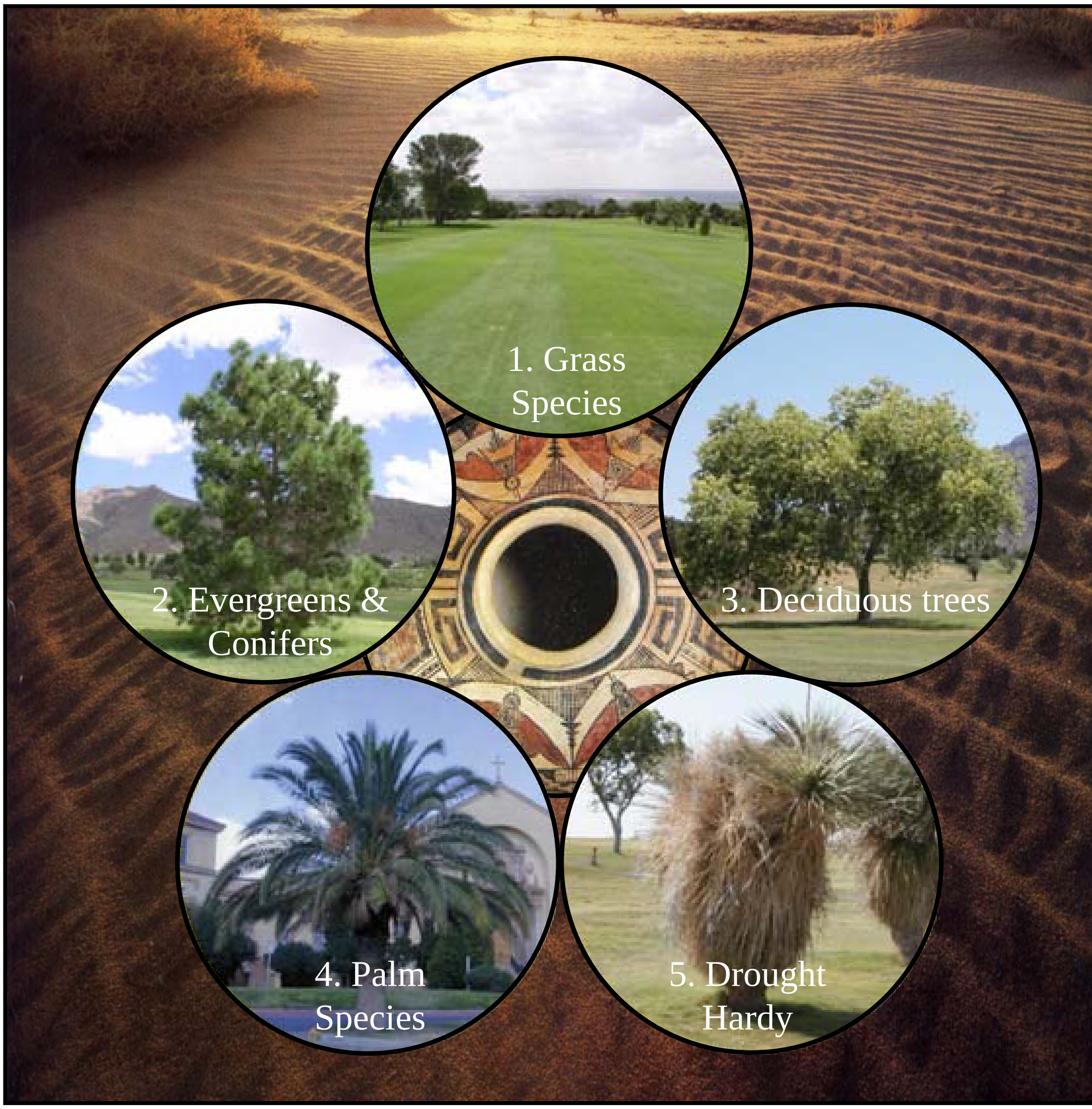
Salt Tolerance of Landscape Plants Common to the Southwest



TR – 316

Texas Agrilife Research Center at El Paso
Texas A&M University System in cooperation with
Texas Water Resource Institute and El Paso Water Utilities

May 2008

Salt Tolerance of Landscape Plants Common to the Southwest

S. Miyamoto[1]

Synopsis

With sharply increasing costs of providing potable water, many communities in the Southwest are attempting to utilize non-potable saline water for irrigating large landscapes. This publication provides the information related to salt effects on growth and leaf injury of various landscaping plants common to the arid areas of the Southwest. The information presented would be useful to landscape planners, managers, and horticulturists for selecting plant species for irrigation with saline water.

Acknowledgement

This material is based upon work supported in part by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture under Agreement No. 2003-34461-13278, Texas Water Resources Institute, Texas Agrilife Research, and El Paso Water Utilities. The following personnel have contributed to this project: Khurram Sheikh, Research Technician; Ignacio Martinez, Agricultural Research Worker; Mark Padilla, Student Technician; and Adrian Portillo, Student Technician.

Contents

[1] S. Miyamoto, Professor, Texas A&M Univ. Agricultural Research Center, 1380 A&M Circle, El Paso, TX.

Introduction

Large urban landscapes in water-short areas of the Southwest are irrigated increasingly with reclaimed or non-potable water with elevated salinity, instead of using potable water. This trend is likely to continue, and will be affecting plant selection as well as landscape design and management practices. Plant selection must be made by considering both foliar and root-induced salt hazards. Plant or leaf damage induced through foliar salt absorption is addressed in a separate publication (Miyamoto and White, 2002), and salt tolerance of landscape plants when the root zone is subject to elevated salinity is the topic of this publication.

The first section of this publication deals with turf and cover grasses, which are often the main component of municipal parks, school yards, and, of course, golf courses. This section presents salt tolerance of traditional turfgrass as well as several uncommon grass species which can be used to stabilize ground surfaces. Section two deals with salt tolerance of evergreens and conifers. These plant groups are well-suited for irrigation with reclaimed water, as they are not only tolerant to foliar injury, but also utilize water during the low evaporation period when there is a surplus of reclaimed water. Section three deals with salt tolerance of deciduous trees, which are highly important as shade trees in the hot desert climate. Section four outlines salt tolerance of native plants which offer water-saving potentials. Section five highlights salt tolerance of palm species which are becoming very popular. The last section deals with vines, ground cover and bedding plants.

Salt tolerance levels are traditionally expressed by soil salinity which causes a 25 or 50% reduction in growth or yield. Soil salinity is expressed by the electrical conductivity of the soil saturation extract, and commonly noted as EC_e. The plant species tested were then classified into five categories using the U.S. Salinity Laboratory scheme for ornamental plants; **sensitive** (0 to 3 dS m^{-1}), **moderately sensitive** (3 to 6 dS m^{-1}), **moderately tolerant** (6 to 8 dS m^{-1}), **tolerant** (8 to 10 dS m^{-1}) and **highly tolerant** (>10 dS m^{-1}). Water use efficiency is not addressed in this paper, but it is a significant factor, especially for maintaining turf. Typically, water use efficiency decreases with soil salinization as plant growth is reduced through salinization.

For the benefit of readers, a number of photographs showing salt damage are included. When examining these photographs, note that one-third of the water applied was drained. This leaching fraction (LF) is high, although it is a level commonly obtained in deep sandy soils. This level of leaching was used not only to assure uniform salt leaching, but also to create the situation where salinity of irrigation water equals EC_e (Appendix A-3). In loamy or clayey soils, the LF is usually lower, as their low permeability limits salt leaching. Under lower leaching, soil salinity would be higher, and salt effects on plants would be greater. Readers may refer to Appendix A-3 which describes a way to compute soil salinity at a lower LF.

Although selection of plants with higher salt tolerance is helpful, readers should also be aware of the fact that the use of salt tolerant plants is not a substitute to good soil and irrigation management. Salinity of the soils which have poor drainage or inadequate water infiltration will eventually reach the level that most plants can not be grown. The use of salt-tolerant plants is primarily a means to deal with high salinity of water used for irrigation, but not a substitute to proper soil selection and handling.

1. Turf and Cover Grasses

Grasses are the diverse plant species adapted to a wide range of soil and climatic conditions. Grass species commercially used for turf in large landscape areas, such as city parks, school yards, and golf course fairways include bermudagrass (*Cynodon sp.*), fescue (*Festuca sp.*), and ryegrass (*Lolium sp.*). The maintenance of these species requires a large amount of water, typically ranging from 35 to 45 inches per year for bermudagrass, and an additional 10 to 20 inches if overseeded with ryegrass or other cool-season grasses. Other species, such as Grama (*Bouteloua sp.)* and wheatgrass species are used for rough or ground cover. Native grass species and certain cool-season grass species are known to survive with limited irrigation. The following experiment was conducted for evaluating growth response of conventional as well as nonconventional grass species to salinity.

Materials and Methods

Seven warm-season and a dozen of cool-season species were evaluated (Table 1.1). Alkali muhly grass (*Muhlenbergia asperifolia*) is native to New Mexico, and grows in saline soils. It forms silt-sized seed, but spreads mostly through rhizomes, and has not yet been used commercially for turf or ground cover. Grama (*Bouteloua sp.*) is a range grass native to the western states, and has been used for golf course roughs. The cool-season grasses tested were 'Fults' or 'Weeping' alkaligrass (*Puccinellia distans*), several cultivars of bluegrass, fescue, ryegrass, wheatgrass (*Thinopyrum sp.*), and Wild ryegrass (*Elymus sp.*) (Table 1.1). Tall wheatgrass, cv. 'Jose' has been used for irrigated pasture, and it becomes dormant during summer months. 'Fults' or 'Weeping' alkaligrass is known for high salt tolerance (Butler et al., 1974).

Seed was placed in sandy loam soil in 5 liter plastic pots, and was irrigated with tap water bi-daily until emergence. The warm-season species were moved to a greenhouse where temperatures were regulated 30º C at night and 40º C during day-hours. Saline water treatments began on June 1, using five solutions containing 800, 2000, 5000, 7500, and 10,000 ppm of dissolved salts (Appendix Table A-2). The electrical conductivity of these solutions was 1.1, 4.4, 9.4, 13.7, and 17.1 dS m^{-1}, respectively. The pots containing the cool-season species were placed in a separate greenhouse (20º to 30º C) in August, and the saline water treatments began. The pots were irrigated when the soil water storage had depleted to half of the maximum storage in an amount to cause a leaching fraction of 30 to 35% (Table A-3 of Appendix). The temperature of the greenhouses was set back to near the ambient level with no heating starting at January, and was elevated again in February after clipping. Photographs of the grasses were taken in September 2002, and February 2003 just prior to clipping. Clipped plants were irrigated for another month, and plant tops harvested again, and dry weights determined for the first cut and for regrowth.

Salinity of the water drained from the pots was approximately 3 times the salinity of the irrigation water (Table A-3 of Appendix). The mean salinity of the soil solution was estimated as the mean of irrigation water and drainage water salinity, or 2 times the salinity of irrigation water. The salinity of the soil saturation extract (EC_e) is about half of the salinity of soil solutions, thus it approximately equals the salinity of irrigation water used (Appendix A-3).

Results

Warm-Season Species: Black grama did not grow at salinity of 2000 mg L^{-1} (4.4 dS m^{-1}), and appeared to be the most sensitive species tested (Fig. 1A). Both Blue grama and

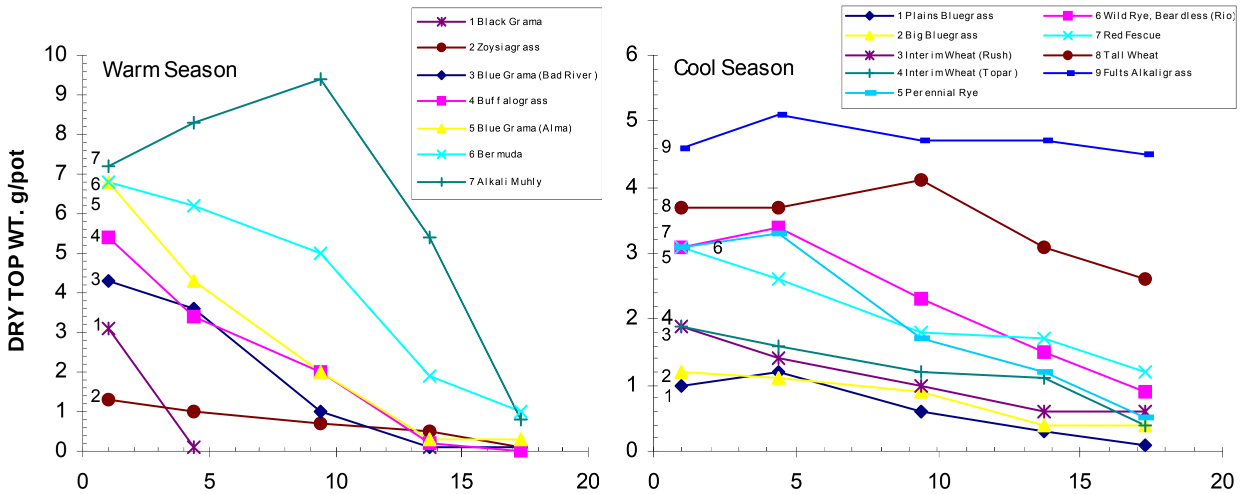


Fig. 1.1. Dry top weight of seven warm-season, and nine cool-season grass species as affected by salinity of irrigation water.

Buffalograss grew well at the lowest salinity, but their growth ceased at 7500 mg L^{-1} (13.7 dS m^{-1}). Zoysiagrass was the slowest to establish, but did show some growth at salinity as high as 7500 mg L^{-1} (13.7 dS m^{-1}). Common bermudagrass tolerated salts better than Blue grama or Buffalograss. Alkali muhly grass has shown a remarkable growth at salinity as high as 5000 mg L^{-1} (9.4 dS m^{-1}), but it decreased to almost zero when irrigated at 10,000 mg L^{-1} (17.1 dS m^{-1}). Both Alkali muhly and common bermudagrass have entered winter dormancy, and so did Black grama and Blue grama when the photograph was taken on January 28, 2003 (Photo Set 1).

Regrowth from the clipping was in proportion to the weight of the first clipping, except for Blue grama 'Alma' at 7500 mg L^{-1}, and Alkali muhly at 10,000 mg L^{-1}. In these cases, no regrowth occurred.

Cool-Season Species: Both Plains bluegrass and Big bluegrass were slow to establish, and so were the Intermediate wheatgrasses, 'Topar' and 'Rush' (Table 1.2). Wild ryegrass was slightly more tolerant than Perennial ryegrass. Tall wheatgrass and 'Fults' or 'Weeping' alkaligrass sustained growth even under salinity as high as 10,000 mg L^{-1} (17.1 dS m^{-1}). These two species produced biomass two to three times greater than other species at high saline treatments, 7500 and 10,000 mg L^{-1} (Fig. 1B). The second group consisting of Wild ryegrass, Perennial ryegrass and Red fescue suffered a significant growth reduction at 5000 mg L^{-1} (9.4 dS m^{-1}). Big bluegrass provided a compact sod cover (Photo Set 1), whereas Plains bluegrass was coarse. Intermediate wheatgrass and wild ryegrass had coarse-textured leaves with recognizable injuries. Red fescue, Tall wheatgrass and 'Fults' or 'Weeping' alkaligrass, all provided dense sod with little leaf injury.

Regrowth from the clipping was in proportion to the weight of the first clipping, except for 'Fults' or 'Weeping' alkaligrass at 10,000 mg L^{-1}. There was regrowth at this salt level, but was weaker than what we projected based on growth prior to the clipping.

Discussion

For salt tolerance classification, we followed the scheme of the U.S. Salinity

Laboratory developed for ornamental plants described in the introduction section. Soil salinity is to be expressed by salinity of the saturation extract, which in our case is approximately equal to salinity of the irrigation water used. The growth and salinity relationships shown in Fig. 1A and Fig. 1B were used to determine salinity corresponding to the 25% reduction in top dry matter.

The top growth of Black grama ceased at salinity of 2000 mg L^{-1} (4.4 dS m^{-1}), thus it was classified as sensitive (0 to 3 dS m^{-1}). Blue grama as well as Buffalograss retained a 75% growth in a salinity range of 3 to 6 dS m^{-1}, thus were classified as moderately sensitive. Blue grama is sensitive to Cl ions (Miyamoto, 1978). The growth response of Buffalograss obtained here coincided with the results obtained by Reid et al. (1993). However, our classification does not coincide with that of Harivandi (1992) where both Blue grama and Buffalograss were placed under a moderately tolerant category (ECe of 6 to 8 dS m^{-1}). The classification by Harivandi (1992) uses a 50% reduction in top growth as a criterion, whereas we used a 25% reduction. This reflected our assessment that turf growth is critical for maintaining public parks and school yards with extensive foot traffic.

The hybrid Zoysiagrass tested can be classified as either moderately sensitive (3 to 6 dS m^{-1}) or moderately tolerant (6 to 8 dS m^{-1}), as salinity which causes a 25% reduction in top growth was 6 dS m^{-1}. Zoysiagrass is rated as tolerant by others using a 50% growth reduction. Precise classification can not be made, as salt tolerance of Zoysiagrass varies significantly among cultivars and accessions (Marcum et al. 1998). Common bermudagrass (*Cynodon dactylon*) is salt-tolerant (8 to 10 dS m^{-1}). Several reports indicate that hybrid bermudagrass (*C. Dactylon x C. transvaalensis*) has different levels of salt tolerance among cultivars (e.g., Dudeck and Peacock, 1993; Francois, 1988). Other warm-season grasses which are salt-tolerant include St. Augustine (*Stenotaphrum secundatum*) which grows well under shade. In the solution culture conducted by Dudeck and Peacock (1993), the growth reduction of Floralawn St. Augustinegrass was similar to that of Tifway II, hybrid bermudagrass.

Seashore paspalum (*P. vaginatum*) is regarded to be among the most salt-tolerant warm-season species, but its tolerance level varies significantly with selection (e.g., Dudeck and Peacock 1985). Unfortunately, some Seashore paspalum can suffer freeze damage. Desert saltgrass (*Distichlis spicata*) can tolerate subfreezing temperatures, and high salinity (Marcum and Kopec, 1997), and is used for covers in saline areas. Alkali muhly offers an option, but has to be field-tested. Several other highly salt tolerant warm-season grass species are available as covers and/or forage crops (Gonzales and Heilman, 1977; Miyamoto et al., 1994).

Bluegrass is regarded as salt-sensitive. The growth of Kentucky bluegrass (*Poa pratensis*) was, for example, reduced by 25% at salinity as low as 3.2 dS m^{-1} in solution culture (Qian et al., 2001). Rough bluegrass (*Poa trivialis*) tolerated salts somewhat better than did Kentucky bluegrass (Greub et al., 1983). Big bluegrass, and to a lesser extent Plains bluegrass tested here maintained growth when irrigated at 2000 mg L^{-1} (4.4 dS m^{-1}) and even at 5000 mg L^{-1} (9.4 dS m^{-1}). These bluegrass species can be classified as moderately sensitive (3 to 6 dS m^{-1}) or moderately tolerant (6 to 8 dS m^{-1}). A hydroponics experiment has shown that Colonial bentgrass (*Agrostis capillaris*) did not survive irrigation with a 8 dS m^{-1} solution, whereas some cultivars of Creeping bentgrass (*Agrostis palustris*), such as 'Mariner', 'Grand Prix' and 'Seaside' sustained growth at 45% of the control (Marcum, 2001). The solution salinity of 8 dS m^{-1} is comparable to 6.0 dS m^{-1} in our experimental setting. A popular cultivar, 'Penncross' appears to be among the least salt-tolerant cultivars (Younger et al., 1967). These results along with other observations indicate that bentgrass is sensitive to moderately sensitive to salts.

Intermediate wheatgrass 'Rush' was moderately sensitive, and 'Topar' moderately tolerant. Other wheatgrass species which fall into the moderately tolerant category include Crested wheatgrass (*Agropyron desertorum*), and Streambank wheatgrass (*Elymus lanceolatus*). Tall wheatgrass (*Agropyron sp.*) usually has higher salt tolerance as discussed later. Perennial ryegrass has been used extensively for overseedings of warm-season grasses. Our test results show it to be moderately salt tolerant (6 to 8 dS m^{-1}), and this classification is consistent with the classification by Harivandi (1992) and Maas (1990). Ryegrass responses to salinity were reported to be consistent across five cultivars (Murcar, 1987). Wild ryegrass 'Rio' (*Elymus triticoides*) was somewhat more tolerant to salts than Perennial ryegrass, and can be categorized as tolerant, along with Tall fescue (*Festuca arundinacea*). Creeping Red fescue (*Festuca rubra*) is moderately sensitive to moderately tolerant as observed here and elsewhere (e.g., Greub et al., 1983). Hard Fescue (*F. ovina*) is usually less tolerant to salts and heat, although it has good wear resistance.

Tall wheatgrass 'Jose' (*Thinopyrum ponticum*) is highly salt tolerant, and it is used extensively for irrigated pasture using saline water. Other tall wheatgrass species such as Fairway wheatgrass (*Agropyron cristatum*) and Western wheatgrass (*Agropyron smithii*) are also tolerant to salts (Butler et al., 1974), but tolerance levels vary with cultivars and accessions (e.g., Shannon, 1978). 'Fults' or 'Weeping' alkaligrass is one of the three *Puccinellia* species. The other two species are Nuttall alkaligrass (*P. airoides*), and Lemmon alkaligrass (*P. Lemmon*). A report indicates that 'Weeping' alkaligrass accession is more salt tolerant than an accession of Lemon alkaligrass (Harivandi et al., 1983). Their resistance to saline water spray is unknown.

Literature Cited

Butler, J.D., J.L. Fults, and G.D. Sanks, 1974. Review of grasses for saline and alkali areas. Proc. 2nd International Turfgrass Research Conference, In: E.C. Roberts (ed.), Blacksburg, VA. ASA, Madison, WI. 1974:551-556.

Dudeck, A. E. and C.H. Peacock, 1985. Effects of salinity on seashore paspalum turf grasses. Agron. J. 77: 47-50.

Dudeck, A.E. and C.H. Peacock, 1993. Salinity effects on growth and nutrient uptake of selected warm-season turfgrasses. Int. Turfgrass Soc Res. J. 7:680-686.

Francois, L.E., 1988. Salinity effects of three turf bermudagrasses. Hort. Science 23:706-708.

Gonzales, C.L. and M.D. Heilman, 1977. Yield and chemical composition of coastal Bermuda grass, Rhodes grass, and volunteer species grown on saline and non-saline soils. J. Range Mgt. 30: 227-230.

Greub, L.J., P.N. Drolsom, and D.A. Rohweder, 1983. Salt tolerance of grasses and legumes for roadside use. Agron. J. 77:76-80.

Harivandi, M.A., 1992. Salinity and turfgrass culture. Turfgrass. Agron. Monograph 32. P. 207-229.

Harivandi, M.A., J.D. Butler, and P.N. Soltanpour, 1983. Effects of soluble salts on ion accumulation in *Puccinellia spp*. J. Plant Nutr. 6:255-266.

Maas, E.V., 1990. Crop Salt Tolerance. In Agricultural Salinity Assessment and Management. K. Tanji, ed.. Amer. Soc. Of Civil Engineers. New York, NY.

Marcum, B.K., 2001. Salinity tolerance of 35 bentgrass cultivars. Hort. Sci. 36: 374-376.

Marcum, B.K., S.J. Anderson, and M.C. Engelke, 1998. Salt gland ion secretion: A salinity tolerance mechanism among five zoysiagrass species. Crop Sci. 38: 806-810.

Marcum, B.K. and D.M. Kopec, 1997. Salinity tolerance of turfgrasses and alternative species in the subfamily *Chloridoideae* (*Poaceae*). Turf Soc. Res. J. 8:735-742.

Miyamoto, S., 1978. Tolerance of some Southwestern range plants to sodium chloride and sulfate. TAES. PR-3480 March. College Station, TX.

Miyamoto, S. and J.M. White, 2002. Foliar salt damage of landscape plants. TAES and TWRI, TR-1202 March.

Miyamoto, S., E.P. Glenn, and N.T. Singh, 1994. Utilization of halophytic plants for fodder production with brackish water in subtropical deserts. In Halaphytes as a Resource for Livestock and for Rehabilitation of Degraded Lands. Sequires V.R. and A.T. Ayoub (Eds). Kluwar Aced. Publishers. Netherlands.

Murcar, N.E., 1987. Salt tolerance in the genus *Lolium* (ryegrass) during germination and growth. Aust. J. Agri. Res. 38:297-307.

Qian, L.Y., S.J. Wilhelm, and K.B. Marcum, 2001. Comparative responses of two Kentucky blue grass cultivars to salinity stress. Crop Sci. 41(6): 1895-1900.

Reid, S.D., A.J. Koski, and H.G. Hughes, 1993. Buffalograss seedling screening in vitro for NaCl tolerance. Hort. Science 28:536.

Shannon, M.G., 1978. Testing salt tolerance variability among Tall Wheatgrass Lines. Agron. J. 70:719-722.

Younger, V.B., O.R. Lunt, and N. Nudge, 1967. Salinity tolerance of seven varieties of creeping bentgrass, *Agrostis palustris Huds*. Agron. J. 59:335-336.

Table 1.1 Grass species used for the experiment.

Common Name	Collected*	Scientific Name	Common Name	Collected*	Scientific Name
Warm Season Grass			**Cool Season Grass**		
Alkali muhly	NM	*Muhlenbergia asperifolia*	'Fults' alkaligrass	ID	*Puccinellia distans*
Bermudagrass	N/A	*Cynodon dactylon*	Bluegrass		*Poa sp.*
Buffalograss	ND	*Buchloe dactyloides*	Big	MT	*P. secunda*
Grama		*Bouteloua sp.*	Plain	MT	*P. arida*
Black	NM	*B. eripoda*	Red fescue	ID	*Festuca rubra*
Blue 'Alma'	NM	*B. gracilis*	Perennial ryegrass	N/A	*Lolium perenne*
Blue 'Bad River'	ND	*B. gracilis*	Intermediate wheatgrass		*Elytrigia sp.*
Zoysiagrass 'Zenith'	GA	*Zoysia sp. Hybrid*	'Rush'	ID	*E. intermedia*
			'Topar'	ID	*E. intermedia*
			Tall wheatgrass		*Thinopyrum ponticum*
			Wild ryegrass 'Rio'	CA	*Elymus triticoides*

* Collected by plant materials centers at Calif. (CA), Idaho (ID), Montana (MT), New Mexico (NM), and N. Dakota (ND).

Table 1.2. Salt tolerance of warm and cool season grass species.

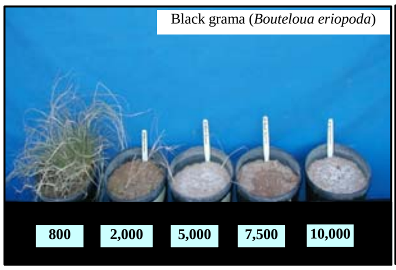
Warm-Season		Cool-Season	
Sensitive (<3 dS m^{-1})			
Black grama	*(Bouteloua eriopoda)*	Kentucky bluegrass	*(Poa pratensis)*
		Rough bluegrass	(*Poa trivialis*)
		Colonial bentgrass	(*Agrostis capillaris*)
Moderately Sensitive (3 to 6 dS m^{-1})			
Bahiagrass	*(Paspalum notatum)*	**Plains bluegrass**	(*Poa arida*)
Blue grama	*(Bouteloua gracilis, 'Alma')*	**Big bluegrass**	(*Poa secunda*)
Buffalograss	*(Buchloe dactyloides)*	Creeping bentgrass	(*Agrostis palustris*)
Blue grama	*(Bouteloua gracilis, 'Bad River')*	Annual ryegrass	(*Lulium multiforum*)
		Intermediate wheatgrass	(*Elytrigia intermedia 'Rush'*)
Moderately Tolerant (6 to 8 dS m^{-1})			
Zoysiagrass 'Zenith'	*(Zoysia hybrid)*	**Intermediate wheatgrass**	(*Elytrigia intermedia 'Topar'*)
		Streambank wheatgrass	(*Elymus lanceolatus*)
		Crested wheatgrass	(*Agropyron desertorum*)
		Red fescue	(*Festuca rubra*)
		Perennial ryegrass	(*Lolium perenne*)
Tolerant (8 to 10 dS m^{-1})			
Bermudagrass	(*Cynodon dactylon*)	Tall fescue	(*Festuca arundinacea*)
St. Augustinegrass	(*Stenotaphrum secundatum*)	**Wild ryegrass 'Rio'**	(*Elymus triticoides*)
Highly Tolerant (>10 dS m^{-1})			
Alkali muhly	(*Muhlenbergia asperifolia*)	**Tall wheatgrass**	(*Thinopyrum ponticum*)
Desert saltgrass	(*Distichlis spicata*)	**'Fults' or 'Weeping' alkaligrass**	(*Puccinellia distans*)

Species with bold print were used in this experiment.

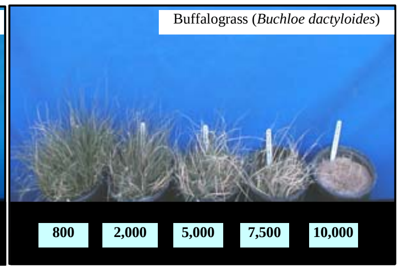
Photo Set 1. Turf and Ground Cover Grasses

Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Black grama	*(Bouteloua eriopoda)*	S	Big bluegrass	*(Poa secunda)*	MS
Blue grama	*(Bouteloua gracilis 'Alma')*	MS	Perennial ryegrass	*(Lolium perenne)*	MT
Buffalograss	*(Buchloe dactyloides)*	MS	Intermediate wheatgrass	*(Elytrigia intermedia 'Rush')*	MT
Zoysiagrass	*(Zoysia japonica)*	MT	Red fescue	*(Festuca rubra)*	MT
Bermudagrass	*(Cynodon dactylon)*	T	Tall wheatgrass	*(Thinopyrum ponticum)*	HT
Alkali muhly	*(Muhlenbergia asperifolia)*	HT	Fults' or 'Weeping' alkaligrass	*(Puccinellia distans)*	HT

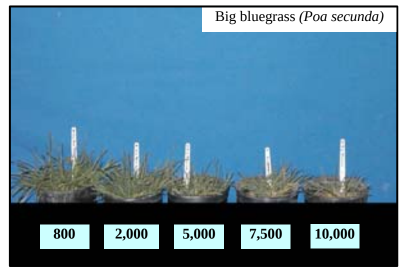
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant, HT: highly tolerant



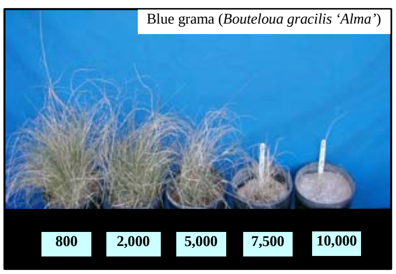
Black grama (*Bouteloua eriopoda*)



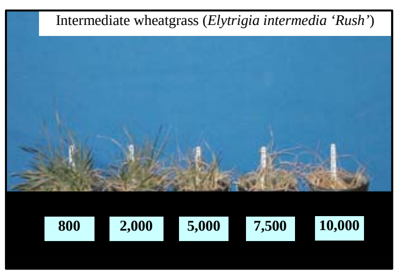
Buffalograss (*Buchloe dactyloides*)



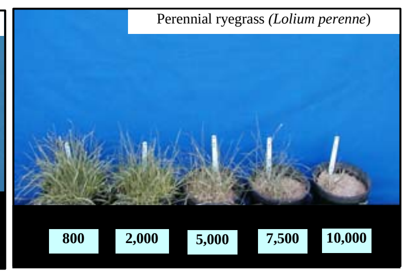
Big bluegrass *(Poa secunda)*



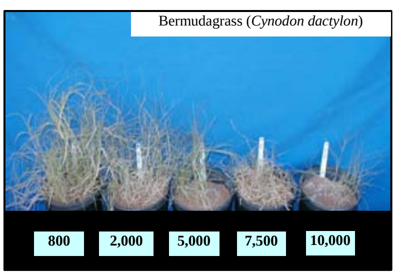
Blue grama (*Bouteloua gracilis 'Alma'*)



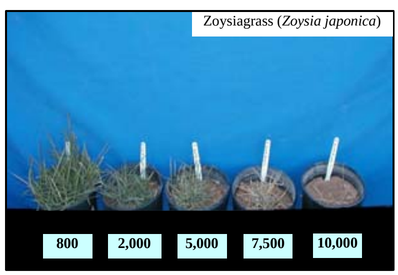
Intermediate wheatgrass (*Elytrigia intermedia 'Rush'*)



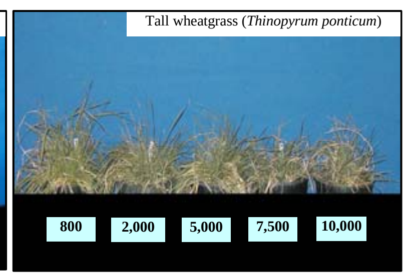
Perennial ryegrass *(Lolium perenne)*



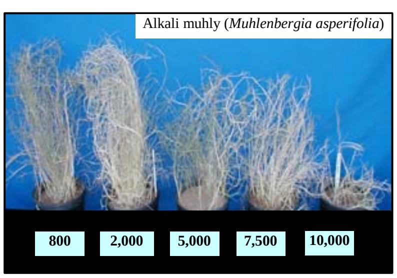
Bermudagrass (*Cynodon dactylon*)



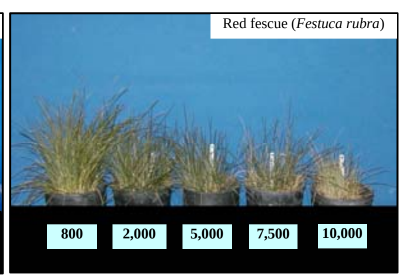
Zoysiagrass (*Zoysia japonica*)



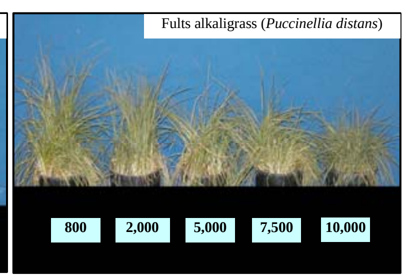
Tall wheatgrass (*Thinopyrum ponticum*)



Alkali muhly (*Muhlenbergia asperifolia*)



Red fescue (*Festuca rubra*)



Fults alkaligrass (*Puccinellia distans*)

2. Salt Tolerance of Evergreens and Conifers

Evergreens and conifers hold a special place in the urban landscape of the Southwest. They provide greenery during the brisk period of winter, and transpire an appreciable amount of water during early spring and fall when reclaimed water is plentiful. Above all, they are usually tolerant to foliar damage caused by foliar salt adsorption (Miyamoto and White, 2002). Foliar damage occurs most commonly with deciduous trees and broadleaf plants when water containing Na or Cl concentrations in excess of 200 mg L^{-1} is applied through overhead sprinklers. Although there are exceptions, evergreens with waxy leaves and conifers can tolerate Na and Cl concentrations up to 350 mg L^{-1} or higher.

High spray resistance makes it possible to maintain evergreens without changing sprinklers when water with elevated salinity is used for irrigation. However, the soils under the tree canopy usually receive drips which have higher salinity, as the trees act as an evaporation tower under frequent and light irrigation. Interception of sprinkled water by tree foliage also lowers salt leaching. Salt tolerance of evergreens and conifers species common to the Southwest is given based on our experiment and other published reports.

Materials and Methods

A total of 19 species of evergreens and conifers was selected for this study (Table 2.1). These species were selected, mainly because they are spray-resistant, except for Texas sage (*Leucophyllum frutescens*). Evergreen trees included four species: Holly oak (*Quercus ilex*), Southern live oak (*Quercus virginiana*), Southern magnolia (*Magnolia grandiflora*), and Texas Mt. laurel (*Sophora secundiflora*). Holly oak is native to the coastal area of California, and was included here because of their high spray resistance. Among the conifers tested, Afghan pine (*Pinus eldarica*) is extensively used. This pine is fast growing, tolerates drought, and highly spray-resistant. Rocky mountain juniper (*Juniperus scopulorum*) and Eastern red cedar (*Juniperus virginiana*) are smaller trees, and their spray tolerance is lower than pines and two cypresses tested, Italian cypress (*Cupressus sempervirens*) and Leyland cypress (*Cupressocyparis leylandii*).

One-year old seedlings were transplanted to 10 liter plastic containers filled with a soil mix of loamy sand and bio-solid (80:20 by volume). They were placed in a greenhouse, and were irrigated with tap water for a month to establish. Saline solutions were prepared by adding NaCl, $MgSO_4$ and $CaCl_2$ to deionized water in amounts of 800, 2000, 5000, 7500 and 10000 ppm (Appendix A-2). The electrical conductivity (EC) of these saline solutions was 1.2, 4.4, 9.4, 13.7 and 17.1 dS m^{-1}, respectively. These values are comparatively high for the total dissolved salts, because Na and Cl are the dominant ionic species. Seedling pots were placed in a greenhouse where temperatures were maintained 20° C at night and 35° C during day-hours. For shrubs, growth was measured by shoot growth, using five shoots per plant. In other cases, growth was measured by the plant height increase. Foliar damage was recorded photographically every two months. Special attention was given to the control of the leaching fraction within a target level of 30 to 35%, and the procedures used are described in Appendix A-3.

The plant species tested were classified following the scheme proposed by the U.S. Salinity Laboratory for ornamental plants: sensitive (< 3 dS m^{-1}), moderately sensitive (3 to 6 dS m^{-1}), moderately tolerant (6 to 8 dS m^{-1}), tolerant (8 to 10 dS m^{-1}), and highly tolerant (> 10 dS m^{-1}). For classification, both the reduction in growth and the increase in leaf injuries were considered. Soil salinity corresponding to these categories must be measured in the soil saturation extract. In our experiment, salinity of the saturation extract was equal to salinity of the irrigation water used, as the leaching fraction was controlled between 30 to 35% (Appendix A-3).

Results

Evergreen Shrubs: Cotoneaster (*Cotoneaster buxifolius*) was the least salt tolerant shrub tested, resulting in plant mortality in 4 months when irrigated with 2000 mg L^{-1} (4.4 dS m^{-1}) water. Growth of Texas mountain laurel (*Sophora secundiflora*) was also severely reduced when irrigated with 2000 ppm water (Photo Set 2A). According to the U.S. Salinity Laboratory classification, these species have to be rated as salt sensitive (< 3 dS m^{-1}). This finding is consistent with an earlier report that Pyrenees cotoneaster (*C. congestus*) is also salt-sensitive (Francois and Clark, 1978).

Yaupon holly (*Ilex vomitoria*), and Dwarf pittosporum (*Pittosporum tobira*) survived 2000 mg L^{-1} (4.4 dS m^{-1}), but not 5000 mg L^{-1} (9.4 dS m^{-1}) water. They can be classified as moderately sensitive (EC_e = 3 to 6 dS m^{-1}). An earlier report (Cooper and Link, 1953) rated Yaupon holly to be moderately tolerant. Our tests indicated that Yaupon holly can suffer massive leaf damage at soil salinity of 5000 mg L^{-1} (9.4 dS m^{-1}), and its growth is reduced at 2000 mg L^{-1} (4.4 dS m^{-1}). Another report (Bernstein et al., 1972) rated Dwarf pittosporum (*P. tobira*) to be at the transition from sensitive to moderately sensitive, coinciding with our test results. Many popular articles rate both Yaupon holly and Pittosporum as salt tolerant, probably because it takes nearly a season to develop leaf injury.

Rosemary (*Rosemarinus officinalis*), and Spreading acacia (*Acacia redolens*) formed the next group of plants which survived irrigation with 5000 mg L^{-1} (9.4 dS m^{-1}) water, but could not make through 7,500 mg L^{-1} (14 dS m^{-1}). At 5000 mg L^{-1}, however, growth was severely decreased and foliar damage was extensive. These species can be classified as moderately tolerant (6 to 8 dS m^{-1}), if growth reductions are not a concern. Rosemary (*Rosmarinus officinalis*) is also rated to be moderately tolerant (6 to 8 dS m^{-1}) by Maas (1990). Rosemary has many cultivars, which can present a cultivar difference in salt tolerance. The variety we used was 'Tuscan Blue,' an upright branching type.

Oleander (*Nerium oleander*) exhibited slight injury of old leaves when irrigated with 7500 mg L^{-1} (14 dS m^{-1}) water (Photo Set 2A). However, shoot growth was reduced significantly even at salinity as low as 2000 mg L^{-1} (4.4 dS m^{-1}). Texas sage (*Leucophyllum frutescens*) responded to saline treatments similarly to Oleander. These plant species have high growth rates. These species can be rated either moderately tolerant (6 to 8 dS m^{-1}) or tolerant (8 to 10 dS m^{-1}) if the growth rate is not a concern. Literature is consistent in regard to salt tolerant nature of these species (e.g., Bernstein et al., 1972; Cooper and Link, 1953).

Evergreen Trees and Conifers: Among the evergreen trees tested, Holly oak (*Quercus ilex*) has shown the least salt tolerance, suffering mortality even at 2000 mg L^{-1} (4.4 dS m^{-1}). Southern live oak (*Quercus virginiana*) performed slightly better, surviving irrigation with 2000 mg L^{-1} water, but not at 5000 mg L^{-1} (Photo Set 2B). Holly oak must be placed under the sensitive category (< 3 dS m^{-1}), and Southern live oak (*Quercus virginiana*) under moderately sensitive (3 to 6 dS m^{-1}).

Southern magnolia (*Magnolia grand-iflora*) grew fast when irrigated with 800 and 2000 mg L^{-1} water. At 5000 mg L^{-1} (9.4 dS m^{-1}), however, growth has declined severely and plant mortality occurred at 7500 mg L^{-1} (9.4 dS m^{-1}) as shown in Photo Set 2A. Magnolia can be classified as moderately sensitive (3 to 6 dS m^{-1}), and this is consistent with an earlier classification by Maas (1990), but not with Cooper and Link (1953) who rated it to be highly salt sensitive.

European olive (*Olea europaea*) was

evaluated as a shrub in this experiment, because the seedlings developed multiple stems, and was rated moderately tolerant (6 to 8 dS m^{-1}). Other reports (Benlloch et al., 1991; Benlloch et al., 1996) indicate that the shoot growth of various olive cultivars was also similarly reduced.

Among the conifers tested, Leyland cypress (*Cupressocyparis leylandii*) has shown the least tolerance, experiencing mortality at 2000 mg L^{-1} (4.4 dS m^{-1}). This species is spray-resistant, but does not seem to tolerate soil salinity. Rocky mountain juniper (*Juniperus scopulorum*), and Eastern red cedar (*Juniperus virginiana*) were able to tolerate 2000 mg L^{-1} (4.4 dS m^{-1}), but not 5000 mg L^{-1} (9.4 dS m^{-1}). These species can be classified either sensitive (< 3 dS m^{-1}), or moderately sensitive (3 to 6 dS m^{-1}). Salt tolerance of these cedars is lower than that of Spreading or Chinese juniper (*Juniperus chinensis*).

Afghan pine (*Pinus eldarica*), Piñon pine (*Pinus edulis*) and Italian cypress (*Cupressus sempervirens*) survived irrigation with 5000 mg L^{-1} (9.4 dS m^{-1}) water, but not 7,500 mg L^{-1} (14 dS m^{-1}). Afghan pine can be classified as moderately tolerant (6 to 8 dS m^{-1}), and Italian stone pine as highly salt tolerant (> 10 dS m^{-1}). These findings with pines are consistent with other reports for other pine species; e.g., Aleppo pine (*Pinus halepensis*) by Francois and Clark (1978), and White pine (*P. strobus*) by Townsend (1980). According to Francois and Clark (1978), Japanese black pine (*Pinus thunbergiana*) is moderately salt-sensitive (3 to 6 dS m^{-1}).

Discussion

There are a number of evergreen shrubs which were previously tested for salt tolerance by others, and these are included in Table 2.2. Note that the plant names in bold print are the species we tested. Additional information is available in Dirr (1978) and Monk and Peterson (1962).

There seems to be a wide range of salt tolerance among Boxwood species. Cooper and Link (1953) rated Boxwood (*Buxus sempervirens*) to be “very poorly salt-tolerant,” as sensitive as Azalea (*A. indica*), whereas Japanese boxwood (*Buxus microphylla*) was rated to be moderately sensitive by Francois and Clark (1978). These species, except for Oriental arborvitae (*Thuja orientalis*) and Silverberry (*Elaeagnus pungens*), are tolerant to foliar-induced salt damage (Miyamoto and White, 2002).

Several evergreen shrubs are moderately tolerant to salts, and include Spreading acacia (*Acacia redolens*), Coyotebush (*Baccharis pilularis*), and Euonymus (*Euonymus japonica*), in addition to Oleander and Texas sage (Table 2.2). These species are drought-hardy, and tolerant to foliar-induced salt damage, except for Texas sage. Salt tolerance of *Acacia sp*. is quite diverse (Tomar, 1997).

Pines are among the most salt tolerant species, especially Italian stone pine. Piñon pine, native to the Southwest, is also salt-tolerant. These species can be used for irrigation with salty water, including brackish water. The opposite spectrum appears to be Holly oaks, of which seedlings could not survive irrigation with 2000 mg L^{-1} (4.4 dS m^{-1}).

There are cases where Live oaks are growing in soils with salinity greater than 4 dS m^{-1}. In fact, many popular articles rate Live oak to be salt-tolerant. Judging from the observation of seedling responses, these field observations appear to be in direct contradiction. Under field conditions, soil salinity varies spatially and temporarily within a root zone of large trees. Tree roots take up water from low-salt zones within the root zone. Once the water in the low-salt zone depletes, trees do not grow, but survive until the next event of rain or irrigation. Trees can perform better under field conditions than in this type of controlled experiments where the entire root system is exposed to relatively uniform salinity. Large woody plants also endure short-duration stress better than small seedlings.

Literature Cited

Benlloch, M., F. Arboleda, D. Barranco, and R. Fernanadez-Escobar, 1991. Response of young olive trees to sodium and boron excess in irrigation water. Hort. Science. 26(7): 867-870.

Benlloch, M., L. Marin, and R. Fernandez-Escobar, 1994. Salt tolerance of various olive varieties. Acta Horticulture 356: 215-217.

Bernstein, L., L.E. Francois and R.A. Clark, 1972. Salt tolerance of ornamental shrubs and ground covers. J. Amer. Soc. Hort. Sci. 97(4): 550-556.

Cooper, W.C., 1953. Salt tolerance of subtropical ornamental plants. Yearbook of Texas Avocado Soc. 6: 47-50.

Dirr, M.A., 1978. Tolerance of seven woody ornamentals to soil applied sodium chloride. J. Arboriculture 4:162-165.

Francois, L.E., and R.A. Clark, 1978. Salt tolerance of ornamental shrubs, trees, and iceplant. J. Amer. Soc. Hort. Sci. 103(2): 280-283.

Maas, E.V., 1990. Crop salt tolerance in agricultural salinity assessment and management. K. Tanji (Ed). ASCE, New York, NY.

Miyamoto, S. and J.M. White, 2002. Foliar salt damage of landscape plants. TAES and TWRI, TR-1202 March.

Monk, R.W. and H.B. Peterson, 1962. Tolerance of some trees and shrubs to saline conditions. Proc. of Amer. Soc. for Horti. Sci. 81: 556-561.

Monk, R.W. and H.H. Wiebe, 1961. Salt tolerance and protoplasmic salt hardiness of various woody and herbaceous ornamental plants. Plant Physiology. 3: 478-482.

Tomar, O.S., 1997. Technologies of afforestation of salt-affected soils. Inter. Tree Crops J. 9: 131-158.

Townsend, A.M., 1980. Response of selected tree species to sodium chloride: J. Amer. Soc. Hort. Sci. 105: 878-883.

Zurayk, R. Preliminary studies on the salt tolerance and sodium relations of common ornamental plants. 1993. Journal of Plant Nutrition. 16(7): 1309-1316.

Table 2.1. Evergreen shrubs, trees and conifers selected for the experiment.

Common Name	Scientific Name	Common Name	Scientific Name
Evergreen shrubs		**Evergreen Trees**	
Cotoneaster	(*Cotoneaster buxifolius*)	Holly oak	(*Quercus ilex*)
Dwarf pittosporum	(*Pittosporum tobira*)	Southern live oak	(*Quercus virginiana*)
European olive	(*Olea europaea*)	Southern magnolia	(*Magnolia grandiflora*)
Oleander	(*Nerium oleander*)	Texas mountain laurel	(*Sophora secundiflora*)
Rosemary	(*Rosmarinus officinalis*)	**Conifers**	
Spreading acacia	(*Acacia redolens*)	Afghan pine	(*Pinus eldarica*)
Texas sage	(*Leucophyllum frutescens*)	Eastern red cedar	(*Juniperus virginiana*)
Yaupon holly	(*Ilex vomitora*)	Italiancypress	(*Cupressus sempervirens*)
		Italian stone pine	(*Pinus pinea*)
		Leyland cypress	(*Cupressocyparis leylandii*)
		Piñon pine	(*Pinus edulis*)
		Rocky mountain juniper	(*Juniperus scopulorum*)

Table 2.2. Salt tolerance of evergreen shrubs, trees, and conifers.

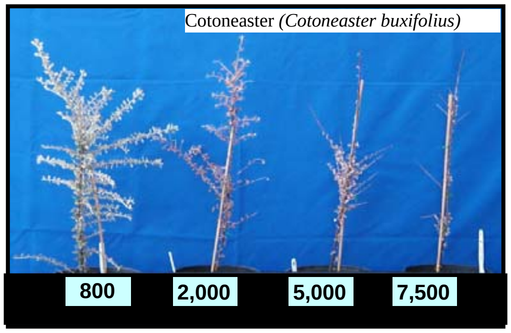
Shrubs		Trees	
Sensitive (<3 dS m^{-1})			
Rose	*(Rosa sp.)*	**Holly oak**	*(Quercus ilex)*
Nandina	*(Nandina domestica)*	**Leyland cypress**	*(Cupressocyparis leylandii)*
Red tip photinia	*(Photinia fraseri)*	Japanese yew	*(Podocarpus macrophyllus)*
Burford holly	*(Ilex cornuta, 'Burfordii')*	**Texas mountain laurel**	*(Sophora secundiflora)*
Chinese holly	*(Ilex cornuta)*		
Pyrenees cotoneaster	*(Cotoneaster congestus)*		
Cotoneaster	*(Cotoneaster buxifolius)*		
Texas mountain laurel	*(Sophora secundiflora)*		
Moderately Sensitive (3 to 6 dS m^{-1})			
Oriental arborvitae	*(Thuja orientalis)*	Rocky mountain juniper	*(Juniperus scopulorum)*
Japanese boxwood	*(Buxus microphylla)*	**Eastern red cedar**	*(Juniperus virginiana)*
Glossy privet	*(Ligustrum lucidum)*	**Southern live oak**	*(Quercus virginiana)*
Indian hawthorn	*(Raphiolepis indica)*	**Southern magnolia**	*(Magnolia grandiflora)*
Yaupon holly	*(Ilex vomitora)*	Japanese black pine	*(Pinus thunbergiana)*
Dwarf pittosporum	*(Pittosporum tobira)*		
Blue point juniper	*(Juniperus chinensis)*		
Hollywood juniper	*(Juniperus chinensis)*		
Spreading juniper	*(Juniperus chinensis)*		
Pyracantha	*(Pyracantha. graeberi)*		
Silverberry	*(Elaeagnus pungens)*		
Moderately Tolerant (6 to 8 dS m^{-1})			
Rosemary, 'Tuscan Blue'	*(Rosmarinus officinalis)*	Aleppo pine	*(Pinus halepensis)*
Spreading acacia	*(Acacia redolens)*	Russian olive**	*(Elaeagnus angustifolia)*
Bottle brush*	*(Callistemon viminalis)*	White pine	*(Pinus strobus)*
Bougainvillea*	*(Bougainvillea spectabilis)*	Arizona cypress	*(Cupressus glabra)*
Coyotebush	*(Baccharis pilularis)*	**European olive**	*(Olea europaea)*
Japanese euonymus	*(Euonymus japonica)*	**Afghan pine**	*(Pinus eldarica)*
Oleander	*(Nerium oleander)*	**Piñon pine**	*(Pinus edulis)*
Texas sage	*(Leucophyllum frutescens)*	**Italian cypress**	*(Cupressus sempervirens)*
European olive	*(Olea europaea)*		
Tolerant (8 to 10 dS m^{-1})			
Four-wing saltbush	*(Atriplex canescens)*		
Highly Tolerant (>10 dS m^{-1})			
		Italian stone pine	*(Pinus pinea)*

* Subject to freeze damage unless protected
** Invasive, not recommended
Species with bold print were used in this experiment.

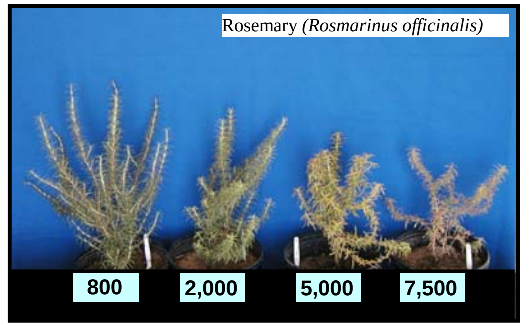
Photo Set 2A. Evergreens and Conifers (Shrubs)

Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Cotoneaster	*(Cotoneaster buxifolius)*	S	Rosemary	(*Rosmarinus officinalis*)	MS
Texas mountain laurel	(*Sophora secundiflora*)	S	Oleander	(*Nerium oleander*)	MT
Yaupon holly	(*Ilex vomitoria*)	MS	Texas sage	(*Leucophyllum frutescens*)	MT
Dwarf pittosporum	(*Pittosporum tobira*)	MS	European olive	(*Olea europaea*)	MT

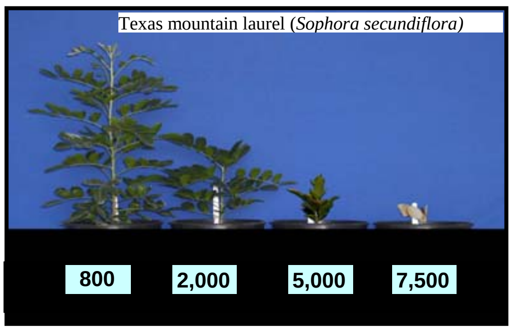
S: sensitive, MS: moderately sensitive, MT: moderately tolerant



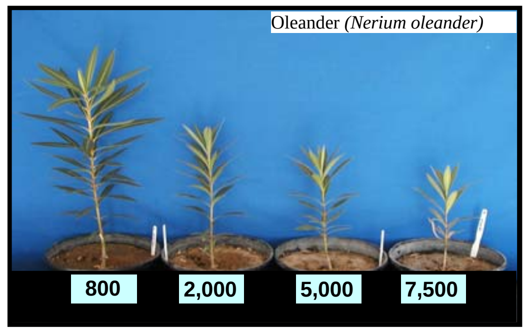
Cotoneaster *(Cotoneaster buxifolius)*



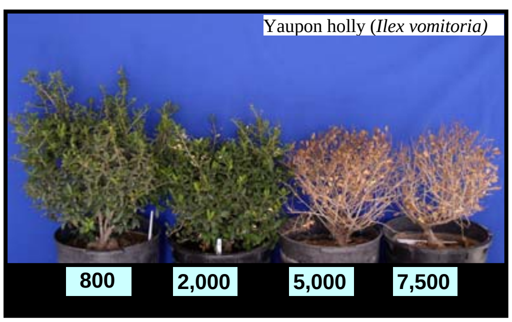
Rosemary *(Rosmarinus officinalis)*



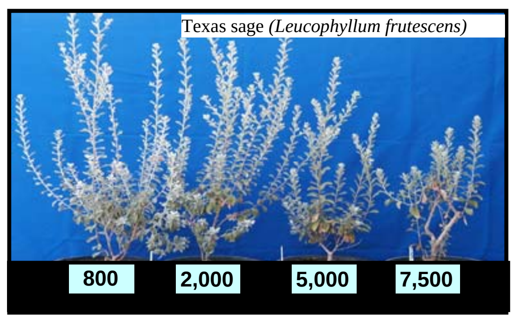
Texas mountain laurel (*Sophora secundiflora)*



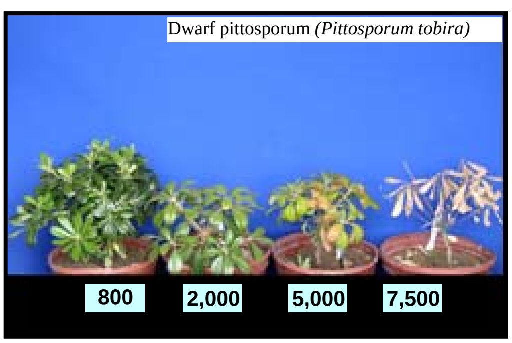
Oleander *(Nerium oleander)*



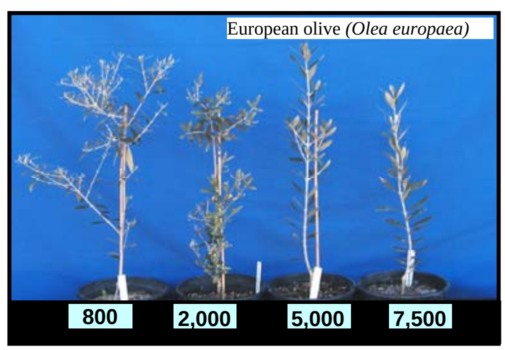
Yaupon holly (*Ilex vomitoria)*



Texas sage *(Leucophyllum frutescens)*



Dwarf pittosporum *(Pittosporum tobira)*



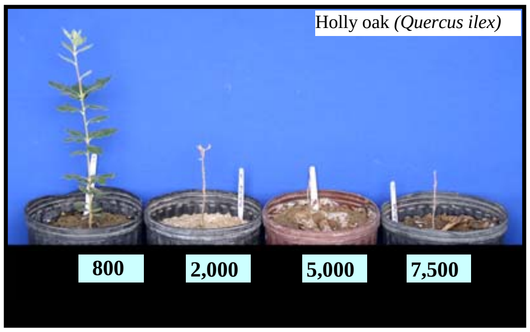
European olive *(Olea europaea)*

Photo Set 2B. Evergreens and Conifers (Trees)

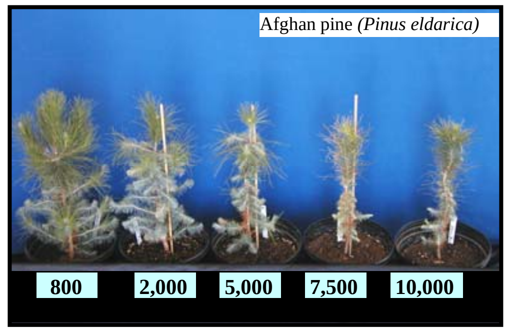
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classifcation
Holly oak	*(Quercus ilex)*	S	Afghan pine	*(Pinus eldarica)*	MT
Rocky mountain juniper	*(Juniperus scopulorum)*	MS	Piñon pine	*(Pinus edulis)*	MT
Eastern red cedar	*(Juniperus virginiana)*	MS	Italian cypress	*(Cupressus sempervirens)*	MT
Southern magnolia	*(Magnolia grandiflora)*	MS	Italian stone pine	*(Pinus pinea)*	HT
Leyland cypress*	*(Cupressocyparis leylandii)*	S	Southern live oak*	*(Quercus virginiana)*	MS

S: sensitive, MS: moderately sensitive, MT: moderately tolerant, HT: highly tolerant

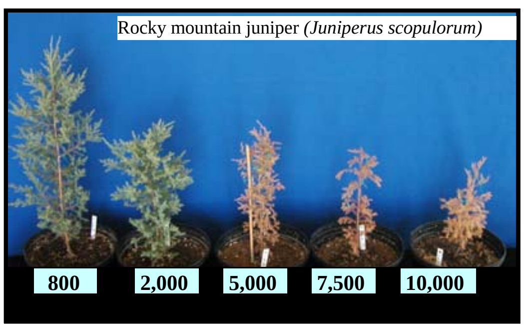
*Not shown



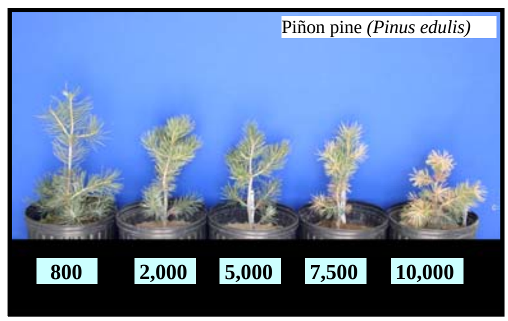
Holly oak *(Quercus ilex)*



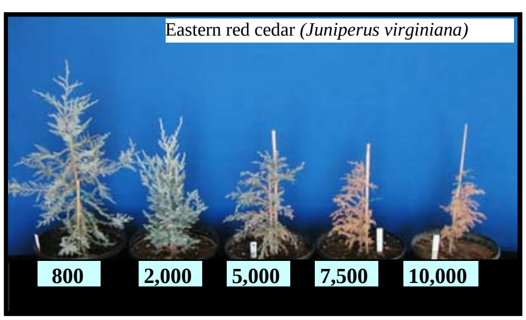
Afghan pine *(Pinus eldarica)*



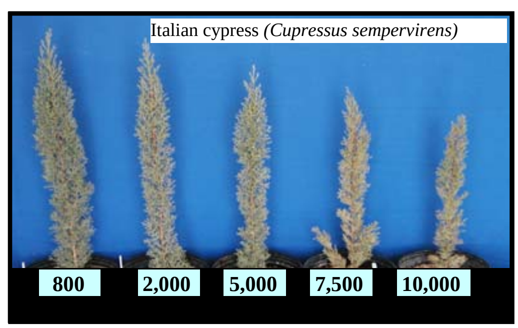
Rocky mountain juniper *(Juniperus scopulorum)*



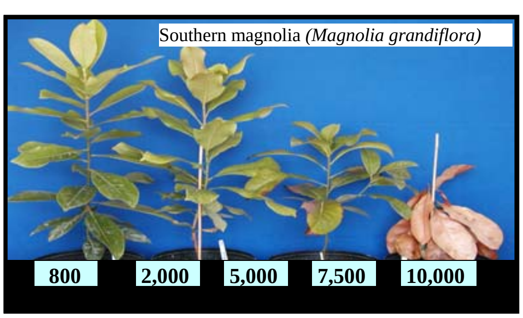
Piñon pine *(Pinus edulis)*



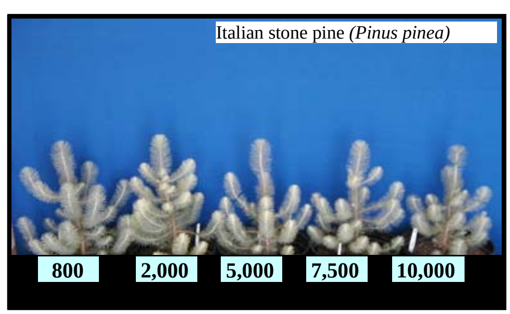
Eastern red cedar *(Juniperus virginiana)*



Italian cypress *(Cupressus sempervirens)*



Southern magnolia *(Magnolia grandiflora)*



Italian stone pine *(Pinus pinea)*

3. Salt Tolerance of Deciduous Trees

Deciduous trees provide shade, a feature desired in the hot desert of the Southwest. In addition, some deciduous trees provide fall color, and others have flowers.

White mulberry trees (*Morus alba*), which yield dense shade, became a popular lawn tree in many subdivisions, parks and school yards. In recent years, however, some communities have banned planting of mulberry because of excessive pollen production. Ash trees (*Fraxinus sp.*) appear to be the most preferred option at the present time. Sycamores (*Plantanus sp.*) are also used, but usually with foliage scorch from salts.

According to botanists, the riparian zones of the Rio Grande and other semi-arid river systems in the Southwest were once dominated by Cottonwood (*Populus fremontii*), and various types of Willow (*Salix sp.*). These native riparian species have largely been replaced by an invasive Salt cedar (*Tamarix sp.*), in part due to salinization of river banks and floodplains, which took place in the past several decades (e.g., Glenn et al., 1998). In the transition zones to the upland desert, native deciduous trees and shrubs, which are drought-tolerant, are found. These include Desert willow (*Chilopsis linearis*), Texas vitex (*Vitex agnus-castus*), Honey mesquite (*Prosopis glandulosa*) and Screwbean mesquite (*P. pubescens*). These species are used in urban landscapes, but not necessarily as a shade trees, as they provide only light shade. Salt tolerance of deciduous trees is described here.

Materials and Methods

A total of 14 deciduous tree species were selected for testing. These species are grouped into large and small categories in Table 3.1. Arizona sycamore (*Platanus wrightii*), Bur oak (*Quercus macrocarpa*) and Red oak (*Quercus shumardii*) are used commonly as a lawn tree or a shade tree. Green ash (*Fraxinus pennsylvanica*), Arizona ash (*Fraxinus velutina*), and Modesto ash (*Fraxinus velutina 'Modesto'*), are also used extensively in the Southwest. *Pistacia atlantica* is larger than *P. chinesis*, and drought-hardy. However, Atlantica offers no fall-color. Chilean mesquite (*Prosopis chilensis*) is a large tree, and has foliage denser than Screwbean mesquite (*Prosopis pubescens*) or Honey mesquite (*Prosopis glandulosa*).

Japanese pagoda tree (*Sophora japonica*) is a lawn or ornamental tree used in a limited space. Desert willow (*Chilopsis linearis*), and Texas vitex (*Vitex agnus-castus*) are small trees native to arroyo or riparian areas of the Southwest. They are drought-hardy, but cast only light shade. Desert olive or New Mexico privet (*Forestieria neomexicana*) is also native to the Southwest and is used as a screen plant more so than as a shade tree. Chitalpa (*Chitalpa tashkentensis*) and Mimosa (*Albizia julibrissin*) are used primarily as flowering trees in all types of landscapes.

The methods used to evaluate the salt tolerance of deciduous trees were the same as those used for evergreens and conifers. In brief, one-year old seedlings were transplanted to 10 liter plastic containers filled with a soil mix of loamy sand and bio-solids (80:20). They were placed in a greenhouse, and were irrigated with tap water for a month to establish them. Saline solutions were prepared by adding NaCl, $MgSO_4$, and $CaCl_2$ to deionized water at five concentrations, 800, 2000, 5000, 7500 and 10000 mg L^{-1} (Appendix A-2). The electrical conductivity (EC) of these solutions was 1.2, 4.4, 9.4, 13.7 and 17.1 dS m^{-1}, respectively. These conductivity values are comparatively high for the total dissolved salts, because Na and Cl are the dominant ionic species.

Seedling pots were placed in a greenhouse where temperatures were maintained at 30º C at night and 40º C during day-hours. Seedling growth and foliar damage were recorded photographically every two-months for 6 months. Special attention was given to the control of the leaching fraction (LF) within a target level of 30 to 35%, and the procedures used are described in Appendix A-3. Plants were classified into five categories, using the method proposed by U.S. Salinity Laboratory (shown in the introduction section).

Results

Detailed results of seedling response to salinity are omitted, and general observations and tolerance classification are shown here.

Large Trees: Seedlings of Arizona sycamore (*Platanus wrightii*), Bur oak (*Quercus macrocarpa*) and Red oak (*Quercus shumardii*) could not tolerate irrigation with 2000 mg L^{-1} (4.4 dS m^{-1}) water (Photo Set 3). Arizona sycamore seedlings died in two months when irrigated with 2000 mg L^{-1} water, and had recognizable leaf injury when irrigated with 800 mg L^{-1} water. Bur oak and Red oak irrigated with 2000 mg L^{-1} water did not die in two months, but did in six months. These results are consistent with the finding from an earlier study with Pin oak (*Quercus palustris*) by Townsend (1980). The study used a hydroponic culture and leaf growth declined by 57% in five weeks when grown in a 4500 mg L^{-1} NaCl solution. This concentration is equivalent to 3000 mg L^{-1} in our experiment. If the experiment continued for six months, like ours, it might have defoliated. The same study by Townsend (1980) also indicates that American sycamore (*Platanus occidentalis*) was highly sensitive to salts, resulting in a 77% reduction in leaf growth and leaf injury in over 80% of the leaves when grown in the 4500 mg L^{-1} solution. All of these species have to be classified as salt sensitive, and may grow if the salinity of irrigation water or of the soil saturation extract is less than 3 dS m^{-1}.

Cottonwood (*Populus fremontii*), Green ash (*Fraxinus pennsylvanica*), and Pistache (*Pistacia atlantica*) have survived irrigation with 2000 mg L^{-1} (4.4 dS m^{-1}) water, but with a significant growth reduction. Atlantica seedlings, photographed after 6 months of the saline treatment are shown in Photo Set 3. None of these plants survived when irrigated with the 5000 mg L^{-1} (9.4 dS m^{-1}) solution.

Cottonwood seedlings defoliated when grown with 2000 mg L^{-1} (4.4 dS m^{-1}) water. This finding is consistent with an earlier report by Jackson et al., (1990). Monk and Peterson (1953) reported that Green ash died when irrigated with a saline solution containing 10,000 mg L^{-1} of NaCl and $CaCl_2$, instead of 5000 mg L^{-1}. However, the concentration of NaCl in the 10,000 saline solution was 5000 mg L^{-1}. Seedling response of Pistache (*P. atlantica*) in a two-year lysimeter study by Picchioni et al. (1990), has shown little growth when irrigated with a saline solution with EC of 8.0 dS m^{-1}. These species can be classified as moderately sensitive (3 to 6 dS m^{-1}).

Black Gum (*Nyssa sylvatica*) survived irrigation with 5000 mg L^{-1} (9.4 dS m^{-1}), but with extensive leaf damage (Photo Set 3). Seedlings irrigated with 2000 mg L^{-1} were in good shape for nearly three months, then became chlorotic. It can be classified as moderately tolerant if leaf injury can be tolerated. If not, it should be rated as moderately sensitive.

Chilean mesquite (*Prosopis chilensis*) tolerated irrigation with 7500 mg L^{-1} (14 dS m^{-1}) water, but the growth was reduced by more than 50%. There was no sign of leaf injury even when irrigated with 7500 mg L^{-1} water (Photo Set 3). This species can be rated as tolerant (8 to 10 dS m^{-1}), provided that the significant growth reduction occurred at 9.4 dS m^{-1} is acceptable.

Chilean mesquite is vigorous, and is almost evergreen in warm climate. Felker et al. (1981) evaluated growth response of six species of *Prosopis* in sand culture. Honey mesquite (*P. grandulosa*) appears to be slightly less tolerant than Chilean mesquite. Salt tolerance of Screwbean mesquite (*P. pubescens*) has not been investigated, but we have observed that it can compete with Salt cedar (*Tamarix sp.*) in highly saline areas.

Small Trees

Seedlings of Japanese Pagoda trees (*Sophora japonica*) irrigated with 2000 mg L^{-1} water did not grow much, and eventually died (Photo Set 3). Townsend (1980) reported that the seedling growth of Japanese Pagoda tree was reduced by 50% when grown in a solution containing 4500 mg L^{-1} of NaCl. The measurement was performed after 5 weeks of the treatment, but not 6 months.

Desert willow (*Chilopsis linearis*) irrigated with 2000 mg L^{-1} water did grow some for several months, and then its growth ceased. Chitalpa (*Chitalpa tashkentensis*) and Texas vitex (*Vitex agnus-castus*) grew some at 2000 mg L^{-1} (4.4 dS m^{-1}), but could not survive irrigation with 5000 mg L^{-1} (9.4 dS m^{-1}) water. Since the growth reduction at 2000 mg L^{-1} (4.4 dS m^{-1}) was so severe, all of those species should be rated as being sensitive (< 3 dS m^{-1}).

Mimosa (*Albizia julibrissin*) and Desert olive (*Forestiera neomexicana*) have tolerated irrigation with 5000 mg L^{-1} (9.4 dS m^{-1}) water. By the sixth month, the growth at 5000 mg L^{-1} (9.4 dS m^{-1}) was severely reduced, and the seedlings grown with 7500 mg L^{-1} (14 dS m^{-1}) died. These species may be rated as moderately sensitive (3 to 6 dS m^{-1}).

Discussion

There is a wide range of salt tolerance among deciduous trees, as summarized in Table 3.2. Fruit and nut bearing trees can be added to the sensitive category (Maas, 1990; Miyamoto et al., 1985). Willows (*Salix sp.*) are also generally sensitive to salts (Crouch and Honeyman, 1986). Sycamore and deciduous oaks are also sensitive, and so are flowering trees such as Crape Myrtle and Chitalpa. These species are also sensitive to sprinkler application of irrigation water (Miyamoto and White, 2002).

The above findings appear to be inconsistent with deciduous trees grown under irrigation in West Texas. Pecan trees are, for example, grown in the Trans-Pecos region with water that has a salinity well exceeding 1000 mg L^{-1} (Miyamoto et al., 1986). In these cases, the water usually contains Ca and SO_4 ions, which are not as deterious as Na and Cl (Miyamoto et al., 1986). In the case of the Middle Rio Grande Valley, pecans are grown with water containing dissolved salts of less than 800 mg L^{-1}, most of which consists of Na, Cl, and SO_4. The saline water used for this experiment consisted mostly of Na and Cl (Appendix A-2).

Large salt-sensitive trees are found growing in saline areas of the Rio Grande Valley where water tables are within 5 to 7 feet. Salinity of these soils when measured in the top few feet is usually elevated, ranging from 4 to 8 dS m^{-1}. Yet, some deciduous trees, especially Weeping willow and Saberian elms (*Ulmus pumila*) do well. In these cases, tree roots are usually absorbing water from the capillary fringe of a shallow water table. The data obtained from a greenhouse experiment are an indicator of salt tolerance when the entire root system is exposed to comparatively uniform soil salinity for a growing season, and the actual tree response to salinity would be more complicated. At the same time, salt tolerance determined based on seedling responses to soil salinity has correlated very well, at least in surface-irrigated mature pecan trees (Miyamoto et al., 1986) and irrigated pistachio trees grown in West Texas (Picchioni et al., 1990).

The seedlings used for this experiment were potted transplants with an established root system. Some of the deciduous trees, especially fruits and nut trees are established from bare-rootstocks. These nursery stocks, especially those which have freshly cut roots, may suffer salt damage more so than seedlings with well-developed root systems.

Literature Cited

Crouch, R.J. and M.N. Honeyman, 1986. The relative salt tolerance of willow cuttings. J. Soil Conser. 42: 103-104.

Felker, P., P. Clark, A.E. Laag, and P.F. Pratt, 1981. Salinity tolerance of the tree legumes: Mesquite (*Prosopis glandulosa, var Torreyana, P. velutina, and P. articulata*), Algarrobo (*P. Chilensis*), Kiawe (*P. Pallida*), and Tamarugo (*P. Tamarugo*) grown in sand culture on nitrogen free media: Plant and Soil 61: 311-317.

Glenn E., R. Tanner, S. Mendez, T. Kehret, D. Moore, J. Garcia, and C. Valdez, 1998. Growth rates, salt tolerance and water use characteristics of native and invasive riparian plants from the delta of the Colorado River. Mex. J. Arid Environ. 40: 281-294.

Jackson, J., J. Ball, and M. Rose, 1990. Assessment of the salinity tolerance of eight Sonoran Desert riparian trees and shrubs, Yuma. AZ. U.S. Bureau of Reclamation, USDI.

Maas, E.V., 1990. Crop salt tolerance in agricultural salinity assessment and management. K. Tangi, ed. ASCE, New York, NY.

Miyamoto, S., G.R. Gobran, and K. Piela, 1985. Salt effects on seedling growth and ion uptake of three pecan rootstock cultivars. Agron. J. 77: 383-388.

Miyamoto, S., T. Riley, G. Gobram, and J. Petticrew, 1986. Effects of saline water irrigation on soil salinity, pecan tree growth and nut production. Irrig. Sci. 7: 83-95.

Miyamoto, S., and J.M. White, 2002. Foliar salt damage of landscape plants induced by sprinkler irrigation, Texas Water Resources Institute TR-1202, College Station, Texas.

Monk, R.W. and H.B. Peterson, 1962. Tolerance of some trees and shrubs to saline conditions. Proc. of Amer. Soc. for Horti. Sci. 81: 556-561.

Picchioni G.A., S. Miyamoto, and J.B. Storey, 1990. Salt effects on growth and ion uptake of pistachio rootstock seedlings. J. Amer. Hort. Sci. 115: 647-653.

Townsend, A.M., 1980. Response of selected tree species to sodium chloride: J. Amer. Soc. Hort. Sci. 105: 878-883.

Table 3.1. Deciduous trees selected for the experiment.

Large Decidous Trees			
Arizona sycamore	*(Platanus wrightii)*	Green ash	*(Fraxinus pennsylvanica)*
Bur oak	*(Quercus macrocarpa)*	Pistacia atlantica	*(Pistacia atlantica)*
Red oak	*(Quercus rubra)*	Black gum	*(Nyssa sylvatica)*
Cottonwood	*(Populus fremontii)*	Chilean mesquite	*(Prosopis chilensis)*
Small Deciduous Trees			
Japanese pagoda	*(Sophora japonica)*	Texas vitex	*(Vitex agnus-castus)*
Desert willow	*(Chilopsis linearis)*	Mimosa silk tree	*(Albizia julibrissin)*
Chitalpa	*(Chitalpa tashkentensis)*	Desert olive	*(Forestiera neomexican)*

Table 3.2. Salt tolerance of deciduous trees.

Small trees		Large Trees	
Sensitive (<3 dS m^{-1})			
Apple*	*(Malus sylvestris)*	**Arizona sycamore**	*(Platanus wrightii)*
Pear*	*(Pyrus communis)*	American sycamore	*(Platanus occidentalis)*
Plum*	*(Prunus domestica)*	Pecan*	*(Carya illinoensis)*
White dogwood	*(Cornus florida)*	Cherry *	*(Prunus avium)*
Crape myrtle	*(Lagerstroemia indica)*	Persimmon*	*(Diospyros virginiana)*
Japanese pagoda	*(Sophora japonica)*	**Green ash**	*(Fraxinus Pennsylvanica)*
Desert willow	*(Chilopsis linearis)*	**Bur oak**	*(Quercus macrocarpa)*
Chitalpa	*(Chitalpa tashkentensis)*	Pin oak	*(Quercus palustris)*
Texas vitex	*(Vitex agnus-castus)*	**Red oak**	*(Quercus shumardii)*
		Willows	*(Salix sp.)*
Moderately Sensitive (3 to 6 dS m^{-1})			
Purple cherry plum	*(Prunus cerasifera)*	**Cottonwood**	*(Populus fremontii)*
Mimosa silk tree	*(Albizia julibrissin)*	**Pistacia atlantica**	*(Pistacia atlantica)*
Desert olive	*(Forestiera neomexicana)*		
Bolleana poplar	*(Populus alba)*		
Moderately Tolerant (6 to 8 dS m^{-1})			
Pomegranate	*(Punica granatum)*	**Black gum**	*(Nyssa sylvatica)*
Pistache, Texas	*(Pistacia texana)*	Sweet gum	*(Liquidambar styraciflua)*
Pistache, Chinese	*(Pistacia chinensis)*		
Siberian elm	*(Ulmus parviflolia)*		
Tolerant (8 to 10 dS m^{-1})			
Honey mesquite	*(Prosopis glandulosa)*	Chilean mesquite	*(Prosopis chilensis)*
Black locust	*(Robinia pseudoacacia)*	Honey locust	*(Gleditsia triacanthos inermis)*
Salt cedar	*(Tamarix sp.)***		
Highly Tolerant (>10 dS m^{-1})			
Screwbean mesquite	*(Prosopis pubescens)*		

* These ratings are for fruit production.

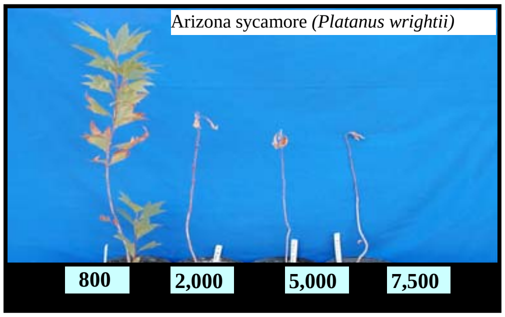
** Highly invasive, not recommended

Species with bold print were used in this experiment.

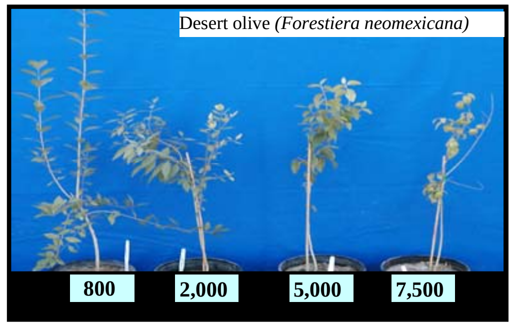
Photo Set 3. Deciduous Tree Seedlings

Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Arizona sycamore	(*Platanus wrightii*)	S	Desert olive	(*Forestiera neomexicana*)	MS
Shumard red oak	(*Quercus shumardii*)	S	Pistacia atlantica	(*Pistacia atlantica*)	MS
Japanese pagoda	(*Sophora japonica*)	S	Black gum	(*Nyssa sylvatica*)	MT
Chitalpa	(*Chitalpa tashkentensis*)	S	Chilean mesquite	(*Prosopis chilensis*)	T

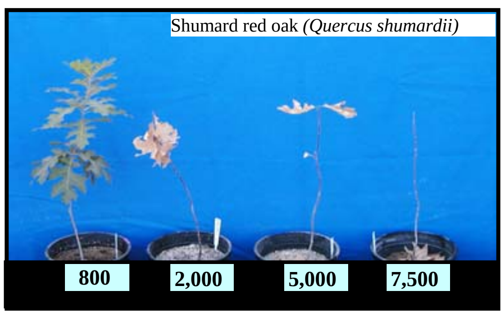
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant



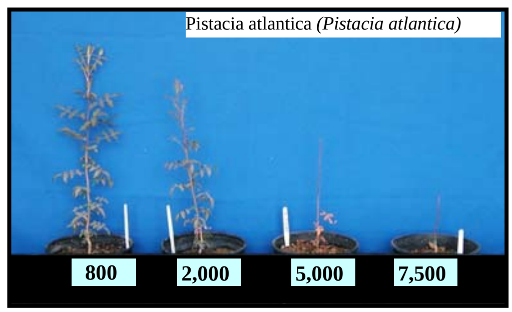
Arizona sycamore *(Platanus wrightii)*



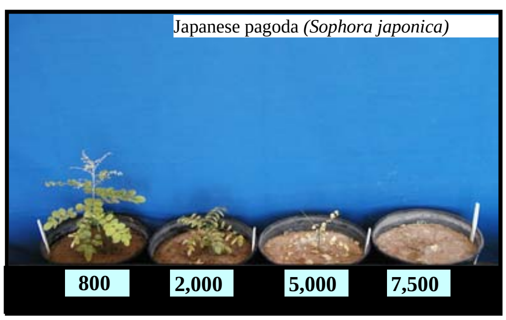
Desert olive *(Forestiera neomexicana)*



Shumard red oak *(Quercus shumardii)*

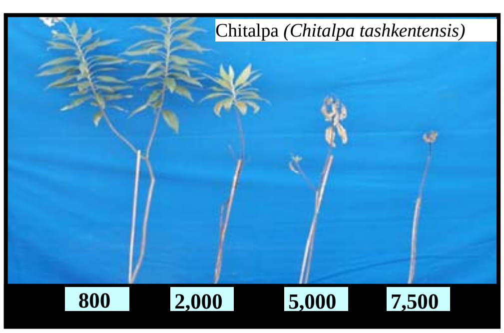


Pistacia atlantica *(Pistacia atlantica)*

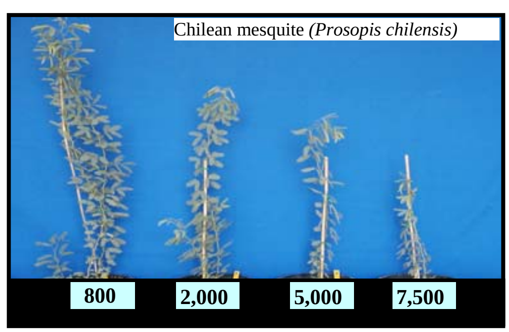


Japanese pagoda *(Sophora japonica)*

Black gum *(Nyssa sylvatica)*



Chitalpa *(Chitalpa tashkentensis)*



Chilean mesquite *(Prosopis chilensis)*

4. Salt Tolerance of Native Plants

There has been an increasing interest in using native plants for landscaping. The primary rationale is to maintain ecological compatibility which includes reduced water use. The majority of the plants native to dry areas of the Southwest are drought-tolerant, thus the native species can be maintained with supplemental or no irrigation once established.

This idea has been demonstrated at various locations. Mesquite (*Prosopis sp*.), Texas sage (*Leucophyllum sp*.), and Desert willow (*Chilopsis sp.*) are, for example, commonly found in various landscapes in the Southwest. Many other native shrubs and trees have also been used as ornamental plants, but with uncertain knowledge about their salt tolerance. Results of our salt tolerance evaluation of popular native plants are reported here.

Materials and Methods

A total of 13 species native to the Southwest was selected for testing (Table 4.1). Bird of paradise (*Caesalpinia mexicana*), Texas sage (*Leucophyllum frutescens*), and Texas mountain laurel are among the favorites in southwestern landscape, and so are Agave (*Agave parryi*), Century plants (*Agave americana*) and Yucca (*Yucca brevifolia*). Spanish broom (*Spartium junceum*) was also included, although it is not native to the Southwest. Popular shrubs native to the Southwest, Coyotebush (*Baccharis pilularis*), Silverberry (*Elaeagnus pungens*), and Rabbit bush (*Chrysothamnus nauseosus*), were excluded as their tolerance was already evaluated (Bernstein et al., 1972). Four deciduous trees, Arizona sycamore (*Platanus wrightii*), Desert willow (*Chilopsis linearis*), Desert olive (*Forestiera neomexicana*), Cottonwood (*Populus fremontii*), and two evergreens, Rocky mountain juniper (*Juniperus scopulorum*), and Piñon pine (*Pinus edulis*) were included here.

One-year old seedlings were transplanted to 3 gallon plastic containers filled with a soil mix of loamy sand and bio-solids (80:20). They were placed in a greenhouse and were irrigated with tap water for a month to establish. Saline solutions were prepared by adding NaCl, $MgSO_4$ and $CaCl_2$ to deionized water, so as to yield dissolved salt contents of 800, 2000, 5000, 7500 and 10000 mg L^{-1} (Appendix A-3). The electrical conductivity of these saline solutions was, respectively, 1.2, 4.4, 9.4, 13.7 and 17.1 dS m^{-1}. These conductivity values are high for the total dissolved salts, because Na and Cl are the dominant ionic species.

Seedling pots were placed in a greenhouse. Special attention was given to control the leaching fraction between 30 to 35%. Under this leaching fraction, salinity of the soil saturation extract approximately equals salinity of irrigation water (Appendix A-3). Increases in plant height and/or shoot growth were measured using five shoots per plant. Foliar damage was recorded photographically every two months. This experiment was concluded after six months of the saline treatments. Growth and leaf injury data were used to classify the tested species using the classification scheme proposed by U.S. Salinity Laboratory (mentioned in the introduction section).

Results

Agaves/Shrubs: Yucca (*Yucca sp.*) did not do well even under moderate salinity, and died when irrigated with 2000 mg L^{-1} (4.4 dS m^{-1}) water (Photo Set 4). It should be rated as sensitive. Mexican bird of paradise (*Caesalpinia mexicana*), and Texas mountain laurel barely survived 2000 mg L^{-1} (4.4 dS m^{-1}) with a major growth reduction. These species can be rated as sensitive. Silverberry (*Elaeagnus pungens*) native to the inter-mountain arroyo is moderately sensitive

(Bernstein et al., 1972). Silverberry is a vigorous grower, especially during spring and fall.

Agave (*Agave parryi*) survived irrigation with 7500 mg L^{-1} (14 dS m^{-1}) water, but the growth was severely reduced at 5000 mg L^{-1} (9.4 dS m^{-1}). It was rated as moderately tolerant. Century plants (*Agave americana*) were salt-tolerant, and grew fine with 5000 mg L^{-1} (9.4 dS m^{-1}) water. However, at the salt level of 7500 mg L^{-1} (13.7 dS m^{-1}), plant growth was reduced significantly. There was no sign of plant injury. The saline treatments of Century plants were extended for another three months, and the plant response remained unchanged. These plants are succulents, and can be classified as tolerant (8 to 10 dS m^{-1}) or highly tolerant (>10 dS m^{-1}). A previous study by Bernstein et al., (1972) indicates that Coyotebush (*Baccharis pilularis*) also falls into the same category.

Texas sage (*Leucophyllum frutescens*) has grown without leaf damage when grown with 5000 mg L^{-1} (9.4 dS m^{-1}) water. However, leaf shedding was noted at the highest salt treatment level (7,500 mg L^{-1}). This shrub can be rated as tolerant. The effect of salts on flowering is yet to be determined.

Trees: Arizona sycamore (*Platanus wrighii*) has shown little tolerance to salts, resulting in plant mortality in three months after irrigation with 2000 mg L^{-1} (4.4 dS m^{-1}) water. Desert willow (*Chilopsis linearis*) barely survived irrigation with 2000 mg L^{-1} (4.4 dS m^{-1}) water for a season, thus was rated as sensitive (Photo Set 4).

Texas vitex (*Vitex agnus-castus*), Desert olive (*Forestiera neomexicana*), and Cottonwood (*Populus fremontii*) survived irrigation with 2000 mg L^{-1} (4.4 dS m^{-1}) water, and can be rated as moderately sensitive. The reduction in growth was significant in both cases, but leaf injury was minimal at 4.4 dS m^{-1} (Photo Set 4).

Piñon pines (*Pinus edulis*) survived irrigation with 5000 mg L^{-1} (9.4 dS m^{-1}) water, and both growth reduction and leaf injury became evident at 7500 mg L^{-1} (14 dS m^{-1}). Piñon may be rated as tolerant (8 to 10 dS m^{-1}).

Discussion

There is a notion that all native plants are stress-tolerant, and are capable of adjusting to any soil, including salt-affected soils. The data obtained seem to indicate that such a notion is not consistent with the reality of plant response to salinity. While the species studied are too limited to draw a definitive conclusion, there is a strong indication that salt tolerance of native species is just as variable as any introduced species, ranging from sensitive to highly tolerant.

There is also an indication that salt tolerance of native species is a reflection of habitat characteristics. The native plant species classified as salt-sensitive in Table 4.2 are found in upland or alluvial washes where soils are usually nonsaline. These include Yucca, Bird of paradise, Texas mountain laurel, Western redbud, Arizona sycamore, Desert willow and Texas vitex. Although guayule (*Pantheniun argentatum*) is seldom used for landscape, this plant is native to rocky desert of West Texas and northwestern Mexico. Our previous study has shown that young seedlings of this shrub can not tolerate salts (Miyamoto et al., 1989). The native plant species classified as moderately sensitive are also native to alluvial washes, and include Silverberry, Desert olive, and Western cottonwood. The results obtained here with cottonwood are consistent with other reports (Glenn et al., 1998; Jackson, 1990).

Highly salt tolerant species, Mesquite, and Pickle weed (*Allenrolfea occidentalis*), are indigenous to low lands consisting of mostly saline, but in some cases, nonsaline soils. Therefore, we would expect that these species are salt-tolerant. Several colonies of Screwbean mesquite are found along the salted riparian areas of the Rio Grande below El Paso where soil salinity of the surface few feet can reach 50 dS m^{-1} and upward. Honey mesquite is also salt-tolerant (Felker et al., 1981). Pickle weed grows in salt crusted soils of salt flats in west Texas, and beginning to spread to the riparian zones of the Rio Grande. This plant, a halophyte, tolerates salinity in excess of sea water (Glenn et al., 1998).

The native plant species which fall into the category of moderately tolerant to tolerant do not seem to fit in the habitat theory. Agaves, which include Century plants, are, for example, indigenous to rocky desert, yet were found to be moderately salt tolerant, perhaps due to the succulent leaf structure. Both Texas sage and Piñon pine are indigenous to uplands, yet these species were found to have some tolerance to salts. Texas sage sheds lower or older leaves, which may lower salt damage.

Maintenance of native species requires water less than what is required for most introduced species, mainly because they can tolerate drought, but not necessarily because they transpire less. In fact, most riparian species, such as cottonwood and mesquite are heavy water users if water is provided (e.g., Glenn et al., 1998). Native species are maintained under deficit irrigation as soon as a desired plant size is obtained. Salinity of soil solution in irrigated soils increases with soil water depletion. Under deficit irrigation, plant roots are exposed to higher levels of salinity even at the same salinity of the saturation extract. The plants classified under moderately sensitive or moderately tolerant can behave as if they are sensitive or moderately sensitive under deficit irrigation. One method of minimizing the increase in salinity is to flush the root zone prior to reducing or terminating irrigation. Infrequent or occasional heavy irrigation also helps control soil salinity for growing native plants under deficit irrigation.

Some native plants, such as Mesquite, are highly salt-tolerant and have a high transpiration rate and a deep rooting pattern. These traits are ideal for irrigation with highly saline wastewater, which includes evaporative cooler bleeder water, reverse osmosis brine reject, and in some case, agricultural drainage water.

Literature Cited

Bernstein, L., L.E. Francois and R.A. Clark, 1972. Salt tolerance of ornamental shrubs and ground covers. J. Amer. Soc. Hort. Sci. 97(4): 550-556.

Felker, P., P. Clark, A.E. Lang and P.F. Pratt, 1981. Salinity tolerance of the tree legumes: Mesquite (*Prosopis glandulosa, var Torreyana, P. velutina, and P. articulata*), Algarrobo (*P. Chilensis*), Kiawe (*P. Pallida*), and Tamarugo (*P. Tamarugo*) grown in sand culture on nitrogen free media: Plant and Soil 61: 311-317.

Glenn, E., R. Tanner, S. Mendez, T. Kehret, D. Moore, J. Garcia, and C. Valdez, 1998. Growth rates, salt tolerance and water use characteristics of native and invasive riparian plants from the delta of the Colorado River. Mex. J. Arid Environ. 40: 281-294.

Jackson, J., J. Ball, and M. Rose, 1990. Assessment of the salinity tolerance of eight Sonoran Desert riparian trees and shrubs, Yuma. AZ. U.S. Bureau of Reclamation.

Miyamoto, S., J. Davis, and L. Madrid, 1989. Salt tolerance of guayule (*Parthenium argentatum*). Texas Agr. Exp. Sta. Tech. Bull. B1651.

Table 4.1. Native plant species used for the experiment.

Shrubs		**Deciduous Trees**	
Bird of paradise	(*Casealpinia mexicana*)	Arizona sycamore	(*Platanus wrightii*)
Texas mountain laurel	(*Sophora secundiflora*)	Desert willow	(*Chilopsis linearis*)
Texas sage	(*Leucophyllum frutscens*)	Desert olive	(*Forestiera neomexicana*)
Spanish broom	(*Spartium junceum*)*	Cottonwood	(*Populus fremontii*)
Agave/Yucca		**Evergreen Trees**	
Agave	(*Agave Parryi*)	Rocky mountain juniper	(*Juniperus scopulorum*)
Century plant	(*Agave americana*)	Piñon pine	(*Pinus edulis*)
Yucca	(*Yucca brevifolia*)		

* These species are not native to the Southwest, but are included here.

Table 4.2. Salt tolerance of plants native to the Southwest.

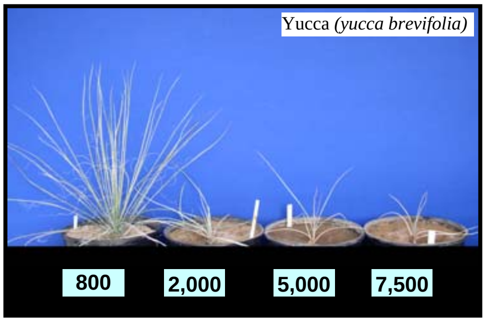
Shrubs/Agave		Trees	
Sensitive (<3 dS m^{-1})			
Yucca	*(yucca brevifolia)*	Western redbud	*(Cercis occidentalis)*
Bird of paradise	*(Caesalpinia mexicana)*	**Arizona sycamore**	*(Platanus wrightii)*
Texas mountain laurel	*(Sophora secundiflora)*	**Desert willow**	*(Chilopsis linearis)*
Guayule	*(Parthenium argentatum)*	**Texas vitex**	*(Vitex agnus-castus)*
Moderately Sensitive (3 to 6 dS m^{-1})			
Silverberry	*(Elaeagnus pungens)*	**Desert olive**	*(Forestiera neomexicana)*
		Cottonwood	*(Populus fremontii)*
		Seep willow	*(Baccharis salicifolia)*
Moderately Tolerant (6 to 8 dS m^{-1})			
Coyotebush	*(Baccharis pilularis)*		
Agave	*(Agave parryi)*		
Tolerant (8 to 10 dS m^{-1})			
Texas sage	*(Leucophyllum frutescens)*	**Piñon pine**	*(Pinus edulis)*
Century plant	*(Agave americana)*	Honey mesquite	*(Prosopis glandulosa)*
Highly Tolerant (>10 dS m^{-1})			
Pickleweed	*(Allenrolfea occidentalis)*	Screwbean mesquite	*(Prosopis pubescens)*

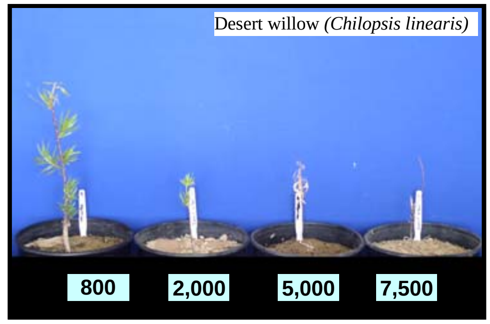
Species with bold print were used in this experiment.

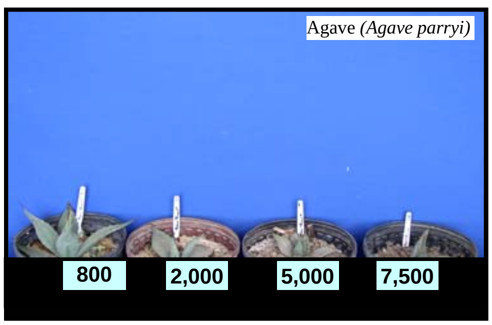
Photo Set 4. Native Plants

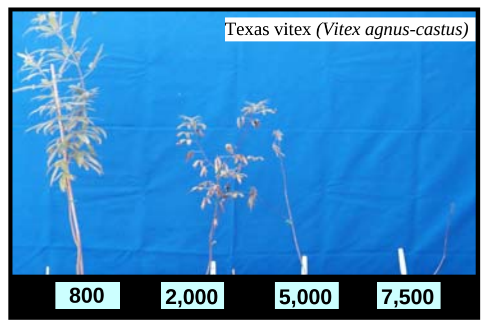
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Yucca	(*yucca brevifolia*)	S	Desert willow	(*Chilopsis linearis*)	S
Agave	(*Agave parryi*)	MT	Texas vitex	(*Vitex agnus-castus*)	MS
Bird of paradise	(*Caesalpinia mexicana*)	S	Desert olive	(*Forestiera neomexicana*)	MS
Texas sage	(*Leucophyllum frutescens*)	T	Piñon pine	(*Pinus edulis*)	HT

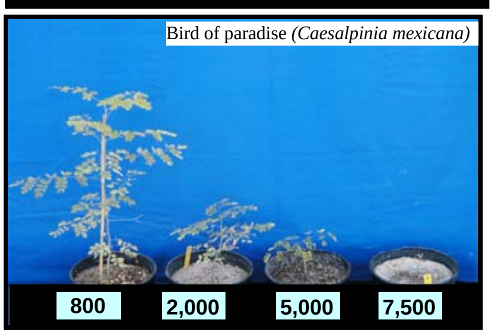
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant, HT: highly tolerant

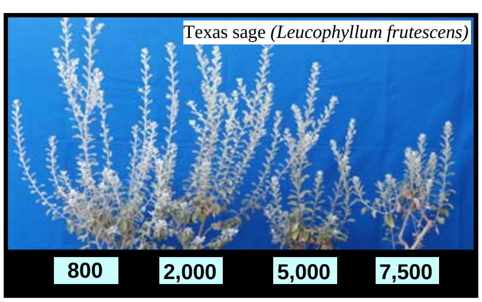


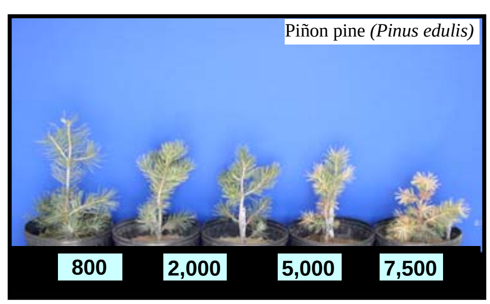












5. Salt Tolerance of Palm Species

Palms have been used extensively as ornamental and street trees in Southern California and Arizona where winter is mild. They establish easily after transplanting in most soils and require minimal care. They produce little litter and require a minimum space for growth. California fan palm (*Washingtonia filifera*) is best known as a western U.S. native palm tree. Mexican fan palm (*Washingtonia robusta*), native of Mexico, along with Mexican blue fan palm (*Brahea armata*), are also planted in the lower desert region of the Southwest.

Many palm species are now planted in the upper desert region of the Southwest, and some have experienced freeze damage. The cold resistance of palms varies with species, and some tolerate subfreezing temperatures (Cornett, 1987). Some species have roots which are susceptible to freeze injury (Larcher and Winter, 1981). The threshold temperature for palm species planted in the Southwest is shown in Table 5.1. Actual survival may depend on the nature of the cold spell, the duration of exposure, and the age as well as the health of the trees. Palms which were just transplanted are most susceptible to freeze damage. Several popular garden books also provide general guidelines for palm species selection for the areas having freezing winter temperatures (Osborne et al., 2002).

Palms are generally regarded as salt-tolerant, but there is a concern that some palm species may suffer from salt injury. According to Furr and Ream (1967), seedling growth of date palm decreases by 30 to 35%, when grown with water containing 6000 ppm (EC = 11 dS m^{-1}) of dissolved salts, and by 45 to 55% at 12,000 ppm (20 dS m^{-1}). A result similar to this was also reported by Aljubru (1992). Salt tolerance of ornamental palms is, however, currently poorly known.

The objective of this study was to evaluate growth response and leaf salt damage of nine cold-resistant palm species when irrigated with water with various salt levels.

Materials and Methods

One year-old seedlings of nine palm species (Table 5.1) were transplanted to 10 liter plastic containers filled with a soil mix of loamy sand and bio-solid (80:20 by volume). They were placed in a greenhouse, and were irrigated with tap water for a month to establish. Starting mid-March, saline treatments began using the saline solutions containing dissolved salt contents of 800, 2000, 5000, and 7500 mg L^{-1}. The electrical conductivity (EC) of these saline solutions was 1.2, 4.4, 9.4, and 13.7 dS m^{-1}, respectively (Appendix Table A-2). Greenhouse temperature was maintained 20° C at night and 40° C during day hours. A special attention was given to control the leaching fraction (LF) within a target level of 30 to 35% as discussed in Appendix A-3. Foliar damage was recorded photographically every two months. The plant species tested were then classified following the scheme proposed by the U.S. Salinity Laboratory for ornamental plants as described in the introduction section.

Results

Palm seedlings photographed six months after the saline treatments are shown in Photo Set 5. Detailed growth data are available in a technical article (Khurram and Miyamoto, 2005). Cabbage palm (*Sabal palmetto*) and Pindo palm (*Butia capitata*) exhibited a sharp reduction in growth, and recognizable leaf injury when salinity of irrigation solution was increased to 2000 mg L^{-1} (4.4 dS m^{-1}). Seedlings have died in two months when irrigated with a saline solution of 5000 mg L^{-1} (9.4 dS m^{-1}). Chinese windmill palm (*Trachycarpus fortunei*) grew fast, but its growth was curtailed and leaf injuries evident at 2000 mg L^{-1} (4.4 dS m^{-1}); and seedlings grown at 5000 mg L^{-1} (9.4 dS m^{-1}) have died by the end of the salt treatments. These three species, especially the first two, seem to be most sensitive among the nine species tested, and were classified as sensitive (0 to 3 dS m^{-1}).

The next three species, Mexican blue fan palm (*Brahea armata*), Brazilian fan palm (*Trithrinax brasiliensis*), and Dwarf blue palmetto (*Sabal minor*) have also experienced a significant growth reduction as well as leaf injury, but not until the salt level was increased to 5000 mg L^{-1} (9.4 dS m^{-1}). The plants grown with 7500 mg L^{-1} water (13.7 dS m^{-1}) might have died if the treatment continued for a longer duration. Growth and leaf injury of cultivar 'Riverside' was not significantly different from Dwarf blue palmetto (*Sabal minor*). These species were classified as moderately sensitive (3 to 6 dS m^{-1}).

The last three species, Mexican fan palm (*Washingtonia robusta*), California fan palm (*Washingtonia filifera*), and Canary Island date palm (*Phoenix canariensis*) have shown the least growth reduction as well as the leaf injury among the treated species. However, at 7500 mg L^{-1} (13.7 dS m^{-1}), both the growth reduction and leaf injury were evident with *Washingtonia* species. Canary Island date palms (*Phoenix canariensis*), both regular and 'Dwarf' type, have shown the least leaf injury even at the highest salt level (13.7 dS m^{-1}). However, the number of seedling leaves was declined at a salt level of 5000 mg L^{-1} (9.4 dS m^{-1}). *Washingtonia* species can be classified as moderately tolerant (6 to 8 dS m^{-1}), and the date palm as tolerant (> 8 dS m^{-1}).

Discussion

This study indicates that growth and leaf injury are highly species dependent. Although there are some physiological indications that growth and survival of palms are related closely to their ability to regulate sodium uptake (unpublished data, this laboratory), the characteristics of native habitats seem to offer a practical indicator of potential salt tolerance. It is not surprising that Canary Island date palm (*Phoenix canariensis*) was found salt tolerant. It is native to the sea-coast. This species seems to be nearly as tolerant as Date palm (*Phoenix dactylifera*) grown for fruits (Table 5.2). California fan palm (*Washingtonia filifera*) and Mexican fan palm (*Washingtonia robusta*) are native to the lower desert region, thus are presumably tolerate heat and salt. All other species tested came from humid and sub-humid habitats, which are likely to be nonsaline.

From the cultural aspect of palms, it is obvious that Mexican fan palm (*Washingtonia robusta*), California fan palm (*Washingtonia filifera*) and Canary Island date palm (*Phoenix canariensis*) are the choice for saline areas. If the soil is permeable enough to allow for a leaching fraction of 30%, these species can be grown with water containing up to 5000 mg L^{-1} of dissolved salts or the conductivity of 10 dS m^{-1}. At the same time, Cabbage palm (*Sabal palmetto*), Pindo palm (*Butia capitata*) and Chinese windmill palm (*Trachycarpus fortunei*) may not be successful in saline areas. The other species tested can be grown adequately with water up to 2000 mg L^{-1} (4.4 dS m^{-1}) if the soil is highly permeable to allow for a high level of leaching.

Literature Cited

Aljubru, H.J. 1992. Effects of sodium chloride on seedling growth of four date palm varieties. Annals of Arid-zone 31:259-262.

Cornett, W.J. 1987. Cold tolerance in the desert fan palm, *Washingtonia filifera* (*Arecaceae*). Madrono 34(1):57-62.

Furr, R.J. and L.C. Ream. 1967. Growth and salt uptake of date seedlings in relation to salinity of the irrigation water. Date Growers Institute 44:2-4.

Khurram, S. and S. Miyamoto 2005. Growth, leaf injuries, and ion uptake of some cold resistant palm seedlings. J. Environ. Hort. 23: 193-198.

Larcher, W. and A. Winter. 1981. Frost susceptibility of palms: Experimental data and their interpretation. Principles 25:143-152.

Osborne, B., Reynoso, T. and G. Stein. 2002. Palms for southern California: A quick reference guide to palms. The Palm Society of Southern California, California.

Table 5.1 Palm species tested and their cold tolerance[1]┘

Common Name	Scientific Name	Native Habitat	Cold Tolerance	
			C	F
Dwarf blue palmetto	(*Sabal minor*)	Southern US	-15.3	4.5
Cabbage palm	(*Sabal Palmetto*)	Southern US	-12.2	10
Chinese windmill palm	(*Trachycarpus fortunei*)	China	-11.9	10.6
California fan palm	(*Washingtonia filifera*)	Western US	-11.1	12
Mexican blue fan palm	(*Brahea armata*)	Mexico	-10.3	13.5
Pindo palm	(*Butia capitata*)	Brazil	-09.9	14.2
Canary Island date palm	(*Phoenix canariensis*)	Canary Islands	-06.3	20.7
Mexican fan palm	(*Washingtonia robusta*)	Mexico	-05.6	21.9
Brazilian fan palm	(*Trithrinax brasiliensis*)	Brazil	-04.4	24.1

[1]┘ Source: Cold Rating Data Base for Palm, 2003, www.tct.netfirms.com

Table 5.2. Salt tolerance of palm species.

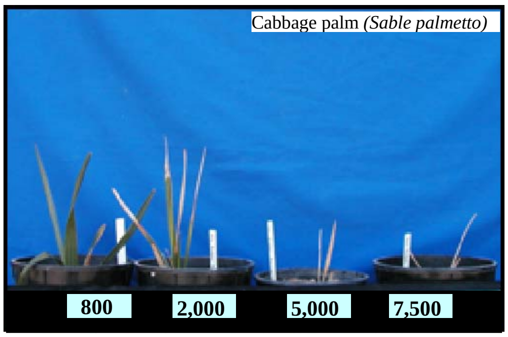
Species		**Foliar injuries[1]-**
Sensitive (<3 dS m^{-1})		
Cabbage palm	(*Sabal palmetto*)	Recognizable
Pindo palm	(*Butia capitata*)	Minimal if any
Chinese windmill palm	(*Trachycarpus fortunei*)	Recognizable
Moderately Sensitive (3 to 6 dS m^{-1})		
Mexican blue fan palm	(*Brahea armata*)	Minimal
Brazilian fan palm	(*Trithrinax brasiliensis*)	Recognizable
Dwarf blue palmetto	(*Sabal minor'Riverside'*)	Minimal
Moderately Tolerant (6 to 8 dS m^{-1})		
Mexican fan palm	(*Washingtonia robusta*)	None
California fan palm	(*Washingtonia filifera*)	None
Tolerant (>8 dS m^{-1})		
Canary Island date palm	(*Phoenix canariensis*)	None
Date palm	(*Phoenix dactylifera*)	None

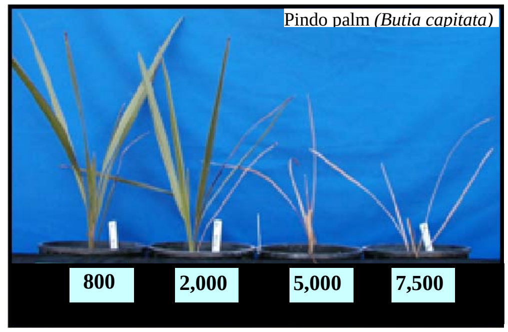
[1]- Projected leaf injury at the upper limit of applicable salinity
Species with bold print were used in this experiment.

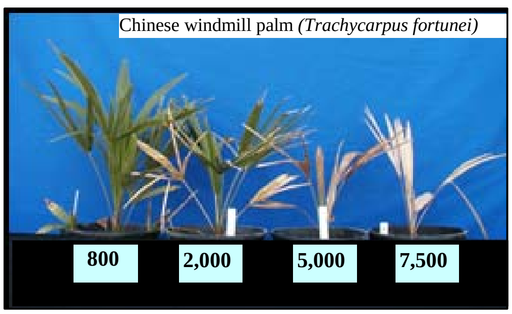
Photo Set 5. Palm Species

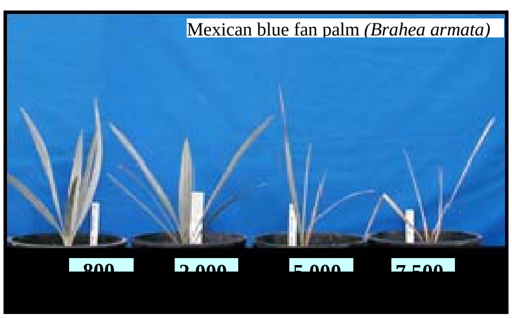
Common Name	Scientific Name	Classifcation	Common Name	Scientific Name	Classification
Cabbage palm	(*Sable palmetto*)	S	Pindo palm	(*Butia capitata*)	S
Chinese windmill palm	(*Trachycarpus fortunei*)	S	Brazilian fan palm	(*Trithrinax brasiliensis)*	MS
Mexican blue fan palm	(*Brahea armata*)	MS	Dwarf blue palmetto	(*Sabal minor 'Riverside'*)	MS
Mexican fan palm	(*Washingtonia robusta*)	MT	Canary Island date palm	(*Phoenix canariensis 'Dwarf'*)	T

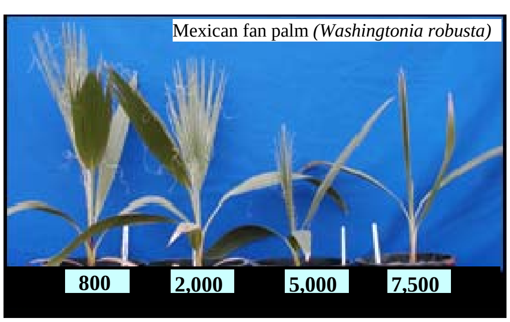
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant

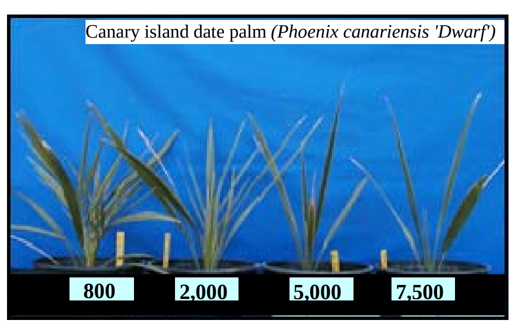












6. Vines, Ground Cover, and Bedding Plants

Ground cover plants along with bedding plants are important components of traditional landscapes, especially at apartment complexes and individual homes. The salt tolerance information presented here was obtained through pot experiments involving irrigation of climbing vines and ground covers with saline water having the total dissolved salt content of 800, 2000, 5000, and 7,500 mg L^{-1} for a period of six months. The electrical conductivity of these solutions was 1.2, 4.4, 9.4, and 13.7 dS m^{-1}, respectively (Appendix Table A-2). The leaching fraction (the proportion of water drained out of the pots) was controlled between 30 and 35%. Under this leaching fraction, salinity of the soil saturation extract (an official method of expressing soil salinity) is approximately equal to that of irrigation water. For additional details on the experimental water and the leaching fraction employed, readers should refer to the Appendix.

The salt tolerance information on six plants species; Lily of the Nile (*Agapanthus africanus*), English ivy (*Hedera helix*), Star jasmine (*Trachelospermum jasminoides*), Vinca (*Vinca major*), Asian jasmine (*Trachelospermum asiaticum*), and Carolina jasmine (*Gelsemium sempervirens*) came from our earlier study which used essentially the same method as above, except for the salinity of experimental water sources which was 1.1, 2.0 and 3.0 dS m^{-1}. The salt tolerance information on bedding plants was obtained through literature search, and should be considered merely an indication, as the experimental methods used in these references vary significantly.

Vines: Four climbing vine species were tested. Virginia creeper (*Parthenocissus quinquefolia*), which provides fall colors and rapid growth, was found salt sensitive (Photo Set 6). Japanese honeysuckle (*Lonicera japonica*) survived irrigation with 2000 mg L^{-1} water, but with extensive leaf damage (Photo Set 6). Our earlier study (Miyamoto and White, 2002) has shown that neither English ivy (*Hedera helix*) nor Star jasmine (*Trachelospermum jasminoides*) can tolerate irrigation with 2000 mg L^{-1} (4.4 dS m^{-1}). Our separate experiment involving sprinkler irrigation has shown that Japanese honeysuckle and Star jasmine also suffer from foliar salt damage when sprinkled with 2 dS m^{-1} water, and English ivy at 3 dS m^{-1} (Miyamoto and White, 2002). In other words, these vines are sensitive to soil salinity as well as saline water sprinkling.

Ground Covers: Vinca (*Vinca major*), Asian jasmine (*Trachelospermum asiaticum*), and Carolina jasmine (*Gelsemium sempervirens*) are used extensively for ground covers. Vinca is, however, among the most spray sensitive plants, and becomes yellowish when sprayed daily with 2 dS m^{-1} water (Miyamoto and White, 2002). Asian jasmine can tolerate saline water spray somewhat better, but leaf injury increases with increasing salt levels beyond 2 dS m^{-1}. The current study shows that these species are also sensitive to soil salinity.

Mexican primrose (*Oenothera berlandieri*) is among the few native flowering plants and grows in wet areas as well as along the ditch bank. They flower profusely during the late spring to early summer months. We conducted tests during summer and spring months. In both cases, they could not survive irrigation with 2000 mg L^{-1} (4.4 dS m^{-1}) water (Photo Set 6). Spring cinquefoil (*Potentilla tabernaemontani*), a perennial shrub, was even more sensitive to salt (Photo Set 6).

Trailing lantana (*Lantana montevidensis*) is a popular flowering ground cover, and flowers almost year around if winter is mild. We tested its salt tolerance during spring through summer months and during spring months, after one growing season. In both cases, the plants irrigated with 2000 mg L^{-1} (4.4 dS m^{-1}) flowered, but not at 5000 mg L^{-1}

(9.4 dS m^{-1}) after the first year of growth (Photo Set 6). *Lantana montevidensis* and *L. camara* can be rated as moderately sensitive to salts. This rating is consistent with a separate study conducted in California (Bernstein et al., 1972).

Fountaingrass is used as a ground cover in large landscapes and as an accent plant in small landscape. It tolerated irrigation with 5000 mg L^{-1} (9.4 dS m^{-1}) water, but with visible leaf tip die-back (Photo Set 6). Both Juniper (*Juniperus chinesis*), and Coyotebush (*Baccharis pilularis*) were previously tested to be moderately tolerant (Bernstein et al., 1972).

Spider plants (*Chlorophytum comosum*) are commonly used as a hanging house plant, but some cultivars as ground cover or bedding plant. They seem to be moderately salt tolerant (Zurayk et al., 1993). However, the experimental method used was unconventional, and this rating may be considered tentative. Bougainvillea (*Bougainvillea spectabilis*) is salt-tolerant, but cannot be grown without some freeze protection in most parts of the Chihuahuan dessert.

Creeping boobialla (*Myoporum parvifolium*) has survived irrigation with 7500 mg L^{-1} (13.7 dS m^{-1}), although its growth was reduced significantly at 5000 mg L^{-1} (9.4 dS m^{-1}). It can be rated as tolerant (8 to 10 dS m^{-1}). Boobialla (Photo Set 6) falls into the category of succulent plants which are capable of taking in large quantities of salts into their cells, similarly to ice plants. These plants are tolerant, or highly tolerant to salts, but do not form a dense cover needed to prevent invasion of weeds, unless salinity is high enough to defer growth of other species.

Bedding Plants: Experimental data on salt tolerance of bedding plants are sketchy, and most of the work was conducted for evaluating the impact of fertigation on nursery plant production. Our study included only a few species: Lily of the Nile (*Agapanthus africanus*) was found sensitive to salt; Trailing lantana (*Lantana montevidensis*) moderately sensitive. Studies conducted in Florida (Poole and Chase, 1986; Sonneveld et al., 1999; Zurayk et al., 1993) have shown that Begonia (*Begonia sp.*) and Gerbera (*Gerbera jamesonii*) are salt-sensitive, while Coleus (*Coleus hybridus*), Carnation (*Dianthus sp.*) and Aster (*Aster sp.*) are moderately sensitive. Geranium (*Pelargonium sp.*) appears to be moderately tolerant. There are, however, some questions on the reliability of these data because the experiments were conducted for evaluating short-term effects of salts or fertilizer on growth.

Irrigation of bedding plants often involves spray-type sprinklers. Tolerance to spray-induced salt damage is reported in Miyamoto and White (2002). Typically, these plants are equally, if not more, susceptible to foliar salt damage. An observation made near the coastal area of Florida has shown that most of the popular bedding plants could not tolerate seawater spray. There were, however, some exceptions. Dusty miller (*Senecio cineraria*), Geranium (*Pelargonium sp.*), and Gerbera (*Gerbera jamesonii*) have survived. Among the species tested in Florida, the following species could not tolerate seawater spray; Alyssum (*Lobularia sp.*), Amaranth (*Amaranthus sp.*), Aster (*Aster sp.*), Coleus (*Coleus hybridus*), Impatiens (*Impatiens wallerana*), Kale (*Kale sp.*), Pansy (*Viola sp.*), Petunia (*Petunia hybrida*), and Verbena (*Aloysia sp.*). The results with Begonia (*Tuberous begonia*), Gazania (*Gazania sp.*), Marigold (*Tagetes sp.*), Salvia (*Salvia officinalis*) and Vinca (*Vinca major*) were variable. Sprinkler irrigation involves frequent watering with lower salt concentrations, thus these results may or may not apply, except for the relative order of tolerance.

Literature Cited

Bernstein, L., L.E. Francois and R.A. Clark, 1972. Salt tolerance of ornamental shrubs and ground covers. J. Amer. Soc. Hort. Sci. 97: 550-

556.

Miyamoto, S. and J.M. White, 2002. Foliar salt damage of landscape plants induced by sprinkler irrigation, Texas Water Resources Institute TR-1202, College Station, TX.

Poole, R., T., and A.R. Chase, 1986. Growth of six ornamental plants and soluble salts of the growing media. Proc. Florida State Hort, Soc. 99: 278-280.

Sonneveld, C., R. Baas, H.M.C. Nijssen, and J. de Hoog, 1999. Salt tolerance of flowers crops grown in soilless culture. J. Plant Nutr. 22: 1033-1048.

Tjia, B., and S. A. Rose, 1987. Salt tolerant bedding plants. Proc, Fla. State Hort. Soc. 100: 181-182.

Zurayk, R., D. Tabbarah, and L. Banbukian, 1993. Preliminary studies on the salt tolerance and sodium relations of common ornamental plants. J. Plant Nutr. 16: 1309-1316.

Table 6.1. Salt tolerances of vines, ground cover and bedding plants.

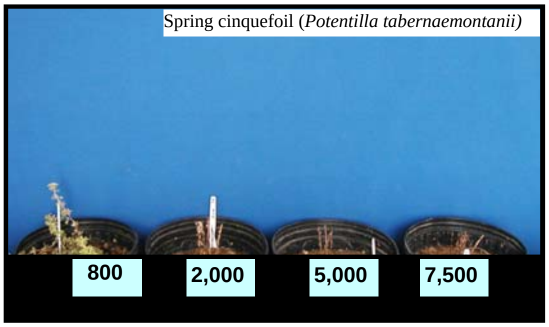
Vines & Bedding Plants		Ground Cover Plants	
Sensitive (<3 dS m^{-1})			
Virginia creeper	*(Parthenocissus quinquefolia)*	**Vinca**	*(Vinca major)*
English ivy	*(Hedera helix)*	**Asian jasmine**	*(Trachelospermum asiaticum)*
Star jasmine	*(Trachelospermum jasminoides)*	**Carolina jasmine**	*(Gelsemium sempervirens)*
Japanese honeysuckle	*(Lonicera japonica)*	**Spring cinquefoil**	*(Potentilla tabernaemontani)*
Lily of the Nile	*(Agapanthus africanus)*	**Mexican primrose**	*(Oenothera berlandieri)*
Begonia	*(Begonia sp.)**		
Gerbera	*(Gerbera jamesonii)*		
Moderately Sensitive (3 to 6 dS m^{-1})			
Coleus	*(Coleus hybridus)**	**Trailing lantana**	*(Lantana montevidensis L.)*
Carnation	*(Dianthus sp.)**	Lantana	*(L. camara)*
Aster	*(Aster sp.)*	**Spreading acacia**	*(Acacia redolens)*
Moderately Tolerant (6 to 8 dS m^{-1})			
Geranium	*(Pelargonium sp.)**	**Fountaingrass**	*(Pennisetum setaceum)*
		Juniper	*(Juniperus chinensis)*
		Coyote bush	*(Baccharis pilularis)*
		Spider plant	*(Chlorophytum comosum)**
Tolerant (8 to 10 dS m^{-1})			
		Bougainvillea	*(Bougainvillea spectabilis)**
		Creeping boobialla	*(Myoporum parvifolium)*
		Ice plant	*(Carpobrotus chilensis)*
		Trailing ice plant	*(Lampranthus spectabilis)*

* Subject to freeze damage without protection or used as annual.
Species with bold print were used in this experiment.

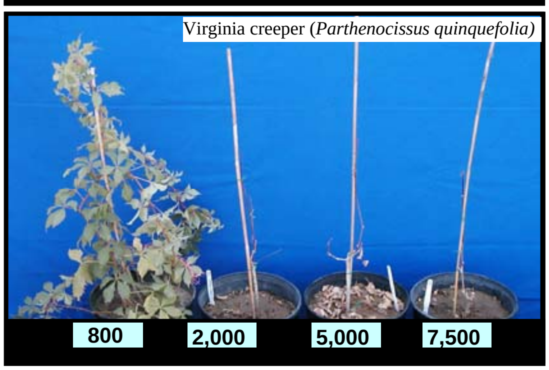
Photo Set 6. Vines and Ground Cover Plants

Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Spring cinquefoil	(*Potentilla tabernaemontanii*)	S	Lantana	(*Lantana montevidensis L.*)	MS
Virginia creeper	(*Parthenocissus quinquefolia*)	S	Spreading acacia	(*Acacia redolens*)	MS
Mexican primrose	(*Oenothera berlandieri*)	S	Fountaingrass	(*Pennisetum setaceum*)	MT
Japanese honeysuckle	(*Lonicera japonica*)	S	Creeping boobialla	(*Myoporum parvifolium*)	T

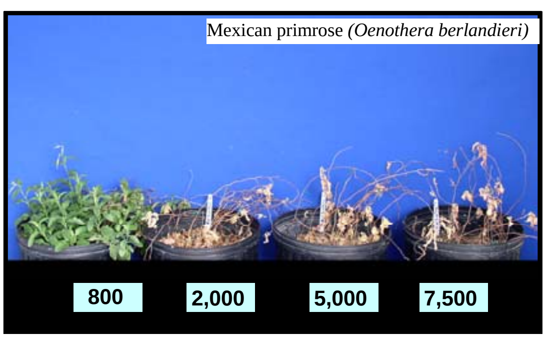
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: Tolerant



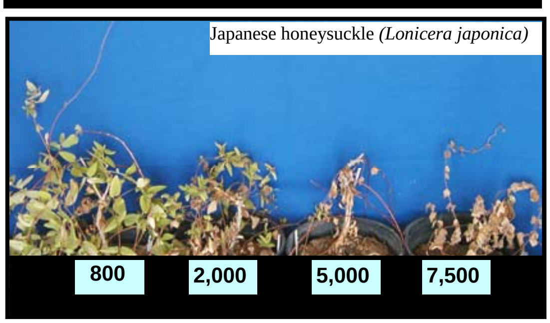
Spring cinquefoil (*Potentilla tabernaemontanii)*



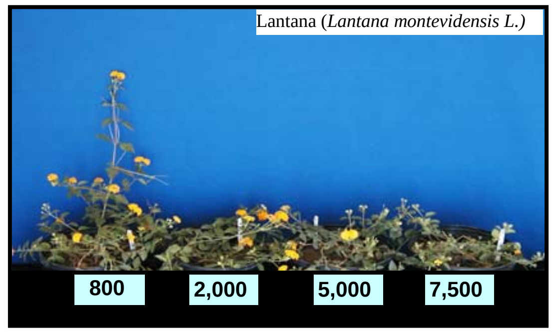
Virginia creeper (*Parthenocissus quinquefolia)*



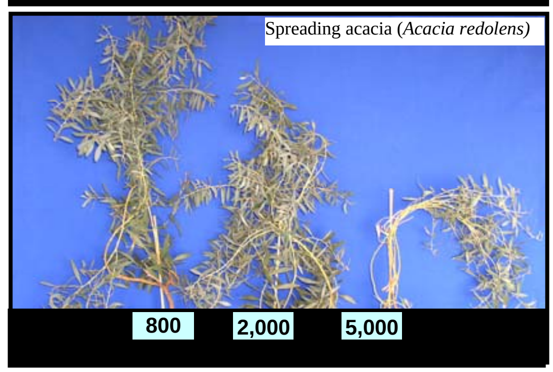
Mexican primrose *(Oenothera berlandieri)*



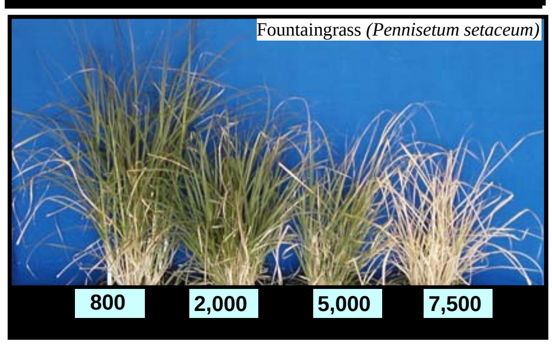
Japanese honeysuckle *(Lonicera japonica)*



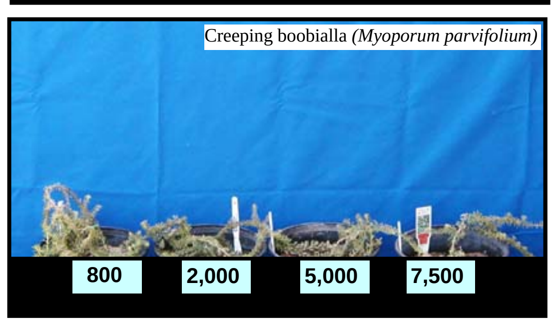
Lantana (*Lantana montevidensis L.)*



Spreading acacia (*Acacia redolens)*



Fountaingrass *(Pennisetum setaceum)*



Creeping boobialla *(Myoporum parvifolium)*

Appendix

A-1. Salinity Terms and Units

Water Salinity: The concentration of dissolved salts is expressed by various units. The unit most commonly used by engineers is ppm, which is the same as mg L^{-1} or g m^{-3}. Chemists often use equivalent units by dividing mg L^{-1} with the equivalent weights shown in Table A-1. The resulting unit is mg L^{-1}. Agronomists, horticulturists and soil scientists often use the electrical conductivity (EC) units for expressing salinity. Plant responses to salinity are closely related to EC, more so than to ppm, as EC relates to the concentration of ionized species. The common unit for EC is dS m^{-1} (decimen per meter), which is the same as mmho/cm.

Soil Salinity: The quantity of soluble salts present per unit mass of soil was once used as a measure of soil salinity. Unfortunately, this unit has a poor correlation to plant growth. The salt concentration of soil solution is a direct measure, but it is difficult to measure. Salinity of the soil saturation extract (EC_e) was thus proposed as a compromise, and has been used as an acceptable measure. The relationship between salinity of the soil solution (EC_s) and EC_e is

$$EC_s = (SWC / FW) EC_e$$

where *SWC* is the saturation water content, and *FW* the field soil moisture content (Rhoades and Miyamoto, 1990). The ratio of *SWC/FW* is usually 2.0 in clayey soils, and is higher in sandy soils with good internal drainage.

A-2. The Composition of Saline Water

The composition of saline water used for the greenhouse experiments is shown in Table A-2. We prepared saline water by adding NaCl, $CaCl_2$, and Mg SO_4 to deionized water. The salinity of these solutions is in the range commonly found in poorly permeable soils of the El Paso Valley. The electrical conductivity of the saline solutions was 1.2, 4.4, 9.4, 13.7, and 17.1 dS m^{-1} for the salt concentrations of 800, 2000, 5000, 7500, and 10,000 mg L^{-1}, respectively. These conductivity values, except for the first one, are high for the dissolved salt content, as Na and Cl are the major species.

A-3. Control of the Leaching Fraction

The leaching fraction (LF) is defined as the ratio of drainage to irrigation.

$$LF = D_d / D_w = EC_w / EC_d$$

where D_w and D_d are the depth of irrigation and drainage, respectively, EC_w is the salinity of irrigation water, and EC_d that of drainage water. We controlled the leaching fraction between 30 to 35% by measuring drainage and adjusting irrigation amounts. Irrigation was initiated when soil water in the pots has depleted by half or slightly more. The quantity of irrigation was first estimated by multiplying 1.3 to the soil water depletion, then the drainage volume measured. Salinity of the drainage water should be approximately 3 times the salinity of irrigation water. Table A-3 shows the average salinity of drainage water observed during the experiments, and is consistent with this estimate.

The mean salinity of the root zone (MSR) in the small pots under the high leaching fraction can be approximated as

$$MSR = (EC_w + EC_d) / 2$$

Salinity of the soil saturation extract (EC_e) is related to

$$EC_e = (FM / SWC) MSR$$

where *FM* is the field soil moisture content, and SWC the saturation water content. The ratio, *FM/SWC*, is typically 0.5, including the present case. When the leaching fraction is controlled at 33%, salinity of the saturation extract is therefore approximately equal to salinity of the irrigation water.

Table A-1. The equivalent weight of salt elements.

Cations		Anions	
Na	22.9	HCO_3	61.0
Ca	20.0	Cl	35.5
Mg	12.2	SO_4	48.0
K	39.1	CO_3	30.0

Table A-2. The composition of saline solutions used in the experiment.

No.	TDS	EC[1]	SAR[2]	TDC[3]	Na	Ca	Mg	Cl	SO_4
	mg L^{-1}	dS m^{-1}			----------mmol (+) L^{-1} (ppm)----------			---mmol (-) L^{-1} (ppm)---	
1	800	1.2	5	9	6 (137)	1.9 (38)	0.7 (9)	5 (178)	2 (96)
2	2000	4.4	24	37	33 (756)	1.9 (38)	1.7 (21)	35 (1243)	2 (96)
3	5000	9.4	38	92	83 (1901)	4.6 (92)	4.6 (56)	88 (3124)	4 (192)
4	7500	13.7	52	138	124 (2840)	6.9 (138)	6.9 (84)	130 (4615)	8 (384)

[1] EC = Electrical conductivity of irrigation water at 25C

[2] SAR = Sodium adsorption ratio

[3] TDC = Total dissolved cations

Table A-3. Salinity of irrigation and drainage water, and the estimated mean salinity of soil solutions.

Treatment	LF [1]	Salinity of irrigation water (ECi)	Salinity of drainage water (ECd)	Mean $\frac{ECi + ECd}{2}$	Estimated extract salinity [1]
	%	------------------------	-dS m^{-1}-	-------------------	
1	35	1.2	4	3	1.3
2	34	4.4	12	8	4.1
3	33	9.4	29	19	9.5
4	34	13.7	41	27	13.6

[1] Leaching Fraction = (ECi / ECd) x 100

[2] The saturation water content was assumed to be two times of the soil water storage

Literature Cited

Rhoades, J.D. and S. Miyamoto, 1990. Testing soils for salinity and sodicity. In Soil Testing and Plant Analysis, 3rd ed., SSSA Book Series no. 3. Soil Sci. Soc. of Am., Madison, WI.