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Testing Crops for Salinity Tolerance

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ABSTRACT

The capability of crops to grow on saline soils varies among species and depends on the concentration of salts present in the rootzone and on various environmental and cultural conditions. Information on the relative tolerance of different crops is essential to the successful management of salt-affected agricultural lands and waters. Results from over 50 years of research have produced salt tolerance data that relate yield reductions of over 90 different crops to soil salinity. These data are presented in tabular form and give threshold salinity values and percent yield reductions expected at salinities exceeding the threshold. The recommended procedure to acquire reliable data, the yield response function used to quantify salt tolerance data, and factors to consider when evaluating or using these data are also described.

INTRODUCTION

Sustained and profitable production of crops on salt-affected soils requires appropriate on-farm management decisions. Growers must know how plants respond to salinity, the relative tolerances of different crops and their sensitivity at different stages of growth, and how different soil and environmental conditions affect salt-stressed plants. For more than **50 years,** scientists at the U. S. Salinity Laboratory in Riverside have determined the responses of many important agricultural crops to soil and water salinity. The results of those studies as well as those obtained at various other locations are crucial for estimating potential yields of crops grown under different levels of salinity.

The most common effect of salinity on plants is a general stunting of growth. The plants usually appear normal, although if compared with nonstressed plants, they may have darker green leaves that, in some cases, are thicker and more succulent. Visual symptoms, such as leaf burn, necrosis, and defoliation occur in some species, particularly woody crops, but these symptoms are rare in herbaceous crops unless plants are severely stressed Consequently, it is difficult to diagnose a moderately salt-affected crop in the field without having a nonstressed crop nearby for comparison.

The most certain method to identify a salinity problem is to determine the salt concentration of the soil. If soil salinity in the rootzone exceeds the tolerance of the crop, yield losses can be estimated from the salt tolerance data.

Crop response to salinity can be quantified by plotting relative growth or yield as a continuous function of increasingly higher levels of soil salinity. This response function generally follows a sigmoidal relationship, i.e., yields tend to be independent of soil salinity, or decrease slowly, at low salt concentrations, then decrease at a greater, but relatively constant, rate at intermediate concentrations; and finally at high concentrations, they begin to decrease more slowly, approaching zero yield asymptotically. With some crops, plants may die before seed or fruit yields have reached zero, thus eliminating the lower part of the sigmoidal curve. In either case, yields at extreme salinity stress are too low to be of commercial value so that accuracy in this part of the response curve is not critical.

PLANT RESPONSE

Plant sensitivity to soil salinity continually changes during the growing season. Most crops are tolerant during germination, but the young developing seedlings are susceptible to injury during emergence from the soil and during early juvenile development. Once established, plants generally become increasingly tolerant during later stages of growth. One of the primary effects of salt stress is that it delays germination and seedling emergence. Delays can be fatal if the emerging seedlings, already weakened by salt stress, encounter additional stresses, such as water stress, extreme temperature fluctuations and/or soil crusting. Because of evaporation at the soil surface, the salt concentration in the seed bed is often greater than at deeper depths. Consequently, the juvenile roots of emerging seedlings are exposed to a greater degree of stress than indicated by the usual measurements of salinity made on composite soil samples taken from throughout the soil profile. The loss of plants during this crucial phase can reduce the plant population density to suboptimal levels and significantly reduce yields.

Experiments designed to test the relative effects of salt stress at different stages of growth indicate that sorghum '*(Sorghum bicolor* (L.) Moench), wheat *(Triticum aestivum* L.), and cowpea *(Vigna unguiculata* (L.) Walp.) are most sensitive during the vegetative and early reproductive stages, less sensitive during flowering, and least sensitive during the grain-filling stage (Maas et al., 1986; Maas and Poss, 1989a; 1989b). Suppression of tiller formation is the most serious effect of salt stress during the vegetative and early reproductive stage of cereals. Apparently, most crops become more tolerant at later stages of growth, but there are some exceptions. For example, salt stress affects pollination of some rice (Oryza ***sativa*** L.) cultivars, thereby decreasing seed set and grain yield. (see Maas and Grattan, 1994, for further discussion and references).

ESTABLISHMENT OF EXPERIMENTS

Traditionally, salt tolerance data have been obtained in small experimental plots. To the extent possible, crops are grown according to commercial practices with adequate moisture and nutrients. Several salinity treatments (preferably six or more, replicated three times) are imposed by irrigating the test crop with artificially-salinized water. A mixture of NaCl and $CaCl_2$ (1:l by wt.) is added to nonsaline irrigation water to obtain a range of salt concentrations that cause yield reductions of 0 to 50% or more. The soil profiles are leached with the respective treatment waters to presalinize the expected rootzone. However, to ensure an acceptable plant stand, all plots are irrigated with approx. 5 cm of nonsaline water just prior to sowing to provide a nonsaline seedbed. Saline irrigations are imposed after the seedlings have emerged and are continued throughout the growing season.

The soil should be sufficiently permeable to allow adequate leaching. Without leaching, salt concentration increases with depth in the rootzone and can vary from that of the irrigation water near the soil surface to concentrations many times higher at the bottom of the rootzone. With such variable salinity, it is difficult to estimate the degree of salt stress to which the plant is responding. Even with the recommended leaching fraction of 50%, salt concentrations roughly double from the top to the bottom of the rootzone.

Having accurate measurements of soil salinity in the rootzone during the growing season is essential to obtain reliable salt tolerance data. **This** requires monitoring salinity at several depths at various times during the season. These salinity values are averaged to estimate the mean soil salinity encountered by the crop. Soil salinity is conveniently estimated from the electrical conductivity **(EC)** of water extracted from the soil at some reference water content, e.g. that present in a saturated soil paste. Although the EC of the saturated-soil extract (EC,) is approximately half that of the soil water at field capacity, it has commonly been used to express the salinity of the soil. It is a reproducible value that is directly proportional to the salt concentration in the soil water. For further details and a description of other methods that measure EC of the soil water directly or indirectly, the reader is referred to Rhoades and Miyamoto (1990).

Many soil and environmental factors interact with salinity to influence crop salt tolerance. Therefore, these factors must be considered before planning any salt tolerance experiments. The soil should be adequately fertilized because the lack of nutrients, rather than salinity, can be the primary factor limiting growth. Plants tested on infertile soils, therefore, may appear more salt tolerant than those grown on fertile soils. Maintaining adequate soil water throughout the growing season is also essential to obtain reliable data. If water is limiting, plants not only must endure water stress, but they are exposed to higher salt concentrations as they extract and concentrate the soil water. It should be noted that salt-stunted plants grown in saline treatments will probably require less water than normal-sized control plants.

The sorghum experiment described by Francois et al. (1984) is typical of the salt tolerance experiments conducted by the U. S. Salinity Laboratory. Usually, two cultivars are tested simultaneously in 6-m-square plots. Including additional cultivars in the small plots, while desirable, compromises the reliability of the plant growth and yield data. Our experience also indicates that six levels of salinity replicated three times are required to obtain reliable data. Furthermore, experiments are normally repeated a second year and the data are combined, although only one year's data were reported for sorghum. The two cultivars, Asgrow Double TX and Northrup Ring NK-265, responded alike to increasing soil salinity. A similar experiment was conducted at Brawley, CA on two cultivars of pearl millet (*Pennisetum glaucum* (L.) R. Br, cvs. 18DB and 23DB). The reduction in shoot dry matter production with increasing salinity indicated that pearl millet is moderately tolerant (L. E. Francois, personal communication). Unfortunately, seed production was well below normal, possibly because pollination was affected by the extreme summer temperatures. The only known data on seed yield also indicate that pearl millet is moderately tolerant (Singh and Chandra, 1979).

YIELD RESPONSE CURVE

Maas and Hoffman (1977) proposed that the yield response curve for agricultural crops could be represented by two linear lines, one, a horizontal line depicting no response to increasing salinity at low concentrations, and the second, a concentration-dependent line whose slope indicates the yield reduction per unit increase in salinity at higher concentrations. The point at which the two lines intersect designates the “threshold”, i.e. the maximum soil salinity that does not reduce yield below that obtained under nonsaline conditions. Figure 1 shows the two-piece model fitted to actual grain yields obtained in a salt tolerance experiment on corn (Zea mays L.). This two-piece linear response function provides a reasonably good fit for commercially acceptable yields when plotted against time- and depth-averaged salinity in the rootzone. For soil salinities exceeding the threshold of any given crop, relative yield (Y_r) can be estimated with the following equation:

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

where a = the salinity threshold expressed in dS/m (1 dS/m = 1 mmho/cm); b = the yield reduction, or slope, expressed in % per dS/m; and EC, = the mean electrical conductivity of saturated-soil extracts taken from the root-zone.

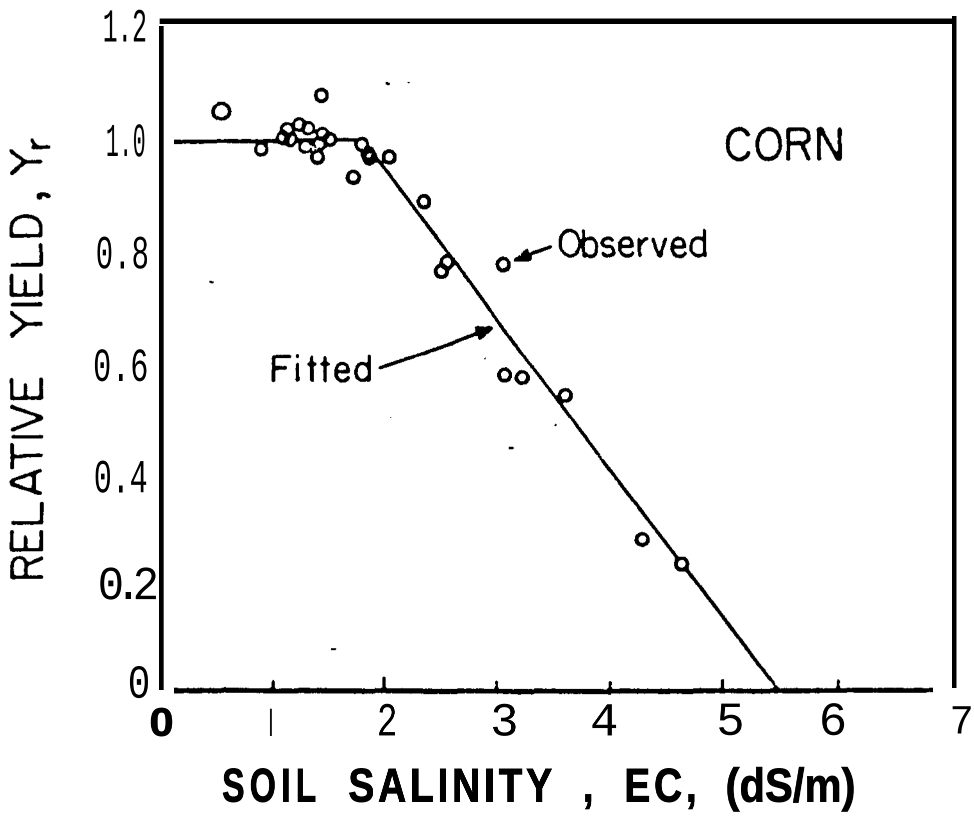

Fig.1. **The** piece-wise linear response **function fitted to actual yield data obtained from corn. Data from Hoffman et al. (1983).**

SALT-RESPONSE THRESHOLDS

Tables 1 and 2 list threshold and slope values for over 90 crops in terms of EC,. Most of the data were obtained where crops were grown under conditions simulating recommended cultural and management practices for commercial production. Consequently, they indicate relative tolerances of different crops grown under different conditions and not under some standardized set of conditions. Furthermore, the data apply only where crops are exposed to fairly uniform salinities from the late seedling stage to maturity. Where crops have particularly sensitive stages, the tolerance limits are given in the footnotes. These data are also intended to apply where chloride is the predominant anion. Plants grown on gypsiferous soils will tolerate EC_e's approximately 2 dS m^{-1} higher than those listed in Table 1. The last column provides a qualitative salt tolerance rating that is useful in categorizing crops in general terms. The limits of these categories are illustrated in Figure 2. Some crops are listed with only a qualitative rating because experimental data are inadequate to calculate the threshold and slope.

Table 1. Salt tolerance of herbaceow crops.'

Common name	Botanical name[b]	Tolerance based on:	Threshold[c] (EC_e) dS/m	Slope (% per dS/m)	Rating[d]
Fiber, grain, and special crops					
Artichoke, Jerusalem	Hellanthus tuberosus L.	Tuber yield	0.4	9.6	MS
Barley[e]	*Hordeum vulgare L.*	Grain yield	8.0	5.0	T
Canola or rapeseed	Brassica campestris L [syn. B. rapa L.]	Seed yield		–	T
Canola or rapeseed	*B.napus L*	Seed yield		–	T
Chick pea	Clcer *arietinum* L	Seed yield			MS
Corn'	Zea mays L.	Ear FW	1.7	12	MS
Cotton	Gossyplum *hirsutum* L	Seed cotton yield	7.7	5 2	T
Crambe	Crambe abyssinica Hochst. ex R.E. Fries	Seed yield	2.0	8.5	MS
Flax	*Unum usitatissimum L*	seed yield	1.7	12	MS
Guat	*Cyamopsis tetragonoloba* (L). Taub.	Seed yield	8.8	17	T
Kenal	Hibiscus *cannabinus* L	stem DW	8.1	11 .6	T
Mllet. channel	*Echinochloa tumerana (Domln)* J.M. Black	Grain yield			T
Millet, pearl	*Pennisetum gloucum* (L) R.Br	Seed yield		–	MT'
Oats	Avena sativa L	Grain yield	–	–	T
Peanut	Arachis *hypogaea* L.	Seed yield	3.2	29	MS
Rice	*Oryza* sativa L	Grain yield	3.0[g]	12[g]	S
Roselle	Hibiscus *sabdaniffa* L.	Stem DW	–	–	MT
Rye	Secale cereale L.	Grain yield	11.4	10.8	T
Safflower	Carthamus tinctorius L.	Seed yield	–	–	MT
Sesame[h]	*Sesamum indicum* L.	PodDW	–		S
Sorghum	*Sorghum bicolor* (L.) Moench	Grain yield	6.8	16	MT
Soybean	*Glycine* max (L.) Merrill	Seed yield	5.0	20	MT
Sugarbeet[i]	Beta vulgaris L.	Storage root	7.0	5.0	T
Sugarcane	*Saccharum officinarum* L	Shoot DW	1.7	5.9	MS
Sunflower	Hellanthus *annuus* L.	Seed yield	–	–	MT
Triticate	X *Triticosecale* Wittmack	Grain yield	6.1	2.5	T

Comm on name	Botanical name[b]	Tolerance based on:	Threshold[c] (EC.) dS/m	Slope(% per dS/m)	Rating[d]
Wheat	*Triticum aestivum* L	Grain yield	6.0	7.1	MT
Wheat (semidwarf)[j]	*T. aestivum* L	Grain yield	8.6	3.0	T
Wheat, Durum	*T. turgidum* L var. *durum* Dest.	Grain yield	5.9	3.6	T
Grasses and forage crops					
Alfalfa	Medicago *sativa* L	Shoot DW	2.0	7 9	MS
Alkaligrass, Nuttall	Puccinella alroldes (N ats. & Coult	Shoot DW		—	T*
Alkali sacaton	Sporobolus alroides To	Shoot DW			T*
Barley (forage)*	Hordeum vulgare L.	Shoot DW	6.0	7.1	MT
Bentgrass, creeping	Agrostis stolonifera L	Shoot DW	—	—	MS
Bermudagrass[k]	Cynodon dactylon (L) Pem.	Shoot DW	6.9	6.4	T
Bluestem, Angleton	Dichanthium aristatum (Polr.) C.E. Hubb. [syn. Andropogon nodosus (Willem) Nash]	Shoot DW			MS*
Broadbean	Vida faba L.	Shoot DW	1.0	9.6	MS
Brome, mountain	Bromus marginatus Nees ex Steud.	Shoot DW	—		MT*
Brome. smooth	B. Inermis Leyss	Shoot DW	—		MT
Buffelgrass	Pennisetum *cilare* (L). Unk. [syn. *Cenchrus cillaris*]	Shoot DW	—		MS*
Bumet	*Poterium sanguisorba* L.	Shoot DW	—		MS*
Canarygrass, read	*Phalaris arundinacea* L	Shoot DW	—	—	MT
Clover, alsike	*Trifolium hybridum* L	Shoot DW	1 . 5	12	MS
Clover, Berseem	*T. alexandrinum* L.	Shoot DW	1.5	5.7	MS
Clover, Hubam	*Melilotus alba* Dost. var. *annua* H.S. Coe	Shoot DW	—		MT*
Clover, ladino	*Trifoloim repens* L.	Shoot DW	1.5	12	MS
Clover, Persian	*T. resupinatum* L	Shoot DW	—		MS*
Clover, red	*T. pratense* L	Shoot DW	1.5	12	MS
Clover, strawberry	*T. fragiferum* L	Shoot DW	1.5	12	MS
Clover, sweet	*Melilotus* sp. Ml.	Shoot DW	—	—	MT*
Clover, white Dutch	*Trifolium repens* L	Shoot DW	—		MS*
Corn (forage)	*Zea* mays L	Shoot DW	1.6	7.4	MS
Cowpea(forage)	*Vigna unguiculata* (L.) Walp.	Shoot DW	2.5	11	MS
Dallsgrass	*Paspalum dilatatum* Pdr.	Shoot DW	—		MS*
Dhalncha	*Sesbania bispinosa* (Linn.) W.F. Wlght [syn. *Sesbania aculeata* (Willd.) Pdr)	Shoot DW	—	—	MT
Fescue. tall	*Festuca elatior* L [syn. *F. arundinacea*]	Shoot DW	3.9	5.3	MT
Fescue. meadow	*Festuca pratensis* Huds.	Shoot DW			MT*
Foxtail. meadow	*Alopecurus pratensis* L	Shoot DW	1.5	9.6	MS
Glycine	*Neonotonia wightii* [syn. *Glycine wightii* or *javanica*]	Shoot DW	—		MS
Gram, black or Urd bean	*Vigna mungo* (L.) Hepper [syn. *Phaseolus mungo* L.]	Shoot DW	—		S
Grama. blue	*Bouteloua gracilis* (HBK) Lag. ox Steud.	Shoot DW		—	MS*
Guinea grass	*Panicum maximum* Jacq.	Shoot DW		—	MT
Hardlnggrass	*Phalaris tuberosa* L var. *stenoptera* (Hack) A.S. Hitchc.	Shoot DW	'4.6	7.6	MT
Kallargrass	*Leptochloa fusca* (L) Kunth [syn. *Diplachne fusca* Beauv.]	Shoot DW	—	—	T
Lablab bean	*Lablab purpureus* (L) Sweet [syll. *Dolichos lablab* L.]	Shoot DW	—	—	MS
Lovegrass[j]	*Eragrostis* sp. N.M. Wolf	Shoot DW	2.0	6.4	MS
Mikvetch, Cicer	*Astragalus cicer* L.	Shoot DW	—	—	MS*
Millet, Foxtail	*Setaria italica* (L.) Beauvois	Dry matter	—		MS
Millet, pearl	*Pennisetum gloucum* (L) R. Br	Dry matter	—	—	MT'

cmlrnm name	Botanical name[b]	Tolerance based m:	Threshold[c] (EC.)	Slope (% dS/m per dS/m)	Rating[d]
Oatgrass, tall	*Arrhenatherum elatius* (L) Beauvois ex J. Presl & K. Presl	Shoot DW	—	—	MS*
Oats (forage)	*Avena sativa* L	Straw DW	—	—	T
Orchardgrass	*Dactylis glomerata L*	shoot DW	1.5	6.2	MS
Panicgrass, blue	*Panicum antidotale* Retz.	Shoot DW	—	—	MS*
Pigeon pea	*Cajanus cajan* (L.) Hum [syn. C. *indicus* (K..) Spre .	Shoot DW	—	—	S
Rape (forage)	*Brassica napus* L			—	MT'
Rescuegrass	*Bromus unioloides* HBK	Shoot DW	—	—	MT'
Rhodesgrass	*Chloris Gayana* Kunth.	Shoot DW	—	—	MT
Rye (forage)	*Secale cereale* L	Shoot DW	7.8	4.9	T
Ryegrass, Italian	*Lolium multiflorum Lam.*	Shoot DW	—	—	MT'
Ryegrass, perennial	*Lolium perenne* L	Shoot DW	5.6	7.8	MT
Ryegrass, Wimmera	*L rigidum* Gaud.		—		MT*
Saltgrass, desert	*Distichlis spicta* L var. *stricta* (Torr.) Bettle	Shoot DW	—	—	T*
Sesbania	*Sesbania exaltata* (Raf.) V.L Cory	Shoot DW	2.3	7.0	MS
Sirato	*Macroptilium atropurpureum (DC.)* Urb.	Shoot DW	—	—	MS
Sphaerophysa	*Sphaerophysa salsula* (Pall.) DC	Shoot DW	2 2	7.0	MS
Sudangrass	*Sorghum bicolor* (L) Moench [syn. *S. sudanense* (Piper) Stapf]	Shoot DW	2.9	4.3	MT
Timothy	*Phleum pratense* L	Shoot DW	—	—	MS*
Trefoil. big	Lotus *pedunculatus C*	Shoot DW	2.3	19	MS
Trefoil, narrowleaf birdsfoot	*L corniculatus* var *tenuifolium* L	Shoot DW	5.0	10	MT
Trefoil, broadleaf birdsfoot	*L corniculatus* L var *arvenis* (Schkuhr) Ser.ex DC	Shcat DW	—	—	MS
Vetch, common	*Vicia angustifolia* L	Shoot DW	3.0	11	MS
Wheat (forage)[j]	*Triticum aestivum* L	Shoot DW	4.5	2.0	MT
Wheat Durum (forage)	*T. turgidum* L. var *durum* Desf.	Shoot DW	2.1	2.5	MT
Wheatgrass, standard crested	*Agropyron sibiricum* (Willd.) Beauvois	Shoot DW	3.5	4.0	MT
Wheatgrass, fairway crested	A *cristatum* (L.) Gaerm.	Shmt DW	7.5	9.9	T
Wheatgrass, intermediate	A *intermedium* (Host) Beauvois	Shoot DW		—	MT*
Wheatgrass, slender	A *trachycaulum* (Link) Malte	Shoot DW	—	—	MT
Wheatgrass, tall	A *elongatum* (Hort) Beauvois	Shoot DW	7.5	4 2	T
Wheatgrass, western	A. *smithii* Rydb.	Shoot DW	—	—	MT'
Wildrye. Altai	*Elymus angustus* Trin.	Shcat DW	—	—	T
Wildrye, beardass	*E. triticoides* Buckl.	Shoot DW	2.7	6.0	MT
Wildrye. Canadian	*E. canadensis* L.	Shoot DW	—	—	MT'
Wildrye. Russian	*E. junceus* Fisch.	Shoot DW	—	—	T
Vegetables and fruit crops					
Artichoke	*Cynara scolymus* L	Head yield	—	—	MT*
Asparagus	Asparagus *officinalis* L	Spear yield	4.1	2.0	T
Bean, common	*Phaseolus vulgaris* L	Seed yield	1.0	19	S
Bean, lima	*P. lunatus* L.	Seed yield	—	—	MT*
Bean. mung	*Vigna radiata* (L.) A. Wilcz	Seed yield	1.9	20.7	S
Cassava	*Manihot esculenta* Crantz	Tuber yield	—	—	MS
Beet, red'	*Beta vulgaris* L	Storage root	4.0	9.0	MT
Broccoli	*Brassica oleracea* L. (Botrytis Group)	Shoot FW	2.8	9.2	MS
Brussel Sprouts	*B. oleracea* L (Gemmifera Group)			—	MS*
Cabbage	8. *oleracea* L. (Capitata Group)	Head FW	1.9	9.7	MS

cmlmon name	Botanical name[b]	Tolerance based on:	Threshold[c] (EC_e) dS/m	Slope (% per dS/m)	Rating[d]
Carrot	*Daucus carota* L	Storage root	1.0	14	S
Cauliflower	*Brassica oleracea* L (Botrytis Group)		—	—	MS[*]
Celery	*Apium graveolens* L var *dulce* (Mill.) Pen.	Petiole FW	1.6	6.2	MS
Corn, sweet	*Zea mays* L	Ear FW	1.7	12	MS
Cowpea	*Vigna unguiculata* (L.) Walp.	Seed yield	4.9	12	MT
Cucumber	*Cucumis sativus* L	Fruit yield	2.5	13	MS
Eggplant	*Solanum melongena* L. var *esculentum* Nees.	Fruit yield	1.1	6.9	MS
Garlic	*Allium sativum* L	Bulb yield	1.7	10	MS
Gram. black or Urd bean	*Vigna mungo* (L) Hepper [syn. *Phaseolus mungo* L.]	Shoot DW			S
Kale	*Brassica oleracea* L (Acephala Group)		—		MS[*]
Kohlrabi	*Brassica oleracea* L (Gongylodes Group)		—	—	MS[*]
Lettuce	*Lactuca sativa* L	Top FW	1.3	13	MS
Muskmelon	*Cucumis melo* L. (Reticulatus Group)	Fruit yield	1.0	6.4	MS
Okra	*Abelmoschus esculentus* (L) Moench	Pod yield	—	—	MS
Onion (bulb)	*Allium cepa* L	Bulb yield	1.2	16	S
Onion (seed)		Seed yield	1.0	6.0	MS
Parsnip	*Pastinaca sativa* L		—	—	S[*]
Pea	*Pisum sativum* L	Seed FW	3.4	10.0	MS
Pepper	*Capsicum annuum* L	Fruit yield	1.5	14	MS
Pigeon pea	*Cajanus cajan* (L) Huth [syn *C. indicus* (K.) Spreng.]	Shoot DW	—	—	S
Potato	*Solanum tuberosum* L	Tuber yield	1.7	12	MS
Pumpkin	*Cucurbita pepo* L var *Pepo*		—	—	MS[*]
Purslane	*Portulaca oleracea* L	Shoot FW	6.3	9.6	MT
Radish	*Raphanum sativus* L	Storage root	1.2	13	MS
Spinach	*Spinacia oleracea* L	Top FW	2.0	7.6	MS
Squash, scallop	*Cucurbita pepo* L var *melopepo* (L) Alef.	Fruit yield	3.2	16	MS
Squash, zucchini	*C. pepo* L var *melopepo* (L) Alef.	Fruit yield	4.7	9.4	MT
Strawberry	*Fragaria* x *Ananassa* Duch.	Fruit yield	1.0	33	S
Sweet potato	*Ipomoea batatas* (L) Lam.	Fleshy root	1.5	11	MS
Tepary bean	*Phaseolus acutifolius* Gray		—	—	MS[*]
Tomato	*Lycopersicon lycopersicum* (L) Karst ex Farw. [syn. *Lycopersicon esculentum* Mi .]	Fruit yield	2.5	9.9	MS
Tomato, cherry	*L. lycopersicum* var. *Cerasiforme* (Dunal) Alef.	Fruit yield	1.7	9.1	MS
Turnip	*Brassica rapa* L (Rapifera Group)	Storage root	0.9	9.0	MS
Turnip (greens)		Top FW	3.3	4.3	MT
Watermelon	*Citrullus lanatus* (Thunb.) Matsum. & Nakai	Fruit yield	—	—	MS[*]
Winged bean	*Psophocarpus tetragonolobus* L. D.C.	Shoot DW	—	—	MT

[a] These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending on climate, soil conditions, and cultural practices. Source: Maas and Grattan (1994).

[b] Botanical and common names follow convention of Hortus Third (Liberty Hyde Bailey Hortorium Staff, 1976) if possible.

[c] In gypsiferous soils, plants will tolerate EC_e's about 2 dS/m higher than indicated.

[d] Ratings are defined by the boundaries in Figure 2. Ratings with an * are estimates.

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

[f] Grain and forage yields of DeKalb XL-75 grown m an organic mu& soil decreased about 26% per dS/m above a threshold of 1.9 dS/m (Hoffman et al.. 1963).

[g] 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.

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

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

[j] Data from one cultivar, 'Probred'.

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

[l] Average for Boer, Wilman, Sand, and Weeping cultivars. Lehmann seems about 50% more tolerant.

Table 2. **Salt** tolerance of woody **crops**[a].

Common name	Botanical name[b]	Td erance based on:	Thresholds (EC_e) dS/m	Slope % per dS/m	Rating[d]
Almond	*Prunus ducils* (MI.) DA. Web4	Shoot growth	1.5	10	S
Apple	*Malus sylvestris* MII.		—	—	S
Apricot	*Prunus armeniaca* L	Shoot growth	1.6	24	S
Avocado	*Persea americana* MII.	Shoot growth		—	S
Banana	*Musa acuminata* Cd la	Fruit yield	—	—	S
Blackberry	*Rubus macropetalus* Doug. ex Hook	Fruit yield	1.5	22	S
Boysenberry	*Rubus ursinus* Cham. and Schlechtend	Fruit yield	1.5	22	S
Castorbean	*Ricinus communis* L .			—	MS*
Cherimoya	*Annona cherimola* MII.	Fdlar injury		—	S
Cherry. sweet	*Prunus avium* L	Foliar injury	—	—	S*
Cherry, sand	*Prunus besseyi* L. H. Baley	Fdlar Injury. stem growth		—	S*
Coconut	Cocos *nucifera* L		—	—	MT*
Currant	*Ribes* sp. L	Fdlar Injury, stem growth	—	—	S*
Date palm	*Phoenix dactylifera* L	Fruit yield	4.0	3.6	T
Fig	*Ficus carica* L.	Plant DW	—	—	MT'
Gooseberry	*Ribes* sp. L.			—	S*
Grape	*Vitis vinifera* L	shoot growth	1.5	9.6	MS
Grapefruit	*Citrus* x *paradisi* Macfady	Fruit yield	1.2	13.5	S
Guava	*Psidium guajava* L	shoot & root growth	4.7	9.8	MT
Guayule	*Parthenium argentatum* A. Gray	Shoot DW Rubber yield	8.7 7.8	11.6 10.8	T T
Jambolan plum	*Syzygium cumini* L.	shoot growth	—	—	MT
Jojoba	*Simmondsia chinensis* (Link) C.K. Schneld	shoot growth	—	—	T
Jujube, Indian	*Ziziphus mauritiana* Lam.	Fruit yield	—	—	MT
Lemon	*Citrus limon* (L) Burm. f.	Fruit yield	1.5	12.8	S
Lime	*Citrus aurantiifolia* (Chrisbn.) Swingle		—	—	S*
Loquat	*Eriobotrya japonica* (Thunb). Lindl.	Foliar Injury		—	S*
Macadamia	*Macadamia integrifolia* Maiden & Betche	Seedling growth	—	—	MS'
Mandarin orange: tangerine	*Citrus reticulata* Blanco	Shoot growth	—	—	S*
Mango	*Mangifera indica* L	Fdlar injury	—	—	S
Natal plum	*Carissa grandiflora* (E.H. Mey) A. D.C.	Shoot growth	—	—	T
Olive	*Olea europaea* L	Seedling growth Fruit yield	—	—	MT
Orange	*Citrus sinensis* (L) Osbeck	Fruit yield	1.3	13.1	S
Papaya	*Carica papaya* L.	Seedling growth Fdlar Injury	—	—	MS
Passion fruit	*Passiflora edulis* Sims.		—	—	S*
Peach	*Prunus persica* (L) Batsch	shoot growth, Fruit yield	1.7	21	S
Pear	*Pyrus communis* L		—	—	S
Pecan	*Carya illinoinensis* (Wangenh.) C. Koch	Nut yield, trunk growth	—		MS
Persimmon	*Diospyros virginiana* L		—	—	S
Pineapple	*Ananas comosus* (L.) Merrill	Shoot DW	—	—	MT
Pistachio	*Pistacia vera* L	Shoot growth	—	—	MS
Plum; Prune	*Prunus domestica* L.	Fruit yield	2.6	31	MS
Pomegranate	*Punica granatum* L	Shoot growth	—	—	MS

Common name	Botanical name[b]	Tolerance based on:	Threshold[c] (EC_e) dS/m	Slope % par dS/m	Rating[d]
Popinac, white	*Leucaena leucocephala (Lam.)* de Wit [syn. *Leucaena glauca* Benth.]	Shoot DW	—	—	MS
Pummel0	*Citrus maxima* (Burm.)	Foliar injury	—	—	S*
Raspberry	*Rubus idaeus* L.	Fruit yield	—	—	S
Rose apple	*Syzygium jambos* (L.) Alston	Foliar injury	—	—	S*
Sapote, white	*Casimoroa edulis* Llave	Foliar injury	—	—	S*
Scarlet wisteria	*Sesbania grandiflora*	Shoot DW	—		MT
Tamarugo	*Prosopis tamarugo* Phil.	Observation	—	—	T
Walnut	*Juglans* spp.	Foliar injury	—	—	S*

[a]These date serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending on climate, soil conditions, and cultural practices. The 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. Source: Maas and Grattan (1994).
[b]Botanical and common names follow the convention of Hortus Third (Liberty Hyde Bailey Hortorium Staff, 1976) where possible.
[c]In gypsiferous soils, plants will tolerate EC_e's about 2 dS/m higher than indicated.
[d]Ratings are defined by the boundaries In Figure 2. Ratings with an * are estimates.

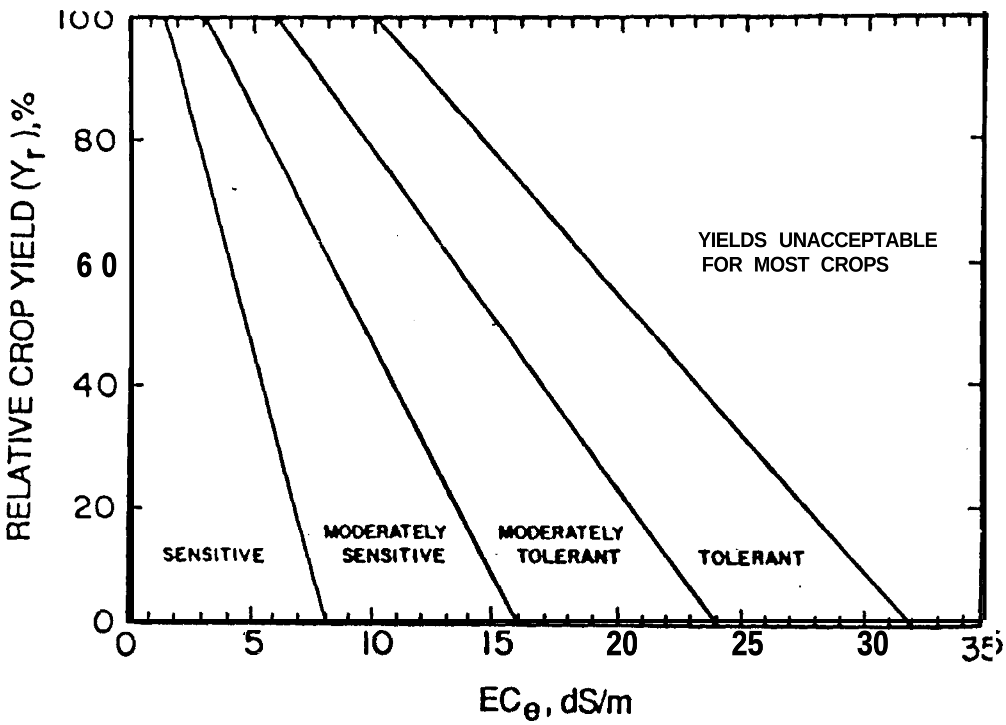

Fig. 2. Divisions for classifying crop tolerance to salinity.

The salt tolerance of trees, vines, and other woody crops is complicated because of additional detrimental effects caused by specific ion toxicities. Many perennial woody species are susceptible to foliar injury caused by the toxic accumulation of Cl- and/or Na' in the leaves. Because different cul tivars and rootstocks absorb C1' and Na' at different rates, considerable variation in tolerance occurs within anindividual species. In the absence ofspecific-ion effects, the salt tolerance data for woody crops are reasonably accurate. Because of the cost and time required to obtain fruit yields, tolerances of several crops are based on vegetative growth. In contrast to other crop groups, most woody species are salt sensitive, even in the absence of specific ion effects. Guayule ***(Parthenium argentatum* A.** Gray) and date palm ***(Phoenix dactylifera*** L.) are relatively salt tolerant and olive (Olea ***europaea*** L.) and a few others are believed to be moderately tolerant.

SPRINKLER-INDUCED FOLIAR INJURY

The salt tolerance data in Table 1 apply to crops irrigated with surface methods, such as furrow or basin-type flooding. Sprinkler-irrigated crops are subject to additional damage from salt spray on the foliage (Maas, 1985). Salts may be directly absorbed by the leaves, resulting in injury and loss of leaves. In crops that normally restrict salt movement from the roots to the leaves, foliar salt absorption can cause serious problems not normally encountered with surface irrigation systems. For example, compared to nonsaline water (EC = 0.6 dS/m), water with an EC = 4.5 dS/m reduced pepper ***(Capsicum annuum*** L.) yields by over 50% when applied by sprinkler, but only 16% when applied to the soil surface (Bernstein and Francois, 1973).

Unfortunately, no information is available to predict yield losses as a function of salinity levels in sprinkler irrigation water. Table 3 lists some susceptible crops and gives approximate salt concentrations in sprinkler water that can cause foliar injury. The degree of injury depends on weather conditions and water stress. For instance, leaves may contain excessive levels of salt for several weeks without any visible injury symptoms and then become severely burned when the weather becomes hot and dry.

Saline irrigation water will assumably reduce yields of sprinkled crops at least as much as those of surface-irrigated crops. Additional reductions in yield could be expected for crops susceptible to sprinkler-induced foliar injury. Sorghum accumulates salt very slowly through the leaves and is relatively tolerant of saline sprinkling waters (Maas, 1985). No data are available to judge the sensitivity of pearl millet.

Table 3. Relative susceptibility of crops to foliar injury from saline sprinkling waters.[a]

Na or Cl concentration (mol m^{-3}) causing foliar injury[b]			
<5	5-10	10-20	>20
Almond	Grape	Alfalfa	Cauliflower
Apricot	Pepper	Barley	Cotton
Citrus	Potato	Corn	Sugarbeet
Plum	Tomato	Cucumber	Sunflowa
		safflower	
		Sesame	
		Sorghum	

Susceptibility based on direct accumulation of salts through the leaves. Source: Maas and Grattan (1994).
bFollar injury is Influenced by cultural and environmental conditions. These data are presented only as general guidelines for daytime sprinkling.

ENVIRONMENTALINTERACTXON

Generally, salt tolerance data are only valid for the climatic conditions in which the data were obtained. Temperature, relative humidity, and air pollution all significantly affect plant responses to salinity. Most crops tolerate more salinity stress if the weather is cool and humid than if it is hot and dry. The combined effects of salinity and conditions of high evaporative demand, whether caused by high temperature, low humidity, wind, or drought, are more stressful than salinity alone. Because climate has a pronounced effect on plant response to salinity, the time of year salt tolerance experiments are conducted can affect the outcome. For example, if the salt tolerance of cool-season vegetable crops was assessed in hot, dry climates, results may underestimate the level of salinity they can tolerate when grown in their normal environment, which is cooler with a lower evaporative demand. Conversely, crops tested in cooler and damper (high humidity) environment than they normally grow in would appear more tolerant than normal.

Air pollution, which is a serious problem around industrial and urban areas, increases the apparent salt tolerance of oxidant-sensitive crops. Ozone, a major air pollutant, decreases the yield of some crops more under nonsaline than saline conditions. Consequently, air-polluted areas should be avoided when evaluating the response of crops to soil salinity stress.

SUMMARY

Salt tolerance ratings cannot provide accurate estimates of actual crop yields that depend on many other growing conditions, including weather, soil type and fertility, water stress, insects, and disease. The ratings are useful, however, in predicting how one crop might fare relative to another on saline soils. As such, they are valuable aids in managing salinity problems in irrigated agriculture.

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