A Training Manual for Training of Trainers Soil Salinity and Water Quality Management For Vegetable and Fruit Crops Production

Volume 3

By

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INTRODUCTION

All soils and irrigation water contain a mixture of soluble salts, not all of which are essential for plants growth. Salts are toxic to plants when present in high concentration. The problems of soil salinity are most widespread in the arid and semi-arid regions. It is also a serious problem in areas where groundwater of high salt content is used for irrigation. The most serious salinity problems are being faced in the irrigated arid and semi-arid regions of the world and it is in these very regions that irrigation is essential to increase agricultural production to satisfy food requirements. However, irrigation is often costly, technically complex and requires skilled management. Failure to apply efficient principles of water management may result in wastage of water through seepage; over-watering and inadequate drainage result in waterlogging and salinity problems which reduce the soil productivity, eventually leading to loss of cultivable land.

All soils and irrigation water contain a mixture of soluble salts, not all of which are essential for plants growth. Most crops do not grow well on soils that contain salts. Some plants are more tolerant to a high salt concentration than others. One reason is that salt causes a reduction in the rate and amount of water that the plant roots can take up from the soil. The salts concentration of soil solution is greater than applied water. This increase in salinity is the results from plant transpiration and soil surface evaporation which selectively remove water concentrating the salts in the remaining soil water.

1. SALT AFFECTED SOIL CLASSIFICATION

A soil may be rich in salts. Salts in soil can develop from the weathering of primary minerals or be deposited by wind or water that carries salts. The most common source of salts in irrigated soils is the irrigation water itself. After irrigation, the water added to the soil is used by the plant or evaporates directly from the moist soil. The salt, however, is left behind in the soil. Three classes of salt affected soils are recognized. The classification is based on pHs (pH of the saturated soil paste), **ECe** (electrical conductivity of the saturation extract of soil, dS m-') and ESP (exchangeable sodium percentage of the soil). The USDA classification of salt-affected soils is given in Table 1.

Table 1. Classes of salt affected soil

Soils	**ECe (dS m^{-1})**	**ESP**	**pH**	**Description**
Saline	> 4	< 15	Usually < 8.5	Non-sodic soils containing sufficient soluble salts to interfere with plant growth of most crops
Saline-sodic	> 4	> 15	Usually < 8.5	Soils with sufficient exchangeable sodium to interfere with growth of most plants, and containing appreciable quantities of soluble salts
Sodic	< 4	> 15	Usually > 8.5	Soils with sufficient exchangeable sodium to interfere with growth of most plants, but without appreciable quantities of soluble salts

2. CROP SALT TOLERANCE

Excess soil salinity causes poor and spotty stands of crops, uneven and stunted growth and poor yields, the extent depending on the degree of salinity. The primary effect of excess salinity is that it renders less water available to plants although some is still present in the root zone. This is because the osmotic pressure of the soil solution increases as the salt concentration increases. Apart from the osmotic effect of salts in the soil solution, excessive concentration and absorption of individual ions may prove toxic to the plants and/or may retard the absorption of other essential plant nutrients.

There is no critical point of salinity where plants fail to grow. As the salinity increases growth decreases until plants become unable to grow and finally die. Plants differ widely in their ability to tolerate salts in the soil. Salt tolerance ratings of plants are based on yield reduction on salt-affected soils when compared with yields on similar non-saline soils. Soil salinity classes generally recognized are given in Table 2.

Table 2. Soil salinity classes and crop growth

Soil Salinity Class	**ECe (dS/m)**	**Plant response**
Non-saline	0-2	Salinity effects mostly negligible
Slightly saline	2-4	Yields of sensitive crops may be restricted
Moderately saline	4-8	Yields of many crops are restricted
Strongly saline	8-16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only a few very tolerant crops yield satisfactorily

The salt content of soils above which plant growth is affected depends on factors like:

- Texture of the soil
- Soil moisture content
- Distribution of salt in the profile
- Composition/type of the salts in the soil
- Species of the plant grown.

Plants grown on saline salt affected soils usually have no very distinctive foliage symptoms. They, however;

- Are generally stunted,
- Have smaller but thicker leaves than the normal plant,
- Have darker green and curled leaves,
- Have stunted fruit development, and
- Show browning of the tip and marginal or interior portions of leaves.

Generally, plants have different tolerances to the effects of osmotic pressure as indicated by yield levels at different ECe values. As a result, selecting of salt-tolerant crops is an important part of working with salt-affected soils. Certain plant species are more salt tolerant as well boron and Na tolerant than others.

3. PREVENTION AND MANAGEMENT

Salinity Threshold of crop is the maximum level of soil salinity that does not reduce the potential yield of the specific crop. Attributed to the difference in the levels of tolerance to the effects of salinity, threshold salinity, yield reduction compared to no salinity, and slope which is the yield reduction per mmhos/cm (dS/m) under threshold are different for different crop species. For instance, *Hordeum vulgare* (Barley) is very tolerant while *Phaseolus vulgaris* (Beans) are very sensitive to salinity. Table 3 provides salt tolerance level for some crops.

Table 3. Crop tolerance and yield potential of selected crops as influenced by irrigation water salinity (ECw) or soil salinity (ECe)

Crops	100 % ECe – ECw	90 % ECe – ECw	75 % ECe – ECw	50 % ECe – ECw	0 % ECe – ECw
Barley	8.0 5.3	10 6.7	13 8.7	18 12	28 19
Cotton	7.7 5.1	9.6 6.4	13 8.4	17 12	27 18
Sorghum	6.8 4.5	7.4 5.0	8.4 5.6	9.9 6.7	13 8.7
Wheat	6.0 4.0	7.4 4.9	9.5 6.3	13 8.7	20 13
Wheat, duram	5.7 3.8	7.6 5.0	10 6.9	15 10	24 16
Soybean	5.0 3.3	5.5 3.7	6.3 4.2	7.5 5.0	10 6.7
Groundnut	3.2 2.1	3.5 2.4	4.1 2.7	4.9 3.3	6.6 4.4
Rice (paddy)	3.0 2.0	3.8 2.6	5.1 3.4	7.2 4.8	11 7.6
Sugarcane	1.7 1.1	3.4 2.3	5.9 4.0	10 6.8	19 12
Maize	1.7 1.1	2.5 1.7	3.8 2.5	5.9 3.9	10 6.7
Bean	1.0 0.7	1.5 1.0	2.3 1.5	3.6 2.4	6.3 4.2
Tomato	2.5 1.7	3.5 2.3	5.0 3.4	7.6 5.0	13 8.4
Cabbage	1.8	2.8	4.4	7.0	12

Crops	100 % ECe – ECw	90 % ECe – ECw	75 % ECe – ECw	50 % ECe – ECw	0 % ECe – ECw
	1.2	1.9	2.9	4.6	8.1
Potato	1.7 1.1	2.5 1.7	3.8 2.5	5.9 3.9	10 6.7
Sweet potato	1.5 1.0	2.4 1.6	3.8 2.5	6.0 4.0	11 7.1
Pepper	1.5 1.0	2.2 1.5	3.3 2.2	5.1 3.4	8.6 5.8
Onion	1.2 0.8	1.8 1.2	2.8 1.8	4.3 2.9	7.4 5.0
Carrot	1.0 0.7	1.7 1.1	2.8 1.9	4.6 3.0	8.1 5.4
Alfalfa	2.0 1.3	3.4 2.2	5.4 3.6	8.8 5.9	16 10
Orange	1.7 1.1	2.3 1.6	3.3 2.2	4.8 3.2	8.0 5.3
Lettuce	1.3 0.9	2.1 1.4	3.2 2.1	5.1 3.4	9.0 6.0

4.1. Leaching Requirements (LR)

The salinity in the root zone is directly related to the water quality, irrigation methods and practices, soil conditions and rainfall. A high salt content in the root zone is normally controlled by leaching. An excess amount of water is applied during the irrigation, where necessary, for the purposes of leaching. This excess amount of water for leaching purposes is called the Leaching Requirement (LR).

To estimate the LR, both the irrigation water salinity (ECw) and the crop tolerance to salinity, which is normally expressed as electrical conductivity of the soil saturation extract (ECe), have to be known. The ECw can be obtained from laboratory analysis, while the ECe should be estimated from the crop tolerance data given in Table 3. This table gives an acceptable ECe value for each crop appropriate to the tolerable degree of yield loss (normally a reduction in yield of 10% or less is accepted).

For surface and sprinkler irrigation method:

ECw

LR(fraction) = 5 ECe – Ecw

For drip irrigation

$$LR\ (\text{fraction}) = \frac{ECw}{2(maxECe)}$$

where, ECw is the salinity of irrigation water (dS m^{-1}) and ECe is the EC corresponding to 90 percent yield potential (dS m^{-1}).

4.2. Other Prevention and Reclamation Practices

The general consideration stated above imply that knowledge of the type and extent of the problem, cause of the problem, properties of the soil, the inputs required and available and the economic considerations of the farming enterprise are imperative if management and prevention of further development of salt affected soils as well as their reclamation are to be carried out effectively. For instance, the management/reclamation procedure consists of:

- The removal of soluble salts (saline soils), or exchangeable Na (sodic soils), or both (saline sodic soils) to the extent necessary to return the salt affected soil to a normal productive state, and
- Finally, preventing the cause to ensure a long-lasting effect of the management and/or reclamation effort

Generally, the presence of adequate natural or artificial drainage system is prerequisite for all management and reclamation works. Without adequate drainage systems, no matter how much water and/or amendments are added, no lasting reclamation of either saline, saline-sodic, or sodic soils is effective (possible). From the major issues raised so far, it seems apparent that the prevention and management of salt affected soils generally depends largely upon water management that is irrigation, drainage and leaching because salts move together with water. In general, the management practices aimed at controlling and/or minimizing salinity and/or sodicity (alkalinity) problems include:

- Proper shaping of seed beds that avoid salt accumulation in the root zone of germinating plants to assure adequate stand or plant population.

- Timing of irrigation: maintain a high level of available water in the plant root zone during critically sensitive plant growth stages.

- Proper land drainage which can be achieved through:

    - Deep tillage: Helps to eliminate horizontal stratification of different textured soils which in turn improves the rate of water flow/movement and so deep leaching
    - Minimum tillage: Maintain soil structure, avoid compaction and facilitate good drainage & deep leaching.
    - Surface mulching: Reduces evaporation, increases leaching & reduces salt accumulation
    - Management of OM/crop residues: Develop desirable soil structures, improve water movement & root penetration, facilitate deep leaching and reduce salt accumulation.
    - Leaching preplanting: Remove accumulated salts before crops are planted
    - Land selection: Avoid cultivation of lands in areas of (a) High water table, (b) Poor drainage, and (c) Clay pans and compactions that will perch added water unless the drainage condition is corrected prior to cropping.
    - Proper crop selection: Planting of salts and sodium tolerant crops
    - Prevention of further salinization and alkalization and resalinization and realkalization processes in the future through prevention of the causes as:
        - Capillary rise of soil water from a saline or alkali shallow water table through:

        - Installation of drainage system to control or lower the water table level

        - Ground waters are often lowered to a depth of 1.5-2.0 m below the ground surface although the depth required depends on factors such as climate, soil type, quality of ground and irrigation water, irrigation method and others. **Question:** Is the drainage technically feasible and economically justified

        - Prevention of flooding to reduce recharging the ground water and the salts that may be added with the flood water

        - Caused by saline or alkaline irrigation water

    - Avoid the use of poor-quality irrigation water
  - Frequent leaching through application of the same irrigation water
- Caused by presence marine fossil salt or alkali deposits
    - Avoid possible contact of both the irrigation & ground waters with such deposit
    - Identify and avoid use of such areas from cultivation
    - Mine and dispose the fossil salt deposit in safe areas

The term reclamation of saline soils refers to the methods used to remove soluble salts from the root zone. Methods commonly adopted or proposed to accomplish reclamation of saline soils are;

Salt leaching

Salt leaching is the most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of the area under reclamation. Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage, i.e. the ponded water drains without raising the water table. Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep.

Quantity of water for leaching

A useful rule of thumb is that a unit depth of water will remove nearly 80 percent of salts from a unit soil depth. Thus 30 cm water passing through the soil will remove approximately 80 percent of the salts present in the upper 30 cm of soil. Similarly, to reduce the salt content of the surface 60 cm of soil to about 20 percent of the original value would require the passage of about 60 cm of water through the soil. For more reliable estimates, however, it is desirable to conduct salt leaching tests on a limited area and prepare leaching curves.

Water management

i. Irrigation frequency

Modifying water management through appropriate irrigation practices can often lead to increased crop yields under saline soil conditions. Most plants require a continuous supply of readily available moisture to grow normally and produce high yields. After an irrigation the soil moisture content is maximum and the salt concentration or the osmotic pressure of the soil solution is minimal: favorable for crop growth. As the soil progressively dries out due to evapotranspiration losses the concentration of salts in the soil solution and, therefore, its osmotic pressure increases making the soil water increasingly difficult to be absorbed by the plants. Thus, infrequent irrigation aggravates salinity effects on growth. On the other hand, more frequent irrigations, by keeping the soil at a higher soil moisture content prevent the concentration of salts in the soil solution and tend to minimize the adverse effects of salts in the soil. For these reasons, crops grown in saline soils must be irrigated more frequently compared to crops grown under non-saline conditions so that the plants are not subjected to excessively high soil moisture stresses due to combined influence of excess salts and low soil water contents. Figure 11 depicts changes in the total soil moisture stress to which the growing plants are subjected in a non-saline soil compared to a saline soil. Several studies have shown that growth of plants was reduced nearly proportionally to the areas under the curves. Thus, when the areas under two such dissimilar stress curves as A and B were equal, the growth of plants was found to be reduced to nearly the same level. If the saline soils were irrigated infrequently plants would be subjected to very high soil moisture stresses with consequent yield losses.

ii. Irrigation method

Irrigation method can play an important role in controlling salts in the root zone. It has been discussed that frequent irrigations are helpful in saline soils in maintaining adequate availability of soil water. Sprinkler irrigation is an ideal method for irrigating frequently and with small quantities of water at a time. Leaching of soluble salts is also accomplished more efficiently when the water application rates are lower than the infiltration capacity of the soil and such a condition cannot be achieved by flood irrigation methods.

iii. Seed placement/ Sloping bed planting

A soil factor of considerable importance in relation to growth of plants is the location of salts in relation to root zone or seed placement. Irrigation practices can often be modified to obtain a more favorable salt distribution in relation to seed location or growing roots. It is well known that salts tend to accumulate in the ridges when using furrow type irrigation. With each irrigation salts leach out of the soil under the furrows and build up on the ridges. Where soil and farming practices permit, furrow planting or side ridge planting may help in obtaining better stands and crop yields under saline conditions.

Certain modifications of the furrow irrigation method including planting in single/double rows or on sloping beds/side ridge are helpful in getting better stands under saline conditions. With double beds, most of the salts accumulate in the center of the bed leaving the edges relatively free of salts. Sloping beds may be slightly better on highly saline soils because seed can be planted on the slope below the zone of salt accumulation.

iv. Other practices

Crops vary not only in their tolerance to salinity but also in their water requirements, optimum growth season, rooting depth and moisture extraction pattern and cultural requirements. Thus, in the absence of proper water and soil management practices, salinity of the soil may be affected differentially under various crop rotations.

Cropping sequences which include crops such as rice, berseem and those requiring frequent irrigations reduce salinity effectively, where drainage is adequate. Therefore, knowledge of the expected salt balance of the root zone under various crop rotations will be extremely helpful in planning the best cropping sequences during and after reclamation (Massoud, 1976).

v. Land leveling

Changes in the micro relief in the order of a few centimeters can result in increasing the salt content on the raised spots and better leaching in the dips. Proper land shaping before cropping can help to correct these elevation differences. Land leveling those results in the formation of shallow profiles or an exposure of an impervious layer close to surface may enhance salinization. Since this operation is executed at an early stage in new surface irrigation projects, it should be carefully evaluated as a possible cause of salinization.

Tillage is another mechanical operation that is usually carried out for seed bed preparation and soil permeability improvement but if it is improperly executed it might form a plough layer or turn a salty soil horizon and bring it closer to the soil surface. Proper monitoring of changes in the soil will help the timely adoption of corrective measures for the control of salinity that might otherwise be accentuated

4. SUITABILITY OF IRRIGATION WATER

Poor quality of water is one of soil main factors turning many a good soil into saline or sodic soil. Water being a universal solvent, several salts are dissolved in it. The salt content of water is dependent on the characteristics of the parent material of the soil through which it passes. Considerable water by is taken up by the plant from the soil and transported. If water contains much salts dissolved in it. These accumulate in the upper layer of the soil having been brought up to the surface by evaporation. If rainfall is not sufficient to leach out these salts, they accumulate over seasons and make the soil saline or sodic.

Irrigation with saline water affects adversely crop growth and productivity. High ground water table, aridity, seepage from canals, poor drainage, back water flow, intrusion of sea water also leads to salinity and sodicity.

The quality of irrigation water is judged by the amount of suspended and dissolved materials it contains. All irrigation water contains dissolved or suspended materials. Suspended materials can be removed with filters. Crop yield can be reduced significantly when the dissolved materials or salinity of the irrigation water, is high enough. In some case, even though the salt content of the water is low, continued irrigation application may gradually build up the salt content in the root zone. Nevertheless, irrigation water quality is commonly assessed in terms of soluble salts content, percentage of sodium, boron and bicarbonates contents. High amounts of exchangeable sodium can cause soil particle dispersion that reduces soil structure and restricts air and water movement into and within the soil. Sodium, chloride, boron and other ions are toxic to many plants when present in sufficient concentrations.

5.1. Content of Irrigation Water

Whatever may be the source of irrigation water, river, tank or ground water, some salts are always dissolved in it. The main soluble constituents are cations (positively charged ions) of calcium, magnesium, sodium and potassium and the anions (negatively charged ions) of sulphate, chloride, bicarbonate, carbonate and nitrate. Some others such as lithium, silicon, bromine, iodine, copper, nickel, cobalt, fluorine, boron, zirconium, titanium, vanadium, barium, rubidium, caesium, arsenic, antimony, chromium, manganese, lead, molybdium, selenium and phosphate and organic matter may also be present in minor quantities. Of these boron, selenium, molybdenum and fluorine if taken up by plants in excessive amounts will be harmful for animals which may feed on such forage or drink such water. Among all these soluble constituents calcium, magnesium, sodium, chloride, sulphate, bicarbonate and boron are of primary importance in determining the quality of irrigation water and its suitability for irrigation.

Under certain condition, the presence of bicarbonate ion causes the precipitation of calcium and magnesium, thus increasing the proportion of sodium and hence increasing the sodium hazard. Chemically, water of low salinity has predominance of calcium and magnesium and bicarbonate while highly saline waters are dominant with chloride and sodium ions. Generally, 80% of waters have more magnesium than calcium and in most cases Mg:Ca ratio is from 1 to 4. Potassium forms 1 to 3% of the total salt content. Sodium and bicarbonate rich water have less than 5% calcium of the total salts. Surprisingly some groundwater sources contain high level of nitrates. Other factors such as texture and structure of the soil, its drainage, crop and climate are equally important in determining suitability of water for irrigation. The quality of irrigation water is generally expressed on the basis of total salt content, relative concentration of sodium to other cations, boron content and bicarbonate content.

5.2. Water Quality Guidelines

Guidelines for evaluation of water quality for irrigation are given in Table 4. The criteria for judging the quality of irrigation water are: total salt concentration as measured by electrical conductivity or total dissolved salts (TDS), relative proportion of sodium as expressed by sodium absorption ration (SAR), bicarbonate content, boron concentration. They emphasize the long-term influence of water quality on crop production, soil conditions and farm management. The guidelines are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent and wastewater. They are based on certain assumptions which are given immediately following the Table. These assumptions must be clearly understood but should not become rigid prerequisites. A modified set of alternative guidelines can be prepared if actual conditions of use differ greatly from those assumed.

Ordinarily, no soil or cropping problems are experienced or recognized when using water with values less than those shown for ‘no restriction on use’. With restrictions in the slight to moderate range, gradually increasing care in selection of crop and management alternatives is required if full yield potential is to be achieved. On the other hand, if water is used which equals or exceeds the values shown for severe restrictions, the water user should experience soil and cropping problems or reduced yields, but even with cropping management designed specially to cope with poor quality water, a high level of management skill is essential for acceptable production. If water quality values are found which approach or exceed those given for the severe restriction category, it is recommended that before initiating the use of the water in a large project, a series of pilot farming studies be conducted to determine the economics of the farming and cropping techniques that need to be implemented.

Table 4 is a management tool. As with many such interpretative tools in agriculture, it is developed to help users such as water agencies, project planners, agriculturalists, scientists and trained field people to understand better the effect of water quality on soil conditions and crop production. With this understanding, the user should be able to adjust management to utilize poor quality water better. However, the user of Table 4 must guard against drawing unwarranted conclusions based only on the laboratory results and the guideline interpretations as these must be related to field conditions and must be checked, confirmed and tested by field trials or experience.

Table 4. Guidelines for evaluating irrigation water quality

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity: (affecting crop) ECw\ or TDS	 dS m^{-1} mg lt^{-1}	 < 0.7 < 450	 0.7 – 3.0 450 - 2000	 > 3.0 > 2000
Infiltration (affecting soil) SAR = 0 – 3 and ECw = = 3 – 6 = = 6 – 12 = = 12 - 20 = = 20 – 40 =		 > 0.7 > 1.2 > 1.9 > 2.9 > 5.0	 0.7 – 0.2 1.2 – 0.3 1.9 – 0.5 2.9 – 1.3 5.0 – 2.9	 < 0.2 < 0.3 < 0.5 < 1.3 < 2.9
Specific ion toxicity (affects sensitive crop) Sodium (Na) surface Sprinkler	 SAR me lt^{-1}	 < 3 < 3	 3 – 9 > 3	 > 9
Chloride (C) Surface Sprinkler	me lt^{-1} me lt^{-1}	< 4 < 3	4 – 10 > 3	> 10
Boron (B)	me lt^{-1}	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous effect (Affect susceptabe crops) Nitrogen (NO_3 - N) Bicarbonate (HCO_3) (overhead sprinkling only)	 me lt^{-1} me lt^{-1}	 < 5 < 1.5	 5 - 30 1.5 - 8.5	 > 30 > 8.5
pH		Normal range 6.5 - 8.4		

The guidelines are a first step in pointing out the quality limitations of a water supply, but this alone is not enough; methods to overcome or adapt to them are also needed. It is beyond the scope of this manual to go into drinking water standards, but this aspect should, nevertheless, be considered during the planning of an irrigation scheme. This is important, because irrigation supplies are also commonly used, either intentionally or unintentionally, as human drinking water. Laboratory determinations and calculations needed to use the guidelines given in Table 5 and Fig. 1, along with the symbols used.

5.3. Classification of Irrigation Water

All irrigation water could be classified based on total salt content, sodium adsorption ratio and Boron content. US salinity laboratory classified irrigation water based on EC and SAR which is depicted in fig.2 the horizontal axis represent conductivity in µmhos/cm and vertical axis represents SAR.

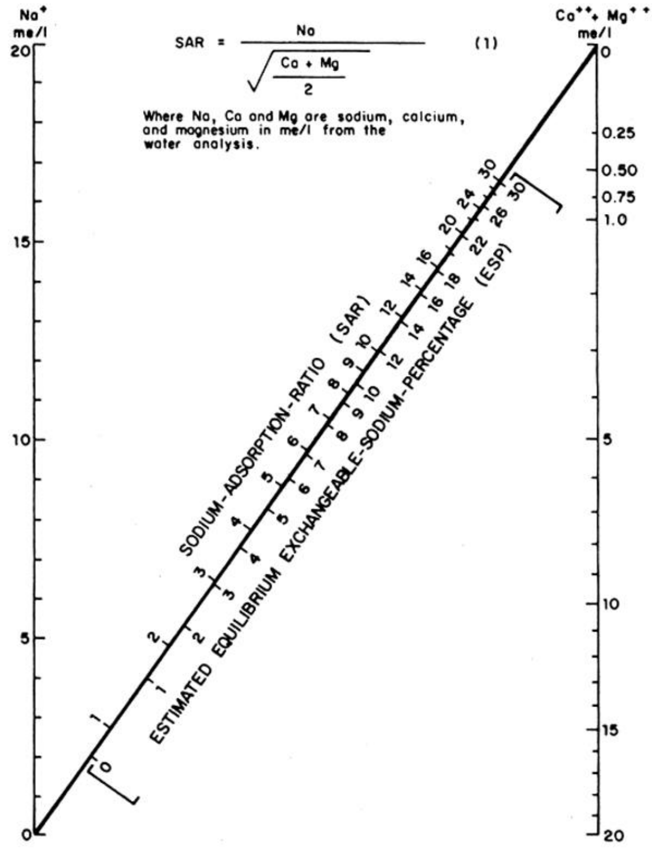

Figure 1. Nomogram for determining the SAR value of irrigation water and for estimating the corresponding ESP value of a soil that is at equilibrium with the water (Richards 1954)

Table 5 Laboratory Determinations Needed to Evaluate Common Irrigation Water Quality Problems

Water parameter	**Symbol**	**Unit**[1]	**Usual range in irrigation water**	
SALINITY				
<u>Salt Content</u>				
Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
(or)				
Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
<u>Cations and Anions</u>				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO_3^{--}	me/l	0 – .1	me/l
Bicarbonate	HCO_3^-	me/l	0 – 10	me/l
Chloride	Cl^-	me/l	0 – 30	me/l
Sulphate	SO_4^{--}	me/l	0 – 20	me/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Basicity	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio[3]	SAR	(me/l)[1], [2]	0 – 15	

The curves running from the left to the right are given in negative slope to consider the dependence of the sodium hazard on the total salt concentration. To use this diagram, with SAR and EC values the corresponding point on the diagram is located, his point gives the class of irrigation water.

Suppose the SAR is 8 ----and EC is 2300 µmhos/cm, SAR and EC values are taken on the coordinates, the corresponding point shows the class of water. With the present example, the water is classified as $C_4 – S_2$ indicating very high salinity water and medium sodium water. With the same SAR of 8 and with EC of 2400 µmhos/cm the water is classified as $\mathbf{C_1 – S_1}$ indicating low sodium and low salinity water. In this classification, irrigation water is classified in to four groups each based on EC and SAR.

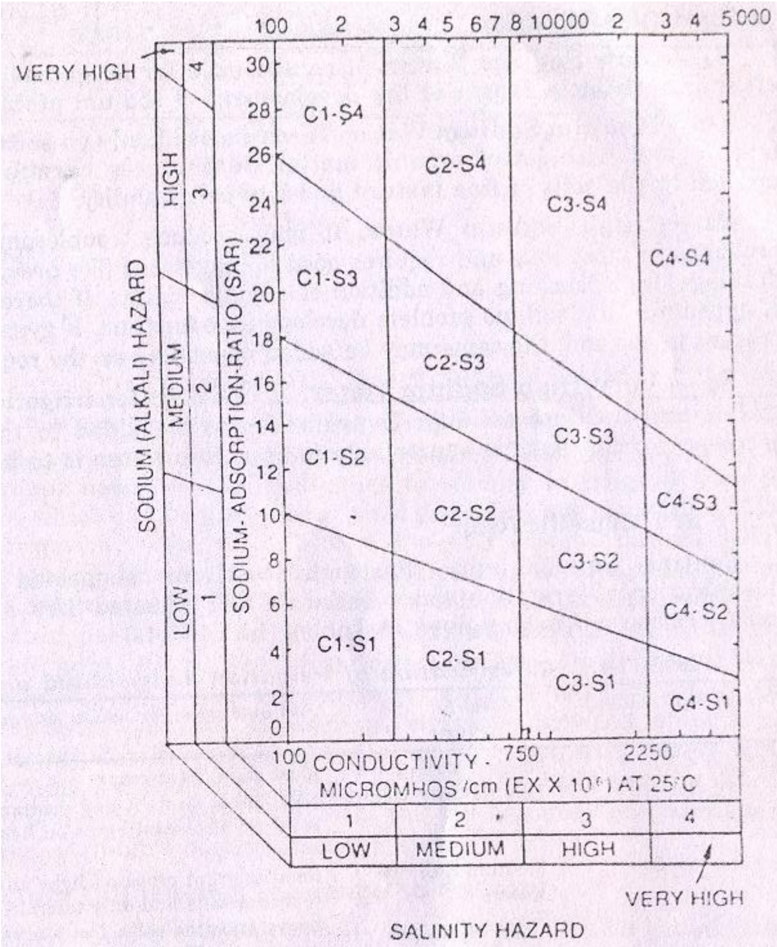

Figure 2. Nomogram for classification of irrigation water

Salinity classification

C_1 – Low salinity water: If electrical conductivity is less than 0.25d S/m, the irrigation water is classified as low salinity water. It can be used for irrigation in all soils and on most crops but leaching is required in case of extremely low permeable soil.

C_2 – Medium salinity water: It has an EC between 0.25 – 0.75 dS/m, this water can be safely used for crops with moderate salt tolerance. The soil should have moderate level of permeability and leaching to avoid accumulation of salts.

C_3 – High salinity water: Water with in ranges of 0.75 – 2.25 dS/m, is called high salinity water. This water cannot be used on soils with poor drainage. This water can be used for salt tolerant crops by providing good drainage and also by practicing management practices for salinity control.

C_4 – Very high salinity water: If EC is more than 2.25 dS/m, the water is classified as very high salinity water. It is not suitable for irrigation water under ordinary conditions, but may be used occasionally if the soil is permeable by providing adequate drainage.

Sodium Classification

S_1 – Low sodium water: It can be used for irrigation on almost all soils with little danger of the development of sodium problem.

S_2 – Medium sodium water: It can be used only on soils of coarse texture and with lot of organic matter. It produces harmful effect if applied to the soils of fine texture and low permeability.

S_3 – High sodium water: It may produce troublesome sodium problems in most soils and requires good management like providing good drainage, high leaching and addition of organic matter. If there is plenty of gypsum in the soil no problem develops for sometimes. If gypsum is not present in the soil, the same may be added depending on the requirement.

S_4 – Very high sodium water: It is not fit for irrigation except at low and medium salinity. Gypsum has to be added to the soil to decreases sodium hazard appreciably in case this water is to be applied to the soil.

5.4. Problems with Poor Quality Water

Several soil and plant related problems arise from use of poor-quality water for irrigation. Some of the problems are mentioned as follows.

Extraction of water

If excessive quantity of soluble salts in the irrigation water accumulate in the crop root zone, the crop has difficulty in extracting enough water. Root growth is also suppressed, increasing the difficulty of water uptake. Salinity stress in plants is often called **physiological drought.** The growth reduction due to increasing salinity is linear within a wide range. The leaves of salt affected plants are smaller and darker than normal leaves. Leaves became succulent if chloride ion is more. Due to reduced uptake of water and other effects, yields are reduced. The reduction in yield due to salinity is more in warm climate than cool climate.

Soil permeability

Soil permeability is reduced due to the deflocculation effect of sodium. If the permeability is reduced, infiltration of water into and through the soil is reduced and when adequate root penetration is inhabited due to the presence of impermeable soil layer caused by calcium carbonate and high exchangeable sodium percentage. Crusting of seedbeds, waterlogging, reduced oxygen and nutrient supply to the crops are the problems due to high sodium content relative to calcium and magnesium.

Toxicity

Toxicity symptoms occur when plants take up excessive amounts of boron, chloride, sodium, sulphate and bicarbonate. Vegetable growth decreases as the osmotic pressure of the soil solution increase. Reduction in growth takes place even without any external toxic symptoms. With increase in salinity, symptoms of salt injury appear. They are thick cuticle, waxy bloom and deep blue-green color of the leaves. At high salt levels, leaf burn appears in barely, sorghum and field beans.

Anatomical and physiological effects

Salinity reduces cell division, cell enlargement and proteins synthesis. It affects the structure and integrity of plant membranes and causes mitochondria and chloroplasts to swell. Sodium and chloride at toxic levels disrupt the structure of the protein molecules. High chloride content hinders the development of xylem.

Nutritional effects

Higher levels of certain ions affect the absorption of other nutrient elements. Higher concentration of sulphate reduces the uptake of calcium and enhances the uptake of sodium. This process causes high levels of sodium in plants, thus causing sodium toxicity. High concentration of calcium reduces the uptake of potassium. High concentration of magnesium induces calcium deficiency in plants.

Soil microorganisms

Nitrate and nitrite producing bacteria are sensitive to high salt concentration than ammonia producing bacteria. Azotobactor is relatively resistant to high salt concentration.

Other effects

Excessive vegetative growth, lodging, delayed crop maturity results due to excessive nitrogen in water. White and black deposits on soil due to high salt content and sodium and leaf burn due to using poor quality irrigation water in sprinkler irrigation are some of the problems. Tilt of the soil will be poor due to high exchangeable sodium percentage. Exchangeable sodium tends to make the moist soil impermeable to air and water and on drying the soil becomes hard and difficult to work. The dense crusts formed interfere with germination and emergence of seedlings. If soluble carbonates are in irrigation water applied to the soil, in absence of calcium and magnesium in the soil, the soil becomes alkaline and unfavorable characteristics develop. Sodium carbonate in irrigation water is extremely toxic to plants.

5.5. Management Practices

When it is inevitable to use water of poor quality for crop production appropriate management practices help to obtain reasonable yields of crops. The success of crop production while irrigating with saline water lies in keeping the rise of salinity beyond certain limits. Some of the important management practices are: (1) application of gypsum to irrigation water rich in sodium and bicarbonate, (2) growing of tolerant crops and varieties, (3) proper method of sowing, (4) application of optimum qualities of manures and fertilizers, (5) proper scheduling of irrigation, (6) providing good drainage and (7) other management practices such as planting aged seedlings of rice, mulching, crop rotation, soil management, leaching etc.

Gypsum Application

Due to its low solubility (0.25 0.30%) and cost gypsum (hydrated calcium sulphate) is suitable for creating a favourable Ca:Na or Ca:Mg ratio in irrigation water. Improvement in Ca:Na ratio or SAR takes place by increasing the calcium ion concentration, decreasing the Mg:Ca ratio and precipitating excessive carbonate ions.

Gypsum used for agricultural purpose should be 65% pure. Gypsum has to be powdered up to 0.5 mm size or passed through 30 mesh sieves. Gypsum requirement has to be calculated based on the relative concentration of sodium, magnesium and calcium ions in irrigation water and the solubility of gypsum. To add 1 meq/1 of calcium, 860 Kg of gypsum of 100% purity per hectare meter of water is necessary. The actual amount of gypsum to be added to irrigation water depends on the amount of calcium and water to be applied for the crop production. Application of saturated solution of gypsum by mechanical device at a constant rate is the best method. As application of gypsum improves, poor quality of water and also alkali soil, gypsum can be applied to the soil if it is alkali soil. If the soil is good and the water is poor quality, gypsum should be applied to water.

Tolerant Crops

The limit of tolerance of various crops to salt is given in Table 6 and Table 7. Salt tolerant crops like barley, cotton, sugar beet is moderately tolerant. Crops like safflower, wheat, soybean etc., can be grown if irrigation water is saline. Growth and yield of crop will be better if the crop is irrigated frequently.

Table 6. Relative tolerance of crops to salinity

Sensitive	Moderately Sensitive	Moderately tolerant	Tolerant
Apple	Cabbage	Safflower	Barley
Carrot	Corn	Soybean	Cotton
Lemon	Cowpea	Wheat	Datepalm
Onion	Grapes		Sugarbeet
Orange	Groundnut		
Pulses	Potato		
	Rice		
	Tomato		
	Sorghum		

Table 7. Relative tolerance of crops to Boron*

Tolerant (2-4 ppm)	Semi-tolerant (1-2 ppm)	Sensitive (0.3-1.0 ppm)
Datepalm	Sunflower	Apple
Sugarbeet	Potato	Grape
Onion	Cotton, Orange	
Cabbage	Tomato, Lemon	
Carrot	Barley	
	Wheat	
	Maize	
	Sorghum	
	Sweet potato	

*Tolerance decrease in decreasing order in each column between the stated

Method of Sowing

Germination of seeds decreases with increasing salinity. It is essential to obtain good crop stand even when poor quality water is used. Seeds have to be placed in the area where salt concentration is less. With furrow irrigation, the salt tends to concentrate mainly in the center of the ridge between furrows and in a third layer along the top of the ridge. The salt concentration is less on the slope of the ridge and bottom of the ridge. The safest place for seed placement is on the side of the ridge or at the bottom of the ridge.

Fertilizer Application

Soils irrigated with poor quality water are generally low fertility especially nitrogen and sometimes phosphorus. Fertility status has to be raised to obtain better crops.

Methods of Irrigation

Poor quality irrigation water is not suitable for use in sprinkler irrigation. Excess quantity of sodium and chloride can be absorbed through leaves wet by the sprinkler water and can cause leaf burn. Poor quality water can be used in drip irrigation system as salt concentration in the root zone of the crop is reduced as salts are pushed to the periphery of the wetted area.

5.6. Other Management Practices

Overaged seedlings: Transplanting of rice with overaged seedlings results in better establishment in salt affect soil than normal aged seedlings. Closer planting has to be adopted for compensating the yield reduction caused by planting overaged seedlings. In case other crops like finger millet, pearl millet etc., transplanting is the better method than direct sowing of these crops for proper establishment.

Mulching: Mulching with locally available plant materials help in reducing salt affected problems by reducing evaporation and by increasing infiltration. Salts are leached into lower layers even with rainfall by application of mulches.

Soil Management: All soil management practices that improve the infiltration rate and maintain favourable soil structure reduce salinity hazard.

Crop Rotation: Inclusion of crops such as rice in the rotation reduces salinity.

~~Table [illegible]~~

RELATIVE BORON TOLERANCE OF AGRICULTURAL CROPS[1,2]

Very Sensitive (<0.5 mg/l)

Lemon	*Citrus limon*
Blackberry	*Rubus spp.*

Sensitive (0.5 - 0.75 mg/l)

Avocado	*Persea americana*
Grapefruit	*Citrus X paradisi*
Orange	*Citrus sinensis*
Apricot	*Prunus armeniaca*
Peach	*Prunus persica*
Cherry	*Prunus avium*
Plum	*Prunus domestica*
Persimmon	*Diospyros kaki*
Fig, kadota	*Ficus carica*
Grape	*Vitis vinifera*
Walnut	*Juglans regia*
Pecan	*Carya illinoiensis*
Cowpea	*Vigna unguiculata*
Onion	*Allium cepa*

Sensitive (0.75 - 1.0 mg/l)

Garlic	*Allium sativum*
Sweet potato	*Ipomoea batatas*
Wheat	*Triticum eastivum*
Barley	*Hordeum vulgare*
Sunflower	*Helianthus annuus*
Bean, mung	*Vigna radiata*
Sesame	*Sesamum indicum*
Lupine	*Lupinus hartwegii*
Strawberry	*Fragaria spp.*
Artichoke, Jerusalem	*Helianthus tuberosus*
Bean, kidney	*Phaseolus vulgaris*
Bean, lima	*Phaseolus lunatus*
Groundnut/Peanut	*Arachis hypogaea*

Moderately Sensitive (1.0 - 2.0 mg/l)

Pepper, red	*Capsicum annuum*
Pea	*Pisum sativa*
Carrot	*Daucus carota*
Radish	*Raphanus sativus*
Potato	*Solanum tuberosum*
Cucumber	*Cucumis sativus*

Moderately Tolerant (2.0 - 4.0 mg/l)

Lettuce	*Lactuca sativa*
Cabbage	*Brassica oleracea capitata*
Celery	*Apium graveolens*
Turnip	*Brassica rapa*
Bluegrass, Kentucky	*Poa pratensis*
Oats	*Avena sativa*
Maize	*Zea mays*
Artichoke	*Cynara scolymus*
Tobacco	*Nicotiana tabacum*
Mustard	*Brassica juncea*
Clover, sweet	*Melilotus indica*
Squash	*Cucurbita pepo*
Muskmelon	*Cucumis melo*

Tolerant (4.0 - 6.0 mg/l)

Sorghum	*Sorghum bicolor*
Tomato	*Lycopersicon lycopersicum*
Alfalfa	*Medicago sativa*
Vetch, purple	*Vicia benghalensis*
Parsley	*Petroselinum crispum*
Beet, red	*Beta vulaaris*
Sugarbeet	*Beta vulgaris*

Very Tolerant (6.0 - 15.0 mg/l)

Cotton	*Gossypium hirsutum*
Asparagus	*Asparagus officinalis*

[1] Data taken from Maas (1984).

[2] Maximum concentrations tolerated in soil-water without yield or vegetative growth reductions. Boron tolerances vary depending upon climate, soil conditions and crop varieties. Maximum concentrations in the irrigation water are approximately equal to these values or slightly less.

Table 17 CITRUS AND STONE FRUIT ROOTSTOCKS LISTED IN ORDER OF INCREASING BORON ACCUMULATION AND TRANSPORT TO LEAVES[1]

Common Name	Botanical Name	Level of Boron accumulation
Citrus		
Alemow	*Citrus macrophylla*	Low
Gajanimma	*Citrus pennivesiculata* or *Citrus moi*	↓
Chinese box orange	*Severinia buxifolia*	
Sour orange	*Citrus aurantium*	
Calamondin	*X Citrofortunella mitis*	
Sweet orange	*Citrus sinensis*	
Yuzu	*Citrus junos*	
Rough lemon	*Citrus limon*	
Grapefruit	*Citrus X paradisi*	
Rangpur lime	*Citrus X limonia*	
Troyer citrange	*X Citroncirus webberi*	
Savage citrange	*X Citroncirus webberi*	
Cleopatra mandarin	*Citrus reticulata*	
Rusk citrange	*X Citroncirus webberi*	
Sunki mandarin	*Citrus reticulata*	
Sweet lemon	*Citrus limon*	
Trifoliate orange	*Poncirus trifoliata*	
Citrumelo 4475	*Poncirus trifoliata X Citrus paradisi*	
Ponkan mandarin	*Citrus reticulata*	
Sampson tangelo	*Citrus X tangelo*	
Cuban shaddock	*Citrus maxima*	
Sweet lime	*Citrus aurantiifolia*	High
Stone Fruit		
Almond	*Prunus dulcis*	Low
Myrobalan plum	*Prunus cerasifera*	↓
Apricot	*Prunus armeniaca*	
Marianna plum	*Prunus domestica*	
Shalil peach	*Prunus persica*	High

[1] Data taken from Maas (1984).

often management options than can be adopted to reduce toxicity and improve yields.

The potentially toxic ions sodium, chloride and boron can each be reduced by leaching in a manner similar to that for salinity, but the depth of water required varies with the toxic ion and may in some cases become excessive. If leaching becomes excessive, many growers change to a more tolerant crop. Increasing the leaching or changing crops in an attempt to live with the higher levels of toxic ions may require extensive changes in the farming system. In cases where the toxicity problem is not too severe, relatively minor changes in farm cultural practices can minimize the impact. In a few cases, an alternative water supply may be available to blend with a poorer supply to lower the hazard from the poorer one.

Alternatives for management of toxicity and to maintain production are discussed in the following sections.

Table 15 RELATIVE TOLERANCE OF SELECTED CROPS TO EXCHANGEABLE SODIUM[1]

Sensitive[2]	Semi-tolerant[2]	Tolerant[2]
Avocado *(Persea americana)*	Carrot *(Daucus carota)*	Alfalfa *(Medicago sativa)*
Deciduous Fruits	Clover, Ladino *(Trifolium repens)*	Barley *(Hordeum vulgare)*
Nuts	Dallisgrass *(Paspalum dilatatum)*	Beet, garden *(Beta vulgaris)*
Bean, green *(Phaseolus vulgaris)*	Fescue, tall *(Festuca arundinacea)*	Beet, sugar *(Beta vulgaris)*
Cotton (at germination) *(Gossypium hirsutum)*	Lettuce *(Lactuca sativa)*	Bermuda grass *(Cynodon dactylon)*
Maize *(Zea mays)*	Bajara *(Pennisetum typhoides)*	Cotton *(Gossypium hirsutum)*
Peas *(Pisum sativum)*	Sugarcane *(Saccharum officinarum)*	Paragrass *(Brachiaria mutica)*
Grapefruit *(Citrus paradisi)*	Berseem *(Trifolium alexandrinum)*	Rhodes grass *(Chloris gayana)*
Orange *(Citrus sinensis)*	Benji *(Melilotus parviflora)*	Wheatgrass, crested *(Agropyron cristatum)*
Peach *(Prunus persica)*	Raya *(Brassica juncea)*	Wheatgrass, fairway *(Agropyron cristatum)*
Tangerine *(Citrus reticulata)*	Oat *(Avena sativa)*	Wheatgrass, tall *(Agropyron elongatum)*
Mung *(Phaseolus aurus)*	Onion *(Allium cepa)*	Karnal grass *(Diplachna fusca)*
Mash *(Phaseolus mungo)*	Radish *(Raphanus sativus)*	
Lentil *(Lens culinaris)*	Rice *(Oryza sativus)*	
Groundnut (peanut) *(Arachis hypogaea)*	Rye *(Secale cereale)*	
Gram *(Cicer arietinum)*	Ryegrass, Italian *(Lolium multiflorum)*	
Cowpeas *(Vigna sinensis)*	Sorghum *(Sorghum vulgare)*	
	Spinach *(Spinacia oleracea)*	
	Tomato *(Lycopersicon esculentum)*	
	Vetch *(Vicia sativa)*	
	Wheat *(Triticum vulgare)*	

Adapted from data of FAO-Unesco (1973); Pearson (1960); and Abrol (1982).

The approximate levels of exchangeable sodium percentage (ESP) corresponding to the three categories of tolerance are: sensitive less than 15 ESP; semi-tolerant 15-40 ESP; tolerant more than 40 ESP. Tolerance decreases in each column from top to bottom. The tolerances listed are relative because, usually, nutritional factors and adverse soil conditions stunt growth before reaching these levels. Soil with an ESP above 30 will usually have too poor physical structure for good crop production. Tolerances in most instances were established by first stabilizing soil structure.

Table 14 CHLORIDE TOLERANCE OF SOME FRUIT CROP CULTIVARS AND ROOTSTOCKS [1]

Crop	Rootstock or Cultivar	Maximum Permissible Cl^- without Leaf Injury [2] Root Zone (Cl_e) (me/l)	Irrigation Water (Cl_w) [3,4] (me/l)
	Rootstocks		
Avocado *(Persea americana)*	West Indian	7.5	5.0
	Guatemalan	6.0	4.0
	Mexican	5.0	3.3
Citrus *(Citrus spp.)*	Sunki Mandarin Grapefruit Cleopatra mandarin Rangpur lime	25.0	16.6
	Sampson tangelo Rough lemon Sour orange Ponkan mandarin	15.0	10.0
	Citrumelo 4475 Trifoliate orange Cuban shaddock Calamondin Sweet orange Savage citrange Rusk citrange Troyer citrange	10.0	6.7
Grape *(Vitis spp.)*	Salt Creek, 1613-3	40.0	27.0
	Dog Ridge	30.0	20.0
Stone Fruits *(Prunus spp.)*	Marianna	25.0	17.0
	Lovell, Shalil	10.0	6.7
	Yunnan	7.5	5.0
	Cultivars		
Berries *(Rubus spp.)*	Boysenberry	10.0	6.7
	Olallie blackberry	10.0	6.7
	Indian Summer Raspberry	5.0	3.3
Grape *(Vitis spp.)*	Thompson seedless	20.0	13.3
	Perlette	20.0	13.3
	Cardinal	10.0	6.7
	Black Rose	10.0	6.7
Strawberry *(Fragaria spp.)*	Lassen	7.5	5.0
	Shasta	5.0	3.3

[1] Adapted from Maas (1984).

[2] For some crops, the concentration given may exceed the overall salinity tolerance of that crop and cause some reduction in yield in addition to that caused by chloride ion toxicities.

[3] Values given are for the maximum concentration in the irrigation water. The values were derived from saturation extract data (EC_e) assuming a 15-20 percent leaching fraction and $EC_e = 1.5\ EC_w$.

[4] The maximum permissible values apply only to surface irrigated crops. Sprinkler irrigation may cause excessive leaf burn at values far below these (see Section 4.3).

Table 21 RECOMMENDED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATER [1]

Element		Recommended Maximum Concentration [2] (mg/l)	Remarks
Al	(aluminium)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As	(arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be	(beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd	(cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co	(cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr	(chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu	(copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F	(fluoride)	1.0	Inactivated by neutral and alkaline soils.
Fe	(iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li	(lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn	(manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo	(molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni	(nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd	(lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Se	(selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Sn Ti W	(tin) (titanium) (tungsten)	----	Effectively excluded by plants; specific tolerance unknown.
V	(vanadium)	0.10	Toxic to many plants at relatively low concentrations.
Zn	(zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

[1] Adapted from National Academy of Sciences (1972) and Pratt (1972).

[2] The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10 000 m^3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3 per hectare per year. The values given are for water used on a continuous basis at one site.

GENERAL DESCRIPTION OF COMMON TOXICITY SYMPTOMS

Symptom	Description
1. Soil Salinity	Symptoms and effects vary widely with species. High salinity causes stunted plants commonly characterized by a deep bluish green color which results from an unusually heavy wax coating on the surfaces. The color may be very pronounced for sugar beets, crucifers, alfalfa, beans, clover and grasses. Cereals and milo may show a reddish color as the plants approach maturity. Salt accumulations in the leaves of many fruit trees cause a burning or necrosis (commonly called "tipburn") on the margins. Chloride (Cl^-) or sodium (Na^+) frequently is involved.
2. Chloride Injury	Chloride injury is described for woody and some other plants as an initial burning and necrosis of the leaf tips. As injury intensifies, burning progresses along the margins and may extend with greater severity into the interveinal area of the leaf.
3. Sodium Injury	May appear as a "spot burn" or necrotic interveinal areas midway between leaf margin and midrib. Such damage has been reported for avocado, raspberry, blackberry, grapefruit, and others. Excessive exchangeable sodium, commonly associated with soil salinity, may cause Ca deficiency. The symptoms are described in the general key to nutrient deficiencies.
4. Excessive Boron	Boron toxicity may occur on plants grown in irrigated soils where the irrigation water contains 1 ppm B or more. With many species, excessive B causes a tip or marginal burn or a general chlorosis of the

leaves. As the leaves mature, continued toxicity causes a dying of the leaf from the tip inward. Plants may show slight to medium toxicity symptoms without a depression in growth. With broadleaf plants, there is marginal necrosis and the leaf may be cupped because of restrictions in the growth of the margins.

5. Excessive Fertilizer	Excessive amounts of highly water soluble fertilizer used over time can cause salinity damage similar to that reported for saline soils. When fertilizer is placed too near the seed, damage or death may occur in the seedling stage. Where excessive fertilizer has been applied to a normally growing plant, the damage appears first as a wilting of leaf margins or the entire leaf, depending on the fertilizer rate. In a few days, the leaves dehydrate and dry with a marginal necrosis. With very high fertilizer rates, the plant may die.
6. Aluminum Toxicity	Plant growth is stunted in strongly acid soils. The principle cause of poor growth is Al toxicity with Mn toxicity and Fe toxicity occurring in some soils. With Al toxicity, the seedlings are very slow to develop and the leaves are a gray-green to reddish-purple characteristic of phosphate deficiency. The leaves are stubby and die back. Sensitive plants may fail to grow beyond the seedling stage. Root growth is severely restricted.
7. Manganese Toxicity	In cereals, Mn toxicity causes leaf tips to die and interveinal necrotic spots called "leaf freckle". With brassica, there is necrosis or scorching or chlorotic mottling of leaf margins; there may be interveinal chlorosis and

necrotic spotting; the leaves may curve or cup upward. With clover and alfalfa, Mn toxicity causes marginal spotty chlorosis and necrosis that proceeds inward as the toxicity increases; leaf margins are distorted and the leaf is cupped downward. Mn toxicity may resemble mild Fe deficiency.

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Table 5 RELATIVE SALT TOLERANCE OF AGRICULTURAL CROPS [1,2]

TOLERANT [3]

Fibre, Seed and Sugar Crops

Barley	*Hordeum vulgare*
Cotton	*Gossypium hirsutum*
Jojoba	*Simmondsia chinensis*
Sugarbeet	*Beta vulgaris*

Grasses and Forage Crops

Alkali grass, Nuttall	*Puccinellia airoides*
Alkali sacaton	*Sporobolus airoides*
Bermuda grass	*Cynodon dactylon*
Kallar grass	*Diplachne fusca*
Saltgrass, desert	*Distichlis stricta*
Wheatgrass, fairway crested	*Agropyron cristatum*
Wheatgrass, tall	*Agropyron elongatum*
Wildrye, Altai	*Elymus angustus*
Wildrye, Russian	*Elymus junceus*

Vegetable Crops

Asparagus	*Asparagus officinalis*

Fruit and Nut Crops

Date palm	*Phoenix dactylifera*

MODERATELY TOLERANT [3]

Fibre, Seed and Sugar Crops

Cowpea	*Vigna unguiculata*
Oats	*Avena sativa*
Rye	*Secale cereale*
Safflower	*Carthamus tinctorius*
Sorghum	*Sorghum bicolor*
Soybean	*Glycine max*
Triticale	*X Triticosecale*
Wheat	*Triticum aestivum*
Wheat, Durum	*Triticum turgidum*

Grasses and Forage Crops

Barley (forage)	*Hordeum vulgare*
Brome, mountain	*Bromus marginatus*
Canary grass, reed	*Phalaris, arundinacea*
Clover, Hubam	*Melilotus alba*
Clover, sweet	*Melilotus*
Fescue, meadow	*Festuca pratensis*
Fescue, tall	*Festuca elatior*
Harding grass	*Phalaris tuberosa*
Panic grass, blue	*Panicum antidotale*
Rape	*Brassica napus*
Rescue grass	*Bromus unioloides*
Rhodes grass	*Chloris gayana*
Ryegrass, Italian	*Lolium italicum multiflorum*
Ryegrass, perennial	*Lolium perenne*
Sudan grass	*Sorghum sudanense*
Trefoil, narrowleaf birdsfoot	*Lotus corniculatus tenuifolium*
Trefoil, broadleaf birdsfoot	*Lotus corniculatus arvenis*
Wheat (forage)	*Triticum aestivum*
Wheatgrass, standard crested	*Agropyron sibiricum*

MODERATELY TOLERANT

Grasses and Forage Crops

Wheatgrass, intermediate	*Agropyron intermedium*
Wheatgrass, slender	*Agropyron trachycaulum*
Wheatgrass, western	*Agropyron smithii*
Wildrye, beardless	*Elymus triticoides*
Wildrye, Canadian	*Elymus canadensis*

Vegetable Crops

Artichoke	*Helianthus tuberosus*
Beet, red	*Beta vulgaris*
Squash, zucchini	*Cucurbita pepo melopepo*

Fruit and Nut Crops

Fig	*Ficus carica*
Jujube	*Ziziphus jujuba*
Olive	*Olea europaea*
Papaya	*Carica papaya*
Pineapple	*Ananas comosus*
Pomegranate	*Punica granatum*

MODERATELY SENSITIVE [3]

Fibre, Seed and Sugar Crops

Broadbean	*Vicia faba*
Castorbean	*Ricinus communis*
Maize	*Zea mays*
Flax	*Linum usitatissimum*
Millet, foxtail	*Setaria italica*
Groundnut/Peanut	*Arachis hypogaea*
Rice, paddy	*Oryza sativa*
Sugarcane	*Saccarum officinarum*
Sunflower	*Helianthus annuus*

Grasses and Forage Crops

Alfalfa	*Medicago sativa*
Bentgrass	*Agrostis stolonifera palustris*
Bluestem, Angleton	*Dichanthium aristatum*
Brome, smooth	*Bromus inermis*
Buffelgrass	*Cenchrus ciliaris*
Burnet	*Poterium sanguisorba*
Clover, alsike	*Trifolium hydridum*
Clover, Berseem	*Trifolium alexandrinum*
Clover, ladino	*Trifolium repens*
Clover, red	*Trifolium pratense*
Clover, strawberry	*Trifolium fragiferum*
Clover, white Dutch	*Trifolium repens*
Corn (forage) (maize)	*Zea mays*
Cowpea (forage)	*Vigna unguiculata*
Dallis grass	*Paspalum dilatatum*
Foxtail, meadow	*Alopecurus pratensis*
Grama, blue	*Bouteloua gracilis*
Lovegrass	*Eragrostis sp.*
Milkvetch, Cicer	*Astragalus cicer*
Oatgrass, tall	*Arrhenatherum, Danthonia*
Oats (forage)	*Avena sativa*

Table 5 (continued)

MODERATELY SENSITIVE		SENSITIVE[3]	
Grasses and Forage Crops		**Fibre, Seed and Sugar Crops**	
Orchard grass	*Dactylis glomerata*	Bean	*Phaseolus vulgaris*
Rye (forage)	*Secale cereale*	Guayule	*Parthenium argentatum*
Sesbania	*Sesbania exaltata*	Sesame	*Sesamum indicum*
Siratro	*Macroptilium atropurpureum*		
Sphaerophysa	*Sphaerophysa salsula*	**Vegetable Crops**	
Timothy	*Phleum pratense*	Bean	*Phaseolus vulgaris*
Trefoil, big	*Lotus uliginosus*	Carrot	*Daucus carota*
Vetch, common	*Vicia angustifolia*	Okra	*Abelmoschus esculentus*
		Onion	*Allium cepa*
Vegetable Crops		Parsnip	*Pastinaca sativa*
Broccoli	*Brassica oleracea botrytis*		
		Fruit and Nut Crops	
Brussels sprouts	*B. oleracea gemmifera*	Almond	*Prunus dulcis*
Cabbage	*B. oleracea capitata*	Apple	*Malus sylvestris*
Cauliflower	*B. oleracea botrytis*	Apricot	*Prunus armeniaca*
Celery	*Apium graveolens*	Avocado	*Persea americana*
Corn, sweet	*Zea mays*	Blackberry	*Rubus sp.*
Cucumber	*Cucumis sativus*	Boysenberry	*Rubus ursinus*
Eggplant	*Solanum melongena esculentum*	Cherimoya	*Annona cherimola*
		Cherry, sweet	*Prunus avium*
Kale	*Brassica oleracea acephala*	Cherry, sand	*Prunus besseyi*
		Currant	*Ribes sp.*
Kohlrabi	*B. oleracea gongylode*	Gooseberry	*Ribes sp.*
Lettuce	*Latuca sativa*	Grapefruit	*Citrus paradisi*
Muskmelon	*Cucumis melo*	Lemon	*Citrus limon*
Pepper	*Capsicum annuum*	Lime	*Citrus aurantiifolia*
Potato	*Solanum tuberosum*	Loquat	*Eriobotrya japonica*
Pumpkin	*Cucurbita peop pepo*	Mango	*Mangifera indica*
Radish	*Raphanus sativus*	Orange	*Citrus sinensis*
Spinach	*Spinacia oleracea*	Passion fruit	*Passiflora edulis*
Squash, scallop	*Cucurbita pepo melopepo*	Peach	*Prunus persica*
Sweet potato	*Ipomoea batatas*	Pear	*Pyrus communis*
Tomato	*Lycopersicon lycopersicum*	Persimmon	*Diospyros virginiana*
		Plum: Prune	*Prunus domestica*
Turnip	*Brassica rapa*	Pummelo	*Citrus maxima*
Watermelon	*Citrullus lanatus*	Raspberry	*Rubus idaeus*
		Rose apple	*Syzgium jambos*
Fruit and Nut Crops		Sapote, white	*Casimiroa edulis*
		Strawberry	*Fragaria sp.*
Grape	*Vitis sp.*	Tangerine	*Citrus reticulata*

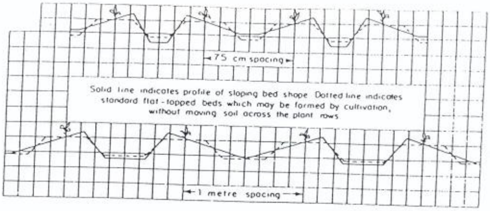
1 Data taken from Maas (1984).

2 These data serve only as a guide to the relative tolerances among crops. Absolute tolerances vary with climate, soil conditions and cultural practices.

3 The relative tolerance ratings are defined by the boundaries in Figure 10. Detailed tolerances can be found in Table 4 and Maas (1984).

FIG 8

a)

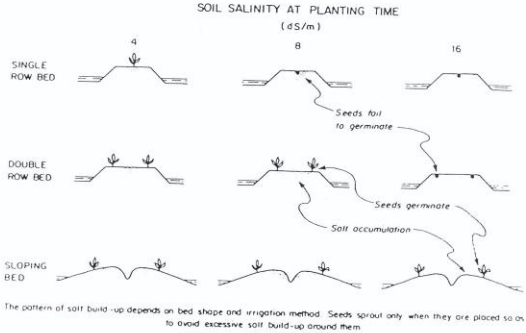


Sloping seedbeds (Bernstein and Ayers 1955)

b)

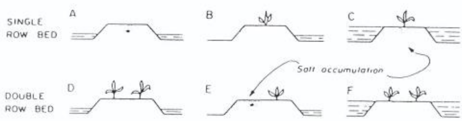
Sloping seedbeds used for salinity and temperature control

c)



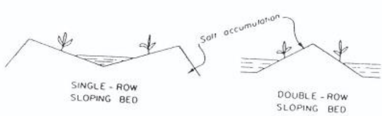
Bed shapes and salinity effects
(Bernstein, Fireman and Reeve 1955)

d)



Flat top beds and irrigation practice
(Bernstein, Fireman and Reeve 1975)

e)



Salinity control with sloping beds
(Bernstein and Fireman 1957)