SALINITY AND PLANT PRODUCTIVITY

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INTRODUCTION

Plant productivity is limited on an estimated one third of the irrigated land in the world or approximately 4×10^7 ha by soluble salt accumulations in the soil, often referred to as soil salinity or salinity. As irrigated agriculture expands, more salinity problems will develop because there are millions of hectares of potentially irrigable land that could become saline. Every year new salinity problem areas develop and are identified. Salinity is the most important problem facing irrigated agriculture, and solving salinity problems is one of the greatest challenges to agricultural scientists.

Much research has been conducted during the past 30 to 40 years to determine the relative tolerance of crops to salinity. Most of the salinity tolerance data available through the early 1960s was compiled into useful relationships by Bernstein in 1964, and these data have been cited and applied throughout the world.[1] Since then, many new salinity tolerance studies have been conducted, and many new management practices have been proposed, evaluated, and some of them practiced to reclaim salt-affected soils for improved crop production. Recently, Maas and Hoffman evaluated existing salinity tolerance data for agricultural crops and presented the data graphically so that the relative tolerance among crops could be easily compared.[2,3]

THE NATURE OF SOIL SALINITY

The soil solution or the water in the soil contains soluble salts, usually as the ionic components. The ions commonly present in the greatest concentrations are Na^+, Ca^{++}, Mg^{++}, Cl^-, HCO_3^- and SO_4^{--}. The proportions and the amounts of each vary widely. Sometimes NO_3^- is present in significant concentrations, and K^+ is generally, but not always, present in low concentrations. Some other ions are present in low concentrations. Total soluble salts or soil salinity generally refers to the total concentration of all ions of the soluble salts. When the total soluble salt concentration in the soil solution is high enough to limit plant growth and productivity, a salinity or soluble salt problem exists. Soils also contain slightly soluble salts like $CaCO_3$, but these salts do not contribute to salinity problems.

Most arid soils contain high residual salt concentrations. These residual salts result from natural weathering processes of soil parent materials, evaporation of lakes, and rainfall and evaporation over centuries. Soil salinity problems may develop in normally non-saline areas when salts are leached from some soils and carried by water to other areas where the water table is near the soil surface because of inadequate drainage; the salts are then left behind as the water evaporates from the soil. The source of water for leaching and transport of soluble salts in arid regions is generally from irrigation. Soluble salts also accumulate in soils irrigated with saline waters, particularly where drainage is poor or when too little water is applied to leach excess salts.

Water is transpired by plants in essentially the pure state just as it is evaporated from a free water surface or from the soil. Therefore, as plants use water, the salts are concentrated in the soil solution. When plants have used one half of the water stored in a soil from irrigation or natural precipitation, the salt concentration in the remaining water or soil solution will be approximately twice the original concentration. When three fourths of the initial water is used, the salt concentration will have increased approximately four times. All irrigation waters contain some salt, and the effects of this salt as plants use water depends upon the salt concentration in the irrigation water. The total soluble salt concentration determines the quality of water for irrigation; such waters are classified based upon their salt concentrations.[4-8]

SALINITY EFFECTS ON PLANTS

Excessive soluble salt concentrations or salinity affects plant growth and production primarily by increasing the osmotic potential of the soils solution.[9] Under some conditions,[10-12] specific ion toxicities can also be important for some crops, particularly woody species. The physiological effects of excess salinity are many, but visual symptoms generally do not become evident until salinity conditions are extreme.

Plants affected by excessive soluble salt concentrations usually appear normal, but there is a general stunting of growth, foliage may be darker green than for normal plants, and sometimes leaves are thicker and more succulent. Woody species often exhibit leaf burn, necrosis, and defoliation resulting from toxic accumulations of Cl or Na. Chlorophyll formation is inhibited in citrus by specific ion toxicities.[13] Occasionally, nutritional imbalances caused by salinity produce specific nutrient-deficiency symptoms.[14,15]

The osmotic effect of salinity is to increase the osmotic potential of the soil solution, thereby making soil water less available for plant uptake. Therefore, salinity-affected crops often appear the same as crops suffering from drought. Many plants adapt to the increased salt concentrations by increasing the osmotic potential of the cell sap.[16,17]

As the salt concentration in the soil solution increases, both the growth rate and ultimate size of most plant species progressively decrease. Salinity effects are frequently not recognized, even though yield reduction may be 20 to 30% because of the general decrease in growth rate and plant size. Not all plant parts are affected the same way, and any relationship between growth response and soil salinity must take this into account.[18,19] The leaf-to-stem ratio of alfalfa is affected, influencing forage quality.[20] Vegetative production is decreased more than seed or fiber production for crops such as barley, wheat, cotton, and some grasses.[2,3,21] In contrast, grain yields of rice and corn may be greatly reduced without appreciable reduction in vegetative production.[22,23] Root yields of root crops are generally decreased much more than top yields.[21,24] In contrast, top growth is affected more than root growth with some other species.

The impact of reduced plant production caused by salinity depends upon the purpose for which the plants are grown. Total yield and quality of crops grown for sale or for feed are generally most important. However, the survival and growth of plants used for landscaping and ground cover may also be important under some conditions.

MEASURING SOIL SALINITY

Soil salinity can be measured by several methods. Plant growth is primarily related to the osmotic potential of the soil solution in the root zone.[25,26] Osmotic potential (Ψ) can be measured directly by freezing point depression, vapor pressure osmometers, or thermocouple psychrometers, or it can be calculated from the electrical conductivity of soil saturation extracts (EC_e) by the equation

$$\Psi = -0.36\ (EC_e)$$

The saturation extract is the soil solution removed from saturated soil by suction or pressure. Measuring EC_e has become widely accepted because the saturation percentage is easy to determine and reproduce in the laboratory over a wide soil textural range. Plant tolerance to salinity is generally based upon EC_e values rather than osmotic potential or total salt concentration. Both osmotic potential and total salt concentration are readily calculated from EC_e based upon the above formula and relationships developed at the U. S. Salinity Laborabory.[27]

Instruments have been developed recently to determine the electrical conductivity of soil water (EC_{sw}) in the field. Salinity sensors permit EC_{sw} measurements at a given point in the soil, and the four-electrode probe can be used to measure an average or integrated EC_{w} in the field.[28,29] The salinity sensors are useful for measuring soil solution salinity under field conditions over the ranges of soil matric potential normally encountered in the field. The four-electrode probe is a simple, rapid, diagnostic technique for determining management practices. Both methods are based upon electrical conductivity and are generally referenced to EC_e values for plant productivity estimates. When specific ion toxicities are evident or suspected, the concentrations of the ions are measured in the saturation extract.

FACTORS INFLUENCING THE EFFECTS OF SALINITY ON PLANT PRODUCTIVITY

Many factors influence plant response to salinity. One factor is the growth stage. Sensitivity to salinity varies with the growth stage for many plants, particularly cereal crops. Rice is tolerant during germination, becomes sensitive during early seedling growth, and then becomes more tolerant as it matures.[30-34] Barley, wheat, and corn are more sensitive during emergence and early seedling growth than during germination and grain development.[21,22,25] Sugar beets are sensitive during germination and become tolerant after that.[35] Varietal differences in salinity tolerance have been observed with wheat, barley, soybeans and some other legumes, and many grasses.[36-42] Rootstocks for tree and vine crops differ in tolerance to total salts and also exhibit a differential susceptibility to specific ion toxicities.[11,43-47]

The availability of plant nutrients can affect salinity tolerance; conversely, salinity and specific ion toxicities can cause nutritional disorders. Conflicting results of some salinity-nutrient interactions are found in the literature. Applications of P have increased plant production under saline conditions in some investigations but not in others. There have been reports that excess P in sand cultures may decrease salt tolerance of some crops; however, P concentrations would seldom be excessive in soils because P is adsorbed and precipitated in the soil. As the salt concentration increases, N requirements of plants generally decrease. The literature contains information on several other interacting effects of salinity and plant nutrients on growth and production. These are not discussed here, but references are provided.[14,38,48-59] Published salinity tolerance lists of crops are generally based on data obtained where nutrient availability was adequate.

Plant response to salinity is influenced by climatic factors. Many crops are less tolerant when grown under dry, hot conditions. Relative yields of alfalfa, beans, beets, carrots, cotton, onions, squash, tomatoes, strawberry clover, and saltgrass are lower in warm than in cool climates.[60] High atmospheric humidity increases the salt tolerance of some crops, and benefits salt-sensitive plants more than tolerant crops.[24]

Irrigation management influences plant productivity in several ways. As previously mentioned, all irrigation waters contain some salt, and as the water passes into the atmosphere through evapotranspiration processes, salts remain in the soil or the soil solution. Unless extra water is added for leaching salts from the root zone, salts will accumulate from irrigation during the season. When the irrigation water contains mod-

Table 1
THE RELATIVE PRODUCTIVITY OF SENSITIVE PLANTS WITH INCREASING SALT CONCENTRATION IN THE ROOT ZONE

Plant name	Scientific names	Relative productivity, % EC_e, mmhos/cm									% Productivity decrease per mmhos/cm increase	Salinity threshold (EC_e)	Ref.
		1	2	3	4	5	6	7	8	9			
Algerian ivy	*Hedera canariensis*	100	81	62	35	0	0	0	0	0	—	1.0	61
Almond	*Prunus dulcis*	100	91	73	55	36	18	0	0	0	18	1.5	2, 3, 12, 62, 63
Apple[a]	*Malus sylvestris*	100	91	75	—	—	—	—	—	—	—	1.0	2, 10, 62
Apricot	*Prunus armeniaca*	100	91	68	45	23	0	0	0	0	23	1.6	2, 3, 10, 62, 63
Avocado	*Persea americana*	100	90	70	—	—	—	—	—	—	—	1.0	3, 10, 62
Bean	*Phaseolus vulgaris*	100	81	62	43	25	6	0	0	0	18.9	1.0	1—3, 10, 25, 64—68
Blackberry	*Rubus* spp.	100	89	67	44	22	0	0	0	0	22.2	1.5	2, 3, 62, 69
Boysenberry	*Rubus ursinus*	100	89	67	44	22	0	0	0	0	22.2	1.5	2, 3, 62, 69
Burford holly	*Ilex cornuta*	100	82	59	36	14	0	0	0	0	—	1.0	61
Burnet	*Sanguisorba minor*	—	—	—	—	—	—	—	—	—	—		70
Carrot	*Daucus carota*	100	86	72	58	44	30	15	1	0	14.1	1.0	1—3, 10, 66, 67
Celery[a]	*Apium graveolens*	100	90	75	—	—	—	—	—	—	—	1.0	67
Grapefruit	*Citrus paradisi*	100	97	81	65	48	32	16	0	0	16.1	1.8	1, 2, 46, 62
Heavenly bamboo	*Nandina domestica*	100	88	75	61	47	34	20	7	0	—	1.0	61
Hibiscus	*Hibiscus rosa-sinensis* cultivar Brilliante	100	86	72	58	42	28	15	0	0	—	1.0	61
Lemon[a]	*Citrus limon*	100	91	75	—	—	—	—	—	—	—	1.0	2, 10, 46, 62
Okra[a]	*Abelmoschus esculentus*	100	90	—	—	—	—	—	—	—	—		2
Onion	*Allium cepa*	100	87	71	55	39	23	6	0	0	16.1	1.2	1—3, 10
Orange	*Citrus sinensis*	100	95	79	63	48	32	16	0	0	15.9	1.7	2, 3, 10, 46, 62
Peach	*Prunus persica*	100	94	73	52	31	10	0	0	0	18.8	3.2	2, 3, 62, 63
Pear[a]	*Pyrus* spp.	100	91	75	—	—	—	—	—	—	—	1.0	10, 62
Pineapple guava	*Feijoa sellowiana*	100	71	34	0	0	0	0	0	0	—	1.2	61
Plum	*Prunus domestica*	100	91	73	55	36	18	0	0	0	18.2	1.5	2, 3, 12, 62
Prune[a]	*Prunus domestica*	100	91	75	—	—	—	—	—	—	—	1.0	10, 62, 63
Pittosporum[b]	*Pittosporum tobira*	100	89	79	69	60	50	40	30	20	—	1.0	61
Raspberry[a]	*Rubus idaeus*	100	80	62	—	—	—	—	—	—	—	1.0	2, 10, 62

Table 1 (continued)
THE RELATIVE PRODUCTIVITY OF SENSITIVE PLANTS WITH INCREASING SALT CONCENTRATION IN THE ROOT ZONE

Plant name	Scientific names	Relative productivity, % EC_e, mmhos/cm 1	2	3	4	5	6	7	8	9	% Productivity decrease per mmhos/cm increase	Salinity threshold (EC_e)	Ref.
Rose	*Rosa* spp.	100	74	36	0	0	0	0	0	0	—	1.0	61, 71
Strawberry	*Fragaria*	100	67	33	0	0	0	0	0	0	33.3	1.0	2, 3, 10, 12, 62
Star jasmine	*Trachelospermum jasminoides*	100	83	61	40	18	0	0	0	0	—	1.6	61

Note: Salt concentration is shown as the electrical conductivity of saturated soil extracts, EC_e.

- Tabled values are estimates based upon the EC_e for a relative yield of 90% and yield reductions for similar crops as EC_e increases. Where no productivity data are given, the plant is listed with others of similar salt tolerance.
- The lower part of the yield curve approaches zero asymptotically to the abscissa. Only linear data are shown.

Table 2
THE RELATIVE PRODUCTIVITY OF MODERATELY SENSITIVE PLANTS WITH INCREASING SALT CONCENTRATION IN THE ROOT ZONE

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Plant name	Scientific names	Relative productivity, % EC_e, mmhos/cm 1	2	3	4	5	6	7	8	9	10	11	12	13	14	% Productivity decrease per mmhos/cm increase	Salinity threshold (EC_e)	Ref.
Alfalfa	*Medicago sativa*	100	100	93	85	78	71	64	56	49	42	34	27	20	12	7.3	2.0	1—3, 10, 25, 70
Arborvitae[b]	*Thuja orientalis*	100	100	91	81	72	62	52	43	33	24	—	—	—	—	—	2.0	61
Bentgrass[a]	*Agrostis palustris*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Bottlebrush[b]	*Callistemon viminalis*	100	94	85	77	68	59	50	41	33	—	—	—	—	—	—	1.5	61
Boxwood	*Buxus microphylla* var. *japonica*	100	96	86	76	65	54	43	32	21	11	0	0	0	0	10.8	1.7	61
Broadbean	*Vicia faba*	100	96	87	77	67	58[c]	48	38	29	19	10	0	0	0	9.6	1.6	1—3, 10, 65—68
Cauliflower[a]	*Brassica oleracea*	100	100	93	85	—	—	—	—	—	—	—	—	—	—	—	2.5	67
Cabbage	*Brassica oleracea* var. *capitata*	100	98	88	79	69	59	50	40	30	20	11	1	0	0	9.7	1.8	1—3, 10
Canarygrass, feed[a]	*Phalaris arundinacea*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		2
Clover, alsike ladino, red, strawberry	*Trifolium* spp.	100	94	82	70	58	40	34	22	10	0	0	0	0	0	12.0	1.5	1—3, 70
Corn, forage	*Zea mays*	100	99	91	84	76	69	61	54	47	39	32	24	17	10	7.4	1.8	1—3, 10, 25
Corn, grain, sweet	*Zea mays*	100	96	84	72	60	48	36	24	12	0	0	0	0	0	12.0	1.7	1—3, 10, 12, 64, 67
Cowpea	*Vigna unguiculata*	100	90	76	61	47	33	19	4	0	0	0	0	0	0	14.3	1.3	2, 3
Cucumber	*Cucumis sativus*	100	100	94	81	68	55	42	29	16	3	0	0	0	0	13.0	2.5	2, 3, 67
Dodonea	*Dedonia viscosa* var. *atropurpurea*	100	94	86	77	68	59	51	42	33	25	17	9	0	0	7.8	1.0	61
Flax	*Linum usitatissimum*	100	96	84	72	60	48	36	24	12	0	0	0	0	0	12.0	1.7	1—3, 10
Grape	*Vitis* spp.	100	95	86	76	66	57	47	38	28	18	9	0	0	0	9.5	1.5	2, 3, 12, 62, 72
Juniper	*Juniperus chinensis*	100	91	81	72	63	54	45	36	27	18	9	0	0	0	9.5	1.5	61
Lantana	*Lantana camera*	100	92	82	72	62	51	41	30	20	9	0	0	0	0	—	1.8	61
Lettuce	*Latuca sativa*	100	91	78	65	52	39	26	13	0	0	0	0	0	0	13.0	1.3	1—3, 67
Lovegrass	*Eragrostis* spp.	100	100	92	83	75	66	58	49	41	32	24	15	7	0	8.5	2.0	2, 3

Table 2 (continued)
THE RELATIVE PRODUCTIVITY OF MODERATELY SENSITIVE PLANTS WITH INCREASING SALT CONCENTRATION IN THE ROOT ZONE

Plant name	Scientific names	Relative productivity, % EC., mmhos/cm 1	2	3	4	5	6	7	8	9	10	11	12	13	14	% Productivity decrease per mmhos/cm increase	Salinity threshold (EC.)	Ref.
Meadow fox-tail	*Alopecurus pratensis*	100	95	85	76	66	56	47	37	27	17	8	0	0	0	9.7	1.5	1—3, 10, 70
Millet, foxtail	*Setaria italica*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		2, 56—59
Muskmelon[a]	*Cucumis melo*	100	100	95	80	—	—	—	—	—	—	—	—	—	—	—	2.5	10, 62
Oleander[b]	*Nerium oleander*	100	100	93	86	79	72	65	58	51	44	37	30	24	—	—	2.0	61
Pea[a]	*Pisum sativum* L.	100	100	90	—	—	—	—	—	—	—	—	—	—	—	—	2.5	65, 67
Peanut	*Arachis hypogaea*	100	100	100	77	49	20	0	0	0	0	0	0	0	0	28.6	3.2	2, 3, 73
Pepper	*Capsicum annuum*	100	93	79	65	51	37	23	8	0	0	0	0	0	0	14.1	1.5	1—3, 67
Potato	*Solanum tuberosum*	100	96	84	72	60	48	36	24	12	0	0	0	0	0	12.0	1.7	1—3, 10, 67
Pyracantha	*Pyracantha braperi*	100	99	90	81	72	62	53	43	34	24	14	6	0	0	9.1	2.0	61
Radish	*Raphanus sativus*	100	90	77	64	51	38	25	12	0	0	0	0	0	0	13.0	1.2	2, 3, 67
Reed canary	*Phalaris arundinacea*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		70
Rice, paddy	*Oryza savita*	100	100	100	88	76	63	51	39	27	15	2	0	0	0	12.2	3.0	1—3, 10, 12, 30—34, 70
Sesbania	*Sesbania exaltata*	100	100	95	88	81	74	67	60	53	47	40	33	26	19	7.0	2.3	2, 3
Spinach	*Spinacia oleracea*	100	100	92	85	77	70	62	55	47	39	32	24	17	9	7.6	2.0	1—3, 10, 67
Squash[a]	*Cucurbita maxima*	100	100	90	74	—	—	—	—	—	—	—	—	—	—	—	2.5	67
Sugarcane	*Saccharum officinarum*	100	98	92	86	81	75	69	63	57	51	45	39	34	28	5.9	1.7	1—3
Silverberry	*Elaeagnus pungens*	100	95	87	78	69	59	50	41	32	23	15	16	0	0	—	1.6	61
Sweet clover[a]	*Melilotus* spp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		57, 58, 64, 70
Sweet potato	*Ipomoea batatas*	100	95	84	73	62	51	40	29	18	7	0	0	0	0	11.0	1.5	1—3, 10, 67
Texas privet	*Ligustrum lucidum*	100	94	85	75	66	56	46	36	26	16	7	0	0	0	9.1	2.0	61
Timothy	*Phleum pratense*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		2
Tomato	*Lycopersicon lycopersicum*	100	100	95	85	75	65	55	46	36	26	16	6	0	0	9.9	2.5	1—3, 10, 67
Trefoil, big	*Lotus uliginosus*	100	100	87	68	49	30	11	0	0	0	0	0	0	0	18.9	2.3	2, 3, 70

Vetch, common	*Vicia sativa*	100	100	100	89	78	67	56	44	33	22	11	0	0	0	11.1	3.0	2, 3, 70
Viburnum	*Viburnum* spp.	100	90	73	58	44	32	20	10	0	0	0	0	0	0	13.2	1.4	61
Xylosma	*Xylosma senticosa*	100	94	81	67	54	40	27	14	0	0	0	0	0	0	13.3	1.5	61

Note: Salt concentration is shown as the electrical conductivity of saturated soil extracts, EC_e

[a] Tabled values are estimates based upon the EC_e for a relative yield of 90% and yield reductions for similar crops as EC_e increases. Where no productivity data are given, the plant is listed with others of similar salt tolerance.

Table 3
THE RELATIVE PRODUCTIVITY OF MODERATELY TOLERANT PLANTS WITH INCREASING SALT CONCENTRATION IN THE ROOT ZONE

Plant name	Scientific names	Relative productivity, % EC$_e$, mmhos/cm: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	% Productivity decrease per mmhos/cm increase	Salinity threshold (Ec$_e$)	Ref.
Alkali sacaton[a]	*Sporobolus airoides*	100	100	—	—	—	—	—	—	—	—	—	—	—	0	0	0	0	0	0	—	—	12, 70
Barley, forage	*Hordeum vulgare*	100	100	100	100	100	100	93	86	79	72	65	58	51	44	37	30	23	15	8	7.0	6.0	1—3, 10, 64, 70
Beet, garden	*Beta vulgaris*	100	100	100	100	91	82	73	64	55	46	38	29	20	11	2	0	0	0	0	9.0	4.0	1—3, 10, 67
Broccoli	*Brassica oleracea* var. *capitata*	100	100	98	89	80	71	61	52	43	34	25	16	6	0	0	0	0	0	0	9.1	2.8	1—3, 10, 67
Bromegrass	*Bromis inermis*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2, 70
Clover, berseem	*Trifolium alexandrinium*	100	97	91	86	80	74	69	63	57	51	46	40	34	29	23	17	11	6	0	5.8	1.5	2, 3, 41
Dallis grass	*Paspalum dilatatum*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10, 70
Dracaena	*Dracaena endivisa*	100	100	100	94	85	76	67	58	49	40	31	22	13	4	0	0	0	0	0	9.1	4.0	61
Euonymus[c]	*Euonymus japonica* var. *grandiflora*	—	—	—	—	—	—	100	77	52	27	0	0	0	0	0	0	0	0	0	—	7.0	61
Fescue	*Festuca elatior*	100	100	100	99	94	89	84	78	73	68	62	57	52	47	41	36	31	25	20	5.3	3.9	1—3, 10, 70
Fig[a]	*Ficus carica*	100	100	100	100	90	85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.2	10, 62
Hardinggrass	*Phalaris tuberosa*	100	100	100	100	97	89	82	74	67	59	52	44	36	29	21	14	6	0	0	7.6	4.6	1, 2, 3, 10, 70
Kale[a]	*Brassica campestris*	100	100	100	100	100	100	90	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5	67
Lime, rangpur[a]	*Citrus aurantifolia*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	62

Kale[a]	*Brassica campestris*	100	100	100	100	100	100	90	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5	67
Lime, rangpur[a]	*Citrus aurantifolia*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	62
Mandarin, cleopatra[a]	*Citrus nobilis*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	62
Milkvetch[a]	*Astragalus*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	70
Olive	*Olea europaea*	100	100	100	100	90	85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.0	2, 10, 62
Orchardgrass	*Dactylis glomerata*	100	97	91	84	78	72	66	60	53	47	41	35	29	22	16	10	4	0	0	6.2	1.5	1—3, 70
Oats	*Avena sativa*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10, 12, 64, 70
Pomegranate[a]	*Punica granatum*	100	100	100	100	90	85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.0	10, 62
Rhodesgrass[a]	*Chloris gayana*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2, 12, 70
Rye, hay[a]	*Secale cereale*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	64, 70
Ryegrass, perennial	*Lolium perenne*	100	100	100	100	100	97	89	82	74	67	59	52	44	36	29	21	14	6	0	7.6	5.6	1—3, 10, 64
Safflower[a]	*Carthamus tinctorius*	100	100	100	100	100	100	97	90	85	80	75	50	—	—	—	—	—	—	—	—	6.5	1, 3, 10, 74
Sorghum[a]	*Sorghum bicolor*	100	100	100	100	98	90	84	78	70	63	56	50	43	36	29	22	15	8	0	—	4.8	1, 3, 10, 64
Soybean	*Glycine max*	100	100	100	100	100	80	60	40	20	0	0	0	0	0	0	0	0	0	0	20.0	5.0	1—3, 10, 40, 64
Sudangrass	*Sorghum sudanense*	100	100	99	95	91	86	82	78	73	69	65	61	56	52	48	43	38	35	30	4.3	2.8	2, 3, 70
Trefoil, birdsfoot	*Lotus corniculatus tenuifolium*	100	100	100	100	100	90	80	70	60	50	40	30	20	10	0	0	0	0	0	10.0	5.0	1—3, 10, 70
Wheat	*Triticum aestivum*	100	100	100	100	100	100	93	86	79	71	64	57	50	43	36	29	21	14	7	7.1	6.0	1—3, 10, 38, 64, 70, 75

Table 3 (continued)
THE RELATIVE PRODUCTIVITY OF MODERATELY TOLERANT PLANTS WITH INCREASING SALT CONCENTRATION IN THE ROOT ZONE

Plant name	Scientific names	Relative productivity, %, EC_e, mmhos/cm: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	% Productivity decrease per mmhos/cm increase	Salinity threshold (Ec.)	Ref.
Wheatgrass, slender	*Agropyron trachycaulum*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Wheatgrass, western[a]	*Agropyron smithi*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	70
Wildrye, beardless	*Elymus triticoides*	100	100	98	92	86	80	74	68	62	56	50	44	38	32	26	20	14	8	2	6.0	2.7	1—3, 10, 70
Wildrye, Canada[a]	*Elymus canadensis*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	70

Note: Salt concentration is shown as the electrical conductivity of saturated soil extracts, EC_e.

[a] Tabled values are estimates based upon the EC_e for a relative yield of 90% and yield reductions for similar crops as EC_e increases. Where no productivity data are given, the plant is listed with others of similar salt tolerance.

[b] The lower part of the yield curve approaches zero asymptotically to the abscissa. Only linear data are shown.

[c] Tabled values are based upon three data points available in the literature.

[d] Tabled values based upon three data points. Productivity drops sharply towards zero for the lower 50% productivity.

Table 4
THE RELATIVE PRODUCTIVITY OF TOLERANT PLANTS WITH INCREASING SALT CONCENTRATION IN THE ROOT ZONE

Plant name	Scientific name	Relative productivity, %, EC_e, mmhos/cm: 4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	% Productivity decrease per mmhos/cm increase	Salinity threshold (EC_e)	Ref.
Barley, grain	*Hordeum vulgare*	100	100	100	100	100	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	5.0	8.0	1—3, 10, 12, 25, 36, 37, 64, 70
Bermuda grass	*Cynodon dactylon*	100	100	100	99	93	87	80	74	67	61	54	48	42	35	29	22	16	10	3	0	0	6.4	6.9	1—3, 10, 12, 70
Bougainvillea[a]	*Bougainvillea spectabilis*	100	100	100	100	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8.5	61
Cotton	*Gossypium hirsutum*	100	100	100	100	98	93	88	83	78	73	67	62	57	52	47	41	36	31	26	21	16	5.2	7.7	1—3, 10, 12, 64
Date	*Phoenix dactylifera*	100	96	93	89	86	82	78	75	71	68	64	60	57	53	49	46	42	39	35	31	28	3.6	4.0	2, 3, 62
Natal plum[a]	*Carissa grandiflora*	—	—	100	—	82	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.0	61
Nutall alkali grass	*Puccinellia nuttalluana*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12, 70
Rescue grass	*Bromus catharticus*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	70
Rosemary[a,c]	*Rosmarinus lockwoodii*	100	95	85	75	—	—	68	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.5	61
Sugarbeet	*Beta vulgaris*	100	100	100	100	94	88	82	76	61	65	59	53	47	41	35	29	24	18	12	6	0	5.9	7.0	1—3, 10, 12, 25, 64
Saltgrass[a]	*Distichlis stricta*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12, 70

Table 4 (continued)
THE RELATIVE PRODUCTIVITY OF TOLERANT PLANTS WITH INCREASING SALT CONCENTRATION IN THE ROOT ZONE

Plant name	Scientific name	Relative productivity, % EC_e, mmhos/cm 4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	% Productivity decrease per mmhos/cm increase	Salinity threshold (EC_e)	Ref.
Wheatgrass, crested	*Agropyron desertorum*	98	94	90	86	82	78	74	70	66	62	58	54	50	46	42	38	34	30	26	22	18	4.0	3.5	1—3, 10
Wheatgrass, fairway	*Agropyron cristatum*	100	100	100	100	97	90	83	76	69	62	55	48	41	34	28	21	14	7	0	0	0	6.9	7.5	2, 3
Wheatgrass, tall	*Agropyron elongatum*	100	100	100	100	98	94	89	85	81	77	73	68	64	60	56	52	47	43	39	35	31	4.2	7.5	1—3, 10, 70
Wildrye, altai	*Elymus angustus*	100	100	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Wildrye, Russian[a]	*Elymus psathyrostachys juncea*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2

Note: Salt concentration is shown as the electrical conductivity of saturated soil extracts, EC_e.

[a] Tabled values are estimates based upon the EC_e for a relative yield of 90% and yield reductions for similar crops as EC_e increases. Where no productivity data are given, the plant is listed with others of similar salt tolerance.

[b] The lower part of the yield curve approaches zero asymptotically to the abscissa. Only linear data are shown.

[c] Tabled values are based upon three data points available in the literature.

REFERENCES

1. Bernstein, L., *Salt Tolerance of Plants*, U. S. Dep. Agric. Inf. Bull., No. 283, U.S. Department of Agriculture, Washington, D.C., 1964, 10—12.
2. Maas, E. V. and Hoffman, G. J., Crop salt tolerance — current assessment, *J. Irrig. and Drain. Div., Proc. Am. Soc. Civ. Eng.*, 103(IR2), 115—134, 1977.
3. Maas, E. V. and Hoffman, G. J., Crop salt tolerance: Evaluation of existing data, in *Managing Saline Water for Irrigation, Proc. Internat. Conf. on Managing Saline Water for Irrigation: Planning for the Future*, Dregne, H. E., Ed., Texas Technical University, Lubbock, Texas, 1977, 187—198.
4. Babcock, K. L., Carlson, R. M., Schulz, R. K., and Overstreet, R., A study of the effect of irrigation water composition on soil properties, *Hilgardia*, 29, 155—164, 1959.
5. Carter, D. L., Managing Moderately Saline (Salty) Irrigation Water, Univ. of Ida. Curr. Inf. Ser., No. 107, University of Idaho, Moscow, 1969, 2.
6. Rhoades, J. D., Quality of water for irrigation, *Soil Sci.*, 113, 277—284, 1972.
7. Wilcox, L. F., Classification and Use of Irrigation Waters, U. S. Dep. Agric. Circ. No. 969, 1955, 9.
8. Wilcox, L. V., Determining the Quality of Water for Irrigation, U.S. Dep. Agric. Inf. Bull. 197, U.S. Department of Agriculture, Washington, D.C., 1958, 3—4.
9. Bernstein, L., Osmotic adjustment of plants to saline media. I. Steady state, *Am. J. Bot.*, 48, 909—918, 1961.
10. Bernstein, L., Crop growth and salinity, in *Drainage for Agriculture, Agronomy* 17, van Schilfgaarde, J., Ed., American Society of Agronomy, Madison, 1974, 39—54.
11. Bernstein, L., Brown, J. W., and Hayward, H. E., The influence of rootstock on growth and salt accumulation in stone-fruit trees and almonds, *Proc. Am. Soc. Hortic. Sci.*, 68, 75—86, 1956.
12. Hayward, H. E. and Bernstein, L., Plant-growth relationships on salt affected soils, *Bot. Rev.*, 24, 584—635, 1958.
13. Carter, D. L. and Myers, V. I., Light reflectance and chlorophyll and caratene contents of grapefruit leaves as affected by Na_2SO_4, NaCl, and $CaCl_2$, *Proc. Am. Soc. Hortic. Sci.*, 82, 217—221, 1963.
14. Lunin, J. and Gallatin, M. H., Salinity-fertility interactions in relation to the growth and composition of beans I. Effect of N, P, and K, *Agron. J.*, 57, 339—342, 1965.
15. Ravikovitch, S. and Porath, A., The effects of nutrients on the salt tolerance of crops, *Plant Soil*, 26, 49—71, 1967.
16. Bernstein, L., Osmotic adjustment of plants to saline media. I. Steady state, *Am. J. Bot.*, 48, 909—918, 1961.
17. Bernstein, L., Osmotic adjustment of plants to saline media. II. Dynamic phase, *Am. J. Bot.*, 50, 360—370, 1963.
18. Bernstein, L. and Pearson, G. A., Influence of integrated moisture stress achieved by varying the osmotic pressure of culture solutions on growth of tomato and pepper plants, *Soil Sci.*, 77, 335—368, 1954.
19. Meiri, A. and Poljakoff-Mayber, A., Effect of various salinity regimes on growth, leaf expansion and transpiration rate of bean plants, *Soil Sci.*, 109, 26—34, 1970.
20. Hoffman, G. J., Maas, E. V., and Rawlins, S. L., Salinity-ozone interactive effects on alfalfa yield and water relations, *J. Environ. Qual.*, 4, 326—331, 1975.
21. Ayers, A. D., Brown, J. W., and Wadleigh, C. H., Salt tolerance of barley and wheat in soil plots receiving several salinization regimes, *Agron. J.*, 44, 307—310, 1952.
22. Kaddah, M. T. and Ghowail, S. I., Salinity effects on the growth of corn at different stages of development, *Agron. J.*, 56, 214—217, 1964.
23. Pearson, G. A., Factors influencing salinity of submerged soils and growth of Calero rice, *Soil Sci.*, 87, 198—206, 1959.
24. Hoffman, G. J. and Rawlins, S. L., Growth and water potential of root crops as influenced by salinity and relative humidity, *Agron. J.*, 63, 877—880, 1971.
25. Bernstein, L. and Hayward, H. E., Physiology of salt tolerance, *Annu. Rev. Plant Physiol.*, 9, 25—46, 1958.
26. Bernstein, L., Tolerance of plants to salinity, *J. Irrig. and Drain Div., Proc. Am. Soc. Civ. Eng.*, 87(IR4), 11, 1961.
27. U.S. Salinity Laboratory Staff, Determination of the properties of saline and alkali soils, in *Diagnosis and Improvement of Saline and Alkali Soils*, Richards, L. A., Ed., U.S. Dep. Agric. Hdbk. No. 60, U.S. Department of Agriculture, Washington, D.C., 1954, 7—23.
28. Oster, J. D. and Ingvalson, R. D., *In situ* measurement of soil salinity with a sensor, *Soil Sci. Soc. Am. Proc.*, 31, 572—574, 1967.
29. Rhoades, J. D. and Ingvalson, R. D., Determining salinity in field soils with soil resistance measurements, *Soil Sci. Soc. Am. Proc.*, 35, 54—60, 1971.

30. **Kaddah, M. T.,** Salinity effects on growth of rice at the seedling and inflorescence stages of development, *Soil Sci.*, 96, 105—111, 1963.
31. **Narale, R. P., Subramanyam, T. K., and Mukherjee, R. K.,** Influence of salinity on germination, vegetative growth and grain yield of rice (*Oriza sativa* var. Dular), *Agron. J.*, 61, 341—344, 1969.
32. **Pearson, G. A. and Ayers, A. D.,** Rice as a Crop for Salt-Affected Soil in Process of Reclamation, U.S. Dep. Agric. Prod. Res. Rep. No. 43, 1960, 7—10.
33. **Pearson, G. A., Ayers, A. D., and Eberhard, D. L.,** Relative salt tolerance of rice during germination and early seedling development, *Soil Sci.*, 102, 151—156, 1966.
34. **Pearson, G. A. and Bernstein, L.,** Salinity effects at several growth stages of rice, *Agron. J.*, 51, 654—657, 1959.
35. **Francois, L. E. and Goodin, J. R.,** Interaction of temperature and salinity on sugarbeet germination, *Agron. J.*, 64, 272—273, 1972.
36. **Ayers, A. D.,** Germination and emergence of several varieties of barley in salinized soil cultures, *Agron. J.*, 45, 68—71, 1953.
37. **Donovan, T. J. and Day, A. D.,** Some effects of high salinity on germination and emergence of barley (*Hardeum vulgare* L. emend Lam.), *Agron. J.*, 61, 236—238, 1969.
38. **Torres, B. C. and Bingham, F. T.,** Salt tolerance of Mexican wheat. I. Effect of NO_3 and NaCl on mineral nutrition, growth and grain production of four wheats, *Soil Sci. Soc. Am. Proc.*, 37, 711—715, 1973.
39. **Greenway, H.,** Plant response to saline substrates. VII. Growth and ion uptake throughout plant development in two varieties of *Hordeum vulgare, Aust. J. Biol. Sci.*, 18, 763—779, 1965.
40. **Abel, G. H. and MacKenzie, A. J.,** Salt tolerance of soybean varieties (*Glycine max.* L. Merrill) during germination and later growth, *Crop Sci.*, 4, 157—161, 1964.
41. **Mitkees, A. I., Selim, M. H., and Mashaly, A.,** Effect of salinity on five berseem varieties in relation to their dry matter and nitrogen contents, *Agric. Res. Rev.*, 50, 19—29, 1972.
42. **Dregne, H. E.,** Effects of Various Salts on Barley Growth, New Mexico Agric. Exp. Stn. Res. Rep. 62, New Mexico Agricultural Experiment Station, Los Cruces, 1962, 2—5.
43. **Cooper, W. C.,** Salt Tolerance of Avocados on Various Rootstocks, Tex. Avocado Soc. Yearb., Texas Avocado Society, Weslaco, 1951, 24—28.
44. **Cooper, W. C.,** Toxicity and accumulation of salts in citrus trees on various rootstocks in Texas, *Florida State Hortic. Soc. Proc.*, 74, 95—104, 1961.
45. **Peynado, A. and Young, R.,** Performance of nucellar red blush grapefruit trees on 13 kinds of rootstocks irrigated with saline and boron-contaminated well water over a 3-year period, *J. Rio Grande Val. Hortic. Soc.*, 16, 52—58, 1962.
46. **Ream, C. L. and Furr, J. R.,** Salt tolerance of some citrus species, relatives and hybrids tested as rootstocks, *J. Am. Soc. Hortic. Sci.*, 101, 265—267, 1976.
47. **Bernstein, L., Francois, L. E., and Clark, R. A.,** Effect of grape rootstocks on chloride accumulation in leaves, *J. Am. Soc. Hortic. Sci.*, 94, 584—590, 1969.
48. **Bernstein, L., Francois, L. E., and Clark, R. A.,** Interactive effects of salinity and fertility on yields of grains and vegetables, *Agron. J.*, 66, 412—421, 1974.
49. **Lunin, J., Gallatin, M. H., and Batchelder, A. R.,** Interactive effects of soil fertility and salinity on the growth and composition of beans, *Proc. Am. Soc. Hortic. Sci.*, 58, 350—360, 1964.
50. **Ehrler, W. and Bernstein, L.,** Effects of root temperature, mineral nutrition, and salinity on the growth and composition of rice, *Bot. Gaz.*, 120, 64—74, 1958.
51. **Langdale, G. W. and Thomas, J. R.,** Soil salinity effects on absorption of nitrogen, phosphorus, and protein synthesis by coastal bermudagrass, *Agron. J.*, 63, 708—711, 1971.
52. **Langdale, G. W., Thomas, J. R., and Littleton, T. G.,** Nitrogen metabolism of stargrass as affected by nitrogen and soil salinity, *Agron. J.*, 65, 468—470, 1973.
53. **Langdale, G. W., Thomas, J. R., and Littleton, T. G.,** Influence of soil salinity and nitrogen fertilizer on spinach growth, *J. Rio Grande Val. Hortic. Soc.*, 25, 61—66, 1971.
54. **Khalil, M. A., Amer, F., and Elgabaly, M. J.,** A salinity-fertility interaction study on corn and cotton, *Soil Sci. Soc. Am. Proc.*, 31, 683—686, 1967.
55. **Maas, E. V., Ogata, G., and Garber, M. J.,** Influence of salinity on Fe, Mn, and Zn uptake by plants, *Agron. J.*, 64, 793—795, 1972.
56. **Ravikovitch, S.,** Effects of brackish irrigation water and fertilizers on millet and corn, *Exp. Agric.*, 9, 181—188, 1973.
57. **Ravikovitch, S. and Yoles, D.,** The influence of phosphorus and nitrogen on millet and clover growing in soils affected by salinity. I. Plant development, *Plant Soil*, 35, 555—567, 1971.
58. **Ravikovitch, S. and Yoles, D.,** The influence of phosphorus and nitrogen on millet and clover growing in soils affected by salinity. II. Plant composition, *Plant Soil*, 35, 569—588, 1971.
59. **Ravikovitch, S. and Navrat, J.,** The effect of manganese and zinc on plants in saline soil, *Soil Sci.*, 121, 25—31, 1976.

60. **Magistad, O. C., Ayers, A. D., Wadleigh, C. H., and Gauch, H. G.,** Effect of salt concentration, kind of salt, and climate on plant growth in sand cultures, *Plant Physiol.*, 18, 151—166, 1943.
61. **Bernstein, L., Francois, L. E., and Clark, R. A.,** Salt tolerance of ornamental shrubs and ground covers, *J. Am. Soc. Hortic. Sci.*, 97, 550—556 1972.
62. **Bernstein, L.,** Salt Tolerance of Fruit Crops, U.S. Dep. Agric. Inf. Bull. 292, U.S. Department of Agriculture, Washington, D.C., 1965, 3—6.
63. **Wadleigh, C. H., Hayward, H. E., and Ayers, A. D.,** First year growth of stone fruit trees on saline substrates, *Proc. Am. Soc. Hortic. Sci.*, 57, 31—36, 1951.
64. **Bernstein, L.,** Salt Tolerance of Field Crops, U.S. Dep. Agric. Inf. Bull. 217, U.S. Department of Agriculture, Washington, D.C., 1960, 4.
65. **Lagerwerff, J. W.,** Osmotic growth inhibition and electrometric salt-tolerance evaluation of plants, *Plant Soil*, 31, 77—96, 1969.
66. **Lagerwerff, J. W. and Holland, J. P.,** Growth and mineral content of carrots and beans as related to varying osmotic and ionic-composition effects in saline-sodic sand cultures, *Agron. J.*, 52, 603—608, 1960.
67. **Bernstein, L.,** Salt Tolerance of Vegetable Crops in the West, U.S. Dep. Agric. Inf. Bull. 205, U.S. Department of Agriculture, Washington, D.C., 1959, 3.
68. **Ayers, A. D. and Eberhard, D. L.,** Response of edible broadbean to several levels of salinity, *Agron. J.*, 52, 110—111, 1960.
69. **Ehlig, C. F.,** Salt tolerance of raspberry, boysenberry, and blackberry, *Proc. Am. Soc. Hortic. Sci.*, 85, 318—319, 1964.
70. **Bernstein, L.,** Salt Tolerance of Grasses and Forage Legumes, U. S. Dep. Agric. Inf. Bull. 194, U.S. Department of Agriculture, Washington, D.C., 1958, 5.
71. **Yaron, B., Zieslin, J., and Halevy, A. H.,** Response of Baccara roses to saline irrigation, *J. Am. Soc. Hortic. Sci.*, 94, 481—484, 1969.
72. **Ehlig, C. F.,** Effects of salinity on four varieties of table grapes grown in sand cultures, *Proc. Am. Soc. Hortic. Sci.*, 76, 323—331, 1960.
73. **Shalhevet, J., Reiniger, P., and Shimshi, D.,** Peanut response to uniform and non-uniform soil salinity, *Agron. J.*, 61, 384—387, 1969.
74. **Francois, L. E., Yermanos, D. M., and Bernstein, L.,** Salt tolerance of safflower, *Calif. Agric.*, 18, 12—14, 1964.
75. **Bernal, C. T., Bingham, F. T., and Oertli, J.,** Salt tolerance of Mexican wheat. II. Relation of variable sodium chloride and length of growing season, *Soil Sci. Soc. Am. Proc.*, 38, 777—780, 1974.