IRRIGATION MANAGEMENT WITH SALINE WATER

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INTRODUCTION

One of the most common water quality concerns for irrigated agriculture is salinity. Recommendations for effective management of irrigation water salinity depend upon local soil properties, climate, and water quality; options of crops and rotations; and irrigation and farm management capabilities.

What Is Salinity?

All major irrigation water sources contain dissolved salts. These salts include a variety of natural occurring dissolved minerals, which can vary with location, time, and water source. Many of these mineral salts are micronutrients, having beneficial effects. However, excessive total salt concentration or excessive levels of some potentially toxic elements can have detrimental effects on plant health and/or soil conditions.

The term “salinity” is used to describe the concentration of (ionic) salt species, generally including: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), carbonate(CO_3^{2-}), sulfate (SO_4^{2-}) and others. Salinity is expressed in terms of electrical conductivity (EC), in units of millimhos per centimeter (mmhos/cm), micromhos per centimeter (μmhos/cm), or deciSiemens per meter (dS/m). The electrical conductivity of a water sample is proportional to the concentration of the dissolved ions in the sample; hence EC is a simple indicator of total salt concentration.

Another term frequently used in describing water quality is Total Dissolved Solids (TDS), which is a measure of the mass concentration of dissolved constituents in water. TDS generally is reported in units of milligrams per liter (mg/l) or parts per million (ppm). Specific salts reported on a laboratory analysis report often are expressed in terms of mg/l or ppm; these represent mass concentration of each component in the water sample. Another term used to express mass concentration is normality; units of normality are milligram equivalents per liter (meq/l). The most common units used in expressing salinity are summarized in Table 1.

Table 1. Units commonly used to express salinity*

<u>Mass Concentration (Total Dissolved Solids):</u> mg/l = milligrams per liter   ppm = parts per million   ppm $\cong$ mg/l
<u>Electrical Conductivity (increases with increasing TDS):</u> conductivity = 1/resistance   (mho = 1/ohm) millimhos/cm = millimhos per centimeter μmhos/cm = micromhos per cm dS/m = deciSiemens per meter 1 dS/M = 1 mmho/cm = 1000 μmho/cm
<u>Salinity Conversions:</u> 0.35 X (EC mmhos/cm) = osmotic pressure in bars 651 X (EC mmhos/cm) = TDS in mg/l* 10 X (EC mmhos/cm) = Normality in meq/l 0.065 X (EC mmhos/cm) = percent salt by weight * Also has been related as: TDS (mg/l) = EC (dS/m) X 640 for EC < 5 dS/m TDS (mg/l) = EC (dS/m) X 800 for EC > 5 dS/m
<u>Normality</u> meq/l = milligram equivalents per liter (*aka* milliequivalents per liter) meq/l = mg/l ÷ equivalent weight equivalent weight = atomic weight ÷ electrical charge Example: To convert 227 ppm calcium concentration to meq/l: ppm = mg/l; therefore 227 ppm = 227 mg/l Calcium atomic weight = 40.078 g/mol valence: +2 (charge = 2) equivalent weight = 40.078 / 2 = 20.04 meq/l = 227 / 20.04 = 11.33 Therefore 227 mg/l = 11.33 meq/l for calcium.
** Compiled from various sources*

Why Is Salinity a Problem?

High salinity in water (or soil solution) causes a high osmotic potential. In simple terms, the salts in solution and in the soil “compete” with the plant for available water. Some salts can have a toxic effect on the plant or can “burn” plant roots and/or foliage. Excessive levels of some minerals may interfere with relative availability and plant uptake of other micronutrients. Soil pH, cation exchange capacity (CEC) and other properties also influence these interactions.

High concentration of sodium in soil can lead to the dispersion of soil aggregates, thereby damaging soil structure and interfering with soil permeability. Hence special consideration of the sodium level or "s*odicity"* in soils is warranted.

How Do You Know if You Have a Salinity Problem?

Water and soil sampling and subsequent analysis are key to determining whether salinity will present a problem for a particular field situation. If wastewater or manure is applied to a field regularly, or if the irrigation water source varies in quality, soil salinity should be monitored regularly for accumulation of salts.

Water quality and soil chemical analyses are necessary to determine which salts are present and the concentrations of these salts. Standard laboratory analyses include total salinity reported as electrical conductivity (EC) or as Total Dissolved Solids (TDS). Salinity indicates the potential risk of damage to plants. General crop tolerances to salinity of irrigation water and soil are listed in Table 2. These values should be considered only as guidelines, since crop management and site specific conditions can affect salinity tolerance.

Table 2. Tolerance* of selected crops to salinity in irrigation water and soil.

Crop	Threshold EC in irrigation water in mmhos/cm or dS/m		Threshold EC in soil (saturated soil extract) in mmhos/cm or dS/m	
	0% yield reduction	50% yield reduction	0% yield reduction	50% yield reduction
Alfalfa	1.3	5.9	2.0	8.8
Barley	5.0	12.0	8.0	18.0
Bermudagrass	4.6	9.8	6.9	14.7
Corn	1.1	3.9	1.7	5.9
Cotton	5.1	12.0	7.7	17.0
Sorghum	2.7	7.2	6.8	11.0
Soybean	3.3	5.0	5.0	7.5
Wheat	4.0	8.7	6.0	13.0
* After Rhoades, et.al. (1992); Fipps (2003) and various sources				

Additional information, including concentrations of specific salt components, indicates the relative risk of sodicity and toxicity. High sodium can present a risk of toxicity to plants. It can also indicate a risk of soil aggregate dispersion, which can result in breakdown of soil structure, and hence reduce the soil's permeability. Relative risk of soil damage due to sodicity is indicated by the Sodium Adsorption Ratio (SAR), which relates the relative concentration of sodium [Na^+] compared to the combined concentrations of calcium [Ca^+] and magnesium [Mg^+]. SAR is calculated by the following equation:

$$SAR = \frac{[Na^+]}{(([Ca^+] + [Mg^+]) / 2)^{1/2}}.$$

MANAGING IRRIGATION TO MITIGATE SALINITY

Minimize Application of Salts

An obvious, if not simple, option to minimize effects of salinity is to minimize irrigation applications and the subsequent accumulation of salts in the field. This can be accomplished through converting to a rain-fed (dryland) production system; maximizing effectiveness of precipitation to reduce the amount of irrigation required; adopting highly efficient irrigation and tillage practices to reduce irrigation applications required; and/or using a higher quality irrigation water source (if available). Since some salts are added through fertilizers or as components (or contaminants) of other soil additives, soil fertility testing is warranted to refine nutrient management programs.

Crop Selection

Some crops and varieties are more tolerant of salinity than others. For instance barley, cotton, rye, and Bermudagrass are classified as salt tolerant (a relative term). Wheat, oats, sorghum, and soybean are classified as moderately salt tolerant. Corn, alfalfa, many clovers, and most vegetables are moderately sensitive to salt. Some relatively salt tolerant crops (such as barley and sugarbeet) are more salt sensitive at emergence and early growth stages than in their later growth stages. Currently crop breeding programs are addressing salt tolerance for several crops, including small grains and forages.

Some field crops are particularly susceptible to particular salts or specific elements or to foliar injury if saline water is applied through sprinkler irrigation methods. Elements of particular concern include sodium (Na), chlorine (Cl), and Boron (B). Tolerances to salinity in soil solution and irrigation water and tolerances to Na, Cl, and B are listed for various crops in references listed in the Additional Information Resources section.

Irrigation Leaching

The classical “textbook” solution to salinity management in the field is through leaching (washing) accumulated salts below the root zone. This is often accomplished by occasional excessive irrigation applications to dissolve, dilute and move the salts. The amount of excess irrigation application required (often referred to as the “leaching fraction”) depends upon the concentrations of salts within the soil and in the water applied to accomplish the leaching. A commonly used equation to estimate leaching fraction requirement (expressed as a percent of irrigation requirement) is:

$$\text{Leaching fraction} = \frac{\text{electrical conductivity of irrigation water}}{\text{permissible electrical conductivity in the soil}} \times 100\ \%$$

Where irrigation water quantity is limited, sufficient water for leaching may not be available. The combined problem of limited water volume and poor water quality can be particularly difficult to manage.

Soil additives and field drainage can be used to facilitate the leaching process. Site specific issues, including soil and water chemistry, soil characteristics and field layout, should be considered in determining the best approach to accomplish effective leaching. For instance, gypsum, sulfur, sulfuric acid, and other sulfur containing compounds, as well as calcium and calcium salts may used to increase the availability of calcium in soil solution to “displace” sodium adsorbed to soil particles and hence facilitate sodium leaching for remediation of sodic soils. In soils with insufficient internal drainage for salt leaching and removal, mechanical drainage (subsurface drain tiles, ditches, etc.) may be necessary.

Irrigation Method Selection

Where foliar damage by salts in irrigation water is a concern, irrigation methods that do not wet plant leaves can be very beneficial. Furrow irrigation, low energy precision application (LEPA) irrigation, surface drip irrigation and subsurface drip irrigation (SDI) methods can be very effective in applying irrigation without leaf wetting. Of course, more advanced irrigation technologies (such as LEPA or SDI) can offer greater achievable irrigation application efficiency and distribution uniformity.

Wetting patterns by different irrigation methods affect patterns of salt accumulation in the seedbed and in the root zone. Evaporation and root uptake of water also affect the salt accumulation patterns. Often the pattern of salt accumulation can be detected by a visible white residue along the side of a furrow, in the bottom of a dry furrow, or on the top of a row. Additional salt accumulations may be located at or near the outer/lower perimeter (outer wetting front) of the irrigated zone in the soil profile.

Seedbed and Field Management Strategies

In some operations, seed placement can be adapted to avoid planting directly into areas of highest salt accumulation. Row spacing and water movement within the soil can affect the amount of water available for seedlings as well as the amount of water required and available for the dilution of salts.

Irrigation Scheduling

Light, frequent irrigation applications can result in a small wetted zone and limited capacity for dilution or leaching of salts. When salt deposits accumulate near the soil surface (due to small irrigation amounts combined with evaporation from the soil surface), crop germination problems and seedling damage are more likely. In arid and semi-arid conditions a smaller wetted zone generally results in a smaller effective root zone; hence the crop is more vulnerable to salt damage and to drought stress injury.

Although excessive deep percolation losses of irrigation are discouraged for their obvious reduction in irrigation efficiency and for their potential to contribute to groundwater contamination, occasional large irrigation applications may be required for leaching of salts. Managing irrigation schedules (amounts and timing) to support a large root zone helps to keep salt accumulations dispersed and away from plant roots, provides for better root uptake of nutrients, and offers improved protection from short-term drought conditions.

Advantages of Organic Matter

Organic matter offers chemical and physical benefits to mitigate effects of salts. Organic matter can contribute to a higher cation exchange capacity (CEC) and therefore lower the exchangeable sodium percentage, thereby helping to mitigate negative effects of sodium. By improving and preserving soil structure and permeability, organic matter helps to support ready movement of water through the soil and maintain higher water holding capacity of the soil. Where feasible, organic mulches also can reduce evaporation from the soil surface, thereby increasing water use efficiency (and possibly lowering irrigation demand). Because some organic mulch materials can contain appreciable salts, sampling and analysis for salt content of these products are recommended.

Special Considerations: SDI maintenance

Some salts, including calcium and magnesium carbonates that contribute to water hardness, merit special consideration for subsurface drip irrigation systems. These salts can precipitate out of solution and contribute to significant clogging of drip emitters and other components (such as filters). Water quality analysis, including acid titration, is necessary to determine appropriate SDI maintenance requirements. Common maintenance practices include periodic acid injection (shock treatment to prevent and/or dissolve precipitates) and continuous acid injection (acid pH maintained to prevent chemical precipitation).

Some excellent references describing water quality considerations and maintenance recommendations for subsurface drip irrigation systems are available from Kansas State University Extension. The publication, “Filtration and

Maintenance Considerations for Subsurface Drip (SDI) Systems" is available at: http://www.oznet.ksu.edu/library/ageng2/mf2361.pdf ; and "Subsurface Drip Irrigation Systems (SDI) Water Quality Assessment Guidelines" can be accessed at: http://www.oznet.ksu.edu/library/ageng2/mf2575.pdf.

ADDITIONAL INFORMATION RESOURCES

Irrigation Salinity Management Information on the Internet

This list of references, though not exhaustive on the subject, has been assembled to aid the reader in accessing additional information on salinity management in agricultural irrigation.

Texas Cooperative Extension and Texas Agricultural Experiment Station
- Irrigation water quality: Critical Salt Levels for Peanuts, Cotton, Corn and Grain Sorghum
  - http://lubbock.tamu.edu/cotton/pdf/irrigwaterqual.pdf
- Irrigation Water Quality Standards and Salinity Management Strategies
  - http://agnews.tamu.edu/drought/DRGHTPAK/SALINITY.HTM
- Irrigation Water Quality Standards and Salinity Management
  - http://itc.tamu.edu/documents/extensionpubs/B-1667.pdf
- What's In My Water?
  - http://itc.tamu.edu/documents/extensionpubs/E-176.pdf
- Maintaining Subsurface Drip Irrigation Systems
  - http://itc.tamu.edu/documents/extensionpubs/L5406.pdf

Kansas State University Research and Extension
- Filtration and Maintenance Considerations for Subsurface Drip (SDI) Systems
  - http://www.oznet.ksu.edu/library/ageng2/mf2361.pdf
- Subsurface Drip Irrigation Systems (SDI) Water Quality Assessment Guidelines
  - http://www.oznet.ksu.edu/library/ageng2/mf2575.pdf

University of Nebraska Cooperative Extension
- Irrigation Water Quality Criteria
  - http://www.ianr.unl.edu/pubs/WATER/g328.htm

Colorado State University Cooperative Extension
- Irrigation Water Quality Criteria
  - http://www.ext.colostate.edu/PUBS/CROPS/00506.html

University of California Agriculture and Natural Resources
- Irrigation Water Salinity and Crop Production
  - http://anrcatalog.ucdavis.edu/pdf/8066.pdf

The University of Arizona Cooperative Extension
- Saline and Sodic Soil Identification and Management for Cotton
  - http://cals.arizona.edu/crops/cotton/soilmgt/saline_sodic_soil.html
  - http://cals.arizona.edu/pubs/crops/az1199.pdf
- Leaching for Maintenance: Determining the Leaching Requirement for Crops
  - http://ag.arizona.edu/pubs/water/az1107.pdf

USDA-ARS George E. Brown, Jr. Salinity Laboratory
Handbook No. 60 Saline and Alkali Soils (out of print, but available online)
http://www.ars.usda.gov/Services/docs.htm?docid=10158
USDA-NRCS National Water and Climate Center
Salinity in Agriculture links
http://www.wcc.nrcs.usda.gov/salinity/
Food and Agriculture Organization (FAO) of the United Nations
The Use of Saline Waters for Crop Production - FAO Irrigation and Drainage Paper 48
http://www.fao.org/docrep/T0667E/T0667E00.htm
Evolution, Extent and Economic Land Classification of Salt Affected Soils
Prognosis of Salinity and Alkalinity - FAO Soils Bulletin 31
http://www.fao.org/docrep/x5870e/x5870e04.htm#TopOfPage
Irrigation with Wastewater
http://www.fao.org/docrep/T0551E/t0551e07.htm

REFERENCES

Fipps, Guy. 2003. Irrigation Water Quality Standards and Salinity Management. Fact Sheet B-1667. Texas Cooperative Extension. The Texas A&M University System, College Station, TX.

Rhoades, J.D., A. Kandiah, and A.M. Mashali. 1992. The Use of Saline Waters for Crop Production. FAO Irrigation and Drainage Paper 48. Food and Agriculture Organization of the United Nations, Rome, 1992.