Use of Saline and Non-potable Water in the Turfgrass Industry: Constraints and Developments

Kenneth B. Marcum

Department of Applied Biological Sciences, East College, Arizona State University, 7001 E. Williams Field Rd. Bldg. 130,
Mesa, AZ 85212, Kenneth.Marcum@asu.edu

Abstract

The need for salt-tolerant turfgrasses is ever-increasing. Rapid urban population growth has put enormous pressures on limited freshwater supplies. Many state and local governments have reacted by placing restrictions on the use of potable water for irrigating turfgrass landscapes, instead requiring use of reclaimed, or other secondary saline water sources. In coastal areas, overpumping, and resultant salt water intrusion of coastal wells used for irrigating turfgrass facilities has widely occurred. The nature and extent of the salinity problem, followed by basic salinity issues and available management choices, will be discussed. Issues facing the turf manager using saline water sources are soil salinization, resulting in direct salt injury to turf, and secondary problems of loss of soil structure ensuing from sodium and bicarbonate effects, resulting in loss of salt leaching potential and soil anaerobiosis. Management choices for the turf manager using saline water are limited. Soil salinity must be maintained below the level deemed detrimental to the turf, by maintaining sufficient leaching. Sodium/bicarbonate affected soils must be managed to maintain sufficient permeability to permit adequate leaching. Finally, salt tolerant turf species/cultivars must be used. Long-term solutions to the salinity problem will require development of improved salt-tolerant turfgrasses. Progress in cultivar development, and future development of potential alternative halophytic turfgrass species will also be discussed.

Media summary

Rapid urbanization has resulted in escalating salinity issues facing turfgrass landscapes. The extent of the salinity problem, salinity management issues, including soil salt-leaching and sodicity-permeability management, use of salt tolerant turf cultivars, and future development of salt tolerant turfgrasses will be discussed.

Key Words

water quality, salinity tolerance, breeding, halophytes

Nature and extent of problem

Shortage of fresh water is one of the major environmental specters confronting humanity in the 21st century. The United Nations predicts that 2.7 billion people will face severe water shortages by 2025 if consumption continues at current rates (Montaigne 2002). Soil salinity is an escalating problem worldwide, with nearly 10% of the earth’s total land surface, or 954 Mha covered with salt-affected soils, and up to 100 Mha saline due to irrigation (Ghassemi et al. 1995; Pessarakli and Szabolics 1999). Between 10 and 20 Mha of irrigated lands deteriorate to zero productivity each year due to salinity (Hamdy 1996; Choukr-Allah 1996).

Critical water shortages are occurring in rapidly growing urban areas, resulting in restrictions on the use of potable water for irrigating turfgrass landscape areas. Turfgrass landscape irrigation is typically considered a low priority use for fresh water, particularly when water shortages occur (Kjelgren 2000). Rapidly expanding population growth is occurring in many arid regions, where soil and water salinity are problems, placing increased demands on limited fresh water resources. Recently, laws have been passed in a number of western states in the U.S.A., requiring the use of saline water sources for turfgrass irrigation (California State Water Resources Control Board 1993; Arizona Department of Water Resources 1995). Saline sources mandated for use on turfgrass can include reclaimed water (sewage effluent), brackish groundwater caused either by salt leaching or seawater intrusion, and other sources. Salinity problems on turf are also becoming acute in coastal areas, where increasing demands on fresh water aquifers are resulting in salt water intrusion (Parker 1975; Murdoch 1987; McCarty and Dudeck 1993). Turfgrass developments in these areas are often required to use brackish water from affected wells, or other secondary water sources. Finally, salinity problems occur on roadside turf in regions where salts are used to remove snow and ice from roadways (Greub et al. 1985).

Salinity issues and management

Salinity problems in turfgrass are often difficult to diagnose, and usually expensive to manage. The major water/soil quality issues related to salinity include:

- total salinity
- sodium hazard, and
- bicarbonate hazard

Total salinity

Saline water and soil contain various salts; the most common being sodium, potassium, calcium, and magnesium associated with anions chloride, sulfate, and carbonate/bicarbonate (Rhoades 1972). Total salinity is expressed either as electrical conductivity (EC) or as total dissolved salts (TDS) in parts per million (PPM). Conversions between units of measurement can be made on the basis that: 1millesiemen per centimeter (mS cm^{-1}) = 1 decisiemen per meter (dS m^{-1}) = 1 millimhos per centimeter (mmhos cm^{-1}) = 1000 µmhos cm^{-1} (EC) ≈ 640 PPM (TDS). Irrigation water salinity is generally classified as: low (<0.25 dS m^{-1} EC), medium (0.25-0.75 dS m^{-1} EC), high (0.75-2.25 dS m^{-1} EC) and very high (>2.25 dS m^{-1} EC), while soil is classified as saline when ECe (electrical conductivity of the saturated paste) > 4 dS m^{-1} (U.S. Salinity Laboratory 1969). The best means of monitoring salinity is by measuring soil ECe, and turfgrass salt tolerances are generally expressed on the basis of ECe (Marcum 1999a).

Salts can quickly accumulate in the soil profile when irrigating with saline water, particularly when evaporative demand is high. For example, the application and evaporation of 2.5 cm of irrigation water having an EC value of 2 dS m^{-1} will deposit ~3.0 kg of salt within a 93 m^2 (1000 ft^2) area. To avoid salt injury, soil salinity must be maintained below the salinity tolerance level of the turfgrass. The leaching percentage required to maintain soil salinity below this level is termed the leaching fraction (LF):

%LF = ($EC_{\text{irrigation water}}$? $EC_{\text{drainage water}}$) X 100 where $EC_{\text{drainage water}}$ is equivalent to the salinity of the rootzone, and consequently the salinity tolerance of the turfgrass. Alternately, average salinity of irrigation water (EC_{water}) can be reduced by: (a) blending saline water with a higher quality source, or (b) alternating low and high quality water sources through time.

Sodium hazard

Turfgrass salinity problems are often compounded by the effects of sodium (Na^+) on the dispersion of soil colloids, resulting in a loss of soil structure. Loss of structure results in compaction-prone soils (of great concern in high traffic areas), with resultant anaerobiosis and loss of rooting. Anaerobiosis also has the effect of increasing the transport of salt to shoots, decreasing plant growth and survival (Barrett-Lennard 2003). Further, leaching potential is lost, accelerating the buildup of salts within the rootzone. Maintenance of good saturated hydraulic conductivity (K_{sat}) is important (a rate of >1.2 cm hr^{-1} is a good goal for medium textured soils). K_{sat} must be maintained above the precipitation rate (PR), otherwise irrigation cycling will be necessary.

Soil colloid dispersion is affected by the ratio of Na^+ to the divalent cations calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the irrigation water, a ratio known as the sodium adsorption ratio (SAR): SAR = $[Na^+] / \{([Ca^{2+}]+[Mg^{2+}])/2\}^{1/2}$. Irrigation waters are classified as to their Na^+ hazard as follows: low (0-10 SAR), medium (10-18 SAR), high (18-24 SAR) and very high (>24 SAR) (U.S. Salinity Laboratory 1969). Clays are more susceptible to deflocculation than silt, and 2:1 (or expanding) clays are particularly susceptible.

Therefore, medium SAR's may be a problem on fine-textured soils only, and particularly on soils rich in illite or montmorillonite. High SARs will be a problem on all soils save sand, and very high SARs should not be used without gypsum or similar amendments.

Gypsum neutralizes the dispersive effects of Na^+ via the reaction:

$2Na^+X + CaSO_4 \rightarrow CaX_2 + Na_2SO_4$

where X is a soil colloid. Gypsum should be incorporated into the soil profile whenever possible, as it has a low solubility (solubility product 9×10^{-6}). The amount required to displace exchangeable Na^+ on the soil colloids depends on the percentage of cation exchange sites taken up by Na^+ which is expressed as the exchangeable sodium percentage (ESP). Ideally, the ESP should be maintained below 15%. Lowering the ESP is a gradual process, with light, frequent gypsum applications being more effective than single, heavy ones. Typical rates vary from 11 to 22 kg per 93 m^2 (1000 ft^2) per month. Gypsum can also be applied at low, maintenance-level rates through the irrigation system with specialized metering equipment.

Bicarbonate hazard

Bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) affect Na^+ hazard indirectly, by precipitating Ca^{2+} and Mg^{2+}, via the reaction:

CO_3^{2-} (or H^+-CO_3^{2-}) + Ca^{2+} (or Mg^{2+}) → $CaCO_3$ (or $MgCO_3$).

The bicarbonate hazard (concentration of bicarbonate in the irrigation water) is generally defined as: low (0-120 PPM), moderate (120-180 PPM), severe (180-600 PPM) or very severe (>600 PPM). When bicarbonates are a problem, acidifying amendments are typically used, such as sulfur or sulfuric acid. Acid reacts directly with bicarbonate to form carbon dioxide. In addition, sulfuric acid will react with soil calcium carbonate to form gypsum, thereby reducing Na^+ hazard, by this reaction: $H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$. Therefore, sulfur products should only be applied in situations where abundant free calcium carbonate is present, which is typical in many arid-land soils. Powdered sulfur can be added to the soil, or onto turf, but application rates must be minimal to avoid turf burn [<2.2 kg per 93 m^2 (1000 ft^2)], and when temperatures are above 21˚C to allow oxidation of the sulfur by soil bacteria to form sulfuric acid. Alternately, sulfuric acid can be injected directly into the irrigation system to neutralize bicarbonates. Injection must be at a low rate, sufficient to neutralize only 70-80% of bicarbonates, otherwise, irrigation water pH will drop precipitously. Sulfuric acid injection is also utilized as a long-term maintenance technique, maintaining soil ESP and Na^+ hazard below harmful levels.

Turfgrass salinity tolerance, salinity tolerance mechanisms, and breeding for tolerance

Turfgrass salinity tolerance

Proper turf management techniques are critical in counteracting salinity. However, as salinity problems continue to escalate, long-term solutions will require development and use of salt tolerant turfgrass genotypes. Turfgrass salinity tolerance is a complex phenomenon, influenced by a number of environmental, edaphic, and plant factors. Salinity tolerance often differs with the stage of plant development (e.g. seedling, juvenile, mature) (Hughes et al. 1975). Climatically, both temperature and relative humidity can influence plant response to salinity (Maas 1986). For example, plants are more sensitive to salinity under hot, dry conditions than under cool, humid ones, probably due to increased evapotranspirational demand, favoring increased salt uptake (Hoffman and Rawlins 1971). Edaphic factors also influence the plant response to salinity (Maas and Hoffman 1977; Harivandi 1988). Soil water content changes have a direct effect on rootzone salinity. Indeed, soil salinity varies with time and depth, increasing as the soil dries between irrigations, and also as depth increases, with salt concentrations approximately that of the irrigation water near the soil surface, but several times higher at the bottom of the root zone (Maas 1986; U.S. Salinity Laboratory 1969). To minimize the effects of variable edaphic and climatic conditions on plant responses to salinity, some researchers have utilized solution or hydroponic culture under controlled environmental conditions (growth chambers, greenhouses) in plant salt-tolerance research.

Owing to the interacting factors discussed above, the absolute salinity tolerance level of a particular turfgrass genotype or cultivar cannot be determined (Maas 1986; Maas and Hoffman 1977). For example, the salinity concentration resulting in a 50% reduction of the shoot dry weight of ‘Tifway’ bermudagrass (green couch), has been variously reported as 33 dS m^{-1} (Dudeck and Peacock 1993), 27 dS m^{-1} (Marcum and Murdoch 1994), 18.6 dS m^{-1} (Dudeck et al. 1983), and 12 dS m^{-1} (Smith et al. 1993). The use of different criteria to measure salinity tolerance further complicates comparisons. For example, shoot weight (Hughes et al. 1975), shoot weight reduction relative to nonsalinized plants (Dudeck and Peacock 1985a), root weight or length (Kik 1989), shoot/leaf length (Horst and Beadle 1984), shoot visual injury (Greub et al. 1985), plant survival (Ahti et al. 1980), and seed germination (Marcar 1987) have all been used as measures of salinity tolerance in turfgrasses. Finally, units used in measuring salinity often vary from study to study, including: total dissolved solids on a weight basis (PPM or mg L^{-1}), total dissolved solids in milliequivalents per liter (meq L^{-1}), or on a conductivity basis (mmhos cm^{-1}, dS m^{-1}). Even with these limitations, tolerances relative to one-another can be estimated between studies having at least one entry in common. **Table 1** is a synopsis of turfgrass salt tolerance research literature. Results are presented in standardized units, i.e. EC$_e$ values (dS m^{-1}) resulting in a 50% shoot yield reduction.

Table 1. Estimated relative salinity tolerances of turfgrasses (after Marcum, 1999a).

C$_3$ (cool season) Turfgrasses	EC$_e$ (dS m^{-1}) for 50% decrease in growth [a]	C$_4$ (warm season) Turfgrasses
	35+ [b]	*Distichlis spicata* var. *stricta*
		Sporobolus virginicus
Puccinellia airoides	25	***Paspalum vaginatum***
Puccinellia distans		***Zoysia matrella***
‘Fults’ [c]		‘Diamond’
Puccinellia lemmoni		Zoysia tenuifolia
	18	***Stenotaphrum secundatum***
		‘Seville’
	15	*Cynodon* spp
		‘FloraTex’

	12	***Zoysia japonica***
		‘El Toro’
Agrostis stolonifera	9	
‘Mariner’		
Festuca arundinaceae	7	
‘Alta’		
Festuca rubra	6	
‘Dawson’		
Lolium perenne	5	***Buchloe dactyloides***
‘Paragon’		*Bouteloua* spp.
Poa pratensis	3	*Axonopus* spp.
‘North Star’		***Eremochloa ophiuroides***
Poa trivialis		
Festuca longifolia/elatior/ovina		
Lolium multiflorum		
Poa annua	2	Paspalum notatum
Agrostis tenuis/canina		

[a] Salinity level of soil saturated paste extract (ECe), representing approximate midrange tolerance per species.

[b] Calculated assuming: 1 dS m^{-1} = 1 mmhos cm^{-1} ≅ 640 ppm

[c] Indented names in single quotes represent the most salt tolerant cultivar currently known within the turf species directly above.

Turfgrass salinity tolerance mechanisms

To date, relatively little progress has been made in breeding for improved salinity tolerance in turfgrasses. However, a number of studies have examined the physiology of turfgrass salinity tolerance. Understanding the mechanisms of salt tolerance may provide biological “markers” suitable for use as selection tools in salt tolerance breeding efforts.

Historically, salinity tolerance has been associated with osmotic adjustment and avoidance of “physiological drought” (Bernstein and Hayward 1958), but modern studies have cast doubt on this. Shoot saline ion exclusion, coupled with minimal yet adequate osmotic adjustment, is now considered central to salinity tolerance in most plant species (Wyn Jones and Gorham 1989; Hu et al. 1998). Saline ion (Cl^- and Na^+) exclusion has been correlated with salinity tolerance among divergent plant genera (Akita and Cabuslay 1990; Rogers et al. 1997). Salt-sensitive plants have been found to accumulate saline ions to toxic levels, well above those required for osmotic adjustment, resulting in shoot sap osmolarities well in excess of the saline growing soil/media (Headley et al. 1992). This was noted in a study comparing eight C_4 turfgrass species belonging to the subfamily Chloridoideae (Marcum 1999b). Salinity tolerance was based on reduction in shoot clipping weights with increasing salinity relative to control plants, with the salinity resulting in 50% yield reduction used as the reference point for comparisons. Salinity tolerance decreased in the order: *Distichlis spicata* spp. *stricta, Sporobolus airoides*, *Sporobolus virginicus*, *Cynodon dactylon*, *Zoysia japonica, Sporobolus cryptandrus*, *Buchloe dactyloides*, and *Bouteloua curtipendula* (**Figure 1**a).

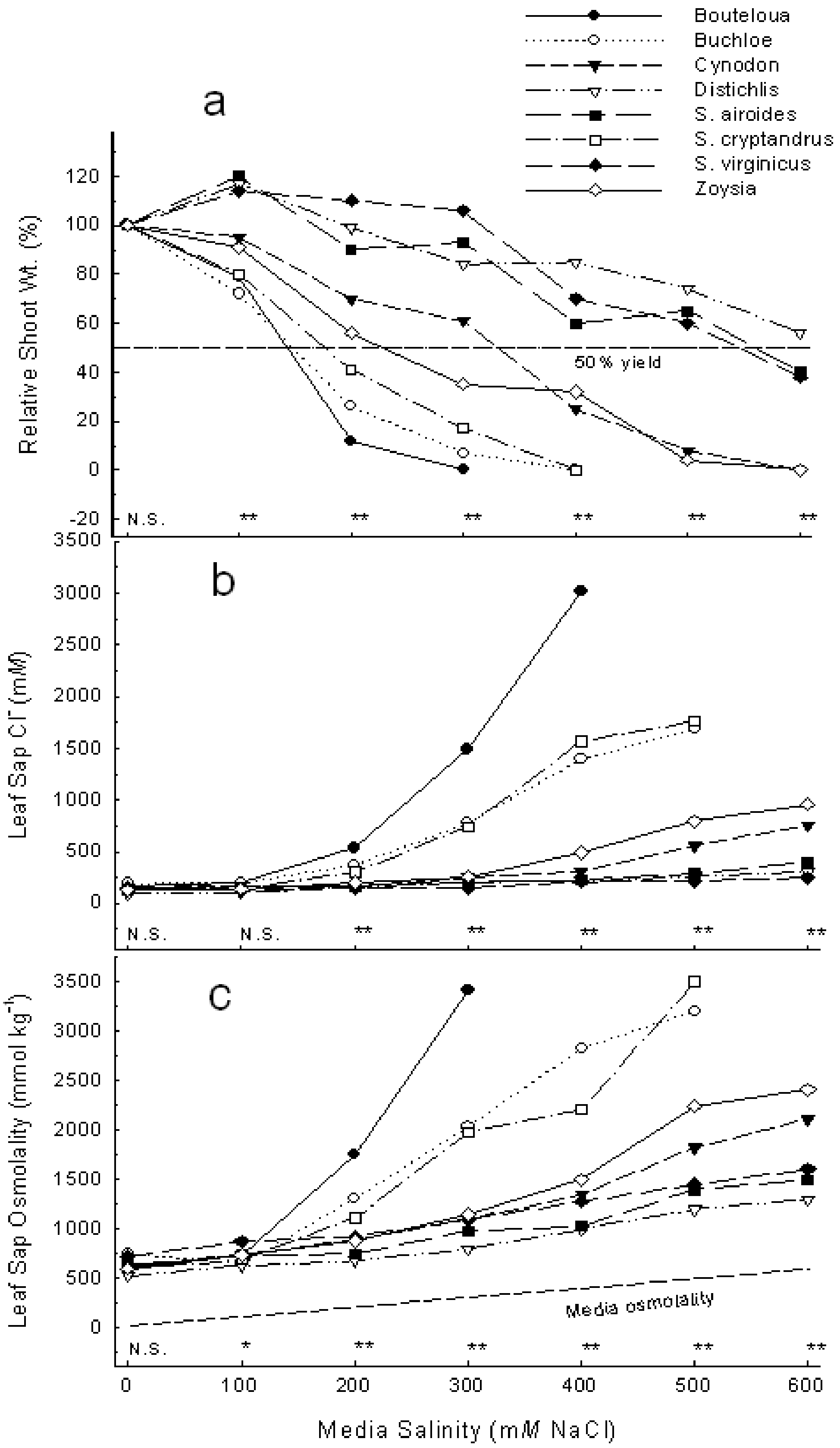
Bouteloua
Buchloe
Cynodon
Distichlis
S. airoides
S. cryptandrus
S. virginicus
Zoysia
a
Relative Shoot Wt. (%)
120
100
80
60
40
20
0
-20
50 % yield
N.S.
**
**
**
**
**
**
b
Leaf Sap Cl⁻ (mM)
3500
3000
2500
2000
1500
1000
500
0
N.S.
N.S.
**
**
**
**
**
c
Leaf Sap Osmolality (mmol kg⁻¹)
3500
3000
2500
2000
1500
1000
500
0
Media osmolality
N.S.
*
**
**
**
**
**
0
100
200
300
400
500
600
Media Salinity (mM NaCl)

Figure 1. a) Relationship between growth and ion relations in 8 turfgrass species at increasing levels of salinity: (a) dry weight of shoot clippings as a percent of control plants, (b) leaf sap Cl- concentration, and (c) leaf sap osmolarity.

All species in the study maintained complete osmotic adjustment, even under high salinity, by maintaining leaf sap osmolalities greater than that of the saline growing media (Figure 1c). However, the salt-sensitive species had greater leaf osmotic adjustment than the salt tolerant species. In parallel, salt-sensitive species had higher leaf Cl^- concentrations under salt stress than salt-tolerant species (Figure 1b). In fact, these relationships demonstrated a perfect trend: the more salt tolerant a species was, the lower the leaf Cl^- concentration, and the lower the osmotic adjustment achieved, demonstrating conclusively that salinity tolerance is associated to salt ion (i.e. Cl^-) exclusion, and minimal shoot osmotic adjustment among these important warm season turfgrass species. In fact, salinity tolerance (salinity resulting in 50% shoot yield) was highly correlated with shoot Cl- ion exclusion ($r=0.80$, $P < .001$), and with leaf sap osmolarity (osmotic adjustment) ($r=0.85$, $P < .001$).

A number of salt-adapted species have salt glands or bladders, which eliminate excess saline ions from shoots by excretion (Flowers et al. 1977; Liphschitz and Waisel 1982). Within the Poaceae (grasses), bicellular leaf epidermal salt glands have been reported to occur in over 30 species within the tribes Chlorideae, Eragrosteae, Aeluropodeae, and Pappophoreae (Liphshchitz and Waisel 1974; Taleisnik and Anton 1988; Amarasinghe and Watson 1989), all members of the subfamily Chloridoideae (Gould and Shaw 1983). Salt glands in the Poaceae consist of a basal cell, attached, or imbedded, into the leaf epidermis, and a cap cell (Liphshchitz and Waisel 1974; Fahn A 1988) (**Figure 2**a).

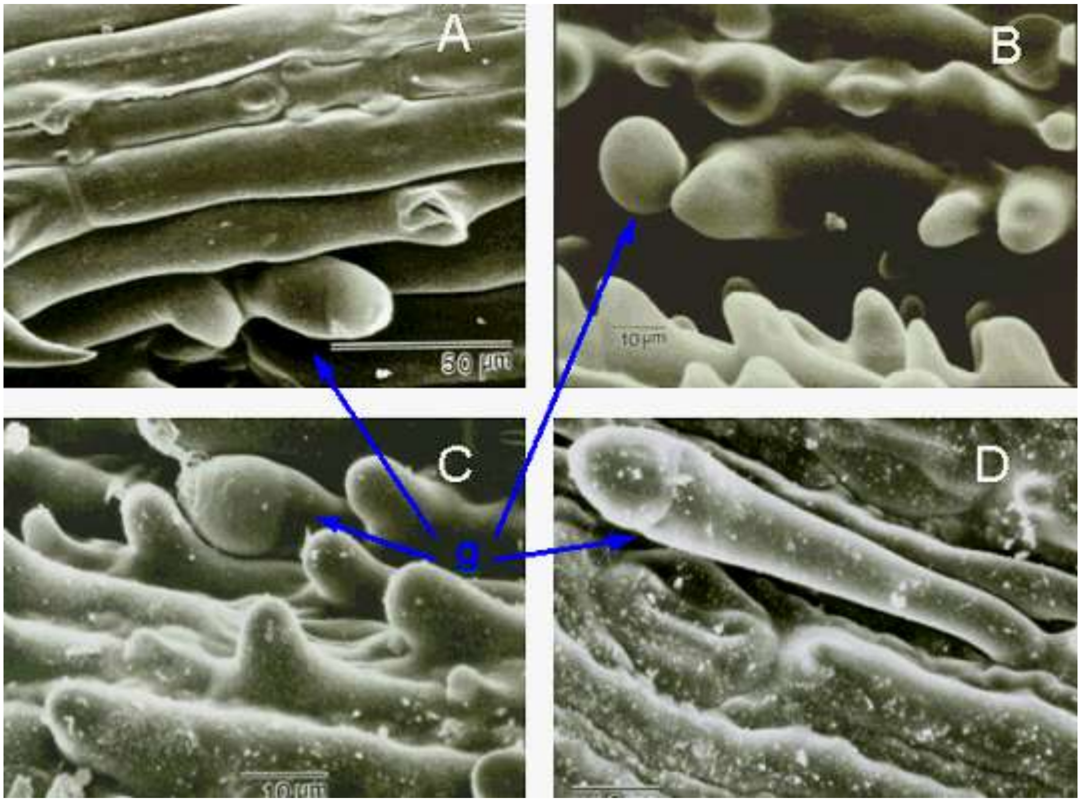

Figure 2. Scanning electron micrographs of salt glands on adaxial leaf surfaces of: (A) *Sporobolus airoides*,

(B) *Distichlis spicata* ssp. *stricta*, (C) *Cynodon dactlyon*, and (D) *Buchloe dactyloides*. Salt glands are labeled as: g. Other protrusions which are not bicellular are papillae.

The glands are characterized by cutinized cell walls, and are often surrounded by papillae. Though the basic, bicellular structure is the same in all Chloridoid species, their appearance varies. In some species, glands are sunk into the epidermis, with the basal cell totally imbedded, e.g. *Distichlis* spp. (Figure 2b). In others, the basal cell is semi-imbedded, e.g. Cynodon spp. (Figure 2c) Finally, the basal cell may extend out from the epidermis, with the gland lying recumbent to the leaf surface, e.g. *Buchloe* spp. (Figure 2d). Salt glands of Poaceae are quite small, though size may vary substantially, from imbedded to elongated, protruding types. Glands ranged in size from 15 μm in length in *Distichlis* spp. to 70 μm in *Buchloe* spp. Salt glands are found on both abaxial and adaxial leaf surfaces of excreting Chloridoid species, longitudinally arranged in parallel rows, adjacent to rows of stomata (Marcum 2001a).

Salt gland Na^+ and Cl^- excretion rates were correlated with both shoot Na^+ and Cl^- concentrations (negative correlation: $r = -0.52$; $P < .05$) and with plant salinity tolerance (positive correlation: $r = 0.70$; $P < .001$). Grasses with higher salt gland excretion rates maintained lower shoot salt ion concentrations, resulting in superior salinity tolerance. **Table 2** shows ion excretion rates for 8 Chloridoid grasses, from *Bouteloua curtipendula* (salt-sensitive) to *Sporobolus virginicus* (halophytic).

Table 2. Cl^- and Na^+ excretion rates in 8 warm season turfgrass species.

Grass species	Cl^- mg/gm/day	Na^+ mg/gm/day
Bouteloua curtipendula	0.7	0.5
Buchloe dactyloides	1.1	1.0
Sporobolus cryptandrus	1.9	1.4
Cynodon dactylon	6.0	2.2
Zoysia japonica	6.4	3.0
Sporobolus airoides	19.0	12.0
Distichlis spicata ssp. *stricta*	45.1	28.3
Sporobolus virginicus	55.0	39.4
LSD(P=0.05)	4.1	2.0

Note that *Sporobolus virginicus* had Na^+ and Cl^- excretion rates more than 75 times higher than *Bouteloua*. Similar strong correlations between salt gland excretion rates, shoot Na^+ and Cl^- concentrations, and salinity tolerance were observed among three Chloridoid grasses in another turf study (Marcum and Murdoch 1994). Relative order of salinity tolerance again followed saline ion excretion rates, with *Zoysia matrella* (highly salt-tolerant) having a Na^+ excretion rate of 730, compared to bermudagrass (salt tolerant) at 660 , and *Zoysia japonica* (moderately salt-sensitive) at 360 $\mu mol\ g^{-1}$ (leaf dry wt) $week^{-1}$, respectively. Same-species differences between studies are due to different saline treatment levels and growing conditions.

Turfgrass salt tolerance breeding

This relationship between salt gland activity and salt tolerance was also found to hold *within* genera. Sodium and Cl^- excretion rates were negatively correlated with salt ion concentrations in shoots, but positively correlated to salinity tolerance among 57 zoysiagrass genotypes (Marcum et al. 1998). In addition, salt gland excretion rates were found to be correlated with the number of glands present per unit leaf surface area (i.e. gland density) (**Figure 3**). Salt gland density (i.e. salt gland number per unit leaf area) represents a simple morphological trait which can be used as a selection tool in breeding for salt tolerance among turfgrasses within the Chloridoideae. Salt gland density in the *Zoyseae* is not influenced by the salinity level of the growing media (Marcum 2003). In other words, salt gland density is innate within a particular genotype; the same whether grown under saline or non-saline conditions. This suggests that the trait is highly heritable, and can be used as a salt tolerance selection tool on turfgrasses not exposed to salinity stress. This makes possible salt tolerance breeding of Chloridoid turfgrasses under non-saline conditions, thereby greatly expediting breeding efforts.

Turfgrass salinity tolerance breeding programs are currently few. Much work has been done in screening existing cultivars or ecotypes for salinity tolerance, including these turfgrass species: *Agrostis stolonifera* (Marcum 2001b), *Buchloe dactyloides* (Wu and Lin 1994) *Cynodon* spp. (Dudeck et al. 1983; Marcum and Pessarakli 2000), *Festuca* spp. (Horst and Beadle 1984), *Lolium perenne* (Rose-Fricker and Wipff 2001), *Paspalum vaginatum* (Dudeck and Peacock 1985b; Lee et al. 2002, 2004a,b), *Poa pratensis* (Horst and Taylor 1983; Rose-Fricker and Wipff 2001), *Stenotaphrum secundatum* (Dudeck et al. 1993), and *Zoysia* spp. (Marcum et al. 1998; Qian et al. 2000). Such work is important, and needs to be updated at regular intervals, due to the rapid introduction of new cultivars.

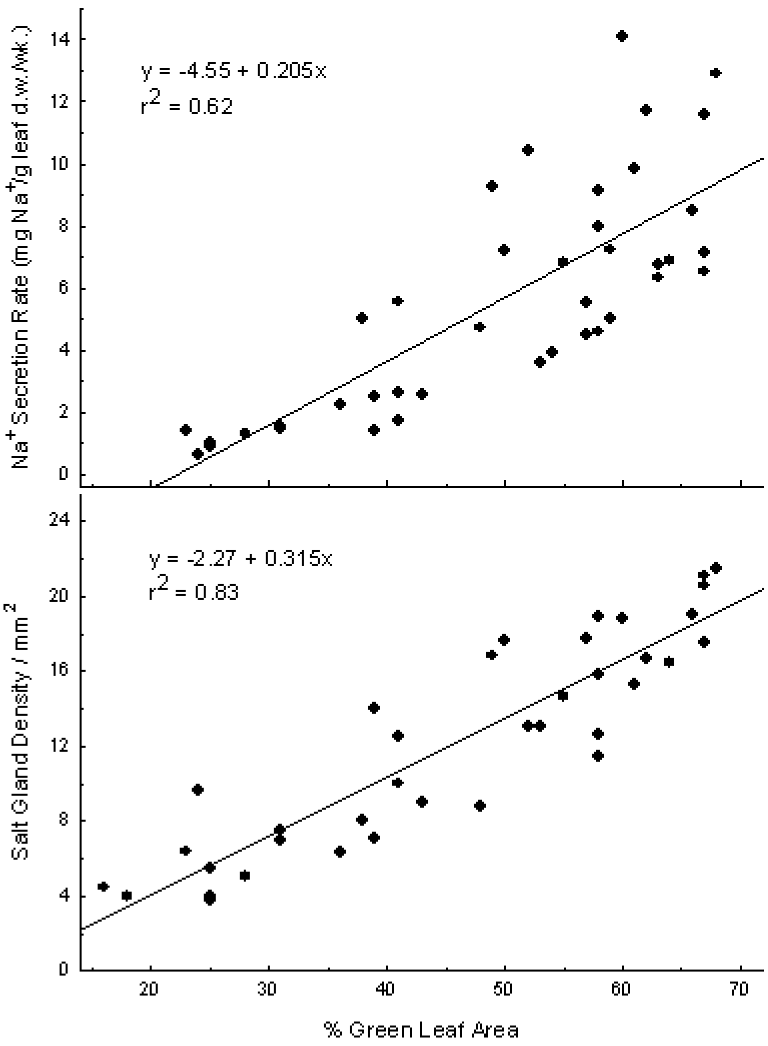

Figure 3. Salt gland excretion activity, and salt gland density, as related to salinity tolerance, within the *Zoysia* genera.

Turfgrass breeding programs having a salinity tolerance component:

Current turfgrass breeding program efforts having a salinity tolerance component are few in number. These are listed below, with current literature citations which describe accomplishments in detail.

Warm season turfgrasses:

- *Paspalum vaginatum* is a warm season species having inherently good salinity tolerance. A number of improved salt tolerant genotypes of this species having improved turf characteristics are being developed (Lee et al. 2002, 2004a,b; Duncan 2003).
- Zoysiagrass cultivars having good salinity tolerance have recently been developed; these have a high degree of salt gland activity (Engelke et al. 2002a; Engelke et al. 2002b).

Cool season turfgrasses:

- A salinity tolerant creeping bentgrass cultivar 'Mariner' has been developed through backcrossing of improved cultivars with seashore ecotypes (Lehman et al. 1998).
- Salinity tolerance screening of breeding lines is currently underway in *Festuca arundinaceae* (Wipff and Rose-Fricker 2003), and in *Festuca rubra* ssp. *rubra* and *commutata* (Sellmann 2001).
- Somaclonal variation is being utilized to establish salt tolerant mutations for breeding efforts in *Agrostis stolonifera* (Redwine 2000) and *Poa pratensis* (Zhnag et al. 2002).

Development of alternative halophytic genera:

Puccinellia spp., also known as alkali grasses, are the most salt-tolerant turf-type cool-season grasses. *Puccinellia distans* [L.] Parl. (weeping alkali grass) has been reported as surviving in soils with ECe values over 46 dS m^{-1} (Butler 1972). The US Salinity Laboratory (1969) categorized *Puccinellia airoides* [Nutt.] Wats & Coult. (nuttall alkali grass) as having high salt tolerance (50% growth decreases at ECe values 12-18 dS m^{-1}), being more salt tolerant than *Cynodon dactylon* but less salt tolerant than *Distichlis spicata* var. *stricta*. Alkali grasses are found inhabiting saline and alkaline sites in cooler portions of North America (Gould and Shaw 1983), and were first considered for use as turfgrasses in Illinois (Sanks 1971) and Colorado (Butler 1972), when found along roadsides where deicing salts had eliminated other grasses. No current turf breeding efforts are known, and only two improved cultivars have been released: 'Fults' (Butler et al. 1974) and 'Salty' (Lehman pers. comm.).

Distichlis spicata var. stricta

Yensen has worked extensively with this species, resulting in development of grain, forage, and turf (cv. NyPaTurf) cultivars (Yensen et al. 1988). In other studies, ecotypes from throughout the western United States are being evaluated for turf growth characteristics and salinity tolerance, in a joint effort of University of Arizona and Colorado State University (Kopec and Marcum 2001; Hughs et al. 2002). Though there is great range in salinity types among ecotypes, some are true halophytes, suffering essentially no leaf firing when grown in full strength seawater (e.g. A-55, A-137) (**Figure 4**). In contrast, *Cynodon* spp. cv. Midiron was dead at EC values in the growth medium of 36 dS m^{-1}.

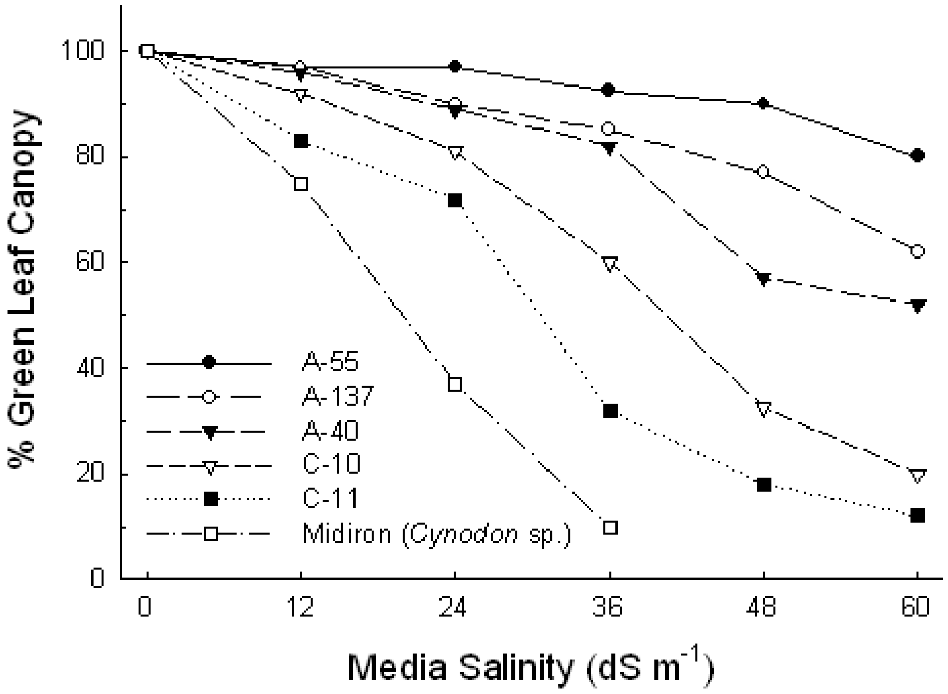

Figure 4. Relative salinity tolerance (% visual green canopy) with increasing salinity of five *Distichlis spicata* accessions and one *Cynodon* cultivar.

Other spp.

Researchers at the Queensland Department of Primary Industries Redlands Research Station in Australia are currently selecting for turf growth characteristics and high salinity tolerance in the native and indigenous grasses *Sporobolus virginicus* and *Zoysia macrantha* (Loch and Lees 2001); these are halophytic species offering great potential for land stabilization in highly saline areas. Depew of EnviroTurf LC has selected turf ecotypes, and subsequently released cultivars of *Sporobolus virginicus* and seashore paspalum (*Paspalum vaginatum*) (Depew et al., 1998).

As water shortages continue to escalate worldwide, increasing use of saline water for turf landscape irrigation will be necessary. Under these conditions, management scenarios for high value turfgrass are often limited and expensive. Due to these limitations, the development of turfgrass cultivars having improved salinity tolerance, coupled with the development of novel halophytic and xerophytic (drought-loving) species should play a central role in the turfgrass industry.

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