IC/IR/2001/11
INTERNAL REPORT
(Limited Distribution)

United Nations Educational Scientific and Cultural Organization
and
International Atomic Energy Agency

THE ABDUS SALAM INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

# SALINE WATER IRRIGATION FOR CROP PRODUCTION

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MIRAMARE – TRIESTE
May 2001

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Salinity is one of agriculture's most complex production problems. Excessive salts from irrigation water or high water tables can severely limit crop production. Years of saline water irrigation on poorly drained soils can eventually make economic crop production impossible. About 10 percent of all land are affected by salinity problems. They occur in every continent in different proportions, more frequently in arid and semi-arid areas than in humid and semi-humid areas.

## WHAT IS IRRIGATION?

***Irrigation:*** applying water to assure sufficient soil moisture is available for good plant growth is called "SUPPLEMENTAL IRRIGATION" because it is used to augment the rainfall that occurs during the growing season. Irrigation is used on full season agronomic crops to provide a dependable yield every year. It is also used on crops where water stress affects the quality of the yield, such as flowers, vegetables and fruits.

## IRRIGATION PLANNING

For irrigation planning purposes, the average precipitation during the growing season is not a good yardstick for determining a need for irrigation. The timing and amounts of rainfall during the season, the soil's ability to hold water and the crop's water requirements are all factors that influence the need for irrigation. Any location in the same region can have what might be considered "wet" or "dry" weeks, months and even years.

## SOIL & WATER COMPATIBILITY

Under irrigation, soil and water compatibility is very important. If they are not compatible, the applied irrigation water could have an adverse effect on the chemical and physical properties of the soil. Determining the suitability of land for irrigation requires a thorough evaluation of the soil properties, the topography of the land within the field and the quality of water to be used for irrigation. A basic understanding of soil/water/plant interactions will help irrigators efficiently manage their crops, soils, irrigation systems and water supplies.

## PERMEABILITY CLASSIFICATION FOR IRRIGATION

Permeability of soil is a measure of the ability of air and water to move through it. The size, shape, and continuity of the pore spaces, which in turn are dependent on the soil bulk density, structure and texture, influence permeability. **Soils with a slow, very slow, rapid or very rapid permeability classification are considered poor for irrigation.**

*Soil Permeability Classes*

| **Classification** | **Infiltration rate (inches/hour)** |
|---|---|
| Very Slow | Less than 0.6 |
| Slow | 0.06 to 0.2 |
| Moderately Slow | 0.2 to 0.6 |
| Moderate | 0.6 to 2.0 |
| Moderately Rapid | 2.0 to 6.0 |
| Rapid | 6.0 to 2.0 |
| Very Rapid | Greater than 20.0 |

## WHAT IS SALINITY?

Since water is a very good solvent, all irrigation waters contain some dissolved salts. Salinity (or Salt Load) is best determined by measuring the TDS (total dissolved solids) or EC (electrical conductivity). Electrical conductivity is a reliable index of salt concentration in water. A conductivity of 1dS/m (decisiemens per meter) indicates a salt concentration of approximately 700 ppm (parts per million). This value will vary to some extent with temperature and types of salts. Salinity is also frequently expressed in mg/l (milligrams per liter). The number of mg/l is equivalent to ppm. Decisiemens per meter is the SI unit for conductivity. The common English unit is millimhos per centimeter (mmhos/cm). One dS/m is equal to one mmhos/cm. These measures are used as a guide to the droughting (osmotic) effect of salinity and are not a guide to the toxic effect.

Expressed as - Electrical conductivity (Ecw) and/or Total dissolved solids (TDS)
Units of Ecw – I mS/cm = 1 dS/m = 1mmhos/cm = 1000 micro mhos/cm, S= Siemens
Total dissolved salts: TDS (ppm or mg/L) = Ecw (mmhos/cm) x 640

## HOW SALINITY (OR SALT LOAD) IS MEASURED:

Soil salinity is determined by measuring the electrical conductivity of the soil solution. The saltier the soil solution, the greater its conductivity. Salty water is measured in a similar way.

## WHERE THE SALT COMES FROM:

Water from rivers and wells always contain dissolved salts. When salty water is used for irrigating plants, it is taken up by the plants or evaporates from the soil surface and leaves, but the salts remain. Consequently, repeated light watering without drainage results in considerable salt accumulation in the soil around the roots or on the leaves. The saltier the water, the more salts accumulate. High water tables also contribute to excess salt in the root zone. Evaporation of water from the soil causes ground water to move toward the surface, carrying salts to the top of the soil.

## EFFECTS OF SALINITY ON PLANTS :

Salinity generally causes stunting of plants. All plant parts – leaves, stems, roots, and fruits – are smaller than normal. The higher the salinity, the more the plant is stunted. Salinity also injures plants indirectly because weaker plants may be less able to resist *frost injury, diseases, or insects.*

*Sodium and chloride*, the two elements most common in saline soils, cause specific injury to certain plants. Excess accumulation causes leaf burns, premature leaf drop, or stem dieback. Salt sensitive plants may be killed. **HOW?**

(i) Increasing the concentration of salts dissolved in water makes it harder for the plant to suck water from the soil. This is called the ***OSMOTIC EFFECT*** of salinity and occurs without salts entering the plant. It is similar to the effect that droughting, causes by missing a few irrigation, has on plants.

(ii) All types of soluble salts cause this problem regardless of whether they are potentially toxic or not.

(iii) Some salts enter the plant and cause it to become sick. This effect is known as toxic effect. Plant tissue analysis (petioles) can detect the presence of toxic salts.

(iv) The rate at which toxic salts enter the plant is proportional to the concentration of salt in water around the roots or landing on leaves. Salt enters the plants much more readily through the leaves than the roots.

## HOW THE PROCESS OF OSMOTIC STRESS STARTS?

Irrigation with saline (Salty) water reduces the ability of the plant's roots to take up water. In between irrigation, as the soil moisture decreases the **salts in the soil solution concentrate to between two to five times their initial value in the irrigation water.** This causes an increase in the osmotic pressure of the soil solution, which makes it more difficult for the plant roots to extract water from the soil. Poor growth due to irrigation with saline water is usually due to the osmotic stress caused by the total concentration of salts rather than due to specific ions.

## SPECIFIC ION EFFECT

Excessive concentrations of chloride and sodium ions in irrigation water can cause toxicity in plants. These ions can be taken up either by roots or by direct contact on the leaves. If irrigation water has salinity close to the critical concentration then its chloride and sodium concentration should be tested.

## HOW CHLORIDE EFFECTS THE PLANT?

*The chloride ion can be taken up by plant roots and accumulate in the leaves.* Excessive accumulation may cause burning of leaf tips or margins, bronzing and premature yellowing of the leaves. In general, most woody plant species (stone fruits, citrus) are sensitive to chloride, whereas most vegetable, forage and fibre crops are less sensitive.

## HOW SODIUM EFFECTS THE PLANT?

Sodium in irrigation water can directly damage plants by root uptake. Typical toxicity symptoms are leaf burn, scorch and dead tissues along the outside edges of leaves in contrast to the symptoms of chloride toxicity, which normally occur initially at the extreme leaf tip. High concentrations of sodium in irrigation water can induce calcium and potassium deficiency in soils low in these nutrients. These crops may respond to fertilization with these nutrients.

## GENERAL VISUAL SYMPTOMS OF SALINITY ON CROP:

Crop yields are usually markedly reduced before visual symptoms of salinity damage become apparent. The first sign of salinity damage is usually stunted growth with plant leaves often having a bluish-green colour. As salt levels in the soil increase to more toxic levels scalding or burning on the tip and edges of the older leaves occurs. The leaf dying and falling off and finally death of the plant follow this. In other cases the youngest leaves may appear yellow or the crop may show signs of wilting even though the soil appears adequately moist.

## THRESHOLD LEVEL OR SENSITIVITIES TO SALINITY LEVELS

Salinity restricts the availability of water to plants by lowering water potential in the soil. It also has an impact on crop physiology and yield. Usually, crop yield is independent of salt concentration when salinity is below some threshold level, then yield gradually decreases to zero as the salt concentration increases to the level which cannot be tolerated by a given crop. The more salt tolerant the crop, the higher the threshold level. At salinity levels greater than the threshold, **crop yield reduces linearly as salinity increases**.

Various crops show different sensitivities to different salinity levels. Some crops are much more tolerant than others. Plants are generally divided into four salinity rating groups: sensitive, moderately sensitive, moderately tolerant, and tolerant.

***Threshold and Zero Yield Salinity Levels for Four-Salinity Group*:**

| Salinity Rating | Threshold Level | Zero yield level |
|---|---|---|
| Sensitive | 1.4 | 08.0 |
| Moderately Sensitive | 3.0 | 16.0 |
| Moderately Tolerant | 6.0 | 24.0 |
| Tolerant | 10.0 | 32.0 |

## HOW MUCH SALT IS TOO MUCH?

Decline in crop performance occurs above a certain level of water salinity and is called the ***crop threshold to salinity***. If salinity is only exerting a droughting (osmotic) effect then the threshold problem may begin differently for different crops at different locations also. In Australia, the threshold that is generally applied to potatoes is 704 mg/L TDS. For every 640 mg/L TDS increase above this, the crop loses about 12 per cent of yield.

***Examples of Crops in Four Salinity Rating Groups:***

| Sensitive | Moderately Sensitive | Moderately Tolerant | Tolerant |
|---|---|---|---|
| Almond | Alfafa | Red beet | Sugarbeet |
| Apple | Broccoli | Safflower | Cotton |
| Avocado | Cabbage | Olive | Date palm |
| Bean | Tomato | Soybean | Bermuda grass |
| Carrot | Lettuce | Wheat | |
| Grapefruit | Corn | Ryegrass | |
| Orange | Cucumber | Wheatgrass | |
| Lemon | Grape | Wildrye | |
| Okra | Peanut | | |
| Onion | Potato | | |
| Strawberry | Radish | | |
| Peach | Rice | | |
| Plum | Sugarcane | | |

Source: **Haman, D. Z. (2000). Bulletin 322, Florida Cooperative Ext. Service, Univ. of Florida**

## *Tolerance of Crops to Sodium Concentrations in Irrigation Water*

| **Tolerance** | **SAR of irrigation water** | **Crop** |
|---|---|---|
| Very sensitive | 2-8 | Fruits, nuts, citrus |
| Sensitive | 8-18 | Beans |
| Moderately | 18-46 | Clover, oats, rice tolerant |
| Tolerant | 46-102 | Wheat, barley, tomato, beet, grasses |

**SAR – Sodium adsorption ratio**

## *Specific Minimum and Maximum value of $Ec_e$ for Various crop:*

| | ***$Ec_e$*, dS/m** | | | ***$Ec_e$*, dS/m** | |
|---|---|---|---|---|---|
| Crop | Min[1] | Max[2] | Crop | Min[1] | Max[2] |
| | | | **FIELD CROPS** | | |
| Cotton | 7.7 | 27 | Corn | 1.7 | 10 |
| Sugar beet | 7.0 | 24 | Flax | 1.7 | 10 |
| Sorghum | 6.8 | 13 | Broadbean | 1.5 | 12 |
| Soybean | 5.0 | 10 | Cowpeas | 1.3 | 8.5 |
| Sugarcane | 1.7 | 19 | Beans | 1.0 | 6.5 |
| | | | **FRUIT AND NUT CROPS** | | |
| Date palm | 4.0 | 32 | Apricot | 1.6 | 06 |
| Fig, Olive | 2.7 | 14 | Grape | 1.5 | 12 |
| Pomegranate | 2.7 | 14 | Boysenberry | 1.5 | 06 |
| Grapefruit | 1.8 | 08 | Avocado | 1.3 | 06 |
| Orange | 1.7 | 08 | Blackberry | 1.5 | 06 |
| Lemon | 1.7 | 08 | Almond | 1.5 | 07 |
| Apple, pear | 1.7 | 08 | Raspberry | 1.0 | 5.5 |
| Peach | 1.7 | 08 | Strawberry | 1.0 | 04 |
| | | | **VEGETABLE CROPS** | | |
| Potato | 1.7 | 10 | Turnip | 0.9 | 12 |
| Broccoli | 2.8 | 13.5 | Sweetpotato | 1.5 | 10.5 |
| Tomato | 2.5 | 12.5 | Lettuce | 1.3 | 08 |
| Cucumber | 2.5 | 10 | Onion | 1.2 | 7.5 |
| Spinach | 2.0 | 15 | Carrot | 1.0 | 08 |
| Cabbage | 1.8 | 12 | Beans | 1.0 | 6.5 |

***$Ec_e$*** - *Estimated electrical conductivity of the average saturation extract in the soil root zone profile for an appropriate yield reduction,* (dS/m),
*This also corresponds to the threshold salinity for given sensitivity group presented in earlier table (if no yield reduction is desired).*

1. Minimum ***$Ec_e$*** does not reduce yield
2. Maximum ***$Ec_e$*** reduces yield to zero
3. ***Source: Haman, D. Z. (2000). Bulletin 322, Florida Cooperative Ext. Service, Univ. of Florida***

## FACTORS AFFECTING THE EXTENT OF PLANT DAMAGE

The extent of yield loss of plants when irrigated with water of a given salinity depends on a number of factors including:

### *(1) Soil type and drainage*

Saline (salty) water can be used more successfully on well drained, sandy soils than on a poorly drained, heavy soil. The key to successfully irrigate with saline water is to get net downward movement or leaching of salts from the root zone. In well drained, sandy soil irrigation water can readily flush salts out of the root zone. How much leaching is required to maintain acceptable growth depends on:

(a) Salt content of irrigation water
(b) Salt tolerance of the crop
(c) Climatic conditions
(d) Soil type
(e) Water management

The amount of additional water required to leach salt from the root zone is called **leaching fraction.** Many research data show that, for many crops, salinisation of a part of the root zone does not significantly affect yield provided a portion of the root zone remains non-saline.

### *(2) Frequency and timing of irrigation*

(a) Salt concentration in the root zone continually changes following irrigation. As the soil dries out the salt concentration in the soil solution increases reducing moisture availability to the plant.
(b) Frequent, light irrigation increases the salt concentrations in the topsoil and should be avoided.
(c) Heavy irrigation can be used to remove salts from within the root zone.
(d) Watering during hot, windy conditions will increase evaporation and therefore increase the concentration of salt.

### *(3) Stage of growth*

Plants are generally more susceptible to salinity damage during **germination** and at the **seedling stage** than when established. This may be due to both increased sensitivity at this growth stage and localised high salinity concentrations within the seedlings' shallow root zone.

### *(4) Rootstocks and varieties*

Rootstock and variety differences are an important factor affecting salt tolerances of tree and vine crops. Varieties and rootstocks of citrus, grapes and fruits have different abilities to absorb and transport sodium and chloride and hence have different salinity tolerances.

***(5) Method of irrigation***

Soil salinity profiles differ markedly among various methods of irrigation because of differences in water distribution.

(a) **Drip** irrigation allows water with higher salt content to be used than other forms of irrigation, as evaporation losses are minimal. Drip irrigation is applied frequently which reduces salinity concentration in the root zone, and , in addition the increase in salinity is due to evaporation in soil surface and is considerably low.

(b) In addition, drip irrigation can reduce the effects of salinity by maintaining a continuously moist soil around the plant roots and by providing steady leaching of salt to the edge of the wetted zone.

(c) Under **Furrow irrigation**, salts accumulate near the crests of the ridges.

(d) **Sprinkler** irrigated crops are potentially subjected to additional damage caused by foliar salt uptake.

***(6) Climate***

Hot, dry conditions increase evaporation thus concentrating the salts. Under such conditions crops are more prone to damage. In regions experiencing heavy seasonal rainfall, salts that have accumulated in the soil are washed past the root zone reducing the effect of salinity.

## SPRINKLER IRRIGATION WITH SALTY WATER:

Sprinkler-irrigated crops are subjected to additional salt damage when wet by saline saline (salty) water than would otherwise occur if irrigated by methods that does not wet the foliage, such as drip or furrow. Crops that are wet by sprinkler irrigation can absorb salt directly through its leaves to levels where it becomes toxic and injury occurs. Since crops sprinkled with saline water are also exposed to soil salinity, reductions caused by saline irrigation water will be at least as great as those for surface irrigated crops. Some crops, which are not sensitive to root uptake of chloride or sodium ions, develop symptoms of leaf burn when sprinkled with saline water. Salt damage caused in this way only scalds or kills the leaves, which receive the salt water.

***LEAF INJURY***

Leaf Injury is related to the concentration of salt in the leaves, but weather conditions and water stress can affect the degree of injury and when it will actually occur. For example – leaves may contain potentially toxic levels of salts (primarily as sodium and chloride) for several weeks and show no injury until the first hot, dry day. Consequently, there are no practical guidelines for predicting leaf injury based on salt concentration in leaves. Leaves that are injured by saline sprinkler irrigation have characteristic injury symptoms.

Older leaves are most affected because they have had a longer time to accumulate salt to toxic levels. Injury begins as chlorosis, yellowing at the tips and along the edges of the older leaves. As injury becomes more severe, necrosis (burning) begins to appear and advances inward towards the midrib of the leaf.

## ***LEAVES SUSCEPTABLE TO SALT INJURY***

Susceptibility to injury is not related to a crop's tolerance to the salinity in the soil. Rather, plants whose leaves are more "**wettable**" such as pepper, potato and tomato tend to be more sensitive than those plants with leaves that do not readily wet. For example, some plants have ***waxy leaves*** **such as cauliflower and sugar beet.** Irrigation water readily runs off the leaf surface. Such leaves are not susceptible to injury under most instances. However, necrotic spots can develop where the sprinkler water remained in depressions on the leaf's surface for extended periods after irrigation.

### ***Foliar Damage through Sprinkler Due to Chloride and Sodium Concentrations in Irrigation Water:***

| **Sensitivity** | **Chloride (mg/L)** | **Sodium (mg/L)** | **Affected Crops** |
|---|---|---|---|
| Sensitive | < 178 | < 114 | Almond, plum, apricot, citrus |
| Moderately sensitive | 178 - 355 | 114 – 229 | Grapes, Tomato, pepper, Potato |
| Moderately tolerant | 355 - 710 | 229 – 458 | Alfafa, Barley, cucumber, Corn |
| Tolerant | > 710 | > 458 | Cauliflower, cotton, sesame, sorghum, sunflower, safflower Sugarbeets |

### ***Practical Strategies to Avoid Leaf Injury Due to Sprinkler Irrigation***

1. Increase the application rate and reduce the frequency of irrigation – provided soil infiltration rate is not exceeded.
   ***Reason:***
   Plants are more susceptible to the number of irrigation rather than the duration of irrigation.
2. Irrigate at night, early in the morning or late in the evening. If not practical then in the cooler, more humid part of the day.
   ***Reason:***
   (i) Watering in the heat of the day concentrates the salts, due to high evaporation.

(ii) Evaporation is less and leaves absorb salt at a slower rate.
(iii) This also affects leaf disease control strategies.

3. Avoid sprinkling during hot, dry periods.

***Reason:***

(i) This weather is conducive to wetting/drying cycles.
(ii) Salt injury is more severe during hot, dry weather.
(iii) High temperatures intensify leaf-burn caused by sodium or chloride.
(iv) Salts also accumulate faster in the soil during hot weather because water loss from the soils through plant use and evaporation is greatest then.
(v) Irrigation may not be enough to leach salts from the root zone.

4. Avoid slow, rotating sprinklers that allow drying between cycles.

***Reason:***

(i) Plants are more susceptible to frequent irrigation with saline water.

5. Move sprinklers downwind to avoid problems associated with salt drift.

***Reason:***

(i)Dry salt can be deposited on leaf surfaces downwind from sprinkler drift. Leaves can absorb this salt during early morning hours when dew forms or when humidity is high.
(ii)Moving sprinklers downwind will wash off previously deposited salts.

6. If a small amount of good quality water is also available, use this water for short (five minutes) before-and-after irrigation.

***Reason:***

(i)Short before-and-after irrigation with good quality water reduces salt accumulation and substantially minimizes yield loss from saline sprinkler irrigation.

7. Irrigate during periods when wind speed is low and use sprinklers, which produce larger droplets – both changes reduce wind drift.
8. Avoid adding other sources of chloride to the crop. For instance use a potassium source rather than muriate of potash.
9. Favour early maturing varieties – most of their growth occurs whilst weather is temperate and moist and they accumulate less chloride over shorter season.
10. If more than one source of water is available, use the least saline for long season varieties.

**TYPES OF SALT PROBLEMS:**

There are three major types of salt problems;

(a) Salinity
(b) Sodicity
(c) Toxicity

***(a) Salinity:***

Salinity refers to the total concentration of dissolved salts in the soil or water. Salinity causes reduced crop growth and yield loss because the plant must redirect energy from growing to extracting pure water from saline (salty) water in its root zone. This additional energy expenditure is called osmotic stress. It is similar in impact to drought stress. Salt mixtures normally found in agriculture include chloride, sulfate and bicarbonate compounds of sodium, calcium and magnesium. Salts in the soil water become more concentrated as evaporation and transpiration occur leaving all the salts behind.

***(b) Sodicity:***

Sodicity, is the presence of excess sodium, it deteriorates soil structure and reduces water penetration into and through the soil. Like drought and salinity, excess proportions of sodium, in comparison to calcium and magnesium, reduce water availability to the crop. The term, sodicity, has replaced the term "alkali" when referring to the effects of excess sodium in soil. Excessive sodium causes soil mineral particles to disperse and water penetration to decrease. High sodium concentrations become a problem when the infiltration rate is reduced to the extent that the crop is not adequately supplied with water or when the hydraulic conductivity of the soil profile is too low to provide adequate drainage. Excess sodium may add to cropping difficulties through crusting seed beds, temporary saturation of the surface soil, high pH and the increased potential for disease, weeds, soil erosion, lack of oxygen and inadequate nutrient availability.

If calcium and magnesium are the predominant cations adsorbed on the soil exchange complex, the soil tends to be easily tilled and have a readily permeable granular structure. Sodium-adsorption- ratio (SAR) of irrigation water is generally a good indicator of the sodium status that will occur in the soil. SAR is defined as:

$$SAR = [C_{Na}] \div [(C_{Ca} + C_{Mg})\ 1/2]$$

where, all ion concentrations ( C ) are in $mol/m^3$ . Na, Ca, and Mg refer to sodium, calcium and magnesium.

***(c) Toxicity***

Toxicity refers to specific salt constituents, such as chloride, boron, sodium and some trace elements, which are toxic to certain crops at relatively low concentrations. Trees and other woody crops are frequently sensitive to these potentially toxic elements.

***Response of Crops***

The response of crops to salinity, sodicity and toxicity varies widely among plant species. The relationship between crop yield and soil salinity has been quantified for many crops under typical growing conditions. The precise relationship, however, depends on a number of soil, crop and environmental factors. Sodicity typically reduces infiltration, which leads to reduced crop yields. Crops can also be sensitive to specific solutes, like chloride and boron. With proper crop selection and appropriate irrigation management, economic yields can be sustained under low to moderate saline conditions.

## EFFECTS OF SALT ON CROP QUALITY

Soil salinity caused either by saline irrigation water or inbuilt salts in the soil may cause detrimental effects on yield and quality of the crop. Few findings are reported here.

- Increased salinity level reduced the fruit size of melons. However, ripening was accelerated.
- Grapefruit yield decreased with the increase of chloride ion concentration. Yield reduction was due to the reduction of fruit in size and weight but there was no difference in juice content.
- Water is safe for potatoes at salinities below 700 mg/L TDS (700 ppm) in Australia.
- A reduction in the seed size of peanut was reported at the soil salinity levels of 3 dS/m. However, there is an increase in seedoil content with increasing salinity upto a point.

## CRITERIA AND STANDARDS FOR ASSESSING SUITABILITY OF SALINE WATER FOR IRRIGATION

The suitability of water for irrigation should be evaluated on the basis of criteria indicative of its potential to create soil conditions hazardous to crop growth (or to animals/humans consuming those crops). Relevant criteria for judging irrigation water quality in terms of potential hazards to crop growth are Primarily:

- ***Permeability and Tilth***

The interactive, harmful effects of excessive exchangeable sodium and high pH in the soil and low electrolyte concentration in the infiltrating water on soil structure, permeability and tilth. These effects are evidenced by disaggregation, crusting, poor tilth (coarse, cloddy and compacted topsoil aggregates) and by a reduced rate of water infiltration.

- ***Salinity***

The general effect of salts on crop transpiration and growth which are thought to be largely osmotic in nature and, hence, related to total salt concentration rather than to the individual concentrations of specific salt constituents. These effects are generally evidenced by reduced transpiration and proportionally retarded growth, producing smaller plants with fewer and smaller leaves.

- ***Toxicity and nutritional imbalance***

The effects of specific solutes, or their proportions, on plant growth, especially those of chloride, sodium and boron. These effects are generally evidenced by leaf burn and defoliation.

- ***Suitability of saline water***

The suitability of the water for irrigation is evaluated in terms of the permeability and crusting hazards using $EC_{iw}$ and estimates of the SAR that will result in the topsoil and permissible limits of SAR.

- SAR and pH are important properties of soil, which influence the soil permeability and tilth. Therefore, any suitable evaluation of the potential permeability hazard of a sodic, saline irrigation water must relate some property of the irrigation water to the SAR (ideally, also pH) that will result in the soil from use of that water. Surface soil SAR values are of most concern for assessing soil permeability problems, because water intake and transmissibility are most generally limited by surface soil properties. The surface soil SAR level resulting from irrigation is more easily predicted at deeper root levels because it is essentially independent of leaching fraction.

- The assessment of the suitability of saline water for irrigation must consider;

**(i)** What level of salinity will result in the soil water considering the initial levels, the amount and salinity of the applied water, resultant chemical reactions and leaching.
**(ii)** How much salinity (and potentially toxic solute concentrations) the crop can tolerate in the soil water.

## HOW SALINE (SALTY) WATER CAN BE USED?

Saline (Salty) water or water which is generally classified as having too much dissolved salt for irrigation, can often be used successfully without hazardous long-term effects on the crops or soils. However, certain conditions need to be met:

- The soil being irrigated must be well drained.
- Salt tolerant crops should be the primary crops grown.
- Rotations should be planned to provide for a sequence of progressively more salt tolerant crops.
- Salt should be leached out of the soil in the spring or winter.
- As the salinity of either the irrigation water or soil solution increases (with prolonged crop water use and through the irrigation season), the volume of irrigation water applied should be progressively increased.
- Adoption of new crop and water management strategies can further facilitate the use of saline water for irrigation.
- To substitute more saline water (later in the irrigation season) for good quality water to irrigate certain crops in the rotation or well-drained soils. Whatever salt buildup might occur in the soil from irrigating with salty water, can be reduced in the following winter or spring from rainfall or irrigation with low-salinity irrigation water.
- Soils do not usually become excessively saline from the use of saline water in a single irrigation season. It may even take several irrigation seasons to affect the level of salt

in the soil solution. The maximum soil salinity in the root zone that results from continuous irrigation with saline water does not occur when salty water is used only in a fraction of the time.

## PROTECT SENSITIVE PLANTS FROM SALTY WATER

- Plant sensitive plants where salty irrigation water cannot drift or splash onto the plants.
- Design protective screens to prevent salt sprays from contacting sensitive plants.
- Irrigate at night or humid atmosphere to reduce transpiration of water from leaves.
- Irrigate with low pressure, low profile systems to ensure adequate irrigation without foliar contact.

## CONFIRMING SALT INJURY

Suspected salt damage to plants must be confirmed before trying to correct it.

Leaf burn and stunting are likely symptoms of a salinity problem but may also be caused by drought. To determine if the damage is caused by salinity, have soil and irrigation water tested.

***Representative yield reduction (percent) due to irrigation water salinity in Hissar, India***

| **Crop** | **Water Salinity (tubewell), EC, dS/m** | | |
|---|---|---|---|
| | **2-4** | **4-6** | **6-8** |
| Cotton | 100 | 70 | 55 |
| Millet | 100 | 79 | 52 |
| Wheat | 100 | 89 | 60 |
| Mustard | 100 | 86 | 67 |
| Average | 100 | 81 | 59 |

## NATURE AND CAUSES OF ENVIRONMENTAL PROBLEMS

**"*SUSTAINABILE AGRICULTURE* is the management and conservation of a natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development in agriculture, forestry and fisheries sectors, conserved land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (FAO, 1989).**

## SOIL DEGRADATION (Salinization and Water logging)

Large and increasing proportions of the world's irrigated land are affected by water logging and excessive salinity. While the exact area affected with this problem is not known, it is estimated that approximately 25 percent of the world's irrigated land is damaged by salinization. Some claim that upto 50 percent of the world's irrigated land may be affected by salt. Serious salt related problems occur within the boundaries of at least 75 countries. Countries with notable salinity problems include Australia, China, Mexico, Russia, USA, India, Pakistan, Egypt, etc.

## SHALLOW GROUND WATER AND POOR (RESTRICTED) DRAINAGE

A close relationship exists between the depth and salinity of shallow ground waters, the soil hydraulic properties and the extent of salt accumulation in soils. This problem in common in semi-arid and arid and relatively low lying and poorly drained lands. This is the result of mobilization of large quantities of salts by excessive irrigation and leaching and the subsequent accumulation of the salt in localized areas due to restricted drainage. Such areas are often found in low lying regions of the landscape where the water table is at or near the soil surface, and where the salts have ascended into the soil due to evaporation driven processes.

Restricted drainage may be due to low permeability of the fine textured soils or to the presence of a shallow groundwater. Shallow ground waters are often related to topographic position. The drainage of waters from the higher elevation regions of valleys and basins may raise the water table in the lower-lying lands so that it is close (within 2 m) to the soil surface.

Permeability of the soils is typically lower in these basin positions *because* of a higher content of alluvial clays generally found in basin soils, which impede the downward movement of water and result in poor drainage. Infiltrated water into the soil (excess of water that is used by the agricultural crops) passes beyond the root zone. This water often *dissolves salts* of geologic origin from the soils in sub-strata and causes water logging in lower areas where it accumulates. When this occurs, soluble salts present in the ground are *mobilized* and *transported* to the lower areas where they accumulate and *over the time* salinize the ground water and soil in the areas where the water tables approach ground level.

## SECONDARY SALINIZATION

While salt affected soils occur extensively under natural conditions, *the salt problems of greatest importance to agriculture arise* when previously productive cultivated soil becomes salinized as a result of irrigation *(Secondary Salinization)*. Human activities have modified (increased) the extent of salt affected areas considerably by redistribution of water (hence salt) through irrigation. The development of large scale irrigation projects, which involves:

(a) diversions of rivers,
(b) construction of large reservoirs and
(c) irrigation of large landscapes

causes large changes in the natural water and salt balances of entire hydro-geological systems. The impact of irrigation often extends well beyond that of the immediate irrigated area; even neighbouring nations can be affected.

## SECONDARY SALINIZATION DUE TO FAULTY DRAINAGE

The problems of ***water logging*** and ***secondary salinity*** prevalent in most irrigated lands ***due to :***

(1) Excessive use of water for irrigation *resulting from*:
  (a) inefficient irrigation systems,
  (b) poor distribution systems and
  (c)poor on-farm management practices
(2) From inadequate and inappropriate drainage management
(3) From the discharge of "spent" drainage water into good quality water supplies which are used elsewhere for crop production.
(4) Generally less than 60 percent water diverted for irrigation is used for crop transpiration.
(5) To prevent water logging and secondary salination, **drainage *must remove*** the precipitation and irrigation water infiltrated into the soil that is in excess of crop demand and any other excessive water.

## WATER POLLUTION

The role of irrigated agriculture in soil salinization has been well recognized. However, it is of relatively recent recognition that salinization of water resources from agricultural activities is a major and widespread phenomenon of possibly even greater concern to the sustainability of irrigation than that of the salinization of soils, per se.

Only in the past few years, it has become apparent that *trace toxic constituents*, such as arsenic etc., in agricultural drainage water may cause pollution a problem that threatens the continuation of irrigation in some projects.

## LEACHING REQUIREMENT AND MAINTAINING SALT BALANCE

To prevent the excessive accumulation of salt in the root zone from irrigation, extra water (or rainfall) must, over a long term, be applied in excess of that needed for Evapo-transpiration (ET) and must pass through the root zone in a minimum net amount. This amount, in fractional terms, is referred to as *the "Leaching Requirement"*. In short we may say, that the fraction of infiltrated water that must pass through the root zone to keep salinity within acceptable levels.

In fields irrigated to steady-state conditions with conventional irrigation management, the salt concentration of the soil water is essentially uniform near the soil surface regardless of the Leaching Fraction but increases with the depth as leaching fraction decreases. *Leaching Fraction is the fraction of infiltrated water that actually passes through the root zone.* Likewise, average root zone salinity increases as leaching fraction decreases. Under such circumstances, *crop yield* is decreased when tolerable levels of salinity are exceeded. Once the soil solution has reached the maximum salinity level compatible with the cropping system, at least as much salt as brought in with additional irrigation must be removed from the root zone; a process which is called , "Maintaining Salt Balance"

## REDUCING SOIL SALINITY

Reduce soil salinity to a level that plants can tolerate by heavy irrigation. This leaches the salts into the soil below the root zone.

***Important Point to remember*:**

The salinity of the water in the soil ***can never be less*** than the salinity of the irrigation water. After the soil salinity has been reduced to a tolerable level, continue to apply extra water periodically to prevent a new buildup of salt. The saltier the irrigation water and the more salt sensitive the plants, the more water is needed for irrigation. Heavy irrigating may be a problem ***because*** too much water is as harmful to the plant as the soil salinity. This is particularly a problem with poorly drained soils.

## STRATEGIES FOR PROTECTING PLANTS FROM SALT DAMAGE

Salts of various kinds occur naturally in soil and water. Many are essential to plant growth. Soil or water containing an over abundance of salt can damage plants. In saline conditions, soil water availability to the crop and protecting it from salt damage, can be accomplished through several strategies such as:

- Confirm that damage is from salinity and not from some other source.
- Leaching salts from the soil profile with enough water periodically to prevent salt accumulation.
- Maintaining high soil water content in the root zone.
- Select more salt tolerant plants.
- Avoid light, frequent sprinkling particularly during the hot part of the day.
- Improve drainage in the field.
- Changing irrigation method.
- Adjusting planting practices in some cropping system.

- Plants can withstand salinity better when healthy – water and fertilize adequately and control pests.

## IRRIGATION WATER QUALITY

The quality of some water is not suitable for irrigating crops. Irrigation water must be compatible with both crops and soils to which it will be applied. The quality of water for irrigation purposes is determined by its salt content. An analysis of water for irrigation should include cations: calcium, magnesium and sodium, and anions: bicarbonate, carbonate, sulfate and chloride. Some crops are sensitive to boron, so it is often included in the analysis.

***Classification of Irrigation Salinity***

| **Salinity class** | **Electrical conductivity, dS/m** | **Potential injury and necessary management** |
|---|---|---|
| Low | < 0.25 | No damage or additional management needed |
| Medium | 0.25 – 0.75 | Damage to salt sensitive plants will occur. Use of low salinity water may be required occasionally |
| High | 0.75 – 2.25 | Damage to plants with low tolerance to salinity will likely occur. Plant growth and quality will be improved with excess irrigation for leaching and/or periodic use low salinity water |
| Very High | > 2.25 | Damage to plants with high tolerance to salinity may occur. Successful use as an irrigation source requires salt tolerance plants, good soil drainage, excess irrigation for leaching, and/or periodic utilization of low salinity water |

## IRRIGATION WATER CLASSIFICATION

Two most important factors to look for in an irrigation water quality analysis are the **Total Dissolved Solids *(TDS)*** and the **Sodium Adsorption Ratio *(SAR)*.** The TDS of a water sample is a measure of the concentration of soluble salts in a water sample and is commonly referred to as the **salinity of the water**.

TDS is expressed in terms of the electrical conductivity (EC) and its units are either:
***Millimhos per centimeter (mmhos/cm),***
***deci-Siemens per meter (dS/m)*** or ***Micromhos per centimeter (mmhos/cm)***
***where: 1000 mmhos/cm = 1mmho/cm = 1dS/m***

The SAR of a water sample is proportional of sodium relative to calcium and magnesium. Since it is a ratio, the SAR has no units.

**Any water with EC greater than 2000 mmhos/cm or SAR value greater than 6 are *not recommended* for continuous irrigation.**

**REMEDY/IMPROVEMENT:**

Calcium added to irrigation water can lower the SAR and reduce the harmful effects of sodium. The effectiveness of added calcium depends on its solubility in the irrigation water. Calcium solubility is controlled by both the source of the calcium (eg. Calcium carbonate, Gypsum, Calcium chloride) and also the concentration of other ions in the irrigation water. Compared to calcium carbonate and gypsum, calcium chloride additions will result in higher concentrations of soluble calcium and will be the most effective at lowering irrigation water SAR. However, calcium chloride is considered more expensive that calcium carbonate and calcium sulfate (gypsum).

## EFFECT & REMEDY OF CARBONATES

Carbonates and bicarbonate ions in the water combine with calcium and magnesium to form compounds, which precipitate out of solution. Removing calcium and magnesium increase the sodium hazard to the soil from irrigation water. The increased sodium hazard is often expressed as "adjusted SAR". The increase of "adjusted SAR" over the SAR is a relative indication of the increase in sodium hazard due to the presence of these ions.

**Remedy/improvement:**

Precipitation of carbonate minerals plugs the drip irrigation systems. To control this problem, the *pH of the irrigation water is generally lowered by adding a mild acid.*

## SALINITY CLASSIFICATION

**C 1 – Low Salinity Water:**
*Can be used* for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of slow and very slow permeability.

**C 2 – Medium Salinity Water:**

Can be used if a moderate amount of leaching occurs. In most cases plants with moderate salt tolerance can be grown without special practices for salinity control.

**C 3 – High Salinity Water:**

Cannot be used on soils with moderately slow to very slow permeability. Even with adequate permeability, special management for salinity control may be required and plants with salt tolerance should be selected.

### C 4 – Very High Salinity Water:

Cannot be used for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soil must have rapid permeability, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt tolerant crops should be selected.

## SODIUM CLASSIFICATION

### S 1 – Low Sodium Water:

Can be used for irrigation on almost all soils with little danger of development of harmful levels of exchangeable sodium.

### S 2 – Medium Sodium Water:

Can be used on coarse textured soils with moderately rapid to very rapid permeability because of appreciable sodium hazard in fine textured soils especially under low leaching conditions.

### S 3 – High Sodium Water:

Cannot be used for irrigation because it produces harmful levels of exchangeable sodium in most soils and requires special soil management, good drainage, high leaching, and high organic matter additions.

### S 4 – Very High Sodium Water:

Cannot be used for irrigation because it is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity.

### BORON:

Boron concentration greater than 2 ppm may be a problem for sensitive crops, especially in years that require large quantities of irrigation water.

## SALINITY CONTROL

In arid and semi-arid climates, irrigation must supply all water requirements of the crop for the growing season. Additional water must be applied to remove the salts from the root zone in order to avoid a build-up of salts, which will exceed the threshold level for a given crop and result in yield reduction.

## (1) Leaching Salts from the Root Zone

To prevent salts from increasing to levels detrimental to crop production, water must drain through the crop root zone. In most instances, natural drainage is sufficient to leach salts from the crop root zone. If natural drainage is not adequate, however, a drainage system must be installed. Where salinity is a hazard, the length of time before productivity is reduced depends on water management drainage and the area's hydro-geology.

The moisture holding capacity of the soil is an indicator on how much water is needed to leach salts from the root zone. The use of soil amendments, such as gypsum, should be considered in conjunction with leaching irrigation application in saline-sodic soils. However, if drainage is not a problem, the use of soil amendments should be avoided since they add to the salinity of the soil.

## (2) Blending & Cycling

Non-saline water can be used to dilute the saline water prior to application. This technique is referred to as mixing or **blending**. Alternatively, the non-saline water can be used intermittently to leach deleterious levels of salts from the soil profile. The intermittent use of non-saline water to augment saline water is termed **cycling.**

### How to do blending?

High salinity water that is unacceptable for use can be made suitable as an irrigation source by diluting with non-saline water. Enough non-saline water must be available to create a mixed water of acceptable quality, i.e. do not end up making a less saline water that is still unacceptable.

Mixing of irrigation sources can occur in irrigation ponds or within the irrigation system itself. When mixing water sources in irrigation ponds, the non-saline water should be added immediately prior to being used so as to reduce evaporative losses. Evaporation of surface water is not only an inefficient use of water; it also increases the salinity of the water remaining in the pond.

## (3) Sodium Hazard

Irrigation water high in sodium and low in calcium and magnesium can deteriorate soil structure. A measure of the sodium hazard of irrigation water is termed the sodium adsorption ratio (SAR). High SAR irrigation water can have adequate infiltration rates if salinity is also high, but when salinity is low, the level of SAR that reduces infiltration rate is much lower than at high salinity. Adding salt (usually gypsum) to water with high SAR is one method of increasing the suitability of the water. Mixing high SAR water with water low in EC and calcium does not reduce the sodium hazard of the mixture appreciably.

*Sodium hazard of irrigation water*

| SAR value | Sodium level | Problem situations |
|---|---|---|
| 0 - 10 | Low | None |
| 10 - 18 | Medium | Problems on fine textured soils with poor leaching |
| 18 - 24 | High | Problems on most soils. GYPSUM additions needed |
| > 24 | Very High | Unsatisfactory unless low salinity, high Ca, and gypsum required |

## (4) Effects of High SAR on Soil Properties

Exchangeable sodium percentage (ESP) is an indicator of the potential for disruption of soil physical properties. When sodium is high in relation to calcium and magnesium, the soil clay and organic matter particles disperse and fill the soil pores. Air and water movement through the soil can be drastically reduced. This results in a waterlogged condition and low soil oxygen. Potassium also disperses clays and organic matter, but levels of K in soils are usually ignored because they are relatively low in comparision to Na in Na-affected Soils. Reduction in permeability will occur when ESP > 15 percent.

The amount of gypsum required to decrease the ESP is dependent on the initial ESP and the texture of the soil. The objective of adding gypsum is to lower the ESP value to below 10 percent. Rates should not exceed 5 tons per acre per application. Light frequent applications are more effective than heavy infrequent applications.

*Approximate rate of pure gypsum needed on high ESP soils*

| Soil Texture | Exchangeable Sodium Percentage (ESP) | | | | |
|---|---|---|---|---|---|
| | 15 | 20 | 30 | 40 | 50 |
| | Gypsum Required (tons/acre) | | | | |
| Coarse | 2 | 3 | 5 | 7 | 9 |
| Medium | 3 | 5 | 8 | 11 | 14 |
| Fine | 4 | 6 | 10 | 14 | 18 |

## (5) Carbonate and High Soil pH

Bicarbonate ($HCO_3^-$) and carbonate ($CO_3^-$) increase soil pH >8 and cause precipitation of calcium and magnesium carbonates. Sodium then becomes the dominant ion in the soil and problems with water infiltration and low oxygen can occur. Continued use of high bicarbonate water leads to high soil pH. When Na is predominant cation in the soil, pH may be as high as 9.5. However, when Ca predominates soil pH generally stabilizes around 8.0. There are two measurements used for assessing the carbonate level of irrigation water:

(a) Bicarbonate content of the water,

(b) Residual Sodium Carbonate (RSC) – is an indicator of the potential for calcium and magnesium precipitation. This measure assesses the potential for the soil to become dominated by sodium.

**Bicarbonate hazard of irrigation water**

| $HCO_3^-$ (ppm) | Relative Hazard |
|---|---|
| 0 – 120 | None to slight hazard |
| 120 – 180 | Moderate hazard |
| 180 – 600 | Severe hazard |
| > 600 | Very severe hazard |

**Assessment of carbonate hazard by RSC equation**

| RSC Value | Potential use |
|---|---|
| < 1.25 | Generally safe for use |
| 1.25 – 2.5 | Marginal |
| > 2.50 | Usually unsuitable for irrigation |

**Correction of high bicarbonate and soil pH**

(1) With moderate levels, acidifying amendments can be used rather than irrigation to reduce soil pH.

(2) Although N fertilizers containing or generating ammonium ($NH_4^+$) generally reduce soil pH, it is important to note that fertilizers containing only nitrate ($NO_3^-$) can increase soil pH. Ammonium sulfate is about three times more acidic than other commonly used nitrogenous fertilizers. Every pound of N added to the soil as ammonium sulfate neutralizes around 2.1 pounds of pure limestone.

(3) Elemental Sulpher may also be used to reduce soil pH.

(4) Acidification of irrigation water – The bicarbonate content of irrigation water can be decreased with sulfuric acid or other acidifying amendments.

**Acidity generated by common nitrogen sources**

| Nitrogen Source | Acidity, pounds |
|---|---|
| Ammonium nitrate | 1.8 |
| Urea | 1.8 |
| Ureaformaldehyde | 1.8 |
| Sulfur coated urea | 3.2 |
| Ammonium sulfate | 5.4 |

**High Iron Irrigation Water**

Irrigation water with iron levels of 0.4 to 0.5 ppm range can cause staining the plants. Adjusting the depth of the intake on ponds between 18-30 inches from the water surface will reduce the amount of iron transferred from pond to landscape as oxidised iron settles down to the bottom of the pond.

## PERIODIC MONITORING OF SOIL SALINITY

Soil should be monitored by soil sampling the surface layer (top 30-cm) on a periodic basis. The Sodium adsorption ratio (SAR) of the soil samples will indicate if there is a buildup of sodium. Generally, soils with SAR of 13 from the saturated extract will exhibit significant physical problems due to dispersion of clay particles. Usually a soil with SAR of 6 or lower from the saturated extract will not have physical problems associated with dispersed clay. However, if periodic sampling indicates that SAR is increasing, say from 6 to 9, then it may be time to consider a corrective action.

## MANAGEMENT FOR CROP PRODUCTION

The crop grown, the quality of water used for irrigation, rainfall pattern and climate, and soil properties determine to a large degree the kind and extent of management practices needed:

- Selection of crop or crop variety that will produce satisfactory yield under existing salinity.
- Special planting procedure that minimizes or compensates for salt accumulation in the vicinity of seed.
- Irrigation to maintain a relatively higher moisture level with periodic leaching.
- Use of land preparation to increase the uniformity of water distribution and infiltration, leaching and removal of salinity.
- Special treatments (such as tillage, deep ploughing, addition of chemical amendments, organic matter and green manuring) to maintain the soil permeability and tilth.

### Acknowledgments

This work was done within the framework of the Associateship Scheme of the Abdus Salam International Centre for Theoretical Physics, Trieste, Italy.

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