sodium Percentage *(James et al., 1982).*

Tolerance to ESP (range at which affected)	Crop	Growth Responsible Under Field Conditions
Extremely sensitive (ESP = 2-10)	Deciduous fruits Nuts Citrus Avocado	Sodium toxicity symptoms even at low ESP values
Sensitive (ESP = 10-20)	Beans	Stunted growth at low ESP values even though the physical condition of the soil may be good
Moderately tolerant (ESP = 20-40)	Clover Oats Tall fescue Rice Dallisgrass	Stunted growth due to both nutritional factors and adverse soil conditions
Tolerant (ESP = 40-60)	Wheat Cotton Alfalfa Barley Tomatoes Beets	Stunted growth usually due to adverse physical conditions of soil
Most tolerant (ESP > 60)	Crested and Fairway wheatgrass Tall wheatgrass Rhodes grass	Stunted growth usually due to adverse physical conditions of soil

Salinity and Growth Stage

Many crops have little tolerance for salinity during seed germination, but have significant tolerance during later growth stages. Some crops such as barley, wheat, and corn are known to be more sensitive to salinity during the early growth period than during germination and later growth periods. Sugar beet and safflower are relatively more sensitive during germination, while the tolerance of soybeans may increase or decrease during different growth periods depending on the variety.

LEACHING FOR SALINITY MANAGEMENT

Soluble salts that accumulate in soils must be leached below the crop root zone to maintain productivity. Leaching is the basic management tool for controlling salinity. Water is applied in excess of the total amount used by the crop and lost to evaporation. The strategy is to keep the salts in solution and flush them below the root zone. The amount of water needed is referred to as the *leaching requirement* or the *leaching fraction.*

Excess water may be applied with every irrigation to provide the water needed for leaching. However, the time interval between leaching does not appear to be critical, provided that crop tolerances are not exceeded. Hence, leaching can be accomplished with each irrigation, every few irrigations, once yearly, or even longer depending on the severity of the salinity problem and salt tolerance of the crop. An occasional or annual leaching event where water is ponded on the surface is an easy and effective method for controlling soil salinity. In some areas, normal rainfall provides adequate leaching.

Determining Required Leaching Fraction

The leaching fraction is commonly calculated using the following relationship:

$$LF = \frac{EC_{iw}}{EC_e} \qquad (1)$$

where

LF = leaching fraction – the fraction of applied irrigation water that must be leached through the root zone

EC_{iw} = electric conductivity of the irrigation water

EC_e = the electric conductivity of the soil in the root zone

Equation 1 can be used to determine the leaching fraction necessary to maintain the root zone at a targeted salinity level. If the amount of water available for leaching is fixed, then the equation can be used to calculate what salinity level will be maintained in the root zone with that amount of leaching. Please note that Equation 1 simplifies a complicated soil water process. EC_e should be checked periodically, and the amount of leaching should be adjusted accordingly.

Based on this equation, Table 13 lists the amount of leaching needed for different classes of irrigation waters to maintain the soil salinity in the root zone at a desired level. However, additional water must be supplied because of the inefficiencies of irrigation systems (Table 14), as well as to remove the existing salts in the soil.

Table 13. Leaching requirement* as related to the electrical conductivities of the irrigation and drainage water.

Electrical conductivity of irrigation water (mmhos/cm)	Leaching requirement based on the indicated maximum values for the conductivity of the drainage water at the bottom of the root zone			
	4 mmhos/cm	8 mmhos/cm	12 mmhos/cm	16 mmhos/cm
	Percent	Percent	Percent	Percent
0.75	13.3	9.4	6.3	4.7
1.00	25.0	12.5	8.3	6.3
1.25	31.3	15.6	10.4	7.8
1.50	37.5	18.7	12.5	9.4
2.00	50.0	25.0	16.7	12.5
2.50	62.5	31.3	20.8	15.6
3.00	75.0	37.5	25.0	18.7
5.00	—	62.5	41.7	31.2

* Fraction of the applied irrigation water that must be leached through the root zone expressed as percent.

Table 14. Typical overall on-farm efficiencies for various types of irrigation systems.

System	Overall efficiency (%)
Surface	50–80
a. Average	50
b. Land leveling and delivery pipeline meeting design standards	70
c. Tailwater recovery with (b)	80
d. Surge	60–90*
Sprinkler (moving and fixed systems)	55–85
LEPA (low pressure precision application)	95–98
Drip	80–90**

*Surge has been found to increase efficiencies 8 to 28 percent over non-surge furrow systems.

**Drip systems are typically designed at 90 percent efficiency, short laterals (100 feet) or systems with pressure compensating emitters may have higher efficiencies.

Subsurface Drainage

Very shallow, saline water tables occur in many areas of Texas. Shallow water tables complicate salinity management, since water may actually move upward into the root zone carrying with it dissolved salts. Water is then extracted by crops and evaporation, leaving behind the salts. Shallow water tables also contribute to the salinity problem by restricting the downward leaching of salts through the soil profile. Installation of a subsurface drainage system may be the only solution available for this situation. The original clay tiles have been replaced by plastic tubing. Modern drainage tubes are covered by a "sock" made of fabric to prevent clogging of the small openings in the plastic tubing.

A schematic of a subsurface drainage system is shown in Figure 2. The design parameters are the distance between drains (L) and the elevation of the drains (d) above the underlying impervious or restricting layer. Proper spacing and depth maintain the water level at an optimum level (shown here as the distance *m* above the drain tubes). The USDA Natural Resources Conservation Service (NRCS) has developed drainage design guidelines that are used throughout the U.S. A drainage computer model developed by Wayne Skaggs at North Carolina State University, DRAINMOD, is also widely used throughout the world for subsurface drainage design.

Seed Placement

Obtaining a satisfactory stand is often a problem when furrow irrigating with saline water. Growers sometimes compensate for poor germination by planting two- or three-times as much seed as normally would be required. However, planting procedures can be adjusted to lower the salinity in the soil around the germinating seeds. Good salinity control is often achieved with a combination of suitable practices, bed shapes, and irrigation water management.

In furrow-irrigated soils, planting seeds in the center of a single-row, raised bed places the seeds exactly where salts are expected to concentrate (Figure 3a). This situation can be avoided using "salt ridges." With a double-row raised planting bed, the seeds are placed near the shoulders and away from the area of greatest salt accumulation. Alternate furrow irrigation may help in some cases. If alternate furrows are irrigated, salts may often be moved beyond the single-seed row to the non-irrigated side of the planting bed. Salts will still accumulate, but accumulation at the center of the bed will be reduced.

With either single- or double-row plantings, increasing the depth of the water in the furrow can improve germination in saline soils. Another practice is to use sloping beds, with the seeds planted on the sloping side just above the water line (Figure 3b). Seed and plant placement is also important with the use of drip irrigation. Typical wetting patterns of drip emitters and

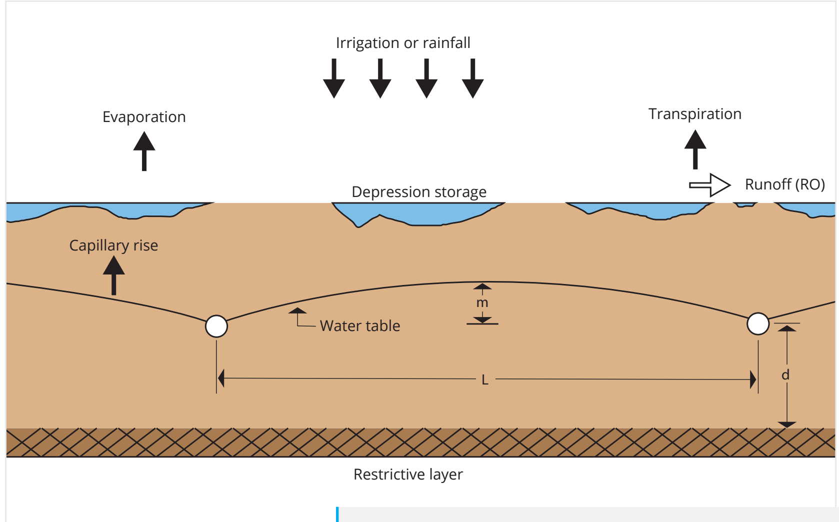

Figure 2. A subsurface drainage system. Plastic draintubes are located a distance (L) apart.

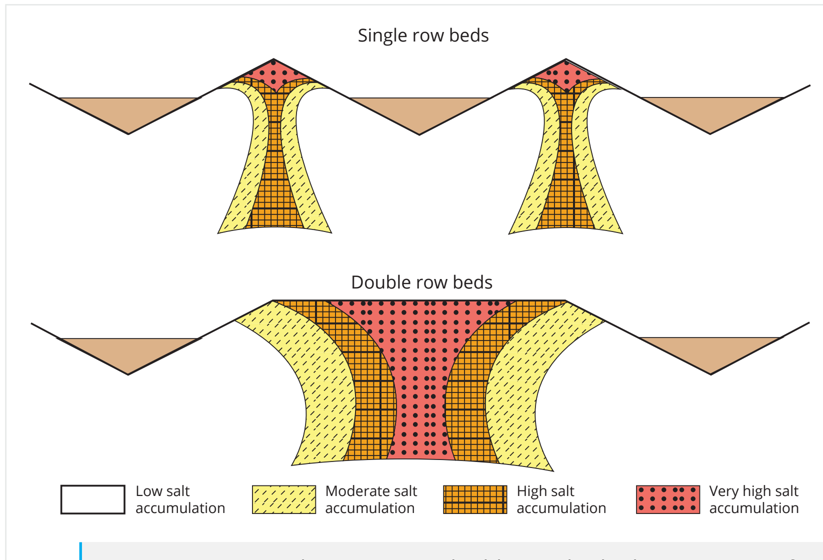

Figure 3a. Single-row versus double-row beds showing areas of salt accumulation following a heavy irrigation with salty water. Best planting position is on the shoulders of the double-row bed.

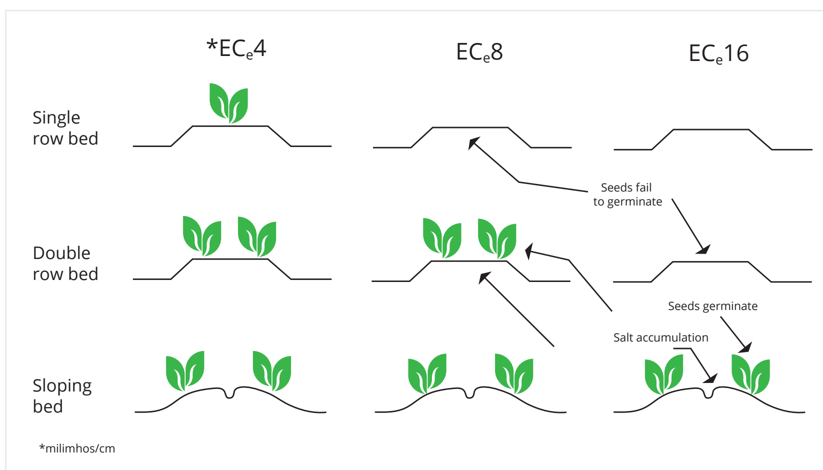

Figure 3b. Pattern of salt build-up as a function of seed placement, bed shape, and irrigation water quality.

micro-sprinklers are shown in Figure 4. Salts tend to move outward and upward, and will accumulate in the areas shown.

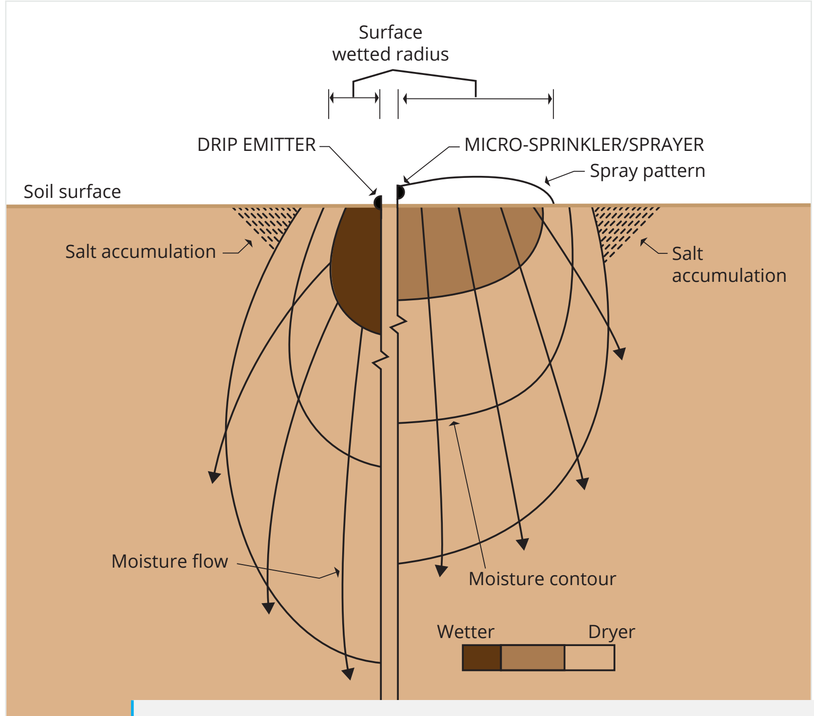

Figure 4. Typical wetting patterns and areas of salt accumulation with drip emitters and micro-sprinklers sprayers.

OTHER SALINITY MANAGEMENT TECHNIQUES

Techniques for controlling salinity that require relatively minor changes are more frequent irrigations, selection of more salt-tolerant crops, additional leaching, pre-plant irrigation, bed forming, and seed placement. Alternatives that require significant changes in management are changing the irrigation method, altering the water supply, land-leveling, modifying the soil profile, and installing subsurface drainage.

Residue Management

The common saying "salt loves bare soils" refers to the fact that exposed soils have higher evaporation rates than those covered by residues. Residues left on the soil surface reduce evaporation. Thus, less salts will accumulate and rainfall will be more effective for leaching.

More Frequent Irrigations

Salt concentrations increase in the soil as water is extracted by the crop. Typically, salt concentrations are lowest following an irrigation and higher just before the next irrigation. Increasing irrigation frequency maintains a more constant moisture content in the soil. Thus, more of the salts are then kept in solution, which aids the leaching process. Surge flow irrigation is often effective at reducing the minimum depth of irrigation, which can be applied with furrow irrigation systems. Therefore, a larger number of irrigations are possible using the same amount of water.

With proper placement, drip irrigation is very effective at flushing salts, and water can be applied almost continuously. Center pivots equipped with LEPA and other close drop spacing water applicators offer similar efficiencies and control as drip irrigation, but is less than half the cost. Both sprinkler and drip provide more control and flexibility in scheduling irrigation than furrow systems.

Pre-plant Irrigation

Salts often accumulate near the soil surface during fallow periods, particularly when water tables are high or when offseason rainfall is below normal. Under these conditions, seed germination and seedling growth can be seriously reduced unless the soil is leached before planting.

Changing Surface Irrigation Method

Surface irrigation methods, such as flood, basin, furrow, and border are usually not sufficiently flexible to permit changes in the frequency of irrigation or depth of water applied per irrigation. For example, with furrow irrigation it may not be possible to reduce the depth of water applied below 3/4 inches. As a result, irrigating more frequently might improve water availability to the crop, but it might also waste water. Converting to ***surge flow irrigation*** may be the solution for many furrow systems. Otherwise, a sprinkler or drip irrigation system may be required.

Chemical Amendments

In sodic soils (or sodium-affected soils), sodium ions have become attached to and adsorbed among the soil particles. This causes a breakdown in soil structure and results in soil sealing (also called cementing), making it difficult for water to infiltrate. Chemical amendments are used to help facilitate the displacement of these sodium ions. Amendments are composed of Sulphur in its elemental form (or related compounds such as sulfuric acid and gypsum). Gypsum also contains calcium, which is an important element in correcting these conditions. Some chemical amendments render the natural calcium in the soil more soluble. As a result, calcium replaces the adsorbed sodium, which helps restore the infiltration capacity of the soil. Polymers are also beginning to be used for treating sodic soils.

It is important to note that the use of amendments does not eliminate the need for leaching. Excess water must still be applied to leach out the displaced sodium. Chemical amendments are only effective on sodium-affected soils. Amendments are ineffective for saline soil conditions and will often increase the existing salinity problem. Table 15 lists the most common amendments. The irrigation books listed under the References section provides equations that are used to determine the amount of amendments needed based on soil analysis results.

Table 15. Various amendments for reclaiming sodic soil and amount equivalent to gypsum.

Amendment	Physical description	Amount equivalent 100% Gypsum
Gypsum*	White mineral	1.0
Sulfur†	Yellow element	0.2
Sulfuric acid*	Corrosive liquid	0.6
Lime sulfur*	Yellow-brown solution	0.8
Calcium carbonate†	White mineral	0.6
Calcium chloride	White salt	0.9
Ferrous sulfate*	Blue-green salt	1.6
Pyrite†	Yellow-black mineral	0.5
Ferric sulfate*	Yellow-brown salt	0.6
Aluminum sulfate*	Corrosive granules	1.3

*Suitable for use as a water or soil amendment.
†Suitable only for soil application.

Pipe Water Delivery Systems Stabilize Salinity

As illustrated in Figure 1, any open water is subject to evaporation, which leads to higher salt concentrations in the water. Evaporation rates from water surfaces often exceed 1/4 inch per day during the summer in Texas. Thus, the salinity content of irrigation water will increase during the entire time water is transported through irrigation canals or stored in reservoirs. Replacing irrigation ditches with pipe systems will help stabilize salinity levels. In addition, pipe systems—including gated pipe and lay-flat tubing—reduce water lost to canal seepage and increases the amount of water available for leaching.

REFERENCES

Ayres, R.S. and D.W. Westcot. 1976. Water Quality for Agriculture. Irrigation and Drainage Paper No. 29. Food and Agriculture Organization of the United Nations. Rome.

Cuena, R.H. 1989. *Irrigation System Design.* Prentice Hall, Englewood Cliffs, NJ. 552pp.

Hoffman, G.S., R.S. Ayers, E.J. Doering and B.L. McNeal. 1980. Salinity in Irrigated Agriculture. In: *Design and Operation of Farm Irrigation Systems.* M.E. Jensen, Editor. ASAE Monograph No. 3. St. Joseph, MI. 829pp.

James, D.W., R.J. Hanks and J.H. Jurinak. 1982. *Modern Irrigated Soils.* John Wiley and Sons, NY.

Jensen, M.E. (Editor). 1980. *Design and Operation of Farm Irrigation Systems.* American Society of Agricultural Engineers, St. Joseph, MI. 829pp.

Longenecker, D.E. and P.J. Lyerly. 1974. B-876 Control of Soluble Salts in Farming and Gardening. Texas Agricultural Experiment Station [Texas A&M AgriLife Extension Service], Texas A&M University System, College Station. June. 36pp.

Pair, C.H. (editor). 1983. *Irrigation.* The Irrigation Assoc., Arlington, VA. 680pp.

Rowe, D.R. and I.M. Abdel-Magid. 1995. *Handbook of Wastewater Reclamation and Reuse.* CRC Press, Inc. 550pp.

Stewart, B.A. and D.R. Nielsen. 1990. *Irrigation of Agricultural Crops.* American Society of Agronomy. 1,218pp.

Tanji, K.K. 1990. *Agricultural Salinity Assessment and Management.* American Society of Civil Engineers. Manuals and Reports on Engineering Practice Number 71. 619pp.

van der Leeden, F., F.L. Troise and D.K. Todd. 1990. *The Water Encyclopedia.* Lewis Publishers. 808pp.