Chapter 4 - Water quality assessment

In this chapter methods, criteria and standards for assessing the suitability of saline waters for crop production are discussed, along with concerns and limitations of using saline waters for irrigation.

Concerns and limitations

Salts exert both general and specific effects on plants which directly influence crop yield. Additionally, salts affect certain soil physico-chemical properties which, in turn, may affect the suitability of the soil as a medium for plant growth. The development of appropriate criteria and standards for judging the suitability of a saline water for irrigation and for selecting appropriate salinity control practices requires relevant knowledge of how salts affect soils and plants. This section presents a brief summary of the principal salinity effects that should be thoroughly understood in this regard.

Effects of Salts on Soils

The suitability of soils for cropping depends heavily on the readiness with which they conduct water and air (permeability) and on aggregate properties which control the friability of the seedbed (tilth). Poor permeability and tilth are often major problems in irrigated lands. Contrary to saline soils, sodic soils may have greatly reduced permeability and poorer tilth. This comes about because of certain physico-chemical reactions associated, in large part, with the colloidal fraction of soils which are primarily manifested in the slaking of aggregates and in the swelling and dispersion of clay minerals.

To understand how the poor physical properties of sodic soils are developed, one must look to the binding mechanisms involving the negatively charged colloidal clays and organic matter of the soil and the associated envelope of electrostatically adsorbed cations around the colloids, and to the means by which exchangeable sodium, electrolyte concentration and pH affect this association. The cations in the "envelope" are subject to two opposing processes:

- they are attracted to the negatively-charged clay and organic matter surfaces by electrostatic forces, and

- they tend to diffuse away from these surfaces, where their concentration is higher, into the bulk of the solution, where their concentration is generally lower.

The two opposing processes result in an approximately exponential decrease in cation concentration with distance from the clay surfaces into the bulk solution. Divalent cations, like calcium and magnesium, are attracted by the negatively-charged surfaces with a force twice as great as monovalent cations like sodium. Thus, the cation envelope in the divalent system is more compressed toward the particle surfaces. The envelope is also compressed by an increase in the electrolyte concentration of the bulk solution, since the tendency of the cations to diffuse away from the surfaces is reduced as the concentration gradient is reduced.

The associations of individual clay particles and organic matter micelles with themselves, each other and with other soil particles to form assemblages called aggregates are diminished when the cation "envelope" is expanded (with reference to the surface of the particle) and are enhanced when it is compressed. The like-electrostatic charges of the particles which repel one another and the opposite-electrostatic charges which attract one another are relatively long-range in effect. On the other hand, the adhesive forces, called Vanderwaal forces, and chemical bonding reactions involved in the particle-to-particle associations which bind such units into assemblages, are relatively short-range forces. The greater the compression of the cation "envelope" toward the particle surface, the smaller the overlap of the "envelopes" and the repulsion between adjacent particles for a given distance between them. Consequently, the particles can approach one another closely enough to permit the adhesive forces to dominate and assemblages (aggregates) to form.

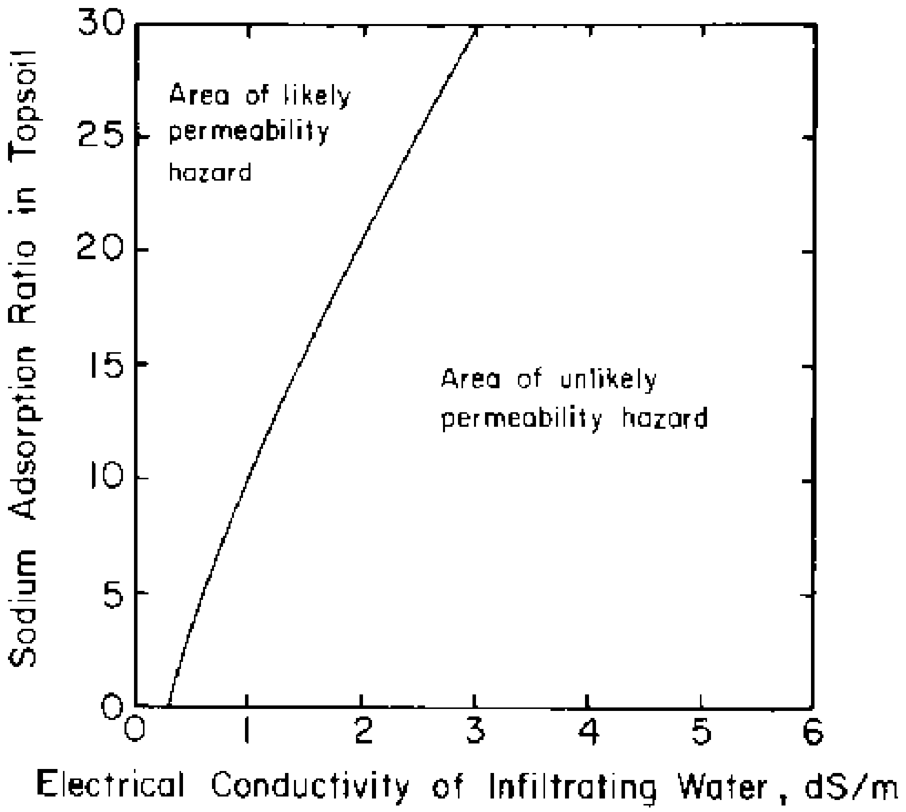
The phenomenon of repulsion between particles causes more soil solution to be imbibed between them (this is called swelling). Because clay particles are plate-like in shape and tend to be arranged in parallel orientation with respect to one another, swelling reduces the size of the inter-aggregate pore spaces in the soil and, hence, permeability. Swelling is primarily important in soils which contain substantial amounts of expanding-layer phyllosilicate clay minerals (smectites like montmorillonite) and which have ESP values in excess of about 15. The reason for this is that, in such minerals, the sodium ions in the pore fluid are first. attracted to the external surfaces of the clay plate. Only after satisfying this do the sodium ions occupy the space between the parallel platelets of the oriented and associated clay particles of the sub-aggregates (called domains) where they create the repulsion forces between adjacent platelets which lead to swelling.

Dispersion (release of individual clay platelets from aggregates) and slaking (breakdown of aggregates into subaggregate assemblages) can occur at relatively low ESP values (<15), provided the electrolyte concentration is sufficiently low. The packing of aggregates is more porous than that of individual particles or subaggregates, hence permeability and tilth are better in aggregated conditions. Repulsed clay platelets or slaked subaggregate assembles can lodge in pore interstices, also reducing permeability.

Thus, soil solutions composed of high solute concentrations (salinity), or dominated by calcium and magnesium salts, are conducive to good soil physical properties. Conversely, low salt concentrations and relatively high proportions of sodium salts adversely affect permeability and tilth. High pH (> 8) also adversely affects permeability and tilth because it enhances the negative charge of soil clay and organic matter and, hence, the repulsive forces between them.

During an infiltration event, the soil solution of the topsoil is essentially that of the infiltrating water and the exchangeable sodium percentage is essentially that pre-existent in the soil (since ESP is buffered against rapid change by the soil cation exchange capacity). Because all water entering the soil must pass through the soil surface, which is most subject to loss of aggregation, topsoil properties largely control the water entry rate of the soil. These observations taken together with knowledge of the effects of the processes discussed above explain why soil permeability and tilth problems must be assessed in terms of both the salinity of the infiltrating water and the exchangeable sodium percentage (or its equivalent SAR value) and the pH of the topsoil. Representative threshold values of SAR (- ESP) and the electrical conductivity of infiltrating water for maintenance of soil permeability are given in Figure 2. Because there are significant differences among soils in their susceptibilities in this regard, this relation should only be used as a guideline. The data available on the effect of pH are not yet extensive enough to develop the third axis relation needed to refine this guideline (Suarez *et al.* 1984; Goldberg and Forster 1990; Goldberg *et al.* 1990).

FIGURE 2: Threshold values of SAR of topsoil and EC of infiltrating water for maintenance of soil permeability (after Rhoades 1982)



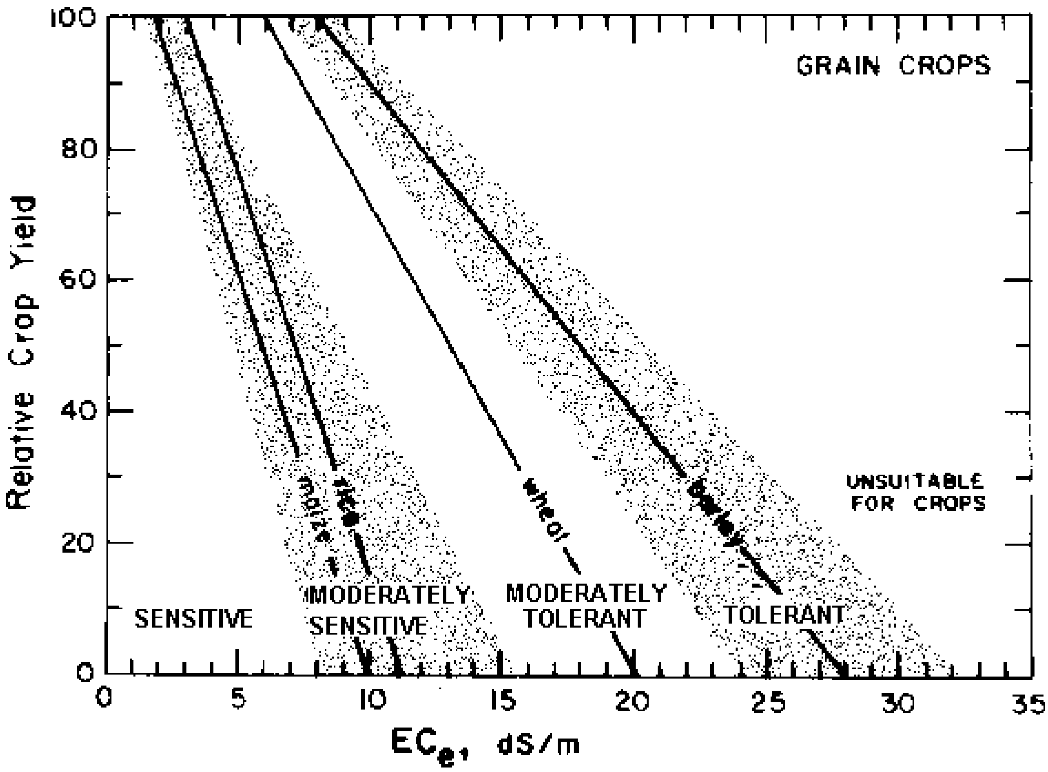
Decreases in the infiltration rate (IR) of a soil generally occur over the irrigation season because of the gradual deterioration of the soil's structure and the formation of a surface seal (horizontally layered arrangement of discrete soil particles) created during successive irrigations (sedimentation, wetting and drying events). IR is even more sensitive to exchangeable sodium, electrolyte concentration and pH than is hydraulic conductivity. This is due to the increased vulnerability of the topsoil to mechanical forces, which enhance clay dispersion, aggregate slaking and the movement of clay in the "loose" near-surface soil, and to the lower electrolyte concentration that generally exists there, especially under conditions of rainfall. Depositional crusts often form in the furrows of irrigated soils where soil particles suspended in water are deposited as the water flow rate slows or the water infiltrates. The hydraulic conductivity of such crusts is often two to three orders of magnitude lower than that of the underlying bulk soil, especially when the electrolyte concentration of the infiltrating water is low and exchangeable sodium is relatively high.

The addition of gypsum (either to the soil or water) can often help appreciably in avoiding or alleviating problems of reduced infiltration rate and hydraulic conductivity. For more specific information on the effects of exchangeable sodium, electrolyte concentration and pH, as well as of exchangeable Mg and K, and use of amendments on the permeability and infiltration rate of soils reference should be made to the reviews of Keren and Shainberg (1984); Shainberg (1984); Emerson (1984); Shainberg and Letey (1984); Shainberg and Singer (1990).

Effects of Salts on Plants

Excess salinity within the plant rootzone has a general deleterious effect on plant growth which is manifested as nearly equivalent reductions in the transpiration and growth rates (including cell enlargement and the synthesis of metabolites and structural compounds). This effect is primarily related to total electrolyte concentration and is largely independent of specific solute composition. The hypothesis that best seems to fit observations is that excessive salinity reduces plant growth primarily because it increases the energy that must be expended to acquire water from the soil of the rootzone and to make the biochemical adjustments necessary to survive under stress. This energy is diverted from the processes which lead to growth and yield.

FIGURE 3 Salt tolerance of grain crops (after Maas and Hoffman 1977)



Growth suppression is typically initiated at some threshold value of salinity, which varies with crop tolerance and external environmental factors which influence the need of the plant for water, especially the evaporative demand of the atmosphere (temperature, relative humidity, windspeed, etc.) and the water-supplying potential of the rootzone, and increases as salinity increases until the plant dies. The salt tolerances of various crops are conventionally expressed (after Maas and Hoffman 1977), in terms of relative yield (Y_r), threshold salinity value (a), and percentage decrement value per unit increase of salinity in excess of the threshold (b); where soil salinity is expressed in terms of EC_e, in dS/m), as follows:

$$Y_r = 100 - b\,(EC_e - a)$$

where Y_r- is the percentage of the yield of the crop grown under saline conditions relative to that obtained under non-saline, but otherwise comparable, conditions. This use of EC_e to express the effect of salinity on yield implies that crops respond primarily to the osmotic potential of the soil solution. Tolerances to specific ions or elements are considered separately, where appropriate.

Some representative salinity tolerances of grain crops are given in Figure 3 to illustrate the conventional manner of expressing crop salt tolerance. Compilations of data on crop tolerances to salinity and some specific ions and elements are given in Tables 12 to 21 (after Maas 1986; 1990).

TABLE 12 Relative salt tolerance of various crops at emergence and during growth to maturity (after Maas 1986)

Crop		**Electrical conductivity of saturated soil extract**	
Common name	**Botanical name**[1]	**50% yield dS/m**	**50% emergence**[2] **dS/m**
Barley	*Hordeum vulgare*	18	16-24
Cotton	*Gossypium hirsutum*	17	15
Sugarbeet	*Beta vulgaris*	15	6-12
Sorghum	*Sorghum bicolor*	15	13
Safflower	*Carthamus tinctorius*	14	12
Wheat	*Triticum aestivum*	13	14-16
Beet, red	*Beta vulgaris*	9.6	13.8
Cowpea	*Vigna unguiculata*	9.1	16
Alfalfa	*Medicago sativa*	8.9	8-13
Tomato	*Lycopersicon lycopersicum*	7.6	7.6
Cabbage	*Brassica oleracea capitata*	7.0	13
Maize	*Zea mays*	5.9	21-24
Lettuce	*Lactuca sativa*	5.2	11
Onion	*A/Hum cepa*	4.3	5.6-7.5
Rice	*Oryza sativa*	3.6	18
Bean	*Phaseolus vulgaris*	3.6	8.0

[1] Botanical and common names follow the convention of Hortus Third where possible.

[2] Emergence percentage of saline treatments determined when non-saline treatments attained maximum emergence.

It is important to recognize that such salt tolerance data cannot provide accurate, quantitative crop yield losses from salinity for every situation, since actual response to salinity varies with other conditions of growth including climatic and soil conditions, agronomic and irrigation management, crop variety, stage of growth, etc. While the values are not exact, since they incorporate interactions between salinity and the other factors, they can be used to predict how one crop might fare relative to another under saline conditions.

Climate is a major factor affecting salt tolerance; most crops can tolerate greater salt stress if the weather is cool and humid than if it is hot and dry. Yield is reduced more by salinity when atmospheric humidity is low. Ozone decreases the yield of crops more under non-saline than saline conditions, thus the effects of ozone and humidity increase the apparent salt tolerance of certain crops.

Plants are generally relatively tolerant during germination (see Table 12) but become more sensitive during emergence and early seedling stages of growth; hence it is imperative to keep salinity in the seedbed low at these times. If salinity levels reduce plant stand (as it commonly does), potential yields will be decreased far more than that predicted by the salt tolerance data given in Tables 13-15, since they apply to growth after seedling establishment.

Significant differences in salt tolerance occur among varieties of some species though this issue is confused because of the different climatic or nutritional conditions under which the crops were tested and the possibility of better varietal adaption in this regard. Rootstocks affect the salt tolerances of tree and vine crops because they affect the ability of the plant to extract soil water and the uptake and translocation to the shoots of the potentially toxic sodium and chloride salts.

TABLE 13 Salt tolerance of herbaceous crops[1] (after Maas 1986)

Crop		**Electrical conductivity of saturated soil extract**		**Rating[4]**
Common name	**Botanical name[2]**	**Threshold[3] dS/m**	**slope %/dS/m**	
Fibre, grain & special crops				
Barley[5]	*Hordeum vulgare*	8.0	5.0	T
Bean	*Phaseolus vulgaris*	1.0	19.0	S
Broadbean	*Vicia faba*	1.6	9.6	MS
Cotton	*Gossypium hirsutum*	7.7	5.2	T
Cowpea	*Vigna unguiculata*	4.9	12.0	MT
Flax	*Linum usitatissimum*	1.7	12.0	MS
Groundnut	*Arachis hypogaea*	3.2	29.0	MS
Guar	*Cyamopsis tetragonoloba*	8.8	17.0	T
Kenaf	*Hibiscus cannabinus*			MT
Maize[6]	*Zea mays*	1.7	12.0	MS
Millet, foxtail	*Setaria italica*			MS
Oats	*Avena sativa*			MT*
Rice, paddy	*Oryza sativa*	3.0[7]	12.0[7]	S
Rye	*Secale cereale*	11.4	10.8	T
Safflower	*Carthamus tinctorius*			MT
Sesame[8]	*Sesamum indicum*			S
Sorghum	*Sorghum bicolor*	6.8	16.0	MT
Soybean	*Glycine max*	5.0	20.0	MT
Sugarbeet[8]	*Beta vulgaris*	7.0	5.9	T
Sugarcane	*Saccharum officinarum*	1.7	5.9	MS
Sunflower	*Helianthus annuus*			MS*
Triticale	*X Triticosecale*	6.1	2.5	T
Wheat	*Triticum aestivum*	6.0	7.1	MT
Wheat (semidwarf)[10]	*T. aestivum*	8.6	3.0	T
Wheat, Durum	*T. turgidum*	5.9	3.8	T
Grasses & forage crops				
Alfalfa	*Medicago sativa*	2.0	7.3	MS
Alkaligrass, Nuttall	*Puccinellia airoides*			T*
Alkali sacaton	*Sporobolus airoides*			T*
Barley (forage)[5]	*Hordeum vulgare*	6.0	7.1	MT
Bentgrass	*A. stolonifera palustris*			MS
Bermudagrass[11]	*Cynodon dactylon*	6.9	6.4	T
Bluestem, Angleton	*Dichanthium aristatum*			MS*
Brome, mountain	*Bromus marginatus*			MT*
Brome, smooth	*B. inermis*			MS
Buffelgrass	*Cenchrus ciliaris*			MS*
Burnet	*Poterium sanguisorba*			MS*
Canarygrass, reed	*Phalaris arundinacea*			MT
Clover, alsike	*Trifolium hybridium*	1.5	12.0	MS
Clover, Berseem	*T. alexandrinum*	1.5	5.7	MS
Clover, Hubam	*Melilotus alba*			MT*
Clover, ladino	*Trifolium repens*	1.5	12.0	MS
Clover, red	*T. pratense*	1.5	12.0	MS

Clover, strawberry	*T. fragiferum*	1.5	12.0	MS
Clover sweet	*Melilotus*			MT*
Clover, white Dutch	*Trifolium repens*			MS*
Cowpea (forage)	*Vigna unguiculata*	2.5	11.0	MS
Dallisgrass	*Paspalum dilatatum*			MS*
Fescue, tall	*Festuca elatior*	3.9	5.3	MT
Fescue, meadow	*F. pratensis*			MT*
Foxtail, meadow	*Alopecurus pratensis*	1.5	9.6	MS
Grama, blue	*Bouteloua gracilis*			MS*
Hardinggrass	*Phalaris tuberosa*	4.6	7.6	MT
Kallargrass	*Diplachne fusca*			T*
Lovegrass[12]	*Eragrostis* sp.	2.0	8.4	MS
Maize (forage)[6]	*Zea mays*	1.8	7.4	MS
Milkvetch, Cicer	*Astragalus cicer*			MS*
Oatgrass, tall	*Arrhenatherum, Danthonia*			MS*
Oats (forage)	*Avena sativa*			MS*
Orchardgrass	*Dactylis glomerata*	1.5	6.2	MS
Panicgrass, blue	*Panicum antidotale*			MT*
Rape	*Brassica napus*			MT*
Rescuegrass, blue	*Bromus unioloides*			MT*
Rhodesgrass	*Chloris gayana*			MT
Rey (forage)	*Secale cereale*			MS*
Ryegrass, Italian	*Lolium italicum multiflorum*			MT*
Ryegrass, perennial	*L. perenne*	5.6	7.6	MT
Saltgrass, desert	*Distichlis stricta*			T*
Sesbania	*Sesbania exaltata*	2.3	7.0	MS
Sirato	*Macroptilium atropurpureum*			MS
Sphaerophysa	*Sphaerophysa salsula*	2.2	7.0	MS
Sudangrass	*Sorghum sudanense*	2.8	4.3	MT
Timothy	*Phleum pratense*			MS*
Trefoil, big	*Lotus uliginosus*	2.3	19.0	MS
Trefoil, narrowleaf birdsfoot	*L. corniculatus tenuifolium*	5.0	10.0	MT
Trefoil, broadleaf birdsfoot[13]	*L. corniculatus arvenis*			MT
Vetch, common	*Vicia angustifolia*	3.0	11.0	MS
Wheat (forage)[10]	*Triticum aestivum*	4.5	2.6	MT
Wheat, Durum (forage)	*T. turgidum*	2.1	2.5	MT
Wheatgrass, stand, crested	*Agropyron sibiricum*	3.5	4.0	MT
Wheatgrass, fairway crested	*A. cristatum*	7.5	6.9	T
Wheatgrass, intermediate	*A. intermedium*			MT*
Wheatgrass, slender	*A. trachycaulum*			MT
Wheatgrass, tall	*A. elongatum*	7.5	4.2	T
Wheatgrass, western	*A. smithii*			MT*
Wildrye, Altai	*Elymus angustus*			T
Wildrye, beardless	*E. triticoides*	2.7	6.0	MT
Wildrye, Canadian	*E. canadensis*			MT*

Wildrye, Russian	*E. junceus*			T
Vegetables & fruit crops				
Artichoke	*Helianthus tuberosus*			MT*
Asparagus	*Asparagus officinalis*	4.1	2.0	T
Bean	*Phaseolus vulgaris*	1.0	19.0	S
Beet, red[8]	*Beta vulgaris*	4.0	9.0	MT
Broccoli	*Brassica oleracea botrytis*	2.8	9.2	MS
Brussel sprouts	*B. oleracea gemmifera*	1.8	9.7	MS*
Cabbage	*B. oleracea capitata*	1.0	14.0	MS
Carrot	*Daucus carota*			S
Cauliflower	*Brassica oleracea botrytis*	1.8	6.2	MS*
Celery	*Apium graveolens*	2.5	13.0	MS
Cucumber	*Cucumis sativus*	1.1	6.9	MS
Eggplant	*Solanum melongena esculentum*			MS
Kale	*Brassica oleracea acephala*			MS*
Kohlrabi	*B. oleracea gongylode*	1.3	13.0	MS*
Lettuce	*Lactuca sativa*	1.7	12.0	MS
Maize, sweet	*Zea mays*			MS
Muskmelon	*Cucumis melo*			MS
Okra	*Abelmoschus esculentus*	1.2	16.0	S
Onion	*Allium cepa*			S
Parsnip	*Pastinaca sativa*			S*
Pea	*Pisum sativum*	1.5	14.0	S*
Pepper	*Capsicum annuum*	1.7	12.0	MS
Potato	*Solarium tuberosum*			MS
Pumpkin	*Cucurbita pepo pepo*	1.2	13.0	MS*
Radish	*Raphanus sativus*	2.0	7.6	MS
Spinach	*Spinacia oleracea*	3.2	16.0	MS
Squash, scallop	*Cucurbita pepo melopepo*	4.7	9.4	MS
Squash, zucchini	*C. pepo melopepo*	1	33	MT
Strawberry	*Fragaria* sp.	1.5	11	S
Sweet potato	*Ipomoea batatas*	2.5	9.9	MS
Tomato	*Lycopersicon lycopersicum*	0.9	9	MS
Turnip	*Brassica rapa*			MS
Watermelon	*Citrullus lanatus*			MS*

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

[2] Botanical and common names follow the convention of Hortus Third where possible.

[3] In gypsiferous soils, plants will tolerate EC_es about 2 dS/m higher than indicated.

[4] T = Tolerant, MT = Moderately Tolerant, MS = Moderately Sensitive and S = Sensitive. Ratings with an* are estimates.

[5] Less tolerant during seedling stage, EC_e at this stage should not exceed 4 or 5 dS/m.

[6] Grain and forage yields of DeKalb XL-75 grown on an organic muck soil decreased about 26% per dS/m above a threshold of 1.9 dS/m.

[7] Because paddy rice is grown under flooded conditions, values refer to the electrical conductivity of the soil water while the plants are submerged. Less tolerant during seedling stage.

[8] Sesame cultivars, Sesaco 7 and 8, may be more tolerant than indicated by the S rating.

[9] Sensitive during germination and emergence, EC_e should not exceed 3 dS/m.

[10] Data from one cultivar, "Probred".

[11] Average of several varieties. Suwannee and Coastal are about 20% more tolerant, and common and Greenfield are about 20% less tolerant than the average.

[12] Average for Boer, Wilman, Sand and Weeping cultavars. Lehmann seems about 50% more

[13] Broadleaf birdsfoot trefoil seems less tolerant than narrowleaf.

TABLE 14 Salt tolerance of woody crops[1] (after Maas 1986)

Crop		Electrical conductivity of saturated soil extract		Rating[4]
Common name	**Botanical name[2]**	**Threshold[3] dS/m**	**slope %/dS/m**	
Almond[5]	*Prunus duclis*	1.5	19.0	S
Apple	*Malus sylvestris*			S
Apricot[5]	*Prunus armeniaca*	1.6	24.0	S
Avocado[5]	*Persea americana*			S
Blackberry	*Rubus* sp.	1.5	22.0	S
Boysenberry	*Rubus ursinus*	1.5	22.0	S
Castorbean	*Ricinus communis*			MS*
Cherimoya	*Annona cherimola*			S*
Cherry, sweet	*Prunus avium*			S*
Cherry, sand	*P. besseyi*			S*
Currant	*Ribes* sp.			S*
Date palm	*Phoenix dactylifera*	4.0	3.6	T
Fig	*Ficus carica*			MT*
Gooseberry	*Ribes* sp.			S*
Grape[5]	*Vitis* sp.	1.5	9.6	MS
Grapefruit[5]	*Citrus paradisi*	1.8	16.0	S
Guayule	*Parthenium argentatum*	15.0	13.0	T
Jojoba[5]	*Simmondsia chinensis*			T
Jujube	*Ziziphus jujuba*			MT*
Lemon[5]	*Citrus limon*			S
Lime	*C. aurantiifolia*			S*

Loquat	*Eriobotrya japonica*			S*
Mango	*Mangifera indica*			S*
Olive	*Olea europaea*			MT
Orange	*Citrus sinensis*	1.7	16.0	S
Papaya[5]	*Carica papaya*			MT
Passion fruit	*Passiflora edulis*			S*
Peach	*Prunus persica*	1.7	21.0	S
Pear	*Pyrus communis*			S*
Persimmon	*Diospyros virginiana*			S*
Pineapple	*Ananas comosus*			MT*
Plum; prune[5]	*Prunus domestic a*	1.5	18.0	S
Pomegranate	*Punica granatum*			MT*
Pummelo	*Citrus maxima*			S*
Raspberry	*Rubus idaeus*			S
Rose apple	*Syzygium jambos*			S*
Sapote, white	*Casimiroa edulis*			S*
Tangerine	*Citrus reticulata*			S*

[1] These data are applicable when rootstocks are used that do not accumulate Na^+ or Cl^- rapidly or when these ions do not predominate in the soil.

[2] Botanical and common names follow the convention of Hortus Third where possible.

[3] In gypsiferous soils, plants will tolerate EC_es about 2 dS/m higher than indicated.

[4] T = Tolerant, MT = Moderately Tolerant, MS = Moderately Sensitive and S = Sensitive. Ratings with an* are estimates.

[5] Tolerance is based on growth rather than yield.

Table 15 Salt tolerance of ornamental shrubs, trees and ground cover[1] (after Maas 1986)

Common name	Botanical name	Maximum permissible[2] EC_e dS/m
Very sensitive		
Star jasmine	*Trachelospermum jasminoides*	1-2
Pyrenees cotoneaster	*Cotoneaster congestus*	1-2
Oregon grape	*Mahonia aquifolium*	1-2
Photinia	*Photinia × fraseri*	1-2
Sensitive		
Pineapple guava	*Feijoa sellowiana*	2-3
Chinese holly, cv. Burford	*Ilex cornuta*	2-3
Rose, cv. Grenoble	*Rosa sp.*	2-3
Glossy abelia	*Abelia × grandiflora*	2-3
Southern yew	*Podocarpus macrophyllus*	2-3
Tulip tree	*Liriodendron tulipifera*	2-3
Algerian ivy	*Hedera canariensis*	3-4
Japanese pittosporum	*Pittosporum tobira*	3-4
Heavenly bamboo	*Nandina domestica*	3-4
Chinese hibiscus	*Hibiscus rosa-sinensis*	3-4

Laurustinus, cv. Robustum	*Viburnum tinusm*	3-4
Strawberry tree, cv. Compact	*Arbutus unedo*	3-4
Crape Myrtle	*Lagerstroemia indica*	3-4
Moderately sensitive		
Glossy privet	*Ligustrum lucidum*	4-6
Yellow sage	*Lantana camara*	4-6
Orchid tree	*Bauhinia purpurea*	4-6
Southern Magnolia	*Magnolia grandiflora*	4-6
Japanese boxwood	*Buxus microphylla var. japonica*	4-6
Xylosma	*Xylosma congestum*	4-6
Japanese black pine	*Pinus thunbergiana*	4-6
Indian hawthorn	*Raphiolepis indica*	4-6
Dodonaea, cv. atropurpurea	*Dodonaea viscosa*	4-6
Oriental arborvitae	*Platycladus orientalis*	4-6
Thorny elaeagnus	*Elaeagnus pungens*	4-6
Spreading juniper	*Juniperus chinensis*	4-6
Pyracantha, cv. Graberi	*Pyracantha fortuneana*	4-6
Cherry plum	*Prunus cerasifera*	4-6
Moderately tolerant		
Weeping bottlebruch	*Callistemon viminalis*	6-8
Oleander	*Nerium oleander*	6-8
European fan palm	*Chamaerops humilis*	6-8
Blue dracaena	*Cordyline indivisa*	6-8
Spindle tree, cv. Grandiflora	*Euonymus japonica*	6-8
Rosemary	*Rosmarinus officinalis*	6-8
Aleppo pine	*Pinus halepensis*	6-8
Sweet gum	*Liquidamabar styraciflua*	6-8
Tolerant		
Brush cherry	*Syzygium paniculatum*	>8[3]
Ceniza	*Leucophyllum frutescens*	>8[3]
Natal palm	*Carissa grandiflora*	>8[3]
Evergreen pear	*Pyrus kawakamii*	>8[3]
Bougainvillea	*Bougainvillea spectabilis*	>8[3]
Italian stone pine	*Pinus pinea*	>8[3]
Very tolerant		
White iceplant	*Delosperma alba*	>10[3]
Rosea iceplant	*Drosanthemum hispidum*	>10[3]
Purple iceplant	*Lampranthus productus*	>10[3]
Croceum iceplant	*Hymenocyclus croceus*	>10[3]

[1] Species are listed in order of increasing tolerance based on appearance as well as growth reduction.

[2] Salinities exceeding the maximum permissible EC_e may cause leaf burn, loss of leaves, and/or excessive stunting.

[3] Maximum permissible EC_e is unknown. No injury symptoms or growth reduction was apparent at 7 dS/m. The growth of all iceplant species was increased by soil salinity of 7 dS/m.

Salt tolerance also depends somewhat upon the type, method and frequency of irrigation. As the soil dries, plants experience matric stresses, as well as osmotic stresses, which also limit water uptake. The prevalent salt tolerance data apply most directly to crops irrigated by surface (furrow and flood) methods and conventional irrigation management. Salt concentrations may differ several-fold within irrigated soil profiles and they change constantly. The plant is most responsive to salinity in that part of the rootzone where most of the water uptake occurs. Therefore, ideally, tolerance should be related to salinity weighted over time and measured where the roots absorb most of the water.

Sprinkler-irrigated crops are potentially subject to additional damage caused by foliar salt uptake and desiccation (burn) from spray contact of the foliage. For example, Bernstein and Francois (1973a) found that the yields of bell peppers were reduced by 59 percent more when 4.4 dS/m water was applied by sprinklers compared to a drip system. Meiri (1984) found similar results for potatoes. The information base available to predict yield losses from foliar spray effects of sprinkler irrigation is quite limited, though some data are given in Table 16. Susceptibility of plants to foliar salt injury depends on leaf characteristics affecting rate of absorption and is not generally correlated with tolerance to soil salinity. The degree of spray injury varies with weather conditions, especially the water deficit of the atmosphere. Visible symptoms may appear suddenly following irrigations when the weather is hot and dry. Increased frequency of sprinkling, in addition to increased temperature and evaporation, leads to increases in salt concentration in the leaves and in foliar damage.

While the primary effect of soil salinity on herbaceous crops is one of retarding growth, as discussed above, certain salt constituents are specifically toxic to some crops. Boron is such a solute and, when present in the soil solution at concentrations of only a few mg/l, is highly toxic to susceptible crops. Boron toxicities may also be described in terms of a threshold value and yield-decrement slope parameters, as is salinity. Available summaries are given in Tables 17 to 19. For some crops, especially woody perennials, sodium and chloride may accumulate in the tissue over time to toxic levels that produce foliar burn. Generally these plants are also salt-sensitive and the two effects are difficult to separate. Chloride tolerance levels for crops are given in Tables 20 and 21.

Sodic soil conditions may induce calcium, as well as other nutrient, deficiencies because the associated high pH and bicarbonate conditions repress the solubilities of many soil minerals, hence limiting nutrient concentrations in solution and, thus, availability to the plant.

TABLE 16 Relative susceptibility of crops to foliar injury from saline sprinkling water[1] (after Maas 1990)

Na or Cl conc ($mmol_c/l$) causing foliar injury[2]			
<5	**5-10**	**10-20**	**>20**
Almond	Grape	Alfalfa	Cauliflower
Apricot	Pepper	Barley	Cotton
Citrus	Potato	Cucumber	Sugarbeet
Plum	Tomato	Maize	Sunflower
		Safflower	
		Sesame	
		Sorghum	

[1] Susceptibility based on direct accumulation of salts through the leaves.

[2] Foliar injury is influenced by cultural and environmental conditions. These data are presented only as general guidelines for day-time sprinkling.

TABLE 17 Boron tolerance limits for agricultural crops (after Maas 1990)

Common name	Botanical name	Threshold[1] g/m^3	Slope % per g/m^3
Very sensitive			
Lemon[2]	*Citrus limon*	<0.5	
Blackberry[2]	*Rubus* sp.	<0.5	
Sensitive			
Avocado[2]	*Persea americana*	0.5-7.5	
Grapefruit[2]	*C. × paradisi*	0.5-7.5	
Orange[2]	*C. sinensis*	0.5-7.5	
Apricot[2]	*Prunus armeniaca*	0.5-7.5	
Peach[2]	*P. persica*	0.5-7.5	
Cherry[2]	*P. avium*	0.5-7.5	
Plum[2]	*P. domestica*	0.5-7.5	
Persimmon[2]	*Diospyros kaki*	0.5-7.5	
Fig, kadota[2]	*Ficus carica*	0.5-7.5	
Grape[2]	*Vitis vinifera*	0.5-7.5	
Walnut[2]	*Juglans regia*	0.5-7.5	
Pecan[2]	*Carya illinoiensis*	0.5-7.5	
Onion	*Allium cepa*	0.5-7.5	
Garlic	*A. sativum*	0.75-1.0	
Sweet potato	*Ipomoea batatas*	0.75-1.0	
Wheat	*Triticum aestivum*	0.75-1.0	3.3
Sunflower	*Helianthus annuus*	0.75-1.0	
Bean, mung[2]	*Vigna radiata*	0.75-1.0	
Sesame[2]	*Sesamum indicum*	0.75-1.0	
Lupine[2]	*Lupinus hartwegii*	0.75-1.0	
Strawberry[2]	*Fragaria sp.*	0.75-1.0	
Artichoke, Jerusalem[2]	*Helianthus tuberosus*	0.75-1.0	
Bean, kidney[2]	*Phaseolus vulgaris*	0.75-1.0	
Bean, snap	*P. vulgaris*	1.0	12
Bean, lima[2]	*P. lunatus*	0.75-1.0	
Groundnut	*Arachis hypogaea*	0.75-1.0	
Moderately tolerant			
Broccoli	*Brassica oleracea botrytis*	1.0	1.8
Pepper, red	*Capsicum annuum*	1.0-2.0	
Pea[2]	*Pisum sativa*	1.0-2.0	
Carrot	*Daucus carota*	1.0-2.0	
Radish	*Raphanus sativus*	1.0	1.4
Potato	*Solarium tuberosum*	1.0-2.0	
Cucumber	*Cucumis sativus*	1.0-2.0	
Lettuce	*Lactuca sativa*	1.3	1.7
Cabbage[2]	*Brassica oleracea capitata*	2.0-4.0	
Turnip	*B. rapa*	2.0-4.0	
Bluegrass, Kentucky[2]	*Poa pratensis*	2.0-4.0	
Barley	*Hordeum vulgare*	3.4	4.4
Cowpea	*Vigna unguiculata*	2.5	12
Oats	*Avena sativa*	2.0-4.0	
Maize	*Zea mays*	2.0-4.0	
Artichoke[2]	*Cynara scolymus*	2.0-4.0	
Tobacco[2]	*Nicotiana tabacum*	2.0-4.0	
Mustard[2]	*Brassica juncea*	2.0-4.0	
Clover, sweet[2]	*Melilotus indica*	2.0-4.0	

Squash	*Cucurbita pepo*	2.0-4.0	
Muskmelon[2]	*Cucumis melo*	2.0-4.0	
Cauliflower	*B. olearacea botrytis*	4.0	1.9
Tolerant			
Alfalfa[2]	*Medicago sativa*	4.0-6.0	
Vetch, purple[2]	*Vicia benghalensis*	4.0-6.0	
Parsley[2]	*Petroselinum crispum*	4.0-6.0	
Beet, red	*Beta vulgaris*	4.0-6.0	
Sugarbeet	*B. vulgaris*	4.9	4.1
Tomato	*Lycopersicon lycopersicum*	5.7	3.4
Very tolerant			
Sorghum	*Sorghum bicolor*	7.4	4.7
Cotton	*Gossypium hirsutum*	6.0-10.0	
Celery[2]	*Apium graveolens*	9.8	3.2
Asparagus[2]	*Asparagus officinalis*	10.0-15.0	

[1] Maximum permissible concentration in soil water without yield reduction. Boron tolerances may vary, depending upon climate, soil conditions and crop varieties.

[2] Tolerance based on reductions in vegetative growth.

These conditions can be improved through the use of certain amendments such as gypsum and sulphuric acid. Sodic soils are of less extent than saline soils in most irrigated lands. For more information on the diagnosis and amelioration of such soils see Rhoades (1982), Rhoades and Loveday (1990 and Keren and Miyamoto (1990).

Crops grown on fertile soil may seem more salt tolerant than those grown with adequate fertility, because fertility is the primary factor limiting growth. However, the addition of extra fertilizer will not alleviate growth inhibition by salinity.

For a more thorough treatise on the effects of salinity on the physiology and biochemistry of plants, see the reviews of Maas and Nieman (1978), Maas (1990) and Lauchli and Epstein (1990).

TABLE 18 Boron tolerances for ornamentals[1] (after Maas 1990)

Common name	Botanical name	Threshold[2] mg/l
Very sensitive		
Oregon grape	*Mahonia aquifolium*	<0.5
Photinia	*Photinia × fraseri*	<0.5
Xylosma	*Xylosma congestum*	<0.5
Thorny elaeagnus	*Elaeagnus pungens*	<0.5
Laurustinus	*Viburnum tinus*	<0.5
Wax-leaf privet	*Ligustrum japonicum*	<0.5
Pineapple guava	*Feijoa sellowiana*	<0.5
Spindle tree	*Euonymus japonica*	<0.5
Japanese pittosporum	*Pittosporum tobira*	<0.5
Chinese holly	*Ilex cornuta*	<0.5
Juniper	*Juniperus chinensis*	<0.5
Yellow sage	*Lantana camara*	<0.5
American elm	*Ulmus americana*	<0.5
Sensitive		
Zinnia	*Zinnia eleganus*	0.5-1.0

Pansy	*Viola tricolor*	0.5-1.0
Violet	*V. odorata*	0.5-1.0
Larkspur	*Delphinium* sp.	0.5-1.0
Glossy abelia	*Abelia × grandiflora*	0.5-1.0
Rosemary	*Rosmarinus officinalis*	0.5-1.0
Oriental arbovitae	*Platycladus orientalis*	0.5-1.0
Geranium	*Pelargonium × hortorum*	0.5-1.0
Moderately sensitive		
Gladiolus	*Gladiolus* sp.	1.0-2.0
Marigold	*Calendula officinalis*	1.0-2.0
Poinsettia	*Euphorbia pulcherrima*	1.0-2.0
China aster	*Callistephus chinensis*	1.0-2.0
Gardenia	*Gardenia* sp.	1.0-2.0
Southern yew	*Podocarpus marcophyllus*	1.0-2.0
Brush cherry	*Syzygium paniculatum*	1.0-2.0
Blue dracaena	*Cordyline indivisa*	1.0-2.0
Ceniza	*Leucophyllus frutescens*	1.0-2.0
Moderately tolerant		
Bottlebrush	*Callistemon citrinus*	2.0-4.0
California poppy	*Eschscholzia californica*	2.0-4.0
Japanese boxwood	*Buxus microphylla*	2.0-4.0
Oleander	*Nerium oleander*	2.0-4.0
Chinese hibiscus	*Hibiscus rosa-senensis*	2.0-4.0
Sweet pea	*Lathyrus odoratus*	2.0-4.0
Carnation	*Dianthus caryophyllus*	2.0-4.0
Tolerant		
Indian hawthorn	*Raphiolephis indica*	6.0-8.0
Natal palm	*Carissa grandiflora*	6.0-8.0
Oxalis	*Oxalis bowiei*	6.0-8.0

[1] Species listed in order of increasing tolerance based on appearance as well as growth reduction.

[2] Boron concentrations exceeding the threshold may cause leaf burn and loss of leaves.

TABLE 19 Citrus and stone fruit rootstocks ranked in order of increasing boron accumulation and transport to scions (after Maas 1990)

Common name	Botanical name
Citrus	
Alemow	*Citrus macrophylla*
Gajanimma	*C. pennivesiculata or C. moi*
Chinese box orange	*Severina buxifolia*
Sour orange	*C. aurantium*
Calamondin	*x. Citrofortunella mitis*
Sweet orange	*C. sinensis*
Yuzu	*C. junos*
Rough lemon	*C. limon*
Grapefruit	*C. x paradisi*
Rangpur lime	*C. x limonia*
Troyer citrange	*x Citroncirus webberi*

Savage citrange	*x Citroncirus webberi*
Cleopatra mandarin	*C. areticulata*
Rusk citrange	*x Citroncirus webberi*
Sunk! mandarin	*C. reticulata*
Sweet lemon	*C. limon*
Trifoliate orange	*Poncirus trifoliata*
Citrumelo 4475	*Poncirus trifoliate x C. paradisi*
Ponkan mandarin	*C. reticulata*
Sampson tangelo	*C. x tangelo*
Cuban shaddock	*C. maxima*
Sweet lime	*C. aurantiifolia*
Stone fruit	
Almond	*Prunus dulcis*
Myrobalan plum	*P. cerasifera*
Apricot	*P. armeniaca*
Marianna plum	*P. domestica*
Shalil peach	*P. persica*

TABLE 20 Chloride tolerance of agricultural crops. Listed in order of increasing tolerance (after Maas 1990)

Crop	Maximum Cl^- concentration[1] without loss in yield (threshold) mol/m^3	Percent decrease in yield at Cl' concentrations[1] above the threshold; (slope) % per mol/m^3
Strawberry	10	3.3
Bean	10	1.9
Onion	10	1.6
Carrot	10	1.4
Radish	10	1.3
Lettuce	10	1.3
Turnip	10	0.9
Rice, paddy[2]	30[3]	1.2[3]
Pepper	15	1.4
Clover, strawberry	15	1.2
Clover, red	15	1.2
Clover, alsike	15	1.2
Clover, ladino	15	1.2
Maize	15	1.2
Flax	15	1.2
Potato	15	1.2
Sweet potato	15	1.1
Broad bean	15	1.0
Cabbage	15	1.0
Foxtail, meadow	15	1.0
Celery	15	0.6
Clover, Berseem	15	0.6
Orchardgrass	15	0.6
Sugarcane	15	0.6
Trefoil, big	20	1.9
Lovegrass	20	0.8
Spinach	20	0.8
Alfalfa	20	0.7

Sesbania[2]	20	0.7
Cucumber	25	1.3
Tomato	25	1.0
Broccoli	25	0.9
Squash, scallop	30	1.6
Vetch, common	30	1.1
Wildrye, beardless	30	0.6
Sudangrass	30	0.4
Wheatgrass, standard crested	35	0.4
Beet, red[2]	40	0.9
Fescue, tall	40	0.5
Squash, zucchini	45	0.9
Hardinggrass	45	0.8
Cowpea	50	1.2
Trefoil, narrow-leaf birdsfoot	50	1.0
Ryegrass, perennial	55	0.8
Wheat, Durum	55	0.5
Barley (forage)[2]	60	0.7
Wheat[2]	60	0.7
Sorghum	70	1.6
Bermudagrass	70	0.6
Sugarbeet[2]	70	0.6
Wheatgrass, fairway crested	75	0.7
Cotton	75	0.5
Wheatgrass, tall	75	0.4
Barley[2]	80	0.5

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

[1] Cl^- concentrations in saturated soil extracts samples in the rootzone. To convert Cl' concentrations to ppm, multiply threshold values by 35. To convert % yield decreases to % per ppm, divide slope values by 35.

[2] Less tolerant during emergence and seedling stage.

[3] Values for paddy rice refer to the Cl" concentration in the soil water during the flooded growing conditions.

TABLE 21 Chloride tolerance limits of some fruit crop cultivars and rootstocks (after Maas 1990)

Crop	Rootstock or cultivar	Maximum permissible Cl' in soil water without leaf injury[1] (mol/m^3)
Rootstocks		
Avocado	West Indian	15
(*Persea americana*)	Guatemalan	12
	Mexican	10
Citrus	Sunki mandarin,	50

	grapefruit	
(*Citrus* sp.)	Cleopatra mandarin, Rangpur lime	50
	Sampson tangelo, rough lemon[2]	30
	Sour orange, Ponkan mandarin	30
	Citrumelo 4475, trifoliate orange	20
	Cuban shaddock, Calamondin	20
	Sweet orange. Savage citrange	20
	Rusk citrange, Troyer citrange	20
Grape	Salt Creek, 1613-3	80
(*Vitis* sp.)	Dog ridge	60
Stone fruit	Marianna	50
(*Prunus* sp.)	Lovell, Shalil	20
	Yunnan	15
Cultivars	Boysenberry	20
Berries[3]	Olallie blackberry	20
(*Rubus* sp.)	Indian Summer raspberry	10
Grape	Thompson seedless, Perlette	40
(*Vitis* sp.)	Cardinal, black rose	20
Strawberry	Lassen	15
(*Fragaria* sp.)	Shasta	10

[1] For some crops, these concentrations may exceed the osmotic threshold and cause some yield reduction.

[2] Data from Australia indicate that rough lemon is more sensitive to Cl" than sweet orange.

[3] Data available for one variety of each species only.

Effects of Salts on Crop Quality

Information on the effects of water salinity and/or soil salinity on crop quality is very scant although such effects are apparent and have been noticed under field conditions. In general, soil salinity, either caused by saline irrigation water or by a combination of water, soil and crop management factors, may result in: reduction in size of the produce; change in colour and appearance; and change in the composition of the produce.

Shalhevet *et al.* (1969) reported a reduction of seed size in groundnuts beginning at soil salinity levels (EC_e) of 3 dS/m. However, there is an increase in seed oil content with increasing salinity up to a point. Table 22 illustrates these effects.

In the case of tomatoes, it was reported (Shalhevet and Yaron 1973) that for every increase in 1.5 dS/m in mean EC_e beyond 2 dS/m, there was a 10 percent reduction in yield. The yield reduction was due only to reduction in fruit size and weight and not to reduction in fruit number. However, there was a marked increase in soluble solids in the extract, which may be an important criterion for tomato juice production. If ever tomato juice processors purchase tomatoes on the basis of total solids content, there would be no economic penalty for salinity in the range up to 6.0 dS/m in EC_e. Table 23 presents the results of this investigation.

The mean pH of the juice was 4.3 with no meaningful differences among treatments. Fruits from higher salinity treatments were less liable to damage and the number of spoiled fruits was less.

TABLE 22 Effect of soil salinity on seed weight and oil content in groundnuts (Shalhevet *et at.* 1969)

EC_e dS/m	Weight of 1000 seeds, g	Oil content % dry weight
1.74	774	48.9
2.92	690	49.0
3.16	676	50.2
4.41	656	47.6
5.61	470	46.2

Table 23 Effect of soil salinity on fruit weight and soluble solid content of tomatoes

EC_e dS/m	Weight per fruit g	% soluble solids	% spoiled fruits
1.6	68.5	4.5	15.5
3.8	59.5	4.5	17.7
6.0	55.8	4.8	12.3
10.2	51.9.	5.9	11.1

Meiri *et al.* (1981) reported that increased salinity reduced fruit size in muskmelons (*Cucumis melo*). However, ripening was accelerated by salinity. Bielorai *et al.* (1978) reported that grapefruit yield decreased with increase in chloride ion concentration; the yield reduction was caused more by reduction in fruit size and weight. Salinity effects on fruit quality were similar to those caused by water stress. Comparing the low and high salinity levels, there is an increase in soluble solids and tritratable acidity in the juice. There were no differences in juice content. Rhoades *et al.* (1989) obtained increases in the quality of wheat, melons and alfalfa from use of saline drainage water for irrigation.