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Site Suitability Assessment for Irrigating Urban Landscapes with Water of Elevated Salinity in the Southwest

Consolidated Final Report

Part I. Water Quality and Plant Salt Tolerance

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December, 2011

Texas A&M University, AgriLife Research Center at El Paso
Texas Water Resources Institute

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Preface and Acknowledgement

With increasing population and demand for potable water, water with elevated salinity and reclaimed water are used for irrigating urban landscape in many communities in the arid Southwest. It not only saves potable water, but also provides the stable supply of irrigation water for maintaining urban greenery and recreational facility, usually at a discounted price. There are many examples of successful use of water with elevated salinity, such as shown in Fig. 1-1. At the same time, there have been reported cases of landscape quality degradation in some of these use sites. The degradation includes foliar damage, stunted growth, premature defoliation, and in some cases, tree mortality. Thinning of turf covers is also reported, especially in sports fields irrigated with water of elevated salinity.

In order to reduce the incidences of landscape quality degradation, Texas AgriLife Research Center at El Paso, in cooperation with both water providers and water users, has been investigating salt tolerance of various landscape plants, and the levels of salt accumulation in different types of soils. The main source of funding came from the Rio Grande Basin Initiative through the Texas Water Research Institute, matched by a local fund from El Paso Water Utilities. The Bureau of Reclamation USDI provided a fund through the Water Conservation Field Service Program to develop soil suitability guidelines, which is shown in a companion report. This report covers spray and soil salinity tolerance of landscape plants, and describes how the information can be used for assessing site suitability. Management capabilities of water users undoubtedly affect quality of landscape, and for this reason, it is an important factor in assessing site suitability. However, it is beyond the scope of this guideline.

This project was assisted by a number of student workers from the University of Texas at El Paso. The task of preparing this report was assisted mainly by Doriana Torres and Yvette Pereyra, student workers. David Ornelas and David Tirre from El Paso Water Utilities have cooperated with our investigation of salt tolerance of landscape plants. This report was reviewed by Jennifer Barr, landscape architect, Gary Bryant, Extension water specialist with Texas AgriLife Extension Service, and by Woodrow Irving, El Paso Field Division of Bureau of Reclamation.

Fig. 1-1. Examples of successful use of water with elevated salinity for landscape irrigation at the City of El Paso

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Part I. Water Quality and Plant Salt Tolerance

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Introduction

Irrigation of urban landscape consumes about half of the municipal water supply in most communities in the arid Southwest. For the sake of conserving potable quality water, it is logical to use non-potable water for irrigating urban greenery, such as golf courses, parks, school yards, apartment landscapes, and streets medians. Non-potable water includes saline water, reclaimed water, storm runoff, and if available, agricultural returnflow. Some concerns, however, have been expressed whether the irrigation use of non-potable water may cause health hazard or contaminate water resources, both ground and surface water. Such a concern is especially strong when treated municipal effluent is used for irrigation of landscape where human contact may occur.

To safeguard against potential health hazard or water contamination, each state has developed various regulations over water quality and water use practices. In the state of Texas, for example, TAC 210 provides specifications over permissible water quality and reuse practices when reclaimed effluent is used for irrigation. These rules and regulations, however, do not consider dissolved salts as a constituent of concern. Salts are not toxic to humans, although they have significant impacts on quality of landscape and economic value of the water. With respect to salts, TAC 210 indicates that salt contents of water to be used for irrigation should be low enough not to cause adverse effects on landscape quality. However, no specific salt concentration which may cause landscape quality degradation is provided.

In 1984, a water quality guideline for landscape use of water was proposed in California in conjunction with irrigation with municipal wastewater (Westcot and Ayers, 1984). The state of California has led soil salinity research, thus it is natural to see that the guideline was first developed in California. However, the guideline was rather general, indicating that the landscape use of water containing 500 to 2000 ppm of dissolved salts may cause ‘moderate’ salt problems. However, no specific examples were offered for what they referred to as ‘moderate’ salt problems. Instead, they emphasized the importance of sodium adsorption ratio of irrigation water (SAR) as a parameter for assessing water suitability for irrigation. This guideline was developed from the FAO guideline for water quality for irrigation of agricultural crops, which include the recommendations for permissible levels of trace elements, besides salinity and sodicity. The emphasis on SAR guidelines is a reflection of prevailing soil problems which exist in the state of California.

The US Golf Association (USGA) has maintained water quality guidelines for irrigating golf courses (USGA, 1994). It states that water containing dissolved salts in excess of 1000 ppm or having the SAR greater than 6 can not be used for irrigating golf courses except in special circumstances. This guideline seems to have been developed independently from the California guidelines which are based on irrigation of agricultural lands. The Texas Guidelines and Regulation covering industrial effluent specify that the SAR of the soils irrigated with the industrial waste-water, including cooling tower blowdown water, shall not exceed 10 regardless of the salinity of the wastewater. There is little explanation as to why the SAR of 10 in soil solution was introduced.

The impact of using water of elevated salinity on landscapes in the Southwest occurred somewhat unexpectedly. The most common salt-induced problem occurred in the form of foliar or leaf damage associated with sprinkler application of water, far more often than leaf damage associated with soil salinization. Foliar damage caused by sprinkling was highly plant species dependent, and sensitive species suffered significant leaf damage when sprinkler irrigated with water having as low as 500 ppm of dissolved salts (Miyamoto and White, 2002, Jordan et al., 2001). Plant damage caused by soil salinization did occur, but it was highly dependent of soil type, besides salinity of irrigation water. Soil salinization can occur in alluvial soils (Entisols) when irrigated with water containing dissolved salts of 1000 ppm or less. However, this is not the case in most Aridisols. (Miyamoto and Chacon, 2006).

These emerging findings indicate that suitability of water for irrigation of urban landscape depends on site characteristics. Site characterization is likely to be the first step towards reducing landscape quality degradation. Once the site is adequately characterized, appropriate modification of the landscape and/or changes in management practices can be developed. This report outlines the knowledge needed for characterizing the sites, and for developing options for improvements or changes in management practices.

Unit Conversion Table

Length

1 inch = 2.54 cm
1 ft = 30.4 cm
1 mile = 5280 ft

Volume

1 gal = 4 qts.
= 3.785 liter
= 8.35 lb.

1 cf = 7.45 gals
1 Acre-inch = 27,152 gals = 3,630 cf
1 Acre-ft = 325,824 gals

Area

1 acre = 43.560 sq ft = 0.405 ha
1 ha = 2.47 acres
1 sq miles = 640 acres

Salinity

1 dS m^{-1} = 1 mmho/cm = 635 - 680 ppm
1 ppm = 1 mg per liter

Sodicity

Sodium Adsorption Ratio
$= Na/ \sqrt{(Ca+Mg)/2}$ in meq L^{-1}

Nutrient content

1 ppm = 2.7 lb/acre-ft = 8.1 lb/3 acre-ft
100 lb/acre = 2.3 lb/1000 sf

Equivalent weight

Na = 23
Ca = 20
Mg = 12.5

Temperature

C = (5/9) (F - 32)

F = (9/5C) + 32

1.1 Landscape Degradation Caused by Salts

For planning irrigation with water of elevated salinity, it is usually assumed by project engineers that all green areas, such as golf courses, parks, schools yards, apartment landscape etc., are perfectly suited for irrigation with non-potable water. The routing of waterlines is thus determined by considering the size of and the distance to the potential use sites. This approach is considered appropriate, as the inclusion of all possible sites usually improves the cost-effectiveness of the project, at least at the time of facility construction.

Observations of various sites irrigated with water of elevated salinity in west Texas and southern New Mexico, however, indicate that these assumptions may not be entirely valid, especially when salinity of water to be used for irrigation exceeds approximately 1000 ppm or when the concentration of Na or Cl ions in the water exceeds the range of 150 to 200 ppm. The most common form of landscape degradation is foliar damage caused by salt adsorption through leaves when irrigated with overhead sprinklers. This problem is highly species-dependent, and sensitive species show leaf damage when the concentration of Na and Cl is around 150 mg L^{-1}. When the Na or Cl concentration reaches 250 ppm, nearly all species can be affected, except for pines and waxy leaf shrubs. Several examples are shown in Fig. 1-2. At this golf course, about 150 mature trees have defoliated in less than three months after the source of water for irrigation was converted to reclaimed water with elevated salinity. A greater number of trees and shrubs were subsequently damaged, and many were pruned or chopped. Broadleaf trees and shrubs are most susceptible to this form of salt damage, but some evergreens can also sustain severe damage (Miyamoto and White, 2002). Since this problem occurs widely, site suitability assessment should include identification of salt sensitive species irrigated with overhead sprinklers. An alternative is to convert the overhead irrigation system to low trajectory or under canopy sprinklers, drips, or bubblers (Ornelas and Miyamoto, 2003).

Landscape degradation caused by soil salinization is another consideration, and has been known to landscape professionals for some time. The extent of degradation depends on salt accumulation in the soil, and soil salinity tolerance of landscape plant species. Experiences in the Southwest show that landscape degradation associated with salt accumulation in soils is usually

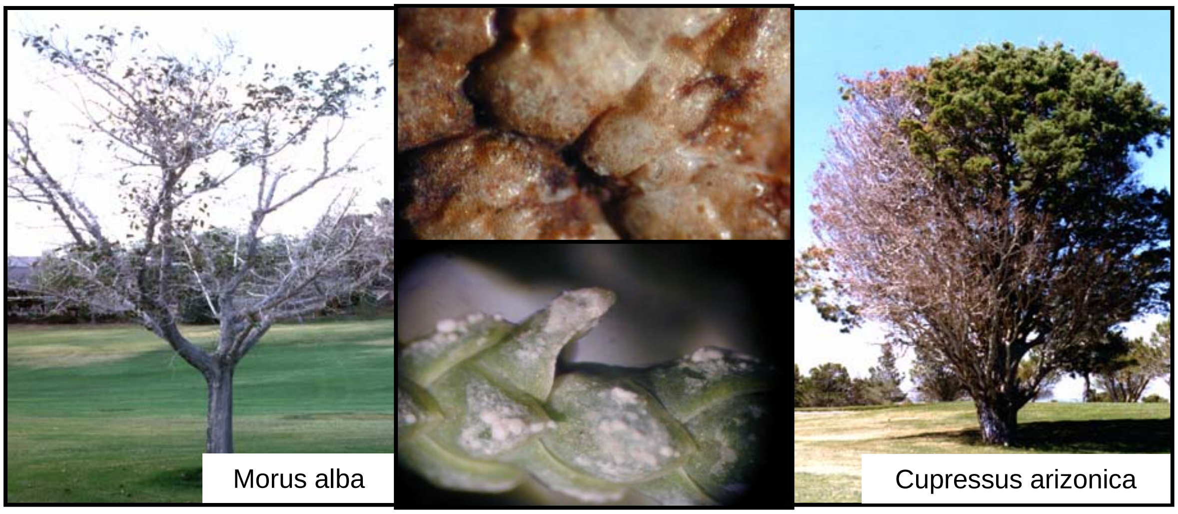

Fig. 1-2. Foliar damage in Mulberry (Morus alba), and Arizona Cypress (Cupressus arizonica).

Fig. 1-3. Salinization of clayey Entisol (a), Aridsol with a calcic horizon (b), and gypsum precipitation (c).

confined to those having low permeability, and mainly affect salt-sensitive types. Soil salinity tolerance of landscape plants is known with a greater certainty than spray resistance as shown in Attachments. The challenge for planning is the projection of salt accumulation potential in diverse soils as it is affected by soil types, irrigation water quality, and by irrigation system and management practices. Provided that the irrigation system is functional and is managed properly, soil type becomes the main controlling factor of soil salinization for a given irrigation water source. The soils which are prone to salinization include clayey alluvial soils (Entisols), and some (but not all) upland soils (Aridisols) indurated with calcium carbonate ($CaCO_3$) commonly referred to as 'caliche' (Fig. 1-3). Once the soil is salinized, plant growth decreases, and the turf cover can become thin, especially under excessive foot traffic. The issues dealing with soil salinization are discussed in Part II of this guideline.

Landscape degradation can also occur when Na, Cl or B are present at the concentrations which cause specific ion effects or toxic effects on plants. Additionally, sodium ions are known to aggravate disintegration of soil aggregates, and disperse soil particles, especially when salinity is low (<1000 ppm in TDS). This can lower soil permeability, thus leading to poor water infiltration, penetration, and reduced salt leaching. This problem is highly soil specific. The soils with weak soil structure, such as Entisols, are most susceptible, but usually not upland soils cemented with $CaCO_3$. The dispersive effect of sodium (Na) is pronounced when the sites irrigated with water of high sodicity receives rainfall or runoff.

Landscape quality degradation caused by various institutional or budgetary constraints is a fact of life. This problem occurs irrespective of water quality, but it is usually magnified when water of elevated salinity is used for irrigation. When reclaimed water is used, landscape codes and maintenance practices may have to be examined. Runoff or ponding of reclaimed water is, for example, a violation of most reclaimed water reuse regulations. Typically, landscape maintenance practices need to be adjusted, including replacement of salt sensitive species, soil improvement, and at times irrigation system alteration. Ideally, site suitability assessment should address the capability of water users to make these necessary changes or adjustments or develop a plan to assist in making the necessary changes. Lowering the prices of water with elevated salinity may not be sufficient to make the necessary changes in a short term. A logical option is then to strengthen site suitability assessment to avoid unsuitable sites.

1.2 Water Quality for Irrigation

1.2.1 Three Types of Water Quality in the Southwest

Quality of water used for irrigation varies with location and time. Nonetheless, they can be grouped into three broad types: calcic, sodic, and gypsic. This broad categorization is useful for assessing impacts on plants and soils.

Calcic Water: This type of water, rich in Ca, but low in Na and TDS, is commonly found in upland areas of the Southwest. The formation may contain limestone. A good example is the groundwater in Tucson, AZ (Table 2.2). This type of low salt groundwater can be found throughout southern Arizona towards the state line between Arizona and New Mexico. Reclaimed municipal effluent at Tucson, AZ has Na concentration greater than Ca due to anthropological additions. When used for irrigating a golf course, this water source seems to have caused no ill effect on turf (Mancino and Pepper, 1992). Another example is groundwater in Deming, NM (located at the tip of the alluvial fan from the Gila Mountain). The concentration of Ca is still greater than that of Na, but Na is being picked up. In fact, many wells in this area have Na concentrations greater than that of Ca. When reaching Las Cruces, NM, the concentration of Na usually exceeds that of Ca, and it begins to pick up SO_4 ions. This pattern continues to the Rio Grande at El Paso, TX. Las Cruces and El Paso are located in the Rio Grande Basin, and water there can be considered in transition to sodic water.

The situation in Las Vegas, NV seems to be similar to Southern NM in terms of ionic composition. The groundwater has the cationic composition similar to the one at Deming, but the anionic composition is similar to the groundwater in the Rio Grande flood plain. Municipal reclaimed water has elevated levels of cations and anions, especially Na, Cl and SO_4. A similar situation also exists with reclaimed municipal effluent along the Rio Grande at El Paso. It is highly enriched with Na and is classified as sodic. The Colorado River has ionic composition similar to that of the Rio Grande, except for the higher proportion of SO_4 and lower proportions of Na than those in the Rio Grande.

Sodic Water: Sodic water is defined here for having Na greater than Ca, and the SAR may exceed around 5.0. Groundwater resources in the Hueco Bolson of the Northwest district of El Paso are believed to have received percolation of the ancient flow of the Rio Grande. The water has higher SAR than the present day flow of the Rio Grande, and low in SO_4 (or high in Cl). It is interesting to observe that the groundwater in the Hueco Bolson has the ionic composition nearly identical to that of the Salt River in Arizona. In any case, reclaimed water along the Rio Grande is enriched with Na, reportedly due to intrusion of saline groundwater into the sewer collection system. The use of these reclaimed water sources caused significant foliar damage when sprinkler irrigated.

Water quality in west Texas is highly variable. Some areas offer low salt water, but tend to be sodic, such as those reported in Van Horn, TX. Some wells yield highly sodic water with Cl as the main anion, rather than HCO_3 or SO_4. Sodicity of groundwater in the Van Horn area can be comparable to that in the Deming area, but bicarbonate contents are lower. Groundwater along the Rio Grande below El Paso had been salinized, and became all sodic. This type of groundwater is used for irrigation during drought when the water supply from the Rio Grande is curtailed. Sodic water also appears in North Central and Central Texas, especially in oil and coal fields. Groundwater in contact with coal or oil is enriched with HCO_3, which causes Ca precipitation.

Gypsic water: Gypsic water is rich in Ca and SO_4. It is a dominant source of water from eastern New Mexico down to far west Texas along the Pecos River Basin. This area was once under the Permian sea, and upon rising of the continent, the perimeter of the ancient sea was left with gypsum, which provide Ca and SO_4 to both surface and groundwater. Groundwater is often saturated with gypsum. All of these wells have been used to irrigate golf courses for many years as a sole source of water for irrigation. However, most broadleaf trees are gone, and only pines and Junipers have survived, but with white stain caused by gypsum crystals. When the concentration of Na is compared, these gypsic water sources usually contain lower concentrations than does sodic water. There are some concerns that the use of gypsic water for irrigation may eventually plug soil pores with gypsum. There are some indications that this process can reduce soil permeability, and increase soil salinity. At present, scientific data are too limited to draw any conclusions.

Table 1.1. Examples of three types of water available for irrigation in the Southwest.

Water Types	EC[y] (dS m^{-1})	TDS[y] (mg L^{-1})	SAR[y]	Na	Ca	Mg	HCO_3	Cl	SO_4
				---------------------------------	----------	----(me L^{-1})----	----------	----------	---------------------------------
Calcic Water									
Tucson, AZ (GW)	0.2	170	1.0	0.9	1.4	0.2	2.0	-	-
Tucson, AZ (RW)	0.7	450	3.7	4.1	2.0	0.6	4.1	-	-
Deming, NM (GW)	0.4	451	1.5	2.0	2.6	0.7	5.0	0.5	0.3
Las Cruces, NM (GW)	1.0	672	1.5	5.4	3.6	4.5	5.9	3.4	10.0
Rio Grande, El Paso (SW)	1.1	860	3.3	6.2	5.1	1.8	3.6	3.6	5.0
Las Vegas, NV (GW)	0.8	643	1.8	3.3	3.3	3.1	2.4	2.7	4.6
Las Vegas, NV (RW)	1.8	1207	3.8	8.6	5.1	5.2	2.4	6.8	9.5
Colorado, Yuma, AZ (SW)	1.0	740	2.2	4.0	4.7	2.1	2.6	2.0	6.3
Sodic Water									
El Paso, TX (GW)	1.1	630	5.6	6.7	2.5	0.4	3.1	5.2	1.6
El Paso, TX (RW)	1.5	880	6.9	9.6	2.9	1.1	2.7	6.2	3.9
Salt River, AZ (SW)	1.5	891	6.4	9.6	3.1	1.3	3.2	10.1	0.8
El Paso, TX (RW)	2.1	1190	9.7	14.3	3.2	1.0	3.1	8.0	6.3
El Paso TX (GW)	3.4	2580	8.7	22.6	9.3	4.2	4.1	15.5	16.1
Tornillo, TX (GW)	4.3	3560	9.2	31.0	13.0	11.0	4.9	19.0	31.0
Van Horn, TX (GW)	0.6	380	4.7	4.3	1.2	0.5	2.4	1.0	1.0
Van Horn, TX (GW)	1.0	879	10.0	9.7	1.1	0.8	4.1	5.4	3.7
Van Horn, TX (GW)	1.8	1188	7.5	11.5	3.0	1.7	3.8	9.0	5.6
Wichita Fall, TX (GW)	1.1	988	4.0	7.4	1.6	5.3	9.8	1.1	1.4
Bastrop, TX (GW)	1.7	1390	21.0	15.6	0.9	0.2	8.5	5.8	3.4
Gypsic Water									
Tualrosa, NM (GW)	3.2	2700	3.7	13.4	15.7	10.4	3.2	6.3	31.0
Midland, TX (Nueva Vista)	1.4	910	3.9	7.4	4.4	3.0	1.1	9.0	4.7
Alamogordo (PW)	1.4	1015	2.0	4.4	7.0	3.4	4.0	4.4	6.8
Alamogordo (RW)	2.7	1512	5.0	12.3	8.7	4.0	5.0	13.7	4.8
Holloman, NM (PW)	1.3	789	2.0	3.1	6.0	2.9	4.0	3.1	4.3
Holloman, NM (RW)	3.7	1873	4.0	11.3	10.1	9.2	2.8	12.7	13.9
Tualrosa, NM (GW)	2.9	2060	0.8	3.1	18.5	8.4	3.4	2.6	22.7
Tualrosa, NM (GW)	3.0	2260	1.3	5.0	19.1	9.9	3.3	3.2	24.9
Pecos River, Artecia (SW)	3.3	2398	3.2	11.3	16.9	9.0	3.1	12.1	22.3
Midland, TX (GW)	2.6	1676	3.4	10.1	8.5	9.4	3.8	9.3	14.9
Midland, TX (GW)	3.5	2220	3.2	11.3	12.4	11.9	1.3	17.4	16.9
Midland, TX (GW)	4.9	3110	3.9	14.6	14.0	14.0	1.3	19.7	21.6

[y] EC: electrical conductivity, TDS: total dissolved salts, SAR: the sodium absorption ratio.

GW: Ground Water, RW: Reclaimed Water, SW: Surface Water, PW: Potable Water.

1.2.2 Water Quality Appraisal

As mentioned in the introduction, water quality guidelines for irrigation uses were proposed by Westcot and Ayers (1984) in California, and independently by the US Golf Association (USGA). The California guidelines focus on soil salinity and soil structural degradation, which has been a major concern of crop growers in the state. The USGA guidelines are straight forward, and seem to have helped raise water quality issues at golf courses.

The most common salt problems we encountered in the Southwest were foliar salt damage induced by overhead sprinkling (Section 1.1). Since Na or Cl are the main ion which causes leaf damage, we used the parameter, instead of salinity, to estimate the extent of the damage for three groups of plant species (discussed later in Section 2). If Na and Cl concentrations are unknown, but EC readings are available, Table 1.1 can be used to estimate Na concentration based on geographic locations for a preliminary estimate.

Another concern has been the impact of irrigation on soil salinity, which is the subject of Part II of this series. In short, soil salinity is affected by land use, and soil type, besides salinity of irrigation water (EC_w). The typical soil salinity observed in different soil types and land use is shown in Table 1.2. (Miyamoto and Chacon, 2006). The information provided in this table should be viewed merely as a guide for preliminary assessment, and details can be attained from this report. For example, the identification of plant species which can tolerate the projected level of soil salinity can be obtained from Table 2.6 as well as from Attachment II through V. Details for estimating soil salinization potential are given in Part II of this series. As a typical role, salts tend to accumulate more in sports fields than in golf course fairways mainly because of soil compaction, and at times due to soil stratification. The salt tolerance of common bermudagrass (the prevailing species used in the Southwest) is around 8 dS m^{-1} in the saturation extract. In sports fields consisting of sandy soils, salt problems are unlikely. If consisting of clayey soils, however, soil salinity is likely to exceed the thresholds when salinity of irrigation water exceeds 2 dS m^{-1}. In the case of well kept golf courses, bermudagrass can be maintained even with salinity as high as 3 dS m^{-1}. These estimates are consistent with field observations in west Texas.

Table 1.2. Tentative water quality guidelines for irrigating urban landscapes in the Southwest.

Foliar Damage Concerns

	Impact Potential [1]		
Na or Cl ppm	Sensitive Species	Moderately Tolerant	Tolerant Species
<100 ~ 150	Significant	Minor	None
150-250	Severe	Minor	None
250-400	Severe	Severe	Stain

Soil Salinization Concerns: Sports Field

EC_w	Projected Soil Salinity (dS m^{-1})		
dS m^{-1}	Sandy loam	Loam	Clay loam
1	1-2	2-5	> 5
2	2-4	4-10	> 10
3	4-6	6-15	> 15

Soil Salinization Concerns: Golf Course [2]

EC_w	Projected Soil Salinity (dS m^{-1})		
dS m^{-1}	Sandy loam	Loam	Clay loam
1	0.5-1	1-2	2-4
2	1-2	2-4	4-8
3	1.5-3	3-6	6-12

[1] For identification of applicable plant species, refer to Table 2.2 and 2.3, plus Attachment I of this report.

[2] Refer to Table 2.6 and Attachment II through V of this report, plus Part II of this series.

The sodium adsorption ratio (SAR) can alter water infiltration rate. The quantitative assessment of its impact is the subject of Part II of this report. In short, water infiltration rates can decrease significantly when SAR reaches 6, and can decrease more than 50% when SAR increases to 12. However, the soil type has a major impact on water infiltration response to sodicity. Alluvial soils (Entisols) with weak soil structure respond most, whereas calcic soils containing large amounts of $CaCO_3$ do not.

2. Salt Tolerance of Landscape Plants

2.1 Spray Resistance

As mentioned in Section 1.2, foliar damage caused by salt absorption through leaves is most common in landscapes irrigated with overhead sprinklers. This problem was first noted in several golf courses and park grounds in west Texas where groundwater of elevated salinity has been used for irrigation. When reclaimed municipal effluent was applied with overhead sprinklers, foliar damage problems appeared in several golf courses and municipal parks in west Texas in a similar fashion. Some examples were previously shown in Fig 1.1. When light application of water is made daily, salts accumulate directly on the leaf surface, and form a thin layer of crust when salinity of irrigation becomes high enough. This type of irrigation scheduling is commonly used in golf courses. Once the salt crust is formed, it is most likely that the gas exchange between the leaves and the atmosphere is curtailed. Foliar damage usually occurs through ion absorption into leaves when salt crust is solubilized following irrigation, rain or condensation events. It mainly affects broadleaf trees and shrubs, and causes leaf burn and, at times, premature defoliation, which eventually leads to tree mortality in a few years. This symptom is often interpreted as having excessive salt accumulation in soils or the water used for irrigation may contain residues of certain herbicides or some undesirable chemicals. This problem usually does not appear in turfgrass, in part because grass blades usually repel water. Some species, such as Saltgrass and Zoysiagrass excrete salt from the leaf surface through salt glands (Marcum et al., 1998). Several reports, however, indicate certain species of bentgrass and fescue may suffer from leaf-induced salt damage.

2.2 Southwestern Experience

Controlled Experiments at El Paso: Test plants (1 gallon size) were transplanted into 3 gallon pots using a highly permeable commercial potting soil mix. They were taken outdoors in March, and irrigated every other day with overhead sprinklers for 30 min. which delivered ½ inch of water per application. Pan evaporation at El Paso during summer months reaches nearly ½ inch per day, and the potential evaporation rate from well-watered crop fields, 1/3 inch per day. The sprinkler was spray-type, discharging 2.5 gallons per min. and was spaced 15 ft apart so as to provide 1 inch of water application per hour. The potted plants were sprinkled every other day (Monday, Wednesday, and Friday, but not on Sunday) until the leaves were completely wet and to cause steady dripping of water from the leaves. Irrigation continued until the end of September for 6 months.

The experiment utilized three saline water sources: tap water (800 ppm or 1.1 dS m^{-1}), a blend of tap water and well water (1260 ppm or 2.0 dS m^{-1}), and saline well water (1850 ppm or 3.0 dS m^{-1}).The corresponding concentrations of Na in these water sources were, respectively, 145, 280, and 425 ppm, and that of Cl 140, 360, and 590 ppm. As soon as sprinkler irrigation was completed, all pots were flushed with tap water. Other properties of the experimental water are shown in Table 2.1. The experimental water sources represent sodic water commonly found in the middle Rio Grande Basin. The proportion of Cl and SO_4 ions was approximately equal in these water samples. As noted in section 1.1, water sources in the Pecos Basin are often rich in Ca and SO_4 ions (Table 1.1).

Plant responses to sprinkler irrigation were evaluated by measuring shoot growth and leaf injuries. Salinity of irrigation water and the corresponding Na and Cl concentration which caused a 25%

Table 2.1. The composition of water sources used for irrigating some landscaping areas in El Paso, TX and Las Vegas, NV.

	Salinity			Sodicity		Cl	pH	Ionic Concentration			
	EC	TDS	TDS	Na	SAR[1]			Na	Ca	Mg	Cl
	dS^{-1}	mg L^{-1}	meq L^{-1}	%		%		---------------- mg L^{-1} (meq L^{-1})---------------			
Controlled Experiment at El Paso											
1	1.1	700	11.2	57	4.0	36	7.4	145 (6.3)	69 (3.5)	16 (1.4)	143 (4.0)[1]
2	2.0	1260	20.4	60	6.0	50	7.9	278 (12.1)	97 (4.8)	43 (3.5)	358 (10.1)
3	3.0	1850	30.7	62	7.5	55	8.1	425 (18.5)	128 (6.4)	71 (5.8)	596 (16.8)
Controlled Experiment at Las Vegas											
1	0.86	493	9.7	37	1.8	27	8.0	76 (3.3)	66 (3.3)	38 (3.1)	92 (2.6)
2	1.87	1059	18.9	50	3.8	36	7.8	198 (8.6)	102 (5.1)	63 (5.2)	241 (6.8)
3	1.92	1199	19.8	54	4.0	33	8.0	214 (9.3)	90 (4.5)	73 (6.0)	234 (6.6)
Field Situations											
A	1.1	620	10.1	63	4.7	65	7.7	148 (6.4)	46 (2.3)	16 (1.4)	200 (6.6)
B	1.7	950	15.2	72	7.4	52	7.0	250 (10.9)	72 (3.6)	9 (0.7)	280 (7.9)
C	2.1	1120	17.9	85	9.8	51	7.6	350 (15.2)	45 (2.3)	5 (0.4)	325 (9.2)

[1] SAR is the sodium absorption ratio.

[2] Numbers in parenthesis are for meq L^{-1}

reduction in shoot growth or leaf injury over 25% of the leaves was estimated through extrapolation of the experimental data. Because of the lack of the standard method of classifying plants for spray resistance, we used the following tentative classification scheme using the salt concentration of irrigation water which causes a 25% reduction in growth or leaf injury: **sensitive** (EC = 1 dS m^{-1}, Na and Cl = 150 ppm), **moderately sensitive** (EC = 1 – 2 dS m^{-1}, Na = 280 ppm, Cl = 360 ppm), **moderately tolerant** (EC = 2 – 3 dS m^{-1}, Na = 425 ppm, Cl = 590 ppm), and **tolerant** as shown in Table 2.2. In addition, leaf injuries were classified into four categories: I) Leaf tip-burn which progressed to margin burn, followed by defoliation, II) Leaf tip-burn, but with limited defoliation, III) Leaf margin burn, followed by darkening and desiccation of some leaves, and IV) Leaf yellowing or discoloration, but not defoliation. Necrosis symptom in this experiment appeared only in Crape Myrtle. Results of this experiment, including photographic records are shown in Attachment I-1.

Plant growth, evaluated by the relative shoot growth was reduced rapidly with increasing salinity, especially in Tea Rose, Lily of the Nile, Crape Myrtle and Ganzania. The growth of Texas Sage, Climbing Rose, and Lantana was also reduced significantly when sprinkled with 3.0 dS m^{-1} water (or 1850 ppm). When grown under surface irrigation, Tea Rose grew better than those under sprinklers. Lantana, Verbena, and Indian Hawthorne (listed under a category “shrubs”) were more tolerant to salts than other flowering plants tested. Vines and ground covers had highly variable growth rates, but most vines have grown 2 to 3 times the initial size when irrigated with tap water. Vinca plants were found exceptionally sensitive to salts, and its leaves were desiccated in a month when sprinkled with 3.0 dS m^{-1} water. Honeysuckle and Star Jasmine experienced a significant growth reduction when sprinkled with 2.0 dS m^{-1} water, whereas Carolina Jasmine, English Ivy and Liriope tolerated sprinkler irrigation with 2.0 dS m^{-1} water. (Both Jasmines and English Ivy are known to experience a significant growth reduction when surface irrigated at 2.0 dS m^{-1}, but not Carolina Jasmine). Growth of Liriope plants was unaffected by sprinkling of 3.0 dS m^{-1} water, but it suffered extensive leaf injuries toward the end of the growing season.

The shrubs tested generally grew slowly, but have shown moderate levels of tolerance, except for Nandina plants. Rosemary plants, known for high tolerance to soil salinity, also suffered a significant growth reduction when sprinkler-irrigated with 2.0 dS m^{-1} water. Euonymous, Hawthorne, Juniper,

Table 2.2. Spray resistance of some landscape plants commonly planted in the Southwest (excerpt from Miyamoto et al., 2004b).

	Sensitive	Moderately Sensitive	Moderately Tolerant	Tolerant
Salinity (dS m^{-1})	<1	1 - 2	2 - 3	>3
Na (mg L^{-1})	<150	280	425	>425
Cl (mg L^{-1})	<150	360	590	>590
	Rose (*Rosa sp.*)	Gazania (*Gazania sp.*)	Verbena (*Verbena sp.*)	Sunflower (*Helianthus sp.*)
	Crape myrtle (*Lagerstroemia sp.*)	Carolina jasmine (*Gelsemium sp.*)	English ivy (*Hedera helix*)	Strawberry (*Fragaria sp.*)
	Nandina (*Nandina domestica*)	Liriope (*Liriope muscari*)	Yaupon holly (*Ilex vomitoria*)	Oleander (*Nerium oleander*)
	Pistachie (*Pistacia spp.*)	Texas sage (*Leucophyllum sp.*)	Afghan pine (*Pinus eldarica*)	Japanese boxwood (*Buxus micropylla*)
	Vinca (*Vinca major*)	Pyracantha (*Pyracantha sp.*)	"Lady Banks" (*Rosa banksiae*)	Mexican stone pine (*Pinus cembroides*)
	Grape (*Vitus sp.*)	Dwarf rosemary (*Rosmarinus sp.*)	Euonymous (*Euonymus japonica*)	
	Photinia, "Red Tip" (*Photinia fraseri*)	Wax-leaf Ligustrum (*Ligustrum sp.*)	Indian hawthorne (*Raphiolepis indica*)	
	Apricot (*Prunus americana*)		Cotoneaster (*Cotoneaster sp.*)	

Cotoneaster, and Boxwood were tolerant to salts, showing no or only a minor reduction in growth when sprinkled at 2.0 dS m^{-1}. Among the tall shrubs or tree species tested, Cottonwood suffered the greatest growth reduction under sprinkler irrigation, followed by Photinia. Shoot growth of other shrubs and/or tree species tested, except for Wax-leaf Ligustrum, was also deterred by sprinkling. Growth of Afghan Pines and Ligustrum was reduced without obvious leaf injuries.

The plant species under Category I first exhibited leaf tip-burn which progressed to margin burn and eventually to defoliation. The plants which fall into this category include Tea Rose, Nandina, Crape Myrtle and Cottonwood, all of which developed tip-burn in two months into the experiment. Lily of the Nile and Honeysuckles also developed leaf tip-burn in two months which progressed to defoliation. Verbena and Lantana did not show any leaf injuries until the middle of summer. These two species could be placed under Category III, because of extensive leaf desiccation, but not defoliation.

The plants under Category II have shown extensive leaf tip-burn, some of which developed to margin burn, but did not lead to extensive defoliation. Climbing Roses, Carolina Jasmine and Liriope plants were placed into this category. Both Climbing Roses and Liriope plants developed leaf tip-burn during the first two months. Pistacia, Cotoneaster, and Pyracantha have also developed leaf tip-burn, but to a lesser extent than did the first group.

The plants under Category III did not show leaf tip-burn for any extended period. Instead, some leaves, usually old or scarred leaves, rapidly developed margin burn which developed into burning or drying of the leaves. These browned leaves did not defoliate rapidly. Vinca, Gazania, Photinia, Euonymous, Asian Jasmine, Star Jasmine, and English Ivy fell into this category. The plants under Category IV developed yellowing leaves after about 2 months, but no leaf injury or defoliation was observed. The plants under this category included Texas Sage, Yaupon Holly, Ligustrum, Afghan Pine, Juniper, and Indian Hawthorne. With the exception of Yaupon Holly and Indian Hawthorne, there was a significant growth reduction without apparent leaf injuries or defoliation.

Controlled Experiment at Las Vegas: Detailed studies of foliar damage caused by sprinkling of municipal and reclaimed water were conducted at the Clark County Sanitation District in Las Vegas, NV. The test focused on woody species adapted to the hot and dry climate of the Southwest. They were grown in 15 gallon containers, placed in an outdoor experimental area, and irrigated with three types of water; potable water, reclaimed municipal effluent, and moderately saline water which was prepared by adding salts to the potable water at the concentration similar to the reclaimed water (Table 2.1). These water sources were applied to the experimental trees using raised sprinklers (Hunter, 200 series) for 18 months. The effect of the treatments was evaluated by visual rating of leaf damage with 0 being no damage, and 10 indicating that all leaves were damaged. In addition, the leaf concentration of Na and Cl were measured.

Results of the experiment have shown a wide range of leaf damage when the reclaimed water was applied with overhead sprinklers (Table 2.3). The first group, which experienced leaf damage ranging from 35 to 70%, is categorized as being “Sensitive.” The report by Jordan et al (2001) indicates that six species (Modesto Ash, Chinese Pistache, Chitalpa, Flowering Plum, Globe Willow, and Mimosa) have exhibited significant leaf injuries even when irrigated with potable water with TDS of 500 ppm. Therefore, these species were placed under “Sensitive” category. The second group of woody species which experienced leaf damage of 24 to 57% was categorized as “Moderately Sensitive.” Note that the reclaimed water tested at Las Vegas site has salinity of 1.87 dS m^{-1}, which falls into the second category (Moderately Sensitive) shown in Table 2.2. However, the Na concentration of the test water was significantly lower than that of the test water No. 2 used at El Paso site (Table 2.1). The third group of plants is classified as “Tolerant,” consisting mostly of pines. However, Raywood Ash (*Fraxinus angustifolia*) which experienced leaf damage as much as 18% can be categorized as “Moderately Tolerant” or “Moderately Sensitive,” if one attempts to follow the scheme proposed at El Paso.

The study conducted at Las Vegas has also reported that increasing Na and/or Cl concentrations in irrigation water resulted in a linear increase in Na or Cl concentrations in leaf tissue

Table 2.3. Spray resistance of some woody species commonly planted in the Southwest (Data from Jordan et al., 2001).

	Sensitive	PIL %	Moderately Sensitive	PIL %	Tolerant	PIL %
Salinity (dS m^{-1})	<1		1 - 2		>2	
Na (mg L^{-1})	<100		200		>200	
Cl (mg L^{-1})	<100		250		>250	
	Modesto Ash (*Fraxinus velutina*)	70	Desert Willow (*Chilopsis linearis*)	57	Raywood Ash (*Fraxinus angustifolia*)	17
	Chinese Pistache (*Pistacia chinensis*)	65	Drake Elm (*Ulmus parvifolia*)	57	Stone Pine (*Pinus pinea*)	10
	Chitalpa (*Chitalpa taskentensis*)	46	Japanese Privet (*Ligustrum japonicum*)	40	African Sumac (*Rhus coriaria*)	7
	Flowering Plum (*Prunus mume*)	39	Palo Verde (*Parkinsonia aculeata*)	40	Mondell Pine (*Pinus brutia*)	6
	Globe Willow (*Salix umbraculifera*)	35	Heritage Oak (*Quercus robur*)	26		
	Mimosa (*Acacla baileyana*)	29	Vitex (*Vitex agnus-castus*)	26		
			Idaho Locust	24		

PIL: Percentage of the leaves which had been damaged through sprinkling of potable or reclaimed water.

as well as general increase in leaf injury. However, there was also a considerable difference in leaf Na or Cl concentrations among the species tested. The study also reported that leaf wax contents varied with plant species, but did not correlate significantly with the extent of leaf damage, according to the author, due to insufficient data set.

Comparing the results from two different sites, it is evident that broad leaf trees are more susceptible to foliar damage than evergreens with waxy leaves or pines. It is also evident that some species suffer leaf damage even when irrigated with potable water with salinity as low as 500 ppm. The uptake of Na and/or Cl ions is likely to be responsible for leaf damage. The species tested are commonly used for landscaping in the Southwest, but there is a need to evaluate other species, especially new plant materials.

Field Observations: For developing a list of trees which exhibit leaf damage when irrigated with overhead sprinklers, we surveyed city parks irrigated with potable water (TDS = 620 ppm, EC = 1.1 dS m^{-1}, Na = 148 ppm and Cl = 200 ppm), and two golf courses irrigated with reclaimed water designated as water B and C in Table 2.1. Additional water quality data are shown in Table 2.1. Both survey fields had sandy soil, and soil salinity readings were mostly below 2 dS m^{-1}, and rarely reaching 3 dS m^{-1} in the soil saturation extract. The species listed in Table 2.4 are those which have shown consistent leaf injuries at least 5 different trees of the same species. We found that Pecans, Cottonwood, Sycamore, Western Soapberry, and Chinese Pistachio are highly sensitive to sprinkler irrigation. Examples of foliar damage caused by sprinkling of potable water are shown in Figure 2.1. Leaf injuries of these species occur at the Na or Cl concentration as low as 150 ppm. The species which are tolerant to saline water spray are mostly pines and waxy leaf shrubs. Photographic display of foliar damage caused by overhead sprinkling is available in Attachment I-1. Although we have not tested, most plants native to the coastal area are likely to be tolerant to saline spray.

Foliar damage caused by overhead sprinkling has been observed throughout west Texas where high salinity water is used for irrigation. Fortunately, the saline water in this region is, as mentioned in Section 1, gypseous (rich in Ca and SO_4 ions). The extent of the leaf injuries observed appeared not to increase in proportion to the increase in TDS, but rather to Na and/or Cl ions (personal observation). When salinity of water used for irrigation exceeds the range of 2000 to 3000 ppm, however, the species which survive through overhead sprinkling have been limited mainly to pines and Layland cypress (*Cupressocyparis leylandii*). Even so, pine needles and waxy leaves are coated with white deposits which are presumably gypsum. There seems to be no indication that the presence or addition of gypsum can reduce leaf damage induced through sprinkling or saline water. Previous studies (e.g. Haynes and Goh, 1977) have shown that unlike plant roots, leaf cell membrane does not have the ability to exclude intake of certain salt elements through increasing co-existing ion species.

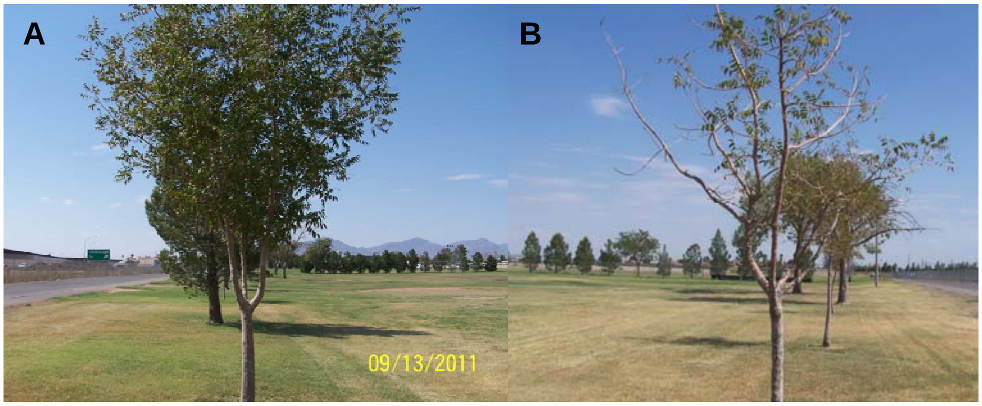

Fig. 2.1. Chinese pistachio which is free from sprinkling (A), and those receiving sprinklers streams (B), both irrigated with potable water (1.1 dS m^{-1}).

Table 2.3 Plant injuries and defoliation caused by daily sprinkler irrigation in the order of increasing tolerance (Miyamoto and White, 2002).

Highly Sensitive: (Significant Damage at 150 to 200 ppm of Na and Cl)		
Pecans	*Carya illinoensis*	Tip then margin burn
Cottonwood	*Populus fremontii*	Margin burn then defoliation
Sycamore	*Platanous acerifolia*	Margin then entire leafburn
Western Soapberry	*Sapindus drummondii*	Tip-burn
Chinese Pistache	*Pistacia chinensis*	Tipburn, then defoliation
Sensitive (Severe damage at 350 ppm of Na or Cl)		
Silverberry	*Elaeagnus pungens*	Margin burn and defoliation
Pomegranate	*Punica granatum*	Margin burn and defoliation
Honey Locust	*Gleditsia triacanthos*	Tipburn, then defoliation
Black Locust	*Robina pseudoacacia*	Tipburn, then defoliation
Shumard Red Oak	*Quercus shumardii*	Tipburn, then defoliation
Bur Oak	*Quercus macrocarpa*	Tipburn, then defoliation
Mulberry	*Morus alba*	Margin burn then defoliation
Poplar	*Populus sp.*	Margin burn then defoliation
Mimosa	*Acacla baileyana*	Tipburn then defoliation
Arizona Cypress	*Cupressus arizonica*	Defoliation
Arborvitae	*Thuja orientalis*	Defoliation
Osage Orange	*Maclura pomifera*	Defoliation
Ornamental Pears	*Pyrus communis*	Defoliation
Arizona, Ash	*Fraxinus velutina*	Tipburn then defoliation
Moderately Sensitive (Recognizable damage at 350 ppm of Na or Cl)		
Raywood Ash	*Fraxinus angustifolia*	Tipburn, then defoliation
Globe Willow	*Salix umbraculifera*	Tipburn then defoliation
Corkscrew Willow	*Salix tortuosa*	Tipburn then defoliation
Weeping Willow	*Salix babylonica*	Tipburn then defoliation
Japanese Pagoda Tree	*Sophora japonica*	Tipburn then defoliation
Live Oak	*Quercus virginiana*	Tipburn, then defoliation
Chittamwood	*Bumelia lanuginosa*	Tipburn, then defoliation
Vitex	*Vitex agnus-castus*	Tipburn, then defoliation
Moderately Tolerant (Slight or occasional damage at 350 ppm of Na or Cl)		
European Olive	*Olea europaea*	Tipburn
Desert Willow	*Chilopsis linearis*	Tipburn
Holly Oak	*Quercus ilex*	Slight to no injury
Alligator Juniper	*Juniperus cleppeana*	Slight to no injury
Juniper	*Juniperus chinensis*	Slight to no injury
Rocky Mt. Juniper	*Juniperus scopulorum*	Slight to no injury
Honey Mesquite	*Prosopis grandulosa*	Slight to no injury
Tolerant (No damage at 350 ppm of Na or Cl)		
Italian Cypress	*Cupressus sempervirens*	No injury
Hollywood Juniper	*Juniperus chinesis “Torulosa”*	No injury
Dwarf Pittosporum	*Pittosporum tobia, compacta*	No injury
Common Oleander	*Nerium oleander*	No injury
Ligustrum	*Ligustrum japonica*	No injury
Euonyomus	*Euonyomus japonica*	No injury
Japanese Black Pine	*Pinus thunbergiana*	No injury
Afghan Pine	*Pinus eldarica*	No injury
Aleppo Pine	*Pinus halepensis*	No injury
Italian Stone Pine	*Pinus pinea*	No injury

2.1.2 California Experience

The state of California has extensive irrigated landscape, and has traditionally led research on salinity tolerance of landscape plants adapted to their climatic conditions. However, research on spray tolerance is a recent event, and has been carried out in a similar fashion to these conducted independently at El Paso and Las Vegas. Their findings are shown in Attachment I-5. Readers should be aware of the fact that many of the plant species grown in California can not survive the severe cold of west Texas and New Mexico.

The California spray tolerance rating is defined as; **Sensitive,** More than 20% of the leaves may develop symptoms when the plants are irrigated with water containing 200 mg of Na per liter and 400 mg/L of chloride and having an electrical conductivity of water (EC_w) of 0.6 dS/m. **Moderate,** Less than 10% of symptoms may develop when the plants are irrigated with water containing 200 mg/L of sodium and 400 mg/L of chloride and having an EC_w of 0.9 dS/m. **Tolerant,** No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 200 mg/L of sodium/L and 400 mg/L of chloride. **Highly Tolerant,** No apparent salt stress symptoms may be observed when the plants are irrigated with water that contains 600 mg/L of sodium and 900 mg/L of chloride and has an EC_w of 2.1 dS/m.

The California rating shown above is similar to the classification scheme proposed at El Paso or Las Vegas (Tables 2.2 and 2.3) if the electrical conductivity of irrigation water (EC_w) is used as the main parameter. When the Na or Cl concentrations of irrigation water is used as the main parameter, the California scheme appears to over-estimate plant tolerance. At the Na concentration of 200 mg/L, for example, nearly all of the broad leaf trees were severely damaged during the experiment at Las Vegas (Table 2.3). The rational for the California clarification scheme seems to stem from the idea that plants with low spray resistance also have low soil salinity tolerance. This idea is probably correct, for example, with Sycamore, Crape Myrtle, and perhaps Nandina. However, the experiment reported in Tables 2.2 and 2.3 as well as Attachment I-1 clearly indicate that sprinkler application of water comparatively low in Na and Cl (148 and 200 ppm) cause a significant growth reduction as well as foliar damage in plants which are not sensitive to elevated soil salinity. For example, Pecans, Pistache, Glove Willow and Cottonwood are four of the most spray-sensitive woody species, but have moderate soil salinity tolerance. Likewise, many of the moderately sensitive species showing in Table 2.2, such as Jasmin, Texas Sage, Pyrocantha and Rosemary can tolerate moderate to high soil salinity (Section 2.3). It would be more realistic to assume that these traits were evolved independently, and be treated separately, especially when salt accumulation in soils is adequately controlled.

2.1.3 Reducing Foliar Damage

There are essentially four categories of measures which can help reduce foliar damage. These are i) modify irrigation management practices, ii) modify sprinkler irrigation systems, iii) replace salt-sensitive plants with tolerant species, and iv) improve water quality. Application of wax coat on plant leaves was once considered an option, but has not been reliable, in part due to leaf yellowing and defoliation when applied during hot summer months.

Modification of Irrigation Management Practices: Several studies conducted with agricultural crops (e.q. Maas et al., 1982) indicate that salt damage decreases with decreasing frequency of irrigation.

Our trials, using four species indicate that decreasing irrigation frequency from daily to every other day decreases salt damage to Cottonwood, Texas Sage, and Lantana, but not to Liriope. The water used for the experiments was water #2 of Table 2.1, and was applied day hours. Several photographs which show the results can be found in Photo Set 10 of Attachment I-1. The reduction in salt damage from bi-daily irrigation was substantial in Texas Sage and Cottonwood, and can be attributed to a reduction in evaporative concentration of salts on the leaf surface, and perhaps improved salt washing, as the quality of water applied per irrigation event has increased with reducing frequency.

The above experiment included another treatment where irrigation water was applied every other day at night, instead of day hours when stomata is closed. All four species tested responded with reduced damage, which was recognizable. This finding is consistent with an earlier finding by Busch and Turner (1967), indicating that night irrigation can reduce foliar salt damage in some agricultural crops. However, bi-daily night irrigation did not alleviate salt damage to the trees.

Irrigation management practices at city parks are typically bi-daily night irrigation, but as shown in Fig. 2.1, salt injury is evident in sensitive species. Reducing irrigation frequency is not a solution, but can help. The constraint for stretching irrigation intervals is the presence of shallow rooted turf. If the site soil is deep, and the turf has good root systems, irrigation intervals can be stretched, and can help reduce foliar salt damage on affected trees.

Modify Irrigation Systems: Since leaf damage caused by foliar salt adsorption is caused by overhead application of water, a logical approach is to reduce or eliminate the direct sprinkling on leaves. In large trees, this objective can be achieved by the use of low trajectory or undercanopy sprinklers. Some sprinkler heads can be converted to low trajectory (10 to 12% angle) simply by changing a nozzle, and others may require the replacement of substantial portions of internal gears. The main concern is to maintain uniformity of water application. Some low trajectory sprinklers may not provide the same water application pattern as the normal trajectory types (e.q., Ornelas and Miyamoto, 2003). Some low trajectory heads may have to be operated at lightly higher water pressure to attain the necessary overlap. An example of low trajectory sprinklers is illustrated in Fig. 2.2.

There has been a concern that the conversion to low trajectory heads may not correct salt damage because of drifts of sprinkler mists. Several studies conducted in Italy indicate that drifts do not seem to cause foliar damage as much as direct sprinkling, as mist particles evaporate rather rapidly. Once salts are crystallized, plant uptake of salts ceases. Field observations in El Paso indeed indicate that foliar damage occurs in the portion directly hit by the sprinkler stream (Fig. 2.3). For low profile

Fig. 2.2. The sprinklers stream from conventional trajectory (A), and low trajectory sprinklers (B and C) used at some golf courses; Rainbird Eagle Series.

Fig. 2.3. Foliar damage caused by partial but direct wetting with sprinkler stream.

landscape plants, sprinklers may have to be converted to a nonsprinkling type of irrigation methods, such as drip and bubblers.

Replace Sensitive Species: Small trees and shrubs planted in lawns are also often affected by sprinkling. These include Crape myrtle, Nandina, Photonia, Pomegranate, Silverberry, and various fruit trees. Some of these species could be replaced by more salt tolerant shrubs listed in Attachment I-1. Many groundcover plants are also susceptible to salt damage through sprinkling. They can also be converted to salt tolerant types, or sprinkler irrigation system can be converted to drip or bubbler irrigation. Broadleaf deciduous trees, used widely for shade in the Southwest, are also susceptible to salt damage when sprinkled. At present, only a few deciduous trees were identified to have some tolerance, and include Mesquite and Raywood Ash. In other words, replacement of deciduous trees is not easy, and one often has to modify irrigation methods or plant them near the sprinkler head to minimize spraying on foliage. Shade trees are an important component of landscape, especially in the Southwest.

Improve Water Quality: Advances in desalting technology, especially membrane processes, made it possible to lower salinity of water supply. However, the cost of desalting is still an obstacle for maintaining urban landscapes. Nonetheless, several golf courses have used desalting technology to treat water for putting greens and flower beds near buildings and entry ways. In the case of reuse of reclaimed water, the cost of treatment can be lowered somewhat if treated at a centralized reclamation plant. Blending with stormwater may be feasible under certain circumstances. Little information is available on the effect of chemical additives on foliar salt damage.

Another concern of desalting using membrane processes is the disposal of concentrate, unless it is a federal property, the disposal practices must meet state codes and regulation. In theory, nanoinfiltration can yield the concentrate rich in Ca and SO_4, which can be used for conditioning sodic irrigation water. A review of this process, however, indicates that a large portion of Na ions are also retained in the concentrate when the water to be treated contains SO_4 in excess of Ca and Mg (Miyamoto et al., 2010). As shown earlier in Table 1.1, ionic composition of sodic water resources in the Southwest, fall into this category. The ionic composition of permeate tends to become sodic after nanoinfiltration, and this can also present sodicity problems if used for landscape irrigation. Nanoinfiltration can yield the concentrate dominated by Ca and SO_4 when used in gypsic water. It can be evaporated to mine gypsum.

2.2 Soil Salinity Tolerance

The ability of landscape plants to sustain growth in salt-affected soils has been studied mainly in California. Broadly speaking, plants must tolerate the osmotic effect, specific ion effects, and at times, toxicity of certain salt elements. The osmotic effect translates to the difficulty of water uptake by roots when salts accumulate in soils, and elevate the osmotic stress of the soil solutions. The specific ion effect involves various physiological or nutritional disorders induced by the abundance of certain ionic elements, such as Na and Cl. The elevated level of Na ions, for example, can induce K or Ca deficiency. It can also accumulate in leaves along with Cl, and cause leaf injuries. In woody species, Na ions adversely affect the integrity of root cells. The toxic effect of certain elements, such as B and Li, causes leaf injuries and other disorders at a very low concentration, around 1 mg/L or less in irrigation water. However, incidences of toxicity are rare in the Southwest.

2.2.1 Southwestern Experience

The information on soil salinity tolerance of landscape plants used in the Southwest is highly limited. Therefore, an experiment was conducted to evaluate soil salinity tolerance of grass, evergreens and conifers, deciduous trees, palms, vines and ground covers, and plants native to the Chihuahuan Desert. The species tested were a total of 64, which, according to a local nursery, account for about 80% of the species commonly planted in the El Paso area.

The test plants were either purchased from or donated by local nurseries in 1 gallon size. They were transplanted into 3 gallon size containing loamy sand in the spring. They were irrigated with saline solutions having five levels of salinity, 800, 2000, 5000, 7500 and 10000 ppm for 6 months. The electrical conductivity (EC) of these solutions was, respectively, 1.2, 4.4, 9.4, 13.7 and 17 dS m^{-1}. About 80% of the salts in these solutions was in the form of NaCl as shown in Table 2.5. Irrigation was initiated when the soil moisture in the potted soil had depleted to about ½ of the initial storage through weighing of pots. Approximately 1/3 of the solutions applied was allowed to drain so as to avoid salt accumulation. Under this irrigation regime, salinity of the soil saturation extract (an official method of determining soil salinity) is approximately equal to the salinity of irrigation water used (Attachment I-2). Plant growth and leaf injury were recorded photographically after 6 months of the treatment.

The procedure used for the experiment involved a leaching fraction of 33% (or 1/3 of the water applied was drained). This leaching fraction is larger than what may be occurring in landscapes, with a possible exception in sand or sandy soils. This level of leaching was chosen, mainly because the average salinity of the soil solutions is approximately twice the salinity of irrigation water at this level of leaching. It has been shown previously that the field capacity of most soils is about ½ of the moisture content of the saturated soil paste (use for determining salinity of the soil saturation extract). In other words, salinity of the irrigation water used for this experiment was approximately equal to the salinity of the soil saturation extract, which is an official method of expressing soil salinity (Rhoades and Miyamoto, 1990).

Table 2.5 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}		me/L	---------------------------------me/L (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

Results were analyzed to determine the soil salinity which causes a 50% growth reduction or foliar salt damage of at least 25% of the leaves. The 50% reduction in growth is a protocol proposed by the US Salinity Laboratory, and was adopted here. In the case of turf and ground cover grass, a 25% reduction in growth instead of the conventional 50% reduction was used. This reflects field observations that growth of turf in high traffic area is critically important. Tested plant species were then classified into five categories, following the US Salinity Laboratory classification: **sensitive** (0-3 dS m^{-1}), **moderately sensitive** (3-6 dS m^{-1}), **moderately tolerant** (6-8 dS m^{-1}), **tolerant** (8-10 dS m^{-1}) and **highly tolerant** (> 10 dS m^{-1}). The EC values shown in salt tolerance classification must be determined in the soil saturation extract made from soil samples collected from the main root zone. In this experiment, it coincides with salinity of irrigation water used. Results are shown in Attachments I-2, I-3 and I-4. Attachments I-2 and I-4 include some species tested elsewhere, and in Attachment I-5 are those which were reported in California.

Examples of soil salinity tolerance of selected landscape plant species are shown in Table 2.6. Note that for each category of plants, there are species of plants which encompass the full spectrum of soil salinity tolerance. One may view this pattern of spread as a consequence of ecological diversity. However, it is evident that salt tolerance has no association with aridity. Desert plants, such as Yucca have little salt tolerance, yet Agave and Century plant do. Deciduous trees have a wide range of soil salinity tolerance, possibly reflecting soil salinity status of their natural habits. Willows and Desert Willow, for example, are native to arroyo and streambed where salts are likely to be leached. A rule of thumb appears to be that plants which are native to nonsaline lands are not salt-tolerant, although there

Table 2.6. Examples of plant species which fall in different salt tolerance categories (excerpt from Miyamoto et al., 2004b).

	Sensitive	Moderately Sensitive	Moderately Tolerant	Tolerant
Salinity (dS m^{-1})	<3	3 - 6	6 - 8	>8
Grass Species	Black grama (*Bouteloua eriopoda*) Bluegrass (*Poa sp.*)	Blue grama (*Bouteloua sp.*) Creeping bentgrass (*Agrostis palustris*)	Zoysiagrass (*Zoysia sp.*) Perennial ryegrass (*Lolium perenne*)	Bermudagrass (*Cynodon dactylon*) Tall fescue (*Festuca arundinacea*)
Ground Covers	English ivy (*Hedera helix*) Gerbera (*Gerbera jamesonti*)	Aster (*Aster sp.*) Lantana (*L. camara*)	Juniper (*Juniperus chinensis*) Coyote brush (*Baccharis pilularis*)	Creeping boobialla (*Myoporum sp.*) Ice plant (*Carpobrotus sp.*)
Deciduous	Desert willow (*Chilopsis linearis*) Willows (*Salix sp.*)	Mimosa silk tree (*Albizia julibrissin*) Cottonwood (*Populus fremontii*)	Pomegranate (*Punica granatum*) Pistache (*Pistacia chinensis*)	Honey mesquite (*Prosopis glandulosa*) Chilean mesquite (*Prosopis chilensis*)
Evergreens	TX Mt. Laurel *(Sophora secundififlora)* Holly oak (*Quercus ilex*)	Yaupon holly (*Ilex vomitoria*) Southern live oak (*Quercus virginiana*)	European olive (*Olea europaea*) Afgan pine (*Pinus eldarica*)	Four-wing saltbush (*Atriplex canescens*) Italian stone pine *(Pinus pinea)*
Natives	Yucca (*Yucca brevifolia*) Arizona sycamore (*Platanus wrightii*)	Silverberry (*Elaeagnus pungens*) Cottonwood (*Populus fremontii*)	Agave (*Agave parryi*) Coyotebush (*Baccharis pilularis*)	Texas sage (*Leucophyllum sp.*) Century plants (*Agave americana*)

are many exceptions. If the plants are native to saline lands, they should be salt-tolerant.

The development of soil salinity tolerance tables, such as Table 2.6, led to the notion that soil salinity-induced salt damage should occur mainly with plants of low salt tolerance, but not with high tolerance, such as Bermudagrass or Mesquite. Some also have raised a serious question on the actual occurrence of salinity problems, because saline water currently used has salinity of 1000 to 1500 ppm with some exceptions in gypseous water (Section I-1.1). After all, these plants have grown normally in a greenhouse when irrigated with water containing 2000, 5000 and even with 7500 ppm of dissolved salts. The corresponding EC of the water was 4.4, 9.4 and 13.7 dS m^{-1}, respectively. These assessments are theoretically correct if salts do not accumulate in soils. In our greenhouse experiment, one third of the water applied was allowed to drain so as to prevent salt accumulation in soils. In reality, irrigation is practiced at lower leaching fractions, and some soils simply do not allow necessary drainage because of low permeability. A consequence has been highly variable and unpredictable occurrence of soil salinization, which affects any of the plants listed, almost independently of their tolerance to soil salinity. In other words, reliable assessment of site suitability can not be made based solely on soil salinity tolerance alone. It requires assessment of soil suitability and irrigation capability at given sites. This makes the assessment task complicated, and is discussed in Part II of this report.

2.2.2 California Experience

Agricultural industry in California has experienced extensive crop damage caused by saline soils, since the beginning of irrigation development in the state. This circumstance led to the establishment of the US Salinity Laboratory at Riverside which then has played the major role in developing soil salinity tolerance information. More recently, various reports from the Laboratory along with reports from other institutions were reviewed by the Extension Service at the University of California, Davis, and is included here as Attachment I-5.

The classification systems used by the UC Davis team and US Salinity Laboratory are as follows:

UC Davis System Permissible EC_e (dS m^{-1})	US Salinity Lab System Permissible EC_e (dS m^{-1})
Sensitive: <2	Sensitive : <3
Moderate: 2-4	Moderately Sensitive: 3-6
Tolerant: 4-6	Moderately Tolerant: 6-8
Highly Tolerant : >6	Tolerant : >8-10
	Highly Tolerant : >10

where EC_e is the electrical conductivity of the soil saturation extract, which is approximately equal to the salinity of irrigation water at a leaching fraction of 33%. In reality, plant response to soil salinity is influenced by the level of soil water depletion prior to irrigation (Part II).

Recall that the work at El Paso followed the US salinity Laboratory classification, which is shown on the right-hand side. There is little substantive difference between the two schemes. However, the UC Davis system considers that soil salinity impacts on landscaping plants are somewhat greater than previously thought by the Salinity Laboratory. The fact that the majority of irrigated lands as well as urban centers in California consist of structurally weak alluvial soils (Entisols) may be an underlying factor. The structure of Entisols easily disintegrates, thus resulting in reduced permeability and salt accumulation. In addition, soil water depletion allowed prior to irrigation is likely to be greater under reduced irrigation, which makes the actual salt hazard greater even at the same salinity in the soil saturation extract. With the exception of communities located in the flood plain, golf courses and urban landscapes in the Southwest are often located on stable upland soils. Under such circumstance, we believe that the US Salinity Laboratory System is applicable. In the case of drip irrigated landscapes, salinity hazard estimate based on soil salinity tests is problematic, due to large spatial variability. Typically, plants tolerate high soil salinity as long as irrigation water is applied consistently or at high frequency. Additional discussions on soils and irrigation management are provided in Section 2.2.3, and Part II of this series.

2.2.3 Reducing Soil Salinity Hazard

One practical way to reduce soil salinity hazard to landscape plants is to use salt tolerant species as much as possible, or at least try not to use salt sensitive species. When dealing with well-drained sandy soils distributed upland areas of El Paso, we found that the exclusion of salt sensitive species shown in Attachment I-4 alone largely eliminates salinity hazards caused by elevated soil salinity.

There have been many attempts to improve soil salinity tolerance of landscape plants, especially of turfgrass through breeding. Such an effort has been among the priority programs at both public and private sectors, and is likely to continue. However it should be kept in mind that soil salinity will increase with the introduction of salt tolerant species if the drainage of the site is not corrected. There have also been many attempts to improve salt tolerance through the addition of certain chemicals and/or microbial products. An addition of Ca compounds to nitrogen fertilizer (NH_4 forms), for example, has shown to improve N uptake and root growth, which may improve growth under salt stress. By the same token, some of these chemicals have not been adequately tested.

Another approach which has been used for many years is to increase the quantity of irrigation in order to leach salts. This method is most effective when used in the spring or the fall when the evaporation rate is low. However, it may not work when the site consists of clay or indurated caliche which has low permeability. In some cases, the site soil and/or the irrigation water may contain excess level of Na, which also lowers potential for salt leaching. These options and issues are discussed in Part II of this series.

Irrigation scheduling adjustments may also help reduce soil salinity hazard. In general, reducing irrigation frequency leads to increased water application per irrigation event, which is helpful for salt leaching to a deeper depth. However, it also allows for a greater degree of soil water depletion prior to irrigation, which accentuates soil salinity hazard, as salinity of soil solution increases. Increasing the frequency of irrigation can lead to salt accumulation at and near the soil surface. Our field trial using common bermudagrass indicates that growth is superior when irrigated twice a week as compared to once a week or three times a week with water of elevated salinity (EC_w of 2 dS m^{-1}). When tap water (EC_w of 0.8 dS m^{-1}) was used for irrigation, growth was similar between the two schedulings, twice or three times a week. The quantity of water applied was at the potential evaporation rate, which is about 70% of the pan evaporation rate at the test site.

Irrigation scheduling of putting greens requires on-time assessment of evapotranspiration rate, especially when water of elevated salinity is used for irrigation. Typically, putting greens with bentgrass are irrigated once or twice a day to maintain firm grass stands. If the evaporation rate is underestimated, salt crust can develop in a matter of a week, which can result in sudden death of the grass. An example is shown in Fig. 2.4. This incidence occurred during unusually warm (or hot) weather in October when the ET monitor was just taken out for service. The green has been irrigated twice a day with water of elevated salinity (EC_w of 2.0 dS m^{-1}).

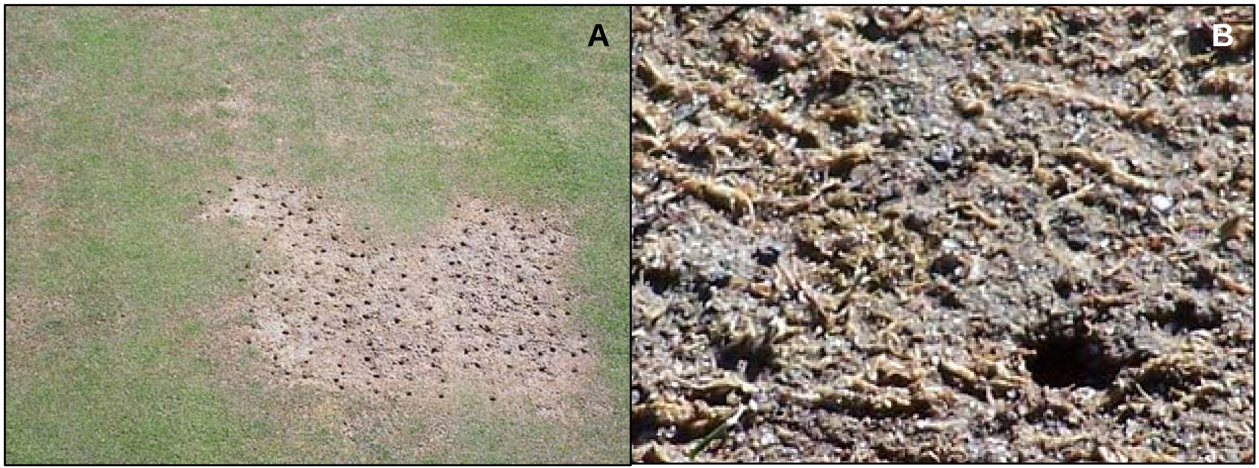

Fig. 2.4. Salt damage on putting greens irrigated with 2 dS m^{-1} water twice a day (A) and a close-up of salt accumulation on dead bentgrass (B).

Irrigation systems have a significant impact on salt accumulation, both in extent and spatial variation. Traditionally, the inadequate overlap of sprinkler application patterns has been considered the main factor. Our observations at a number of golf courses indicate that soil salinity under the 100% overlap layout is fairly uniform with the lowest range of standard deviation (<15%). However, high levels of salt accumulation can result in the outer edges where no overlap occurs when sprinkler heads are placed along the two laterals buried along a fairway. The outer edge region under the system simply does not receive enough water to leach salts. This can lead to loss of grass cover along the edge of the fairway and, at times, of rough unless there is sufficient precipitation. Another case where we observe consistently high soil salinity is under tree canopy, especially where evergreen trees are hit with sprinklers. Tree canopies act as an evaporation tower when sprinkled. In these cases, the irrigation system needs to be reworked. In the case of drip irrigation, salts tend to be trapped between two lines as the wetting fronts face each other. This problem is minimal in a single dripline or a tree loop system.

With the exception of putting greens and flower beds, the field experience in the El Paso-Alamogordo area indicates that soil selection or improvements at the time of landscape development is critical for controlling salt accumulation in soils. Soil salinization usually occurs in clayey soils and in the soils with poor internal drainage. The best way to reduce this problem is to select or improve soil permeability. This means that a greater effort should be placed on planning and design. Details on soil selection and improvements are given in Part II of this report.

2.3 Specific Ion Effects and Boron Toxicity

Sodium (Na) ions have been known to cause leaf injury and stunted growth, as well as nutrient imbalance (e.g., Maas, 1986). In a practical term, this translates to a greater degree of damage to plants when the proportion of Na increases in soil solutions having the same salinity. This effect is significant in woody species. Pecan trees, for example, grow well when irrigated with gypseous water having salinity over 2500 ppm or an EC_w as high as 3.0 dS m^{-1}. Gypseous water contains mostly Ca and SO_4 ions. When irrigation water contains mostly Na ions, however, growth of pecans can decline at an EC_w as low as 1 dS m^{-1} (Miyamoto et al., 1986). A specific effect of Na also appears in some fruit crops (e.g., Maas, 1986). In woody species, Na is retained in roots and bark before it is transported to leaves. In the case of pecans, for example, it takes the entire growing season to observe an increase in leaf Na concentration. If leaf analysis is to be performed, it should be sampled at the end of a growing season. Otherwise, no remarkable Na concentration can be detected. Leaf injury caused by the accumulation of Na begins at leaf tips, typically towards the end of a growing season. When Na ions accumulate in roots and bark, leaves may become yellow, and defoliate prematurely. Sodium ions accumulated in roots damage root cells, and trees can undergo branch dieback, and eventually tree mortality.

Chloride (Cl) ions can also cause specific effects which include leaf injuries and at times, defoliation. Chloride ions are readily transported to leaves, thus its impact is rapid, often a matter of a week or two to show leaf-burn or scorching. This rapid transport process differs from the Na effect which takes a longer period; Chloride causes leaf margin burn and may or may not cause defoliation. If defoliated, trees can develop new sets of leaves. The effect of Cl ions can occur not only in woody species, but also in various field crops, as reviewed by Maas (1990). Fescue and Ryegrass, for example, experience growth reduction when the concentration of Cl ions reaches 40 to 50 meq/L or 1420 to 1775 ppm (Maas, 1990). However, salinity of typical irrigation water in the Southwest is likely to be high enough to cause a significant growth reduction at the level of Cl concentration.

High levels of sodium adsorption ratio (SAR) cause disintegration of soil aggregates, and reduce soil permeability; thus can adversely affect plant growth. This problem is most acute in alluvial soils, which have weak soil structure. A rule of thumb in alluvial soils (Entisols) is that soil permeability begins to decline when the SAR of irrigation water reaches 6, and it becomes serious when it exceeds a range of 9 to 12, depending on soil types. This problem is discussed in Part II of this guideline series.

There has been an idea that Na or Cl sensitive plants are also sensitive to salinity. Therefore, there is little practical rational to separable specific ion effects from salinity or osmotic effect. This idea appears to apply to many field crops, but not always in woody species. One simple method of reducing the gap in impact assessment based on salinity measurements, instead of Na or Cl concentration is to use EC instead of TDS. The solution containing 2000 ppm of NaCl, for example, yields an EC of 3.8 dS m^{-1}, where as 2000 ppm of $CaSO_4$ yields an EC of 2.1 dS m^{-1}.

Boron (B) is an essential element for plant growth, but can cause toxic effects at the concentration as low as 1 ppm. Toxicity has been reported mainly in the Central Valley of California, but rarely in the Southwest. Boron is stored in soils largely as a libel form with a small portion as water soluble. Nonetheless, B toxicity is related to the concentration of dissolved B in the soil extract. The uptake of B is passive (similarly to Cl uptake). Boron toxicity can appear in many species of plants (Maas, 1990). Examples of boron tolerance of landscape plants are shown in Table 2.7. The threshold concentration is in irrigation water, and should be considered merely as an indication.

Table 2.7. Examples of plant species which fall in different boron tolerance categories (Maas, 1990).

Boron (ppm)	Very Sensitive (<0.5)	Sensitive (0.5-1)	Moderately Sensitive (1-2)	Moderately Tolerant (2-4)
	Oregon grape	Zinnia	Marigold	Bottlebrush
	Photinia	*(Zinnia eleganus)*	*(Calendula officinalis)*	*(Callistemon citrinus)*
	(Photinia x fraseri)	Pansy	Southern yew	Japanese boxwood
	Wax-leaf privet	*(Viola tricolor)*	*(Podocarpus sp.)*	*(Buxus microphylla)*
	(Ligustrum japonicum)	Violet	Brush cherry	Oleander
	(Pittosporum tobira)	Rosemary	*(Syzygium sp.)*	*(Nerium oleander)*
	Chinese holly	*(Rosmarinus sp.)*		Sweet pea
	(Ilex cornuta)	Oriental arborvitae		*(Lathyrus odoratus)*
	Juniper	*(Platycladus sp.)*		Carnation
	(Juniper chinensis)	Geranium		*(Dianthis sp.)*
	Latana	*(Pelargonium sp.)*		Indian hawthorn
	(Latana Camara)			*(Raphiolepis indica)*

3. Site Survey for Suitability Assessment

For maintaining landscapes with water of elevated salinity, plant species and their general growth requirements, such as water requirements, and salt tolerance should be checked. When dealing with salt tolerance, a caution should be exercised, as most nurseries equate salt tolerance with soil salinity tolerance rather than spray resistance. There is also a notion that salt problems can be ruled out simply because the landscape is using a so-called salt-tolerant plant. Such a notion is overly optimistic or even risky. Soil salinity usually varies more than the difference in plant soil salinity tolerance. It is necessary to know if the soil is permeable enough to maintain the salt balance, and that irrigation water is applied correctly using appropriate irrigation systems and management practices.

3.1.1 Plant Species Inventory

The survey or identification of plant species is the first step towards making site suitability assessment. If a plant material listing is available, this task can be made simple, provided that plant species planted coincide with the design. This is not always the case. Once the species are identified, determine salt tolerance using the information provided in this report. If the landscape is irrigated with overhead sprinklers, make sure to identify the species sensitive to spray. If the entire landscape is planted with pines, the survey may not be needed. Once the species are identified, the information on water requirements should also be obtained.

If salt-sensitive broadleaf trees are present, consider relocating to an area where non-sprinkling methods of irrigation can be practiced. If the species belongs to a highly sensitive category, irrigation system modification may be required. Potential water users should be informed about these constraints prior to using water of elevated salinity.

3.1.2 Soil and Irrigation Survey

The main objective of the soil survey is to determine if the site will allow adequate salt leaching. Details are discussed in Part II of this series. In brief, there are three ways of conducting this task. The first method is to utilize a soil map, if available. The soil survey reports (available for most counties) indicate soil types which are conducive or not conducive to salt leaching. However, site inspection may be required as the site soils including the depth and the slope may have been modified during construction.

The soil map is not always available, especially in upland areas. If the site had been irrigated, leachability of salts can be determined by testing soils for salinity and/or permeability. We recommend the soil saturation extract method (Rhoades and Miyamoto, 1990), mainly because soil salinity tolerance is given by the salinity readings obtained by the method. Once the salinity of the existing landscape soil is determined, soil salinity after conversion to water of elevated salinity can be estimated, in most cases, using the assumption of proportional increase in soil salinity with increasing salinity of irrigation water. This method is applicable when the site has been irrigated for at least a season with the recommended scheduling and that sodicity of irrigation water is not high enough to cause a significant reduction in soil permeability. If the site to be irrigated has no history of steady irrigation, and that the applicable soil map is not available, testing of soil physical properties is required, unless the site consists of well-drained sandy soils. The procedure is described in Part II of this series.

The irrigation survey consists of system suitability and functionality, and irrigation rates and schedule. If reclaimed municipal effluent is to be used, water runoff or ponding and sprinkler drifts need to be evaluated, as these features are regulated by the state law (TAC 210). The cost of making appropriate changes should be determined prior to water conversion.

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Attachment I-1

Foliar Salt Damage of Landscape Plants Induced by Sprinkler Irrigation

S. Miyamoto and John M. White

Introduction

As the supply of potable water becomes scarce and costly, there is an increasing need to maintain urban landscapes with non-potable water. Saline water having salinity in excess of drinking water standards (1000 ppm in Texas, and 500 ppm in New Mexico) is among the readily available resources for irrigation, and includes saline ground water, agricultural drainage water, industrial wastewater, and reclaimed municipal effluent with elevated salinity. Quality of some of these water sources is shown in Table 1.

Although the use of saline water for irrigation can significantly increase water management options, high salinity can damage landscape plants if not managed correctly. Salt damage occurs as a result of salt accumulation in the soils or salt adsorption through leaves when saline water is applied with sprinklers. Salt damage associated with sprinkler irrigation appears in sensitive plants as moderate leaf injuries, such as leaf tip or light margin burn, when salinity of irrigation water reaches about 600 ppm (Miyamoto et al., 2001). When salinity increases to 1000 ppm, foliar salt damage becomes common. However, the actual sprinkler-induced salt damage varies widely with plant species, frequency and types of sprinklers used, as well as day vs night irrigation (Busch and Turner, 1967; Maas et al., 1982; Eaton and Harding, 1959). In general, trees and shrubs are prone to this form of damage, whereas grass species are tolerant. It is also known that Na and Cl are the primary ions responsible for the damage (Maas, 1985). These findings are based primarily on experiences or observations involving agricultural crops, and the information on landscape plant response to sprinkler irrigation with saline water is presently scarce.

We had opportunities to observe incidents of plant damage induced by sprinkler irrigation in El Paso, TX. In addition, we conducted an experiment for evaluating plant growth and salt damage under daily sprinkler irrigation. These observations are reported in this publication in three parts; Part I describes growth and leaf injuries of twenty-eight plant species irrigated daily with sprinklers at three levels of salinity; Part II foliar salt damage in trees and shrubs sprinkler-irrigated in several landscape areas in El Paso; Part III addresses practical ways to minimize foliar salt damage induced by sprinkler irrigation.

Table 1. The composition of water sources used for irrigating some landscaping areas in El Paso, TX.

	Salinity			Sodicity		Cl	pH	Ionic Concentration			
	EC	TDS	TDS	Na	SAR			Na	Ca	Mg	Cl
	dS^{-1}	mg L^{-1}	meq L^{-1}	%	%	%		-------- mg L^{-1} (meq L^{-1})-------			
Controlled Equipment											
1	1.1	700	11.2	57	4.0	36	7.4	145 (6.3)	69 (3.5)	16 (1.4)	143 (4.0)[1]-
2	2.0	1260	20.4	60	6.0	50	7.9	278 (12.1)	97 (4.8)	43 (3.5)	358 (10.1)
3	3.0	1850	30.7	62	7.5	55	8.1	425 (18.5)	128 (6.4)	71 (5.8)	596 (16.8)
Field Situations											
A	1.1	620	10.1	63	4.7	65	7.7	148 (6.4)	46 (2.3)	16 (1.4)	200 (6.6)
B	1.7	950	15.2	72	7.4	52	7.0	250 (10.9)	72 (3.6)	9 (0.7)	280 (7.9)
C	2.1	1120	17.9	85	9.8	51	7.6	350 (15.2)	45 (2.3)	5 (0.4)	325 (9.2)

[1]-Numbers in parenthesis are for meq L^{-1}

I. Growth and Leaf Injuries of Selected Plants Grown under Sprinklers

Landscapes around apartment buildings, shopping malls, and office buildings utilize a number of flowering shrubs and ground covers. When turf is incorporated, these landscapes are usually irrigated with sprinklers, and the shrubs and ground cover plants are subjected to sprinkling. We carried out a controlled experiment to evaluate potential impacts of sprinkler irrigation on shrubs and ground covers. Growth responses and leaf injuries are reported here with applicable scientific names of the tested plants in Table 2.

Materials and Methods

Twenty-eight plant species commonly found in landscape areas of El Paso were purchased in one-gallon size, then were transplanted into 3 gallon plastic pots using commercial potting soil. The newly potted plants were kept in a cool greenhouse at 10C (50F) for a month, prior to moving to an outdoor test area on March 17. Tap water (700 ppm) was used for irrigation until March 24, and the experiment involving sprinkler irrigation began on March 25. The experiment used three saline solutions (numbered 1 through 3 in Table 1) which were prepared by blending saline well water with the tap water to yield salinity levels of 1.1, 2.0, and 3.0 dS m^{-1} (or 700, 1260 and 1850 mg L^{11} of total dissolved salts). The ionic composition of these solutions is typical for ground and surface water sources in the middle Rio Grande Basin, and the Na and Cl ions accounted for 60 and 50% of the cation or the anion total, respectively.

Spray nozzles rated at 10 L/min (2.6 gallon per min.) at a water pressure of 2.1 kg cm^{-2} (30 psi) were placed 5 meters (16 ft) apart to have an average application rate of 2.5 cm/hr (1 inch per hr). The potted plants were sprinkled every other day for the first 2 months, and daily applications except for Saturday and Sunday for the next 4 months, using approximately 1 cm of water (0.39 inch) per application during early morning hours; 8:00 to 8:25 am. The quantity of water applied was sufficient not only to wet the leaves, but also to cause steady dripping of water from the leaves. All potted soils were watered manually below the canopy with tap water, every 4 to 5 days during March, April and September, every 2 to 3 days during May through August in quantities sufficient to achieve a leaching fraction of about 30%. This procedure was used to prevent salt accumulation in the potted soils, and to keep soil salinity below the threshold values given by Bernstein et al. (1972). The treatment involving no sprinkler, but irrigated manually with the tap water, was also included as a reference.

Plant growth was assessed by measuring the plant height, the width, and the length of 5 shoots per plant on September 25, six months after the initiation of the experiment. Leaf damage was assessed by counting the number of leaves with tip or margin burn. The incidences of defoliation were also noted. These measurements were performed in triplicate, using three plants per treatment. Salt tolerance was expressed by the salinity of irrigation water which causes a 25% reduction in shoot growth or leaf injuries in 25% of the leaves, through a numerical interpolation.

Plant Growth

Flowering plants irrigated with tap water grew almost twice the initial size of the plants during the test period of March 25 through September 25. However, plant growth, evaluated by the relative shoot growth (Table 2), was reduced with increasing salinity, especially in Tea Rose, Lily of the Nile, Crape Myrtle and Gazania. The growth of Texas Sage, Climbing Rose, and Lantana was also reduced significantly when sprinkled with 3.0 dS m^{-1} water (or 1850 ppm). When grown under surface irrigation, Tea Rose grew better than those under sprinklers. Lantana, Verbena, and Indian Hawthorne (listed under a category "shrubs") were more tolerant to salts than the other flowering plants tested (Photo Set 1).

Vines and ground covers had highly variable growth rates, but most vines have grown 2 to 3 times of the initial size when irrigated with the tap water. Vinca was found exceptionally sensitive to salts, and its leaves were desiccated in a month when sprinkled with 3.0 dS m^{11} (Photo Set 2). Honeysuckle and Star Jasmine experienced a significant growth reduction when sprinkled with 2.0 dS m^{11} water, whereas Carolina Jasmine, English Ivy and Liriope tolerated sprinkler irrigation with 2.0 dS m^{-1} water. (Both Jasmines and English Ivy are known to experience a significant growth reduction when surface-irrigated at 2.0 dS m^{11}, but not Carolina Jasmine). Growth of Liriope plants was unaffected by sprinkling of 3.0 dS m^{11} water, but it suffered extensive leaf injuries toward the end of the growing season.

The tested shrub species generally grew slowly, but have shown higher levels of tolerance, except for Nandina plants (Photo Set 3). Rosemary plants, known for high tolerance to soil salinity, also suffered a significant growth reduction when sprinkler-irrigated at 2.0 dS m^{11}. Euonymous, Hawthorne, Juniper, Cotoneaster, and Boxwood were more tolerant to salts, showing no or only a minor reduction in growth when sprinkled at 2.0 dS m^{11}. Among the tall shrubs or tree species tested, Cottonwood suffered the greatest growth reduction due to sprinkler irrigation, followed by Photinia (Table 2). Shoot growth of other shrubs and/or tree species tested, except for Wax-leaf Ligustrum, was also deterred by sprinkling. Also note that the growth of Afghan Pines and Ligustrum was reduced without obvious leaf injuries (Photo Set 4).

Leaf Injuries

Leaf injuries usually appear in the form of either tip-burn, margin burn, or necrosis. Necrosis symptom in this experiment appeared only in Crape Myrtle. Two species which exhibited no recognizable leaf injury were Boxwood and Rosemary. In all other cases, it was found convenient to group them into four categories: I) Leaf tip-burn which progressed to margin burn, followed by defoliation, II) Leaf tip-burn, but with limited defoliation, III) Leaf margin burn, followed by darkening and desiccation of some leaves, and IV) Leaf yellowing or discoloration, but no defoliation.

The plant species under Category I first exhibited leaf tip-burn which progressed to margin burn and eventually to defoliation. The plants which fall into this category included Tea Rose, Nandina, Crape Myrtle and Cottonwood, all of which developed tip-burn in two months into the experiment. Lily of the Nile and Honeysuckles also developed leaf tip-burn in two months which progressed to defoliation. Verbena and Lantana did not show any leaf injuries until the middle of summer. These two species could be placed under Category III, because of extensive leaf desiccation, but not defoliation.

The plants under Category II have shown extensive leaf tip-burn, some of which developed to margin burn, but did not lead to extensive defoliation. Climbing Roses, Carolina Jasmine and Liriope plants were placed into this category. Both Climbing Roses and Liriope plants developed leaf tip-burn during the first two months. Pistacia, Cotoneaster, and Pyracantha have also developed leaf tip-burn, but to a lesser extent than did the first group.

The plants under Category III did not show leaf tip-burn for any extended period. Instead, some leaves, usually old or scarred leaves, rapidly developed margin burn which developed into burning or drying of the leaves. The browned leaves usually do not defoliate rapidly. Vinca, Gazania, Photinia, Euonymous, Asian Jasmine, Star Jasmine, and English Ivy fell into this category.

The plants under Category IV developed yellowing leaves after about 2 months, but no leaf injury or defoliation was observed. The plants under this category included Texas Sage, Yaupon Holly, Ligustrum, Afghan Pine, Juniper, and Indian Hawthorne. Note that Yaupon Holly and Indian Hawthorne were found to be comparatively salt tolerant, thus resulting in the limited growth reduction. However, the other species suffered significant growth reductions without apparent leaf injuries or defoliation. Plant classification based on these categories is given in Table 2.

Table 2. Shoot growth relative to the control plants grown under surface-watering, the extent of leaf injuries and salinity of irrigation water which may cause a growth reduction by 25% or leaf injuries on 25% of the leaves.

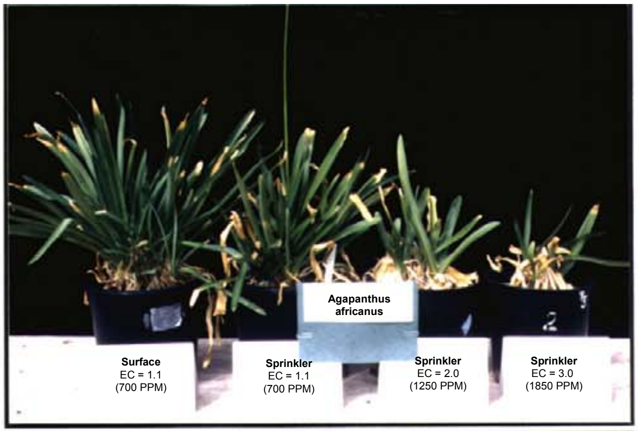
Plant Name		Salinity	Shoot Length			Leaf Injuries[2]-			Injury	Salt
Common	Scientific	dS m^{-1} ÷	1.1	2.0	3.0	1.1	2.0	3.0	Category[3]-	Tolerance
			%							dS m^{-1}
Flowering Plants										
Tea Rose	*Rosa sp., Hybrid*		97	15	9	M	M	H	I	<2
Lily of the Nile	*Agapanthus africanus*		81	32	0	EH	EH	EH	I	< 2
Crape Myrtle	*Lagerstroemia indica*		84	60	51	L	L	L	I	< 2
Gazania	*Gazania sp.*		93	75	33	M	H	H	III	< 2
Texas Sage	*Leucophyllum frutescens*		86	67	56	N	N	N	IV	< 2
"Lady Banks" Rose	*Rosa banksiae*		83	71	66	M	M	M	II	< 2
Trailing Lantana	*Lantana montevidensis*		97	95	72	L	L	L	I	< 3
Verbena	*Verbena sp.*		90	82	78	L	L	L	I	< 3
Vines and Ground Covers										
Vinca	*Vinca major*		46	36	-	M	H	-	III	<1[1]-
Japanese Honeysuckle	*Lonicera japonica*		81	55	34	L	M	H	I	< 2
Star Jasmine	*Trachelospermum jasminoides*		84	52	39	M	M	H	III	< 2
Asian Jasmine	*Trachelospermum asiaticum*		82	66	59	M	H	H	III	< 2
Carolina Jasmine	*Gelsemium sempervirens*		84	82	65	L	L	L	II	< 3
English Ivy	*Hedera helix*		85	80	77	H	EH	EH	III	< 3
Liriope	*Liriope muscari*		98	95	90	H	H	H	II	> 3
Shrubs, low										
Nandina	*Nandina domestica "Nana"*		72	69	12	L	M	H	I	< 1
Dwarf Rosemary	*Rosmarinus officinalis*		83	64	59	N	N	N	N/A	< 2
Yaupon Holly	*Ilex vomitoria*		80	70	67	N	N	N	IV	< 2
Euonymous	*Euonyomus japonica*		88	71	69	M	H	H	III	< 2
Indian Hawthorne	*Raphiolepis indica*		88	76	74	N	N	N	IV	< 3
Buffalo Juniper	*Juniperus sabina*		99	80	67	N	N	N	IV	< 3
Cotoneaster	*Cotoneaster buxifolius*[1]-		98	93	85	M	H	M	II	< 3
Japanese Boxwood	*Buxus micropylla "japonica"*		97	92	81	N	N	N	N/A	> 3
Shrubs tall, and Trees										
Cottonwood	*Populus fremontii*		60	45	-	H	H	-	I	<1
Photinia	*Photinia fraseri "Red Tip"*		72	55	32	M	M	H	III	< 1
Pistacia 'UCB-3'	*Pistacia sp.*		70	68	42	L	L	M	II	< 1
Pyracantha	*Pyracantha graeberi*		73	61	55	L	M	M	II	< 2
Afghan Pine	*Pinus eldarica*		76	66	58	N	N	N	IV	< 2
Ligustrum	*Ligustrum japonicum*		87	66	37	N	N	N	IV	< 2

[1]-*C. buxifolius* is often marketed as *C. Glaucophyllus*

[2]-L: Less than 25% leaves had injuries, M: 25-50%, H: >50-75%, EH: >75%, N: Not significant

[3]-Leaf injury categories : refer to the test.

Photo Set 1. Flowering Perennials and Shrubs



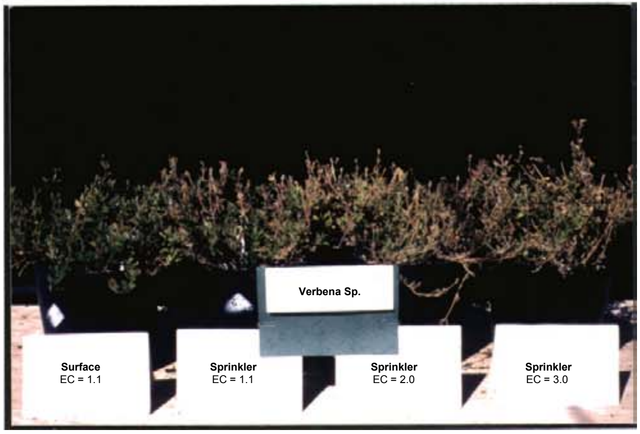
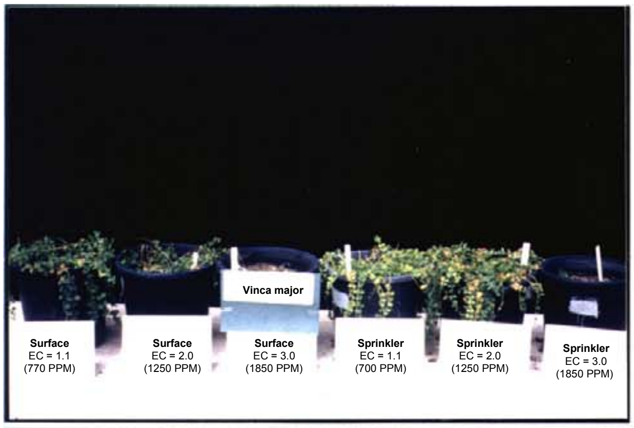
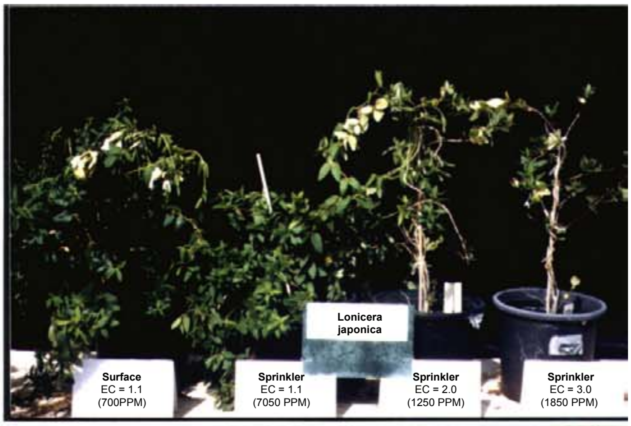
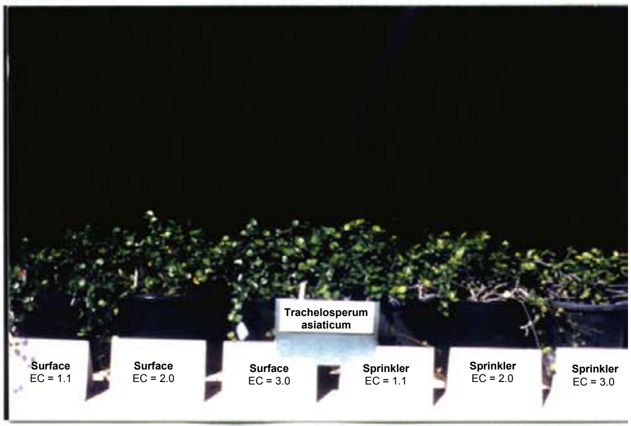


Photo Set 2. Vines and Ground Covers







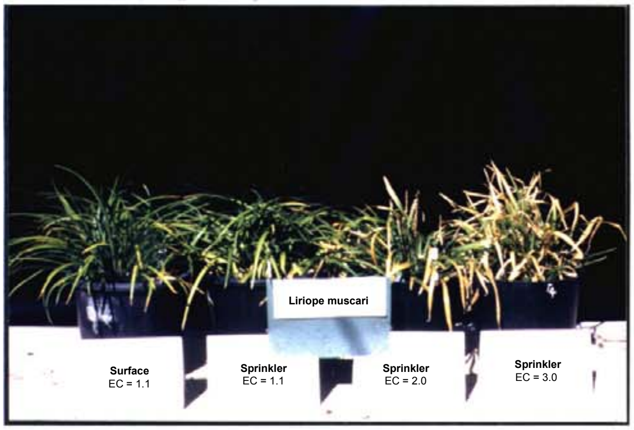
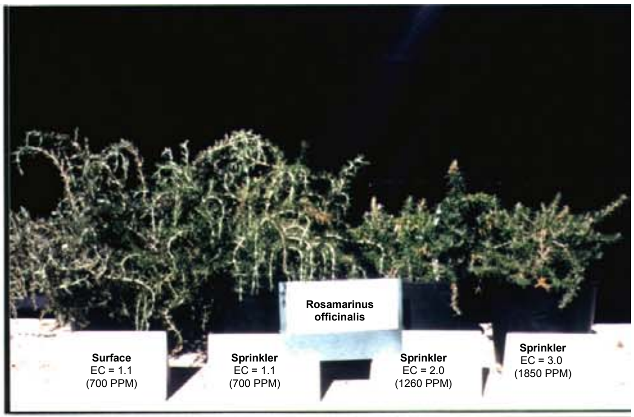


Photo Set 3. Shrubs, Low Profile



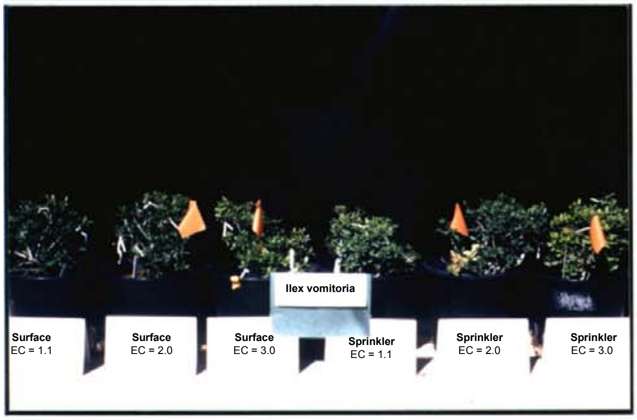
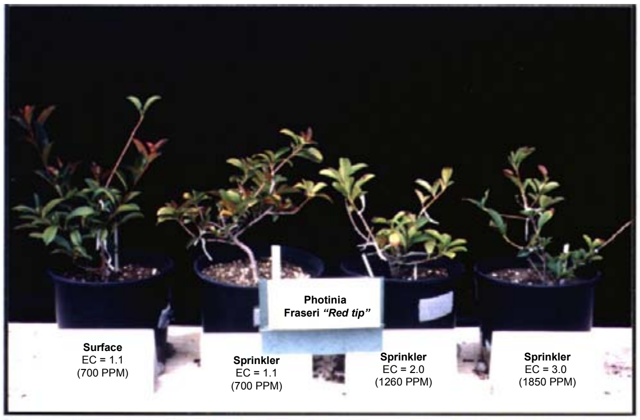
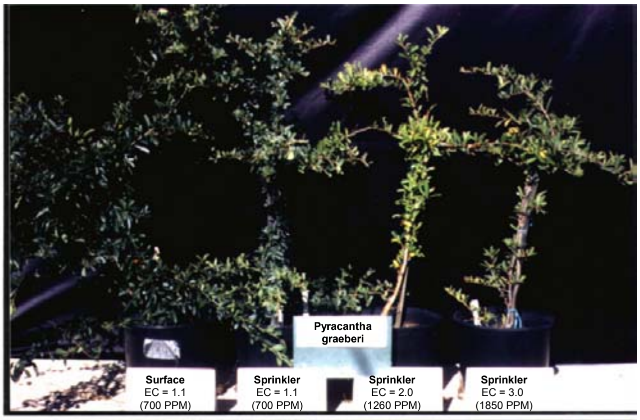
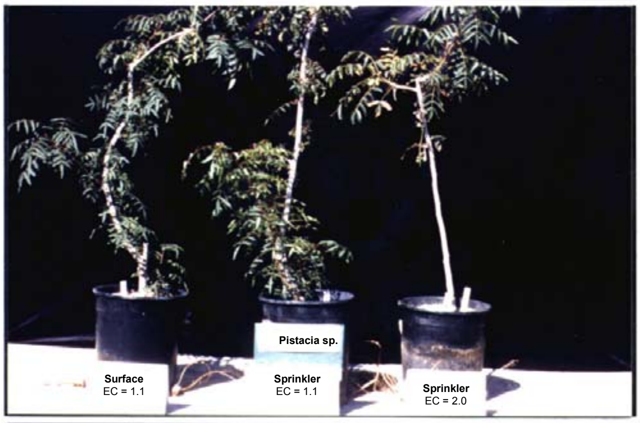
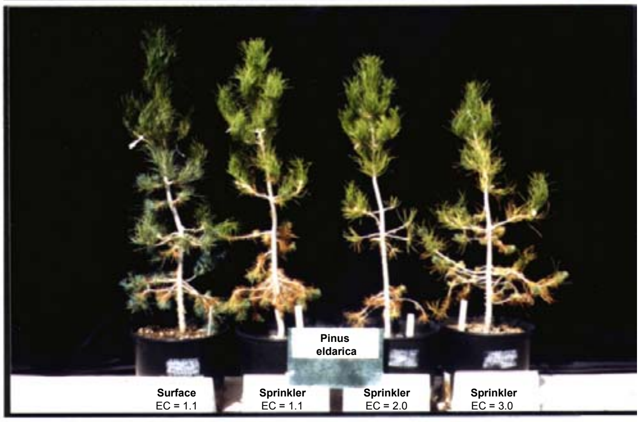


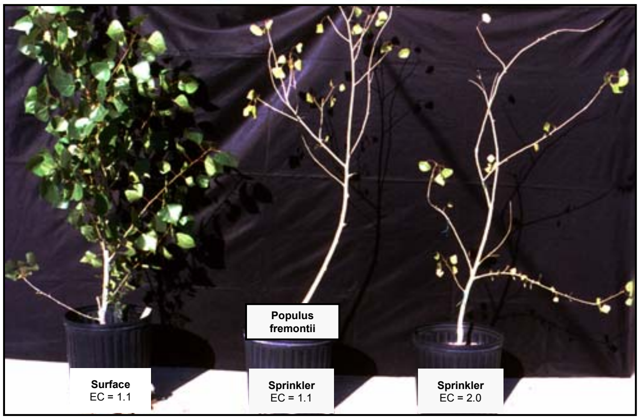
Photo Set 4. Shrubs, Tall and Trees











II Salt Damage to Trees and Shrubs Irrigated with Sprinklers

Large landscapes utilizing turf, such as golf courses, city parks, and school grounds are usually irrigated with high volume sprinklers, capable of reaching a radius of 18 to 24m (60 to 80 ft). These sprinklers are ideal for irrigating large turf areas, but they also wet shrub and tree foliage, and can induce foliar salt damage. Foliar damage caused by daily irrigation is reported here, and those irrigated at longer intervals in Part III. Readers should refer to Table 3 for scientific names of the plants cited.

Evaluation Procedures

Two large landscape areas irrigated daily with saline water for three seasons were surveyed for leaf damage at the end of August. These landscapes were once irrigated with potable water, using high pressure sprinklers (80 to 100 psi). The saline water used had 1120 ppm of dissolved salts, and the mean Na and Cl concentrations of 350 and 325 ppm, respectively (Water C of Table 1). The annual water use at the first site was estimated to be 150 cm (60 inches), and the second site nearly 250 cm (100 inches). An additional site irrigated with water having 620 ppm of dissolved salts (Water A of Table 1) was also surveyed.

The leaf damage survey was made visually, and affected as well as unaffected plants were photographed. Soil samples were taken to a depth of 8 to 12 inches just outside the driplines, and were analyzed for salinity of the saturation extract. In addition, leaf samples were collected from selected trees, and were observed under a microscope at a magnification ratio of 40. The survey results were considered reliable only if more than five plants of the same species exhibited salt damage in a consistent fashion and that the soil salinity did not exceed 3 $dS\ m^{-1}$. The total landscape areas surveyed amounted to 75 ha (185 acres); 55 ha (135 acres) irrigated with 1120 ppm water, and 20 ha (50 acres) irrigated with 620 ppm water.

Highly Sensitive Species

The plants under this category exhibited leaf injuries and defoliation to various degrees when sprinkler-irrigated with water containing 620 ppm of dissolved salts (Water A of Table 1). Crape Myrtle, Pecans, Cottonwood, Sycamore, and Western Soapberry were found to be in this category. However, leaf injuries to Crape Myrtle and Sycamore were also noted when irrigated with non-sprinkling methods. Cottonwood is widely used as a shade tree in the Southwest. It is fast-growing. The leaf surface is smooth, and the leaf margin burn as well as defoliation were visible without salt accumulation on the leaves (Photo Set 8a). Leaf injuries and defoliation were observed more in Western Cottonwood (*P. fremontii*) than in Lanceleaf Cottonwood (*P. acuminata*). Two small Honey Locust trees were found defoliated in one of the survey area irrigated with 620 ppm water. These observations did not satisfy the criteria set, thus they were excluded from the list under the highly sensitive category.

Sensitive Species

The plants under this category suffered severe salt damage when salinity increased to 1120 ppm (or Na and Cl concentrations reaching 300 to 350 ppm). Silverberry and Pomegranate were in this category, and both suffered severe defoliation (Photo Set 5). Pomegranate is among the most tolerant fruit trees against soil salinity. Silverberry leaves have the water-adsorptive surface beneath their leaves (Photo Set 8b). Many deciduous trees, including Honey Locust, Black Locust, Chinese Pistache, Bur Oak, Red Oak, Mulberry, and Poplar are also prone to foliar salt damage (Photo Set 5). These species, except for Poplar are known to be tolerant to soil salinity. Salts are retained readily on these leaves, and are presumably adsorbed into the leaves (Photo Set 8c and 8d). Other salt-sensitive deciduous trees or shrubs include Osage Orange, Mimosa, and Ornamental Pears, all of which suffered extensive defoliation.

Arizona Cypress is among the most salt sensitive *Cupressus* (Photo Set 5). This specie has the leaf structure on which salts tend to accumulate between scales more so than on the scales (Photo Set 8f). It is possible that the wettability is higher between the scales than at the hump of the scales. Arborvitaes, both American and Oriental species, are also salt-sensitive, and have the leaf structure similar to Arizona Cypress, but it is tender and lacks hard scales.

Arizona Ash is becoming the most widely used shade trees in the survey areas. Ash leaves exhibited tip-burn and defoliation. Green Ash (*F. Pennsylvanica*) which adapted to cooler climates can not tolerate salts, whereas there were indications that Raywood Ash (*F. oxycarpa*) could be somewhat more tolerant than Arizona Ash.

Osage Orange (*Maclura pomifera*) is a hardy ornamental tree with softball size fruits resembling oranges with rough skin. This tree has dark green broad leaves which defoliate readily upon sprinkling of moderately saline water. Ornamental pears also have broad leaves which easily defoliate upon sprinkling.

Moderately Sensitive Species

The plants under this category suffered moderate salt damage when sprinkler-irrigated with water containing 1120 ppm of dissolved salts or 350 ppm of Na or Cl ions. *Salix species*, such as Globe Willow, Corkscrew Willow, and Weeping Willow (Photo Set 6) were found to be in this category. Leaf damage began with tip-burn which extend eventually to a large portion of the leaves. Globe Willow and Corkscrew Willow are more sensitive to this form of injury than Weeping Willow.

Japanese Pagoda Tree (*Sophora japonica*) is an ornamental tree. The leaves of this tree had extensive tip-burn, but with minimal defoliation. The lower branches of Chittamwood (*Bumelia lanuginosa*) defoliated when hit by sprinkler streams (Photo Set 6). Live Oaks sustained moderate damage. The young oak tree shown in Photo Set 6 is Southern Live Oak, and has sustained a considerable degree of defoliation.

Moderately Tolerant Species

The plants under this category suffered only slight or occasional leaf damage, when irrigated daily with the water containing 1120 ppm of dissolved salts, and include European Olive, Desert Willow (*Chilopsis linearis*), and some Junipers. Holly Oak (*Quercus ilex*), which is of Mediterranean origin, suffered only a slight leaf tip-burn and is the most salt tolerant *Quercus*. This oak is manageable in size and shape. However, it produces large quantities of acorns. Honey Mesquites (*P. grandulosa*) are included in this group, but can also be placed under the tolerant category. It is among a very few shade trees which can tolerate sprinkling with moderately saline water. Salt tolerance of *P. alba* is unknown.

Tolerant Species

The plants under this category have shown no recognizable salt damage when irrigated with the saline water containing 1120 ppm of dissolved salts at a Na concentration of 350 ppm, and include Italian Cypress, and Hollywood Juniper (Photo Set 7). These species have scaley leaves, and salts tend to accumulate on the ridge of the scales (Photo Set 7). Pittosporum, Oleanda, Ligustrum and Euonyomus, all of which have leathery leaves, are also among a few species which tolerated salts.

Pines widely planted in the survey area include Afghan (or Mondale), Aleppo, Japanese Black, Italian Stone, and Pinon. All of these species are tolerant to salts (Photo Set 7). Salts are deposited on the ridge of the needle-shaped leaves (Photo Set 8h), but not into the low-lying seams where stomata are present.

Although not listed on Table 3, we found several Century plants (*Agave americana*), Soap Tree Yucca (*Yucca elata*), Spanish Bayonet (*Yucca aloifolia*) growing in areas with sprinklers without any leaf injuries. Likewise, several species of ice plants or "finger plants" (*Dolospherma*, and *Drosanthemum*) were noted in planters sprinkled with water containing 1120 ppm of dissolved salts with no apparent injures.

Table 3. Plant injuries and defoliation caused by daily sprinkler irrigation in the order of increasing tolerance.

Highly Sensitive: (Significant Damage at 150 to 200 ppm of Na and Cl)		
Pecans	*Carya illinoensis*	Tip then margin burn
Cottonwood	*Populus fremontii*	Margin burn then defoliation
Sycamore	*Platanous acerifolia*	Margin then entire leafburn
Western Soapberry	*Sapindus drummondii*	Tip-burn
Sensitive (Severe damage at 350 ppm of Na or Cl)		
Silverberry	*Elaeagnus pungens*	Margin burn and defoliation
Pomegranate	*Punica granatum*	Margin burn and defoliation
Honey Locust	*Gleditsia triacanthos*	Tipburn, then defoliation
Black Locust	*Robina pseudoacacia*	Tipburn, then defoliation
Chinese Pistache	*Pistacia chinensis*	Tipburn, then defoliation
Shumard Red Oak	*Quercus shumardii*	Tipburn, then defoliation
Bur Oak	*Quercus macrocarpa*	Tipburn, then defoliation
Mulberry	*Morus alba*	Margin burn then defoliation
Poplar	*Populus sp.*	Margin burn then defoliation
Mimosa	*Acacla baileyana*	Tipburn then defoliation
Arizona Cypress	*Cupressus arizonica*	Defoliation
Arborvitae	*Thuja orientalis*	Defoliation
Osage Orange	*Maclura pomifera*	Defoliation
Ornamental Pears	*Pyrus communis*	Defoliation
Arizona, Ash	*Fraxinus velutina*	Tipburn then defoliation
Moderately Sensitive (Recognizable damage at 350 ppm of Na or Cl)		
Raywood Ash	*Fraxinus angustifolia*	Tipburn, then defoliation
Globe Willow	*Salix umbraculifera*	Tipburn then defoliation
Corkscrew Willow	*Salix tortuosa*	Tipburn then defoliation
Weeping Willow	*Salix babylonica*	Tipburn then defoliation
Japanese Pagoda Tree	*Sophora japonica*	Tipburn then defoliation
Live Oak	*Quercus virginiana*	Tipburn, then defoliation
Chittamwood	*Bumelia lanuginosa*	Tipburn, then defoliation
Vitex	*Vitex agnus-castus*	Tipburn, then defoliation
Moderately Tolerant (Slight or occasional damage at 350 ppm of Na or Cl)		
European Olive	*Olea europaea*	Tipburn
Desert Willow	*Chilopsis linearis*	Tipburn
Holly Oak	*Quercus ilex*	Slight to no injury
Alligator Juniper	*Juniperus cleppeana*	Slight to no injury
Juniper	*Juniperus chinensis*	Slight to no injury
Rocky Mt. Juniper	*Juniperus scopulorum*	Slight to no injury
Honey Mesquite	*Prosopis grandulosa*	Slight to no injury
Tolerant (No damage at 350 ppm of Na or Cl)		
Italian Cypress	*Cupressus sempervirens*	No injury
Hollywood Juniper	*Juniperus chinesis "Torulosa"*	No injury
Dwarf Pittosporum	*Pittosporum tobia, compacta*	No injury
Common Oleander	*Nerium oleander*	No injury
Ligustrum	*Ligustrum japonica*	No injury
Euonyomus	*Euonyomus japonica*	No injury
Japanese Black Pine	*Pinus thunbergiana*	No injury
Afghan Pine	*Pinus eldarica*	No injury
Aleppo Pine	*Pinus halepensis*	No injury
Italian Stone Pine	*Pinus pinea*	No injury

Photo Set 5. Sensitive Shrub or Tree Species


Elaeagnus pungens


Punica granatum


Gleditsia triacanthos


Pistacia chinensis


Populus fremontii

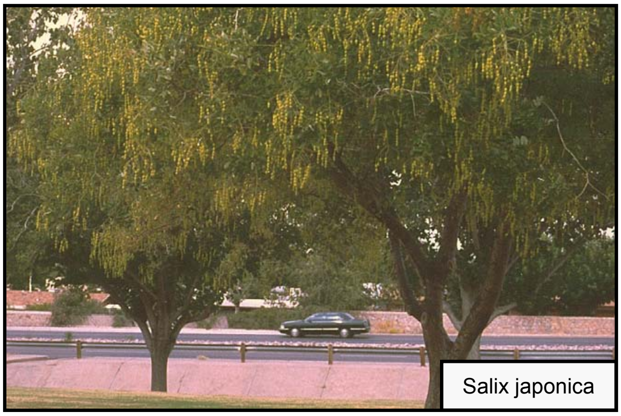

Morus alba


Cupressus arizonica

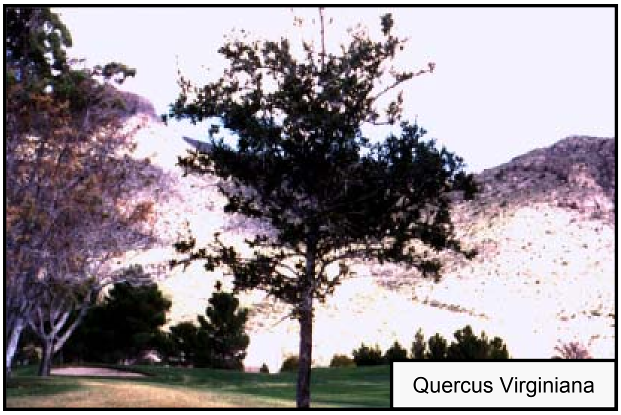

Thuja orientalis

Photo Set 6. Moderately Sensitive to Moderately Tolerant Species.

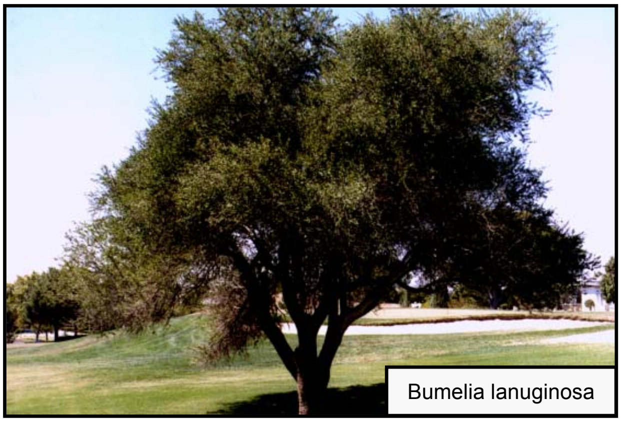

Salix babylonica


Salix japonica


Olea europea


Quercus Virginiana


Juniperus chinensis

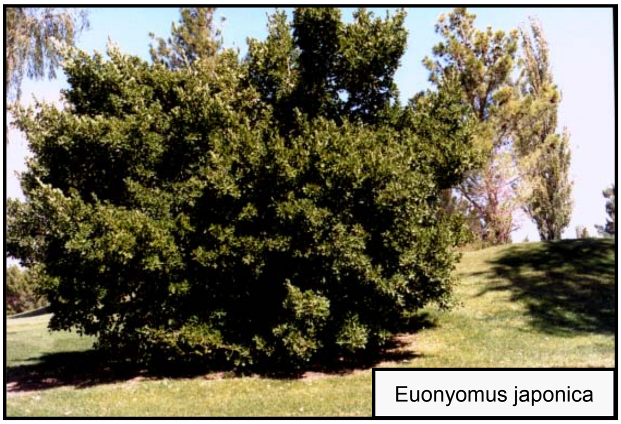

Bumelia lanuginosa


Juniper scopulorum

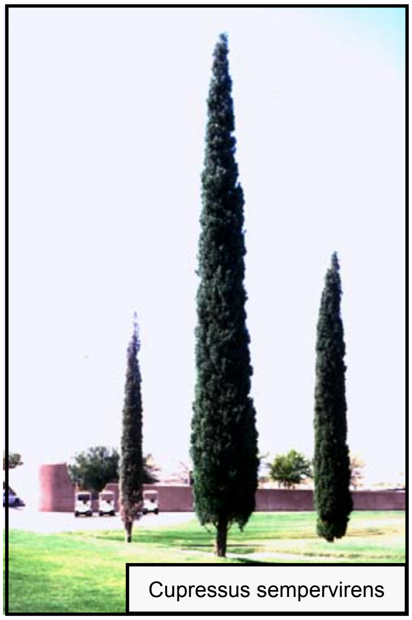

Prosopis glandulosa

Photo Set 7. Tolerant Species.


Pittosporum tobia

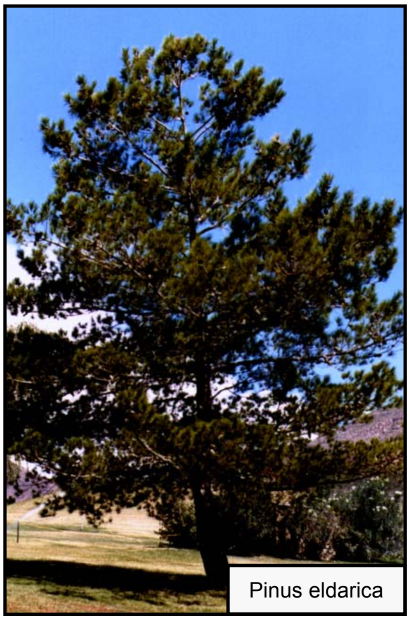

Euonyomus japonica


Prosopis grandulosa


Cupressus sempervirens

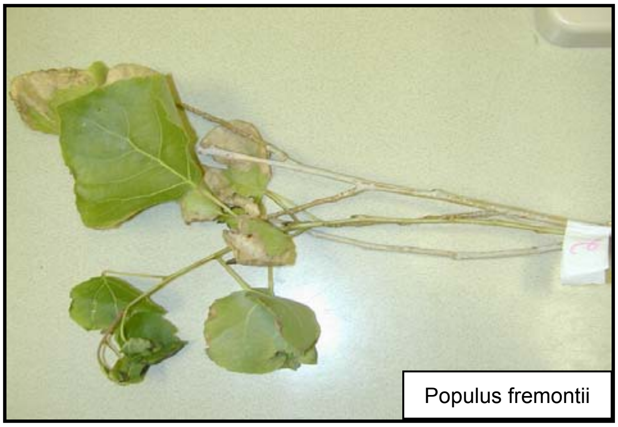

Juniper chinensis


Pinus thunbergii


Pinus eldarica


Pinus halepensis

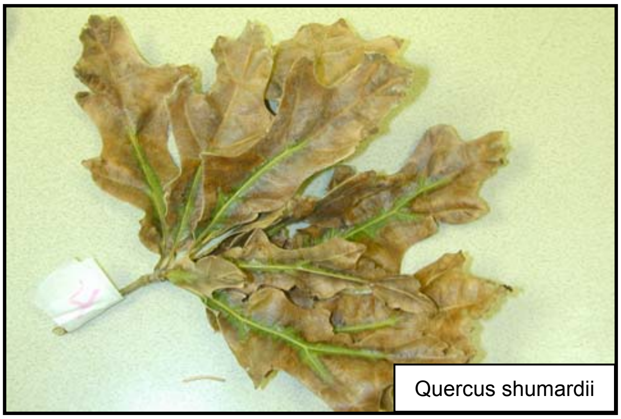
Photo Set 8. Leaf Injuries and Salt Accumulation on Leaves (40x).

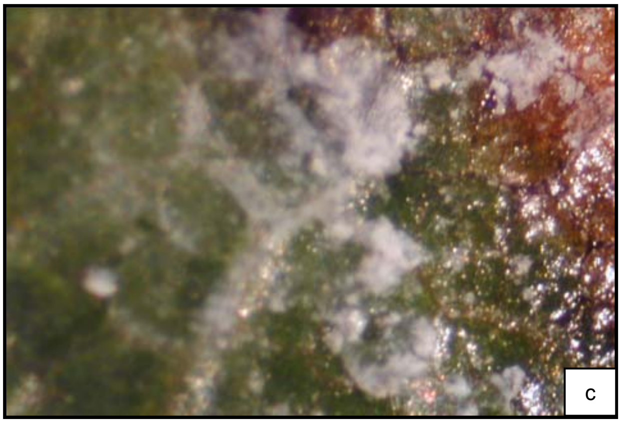

Populus fremontii


a


Elaeagnus pungens


b

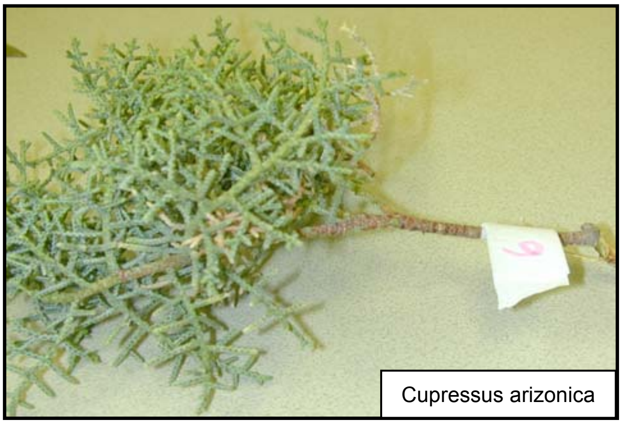

Quercus shumardii


c


Morus alba

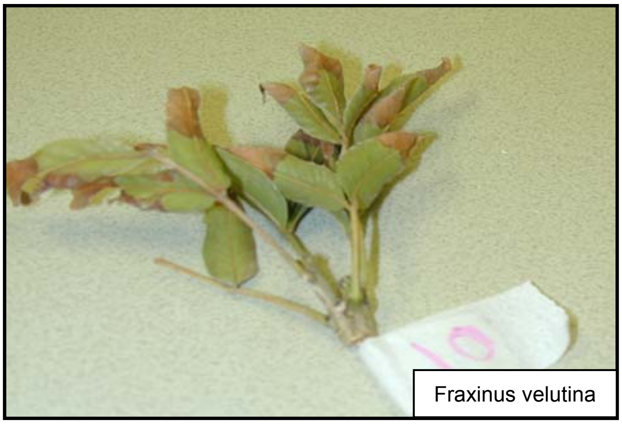

d

Photo Set 8. Leaf Injuries and Salt Accumulation (cont'd).

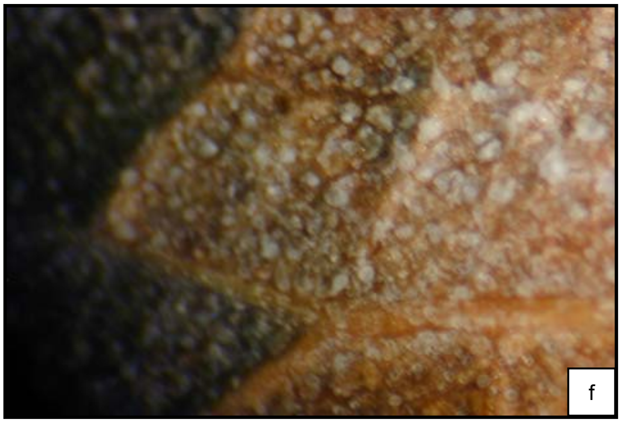


Cupressus arizonica

e



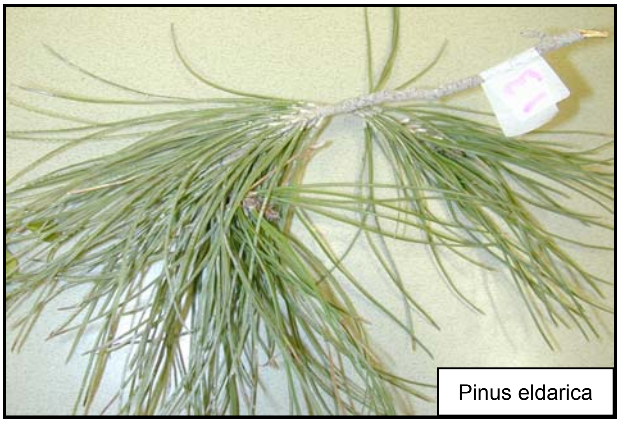
Fraxinus velutina



f

Juniperus chinensis

g



Pinus eldarica

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III Reducing Foliar Salt Damage of Landscape Plants

There are essentially three ways to reduce salt damage; i) change or modify the sprinkler system, ii) replace plants with salt tolerant types, and iii) modify landscape irrigation management practices. In some cases, lowering salinity of irrigation water may be possible, but it is usually too costly for irrigation uses. If feasible, the measures to modify water quality should be implemented during summer months when salt damage is most pronounced.

Modification of Sprinkler System

Leaf damage occurs as a result of salt adsorption from sprinkler-applied water. Therefore, one of the most effective methods of reducing foliar salt damage is to reduce direct sprinkling onto the leaves. In large trees, this objective can be achieved by using sprinklers with low trajectory or under-canopy sprinklers. The conversion to low-angle sprinklers or low pressures has been effective, but may require placement of additional laterals, if the overlap becomes inadequate. This option, however, may not work in shrubs or low profile trees. Repositioning or changing of sprinkler heads may be necessary in such cases.

The effect of sprinkler types on leaf damage is not well understood. A conventional wisdom is to use sprinklers which produce the least amount of mist and drifts. In fact, there are many indications that the use of large high pressure sprinklers operated around 100 psi is compounding the problem. Such a system is highly effective in irrigating large turf areas, but unfortunately also wet tree foliage. Some manufactures are producing sprinklers for windy areas, which should be tested for reducing salt damage. Spray type sprinklers which have relatively high application rates under low pressures (no more than 40 psi), usually cause less leaf damage as compared to high pressure sprinklers. Rotor heads which generate multiple sprinkler streams, some refer to as "finger streams" generate less mist than impact-types.

If possible, the irrigation zones for the areas with salt sensitive plants should be separated from the turf area which requires frequent irrigation. This provides an option to irrigate the tree or shrub areas less frequently or with other methods of irrigation. The sequence of valve opening/closure may be made to irrigate the areas with trees or shrubs at once or in a close consecutive sequence. Otherwise, a situation may result where trees will be sprayed once from one sprinkler, and at a later time, by another sprinkler from the other direction.

Plant Selection

The information presented in Parts I and II may help evaluate the suitability of various plants for sprinkler irrigation. Obviously, the tolerance to soil salinity must also be considered. When evaluating salt tolerance, note that the information presented is for daily sprinkler irrigation. If irrigation intervals can be extended, salt damage can be reduced as discussed in a later section.

A traditional landscape with turf and flowering annuals or perennials commonly uses frequent sprinkler irrigation, mainly to meet the cultural requirement of turf and shallow rooted flowers. In such cases, the use of saline water is not recommended. However, if the flowing plants can be substituted with salt tolerant shrubs, such as Boxwood, Hawthorne, Junipers, and Euonymous, foliar damage caused by salts can be reduced significantly.

The traditional landscape commonly used in golf course and parks involves irrigation of turf and trees with large high trajectory sprinklers. At present, selection for deciduous shade trees for saline water irrigation is highly limited, namely to Mesquite (*Prosopsis sp.)* and perhaps Holly Oak. Most broadleaf trees can not tolerate sprinkler application, and the landscape can be transformed to those which are dominated by pines or dead trees (Photo Set 9). Eucalyptus are also known to tolerate saline spray, but are seldom used in the upper desert area. There is a need to find additional shade tree species which can tolerate sprinkler- induced salt damage.

Salt tolerance of native or drought-tolerant plants have not been adequately studied. While some species such as Junipers and Mesquites were found to tolerate sprinkling, others resulted in unexpectedly severe damage, and include Texas Sage, Rosemary, Lantana, and Verbena. The leaves of Texas Sage and of Verbena are water-adsorptive. The leaflets of Rosemary are water-repellent, except for the joint to the stems, from which salts are likely to be adsorbed. Additional research is needed to establish their tolerance against sprinkling of saline water.

Modifying Management Practices

Controlled Experiment: A controlled experiment was conducted for evaluating effects of irrigation intervals, night vs day irrigation, and several anti-transpirants (which cause stomata closure) on foliar salt damage. The experimental setting was similar to the one shown in Part I, using water 2 of Table 1. Plants sprinkled with water 1 (potable water) were used as a reference. As of the earlier experiment, soil salinity was kept low using leaching irrigation with the potable water.

Results have shown that reducing irrigation from daily to every other day can reduce leaf damage in some plants, such as Cottonwood, Texas Sage, and Lantana, but not Liriope which is sensitive to soil salinity (Photo Set 10). In this experiment, the quantity of water sprinkled per application was kept the same for daily or every other day irrigation, thus presumably yielding the same level of salt washing from the leaves. The primary difference was the frequency of wetting which triggers salt adsorption into the leaves. Other studies (e.g., Maas et al., 1982) also indicate that salt damage decreases with decreasing frequency of irrigation.

Leaf damage was also found recognizably less in plants irrigated during night hours when stomata is closed (photo set 10) . Other studies also indicated that night irrigation reduces foliar salt damage (Busch and Turner, 1967). One of the chemicals tested made leaves less wettable, and has reduced salt injury. However, the leaves sprayed with anti-transpirants became yellow and many have eventually defoliated (Photo Set 10), presumably due to heat damage associated with stomata closure or leaf coating.

Field Observations: Leaf damage under field conditions was affected primarily by sprinkling patterns, plant types, and types of sprinklers used. If the plants are sensitive, sprinkler irrigation caused defoliation regardless of daily or every other day (bi-daily) irrigation when salinity of the irrigation water was as high as 1120 ppm. However, Mulberry and Ash trees seemed to have sustained generally less damage from bi-daily irrigation. Under these field conditions, the quantity of water sprinkled for bi-daily irrigation was twice that of the daily irrigation per application, which could have affected salt washing from the leaves. Foliar damage was also found to be significant in highly sensitive plants (listed in Table 3) when irrigated daily with low salt water (Water A of Table 1). However, foliar salt damage has been minimal or not recognizable at landscape areas sprinkler-irrigated every 2 to 3 days using Water 1 of Table 1, having a low Cl concentration.

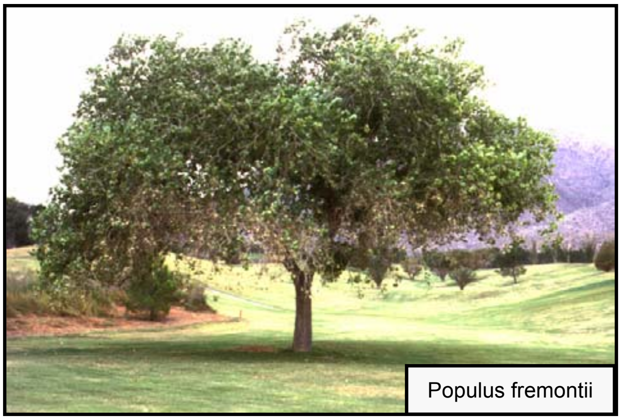
These observations indicate that increasing irrigation intervals and the quantity of irrigation per application may help reduce foliar salt damage, although it may not correct the problem. The landscape maintenance under sprinkler irrigation with moderately saline water should include ways to reduce irrigation frequency, which include measures to increase water infiltration, soil water holding capacity, and the use of drought tolerant plants. Once foliar damage appears, sprinkler modification should be evaluated without delay. Trees experiencing foliar salt damage and defoliation will progress to die-back of branches in a few years. In addition, soil salinity under the tree canopy tends to increase with water interception and evaporation from tree foliage.

Photo Set 9. Patterns of Tree Damage.


Sprinkler Damage
(Robina pseudoacacia)


Pinus halepensis


Fraxinus velutina


Populus fremontii


High Pressure Sprinkler


Low Angle Sprinkler on Morus alba


Landscape Transformation


Landscape Transformation

Photo Set 10. Irrigation Management on Salt Damage.

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About the Cover

The upper-photo is a microscope (200x) picture of halite (NaCl) crystals developed on the needle-like thenardite (Na_2SO_4) crystal, taken by Dr. Fares Howari, Research Associate. The lower photo shows defoliation of broadleaf trees hit by a sprinkler stream.

Unit Conversion Table

Length

1 inch = 2.54 cm
1 ft = 30.4 cm
1 mile = 5280 ft

Volume

1 gal = 4 qts.
= 3.785 liter
= 8.35 lb.

1 cf = 7.45 gals
1 Acre-inch = 27,152 gals = 3,630 cf
1 Acre-ft = 325,824 gals

Area

1 acre = 43.560 sq ft = 0.405 ha
1 ha = 2.47 acres
1 sq miles = 640 acres

Salinity

1 $dS\ m^{-1}$ = 1 mmho/cm = 635 - 680 ppm
1 ppm = 1 mg per liter

Sodicity

Sodium Adsorption Ratio
$= Na/\sqrt{(Ca+Mg)/2}$ in meq L^{-1}

Nutrient content

1 ppm = 2.7 lb/acre-ft = 8.1 lb/3 acre-ft
100 lb/acre = 2.3 lb/1000 sf

Equivalent weight

Na = 23 Ca = 20
Mg = 12.5

Temperature

C = (5/9) (F - 32)
F = (9/5C) + 32

Attachment I-2

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

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Contents

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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

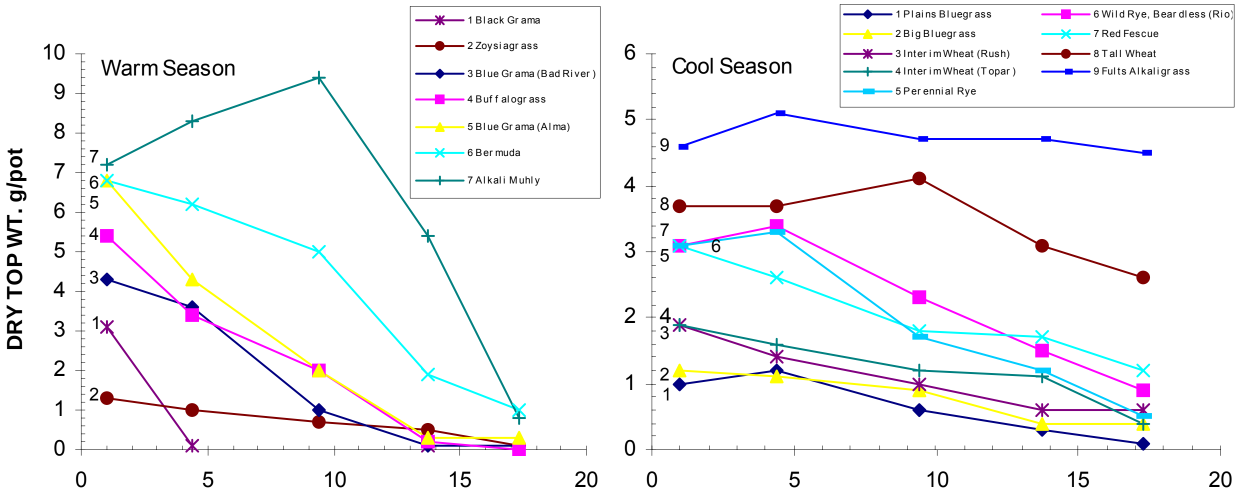

Fig. 1.1. Dry top weight of seven warm-season, and nine cool-season grass species as affected by salinity of irrigation water.

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.

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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.

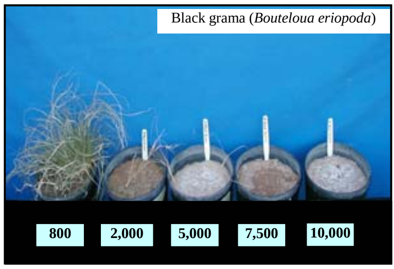
Warm-Season		Cool-Season	
Sensitive (<3 dS m^{-1})			
Black grama	*(Bouteloua eriopoda)*	Kentucky bluegrass	*(Poa pratensis)*
		Rough bluegrass	(*Poa trivialis*)
		Colonial bentgrass	(*Agrostis capillaris*)
Moderately Sensitive (3 to 6 dS m^{-1})			
Bahiagrass	*(Paspalum notatum)*	**Plains bluegrass**	(*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*)

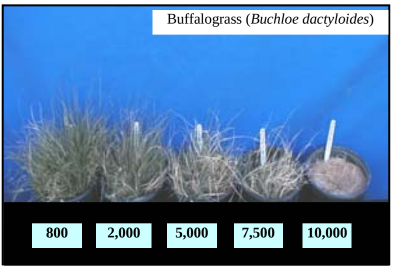
Species with bold print were used in this experiment.

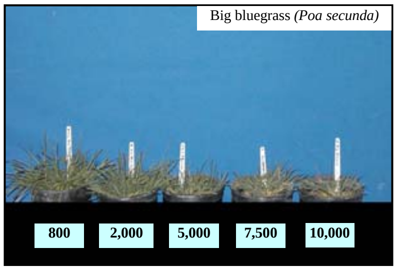
Photo Set 1. Turf and Ground Cover Grasses

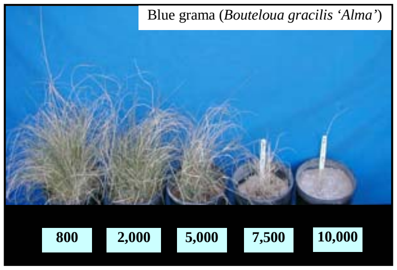
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Black grama	*(Bouteloua eriopoda)*	S	Big bluegrass	*(Poa secunda)*	MS
Blue grama	*(Bouteloua gracilis 'Alma')*	MS	Perennial ryegrass	*(Lolium perenne)*	MT
Buffalograss	*(Buchloe dactyloides)*	MS	Intermediate wheatgrass	*(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

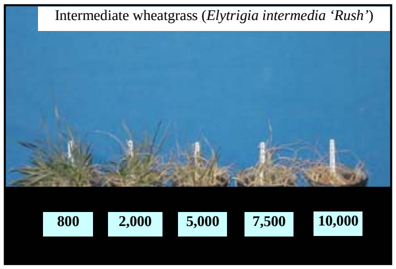
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant, HT: highly tolerant

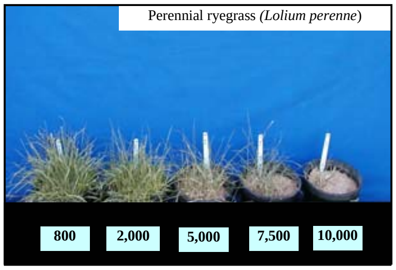

Black grama (*Bouteloua eriopoda*)

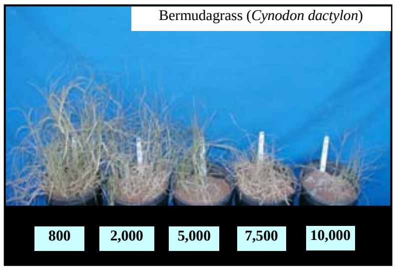

Buffalograss (*Buchloe dactyloides*)

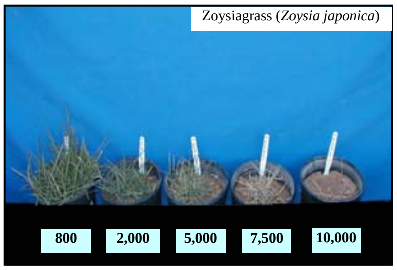

Big bluegrass *(Poa secunda)*

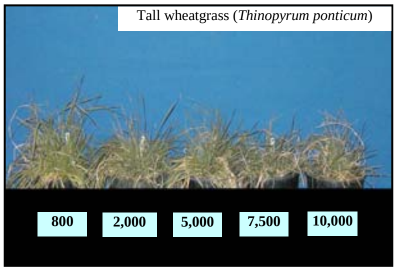

Blue grama (*Bouteloua gracilis 'Alma'*)

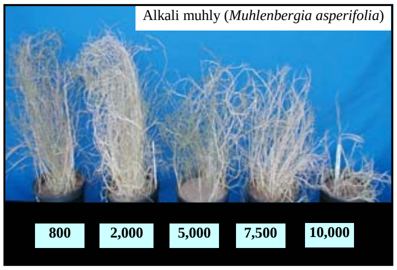

Intermediate wheatgrass (*Elytrigia intermedia 'Rush'*)

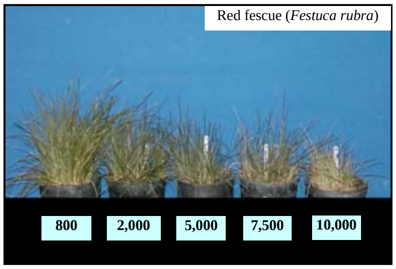

Perennial ryegrass *(Lolium perenne)*

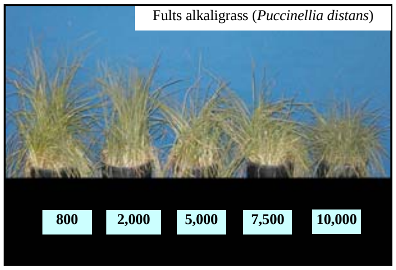

Bermudagrass (*Cynodon dactylon*)


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 grandiflora*) 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.

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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

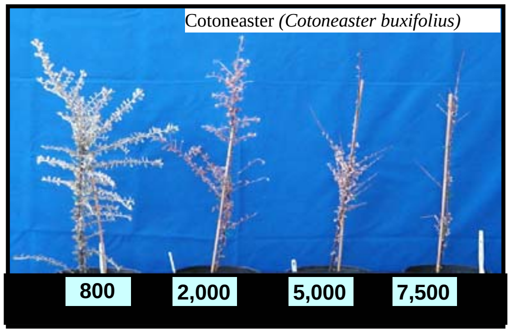
** Invasive, not recommended

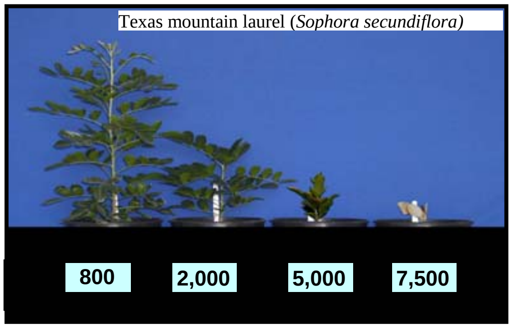
Species with bold print were used in this experiment.

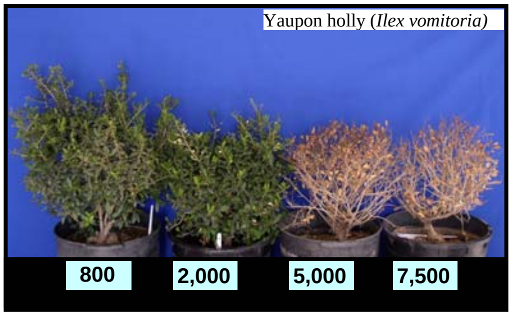
Photo Set 2A. Evergreens and Conifers (Shrubs)

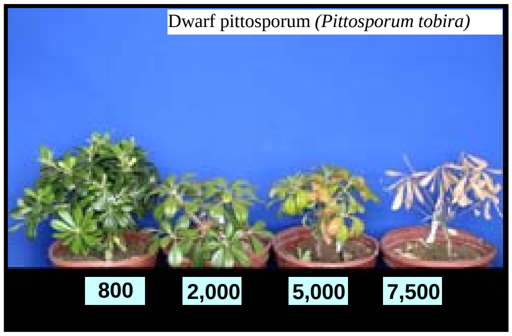
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Cotoneaster	*(Cotoneaster buxifolius*)	S	Rosemary	(*Rosmarinus officinalis*)	MS
Texas mountain laurel	(*Sophora secundiflora*)	S	Oleander	(*Nerium oleander*)	MT
Yaupon holly	(*Ilex vomitoria*)	MS	Texas sage	(*Leucophyllum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

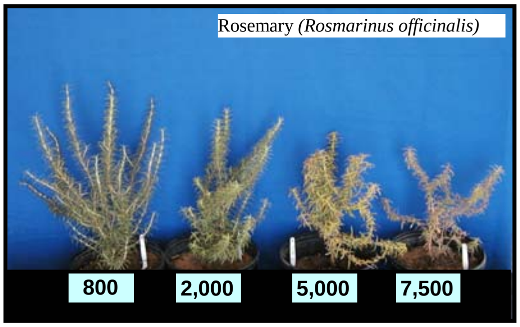
S: sensitive, MS: moderately sensitive, MT: moderately tolerant

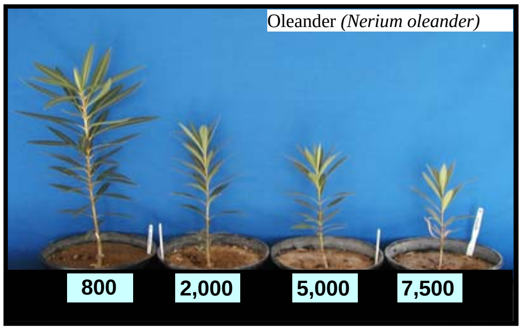

Cotoneaster *(Cotoneaster buxifolius)*

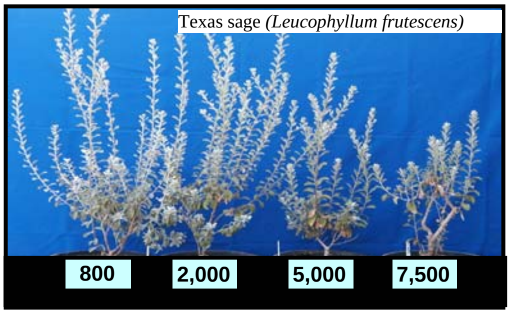

Texas mountain laurel (*Sophora secundiflora)*


Yaupon holly (*Ilex vomitoria)*


Dwarf pittosporum *(Pittosporum tobira)*


Rosemary *(Rosmarinus officinalis)*


Oleander *(Nerium oleander)*


Texas sage *(Leucophyllum frutescens)*

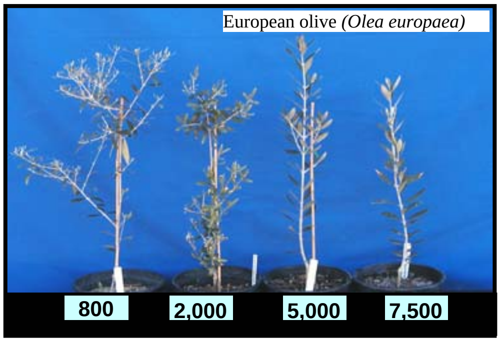
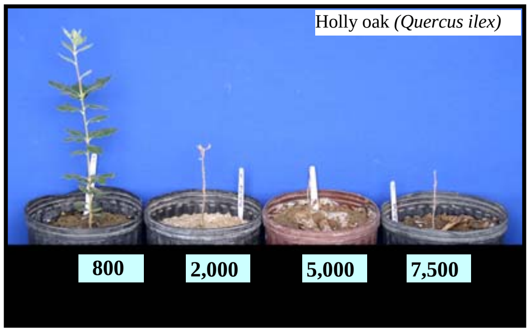

European olive *(Olea europaea)*

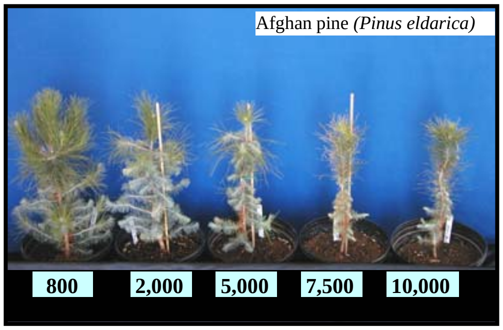
Photo Set 2B. Evergreens and Conifers (Trees)

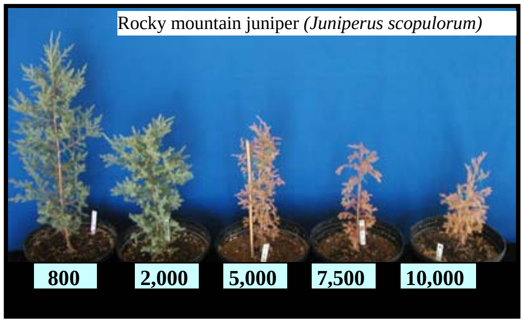
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classifcation
Holly oak	*(Quercus ilex)*	S	Afghan pine	*(Pinus eldarica)*	MT
Rocky mountain juniper	*(Juniperus scopulorum)*	MS	Piñon pine	*(Pinus edulis)*	MT
Eastern red cedar	*(Juniperus virginiana)*	MS	Italian cypress	*(Cupressus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

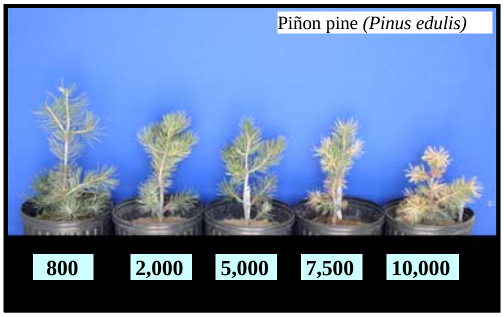
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, HT: highly tolerant

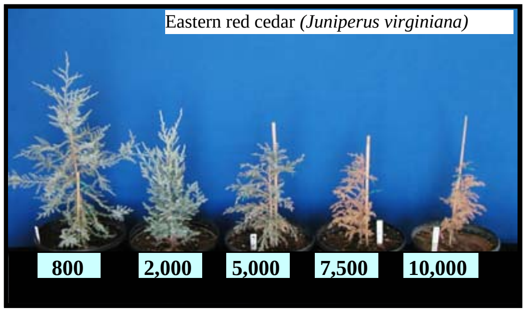
*Not shown

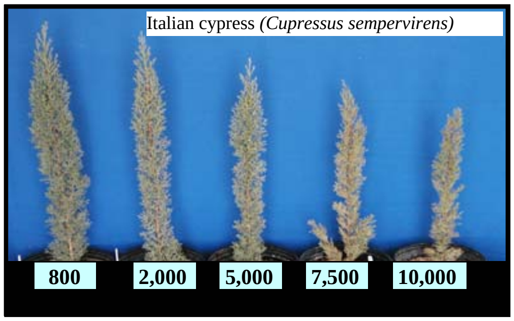

Holly oak *(Quercus ilex)*

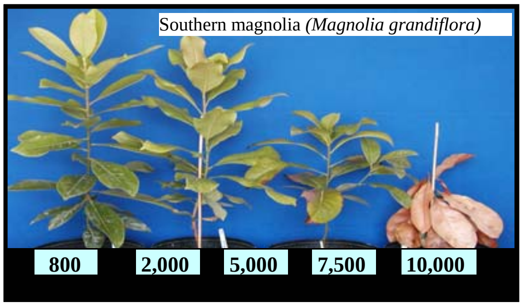

Afghan pine *(Pinus eldarica)*

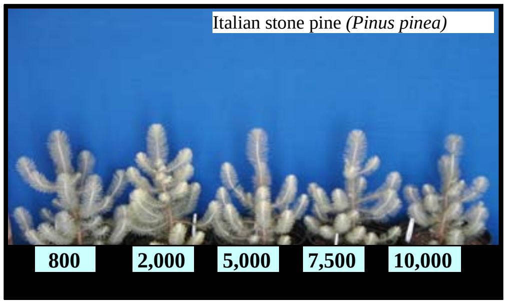

Rocky mountain juniper *(Juniperus scopulorum)*


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.

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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.

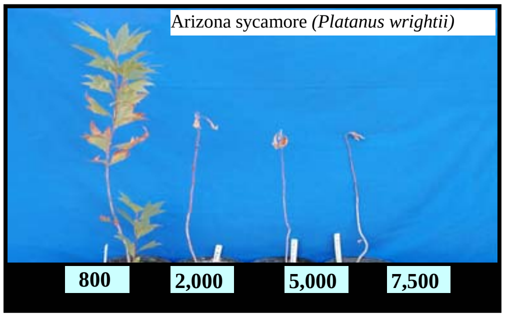
** Highly invasive, not recommended

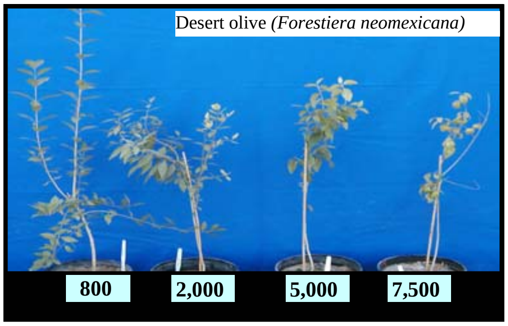
Species with bold print were used in this experiment.

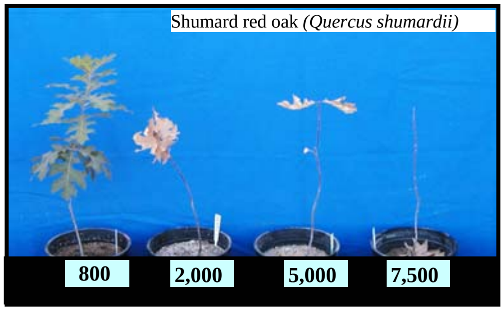
Photo Set 3. Deciduous Tree Seedlings

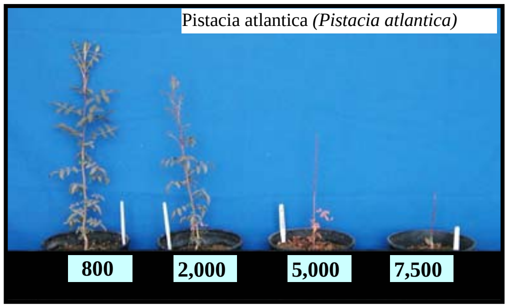
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Arizona sycamore	(*Platanus wrightii*)	S	Desert olive	(*Forestiera neomexicana*)	MS
Shumard red oak	(*Quercus shumardii*)	S	Pistacia atlantica	(*Pistacia atlantica*)	MS
Japanese pagoda	(*Sophora japonica*)	S	Black gum	(*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)*

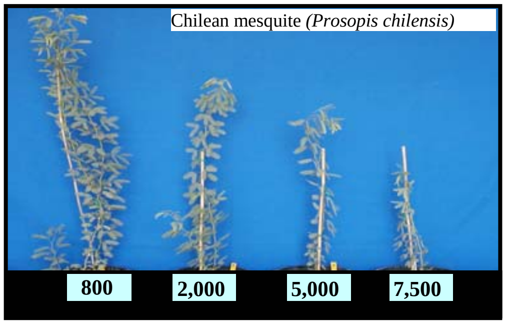

Shumard red oak *(Quercus shumardii)*


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.

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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.

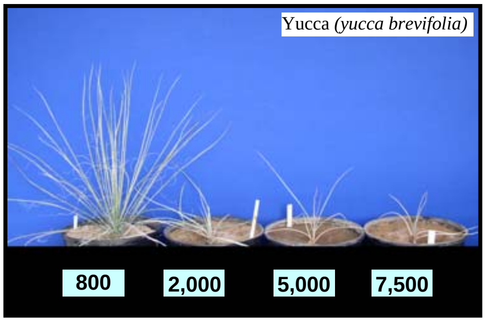
Shrubs/Agave		**Trees**	
Sensitive (<3 dS m^{-1})			
Yucca	*(yucca brevifolia)*	Western redbud	*(Cercis occidentalis)*
Bird of paradise	*(Caesalpinia mexicana)*	**Arizona sycamore**	*(Platanus wrightii)*
Texas mountain laurel	*(Sophora secundiflora)*	**Desert willow**	*(Chilopsis linearis)*
Guayule	*(Parthenium 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)*

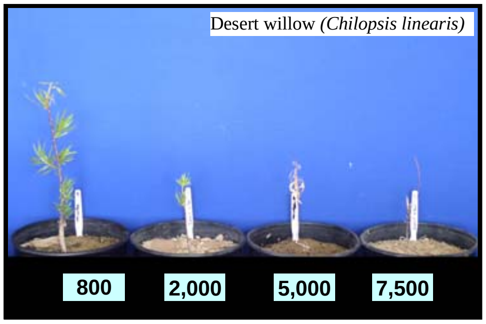
Species with bold print were used in this experiment.

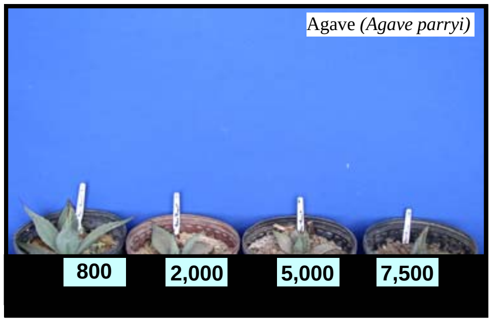
Photo Set 4. Native Plants

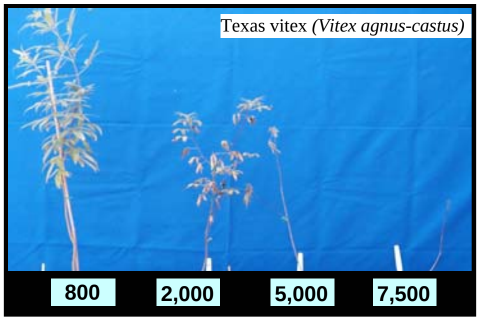
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Yucca	(*yucca brevifolia*)	S	Desert willow	(*Chilopsis linearis*)	S
Agave	(*Agave parryi*)	MT	Texas vitex	(*Vitex agnus-castus*)	MS
Bird of paradise	(*Caesalpinia mexicana*)	S	Desert olive	(*Forestiera neomexicana*)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

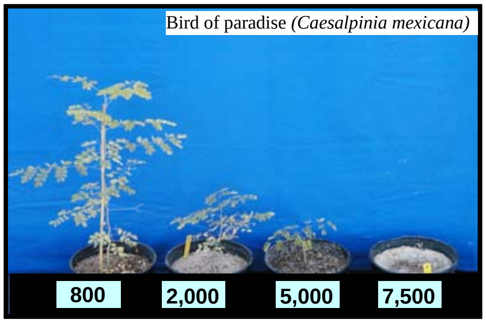
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant, HT: highly tolerant

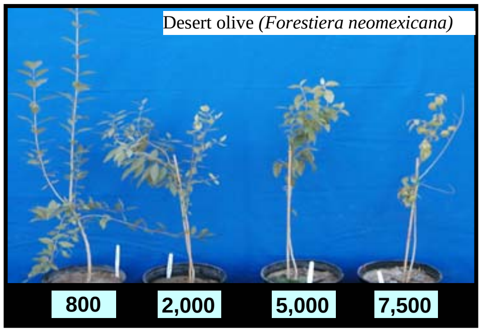


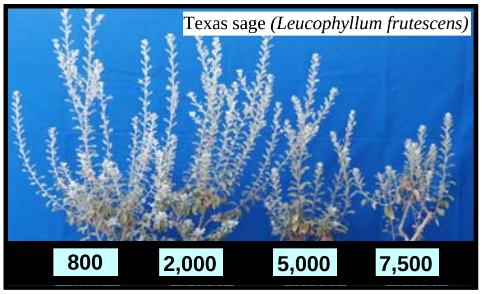


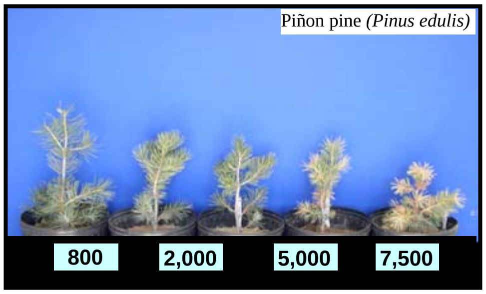












5. Salt Tolerance of Palm Species

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.

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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

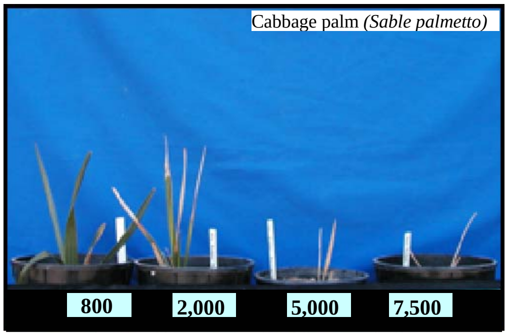
[1]- Projected leaf injury at the upper limit of applicable salinity

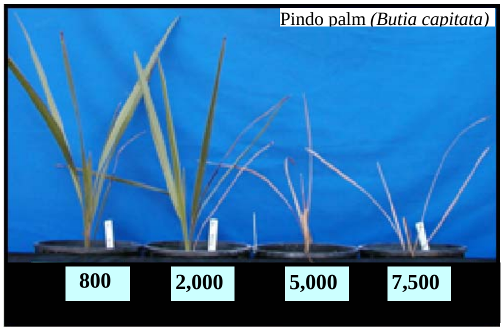
Species with bold print were used in this experiment.

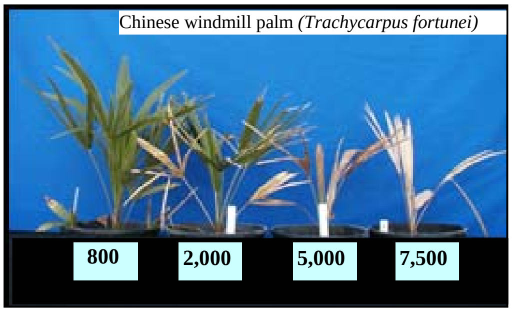
Photo Set 5. Palm Species

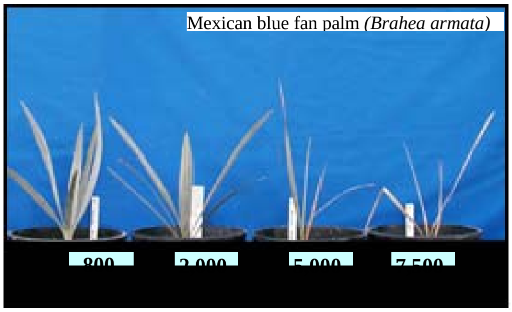
Common Name	Scientific Name	Classifcation	Common Name	Scientific Name	Classification
Cabbage palm	(*Sable palmetto*)	S	Pindo palm	(*Butia capitata*)	S
Chinese windmill palm	(*Trachycarpus fortunei*)	S	Brazilian fan palm	(*Trithrinax brasiliensis)*	MS
Mexican blue fan palm	(*Brahea armata*)	MS	Dwarf blue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

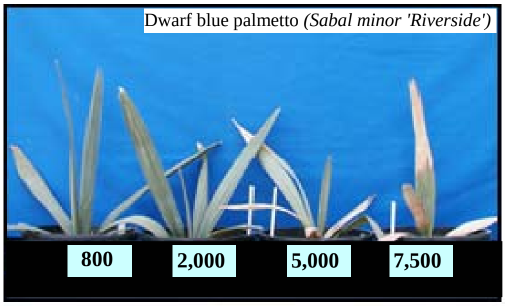
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant

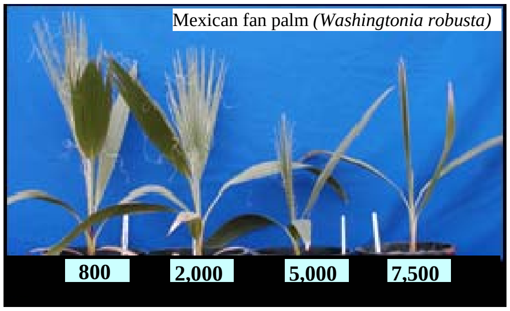


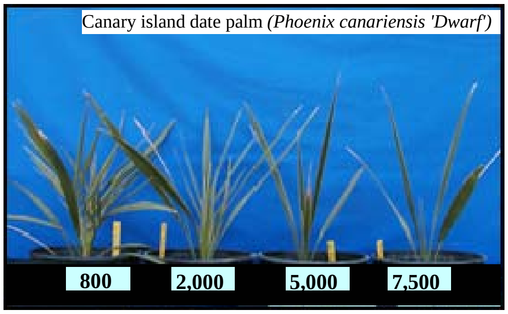












6. Vines, Ground Cover, and Bedding Plants

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.

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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.

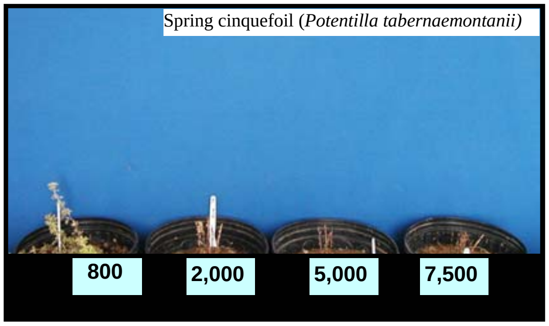
Vines & Bedding Plants		**Ground Cover Plants**	
Sensitive (<3 dS m^{-1})			
Virginia creeper	*(Parthenocissus quinquefolia)*	**Vinca**	*(Vinca major)*
English ivy	*(Hedera helix)*	**Asian jasmine**	*(Trachelospermum asiaticum)*
Star jasmine	*(Trachelospermum jasminoides)*	**Carolina jasmine**	*(Gelsemium 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)*

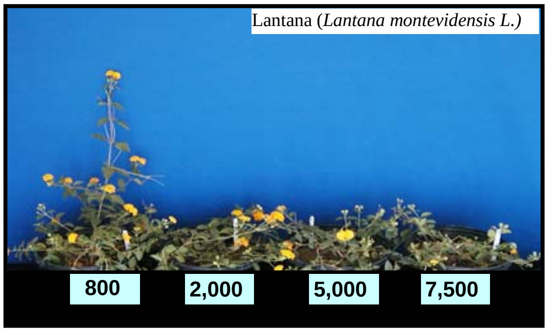
* Subject to freeze damage without protection or used as annual.
Species with bold print were used in this experiment.

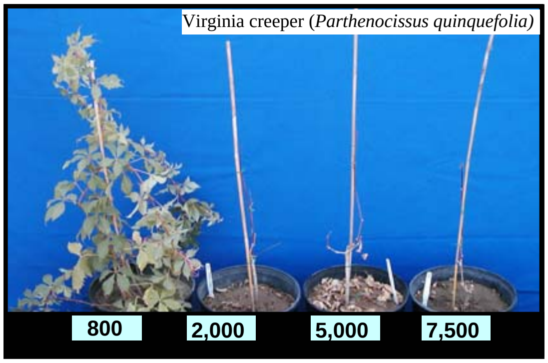
Photo Set 6. Vines and Ground Cover Plants

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

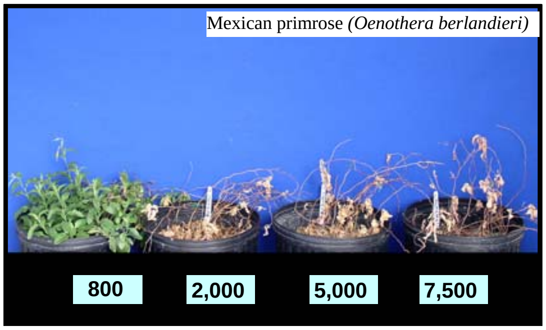
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: Tolerant

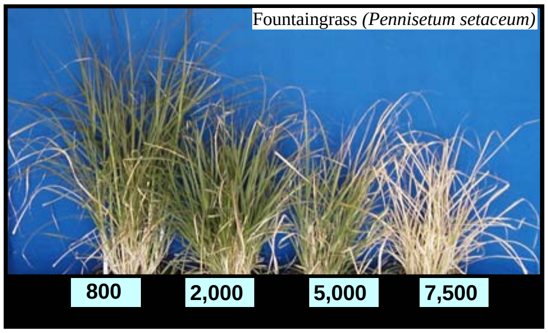

Spring cinquefoil (*Potentilla tabernaemontanii)*

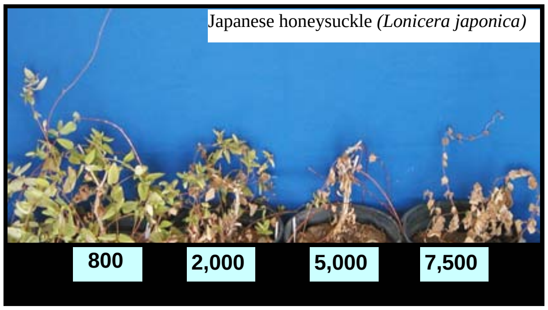

Lantana (*Lantana montevidensis L.)*

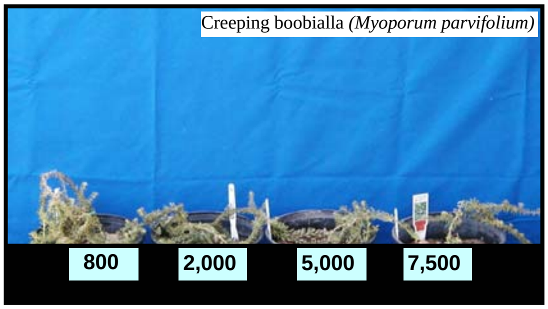

Virginia creeper (*Parthenocissus quinquefolia)*


Spreading acacia (*Acacia redolens)*


Mexican primrose *(Oenothera berlandieri)*


Fountaingrass *(Pennisetum setaceum)*


Japanese honeysuckle *(Lonicera japonica)*


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.

Attachment I-3

Photo Guide: Landscape Plant Response to Salinity

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Texas A&M University Research and Extension Center at El Paso
David Ornelas, El Paso Water Utilities

Synopsis

With increasing costs of securing potable water, there is a need to utilize reclaimed or saline nonpotable water for irrigating landscapes. The photo sets shown here were developed from research work performed by Texas A&M University Research and Extension Center at El Paso during the period of 2001 through 2003. The objective of the research was to evaluate salt tolerance of landscape plants common to the Southwest. Photo sets included in this publication are partial results of the research, and may be useful to landscape planners, water managers, and landscape maintenance professionals. A complete list of plant salt tolerance is available in a companion publication entitled “Landscape Plant Lists for Salt Tolerance Assessment.”

Contents

How this Document was Developed

Plant Responses to Soil Salinity (Photo Series A): The experiment to evaluate plant tolerance to soil salinity was conducted in a greenhouse. One gallon size plants were transplanted to 3 gallon pots containing loamy sand, and were irrigated with solutions of five levels of salinity; 800, 2000, 5000, 7500 and 10000 ppm for 6 months. The electrical conductivity (EC) of these solutions was, respectively, 1.2, 4.4, 9.4, 13.7 and 17 dS m^{-1}. About 80% of the salts in these solutions were in the form of NaCl as shown in Appendix. About 1/3 of the solutions applied was allowed to drain so as to avoid salt accumulation. Under this irrigation regime, salinity of the soil saturation extract (an official method of determining soil salinity) is approximately equal to the salinity of irrigation water used. Plant growth and leaf injury were recorded photographically.

Results were analyzed to determine the soil salinity which causes a 50% growth reduction or foliar salt damage on at least 25% of the leaves. In the case of turf and ground cover grasses, a 25% reduction in growth, instead of the conventional 50% reduction was used. This reflects field observation that growth of turf in high traffic area is critically important. Tested plant species were then classified into five categories, following the US Salinity Laboratory classification: sensitive (0 – 3 dS m^{-1}), moderately sensitive (3 – 6 dS m^{-1}), moderately tolerant (6 – 8 dS m^{-1}), tolerant (8 – 10 dS m^{-1}) and highly tolerant (>10 dS m^{-1}). The EC values shown in salt tolerance classification must be determined in the soil saturation extract made from soil samples collected from the main root zone.

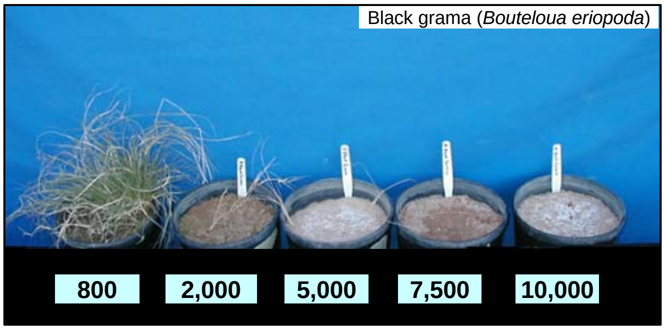
Tolerance against Saline Water Sprinkling (Photo Series B): Test plants (1 gallon size) were transplanted into 3 gallon pots using a highly permeable commercial soil mix. They were taken outdoors in March, and irrigated every other day with overhead sprinklers for 30 min which delivered 1/2 inch of water. Irrigation continued until the end of September for 6 months. The experiment used three saline water sources; tap water (800 ppm or 1.1 dS m^{-1}), a blend of tap water and well water (1260 ppm or 2.0 dS m^{-1}), and saline well water (1850 ppm or 3.0 dS m^{-1}). The corresponding concentrations of Na in these water sources were, respectively, 145, 280, and 425 ppm, and that of Cl was 140, 360 and 590 ppm (Appendix). As soon as sprinkler irrigation was completed, all pots were flushed with tap water.

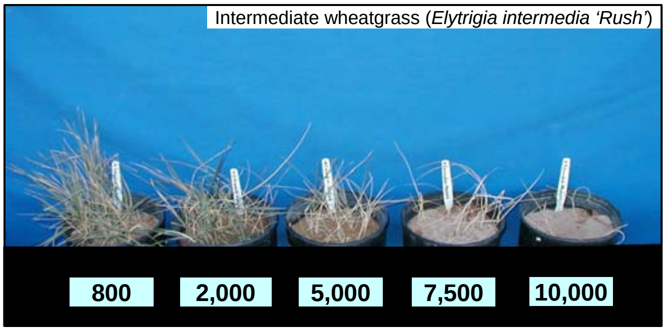
Plant responses to the sprinkler irrigation were evaluated by measuring shoot growth and leaf injuries. Salinity of irrigation water and corresponding Na and Cl concentrations which caused a 25% reduction in shoot growth or leaf injury over 25% of the leaves were determined. Because of the lack of the standard method of classifying plants for spray resistance, we used the following tentative classification: sensitive (< 1 dS m^{-1}, Na and Cl < 150 ppm), moderately sensitive (1 – 2 dS m^{-1}, Na < 280 ppm, Cl < 360 ppm), moderately tolerant (2 – 3 dS m^{-1}, Na < 425 ppm, Cl < 590 ppm), and tolerant (> 3 dS m^{-1}). Additional observations of plant response to sprinkler irrigation (Photo Series B – 4 through B – 7) were made at a golf course where irrigation water used had a dissolved salt content of 1120 ppm (2.1 dS m^{-1}, Na = 350 ppm, Cl = 325 ppm).

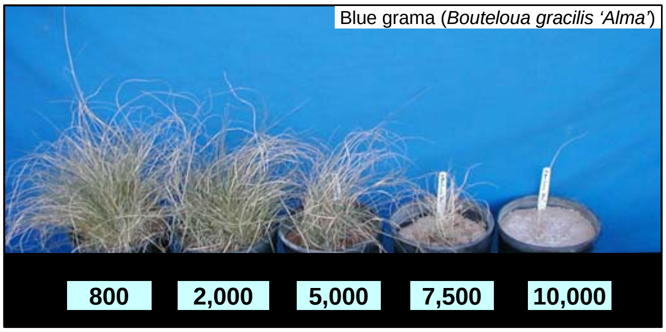
Photo Set A-1. Turf and Ground Cover Grasses (Warm Season Species)

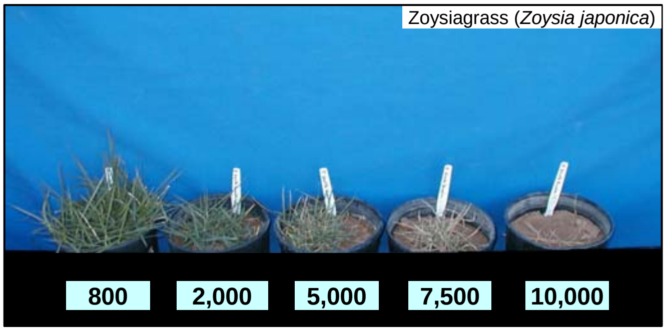
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Black grama	(*Bouteloua eriopoda*)	S	Intermediate wheatgrass	(*Elytrigia intermedia 'Rush'*)	MT
Blue grama	(*Bouteloua gracilis 'Alma'*)	MS	Zoysiagrass	(*Zoysia japonica*)	MT
Buffalograss	(*Buchloe dactyloides*)	MS	Bermudagrass	(*Cynodon dactylon*)	T
Blue grama	(*Bouteloua gracilis 'Bad River'*)	MS	Alkali muhly	(*Muhlenbergia asperifolia*)	HT

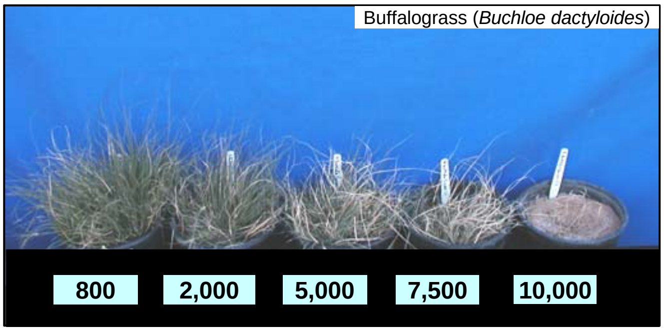
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant, HT: highly tolerant

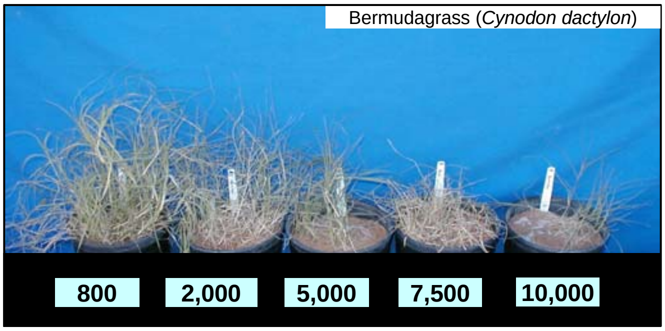

Black grama (*Bouteloua eriopoda*)

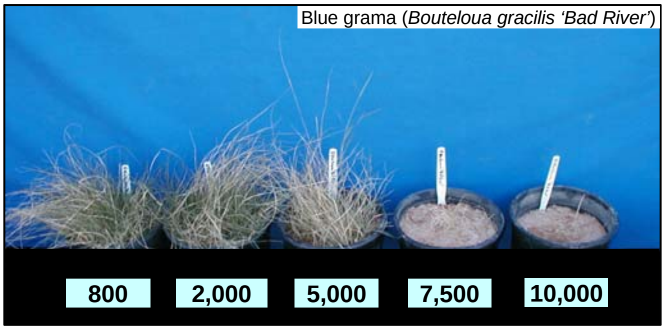

Intermediate wheatgrass (*Elytrigia intermedia 'Rush'*)


Blue grama (*Bouteloua gracilis 'Alma'*)


Zoysiagrass (*Zoysia japonica*)


Buffalograss (*Buchloe dactyloides*)


Bermudagrass (*Cynodon dactylon*)


Blue grama (*Bouteloua gracilis 'Bad River'*)

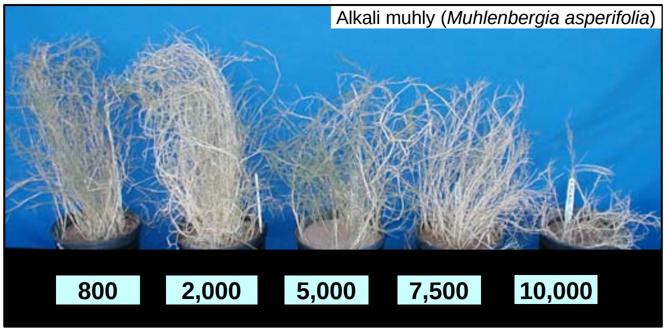
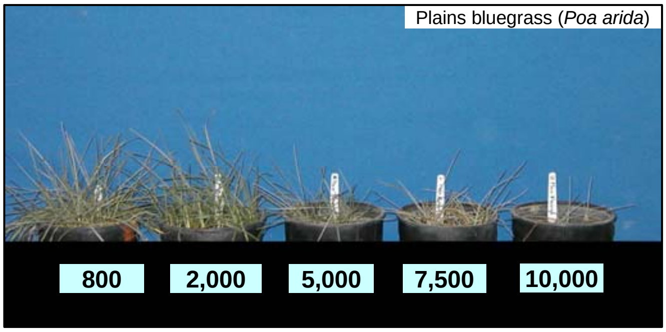
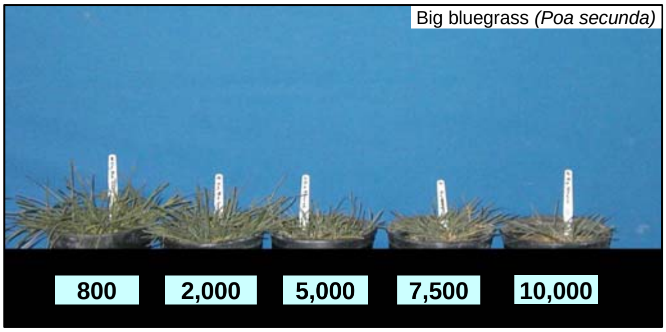

Alkali muhly (*Muhlenbergia asperifolia*)

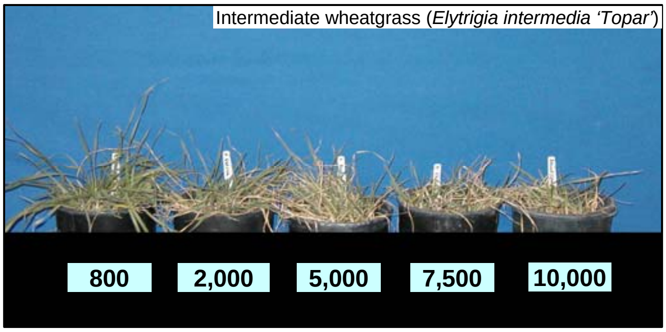
Photo Set A-1. Turf and Ground Cover Grasses (Cool Season Species)

Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Plains bluegrass	(*Poa arida*)	MS	Ryegrass	(*Secale cereale L.*)	MT
Big bluegrass	(*Poa secunda*)	MS	Beardless wild rye	(Le*ymus triticoides 'Rio'*)	T
Intermediate wheatgrass	(*Elytrigia intermedia ‘Topar'*)	MT	Tall wheatgrass	(*Thinopyrum ponticum*)	HT
Red fescue	(*Festuca rubra*)	MT	Fults alkaligrass	(*Puccinellia distans*)	HT

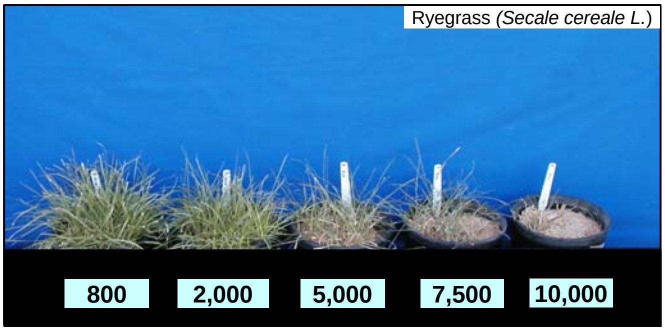
MS: moderately sensitive, MT: moderately tolerant, T: tolerant, HT: highly tolerant

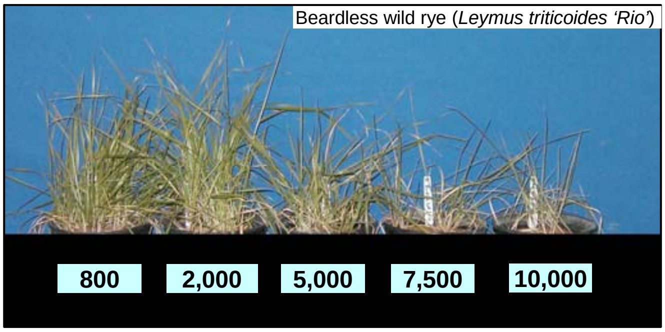

Plains bluegrass (*Poa arida*)

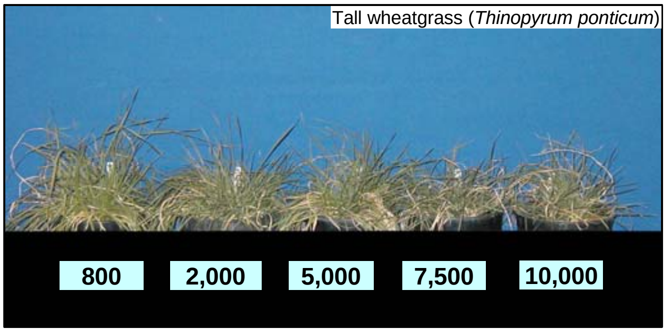

Big bluegrass *(Poa secunda)*


Intermediate wheatgrass (*Elytrigia intermedia ‘Topar’*)


Red fescue (*Festuca rubra*)


Ryegrass *(Secale cereale L.)*


Beardless wild rye (*Leymus triticoides ‘Rio’*)


Tall wheatgrass (*Thinopyrum ponticum*)

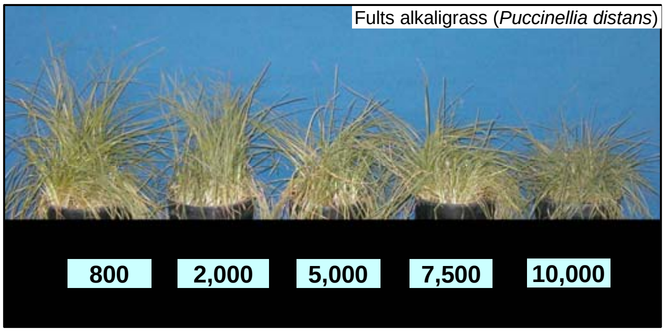
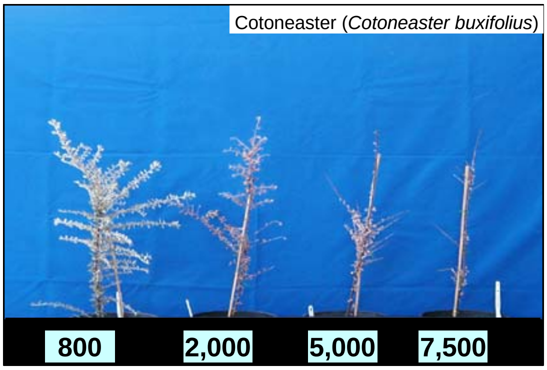
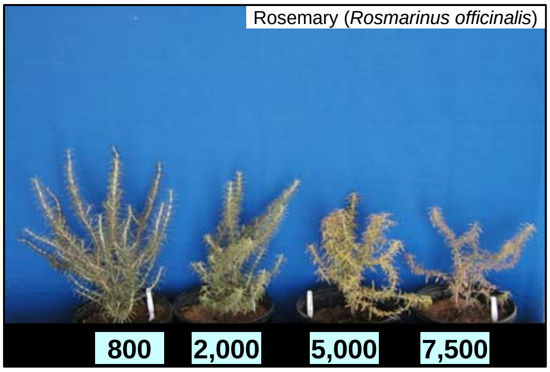

Fults alkaligrass (*Puccinellia distans*)

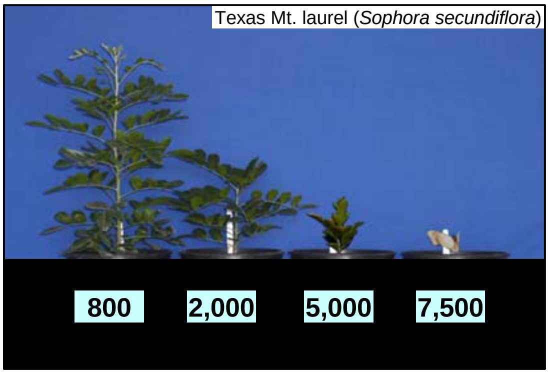
Photo Set A-2. Evergreens and Conifers (Shrubs)

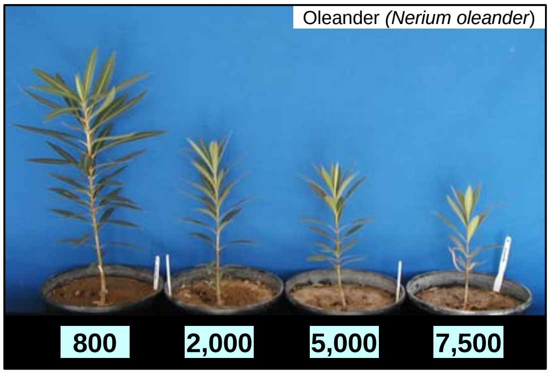
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Cotoneaster	(*Cotoneaster buxifolius*)	S	Rosemary	(*Rosmarinus officinalis*)	MS
Texas Mt. laurel	(*Sophora secundiflora*)	S	Oleander	(*Nerium oleander*)	MT
Yaupon holly	(*Ilex vomitoria*)	MS	Texas sage	(*Leucophyllum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

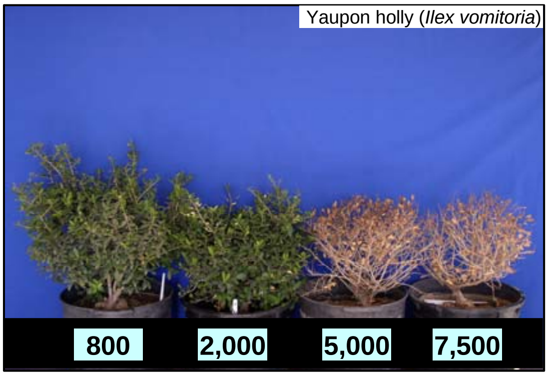
S: sensitive, MS: moderately sensitive, MT: moderately tolerant

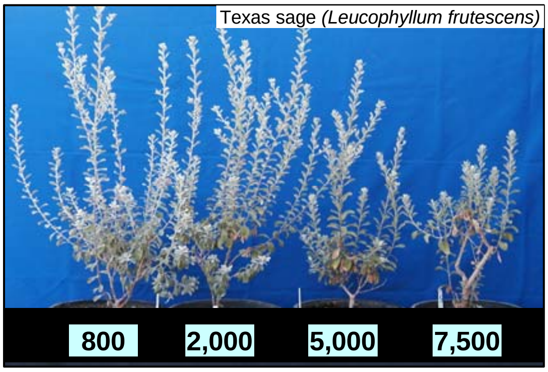

Cotoneaster (*Cotoneaster buxifolius*)

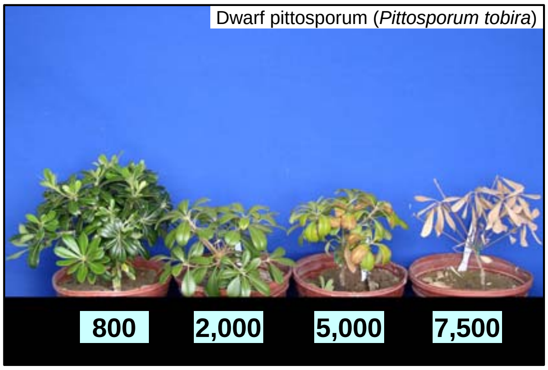

Rosemary (*Rosmarinus officinalis*)


Texas Mt. laurel (*Sophora secundiflora*)


Oleander (*Nerium oleander*)


Yaupon holly (*Ilex vomitoria*)


Texas sage (*Leucophyllum frutescens*)


Dwarf pittosporum (*Pittosporum tobira*)

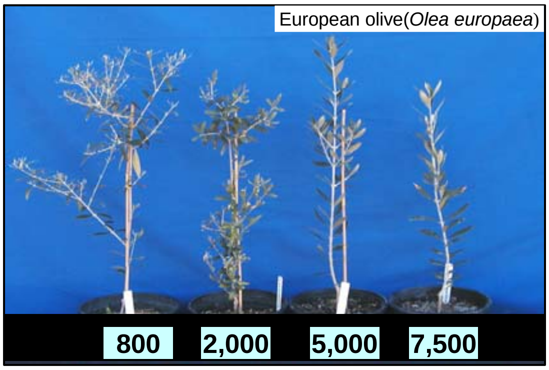
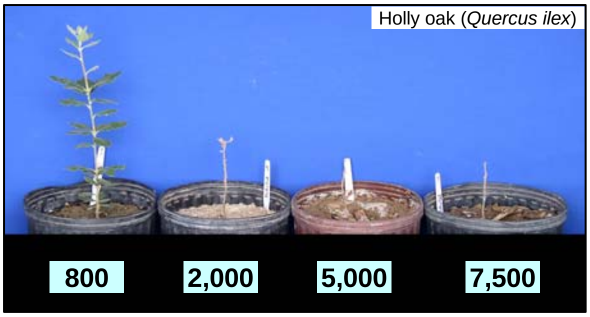

European olive(*Olea europaea*)

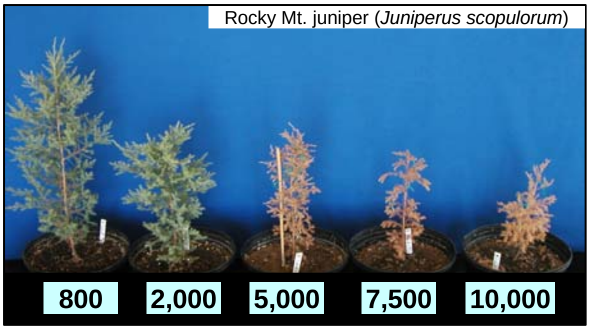
Photo Set A-2. Evergreens and Conifers (Trees)

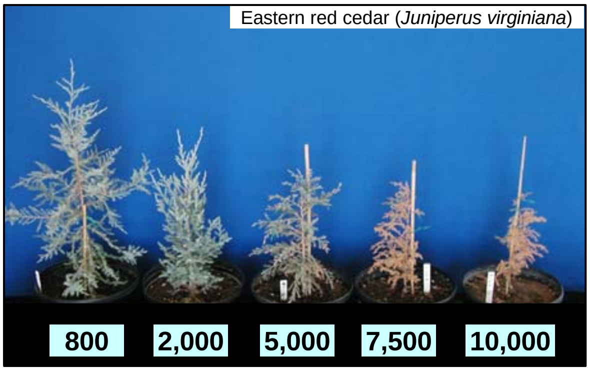
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classifcation
Holly oak	(*Quercus ilex*)	S	Afghan pine	(*Pinus eldarica*)	MT
Rocky Mt. juniper	(*Juniperus scopulorum*)	MS	Piñon pine	(*Pinus edulis*)	MT
Eastern red cedar	(*Juniperus virginiana*)	MS	Italian cypress	(*Cupressus sempervirens*)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

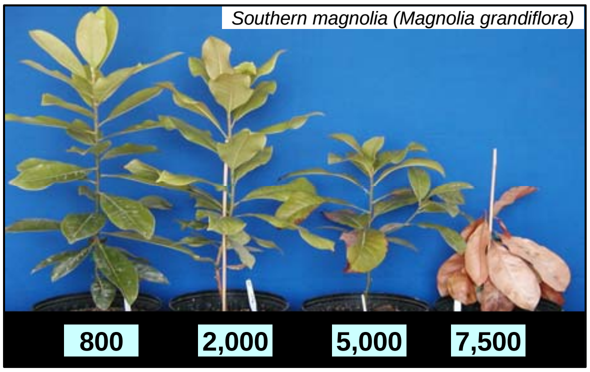
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, HT: highly tolerant

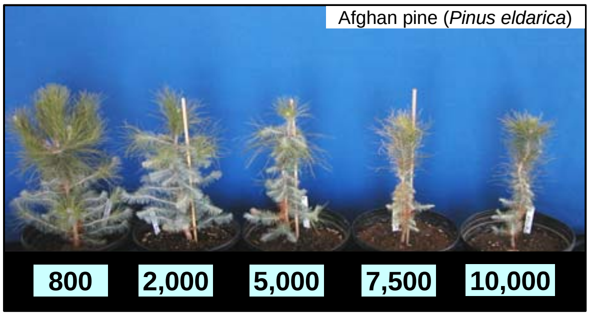
*Not shown

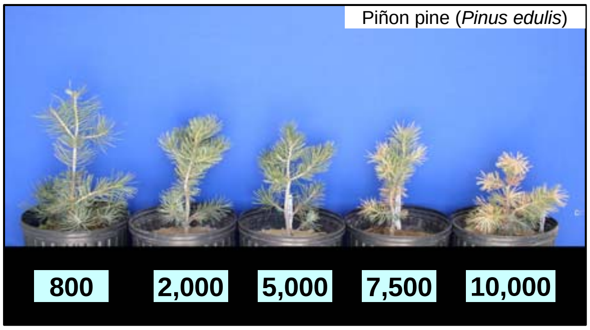

Holly oak (*Quercus ilex*)

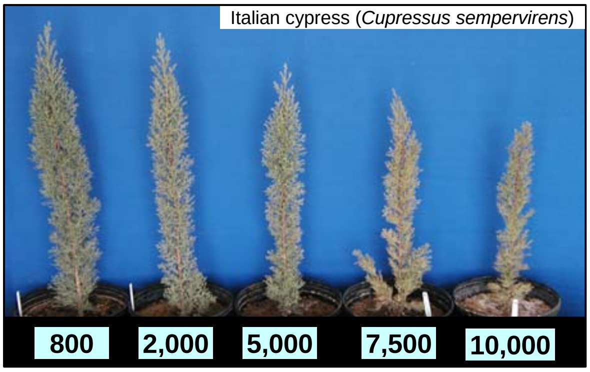

Rocky Mt. juniper (*Juniperus scopulorum*)


Eastern red cedar (*Juniperus virginiana*)


Southern magnolia (Magnolia grandiflora)


Afghan pine (*Pinus eldarica*)


Piñon pine (*Pinus edulis*)


Italian cypress (*Cupressus sempervirens*)

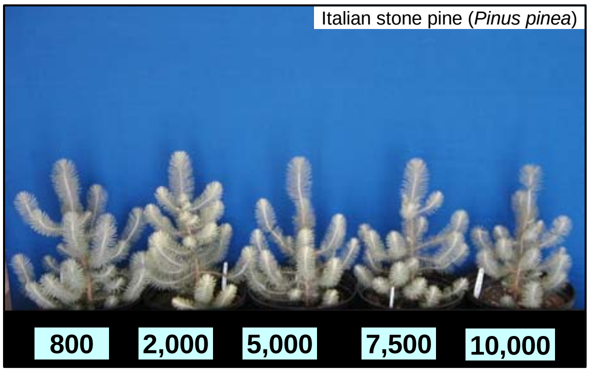
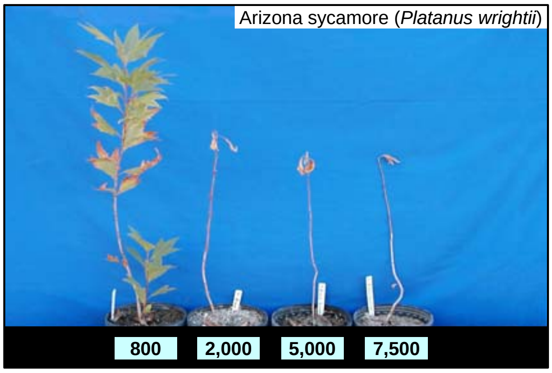
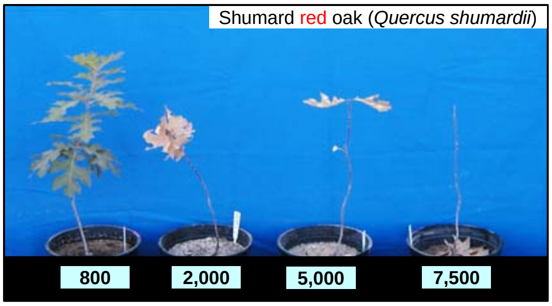

Italian stone pine (*Pinus pinea*)

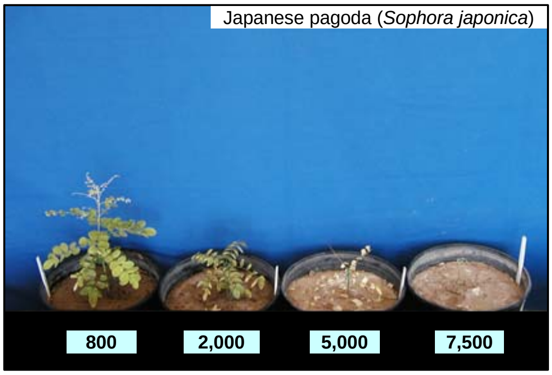
Photo Set A-3. Deciduous Trees

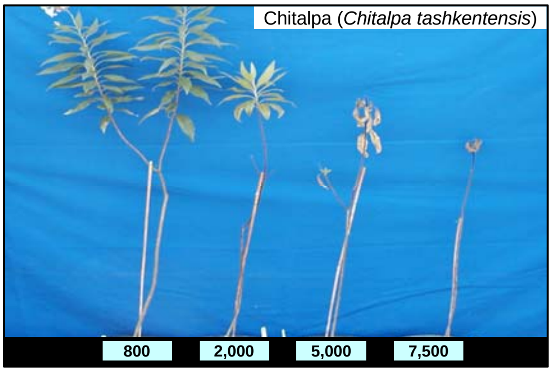
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Arizona sycamore	(*Platanus wrightii*)	S	Desert olive	(*Forestiera neomexicana*)	MS
Shumard red oak	(*Quercus shumardii*)	S	Pistacia atlantica	(*Pistacia atlantica*)	MS
Japanese pagoda	(*Sophora japonica*)	S	Black gum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

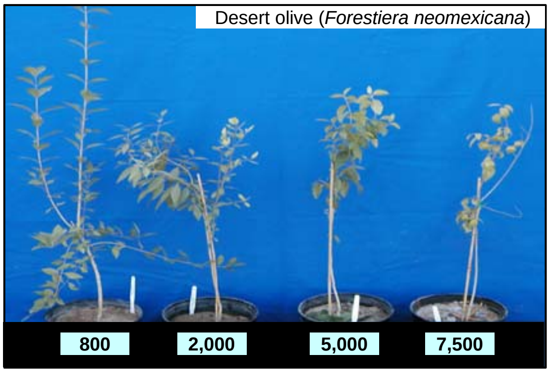
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant

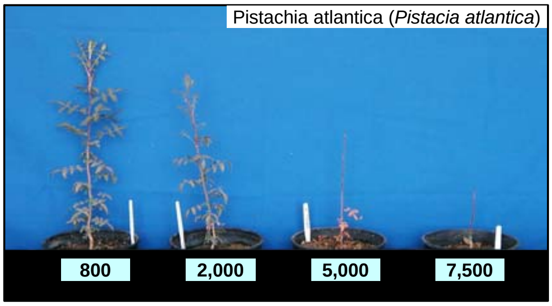

Arizona sycamore (*Platanus wrightii*)

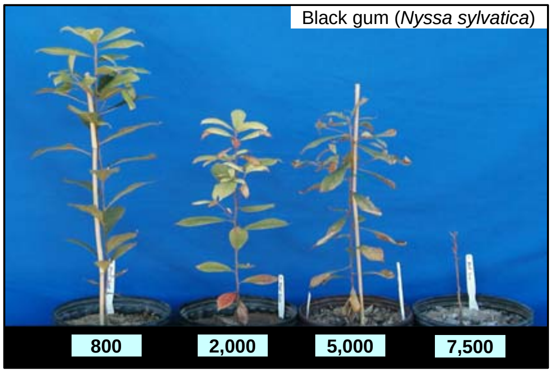

Shumard red oak (*Quercus shumardii*)


Japanese pagoda (*Sophora japonica*)


Chitalpa (*Chitalpa tashkentensis*)


Desert olive (*Forestiera neomexicana*)


Pistachia atlantica (*Pistacia atlantica*)


Black gum (*Nyssa sylvatica*)

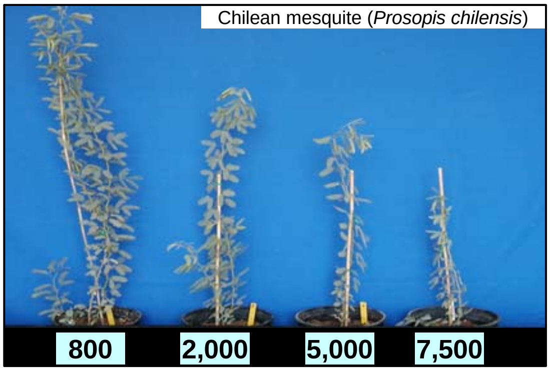
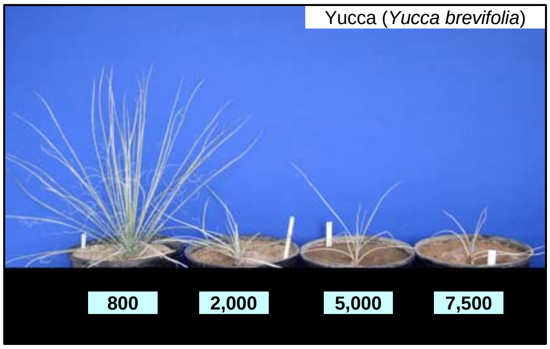
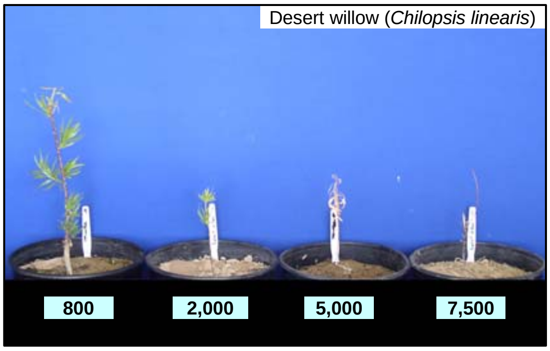

Chilean mesquite (*Prosopis chilensis*)

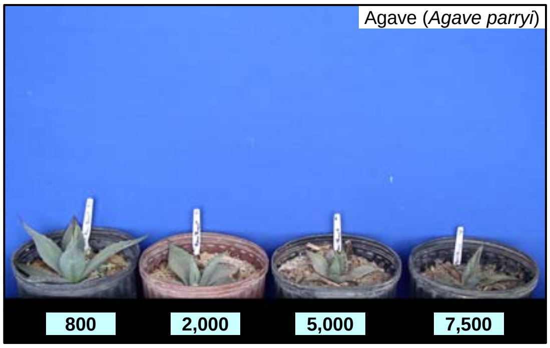
Photo Set A-4. Native Plants

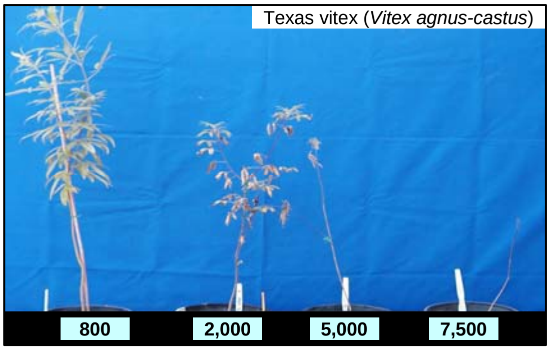
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Yucca	(*Yucca brevifolia*)	S	Desert willow	(*Chilopsis linearis*)	S
Agave	(*Agave parryi*)	MT	Texas vitex	(*Vitex agnus-castus*)	MS
Bird of paradise	(*Caesalpinia mexicana*)	S	Desert olive	(*Forestiera neomexicana*)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

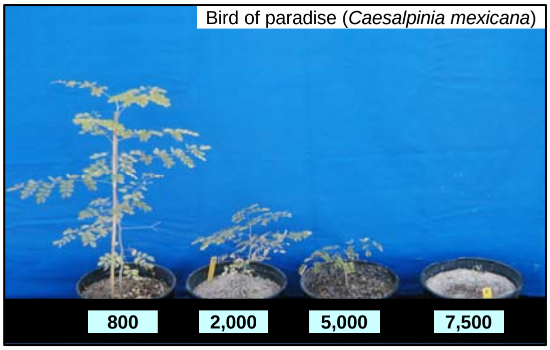
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant, HT: highly tolerant

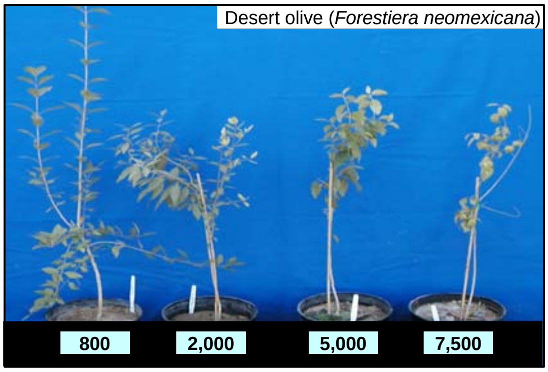

Yucca (*Yucca brevifolia*)

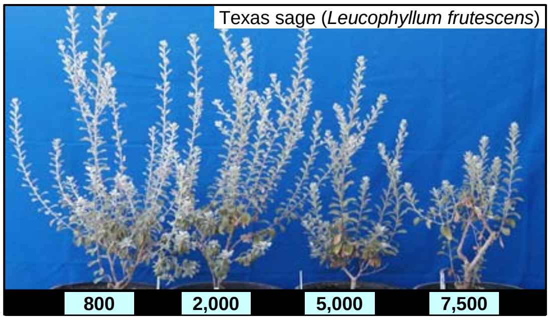

Desert willow (*Chilopsis linearis*)


Agave (*Agave parryi*)


Texas vitex (*Vitex agnus-castus*)


Bird of paradise (*Caesalpinia mexicana*)


Desert olive (*Forestiera neomexicana*)


Texas sage (*Leucophyllum frutescens*)

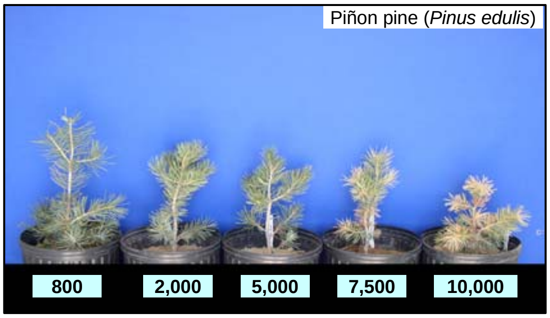
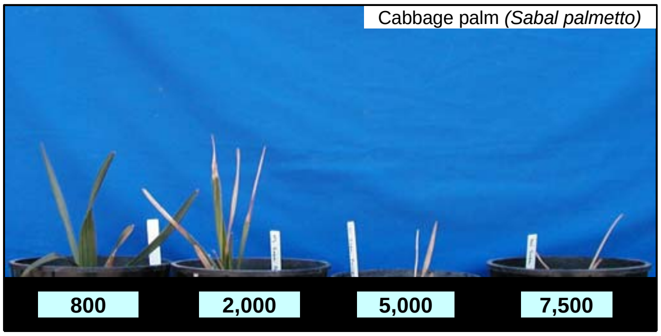
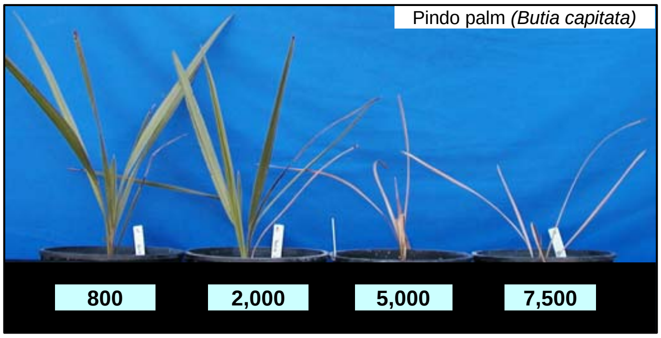

Piñon pine (*Pinus edulis*)

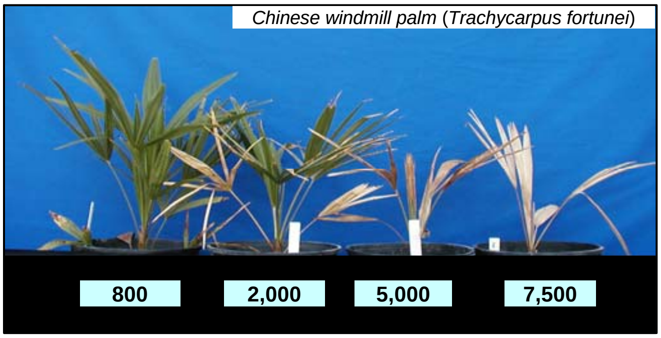
Photo Set A-5. Palm Species

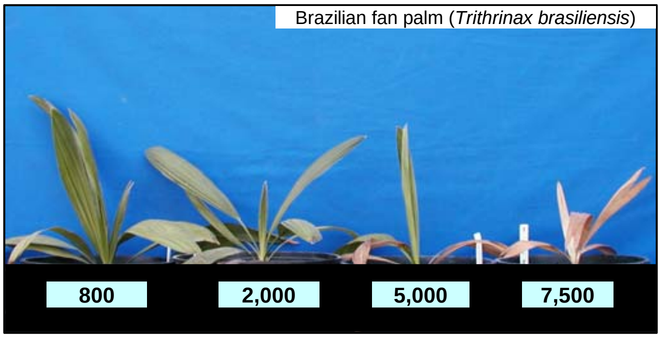
Common Name	Scientific Name	Classifcation	Common Name	Scientific Name	Classification
Cabbage palm	(*Sabal palmetto*)	S	Pindo palm	(*Butia capitata*)	S
Chinese windmill palm	(*Trachycarpus fortunei*)	S	Brazilian fan palm	(*Trithrinax brasiliensis)*	MS
Mexican blue fan palm	(*Brahea armata*)	MS	Dwarf blue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

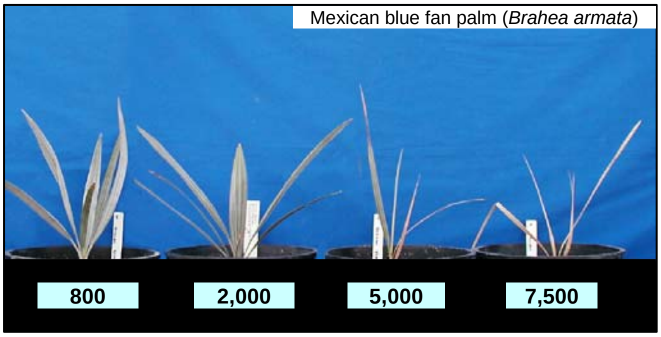
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant

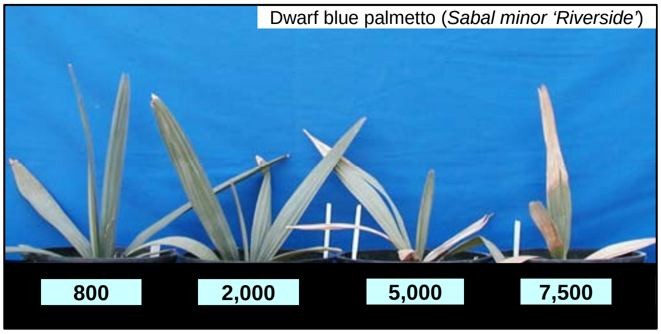

Cabbage palm *(Sabal palmetto)*

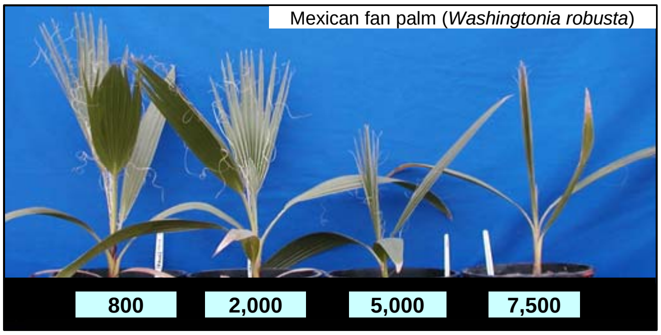

Pindo palm *(Butia capitata)*


Chinese windmill palm (*Trachycarpus fortunei*)


Brazilian fan palm (*Trithrinax brasiliensis*)


Mexican blue fan palm (*Brahea armata*)


Dwarf blue palmetto (*Sabal minor 'Riverside'*)


Mexican fan palm (*Washingtonia robusta*)

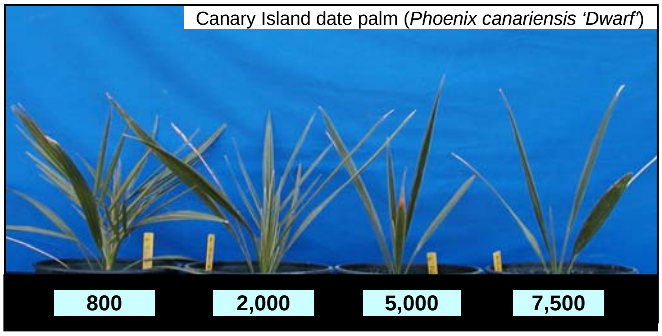
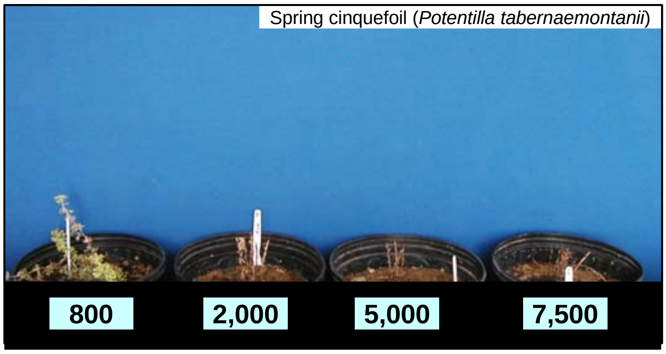
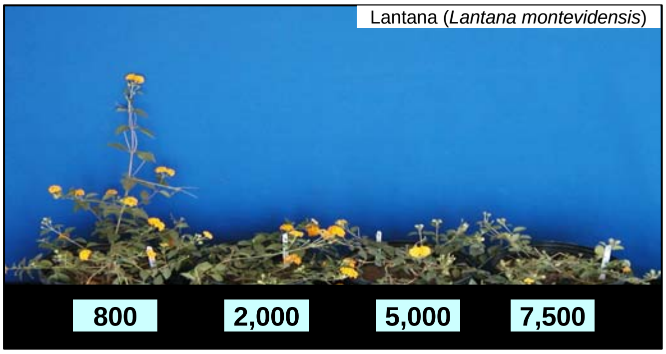

Canary Island date palm (*Phoenix canariensis 'Dwarf'*)

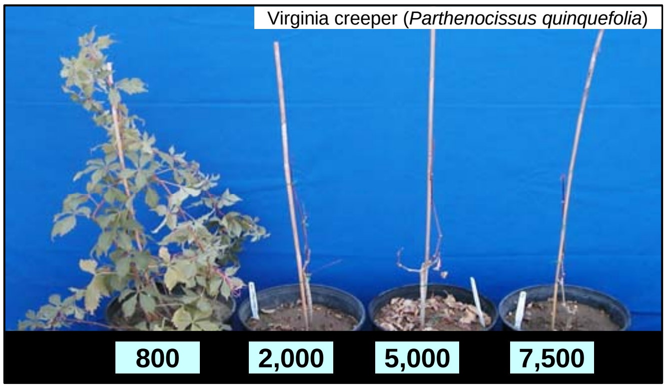
Photo Set A-6. Vines and Ground Cover Plants

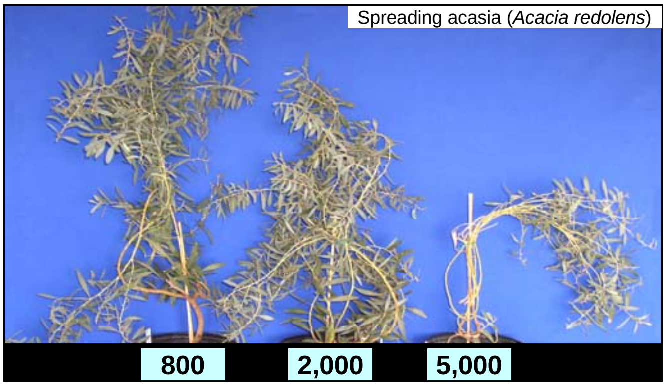
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Spring cinquefoil	(*Potentilla tabernaemontanii*)	S	Lantana	(*Lantana montevidensis*)	MS
Virginia creeper	(*Parthenocissus quinquefolia*)	S	Spreading acasia	(*Acacia redolens*)	MS
Mexican primerose	(*Oenothera berlandieri*)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

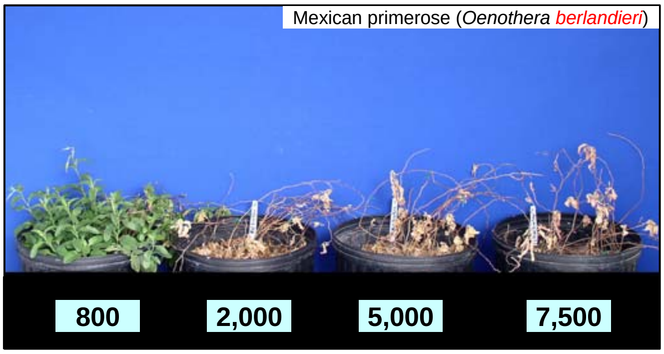
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: Tolerant

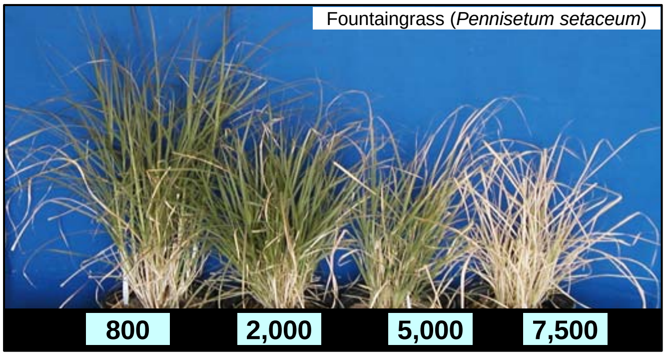

Spring cinquefoil (*Potentilla tabernaemontanii*)

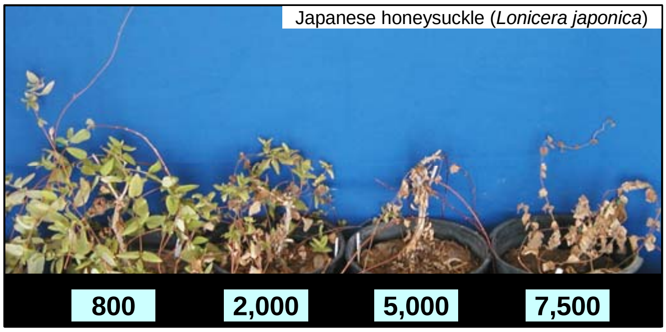

Lantana (*Lantana montevidensis*)


Virginia creeper (*Parthenocissus quinquefolia*)


Spreading acasia (*Acacia redolens*)


Mexican primerose (*Oenothera berlandieri*)


Fountaingrass (*Pennisetum setaceum*)


Japanese honeysuckle (*Lonicera japonica*)

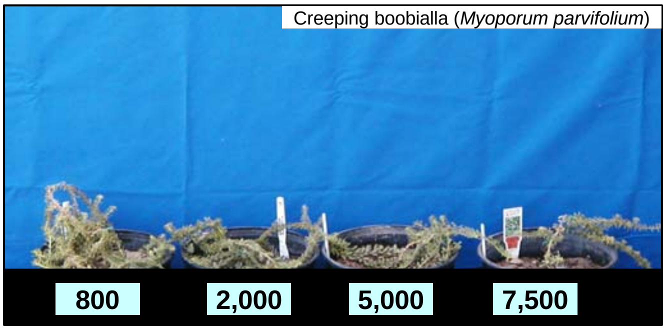
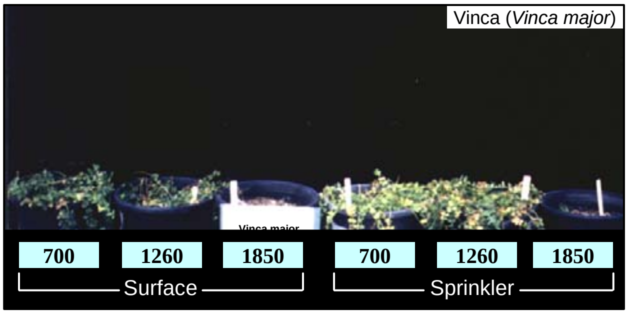
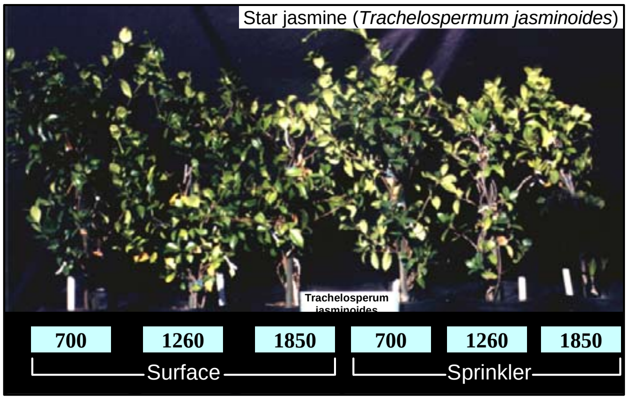

Creeping boobialla (*Myoporum parvifolium*)

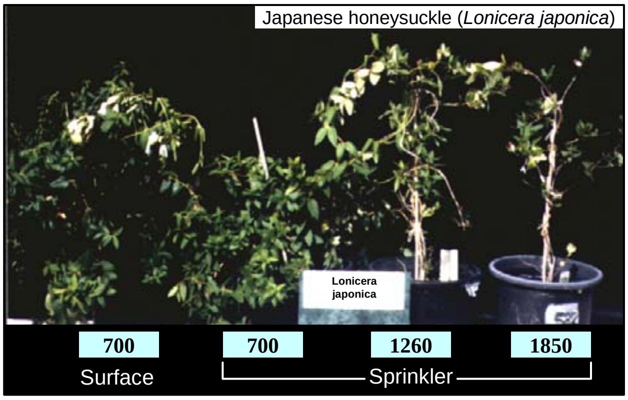
Photo Set B-1. Vines and Ground Covers Under Sprinklers.

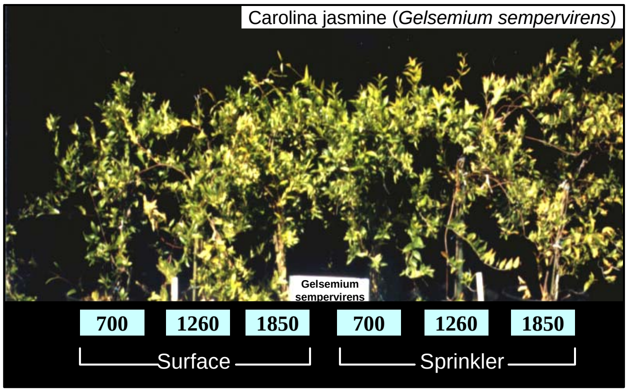
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Vinca	(*Vinca major*)	S			
Star jasmine	(*Trachelospermum jasminoides*)	MS	Japanese honeysuckle	(*Lonicera japonica*)	MS
Carolina jasmine	(*Gelsemium sempervirens*)	MS	Asian jasmine	(*Trachelospermum asiaticum*)	MS
Lirope	(*Liriope muscari*)	MS	English ivy	(*Hedera helix*)	MT

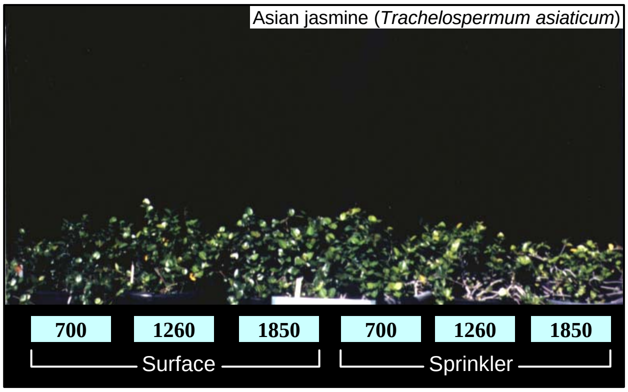
S: sensitive, MS: moderately sensitive, MT: moderately tolerant

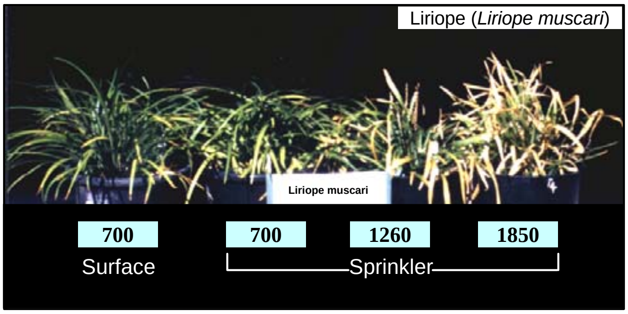

Vinca (*Vinca major*)


Star jasmine (*Trachelospermum jasminoides*)


Japanese honeysuckle (*Lonicera japonica*)


Carolina jasmine (*Gelsemium sempervirens*)


Asian jasmine (*Trachelospermum asiaticum*)


Liriope (*Liriope muscari*)

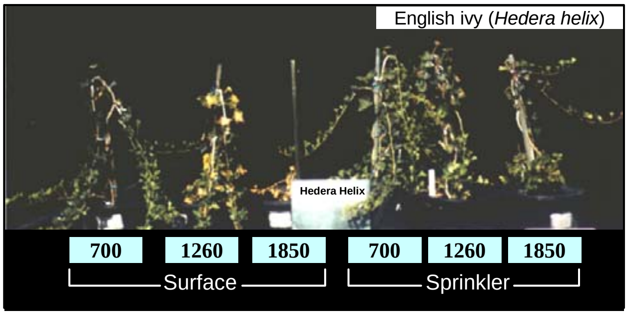
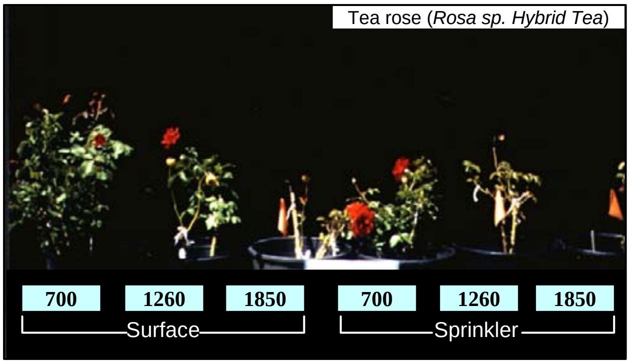
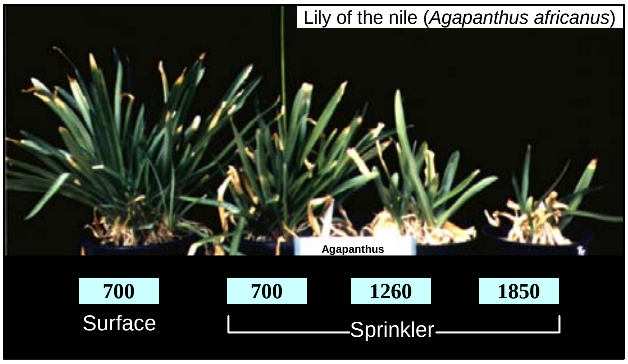

English ivy (*Hedera helix*)

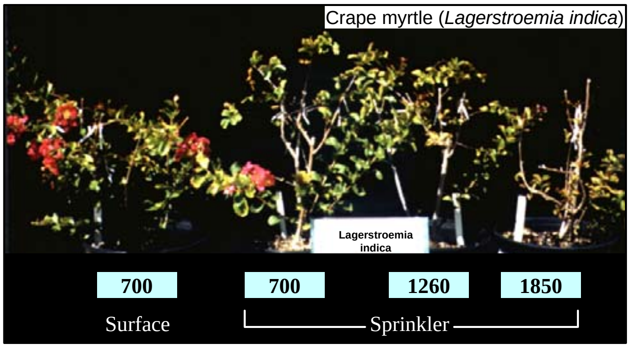
Photo Set B-2. Flowering Perennials and Shrubs Under Sprinklers.

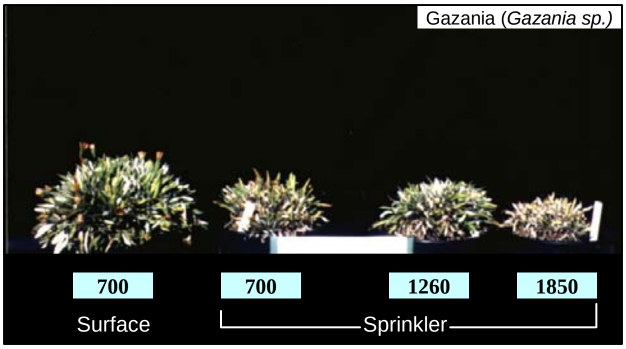
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Tea rose	(*Rosa sp. Hybrid Tea*)	S	Lily of the nile	(*Agapanthus africanus*)	S
Crape myrtle	(*Lagerstroemia indica*)	S	Gazania	(*Gazania sp.*)	MS
Texas sage	(*Leucophyllum frutescens*)	MS	"Lady Banks" Rose	(*Rosa banksiae*)	MT
Trailing lantana	(*Lantana montevidensis*)	MS	Verbena	(*Verbena sp .*)	MT

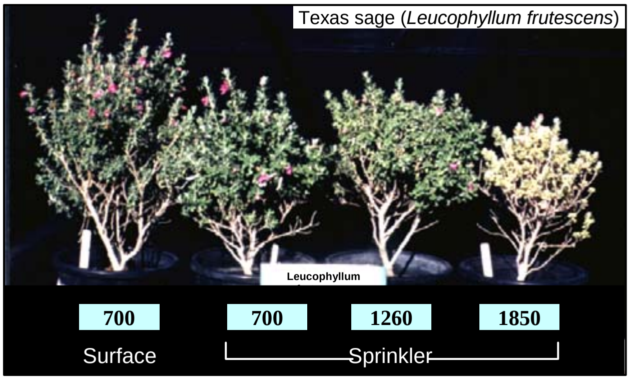
S: sensitive, MS: moderately sensitive, MT: moderately tolerant

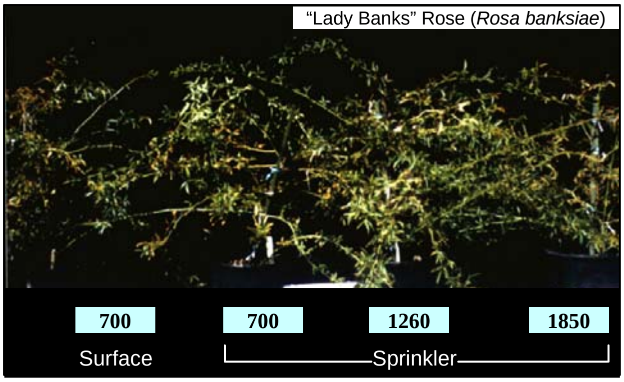

Tea rose (*Rosa sp. Hybrid Tea*)

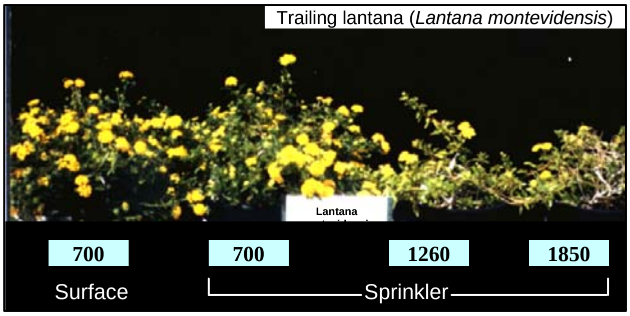

Lily of the nile (*Agapanthus africanus*)


Crape myrtle (*Lagerstroemia indica*)


Gazania (*Gazania sp.*)


Texas sage (*Leucophyllum frutescens*)


"Lady Banks" Rose (*Rosa banksiae*)


Trailing lantana (*Lantana montevidensis*)

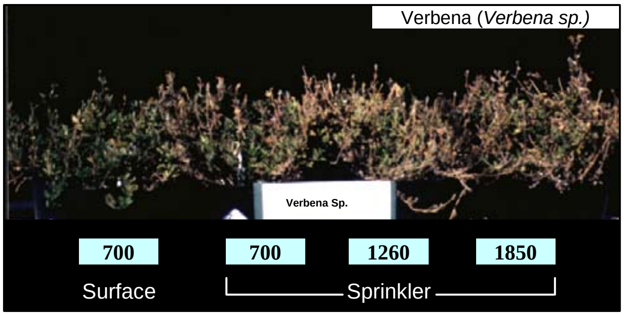
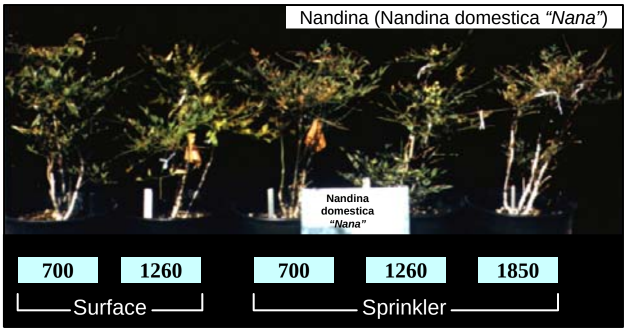
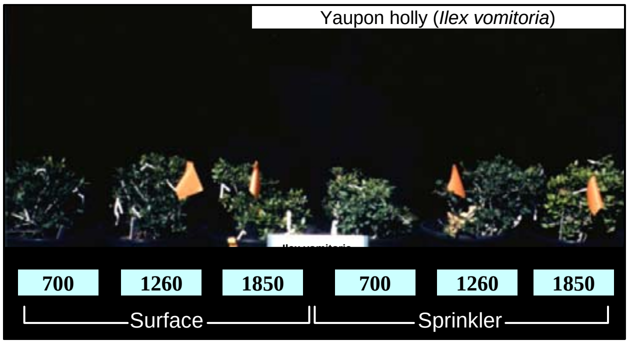

Verbena (*Verbena sp.*)

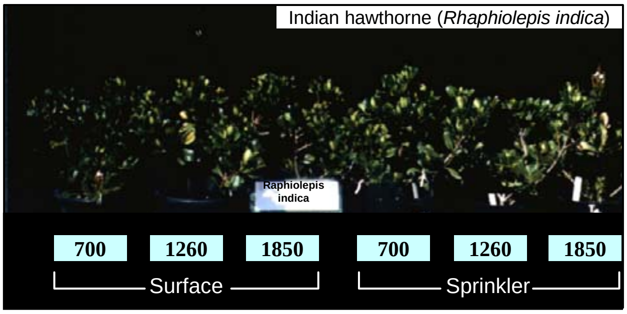
Photo Set B-3. Shrubs Under Sprinklers.

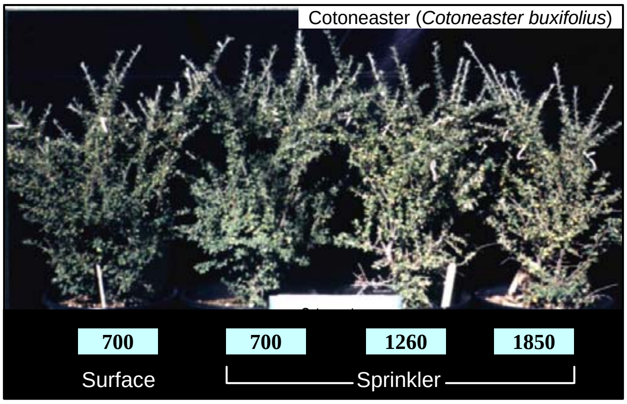
Common Name	Scientific Name	Classification	Common Name	Scientific Name	Classification
Nandina	(*Nandina domestica "Nana"*)	S	Dwarf rosemary	(*Rosmarinus officinalis*)	MS
Yaupon holly	(*Ilex vomitoria*)	MT	Euonymus	(*Euonymus japonica*)	MT
Indian hawthorne	(*Rhaphiolepis indica*)	MT	Buffalo juniper	(*Juniperus sabina "Buffalo"*)	MT
Cotoneaster	(*Cotoneaster buxifolius*)	T	Japanese Boxwood	(*Buxus microphylla*)	T

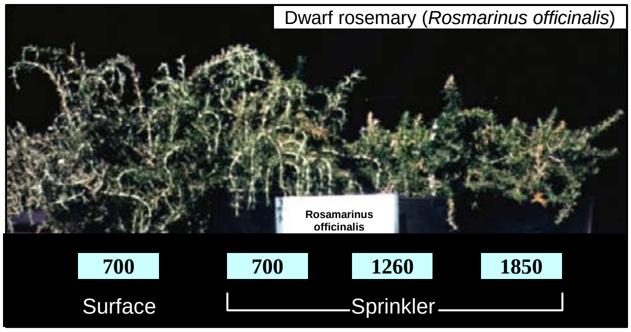
S: sensitive, MS: moderately sensitive, MT: moderately tolerant, T: tolerant

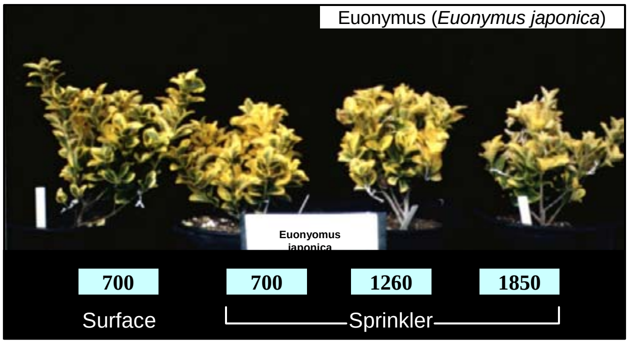

Nandina (Nandina domestica *“Nana”*)

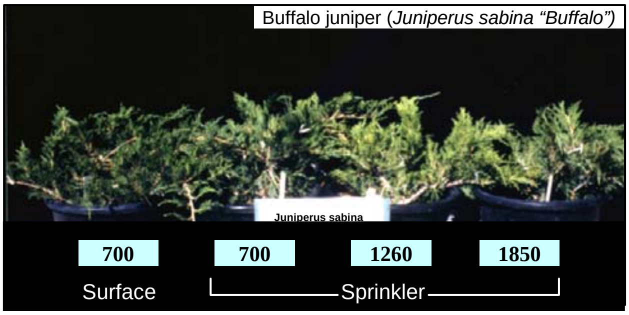

Yaupon holly (*Ilex vomitoria*)


Indian hawthorne (*Rhaphiolepis indica*)


Cotoneaster (*Cotoneaster buxifolius*)


Dwarf rosemary (*Rosmarinus officinalis*)


Euonymus (*Euonymus japonica*)


Buffalo juniper (*Juniperus sabina “Buffalo”*)

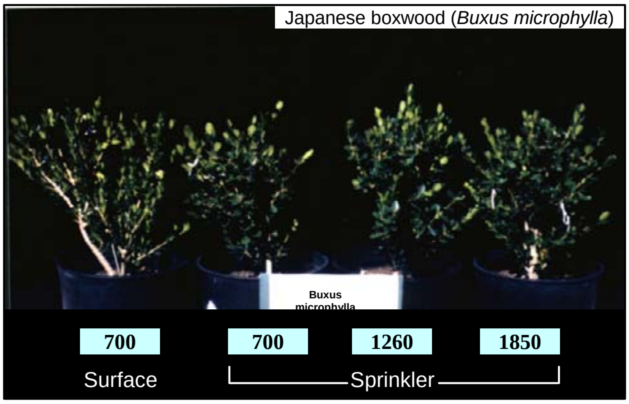

Japanese boxwood (*Buxus microphylla*)

Photo Set B-4. Salt Sensitive Shrub or Trees under Sprinklers.


Silverberry (*Elaeagnus pungens*)


Pomegranate (*Punica granatum*)


Honey locust (*Gleditsia triacanthos*)


Chinese pistache (*Pistacia chinensis*)


Cottonwood (*Populus fremontii*)

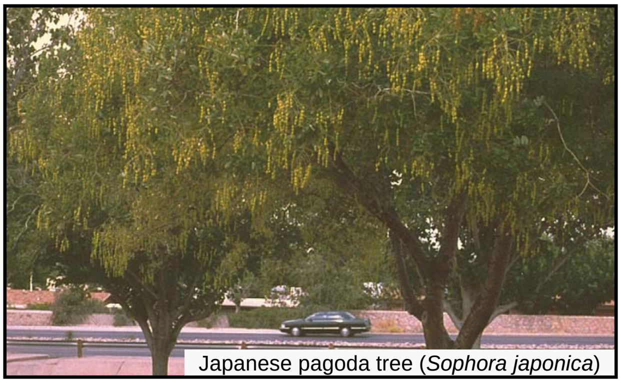

White mulberry (*Morus alba*)


Arizona cypress (*Cupressus arizonica*)

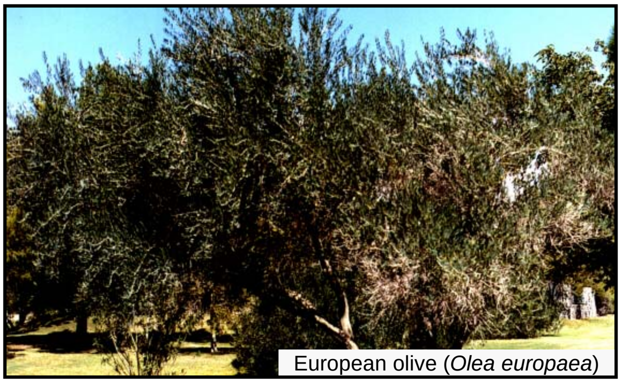

Oriental arborvitae (*Thuja orientalis*)

Photo Set B-5. Moderately Sensitive to Tolerant Trees Under Sprinklers.

Weeping willow (*Salix babylonica*)



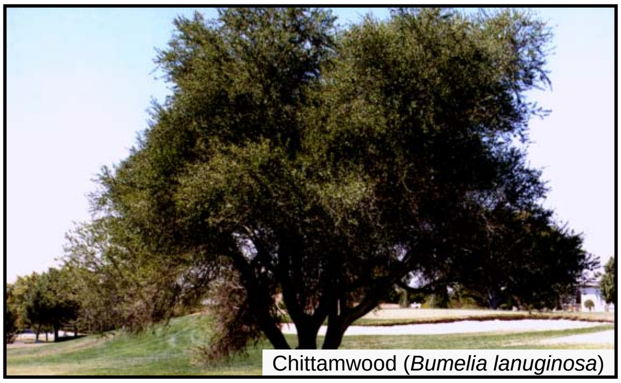
Japanese pagoda tree (*Sophora japonica*)



European olive (*Olea europaea*)

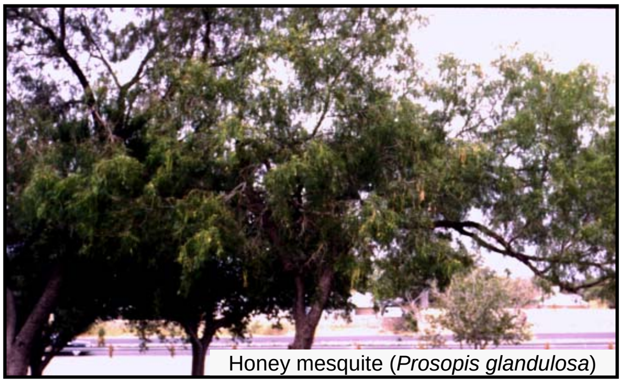
Southern live oak (*Quercus virginiana*)

Juniper (*Juniperus chinensis*)



Chittamwood (*Bumelia lanuginosa*)

Rocky Mt. juniper (*Juniper scopulorum*)



Honey mesquite (*Prosopis glandulosa*)

Photo Set B-6. Leaf Injuries and Salt Accumulation Under Sprinklers.

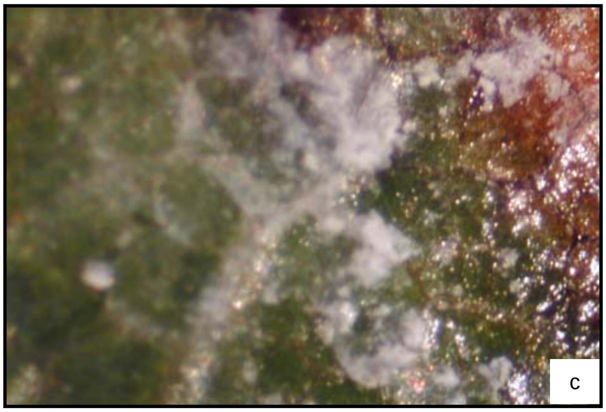

Cottonwood (*Populus fremontii*)


a


Silverberry (*Elaeagnus pungens*)


b

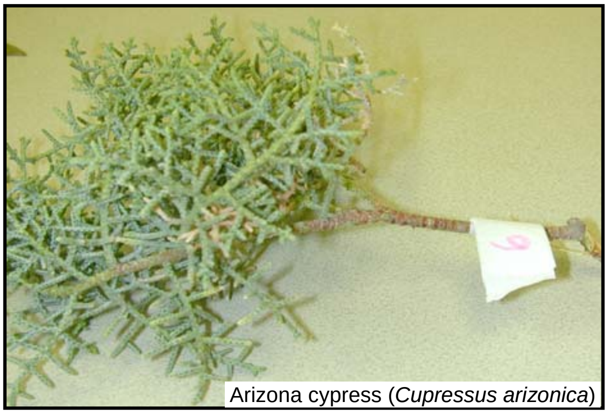

Shumard red oak (*Quercus shumardii*)


c

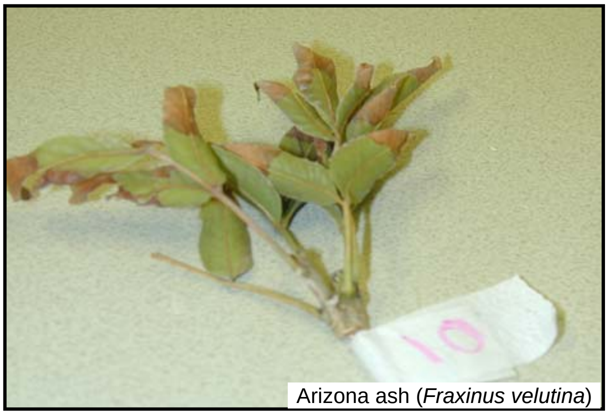

White mulberry (*Morus alba*)

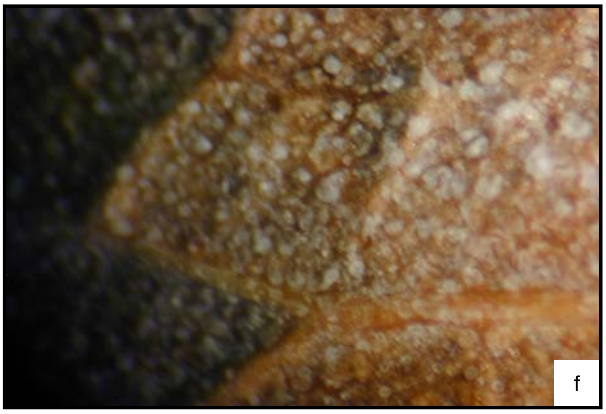

d

Photo Set B-7. Leaf Injuries and Salt Accumulation Under Sprinklers (cont'd).


Arizona cypress (*Cupressus arizonica*)

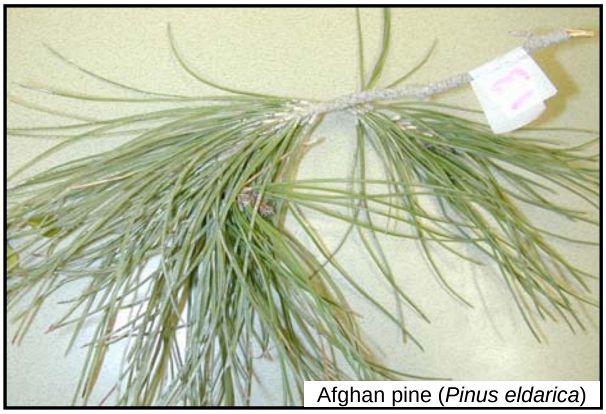

e


Arizona ash (*Fraxinus velutina*)


f


Juniper (*Juniperus chinensis*)


g


Afghan pine (*Pinus eldarica*)


h

Acknowledgement

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Related Publications

Miyamoto, S., I Martinez, M. Padilla, A. Portillo and D. Ornelas, 2004. Landscape Plant Lists for Salt Tolerance Assessment. Texas A&M Univ. Research Center and El Paso Water Utilities. March, 2004.

D. Ornelas and S. Miyamoto, 2003. Sprinkler conversion to reduce foliar salt damage. Water Reuse Conference, San Antonio, TX.

Miyamoto, S., and J.M. White, 2002. Foliar Salt Damage of Landscape Plants Induced by Sprinkler Irrigation. Texas Water Resources Institute. Pub. TR-1202. College Station, TX.

Miyamoto, S., 2000. Soil Resources of El Paso; Characteristics, Distribution and Management Guidelines. Texas A&M Univ. Agr. Res. Ctr. at El Paso.

Appendix: Ionic Composition of Irrigation Water Sources

Plant Response to Soil Salinity

Photo Sets: A – 1 through A – 6

Dissolved salts	Conductivity	Na	Cl
ppm	dS m^{-1}	-----ppm-----	
800	1.2	140	180
2000	4.4	760	1230
5000	9.4	1900	3090
7500	13.7	2800	4600
10000	17.0	3800	6190

Plant Response to Sprinkling

Photo Sets: B – 1, B – 2, B – 3

Dissolved salts	Conductivity	Na	Cl
ppm	dS m^{-1}	-----ppm-----	
700	1.1	140	140
1260	2.0	280	360
1850	3.0	425	590
Photo Sets: B – 4 through B – 7			
1120	2.1	350	550

Attachment I-4

Landscape Plant Lists for Salt Tolerance Assessment

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Texas A&M University Agricultural Research and Extension Center at El Paso
Texas Agricultural Experiment Station

David Ornelas, El Paso Water Utilities

Contents

A. Salt Tolerance Tables

B. Spray Resistant Tables

How Salt Tolerance Tables were Developed

Plant Responses to Soil Salinity (Table Series A): The experiment to evaluate plant tolerance to soil salinity was conducted in a greenhouse. One gallon size plants were transplanted to 3 gallon pots containing loamy sand, and were irrigated with solutions of five levels of salinity; 800, 2000, 5000, 7500 and 10000 ppm for 6 months. The electrical conductivity (EC) of these solutions was, respectively, 1.2, 4.4, 9.4, 13.7 and 17 dS m^{-1}. About 80% of the salts in these solutions were in the form of NaCl. About 1/3 of the solutions applied was allowed to drain so as to avoid salt accumulation. Under this irrigation regime, salinity of the soil saturation extract (an official method of determining soil salinity) is approximately equal to the salinity of irrigation water used. Plant growth and leaf injury were recorded photographically.

Results were analyzed to determine the soil salinity which causes a 50% growth reduction or foliar salt damage on at least 25% of the leaves. In the case of turf and ground cover grasses, a 25% reduction in growth, instead of the conventional 50% reduction was used. This reflects field observation that growth of turf in high traffic area is critically important. Tested plant species were then classified into five categories, following the US Salinity Laboratory classification: sensitive (0 – 3 dS m^{-1}), moderately sensitive (3 – 6 dS m^{-1}), moderately tolerant (6 – 8 dS m^{-1}), tolerant (8 – 10 dS m^{-1}), and highly tolerant (>10 dS m^{-1}). The EC values shown in salt tolerance classification must be determined in the soil saturation extract made from soil samples collected from the main root zone.

Tolerance against Saline Water Sprinkling (Table Series B): Test plants (1 gallon size) were transplanted into 3 gallon pots using a highly permeable commercial soil mix. They were taken outdoors in March, and irrigated every other day with overhead sprinklers for 30 min which delivered 1/2 inch of water. Irrigation continued until the end of September for 6 months. The experiment utilized three saline water sources: tap water (800 ppm or 1.1 dS m^{-1}), a blend of tap water and well water (1260 ppm or 2.0 dS m^{-1}), and saline well water (1850 ppm or 3.0 dS m^{-1}). The corresponding concentrations of Na in these water sources were, respectively, 145, 280, and 425 ppm, and that of Cl was 140, 360 and 590 ppm. As soon as sprinkler irrigation was completed, all pots were flushed with tap water.

Plant responses to the sprinkler irrigation were evaluated by measuring shoot growth and leaf injuries. Salinity of irrigation water and corresponding Na and Cl concentrations which caused a 25% reduction in shoot growth or leaf injury over 25% of the leaves was determined. Because of the lack of the standard method of classifying plants for spray resistance, we used the following tentative classification: sensitive (< 1 dS m^{-1}, Na and Cl < 150 ppm), moderately sensitive (1 – 2 dS m^{-1}, Na < 280 ppm, Cl < 360 ppm), moderately tolerant (2 – 3 dS m^{-1}, Na < 425 ppm, Cl < 590 ppm), and tolerant (> 3 dS m^{-1}). Additional observations of plant response to sprinkler irrigation (Table B-2) were made at a golf course where irrigation water used had a dissolved salt content of 1120 ppm (2.1 dS m^{-1}, Na = 350 ppm, Cl = 325 ppm). Tolerance of trees against sprinkler application, shown in Table B-2 is based on daily irrigation using ¼ inch per application. This scheduling is commonly used in golf courses in El Paso.

How to Use Salt Tolerant Tables

Salt tolerant tables have been used by horticulturists and landscape planners to identify salt-sensitive species to avoid damage. They are also used to identify salt tolerant species for saline conditions. Salinity of irrigation water and soils must be known in order to make the full use of salt tolerance tables. Irrigation water analysis should include the determination of Na and Cl concentrations, besides the total dissolved salt contents or the electrical conductivity (EC). Soil salinity has to be measured in the soil saturation extract (Rhodes and Miyamoto, 1990), as plant salt tolerance to soil salinity is given by the salinity of the saturation extract (EC_e). Unfortunately, many laboratories use 1:1 or 1:2 extract, without knowing a way to convert the results to salinity of the saturation extract. Soil samples have to be collected from multiple locations as soil salinity is spatially variable.

Once soil and water testing results are obtained, the salt concentration factor (SCF) should be estimated by dividing soil salinity (EC_e) with salinity of irrigation water (EC_w). This parameter is a measure of salt accumulation potential, and varies not only with soil type, but also with soil and irrigation management practices used. Examples are shown in Appendix for municipal parks and golf courses in the El Paso area. If the SCF determined for a given site exceeds what is shown in the appendix, the causes of high levels of salt accumulation should be investigated prior to attempting to look for salt tolerant plants. The common causes include inadequate irrigation, high clay contents, and soil compaction.

Tolerance to Soil Salinity (Table A-1 through A-6): Soil salinity measured in the soil saturation extract can be compared directly with the plant salt tolerant values shown in salt tolerance tables. If soil salinity is determined only at one location of an area of concern, a factor of 1.3 should be multiplied to account for typical spatial variation, then compare against the plant salt tolerance level.

If salinity of irrigation water is expected to change, soil salinity upon conversion can be estimated by multiplying the projected salinity of the irrigation water to the SCF. If no soil salinity data are available, determine SCF in a similar soil type under a similar land use, or use Appendix for an estimate. The SCF increases with increasing clay contents of the soil (or the saturation water content) and with soil compaction.

Tolerance to Sprinkling (Tables B-1 and B-2): Salinity of irrigation water used for sprinkler irrigation can be compared directly with the salt tolerance levels shown in Tables B-1 and B-2. In some cases, reclaimed water is stored in a reservoir during winter months, and salinity of the supply can increase. If Na and Cl data are available, use them, instead of the conductivity value. These ions affect plant growth and increase leaf injury. In the case of pines and junipers, Cl damage occurs first as Cl ions are more mobile than Na. In broad leaf plants with rapid ion uptake, both Na and Cl seem to affect almost equally. Calcium ions usually do not affect foliar salt damage, as they precipitate on leaf surfaces upon water evaporation. Actual ion absorption through foliage and leaf salt damage will be affected by irrigation scheduling, climate, types of sprinklers used (Miyamoto and White, 2002). For visual identification of salt damage of various plant species, refer to a companion paper entitled "Photo Guide: Landscape Plant Response to Salinity".

Salt Tolerance Tables

(Tables A-1 through A-6)

Table A-1. 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 - 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	(*Lolium multiforum*)
		Intermediate wheatgrass	(*Elytrigia intermedia 'Rush'*)
Moderately Tolerant (6 - 8 dS m^{-1})			
Zoysiagrass 'Zenith'	(*Zoysia sp. hybrid*)	**Intermediate wheatgrass**	(*Elytrigia intermedia 'Topar'*)
		Streambank wheatgrass	(*Elymus lanceolatus*)
		Crested wheatgrass	(*Agropyron desertorum*)
		Red fescue	(*Festuca rubra*)
		Perennial ryegrass	(*Lolium perenne*)
Tolerant (8 - 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 alkaligrass**	(*Puccinellia distans*)

* Species with bold print were from our experiment.

Table A-2. Salt tolerance of evergreen shrubs and 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 Mt. laurel**	(*Sophora secundiflora*)
Chinese holly	(*Ilex cornuta*)		
Pyrenees cotoneaster	(*Cotoneaster congestus*)		
Cotoneaster	(*Cotoneaster buxifolius*)		
Texas Mt. laurel	(*Sophora secundiflora*)		
Moderately Sensitive (3 - 6 dS m^{-1})			
Oriental arborvitae	(*Thuja orientalis*)	**Rocky Mt. 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 vomitoria*)	Japanese black pine	(*Pinus thunbergiana*)
Dwarf pittosporum	(*Pittosporum tobira*)		
Blue point juniper	(*Juniperus chinenses*)		
Hollywood juniper	(*Juniperus chinenses*)		
Spreading juniper	(*Juniperus chinenses*)		
Pyracantha	(*Pyracantha fortuneana*)		
Silverberry	(*Elaeagnus pungens*)		
Moderately Tolerant (6 - 8 dS m^{-1})			
Rosemary	(*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 arizonica*)
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 - 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

Table A-3. 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*)	**Shumard red oak**	(*Quercus shumardii*)
		Willows	(*Salix sp.*)
Moderately Sensitive (3 - 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 - 8 dS m^{-1})			
Pomegranate	(*Punica granatum*)	**Black gum**	(*Nyssa sylvatica*)
Pistache, texas	(*Pistacia texana*)	Sweet gum	(*Liquidambar styraciflua*)
Pistache, chinese	(*Pistacia chinensis*)		
Chinese elm	(*Ulmus parvifolia*)		
Tolerant (8 - 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

Table A-4. Salt tolerance of plants native to the Southwest.

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

Table A-5. 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 - 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 - 8 dS m^{-1})		
Mexican fan palm	(*Washingtonia robusta*)	None
California fan palm	(*Washingtonia filifera*)	None
Tolerant (8 - 10 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

Table A-6. 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 tabernaemontanii*)
Lily of the Nile	(*Agapanthus africanus*)	**Mexican primerose**	(*Oenothera berlandieri*)
Begonia	(*Begonia sp.*)*		
Gerbera	(*Gerbera jamesonti*)		
Moderately Sensitive (3 - 6 dS m^{-1})			
Coleus	(*Coleus hybridus*)*	**Trailing lantana**	(*Lantana montevidensis*)
Carnation	(*Dianthus sp.*)*	Lantana	(*L. camara*)
Aster	(*Aster sp.*)	**Spreading acasia**	(*Acacia redolens*)
Moderately Tolerant (6 - 8 dS m^{-1})			
Germanium	(*Pelargonium sp.*)*	**Fountaingrass**	(*Pennisetum setaceum*)
		Juniper	(*Juniperus chinensis*)
		Coyote brush	(*Baccharis pilularis*)
		Spider plant	(*Chlorophytum comosum*)*
Tolerant (8 - 10 dS m^{-1})			
		Bougainvillea	(*Bougainvillea spectabillis*)*
		Creeping boobialla	(*Myoporum parvifolium*)
		Ice plant	(*Carpobrotus chilensis*)
		Trailing Ice plant	(*Lampranthus spectabilis*)

* Subject to freeze damage without protection or used as annual.

Spray Resistant Tables

(Tables B-1 and B-2)

Table B-1. Spray Resistance: Ground Covers, Shrubs and Tree Seedlings.

Plant Name			Plant Name		
Common	Scientific	Classification[1] -	Common	Scientific	Classification[1] -
Flowering Annuals and Perennials			**Shrubs**		
Tea rose	*Rosa sp. Hybrid Tea*	S	**Nandina**	*Nandina domestica*	S
Lily of the nile	*Agapanthus africanus*	S	**Photinia, "Red Tip"**	*Photinia fraseri*	S
Crape myrtle	*Lagerstroemia indica*	S	**Pyracantha**	*Pyracantha fortuneana*	MS
Gazania	*Gazania sp.*	MS	**Dwarf rosemary**	*Rosmarinus officinalis*	MS
Texas sage	*Leucophyllum frutescens*	MS	Wild Lilac	*Ceanothus thyrsiflorus*	MS
"Lady Banks" Rose	*Rosa banksiae*	MT	**Yaupon holly**	*Ilex vomitoria*	MT
Trailing lantana	*Lantana montevidensis*	MT	**Euonymous**	*Euonymus japonica*	MT
Verbena	*Verbena sp.*	MT	**Indian hawthorne**	*Raphiolepis indica*	MT
Sunflower	*Helianthus sp.*	T	**Buffalo juniper**	*Juniperus sabina 'Buffalo'*	MT
			Cotoneaster	*Cotoneaster buxifolius*	MT
			Japanese boxwood	*Buxus micropylla*	T
			Oleander	*Nerium oleander*	T
Vines and Ground Covers			**Tree Seedlings**		
Vinca	*Vinca major*	S	**Pistachie 'UCB-3'**	*Pistacia spp.*	S
Grape	*Vitus sp.*	S	Plum	*Prunus domestica*	S
Japanese honeysuckle	*Lonicera japonica*	MS	Apricot	*Prunus americana*	S
Liriope	*Liriope muscari*	MS	Mexican buckeye	*Ungnadia speciosa*	S
Star jasmine	*Trachelospermum jasminoides*	MS	Chinese pistache	*Pistachia chinensis*	S
Asian jasmine	*Trachelospermum asiaticum*	MS	Sweet gum	*Liquidambar* styraciflua	S
Carolina jasmine	*Gelsemium sempervirens*	MS	Wax-leaf Ligustrum	*Ligustrum japonicum*	MS
English ivy	*Hedera helix*	MT	**Afghan pine**	*Pinus eldarica*	MT
Strawberry	*Fragaria sp.*	T	Mexican stone pine	*Pinus cembroides*	T

[1] - **S: Sensitive** (< 1 dS m^{-1}, Na and Cl < 150 ppm), **MS: moderately sensitive** (1 – 2 dS m^{-1}, Na < 280 ppm, Cl < 360 ppm), **MT: moderately tolerant** (2 – 3 dS m^{-1}, Na < 425 ppm, Cl < 590 ppm), and **T:tolerant** (> 3 dS m^{-1}).

Table B-2. Spray Resistance: Mature Trees.

Highly Sensitive: (Significant Damage at 150 to 200 ppm of Na and Cl)		
Pecans	*Carya illinoensis*	Tip then margin burn
Cottonwood	*Populus fremontii*	Margin burn then defoliation
Sycamore	*Platanous acerifolia*	Margin then entire leafburn
Western Soapberry	*Sapindus drummondii*	Tip-burn
Sensitive (Severe damage at 350 ppm of Na or Cl)		
Silverberry	*Elaeagnus pungens*	Margin burn and defoliation
Pomegranate	*Punica granatum*	Margin burn and defoliation
Honey Locust	*Gleditsia triacanthos*	Tipburn, then defoliation
Black Locust	*Robina pseudoacacia*	Tipburn, then defoliation
Chinese Pistache	*Pistacia chinensis*	Tipburn, then defoliation
Shumard Red Oak	*Quercus shumardii*	Tipburn, then defoliation
Bur Oak	*Quercus macrocarpa*	Tipburn, then defoliation
White Mulberry	*Morus alba*	Margin burn then defoliation
Poplar	*Populus sp.*	Margin burn then defoliation
Mimosa	*Acacia baileyana*	Tipburn then defoliation
Arizona Cypress	*Cupressus arizonica*	Defoliation
Oriental Arborvitae	*Thuja orientalis*	Defoliation
Osage Orange	*Maclura pomifera*	Defoliation
Ornamental Pears	*Pyrus communis*	Defoliation
Arizona, Ash	*Fraxinus velutina*	Tipburn then defoliation
Moderately Sensitive (Recognizable damage at 350 ppm of Na or Cl)		
Raywood Ash	*Fraxinus angustifolia*	Tipburn, then defoliation
Globe Willow	*Salix matsudana 'umbraculifera'*	Tipburn then defoliation
Corkscrew Willow	*Salix matsudana 'tortuosa'*	Tipburn then defoliation
Weeping Willow	*Salix babylonica*	Tipburn then defoliation
Japanese Pagoda Tree	*Sophora japonica*	Tipburn then defoliation
Live Oak	*Quercus virginiana*	Tipburn, then defoliation
Chittamwood	*Bumelia lanuginosa*	Tipburn, then defoliation
Texas Vitex	*Vitex agnus-castus*	Tipburn, then defoliation
Moderately Tolerant (Slight or occasional damage at 350 ppm of Na or Cl)		
European Olive	*Olea europaea*	Tipburn
Desert Willow	*Chilopsis linearis*	Tipburn
Holly Oak	*Quercus ilex*	Slight to no injury
Alligator Juniper	*Juniperus deppeana pachyphlaea*	Slight to no injury
Juniper	*Juniperus chinensis*	Slight to no injury
Rocky Mt. Juniper	*Juniperus scopulorum*	Slight to no injury
Honey Mesquite	*Prosopis grandulosa*	Slight to no injury
Tolerant (No damage at 350 ppm of Na or Cl)		
Italian Cypress	*Cupressus sempervirens*	No injury
Hollywood Juniper	*Juniperus chinensis 'Torulosa'*	No injury
Dwarf Pittosporum	*Pittosporum tobia, compacta*	No injury
Oleander	*Nerium oleander*	No injury
Ligustrum	*Ligustrum japonica*	No injury
Euonyomus	*Euonyomus japonica*	No injury
Japanese Black Pine	*Pinus thunbergiana*	No injury
Afghan Pine	*Pinus eldarica*	No injury
Aleppo Pine	*Pinus halepensis*	No injury
Italian Stone Pine	*Pinus pinea*	No injury

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Related Publications

Miyamoto, S., I Martinez, M. Padilla, A. Portillo and D. Ornelas, 2004. Photo guide: Landscape plant response to soil salinity. Texas A&M Univ. Research Center and El Paso Water Utilities. March, 2004.

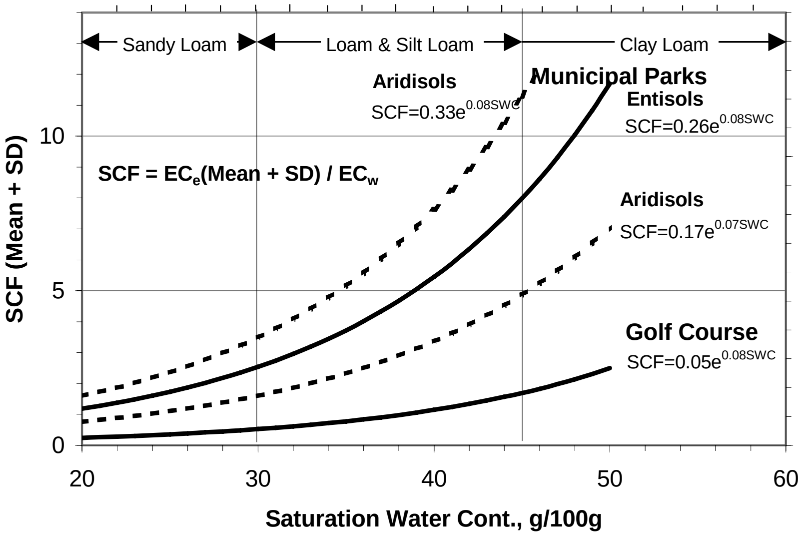
D. Ornelas and S. Miyamoto, 2003. Sprinkler conversion to reduce foliar salt damage. Water Reuse Conference, San Antonio, TX.

Miyamoto, S., and J.M. White, 2002. Foliar Salt Damage of Landscape Plants Induced by Sprinkler Irrigation. Texas Water Resources Institute. Pub. TR-1202. College Station, TX.

Miyamoto, S., 2000. Soil Resources of El Paso; Characteristics, Distribution and Management Guidelines. Texas A&M Univ. Agr. Res. Ctr. at El Paso.

Rhoades, R.J., and S. Miyamoto, 1990. Testing soils for salinity and sodicity. In “Soil Testing and Plant Analysis.” Amer. Soc. Of Agronomy, Madison, WI.

Appendix: Salt Concentration Factors



Appendix I. The salt concentration factor (SCF) expressed as the mean plus the standard deviation (SD) as related to the saturation water content or soil textures of golf courses and municipal parks. The lines drawn are the best fit lines based on actual soil salinity measurements.

Attachment I-5

Chapter V. Tolerance by Landscape Plants of Salinity and of Specific Ions

C. Grieve, L. Wu, L. Rollins, and A. Harivandi

In many communities where recycled water is available, the salinity of the recycled water is somewhat higher than the salinity of municipal drinking water. Therefore, in using recycled water to irrigate golf courses, parks, and other landscapes, it may be beneficial to include salt-tolerant plants, as much as possible, in a landscape's design. The information in this chapter is provided in the hope that it will help park designers, landscapers, maintenance personnel, and others who work with plants to specify, install, and nurture trees, shrubs, ground covers, floricultural plants, and turfgrasses that can thrive when irrigated with recycled water.

Quite a few landscape plants can withstand small or moderate amounts of salt; many are listed in this chapter. Because native Californian plants are favored for park design by the cities of Los Angeles and San Diego and by a number of other communities and individuals in the state, we have included salt tolerance information for native plants to the extent that it is available.

Tolerance by Landscape Plants of Salinity and of Specific Ions. 2007 Chapter V in *Salt Management Guide for Landscape Irrigation with Recycled Water in Coastal Southern California: A Comprehensive Literature.* K. Tanji, ed. A peer reviewed report to WaterReuse Foundation and National Water Research Institute

The responses of plants to salts are manifested in two ways. The osmotic effect produced by total salinity decreases the soil water potential, which causes water in the soil to become less available to plants. And when specific constituents (ions) of salts are present in high concentrations, they can disrupt the plant's mineral nutrient status, sometimes becoming toxic. At times, concentrations of ions such as sodium (Na^+), chloride (Cl^-), and boron (B) in soil or irrigation water, or both, can prove to be a major constraint in choosing plants or in deciding where to position plants within a landscape. We describe some of the effects of these salt ions on plants and the concentrations at which the ions can become a problem. In addition, we outline a number of management practices that can be used to minimize salt injury to plants.

When one is preparing for landscape irrigation with recycled water, environmental quality is an important consideration, especially when the landscape is situated within an urban area. To use the lists of plants in this chapter successfully, information regarding water quality, irrigation management, physical and chemical properties of the soil, and any unfavorable environmental conditions should be obtained and thoroughly reviewed.

In addition to choosing plant species that are sufficiently salt tolerant, the landscape professional must select species that adapt well to local climates. California has many different climatic zones ranging from cool, relatively dry, temperate regions in the inland valleys and high mountains to extremely dry, hot deserts to humid, foggy zones along the coast. Since information on the adaptation of plants to climate is readily available elsewhere, we will not further cover the topic in this chapter.

V.A. General Information Regarding Salt Tolerance

V.A.1. Defining Plant Salt Tolerance

The salt tolerance of a plant is often defined as the plant's inherent ability to withstand the effects of high salts in the root zone or on its leaves without significant adverse effects. The actual salt tolerance of a plant will vary, depending on the growth stage at which salinization is initiated and the final level of salinity to which the plant is subjected (Lunin et al., 1963). Another reason for variation is that the genes that determine a plant's salt tolerance function in combination with other genes, some of which influence both quantitative traits and environmentally influenced traits, such as salt tolerance (Shannon, 1997).

A crop's salt tolerance can be described as a complex function of its yield decline in response to salinity. The yield response curve is typically valid for a range of concentrations of salts and is sigmoidal in shape. Mathematical descriptions of these relationships have proven useful for crop simulation modeling (van Genuchten and Hoffman, 1984). However, because crop survival rates tend to be very low at high salinities, the validity of the bottom part of the yield response curve is often in doubt. Maas and Hoffman (1977) proposed a two-piece linear model described by two parameters: the threshold (electrical conductivity of the extract of a saturated soil paste [EC_e] at which significant yield reduction begins), and the slope (percentage of expected yield decline per unit increase in salinity above the threshold value). In landscape plants, aesthetic quality of the plants is more important than yield of crop plants. Nevertheless, the concept of salt tolerance is of value for landscape plants.

V.A.2. Response of a Plant to Salinity

Lauchli and Epstein (1990) conclude that salinity is stressful for many plants because of two concurrent processes: the osmotic effect and specific-ion effects described earlier. The authors examine the various mechanisms by which plants respond to osmotic effects and to the effects of specific ions. They point out that a plant typically responds to the osmotic effects of salinity by absorbing salt from the medium and by synthesizing organic solutes internally so as to make the water potential gradient more favorable for water uptake.

To evaluate what is known about the responses of plants to salinity, Lauchli and Epstein review and then summarize results from a number of studies on the topic. They describe how plants respond during the two successive stages of growth—development and vegetative growth. They conclude the following:

- It is not possible to establish a distinct dividing line between saline stress, on the one hand, and lack of stress, on the other. Instead, a continuum exists between the two.
- The sensitivity of a plant to salinity changes during the development of the plant.
- The integration of responses in the whole plant is critical for the health and survival of a plant under saline conditions.
- Highly salt-tolerant plants (halophytes) tend to absorb salt ions from the medium and sequester them in the vacuoles of cells. Such plants also manufacture organic solutes to balance the osmotic changes that occur in the cell cytoplasm.
- Salt-sensitive plants, referred to as nonhalophytes or glycophytes, tend to exclude sodium and chloride from their shoots and, especially, from their leaves. Consequently, when subjected to salinity, glycophytes must rely more extensively on the synthesis of organic solutes than do halophytes.
- The presence of calcium at elevated concentrations sometimes can help to mitigate the adverse effects of salinity.

The initial and primary effect of salinity, especially at low to moderate concentrations of salt, results from osmotic effects (Munns and Termaat, 1986). Maturity may be delayed or advanced, depending on the species. For example, salt-related stress in wheat accelerates its development and causes early maturity, whereas salt-related stress in rice causes the plants to mature more slowly. The magnitude of a plant's response to salinity depends not only on the species but also on the interactive effects of environmental factors such as relative humidity, temperature, radiation, and air pollution (Shannon et al., 1994).

Depending on the composition of the irrigation water, ion toxicities or nutritional deficiencies may also arise. These result from a preponderance of a certain specific ion or from competitive effects among cations or anions (Grattan and Grieve, 1999). The osmotic effects of salinity contribute to a reduced rate of growth and to changes in the color of leaves. They also can lead to morphological changes such as smaller leaves or shorter stature or, frequently, to fewer leaves and nodes. Ionic effects generally manifest as damaged leaves or formative plant tissue or as symptoms typical of nutritional disorders. Thus, high concentrations of sodium or chloride ions may accumulate in leaves or in portions of leaves and result in the "scorch" or "firing" of leaves, whereas symptoms of nutritional deficiency are often similar to those that occur in the absence of salinity.

Environmental stresses can cause physiological and morphological disruptions in root tissues. Salinity, for example, decreases the integrity and increases the permeability of cell membranes and ultimately results in reduced growth and yield. Such changes may also increase a plant's susceptibility to invasion by pathogens. Chrysanthemum, a relatively salt-tolerant floral species, showed a definite predisposition to infection by *Phytophthora cryptogea* when it was affected by salinity. MacDonald (1982) reported a strong positive relationship between the degree of salt stress and the severity of this root rot.

V.A.3 Symptoms of Salt-Related Stress

The typical observable symptom of a plant injured by salt-related stress is leaf chlorosis (a scorched-like appearance). It is detrimental physically and aesthetically to plants. If subjected to severe salt-related stress, the whole leaf blade may become chlorotic and die. Under moderate salt-related stress, symptoms are similar among salt-sensitive species of plants, although the symptoms on the leaves have a slightly different pattern of distribution.

Species assessed to be "highly tolerant" are unlikely to develop any symptoms of salt-related stress when irrigated with recycled water, even during the dry and warm summer season. Such species include the tree known as Mexican pinon pine (*Pinus cembriodes*), the shrub known as oleander (*Nerium oleander*), the ground cover red apple iceplant (*Aptenia cordifornia*), and the grass known as alkali sacaton *(Sporobolus airoides*). All of these species can tolerate salt spray containing over 1,000 mg of sodium chloride/L, and all are tolerant of soil with a salinity of 10 decisiemens/m (dS/m), or even greater. These plants require only routine management practices.

Plants assessed to be "tolerant" are generally able to tolerate spray with water (i.e., wetted foliage from sprinkler irrigation) that contains concentrations of salt equivalent to those found in most recycled waters and generally do not develop apparent symptoms of salt-related stress if the salinity of the soil remains below an EC_e of 6 dS/m. However, when the foliage of a tolerant plant is exposed to concentrations of salt exceeding 200 mg of sodium/L and 300 mg of chloride/L, symptoms of salt-related stress begin to appear.

Species determined to be "moderately tolerant" can tolerate spray with water containing the concentrations of salts found in most recycled waters. Under such conditions, their aesthetic quality generally remains acceptable, though they may develop symptoms of salt-related stress near the end of the growing season, by which time leaves may have accumulated considerable salt or the salinity of the soil may have exceeded the permissible level. In areas where wet seasons recur cyclically and frequently, moderately tolerant plants will likely do very well through most of the year, even if irrigation is discontinued during the wet seasons.

Plants deemed "sensitive" may develop symptoms of salt-related stress under a spray of water containing a concentration of sodium that reaches or exceeds 200 mg/L and a concentration of chloride that reaches or exceeds 400 mg/L, especially if the weather is warm and dry. One such species is liquidambar (*Liquidambar styraciflua*). Typical symptoms of salt-related and boron-related stresses for plant species are shown in plates 1 and 2 (Gallery), respectively. Plants sensitive to salt spray from sprinkler irrigation tend also to be sensitive to salinity in the soil. For example, roses may develop severe symptoms of salt-related stress if the salinity in the soil reaches or exceeds 3 dS/m. Research with agronomic plants (Benes et al., 1996) has shown that, for some crops, postwashing (finishing an irrigation, then giving a brief, freshwater rinse) can greatly reduce foliar injury from sprinkling.

V.B. Salt Tolerance of Trees, Shrubs, and Ground Covers

V.B.1. Findings from Recent Research

Based on a recent series of experiments, Wu and Dodge (2005) compiled salt tolerance information for over 200 species of trees and palms, shrubs, and ground covers. Reproduced here as Tables V.B.1.1, V.B.1.2, and V.B.1.3, the lists work fairly well as a plant selection guide for decision-makers in the field of landscape management.

These lists were developed by a team of University of California–Davis researchers who used sprinkler and drip irrigation systems and waters with salinities near the upper level found in most recycled waters. The field trials were aimed at differentiating the salt tolerance of landscape plants based on the aesthetic effects of salinity, rather than yield reduction as would be done with agronomic crops (Wu et al., 2001). The response of the plants to saline stress was evaluated visually or measured by using image analysis technology (Lumis et al., 1973; Wu et al., 2001; Wu and Guo, 2005).

The researchers reviewed the relatively scant literature to date on the relationship between the tolerance by plants of salinity in the water applied to leaves, as compared to tolerance of salinity in the water applied to roots. In one study, these two characteristics were found to have evolved independently between different ecotypes for a species of creeping bentgrass, *Agrostis stolonifera L.*, in a seacoast environment (Ashraf et al., 1986). In another study that involved salt-tolerant creeping fescue cultivars (*Festuca rubra L.*), the characteristics of leaf wettability were found to be responsible for tolerance of salt spray (Humphreys, 1986). There appears to exist a positive relationship between the salt tolerance by many landscape plants for saline spray and their tolerance of salinity in the root zone (Wu et al., 2001). In some cases, the tolerance for salts entering the plant via its roots was found to be three to four times higher than the tolerance for salts entering the plant through leaves (Wu et al., 2001). Exceptions were certain fruit trees grafted onto rootstocks of different species. Their tolerance of salt spray and tolerance of soil salinity may be unrelated.

Based on the results of their field trials, which were conducted in the summer months, and information found in the literature, the researchers estimated the salt tolerances of over 200 species of plants for landscapes (Tables V.B.1.1, V.B.1.2, and V.B.1.3).

Although five or six descriptors have been used to categorize the salt tolerance of crop species (Maas and Grattan, 1999), that number was deemed unnecessarily high for differentiating salt tolerance in landscape plants because landscapes often include plants with a wide range of salt tolerance. Instead, these researchers categorized plants using four descriptors for the plants' ability to tolerate salts in irrigation water: highly tolerant, tolerant, moderately tolerant, or sensitive. They concluded that ranking based on the visual quality of the plants was a practical approach.

Table V.B.1.1.Tolerance by selected landscape tree species of salt spray and of soil salinity.[a]

Botanical name	Common name	Tolerance of salt spray[b]	Tolerance of soil salinity[c]
Acer rubrum L.	Red maple	Sensitive	Sensitive
Acer pseudoplatanus L.	Sycamore maple	Sensitive	Sensitive
Albizia julibrissin Durazz.	Silk tree	Sensitive	Sensitive
Araucaria heterophylla (Salisb.)	Norfolk Island pine	Highly tolerant	Tolerant
Averrhoa carambola L.	Carambola, starfruit	Moderate	Moderate
Bauhinia purpurea L.	Orchid tree	Sensitive	Moderate
Callistemon citrinus Curtis.	Lemon bottlebrush	Tolerant	Moderate
Carya illinoinensis Koch.	Pecan	Moderate	Moderate
Cedrus deodara D. Don	Deodar cedar	Moderate	Moderate
Celtis sinensis Pers.	Chinese hackberry	Sensitive	Sensitive
Citrus limon L.	Lemon	Sensitive	Sensitive
Citrus paradisi Macf.	Grapefruit	Sensitive	Sensitive
Citrus reticulata Blanco.	Tangerine	Sensitive	Sensitive
Citrus sinensis Osbeck.	Orange	Sensitive	Sensitive
Coccoloba uvifera L.	Sea grape	Highly tolerant	Tolerant
Cornus mas L.	Cornelian cherry	Sensitive	Sensitive
Cotoneaster microphyllus Lindl.	Rockspray or little-leaf cotoneaster	Tolerant	Moderate
Cupressus sempervirens L.	Italian cypress	Moderate	Moderate
Diospyros digyna L.	Black sapote	Moderate	Moderate
Diospyros virginiana L.	American persimmon	Sensitive	Sensitive
Eriobotrya japonica Lindl.	Loquat	Moderate	Moderate
Euryops pectinatus	Golden marguerite	Sensitive	Sensitive
Ficus carica L.	Edible fig	Tolerant	Tolerant
Forsythia intermedia Zabel	Forsythia	Tolerant	Tolerant
Fraxinus oxycarpa Bieb. Ex Willd.	Raywood ash	Moderate	Moderate
Gingko biloba L.	Gingko	Sensitive	Sensitive
Grevillea robusta Cunn.	Silk oak	Highly tolerant	Tolerant
Jacaranda mimosifolia D. Don.	Jacaranda	Sensitive	Sensitive
Juniperus silicicola Bail.	Southern red cedar	Highly tolerant	Tolerant
Juniperus virginiana L.	Skyrocket juniper	Highly tolerant	Tolerant
Koelreuteria paniculata Laxm.	Golden rain tree	Moderate	Moderate
Lagerstroemia indica L.	Crape myrtle	Sensitive	Sensitive
Ligustrum japonicum Thunb.	Japanese privet	Moderate	Moderate
Liquidambar styraciflua L.	Sweetgum	Sensitive	Sensitive
Litchi chinensis Sonn.	Lychee	Sensitive	Sensitive
Malus sylvestris Mill.	Crabapple	Sensitive	Sensitive
Mangifera indica L.	Mango	Sensitive	Sensitive
Mangnolia grandiflora L.	Southern magnolia	Sensitive	Sensitive
Manilkara zapota	Sapodilla	Tolerant	Tolerant
Musa acuminata Colla.	Banana	Sensitive	Sensitive
Olea europaea L.	Olive	Sensitive	Sensitive
Parthenium argentatum Gray.	Guayule	Highly tolerant	Highly tolerant
Persea americana Mill.	Avocado	Moderate	Moderate
Pinus cembroides Zucc.	Mexican stone pine	Highly tolerant	Tolerant

Pinus clausa Vasey	Sand pine	Highly tolerant	Tolerant
Pinus elliotti Engelm.	Florida slash pine	Moderate	Moderate
Pinus halepensis Mill.	Aleppo pine	Moderate	Moderate
Pinus thunbergii Parl.	Japanese black pine	Moderate	Moderate
Pistachia chinensis Bunge.	Chinese pistache	Sensitive	Sensitive
Platycladus orientalis Franco	Oriental arborvitae	Moderate	Moderate
Plumaria spp. L.	Frangipani	Tolerant	Tolerant
Plumbago auriculata Lam.	Cape plumbago	Tolerant	Moderate
Prunus armeniaca L.	Apricot	Sensitive	Sensitive
Prunus caroliniana Ait.	Carolina laurel cherry	Moderate	Sensitive
Prunus dulcis D. A. Webb.	Almond	Sensitive	Sensitive
Prunus persica Batsch	Peach	Sensitive	Sensitive
Prunus spinosa L.	Blackthorn	Tolerant	Moderate
Psidium guajava L.	Guava	Sensitive	Sensitive
Punica granatum L.	Pomegranate	Moderate	Moderate
Pyrus communis L.	Pear	Sensitive	Sensitive
Pyrus spinosa Forssk.	Almond-leaved pear	Moderate	Moderate
Quercus agrifolia Nee	Coast live oak	Tolerant	Tolerant
Quercus laurifolia Michux	Laurel oak	Sensitive	Sensitive
Quercus suber L.	Cork oak	Moderate	Moderate
Quercus virginiana Mill.	Live oak	Highly tolerant	Tolerant
Sapium sebiferum Roxb.	Chinese tallow tree	Highly tolerant	Tolerant
Schefflera actinophylla Harms	Schefflera, umbrella tree	Moderate	Moderate
Sequoia sempervirens Endl.	Coast redwood Var. Aptos Blue	Sensitive	Sensitive
Sequoia sempervirens Endl.	Coast redwood Var. Los Altos	Moderate	Moderate
Syzgium jambos Alston	Rose apple	Sensitive	Sensitive
Ulmus parvifolia Drake	Drake elm	Moderate	Moderate
Ulmus parvifolia Jacq.	Chinese elm	Moderate	Moderate
Palm			
Butia capitata Becc.	Pindo palm	Tolerant	Tolerant
Chamaerops humilis L.	European fan palm	Tolerant	Tolerant
Phoenix canariensis Chabaud.	Canary Island date	Moderate	Moderate
Phoenix dactylifera L.	Date palmetto	Tolerant	Tolerant
Sabal palmetto Lodd.	Cabbage palmetto	Tolerant	Tolerant
Serenoa repens Small	Saw palm	Tolerant	Tolerant
Washingtonia robusta Wendl.	Washingtonia palm	Tolerant	Tolerant
Chrysalidocarpus lutescens Wendl.	Areca palm	Moderate	Moderate
Caryota mitis Lour.	Fishtail palm	Moderate	Moderate
Rhapis excelsa Henry	Lady palm	Moderate	Moderate
Acoelorrhaphe wrightii Becc.	Paurotis palm	Moderate	Moderate
Phoenix roebelinii O'Brien.	Pygmy date palm	Moderate	Moderate
Phoenix reclinata Jacq.	Senegal date palm	Moderate	Moderate
Syagrus romanzoffiana L.	Queen palm	Moderate	Moderate
Nolina recurvata Hemsle	Ponytail palm (not a true palm)	Moderate	Moderate

[a] Data in the table adapted from Wu and Dodge, 2005 (in press).

[b] Tolerances of salt spray are defined by the degree of salt stress symptoms developed in the leaves of the plants and the salt concentrations in the irrigation water as follows:

Highly tolerant: No apparent salt stress symptoms may be observed when the plants are irrigated with water that contains 600 mg of sodium L^{-1} and 900 mg of chloride L^{-1} and has an EC_{iw} of 2.1 dS/m.

Tolerant: No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1}.

Moderate: Less than 10% of symptoms develop when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1} and having an EC_{iw} of 0.9 dS/m.

Sensitive: More than 20% of the leaves may develop symptoms when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1} and having an EC_{iw} of 0.6 dS/m.

[c] The definitions of soil salinity tolerance are as follows:

Highly tolerant: Permissible soil EC_e greater than 6 dS m^{-1},
Tolerant: Permissible soil EC_e greater then 4 and less than 6 dS m^{-1},
Moderate: Permissible soil EC_e greater than 2 and less than 4 dS m^{-1}, and
Sensitive: Permissible soil EC_e less than 2 dS m^{-1}.

Table V.B.1.2. Tolerance by landscape shrub species of salt spray and of soil salinity.[a]

Botanical name	Common name	Tolerance of salt spray[b]	Tolerance of soil salinity[c]
Abelia grandiflora Rehd.	"Edward Goucher" Abelia	Sensitive	Sensitive
Acacia redolens Maslin.	Prostrate acacia	Tolerant	Tolerant
Acalypha wilkesiana Muell.	Copper leaf	Sensitive	Sensitive
Agave americana L.	Century plant	Highly tolerant	Tolerant
Arctostaphylos densiflora M.S.Bac	Vine hill manzanita	Tolerant	Tolerant
Bambusa sp. Schreb.	Bamboo	Moderate	Moderate
Buddleja davidii Franch.	Butterfly bush	Sensitive	Sensitive
Buxus microphylla Mull. Arg.	Japanese boxwood	Tolerant	Moderate
Calliandra haematocephala Hassk.	Powder puff tree	Sensitive	Sensitive
Callistemon rigidus R. Br.	Bottlebrush	Moderate	Moderate
Camellia japonica L.	Camellia	Sensitive	Sensitive
Cannax generalis Bailey.	Canna lily	Moderate	Moderate
Carica papaya L.	Papaya	Moderate	Moderate
Carissa macrocarpa A. DC.	Natal plum	Highly tolerant	Tolerant
Ceanothus thyrsiflorus Esch.	Blue blossom	Tolerant	Moderate
Cestrum aurantiacum Lindl.	Orange cestrum	Moderate	Moderate
Codiaeum variegatum Blume.	Croton	Sensitive	Sensitive
Cornus mas L.	Cornelian cherry	Sensitive	Sensitive
Cotoneaster congestus Baker	Pyrenees cotoneaster	Sensitive	Sensitive
Cotoneaster microphylla Lindl.	Rockspray cotoneaster	Moderate	Sensitive
Dracaena deremensis Engler.	Dracaena	Moderate	Moderate
Elaeugnus pungens Thunb.	Silverthorn, silverberry	Highly tolerant	Tolerant
Escallonia rubra Pers.	Escallonia	Tolerant	Moderate
Eugenia unifora L.	Surinam cherry	Sensitive	Sensitive
Euphorbia milii Ch. Des Moulins	Crown of thorns	Highly tolerant	Highly tolerant
Euphorbia pulcherrima Willd.	Poinsetta	Sensitive	Sensitive
Euryops pectinatus L.	Golden shrub daisy	Tolerant	Moderate
Forsythia intermedia Zabel	Hybrid forsythia	Moderate	Moderate
Gamolepis chrysanthemoides DC.	African bush daisy	Highly tolerant	Tolerant
Gardenia augusta Merrill	Cape jasmine, gardenia	Moderate	Moderate
Heliconia sp.	Heliconia	Moderate	Moderate
Hibiscus rosa L.	Rose of China, garden hibiscus	Moderate	Moderate
Hydrangea macrophylla Ser.	Hydrangea	Tolerant	Moderate
Ilex cornuta Burford	Chinese holly	Moderate	Moderate
Ilex vomitoria Ait.	Yaupon holly	Tolerant	Tolerant
Ilex vomitoria Nana	Dwarf Yaupon holly	Highly tolerant	Tolerant
Ixora coccinea L.	Ixora	Sensitive	Sensitive
Jasminum polyanthum Franch.	Jasmine	Moderate	Moderate
Jatropha multifida L.	Coral plant	Sensitive	Moderate
Justicia brandegeana Wassh.	Shrimp plant	Sensitive	Sensitive
Lantana camara L.	Lantana	Highly tolerant	Tolerant
Mahonia aquifolium Nutt.	Oregon grape	Sensitive	Sensitive
Mahonia pinnata Fedde	California holly grape	Sensitive	Sensitive
Murraya paniculata L.	Orange jessamine	Sensitive	Sensitive
Myrica cerifera L.	Wax myrtle	Highly tolerant	Tolerant
Myrtus communis L.	True myrtle	Tolerant	Tolerant
Nandina domestica Thunb.	Heavenly bamboo	Sensitive	Sensitive

Nerium oleander L.	Oleander	Highly tolerant	Tolerant
Opuntia sp. Miller	Opuntia cactus	Moderate	Tolerant
Parthenium argentatum Gray.	Guayule	Highly tolerant	Highly tolerant
Pentas lanceolata Deflers	Pentas, Egyptian star-cluster	Sensitive	Sensitive
Photinia glabra Maxim.	Japanese Photinia	Sensitive	Sensitive
Photinia fraseri Dress	Photinia	Sensitive	Sensitive
Pittosporum tobra Aiton	Mock orange	Highly tolerant	Tolerant
Plumbago auriculata am.	Cape plumbago	Tolerant	Tolerant
Podocarpus macrophyllus D. Don	Yew pine	Sensitive	Sensitive
Pyracantha coccinea Roem.	Red firethorn	Moderate	Moderate
Raphiolepis indica Lindl.	Indian hawthorn	Highly tolerant	Tolerant
Rosa sp. L.	Rose	Sensitive	Sensitive
Russelia equisetiformis Schlecht & Cham.	Firecracker plant	Moderate	Moderate
Sambucus callicarpa Greene	Coast red elderberry	Tolerant	Moderate
Schefflera arboricola L.	Dwarf Shefflera	Moderate	Moderate
Strelitzia reginae Bankses Dryander	Bird of paradise	Moderate	Moderate
Viburnum odoratissimum Ker.	Sweet Viburnum	Moderate	Moderate
Viburnum suspensum Lindl.	Sandankwa Viburnum	Moderate	Moderate
Yucca aloifolia L.	Spanish bayonet	Highly tolerant	Highly tolerant

[a] Data in the table adapted from Wu and Dodge, 2005 (in press).

[b] Tolerances of salt spray are defined by the degree of salt stress symptoms developed in the leaves of the plants and the salt concentrations in the irrigation water as follows:

Highly tolerant:	No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 600 mg of sodium L^{-1} and 900 mg of chloride L^{-1} and having an EC_{iw} of 2.1 dS/m.
Tolerant:	No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1}.
Moderate:	Less than 10% symptoms may be observed when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1} and having an EC_{iw} of 0.9 dS/m.
Sensitive:	More than 20% of the leaves may develop symptoms when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1} and having an EC_{iw} of 0.6 dS/m.

[c] The definitions of soil salinity tolerance are

Highly tolerant:	Permissible soil EC_e greater than 6 dS m^{-1},
Tolerant:	Permissible soil EC_e greater then 4 and less than 6 dS m^{-1},
Moderate:	Permissible soil EC_e greater than 2 and less than 4 dS m^{-1}, and
Sensitive:	Permissible soil EC_e less than 2 dS m^{-1}.

Table V.B.1.3. Tolerance by various landscape ground covers and vine species of salt spray and of soil salinity.[a]

Botanical name	Common name	Tolerance of salt spray[b]	Tolerance of soil salinity[c]
Adiantum sp. L.	Maidenhair fern	Moderate	Moderate
Ajuga repens	Carpet bugle	Sensitive	Sensitive
Aloe vera Burm. f.	Aloe	Highly tolerant	Tolerant
Alternanthera ficoidea R. Br.	Joyweed	Moderate	Moderate
Aptenia cordifolia N. E. Br.	Red apple iceplant	Tolerant	Tolerant
Arctostaphylos densiflora "Lynne" M. S. Back.	Lynne's vine hill manzanita	Moderate	Moderate
Athyrium filix-femina Rith.	Lady fern	Sensitive	Sensitive
Bromeliaceae sp. L.	Bromeliads	Moderate	Moderate
Caladium sp. Vent.	Caladium	Sensitive	Sensitive
Carissa macrocarpa A. DC.	Natal plum	Highly tolerant	Tolerant
Carpobrotus edulis L. Bolus.	Hottentot fig	Highly tolerant	Tolerant
Catharanthus roseus G. Donf.	Periwinkle	Tolerant	Moderate
Chlorophytum comosum Jacq.	Spider plant	Moderate	Moderate
Cuphea hyssopifolia Kunth.	False heather	Moderate	Tolerant
Cyperus alternifolius L.	Umbrella sedge	Moderate	Moderate
Delosperma "Alba" N. E.	White iceplant	Highly tolerant	Highly tolerant
Dietes spp. Salisb. ex Klatt.	African Iris	Moderate	Moderate
Drosanthemum hispidum Schwantes.	Rosea iceplant	Highly tolerant	Highly tolerant
Ficus pumila L.	Creeping fig	Highly tolerant	Tolerant
Hemerocallis sp. L.	Daylily	Moderate	Moderate
Malephora crocea Schwantes.	Iceplant	Highly tolerant	Highly tolerant
Juniperus chinensis L.	Chinese juniper	Moderate	Moderate
Juniperus conferta Parl.	Shore juniper	Tolerant	Tolerant
Juniperus horizontalis Moench.	Creeping juniper	Highly tolerant	Tolerant
Juniperus procumbens Siebild ex Endl.	Japanese garden juniper	Moderate	Moderate
Kalanchoe sp. Adans.	Kalanchoe	Moderate	Moderate
Lampranthus productus N. E. Br.	Purple iceplant	Highly tolerant	Highly tolerant
Liriope muscari L. H. Bail.	Lilyturf (Liriope)	Moderate	Moderate
Iris hexagona Walter	Iris	Moderate	Moderate
Nephrolepis exaltata Schott.	Sword fern	Highly tolerant	Tolerant
Peperomia obtusifolia Dietr.	Peperomia	Sensitive	Sensitive
Portulaca grandiflora Hook.	Purslane (rose moss)	Moderate	Sensitive
Rosmarinus officinalis L.	Rosemary	Moderate	Moderate
Salvia farinacea Benth.	Mealycup sage	Sensitive	Sensitive
Tigridia pavonia Ker Gawler	Tiger flower	Tolerant	Moderate
Tradescantia pallida Hunt.	Purple queen	Highly tolerant	Tolerant
Tulbaghia violacea Harvey	Society garlic	Moderate	Moderate
Verbena sp. L.	Verbena	Sensitive	Sensitive
Zamia integrifolia L. f.	Coontie	Highly tolerant	Tolerant
Vine			
Allamanda cathartica L.	Allamanda	Tolerant	Tolerant
Allamanda blanchetii A. DC.	Purple Allamanda	Moderate	Moderate
Antigonon leptopus Hookery	Coral Vine	Sensitive	Moderate
Bougainvillea glabra Choisy	Bougainvillea	Highly tolerant	Tolerant
Campsis radicans Seem.	Trumpet creeper	Sensitive	Sensitive
Clerodendrum thomsoniae Balf. f.	Bleeding heart vine	Sensitive	Sensitive
Clytostoma callistegioides Miers ex Bur.	Violet trumpet vine	Sensitive	Sensitive
Cyperus altenifolius L.	Umbrella sedge	Moderate	Moderate

Epipremnum sp. Schott.	Pothos	Moderate	Moderate
Ficus pumila L.	Creeping fig	Highly tolerant	Tolerant
Hedera canariensis Willd.	Algerian ivy	Highly tolerant	Tolerant
Hedera helix L.	English ivy	Moderate	Moderate
Hylocereus undatus Britton & Rose	Night blooming cereus	Moderate	Moderate
Ipomoea pescaprae R. Br.	Railroad vine	Highly tolerant	Tolerant
Ipomoea stolonifera Gmel.	Seafoam morning glory	Highly tolerant	Tolerant
Philodendron williamsii Hook.	Philodendron	Moderate	Moderate
Passiflora incanata L.	Passion flower	Sensitive	Sensitive
Salvia farinacea Benth.	Mealycup sedge	Sensitive	Sensitive
Tecomaria capensis Spach.	Cape honeysuckle	Tolerant	Tolerant
Trachelospermum jasminoides Lem.	Star jasmine	Tolerant	Tolerant

[a] Data in the table adapted from Wu and Dodge, 2005 (in press).

[b] Tolerances of salt spray are defined by the degree of salt stress symptoms developed in the leaves of the plants and the salt concentrations in the irrigation water as follows:

Highly tolerant:	No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 600 mg of sodium L^{-1} and 900 mg of chloride L^{-1} and having an EC_{iw} of 2.1 dS/m.
Tolerant:	No apparent salt stress symptoms may be observed when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1}.
Moderate:	Less than 10% symptoms may be observed when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1} and having an EC_{iw} of 0.9 dS/m.
Sensitive:	More than 20% of the leaves may develop symptoms when the plants are irrigated with water containing 200 mg of sodium L^{-1} and 400 mg of chloride L^{-1} and having an EC_{iw} of 0.6 dS/m.

[c] The definitions of soil salinity tolerance are

Highly tolerant:	Permissible soil EC_e greater than 6 dS m^{-1},
Tolerant:	Permissible soil EC_e greater then 4 and less than 6 dS m^{-1},
Moderate:	Permissible soil EC_e greater than 2 and less than 4 dS m^{-1}, and
Sensitive:	Permissible soil EC_e less than 2 dS m^{-1}.

V.B.2. Other Sources of Information

Literature regarding the response of plants to salinity has accumulated so rapidly over the years that a comprehensive bibliography is needed to help search for key references. Fortunately, L. E. Francois and E. V. Maas of the U.S. Salinity Laboratory assembled such a bibliography in 1978. It contains 2,350 literature citations from 1900 to 1977, including citations for papers that describe the effects of salt and boron on whole plants. Key phrases for each citation include plant name, experimental materials and methods, treatments and variables evaluated, and results or data obtained. The bibliography has four sections, one listing common plant names, another listing botanical names, another describing treatments, and yet another organized by results.

An updated version of this bibliography that currently includes over 6,200 literature citations exists on the Salinity Laboratory's website at www.ars.usda.gov/Services

/docs.htm?docid=8908. It is available to everyone, with no password needed to access it, as of 2006.

Researchers at the Salinity Laboratory have written a number of key papers over the years. In one of the earliest papers, "Salt Tolerance of Ornamental Shrubs and Ground Covers" (Bernstein, Francois, and Clark, 1972), the authors describe their experiments on 25 species of plants salinized with sodium chloride and calcium chloride. They discovered that overall salt tolerance does not correlate well with tolerance to injury by chloride or sodium (specific ions). They also concluded that survival of a plant under highly saline conditions is not necessarily a good indicator of overall salt tolerance. The paper includes several tables and one illustration comparing the salt tolerances of various shrubs and ground covers.

Another key reference by Salinity Laboratory researchers is "Salt Tolerance of Ornamental Shrubs, Trees, and Iceplant" (Francois and Clark, 1978). As with the earlier study, the researchers artificially salinized plants with combination of sodium chloride and calcium chloride salts in the water or soil. They evaluated 10 species of shrubs, 2 species of trees, and 4 species of iceplant. Tolerant varieties were reported to include Texas sage (*Leucophyllum frutescens*), brush cherry (*Syzygium paniculatum*), Aleppo pine (*Pinus halepensis*), croceum iceplant (*Hymenocyclus croceus*), purple iceplant (*Lampranthus productus*), rosea iceplant (*Drosanthemum hispidum*), and white iceplant (*Delosperma alba*). Those species were affected little, if at all, by soil with salinities as high as an EC_e (electrical conductivity of the saturated soil paste extract) of 7 dS/m. Sensitive species included glossy abelia (*Abelia grandiflora*), photinia (*Photinia fraseri*), Oregon grape holly (*Mahonia aquifolium*), and Pyrenees cotoneaster (*Cotoneaster congestus*). Each of those was severely damaged, or killed, when the EC_e measured 4 dS/m. Another important finding by these researchers was that leaves typically were injured only at levels of salinity that suppressed growth by 50% or more.

Another pertinent reference by Salinity Laboratory researchers is "Salt Tolerance of Plants" (Maas, 1986). In that journal article, Maas examined the salt tolerance of both crops and ornamental plants, including the criteria for establishing salt tolerance, the factors that influence the salt tolerance of plants, and the relative salt tolerances for herbaceous crops, woody crops, and ornamentals in a series of five tables. Maas pointed out that susceptibility to foliar injury varies considerably among species and depends more on leaf characteristics and the rate of absorption of water than on tolerance of soil salinity. Maas examined the effects of chloride, sodium, and boron on both crops and ornamental plants and provided several tables listing sensitivities of plants to chloride, sodium, and boron.

The Salinity Laboratory's parent organization, the U.S. Department of Agriculture, published a series of leaflets known as Home and Garden Bulletins during the 1960s and 1970s. One of those, the leaflet titled "Reducing Salt Injury to Ornamental Shrubs in the West" (Home and Garden Bulletin No. 95), describes how salinity affects plants, outlines how to diagnose salt injury, and presents a few strategies for coping with salinity (Bernstein, 1964). This leaflet is available at certain libraries: visit www.worldcatlibraries.org on the Internet, click on "Try a search," and enter the leaflet's author and title. The mentioned leaflet has been superseded by another one in the series, "Salt Injury to Ornamental Shrubs and Ground Covers" (Francois, 1980), which includes a table showing the relative tolerances of 41 different trees, shrubs, and ground covers. A PDF of this leaflet can be downloaded from the Internet at www.agnic.msu.edu/hgpubs/modus/morefile/hg231_80.pdf. Though both leaflets were written in earlier decades, they contain pertinent general information.

Bernstein (1980) examined the effects of salinity on fruit trees, such as apple, plum, prune, apricot, and almond, which are occasionally used in landscapes. He relates that the relative importance of osmotic effects and specific ion effects on inhibiting plant growth varies widely, depending on the species. He further states that the yields of some species of fruit tree are relatively unaffected by elevated levels of chloride and sodium ions, even when the leaves are severely injured. However, the yields of certain other species of fruit trees are greatly affected by injuries related to chloride or sodium toxicity. Bernstein outlines several other conclusions, too. First, most fruit trees used as crops are salt sensitive. Second, if the salt tolerance for a particular type of fruit tree tends to vary, it is mainly because different varieties or rootstocks absorb toxic ions at different rates. Third, although salinity generally impairs the quality of fruit, in certain cases it can be beneficial to the fruit quality. Fourth, for sprinkler-irrigated trees, uptake of chloride or sodium by wetted leaves can cause severe leaf burn. And fifth, irrigating infrequently, which is often recommended for ornamental trees and shrubs, can accentuate the effect of salinity on fruit trees.

The book *Abiotic Disorders of Landscape Plants: a Diagnostic Guide* (Costello et al., 2003) provides useful guidelines for assessing the salt tolerance of a plant and diagnosing plant-related problems. The authors list the salinity tolerances and boron tolerances of 610 landscape plants in a table in that book. Entries are listed within categories (shrub, tree, palm, ground cover, vine, herbaceous plant, and turfgrass) and are sorted alphabetically by botanical or scientific name. The list is useful for comparing species and for discovering the salt tolerance or boron tolerance of a particular plant already chosen for a landscape. The authors also provide a table of the same plants sorted according to salt tolerance, as well as a table sorted according to boron tolerance, with each entry appearing in one of three columns: high, moderate, or low tolerance. These tables are helpful when one is seeking a particular plant to satisfy a known salt tolerance or boron tolerance.

Abiotic Disorders of Landscape Plants: a Diagnostic Guide provides several other useful types of information. One table in the book lists 12 different common fertilizers and the relative salinity of each. Another table in the book displays the salt content of seven kinds of commercially available organic soil amendments, including, for example, chicken manure, steer manure, peat, and redwood compost. Another of the book's tables provides guidance for readers who need to interpret chemical data resulting from laboratory tests of soil, water, or plant tissue. Yet another table in the book lists the methodology and criteria used in evaluating the salinity and boron tolerance data for another of the book's tables. Still another table provides a summary of salt-related problems.

Equally useful, if not more so, is information in Chapters 1, 4, 5, and 6 of the aforementioned book on a structured process for diagnosing plant problems caused by salinity or other abiotic agents. Chapter 6 illustrates the process by outlining six case studies.

Salt tolerances for 18 species of eucalyptus—often used in California's landscapes due to their adaptability to the climate, their ability to tolerate little to no irrigation, their relative lack of natural pests, and their fairly high rate of growth—are included in the aforementioned book on abiotic disorders of landscape plants (Costello et al., 2003). A list of 60 species of eucalyptus, plus numerous species of casuarina, acacia, and other Australian shrubs and small trees, appears in an appendix of a book published by the UN Food and Agriculture Organization (Tanji and Kielen, 2002). The list of salt-tolerant plants originated from the Australia Department of Agriculture's farm-revegetation project as part of its sustainable rural development program in 1998.

Many books have been published over the years to help people choose landscape trees, shrubs, and ground covers for California's cool, marine coastal climates and its dry, warm inland climates. Many focus on water-conserving plants because minimizing water usage continues to be one of California's perennial challenges. Very few of the available books contain information about choosing salt-tolerant plants for those same California climate zones. One book that does, by Perry (1981), provides not only a list of plants tolerant of saline soils but also a list of those that do well in the presence of salt spray. Table V.B.2.1 in this chapter, excerpted and adapted from the lists in Perry's book, displays the relative salt tolerance of 36 species of shrubs and trees that are well adapted to the climatic zones of the Los Angeles and San Diego areas.

A number of websites contain helpful information. Currently, the following relevant links are active:

- www.edis.ifas.ufl.edu/EP012 At this site of the University of Florida's Institute of Food and Agricultural Sciences, there are two fairly extensive tables that list the salt tolerances of a number of trees, shrubs, ground covers, vines, and grasses recommended by the institute for landscapes in northern Florida and for southern portions of the state. Many species listed are popular elsewhere in the United States, including California.
- www.denverwater.org At this website of Denver Water, Colorado's largest water utility, click on the side heading "Recycled Water" and then click on the hyperlink "Effects of Recycled Water on Trees and Shrubs" that subsequently emerges on the main window for a number of tips for keeping trees and shrubs healthy when one is irrigating them with recycled water.
- www.sanjoseca.gov/sbwr/Landscape/GuidePlantList.htm This section of the website for the city of San Jose, Calif., has a list of locally available plants for landscapes found to be compatible with irrigation by local recycled water. The list includes 47 species of trees, 29 species of shrubs, 10 species of ground covers, 3 species of vines, 7 species of perennials, and 13 species of native grasses. The vast majority are relatively common varieties that are popular for landscapes elsewhere in California.

In light of the ever-changing and ephemeral nature of websites and their links, the aforementioned may or may not continue to be active. In any case, a search engine can be used to discover alternate relevant links.

V.C. Salt Tolerance of Floricultural Species

Beginning over 50 years ago, researchers at the University of California–Los Angeles, the U.S. Salinity Laboratory in Riverside, and the Metropolitan Water District in La Verne evaluated the salt tolerance of many agronomic and horticultural species. Their legacy—salt tolerance ratings assigned to a number of species and the recommendations for soil, plant and irrigation management practices—is still valid and pertinent today. It should be noted, however, that some varieties and cultivars of major crops have changed and that in some cases there can be significant varietal differences in salt tolerance. This finding is particularly true with perennial crops where rootstock, as well as scion, varieties have changed over the years.

The work of earlier researchers indicated that waters containing 500 parts per million (ppm, or mg/L) of total dissolved solids (TDS) are likely to reduce the growth or cause leaf burn only for the most salt-sensitive plants or for plants grown either in poorly suited soil, along with unfavorable temperature, sunlight, or humidity or with inappropriate irrigation management practices (Pearson, 1949).

They determined that waters containing 800 to 1,000 ppm of TDS also may be used without risk, provided that the kinds of salts contributing to salinity (e.g., sodium, chloride, and sulfate) are considered. Most types of fuchsia (*Fuchsia* spp.), camellia (*Camellia* spp.), and rhizomatous begonia (*Begonia* spp.), for example, grow well in waters of 800 ppm of TDS if sulfate is the principal anion. Yet the same water can cause problems for certain varieties of azaleas and for the Rex begonia. These earlier researchers also found that saline waters dominated by chloride may cause unsightly leaf burn, particularly with sprinkler irrigation.

In the late 1940s, researchers found that calcium-dominated saline waters seemed less detrimental to the growth of plants than did waters containing high concentrations of sodium. Their work suggested that plants may be adversely affected by interactions or imbalances of ions, either in the plant, in the water, or in the soil (Hayward and Wadleigh, 1949). For example, levels of calcium that meet the nutritional requirements of plants not subjected to sodium-based salinity may be inadequate for plants that are exposed to high levels of sodium (Hayward and Bernstein, 1958). Water in the soil that is dominated by sodium not only reduces the availability of calcium but also reduces the mobility and transport of calcium to actively growing tissues. Salinity-induced nutritional disorders may result from the effects of sodium-dominated salinity on nutrient availability, as well as on the uptake, transport, and partitioning of competitive ions within the plant.

In the 1940s and 1950s, researchers examined the effects of specific ions such as boron, chloride, and bicarbonate in soils and irrigation waters on the health of floral species. Azaleas (*Rhododendron* spp.), for example, were found to be relatively sensitive to nutritional imbalances, and even with only slightly saline conditions, calcium deficiency was induced by bicarbonate in the irrigation water (Lunt et al., 1956). Researchers reported that floral species typically respond to salinity by growing less: the length and weight of flowering stems were reduced, or flowers were fewer or smaller. Boron, however, was less detrimental than salinity to the number, size, length, and width of flowering stems of azalea and gardenia (*Gardenia* spp.; Lunt et al., 1957), carnation (*Dianthus caryophyllus*; Lunt et al., 1956), China aster (*Callistephus chinensis*; Kohl et al., 1957), gladioli (*Gladiolus* spp.; Kofranek et al., 1957), and poinsettia (*Euphorbia pulcherrima*; Kofranek et al., 1956). Once the boron tolerance limits for the species were exceeded, injury was characterized by interveinal chlorosis, marginal leaf scorch, and finally, leaf abscission. Refer to Table V.C.1 for boron tolerance limits of selected floral species.

Some researchers in the 1960s and later conducted salt tolerance trials in which they used a single salt, generally sodium chloride, as the salinizing agent. Other researchers, however, have recommended using saline water with sodium/(sodium + calcium) ratio, i.e., $Na^+/(Na^+ + Ca^{2+})$, in the range of 0.1 to 0.7 in experimental studies, as this recommendation better reflects the ion ratios in irrigation water or in the water in the soil for most horticultural crops (Pearson, 1949; Bernstein, 1975). The uncharacteristic salinizing composition of the former may induce ion imbalances that contribute to calcium-related physiological disorders in certain crops (Shear, 1975; Sonneveld, 1988). Furthermore, the use of single-salt solutions in salt tolerance experiments may result in misleading and erroneous interpretations of a plant's response to salinity.

Grattan and Grieve (1999) examined the relationship between a horticultural crop's mineral nutrients and its salinity tolerance. They reviewed the literature that pertains to salinity and mineral nutrition, particularly nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and boron, and briefly examined the potential interactions between certain micronutrients—copper, iron, manganese, molybdenum, and zinc—and salinity. They concluded that a multiplicity of salinity-nutrient interactions occur simultaneously for many types of plants and that whether those interactions ultimately affect the plant as measured by yield, quality, size or elongation, etc. depends on the levels of salinity, the composition of salts, the species, the nutrients, and a host of other environmental factors.

Even under nonsaline conditions, significant economic losses have been linked to inadequate calcium nutrition of horticultural crops. A number of factors can influence the amount of plant-available calcium, including the total supply of calcium, the nature of the counter-ions, the pH of the substrate, and the ratio of calcium to other cations in the irrigation water (Grattan and Grieve, 1999). Calcium-related disorders may even occur in plants grown on substrates where the calcium concentration appears to be adequate (Pearson, 1949; Bernstein, 1975). Symptoms indicating nutritional deficiency are generally caused by differences in calcium partitioning to the growing regions of the plant. All parts—leaves, stems, flowers, and fruits—actively compete for the pool of available calcium, and each part independently influences the movement of calcium. Organs that transpire more actively are likely to have the highest concentrations of calcium.

In agricultural crop plants that consist of large heads enveloped by outer leaves, such as cabbage and lettuce, excessive transpiration by the outer leaves diverts calcium from the rapidly growing embryonic plant tissue (Bangerth, 1979). A deficiency of calcium manifests as internal browning in the younger tissues of cabbage and lettuce and as "blackheart" in celery. Calcium deficiency may also occur in reproductive tissues and cause decreases in quality such as "blossom end rot" of tomato, melon, and pepper; "soft nose" of mango and avocado; and cracking and "bitter pit" of apple. Artichokes grown under arid, but nonsaline, conditions can exhibit calcium deficiency, with injury appearing as necrosis of inner bracts (Francois, 1995).

Horticultural crops that are susceptible to calcium-related disorders without salinity become even more so under saline conditions. As the concentration of salt in the root zone increases, the plant's requirement for calcium also increases (Bernstein, 1975). At the same time, the uptake of calcium from the substrate may be depressed because of ion interactions, chemical precipitation, and increases in ionic strength (Grattan and Grieve, 1999). When these susceptible crops are also challenged by salinity, their market quality can decline significantly.

Very little information is available on the differential partitioning of calcium and any resulting patterns of injury in floricultural species. Certain varieties of Asiatic hybrid lilies are susceptible to calcium-related disorders, whereas others are immune. Injury on "Star Gazer," "Acapulco," and "Muscadet" manifests as necrosis of the upper leaves (Chang et al., 2004) and on "Pirate," as white-gray cross bands on the leaves, as well as tip burn (Berghoef, 1986). The varieties "Alliance" and "Helvetia" appear to be resistant to the disorder (Chang et al., 2004). Poinsettia (*Euphorbia pulcherrima*) also exhibits variety-dependent susceptibility to calcium deficiency, with injury usually appearing as marginal necrosis of the bracts. Wissemeier (1993) demonstrated that "Angelika" and "Supjibi" were sensitive. In contrast, injuries do not appear to occur in the varieties "Diva Starlight" and "Lilo."

The effect of salinity on the sensitivity of floral crops to calcium-related disorders has not been widely explored. One study, however, was conducted with poinsettia, a moderately salt-tolerant crop (Cox, 1991; Dole and Wilkins, 1999). No visible symptoms associated with excess fertilizer salinity were observed in "Red Sails" poinsettia (Cox, 2001) or "V−14 Glory" poinsettia (Ku and Hershey, 1991), although measurements of EC revealed that salinity levels in the root zone exceeded the satisfactory range for the crop (Hartmann et al., 1988).

Other information on the salt tolerance of floral species results from studies of the responses of plants to chloride-dominated saline irrigation waters. Such water typically contains both sodium chloride and calcium chloride. A few researchers evaluated the salt tolerance of floral crops by using irrigation waters prepared to simulate recycled or saline waters typical of a specific location or site. Dutch growers often use solutions with compositions of salts adjusted to the average found in surface waters in the western Netherlands (Bik, 1980; Sonneveld, 1988).

Saline waters (EC = 2.5 to 4.5 dS/m) from local wells in Israel continue to be used successfully for growing floral species on over 700 ha throughout the Negev Desert (Shillo et al., 2002). Arnold and fellow researchers (2003) demonstrated that recycled runoff from a plant nursery and water from a constructed wetland were suitable for irrigating certain bedding plants and flowers. Recent floriculture research at the U.S. Salinity Laboratory involved the use of artificial waters specially prepared to mimic three waters used for irrigation in California: the sodium- and sulfate-dominated drainage effluents from the San Joaquin Valley, various concentrations of Colorado River water, and groundwaters affected by seawater intrusion along the California coast (Grieve et al., 2005; Carter et al., 2005; and Grieve et al., 2006).

An important caveat to bear in mind is that research on the salt tolerance of floricultural species continues to be largely devoted to providing information useful for helping commercial floricultural growers maintain the productivity, quality, and profitability of their plants. The standards of quality for plants in landscapes are far less stringent. For example, because exposure of a plant to salinity generally decreases the length of the stems and the number of florets—two major determinants of quality in commercial flowers—growers of floricultural crops are likely to use the highest quality of water available to maximize the plant's height and number of blooms. However, a slightly shorter flowering plant with somewhat fewer florets would be aesthetically acceptable for use in a landscape—as long as its overall health remains uncompromised, its stems are robust, its leaves and flowers remain true to color, and its flowers and leaves sustain no visible salt injury. Take the specific example of two species of statice grown to be sold as flowers, *Limonium perezii* and *L. sinuatum*, which complete their life cycles in water saltier than seawater (Aronson, 1989). To discover if either could produce marketable cut flowers at lower salinities, both species were grown under irrigation with waters ranging from 2 to 30 dS/m (Grieve et al., 2005). Both species of statice flowered and set seed in all treatments, but their height decreased consistently and significantly as salinity increased, with plants receiving the most saline treatment growing only one-third as tall as those irrigated with nonsaline waters. However, even under severe salt-related stress, both produced healthy plants with attractive foliage and colorful flowers on sturdy, albeit short, stems. The salt tolerance of both species for use as marketable cut flowers is rated as "low" based on stem length (Farnham et al., 1985), but for use in a landscape, they would fall in the "very tolerant" category.

It should also be noted that the effects of salinity on floral crops are not always adverse. Salt-related stress can beneficially affect the yield, quality, and disease resistance of a plant. In some instances, the uptake and accumulation of salinizing ions stimulates growth. Cabrera (2001) and Cabrera and Perdomo (2003) observed a positive correlation between relatively high leaf-chloride concentrations (0.45%) and dry weight for container-grown rose ("Bridal Pink" on *Rosa manetti* rootstock). Yield and quality were unaffected. Salinity imposed early in the life cycle of some cut-flower species tends to limit vegetative growth with favorable results. Salinity-induced reduction in the length of leaf-supporting stems may be beneficial in chrysanthemum, where tall cultivars are treated with growth regulators to keep the plants compact and short. While plant height is often reduced by moderate salinity, the length of time to maturity and the size of developing floral buds generally remain unaffected by stress (Lieth and Burger, 1989).

Application of salinity after some optimal period of vegetative growth tends to enhance reproductive growth and often improves quality. Shillo and coresearchers (2003) reported that salinity imposed on *Eustoma grandiflorum* during its final stages of vegetative growth resulted in significant increases in the number of flowers and in stem weight and diameter. Another benefit of salt treatment was the production of more compact flower clusters, the compactness of which prevents developing buds from drooping. Similar positive effects have been noted with carnation. Salt-related stress during its early reproductive growth resulted in shorter, more robust flower-bearing stalks with larger developing buds (Baas et al., 1995).

Some of the significant varietal differences in salt tolerance reported for cut-flower crops (Table V.C.2) may be due to differences in climate, nutrition, composition of the salinizing medium, and the duration of exposure to salinity. These differences become very important in selecting plants for landscapes irrigated with recycled waters.

In trials conducted under nearly identical cultural conditions, Sonneveld and coresearchers (1987, 1999) reported that the carnation cultivar "Beauty" was significantly more tolerant of soil salinity than were either "Scania" or "Nora Barlo." In the same study, the hybrid lilies "Star Gazer" and "Connecticut King" both produced lighter-weight flowers when the salinity in the soil extract exceeded 1.2 dS/m. Also, the lilies produced 9.6 and 4.6% fewer flowers, respectively, with each unit increase in salinity. Additional information regarding varietal differences in salt tolerance for selected cut flowers is included in Table V.C.3.

The parameters used to assess the salt tolerance of cut flowers need to be considered to accurately assign a tolerance category to a species. Generally, flower quality is less sensitive to salinity than is vegetative growth. For example, once the threshold of "Fabiola" gerbera (*Gerbera jamesonii*) is exceeded, yield based on the number of flower-bearing stalks per plant declines 17% for each unit increase in salinity, but the diameter of the flowers is relatively insensitive, declining only 3% per unit increase. Likewise, the number and weight of flowering stalks in *Anthurium spathes* are more affected by salinity than are the diameter of its flowers. The salt tolerance of the poinsettia variety "Barbara Ecke Supreme" is higher when the rating is based on the diameter of bracts rather than on injury to leaves and an increase in abscissions—the dropping of flowers, fruits, or leaves from the plant (Kofranek et al., 1956).

Salt tolerance ratings of some flower crops as shown in Table V.C.1 are derived from data collected from closely related plants of horticultural and agronomic value. Data regarding the salt tolerance of ornamental *Brassica* species such as kale and cabbage are virtually nonexistent, but it would be reasonable to assume that their salt tolerance would not vary sharply from that of the same leafy vegetables grown under agronomic conditions. Similarly, the *Carthamus tinctorius* varieties of safflower used as cut flowers and bedding plants will likely fall into the same salt tolerance category as the well-known seed oil-producing variety. The commercially important pistachio tree (*Pistacia vera*) and its close relatives are also relatively tolerant of both salt and excess boron stresses (Ferguson et al., 2002). *P. atlantica* and *P terebinthus* are attractive ornamentals, potentially useful for salt-affected sites.

Table V.C.1. Boron tolerance limits for cut flowers.

Sensitivity to boron	Species		Threshold (g/m^3)	Reference
	Botanical name	Common name		
Sensitive	*Delphium* sp.	Larkspur	0.5–1.0	Eaton, 1944
	Pelargonium x *hortorum*	Geranium	0.5–1.0	Kofranek et al., 1958
	Viola odorata	Violet	0.5–1.0	Eaton, 1944
	Viola tricolor	Pansy	0.5–1.0	Eaton, 1944
	Zinnia elegans	Zinnia	0.5–1.0	Eaton, 1944
Moderately sensitive	*Calendula officinalis*	Marigold	1.0–2.0	Francois and Clark, 1979
	Callistephus officinalis	China aster	1.0–2.0	Kohl et al., 1957
	Euphorbia pulcherrima	Poinsettia	1.0–2.0	Kofranek et al., 1956
	Gardenia sp.	Gardenia	1.0–2.0	Lunt et al., 1957
	Gladiolus sp.	Gladiola	1.0–2.0	Kofranek et al., 1957
Moderately tolerant	*Dianthus carophyllus*	Carnation	2.0–4.0	Lunt et al., 1956
	Lathyrus odoratus	Sweet pea	2.0–4.0	Eaton, 1944

Table V.C.2. Salt tolerance of selected landscape flower crops.

Botanical name	Common name	Salt tolerance[a]	Reference(s)
Agapanthus orientalis	Lily of the Nile	Sensitive	Skimina, 1980
Ageratum houstonianum	Ageratum	Moderately sensitive	Devitt and Morris, 1987
Alstroemeria hybrids	Inca lily, Peruvian lily	Very sensitive	Sonneveld, 1988
Amaranthus hypochondriacus	Pygmy torch	Tolerant	Aronson, 1989
Amaranthus tricolor	Love-lies-bleeding	Tolerant[b]	Aronson, 1989
Anthurium andreanum	Anthurium	Very sensitive	Sonneveld and Voogt, 1983
Antirrhinum majus	Snapdragon	Moderately sensitive	Carter et al., 2005
Artemesia stelleran	Dusty Miller	Moderately sensitive[c]	Glattstein, 1989
Begonia bunchii	Begonia	Sensitive	Pearson, 1949
Begonia Rex-cultorum	Rex begonia	Very sensitive	Pearson, 1949
Begonia ricinifolia	Begonia	Sensitive	Pearson, 1949
Bouvardia longiflora	Bouvardia	Moderately sensitive	Sonneveld et al., 1999
Brassica oleracea	Ornamental cabbage	Sensitive[b]	Maas and Grattan, 1999
Brassica oleracea	Ornamental kale	Sensitive[b]	Shannon et al., 2000
Calendula officinalis	Pot marigold	Moderately tolerant	Chaparzadeh et al., 2003
Callistephus chinensis	China aster	Moderately sensitive	Kohl et al., 1957
		Moderately tolerant	Sonneveld et al., 1999
Calocephalus brownii	Cushion bush	Moderately sensitive	Costello et al., 2003
Camellia japonica	Camellia	Sensitive	Pearson, 1949
Carathamus tinctorius	Safflower	Moderately tolerant[b]	Beke and Volkmer, 1994
Catharanthus roseus	Vinca	Sensitive	Arnold et al., 2003; Huang and Cox, 1988
Celosia argenta cristata	Crested coxcomb	Moderately sensitive	Devitt and Morris, 1987
Celosia argenta cristata	Chief celosia	Tolerant	Carter et al., 2005
Cereus peruviana	Apple cactus	Moderately sensitive	Costello et al., 2003
Chlorophytum comosum	St. Bernard's lily	Tolerant	Zurayk et al., 1993
Chrysanthemum morifolium	Mum	Moderately tolerant	Kofranek et al., 1953; Pearson, 1949
Clematis orientalis	Clematis	Very tolerant	Krupenikov, 1946
Coleus blumei	Coleus	Tolerant	Zurayk et al., 1993
Codiaeum punctatus	Croton	Moderately tolerant	Farnham et al., 1985
Consolida ambigua	Larkspur	Sensitive	Arnold et al., 2003
Cosmos bipinnatus	Cosmos	Very sensitive	Devitt and Morris, 1987
Coreopsis grandiflora	Coreopsis	Moderately sensitive[c]	Glattstein, 1989
Crassula ovata	Jade plant	Moderately sensitive	Skimina, 1980
Cyclamen persicum	Cyclamen	Sensitive	Bik, 1980
Cymbidium spp.	Orchid	Very sensitive	de Kreij and van den Berg, 1990
Dianthus barbatus	Pinks	Moderately sensitive	Monk and Peterson, 1961
Dianthus caryophyllus	Carnation	Moderately tolerant	Baas et al., 1995
Dianthus chinensis	Carnation	Moderately tolerant	Devitt and Morris, 1987
Eschscholzia californica	California poppy	Moderately tolerant[c]	Glattstein, 1989
Euphorbia pulcherrima	Poinsettia "Red Sails"	Sensitive	Cox, 1991
Euphorbia pulcherrima	Poinsettia "Barbara Ecke"	Very sensitive	Kofranek et al., 1956

Euryops pectinatus	Golden marguerite	Sensitive	Wu et al., 1999
Eustoma grandiforum	Lisianthus	Moderately sensitive	Shillo et al., 2002
Felicia amelloides	Felicia	Sensitive	Farnham et al., 1985; Skimina, 1980
Fuchsia hybrida	Fuchsia	Very sensitive	Pearson, 1949
Gardenia augusta	Gardenia	Sensitive	Lunt et al., 1957
Gazania aurantiacum	Gazania	Moderately tolerant	Costello et al., 2003
Gerbera jamesonii	Gerbera daisy	Moderately sensitive	Sonneveld and Voogt, 1983; Baas et al., 1995; Savvas et al., 2002
Gazania spp.	Treasure flower	Very tolerant	Perry, 1989
Gladiolus spp.	Gladiola	Sensitive	Kofranek et al., 1957
Gomphrena globosa	Globe amaranth	Moderately sensitive	Kang and van Iersel, 2002
Gyposphila paniculata	Baby's breath	Moderately tolerant[c]	Shillo et al., 2002
Helianthus annuus	Sunflower	Moderately tolerant	Ashraf and O'Leary, 1995
Helianthus debilis	Cucumber leaf	Very tolerant	Costello et al., 2003
Hibiscus rosa-sinensis	Hibiscus	Sensitive	Bernstein et al., 1972
Hippeastrum hybridum	Amaryllis	Very sensitive	Shillo et al., 2002; Sonneveld and Voogt, 1983
Hymenocallis keyensis	Spiderlily	Moderately tolerant	Costello et al., 2003
Impatiens × *hawkeri*	Impatiens	Sensitive	Todd and Reed, 1988
Kalanchoe spp.	Kalanchoe	Moderately tolerant	Costello et al., 2003
Kochia childsii	Kochia	Tolerant	Monk and Peterson, 1961
Lathyrus japonica	Sweet pea	Moderately tolerant	Costello et al., 2003
Lilium spp.	Asiatic hybrid lily	Sensitive	Sonneveld, 1988
Lilium spp.	Oriental hybrid lily	Sensitive	Sonneveld and Voogt, 1983
Limonium spp.	Japanese Limonium	Very tolerant	Shillo et al., 2002
Limonium latifolium	Sea lavender	Very tolerant	Aronson, 1989
Limonium perezii	Statice	Sensitive	Farnham et al., 1985
		Very tolerant	Grieve et al., 2005; Carter et al., 2005
Limonium sinuatum	Statice	Very tolerant	Grieve et al., 2005; Carter et al., 2005
Lobularia maritima	Sweet Alyssum	Moderately tolerant	Monk and Peterson, 1961
Matthiola incana	Stock	Very tolerant	Lunt et al., 1964; Wigdor et al., 1958
Narcissus tazetta	Paperwhite Narcissus	Sensitive	Arnold et al., 2003
Oenthera speciosa	Mexican evening primrose	Moderately tolerant	Costello et al., 2003
Ophiopogon jaburan	Giant turf lily	Moderately sensitive	Skimina, 1980
Ornithogalum arabicum	Arabian star flower	Very sensitive	Shillo et al., 2002
Pelargonium × *hortorum*	Geranium	Sensitive	Kofranek et al., 1958
Pelargonium domesticum	Geranium	Tolerant	Zurayk et al., 1993
Pelargonium peltatum	Ivy geranium	Moderately tolerant	Costello et al., 2003
Petunia hybrida	Petunia	Tolerant	Devitt and Morris, 1987
Portulaca grandiflora	Moss rose	Very tolerant	Devitt and Morris, 1987
Phalaenopsis hybrid	Orchid	Very sensitive	Wang, 1998
Protea obtusifolia	Protea	Moderately tolerant	Rodrigues-Perez et al., 2000
Rhododendron hybrids	Azalea	Moderately sensitive	Cabrera, 2003

Rhododendron obtusum	Azalea	Sensitive	Pearson, 1949; Lunt et al., 1957
Rosa × *hybrida*	Rose	Sensitive	Cabrera and Perdomo, 2003; Fernández Falcón et al., 1986
Stapelia gigantea	Starfish flower	Moderately tolerant	Costello et al., 2003
Strelitzia reginae	Bird of paradise	Very sensitive	Farnham et al., 1985
Tagetes erecta	Marigold	Moderately tolerant	West et al., 1980
Tagetes patula	Marigold	Moderately tolerant	Devitt and Morris, 1987
Trachelium caeruleum	Blue throatwort	Sensitive	Shillo et al., 2002
Tropaeolum majus	Nasturtium	Moderately sensitive[c]	Glattstein, 1989
Vinca major	Periwinkle	Moderately tolerant	Costello et al., 2003
Vinca minor	Myrtle	Sensitive	Farnham et al., 1985
Viola × *wittrockiana*	Pansy	Sensitive	Arnold et al., 2003
Zinnia elegans	Zinnia	Moderately sensitive	Devitt and Morris, 1987

[a] Criteria for assigning salt tolerance: not more than 50% reduction in growth, no visually observable foliar burn, and maximum permissible EC_e ($dS\ m^{-1}$) as follows:

<2, very sensitive;
2–3, sensitive;
3–4, moderately sensitive;
4–5, moderately tolerant;
5–6, tolerant; and
>6, very tolerant.

[b] Based on salt tolerance classification of related agronomic or horticultural species or variety.

[c] Only qualitative data are available.

Table V.C.3. Varietal differences in salt tolerance for selected cut-flower crops.

Common name	Variety	Threshold EC_e ($dS\ m^{-1}$)	Slope (%)	Reference
Carnation	Adefie	1.1	2.1	Sonneveld et al., 1999
	Beauty	4.3	3.9	Sonneveld et al., 1999
	Princess white	5.0	—	Devitt and Morris, 1987
	Scania	1.2	6.9	Sonneveld and Voogt,1987
	Nora Barlo	1.2	5.5	Sonneveld and Voogt,1987
Chrysanthemum	Indianapolis white	2.4	—	Rutland,1972
	Spider	>0.8	6.8	Sonneveld and Voogt, 1987
	Horim	>0.8	12.1	Sonneveld and Voogt, 1987
	Maghi[a]	>8.0	—	Rahi and Datta, 2000
	Basantika[a]	>8.0	—	Rahi and Datta, 2000
	Bronze Kramer	6.0	9.0	Kofranek et al., 1953
	Albatross	2.0	—	Lunt et al., 1962
Gerbera	Beauty	1.5	9.8	Sonneveld et al., 1999
	Mandarine	<0.6	5.1[b]	Sonneveld and Voogt, 1983
	Fabiola	<0.6	6.5[b]	Sonneveld and Voogt, 1983
Rose	Baccara	1.0	10	Yaron et al., 1969
	Grenoble	2.1	20	Bernstein et al., 1972
	Forever yours	1.8	—	Hughes and Hanan, 1978
	Sonia	1.0	10	Zeroni and Gale, 1989
	Europa	2.1	5.3	Sonneveld et al.,1999
	Madelon	4.8[c]	2.0	Baas and Berg, 1999
	Kardinal	2.2	20	Wahome et al., 2000
	Bridal pink	5.4[d]	—	Cabrera, 2001

[a] Plants grown from cuttings subjected to mutagenesis by gamma irradiation resulted in more salt-tolerant genotypes.

[b] Based on weight of peduncle.

[c] Recirculating irrigation system.

[d] EC of leachate.

V.D. Salt Tolerance of Turfgrasses

The quality of a turfgrass stand is the net result of inherent genetic characteristics of the particular species being grown and the interactions of climate, pests, and the soil. In arid and semiarid regions where rainfall is insufficient to leach salt out of the root zone, excessive amounts of soluble salts may accumulate in the root zone. This phenomenon can impose limits on the production or the management of quality turf (Carrow and Duncan, 1998; Marcum, 2006). Salinity-related stress on turfgrasses is also a serious problem near the seacoast, both because the concentration of salt in the air typically is higher than that found inland and because shallow water tables may be unusually saline.

Wherever salinization of soils occurs, it is a continuous process resulting from various combinations of these factors: insufficient rainfall, inadequate irrigation, poor drainage, irrigation with water of poor quality, and the upward movement of salts from saline shallow groundwater.

As a general rule, if the amount of water applied to the soil (irrigation plus natural precipitation) exceeds evapotranspiration, salt moves downward. Conversely, if evapotranspiration exceeds the amount of water applied, salt movement is upward. In the latter case, salt drawn to the soil surface gradually accumulates to levels toxic to turfgrasses.

Depending on the salinity tolerance of the turfgrass grown, full stands of grass can sometimes be established at low or moderate levels of soil salinity. Turfgrass growth in highly saline soils, however, is restricted (Carrow and Duncan, 1998).

The symptoms of salinity-related stress in turfgrasses are likely to vary somewhat, because existing salt can result in osmotic stress (physiological drought), nutritional imbalances, toxicity, or a combination of these maladies. In general, however, the following symptoms are associated with turfgrass grown under saline conditions:

- Turf is likely to appear blue-green or light bright-green in color during the early stages of salt stress. This coloration is followed by irregular shoot growth.
- Necrotic spots may develop on leaves if toxicity from a specific ion (such as boron) occurs.
- As salinity-related stress increases, the shoots increasingly wilt and become progressively darker green.
- Higher levels of salinity cause burning of the tips of leaves, with the burn eventually extending downward toward the entire leaf surface. At this level, shoot growth is greatly reduced and turfgrass is stunted. As salinity-related stress increases, leaves generally become finer textured and the growth of roots is stunted, often resulting in

shallow roots. If corrective steps are not taken, the growth of grass will be minimal, the density of shoots will decrease, and individual plants will die, thinning the stand. The extent of salt uptake and its consequent effects on the growth of turf are directly related to the concentration of salt in the soil water. Growth of most turfgrasses is not significantly affected by salt levels below an EC_e of 2 dS/m. In soils with salt levels of more than 2 dS/m, the growth of most turfgrasses is gradually restricted. Some notable exceptions, however, would include bermudagrass and seashore paspalum, which can tolerate soil salinities greater than an EC_e of 10 dS/m. Due to pronounced differences among turfgrass species and cultivars in their tolerance to both individual salt ions and total salinity, each turfgrass must be individually evaluated with regard to a specific type of soil salinity.

- Higher levels of salinity cause burning of the tips of leaves, with the burn eventually extending downward toward the entire leaf surface. At this level, shoot growth is greatly reduced and turfgrass is stunted. As salinity-related stress increases, leaves generally become finer textured and the growth of roots is stunted, often resulting in shallow roots. If corrective steps are not taken, the growth of grass will be minimal, the density of shoots will decrease, and individual plants will die, thinning the stand.

Due to many interacting factors, the “absolute” salinity tolerance of a turfgrass species cannot be determined. However, different turfgrasses can be compared, with relative salt tolerance given in terms of the acceptable salt content of the soil root zone, expressed as the EC_e of soil water extract. Table V.D.1 (Harivandi et al., 1992; Marcum, 1990; Marcum, 1999) is a general guide to the salt tolerance of turfgrass species (substantial differences in salt tolerance exist among cultivars within species) and shows, for example, that Kentucky bluegrass (*Poa pratensis*) tolerates soil salinity at EC_e levels up to 3 $\mathrm{dS\ m^{-1}}$. As the table indicates, soils with an EC_e below 3 $\mathrm{dS\ m^{-1}}$ are considered satisfactory for growing most turfgrasses. Soils with an EC_e above 10 $\mathrm{dS\ m^{-1}}$ successfully support only highly salt-tolerant turfgrass species. Salt tolerances of warm-season and cool-season turfgrass cultivars, given in terms of both top growth and root growth, have been summarized by Carrow and Duncan (1998).

Much work has been done in screening existing cultivars or ecotypes for salinity tolerance, including these turfgrass species: *Agrostis stolonifera (*Marcum, 2001), *Buchloe dactyloides* (Wu and Lin, 1994), *Cynodon* spp. (Dudeck et al., 1983; Francois, 1988; and Marcum, 1999), *Distichlis spicata* (Marcum et al., 2005), *Festuca* spp. (Horst and Beadle, 1984; and Leskys et al., 1999), *Lolium perenne* (Rose-Frincker and Wipff, 2001), *Paspalum vaginatum* (Dudeck and Peacock, 1985; Marcum and Murdoch, 1990; and Lee et al., 2004a; 2004b), *Poa* *pratensis* (Qian et al., 2001; Qian and Suplick, 2001; and Rose-Fricker and Wipff, 2001), *Puccinellia* spp. (Harivandi et al., 1982, 1983), *Stenotaphrum secundatum* (Dudeck et al., 1993), and *Zoysia* spp. (Marcum et al., 1998; and Qian et al., 2000). Such work is important and needs to be updated at regular intervals, in order to keep up with the rapid introduction of new cultivars.

The turfgrass industry is expanding rapidly at the same time that pressures from the domestic, agricultural and ecological sectors are placing increasing demands on freshwater resources. Allocation of high-quality waters to high-priority uses has resulted in the transition of landscape sites, parklands, and golf courses to the use of recycled waters. From a survey of golf course superintendents who currently use recycled water for irrigation in the southwestern United States, Devitt et al. (2004) concluded that golf course personnel, while not opposing the switch to reuse water, found that significant changes in turfgrass management practices were required to minimize negative impacts of recycled water.

Table V.D.1. California turfgrass species tolerate various levels of soil salinity.[a]

Sensitive (<3 dS m^{-1})	**Moderately sensitive (3 to 6 dS m^{-1})**	**Moderately tolerant (6 to 10 dS m^{-1})**	**Tolerant (>10 dS m^{-1})**
Annual bluegrassess (*Poa annua*)	Annual ryegrass (*Lolium moltiflorum*)	Course-leaf zoysiagrasses (*Japonica* type)	Alkaligrass (*Puccinellia* spp.)
Colonial bentgrass (*Agrostis tenuis*)	Buffalograss (*Buchloe dactyloides*)	Perennial ryegrass (*Lolium perenne*)	Bermudagrasses (*Cynodon* spp.)
Hard fescue (*Festuca longifolia*)	Creeping bentgrass (*Agrostis palustris*)	Tall fescue (*Festuca arundinacea*)	Fineleaf zoysiagrasses (*Matrella* type)
Kentucky bluegrass (*Poa pratensis*)	Slender, creeping red, and Chewings fescues (*Festuca rubra*)		Saltgrass (*Distichlis* spp.)
Rough bluegrass (*Poa trivialis*)			Seashore paspalum (*Paspalum vaginatum*)
			St. Augustine grass (*Stenotaphurm secundatum*)

[a] Grasses listed here are grouped by their tolerance of soil salinity (expressed as the EC_e of soil paste extract).

V.E. Salt Tolerance of Native Plants

Much information has been published, both in books and on the Internet, to describe California's native plants. However, few sources of information are available regarding the salt tolerances of such plants. *Southwestern Landscaping with Native Plants* (Phillips, 1987) provides relative salt tolerances (as well as other horticultural information) for numerous trees, shrubs, and ground covers that are native to southeastern California, Nevada, Arizona, New Mexico, southern Colorado, southern Utah, and western Texas (see Table V.E.1.1). We have excerpted from that book and then consolidated and edited relevant data for those species of plants reported to be natives of California. The result is Table V.E.1.2, which lists 21 different varieties of shrubs, trees, and ground covers that may be useful for landscape projects in southern California. It is important, however, that the plants featured in this table are arid land varieties; therefore, some may not be particularly well suited for landscapes in Los Angeles or San Diego or elsewhere along the southern California coastal plain. Cross-checking these entries against other sources of horticultural information is recommended.

In the absence of published quantitative data from controlled experiments or field trials involving the salinity of native plants, qualitative salt tolerance information may prove useful. The key is to collect such information with care and to test the information thoroughly for soundness. One method for qualitatively estimating the salt tolerance of a plant is to infer that if the plant originated in an area where saline soils are common, then that plant may do well in other saline environments. Such reasoning is not without risk, however, because many other environmental factors are important during the establishment and growth of a plant and because one or more of those factors may not match between the plant's native origin and the desired site. For example, the microclimate where a plant originally thrived in the wild may not match that of the intended landscape even though the salinity of the soil and perhaps various other factors may be similar.

Another strategy that might work well is to choose several different desirable native species for your landscaping project and then attempt to research those or similar plants in Costello et al. (2003) or other references that list salt tolerance data for "conventional" ornamental plants. It may be that one or more of the California native plants for which information is sought have already become a somewhat popular plant and that their salt tolerance is listed in one of the aforementioned sources.

Table V.E.1.1. Salt tolerance of selected California native trees, shrubs, and ground covers.[a]

Botanical name	Common name	type	Native range	Salt tolerance
Artemesia tridentata	Bigleaf sage	Shrub	Dakotas, Rockies, Sierra Nevada, and Cascades; predominant in Great Basin region	Low to moderate
Atriplex canescens	Fourwing saltbush (Chamiso)	Shrub	New Mexico north to South Dakota and west to California	Excellent
Baccharis emoryii	Broom Baccharis	Shrub	Texas, New Mexico, Arizona, California, Nevada, Utah, Colorado	Good
Baccharis pilularis	Dwarf coyotebush	Ground cover	California coast—Sonoma to Monterey counties	Undocumented; coastal native origin suggests tolerance fair or better
Berberis repens	Creeping Mahonia	Ground cover	Texas, New Mexico, Arizona, California; north to Nebraska and British Columbia	Very poor
Bouteloua gracilis	Blue Grama	Ground cover	Wisconsin to Alberta, Canada; Missouri, Texas, southern California, New Mexico	Fair
Ceratoides lanata	Winterfat	Shrub	Canada south to Mexico, Rocky Mountains west to Pacific Coast	Fair
Chamaebatieria millefolium	Fernbush	Shrub	Idaho south to New Mexico, Arizona, California	Fair
Chilopsis linearis	Desert willow (Flor de Mimbres)	Tree	Central Texas west to California, northern Mexico	Very good
Chrysothamnus nauseosus	Chamisa (Rabbitbrush)	Shrub	Western Canada south to California, Texas, northern Mexico	Moderate
Cowania mexicana	Cliffrose	Shrub	Southern Colorado west to southeastern California, Mexico	Fair
Elaeagnus angustifolia “King Red”	Russian olive	Tree	Southern Europe and southwestern Asia. Naturalized in western U.S.	Excellent
Fallugia paradoxa	Apache plume	Shrub	Texas west to California; Colorado to Mexico	Fair
Fraxinus species	Ash	Tree	Texas to California, Colorado and Utah south to Mexico	Fair to poor
Gaillardia species	Blanketflower	Ground cover	Throughout North America	Good
Linum lewisii	Blue flax	Ground cover	Alaska east to Saskatchewan and south to Kansas, Texas, New Mexico, Arizona, California	Fair to poor
Penstemon ambiguus	Bush penstemon	Ground cover	Kansas, Colorado, Utah, Texas west to California	Fair
Populus tremuloides	Quaking aspen	Tree	Alaska east to Labrador, south to Virginia; Rocky Mountains south to New Mexico and Arizona	Poor
Populus fremontii and subspecies	Cottonwood	Tree	Nevada, Southwestern Utah, northern California, Arizona, New Mexico	Fair
Rhus microphylla	Littleleaf sumac (Lemita)	Shrub	Washington to Missouri, California east to Texas	Fair
Rhus trilobata	Threeleaf sumac (Lemita)	Shrub	Washington to Missouri, California east to Texas	Poor to moderate

[a] Adapted from Phillips (1987).

Table V.E.1.2. Salt-tolerant trees and shrubs for coastal southern California.[a]

Botanical name	Common name	Type of plant	Tolerant of saltwater spray?	Tolerant of saline soil?
Acacia longifolia	Sydney golden wattle	Shrub	Yes	No
Acacia melanoxylon	Blackwood acacia	Shrub	Yes	No
Albizia lophantha	Plume Albizia	Tree	Yes	No
Arctostaphylos edmundsii	Little Sur manzanita	Shrub	Yes	No
Artemisia pycnocephala	Sandhill sage	Shrub	No	Yes
Atriplex species	Saltbush	Shrub	Yes	Yes
Baccharis pilularis	Dwarf chaparral broom	Shrub	Yes	No
Caesalpinia gilliesii	Bird of paradise bush	Shrub or small tree	Yes	No
Callistemon species	Bottlebrush	Shrub or small tree	Yes	Yes
Casuarina species	Beefwood	Tree	No	Yes
Elaeagnus angustifolia	Russian olive	Small tree	No	Yes
Elaeagnus pungens	Silverberry	Shrub	Yes	No
Encelia californica	California Encelia	Shrub	Yes	No
Eriogonum giganteum	St. Catherine’s lace	Shrub	Yes	No
Eucalyptus camaldulensis	Red gum	Tree	No	Yes
Eucalyptus rudis	Desert gum	Tree	No	Yes
Eucalyptus torquata	Coral gum	Tree	Yes	Yes
Hakea suaveolens	Sweet Hakea	Shrub	Yes	No
Jasminum humile	Italian jasmine	Shrub	Yes	No
Lavatera assurgentiflora	Tree mallow	Shrub	Yes	Yes
Leptospermum laevigatum	Australian tea tree	Small tree	Yes	No
Melaleuca nesophila	Pink Melaleuca	Tree or large shrub	Yes	Yes
Melaleuca styphelioides	Black tea tree	Tree	Yes	No
Metrosideros tomentosus	New Zealand Christmas tree	Tree or large shrub	Yes	Yes
Myoporum laetum	Myoporum	Shrub or tree	No	Yes
Nerium oleander	Oleander	Shrub	No	Yes
Pinus halepensis	Aleppo pine	Tree	No	Yes
Pinus pinea	Italian stone pine	Tree	Yes	No
Pinus torreyana	Torrey pine	Tree	Yes	No
Pittosporum crassifolium	Pittosporum	Shrub	Yes	Yes
Pittosporum phillyraeoides	Willow Pittosporum	Shrub	Yes	Yes
Prunus lyonii	Catalina cherry	Shrub or tree	Yes	No
Rhus integrifolia	Lemonade berry	Shrub	Yes	No
Schinus terebinthifolius	Brazilian pepper	Tree	No	Yes
Tamarix species	Tamarisk	Tree	No	Yes
Zizyphus jujuba	Chinese jujube	Small tree	No	Yes

[a] All these plants survive well in the climate zones of the Los Angeles and San Diego areas. After Perry, 1981.

Plate 1. Salt-damaged plants and leaves.

Photo VH-1: Hibiscus does not tolerate salt very well, with leaf burn occurring even under the mildest salt treatment. Severe leaf burn is shown above.

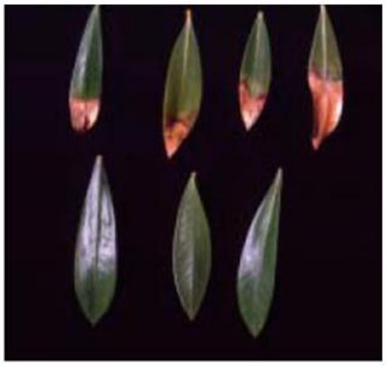


Photo VH-2: Bottlebrush is rated as moderately salt tolerant. Older leaves subjected to salt often exhibit "tip burn", as seen here.

Photo VH-3: Bougainvillea, which is not well-adapted to sand cultures, is highly salt tolerant if grown in soil.

Photo VH-4: Ivy is only slightly salt tolerant. "Bronzing" and curvature of the leaves, as shown here, is likely due to chloride toxicity.

Photo VH-5: Xylosma is moderately salt tolerant. Response to salt often varies from plant to plant.

Photo VH-6: Holly has very poor salt tolerance. This specimen exhibits moderate "bronzing" of leaves.

Photos VH-7, VH-8, VH-9: Cotoneaster has very poor salt tolerance. Shown here, left to right, are: normal plant, plant grown at low salt level (EW$_{iw}$ 3.1 dS/m), plant grown at high salt levels (EC$_{iw}$ 6.2 dS/m).

Photos VH-10, VH-11, VH-12: The tulip tree (*Liriodendron tulipifera*) is very sensitive to salt. Photo above shows, from left to right, a normal leaf, a leaf from plant grown with water of 2,000 ppm TDS, and leaf from plant gown at 4,000 ppm TDS. Photos at left show leaf damage two months after beginning of salinity treatment.

Photos VH-13, VH-14: Shown at right are crape myrtle leaves from plants grown with high-salt water (left, EC$_{iw}$ 6 dS/m), low-salt water (3 dS/m), and the control. Samples shown at far right exhibit "tip burn" and "bronzing".

Plate 2. Boron-damaged eucalyptus tree.

Photos VH-19, VH-20, VH-21: Leaves of the eucalyptus in all of the above photos show signs of boron damage (B=25 ppm; EC_i=2).

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