Relative NaCl Tolerance of Kentucky Bluegrass, Texas Bluegrass, and Their Hybrids

M. R. Suplick-Ploense,* Y. L. Qian, and J. C. Read

ABSTRACT

Government regulations to force water conservation have escalated the use of secondary water high in soluble salts for turfgrass irrigation in the arid and semiarid western USA, thus increasing the need for more salt-tolerant turfgrasses. This study was initiated to determine the variability in salt tolerance within and among two *Poa* species and their hybrids. Two experiments were conducted during 2000 in the greenhouse at Fort Collins, CO, in solution culture to examine the effects of NaCl on leaf firing and shoot and root growth reduction of nine Kentucky bluegrass (KBG; *Poa pratensis* L.) cultivars representing three ecotypes, three Texas bluegrass (TBG; *P. arachnifera* Torr.) accessions, and five of their hybrids (*P. pratensis* × *P. arachnifera*). In Exp. I, conducted during late winter through spring 2000, overall salt tolerance based on leaf firing and electrical conductivity (EC) of 50% shoot growth reduction (EC_{shoot} 50) placed seven KBG cultivars in the most tolerant group. In Exp. II, conducted during summer though early fall 2000, overall salt tolerance rankings placed 4 KBG and 3 TBG cultivars in the most tolerant group. On the basis of percentage leaf firing and the salinity levels that caused 25 and 50% shoot growth reduction, compact (low, compact growth habit) and aggressive (aggressive, lateral growth habit) KBG ecotypes showed more salt tolerance than common ecotypes in both Exp. I and II. A broad range of variability in leaf firing and shoot and root growth reduction in response to salinity was found to exist within and among these *Poa* species and their hybrids, indicating that improvement in the salt tolerance of bluegrasses may be possible. Additionally, differences in salt tolerance of KBG and TBG between Exp. I and Exp. II suggested that environmental conditions could affect bluegrass salt tolerance expression.

Demands on fresh water resources in the western USA have resulted in codified limitations on the permissible area devoted to turfgrass (Clark Co., NV, 1992; City of Aurora, CO, 1998) as well as the quantity of potable water relegated to its irrigation (Hull and Pearson, 1999; City of Albuquerque, NM, 2000). As a result, secondary or effluent water, often containing high concentrations of NaCl, the only municipal water supply expected to increase in this region in the future (Oad and DiSpigno, 1996), is increasingly being used as an irrigation source for turfgrass whenever available (Gill and Rainville, 1994; Marcum et al., 1998; San Diego County, CA, 2000). Freshwater conservation mandates in rapidly growing metropolitan areas of the arid and semiarid western USA, where saline soils are common, has increased the need for more salt-tolerant turfgrasses.

Kentucky bluegrass, considered to be salt-sensitive with an average threshold EC of 3 dS m^{-1} (Carrow and Duncan, 1998), is the most widely used cool-season turfgrass species in the more temperate regions of the western USA (Christians, 1998). Texas bluegrass is native to the southern Great Plains, and persists under extended periods of high temperature (Gould, 1975). 'Reveille' hybrid bluegrass (HBG), a hybrid between KBG and TBG and recently released as a heat-resistant hybrid bluegrass for the southwestern USA (Read et al., 1999), may increase the area of bluegrass planted under saline conditions.

Several studies have been conducted to assess the effect of salinity on KBG (Grueb et al., 1983; Horst and Taylor, 1983; Torello and Spokas, 1983; Torello and Symington, 1984; Butler et al., 1985; Qian et al., 2001). However, screening of the considerable amount of KBG plant material released during the past 15 yr for salt tolerance has received little attention. Although KBG is generally ranked as a salt-sensitive turfgrass, variability in salt tolerance has been shown to exist among cultivars. Horst and Taylor (1983), examining germination and initial growth in saline solution culture, reported significant differences in salt tolerance during germination and initial growth between 44 KBG cultivars. Variability in salt tolerance at the species level has likewise been demonstrated in bluegrass. Grueb et al. (1983) found Rough stalk bluegrass (*P. trivialis* L.) to be more salt-tolerant than a group of six KBG cultivars, within which group there was significant variability in visual appearance under salt stress. Demonstrated inter- and intra- specific variability in salt tolerance among the *Poa* spp. suggests that genetic improvement in the salt tolerance of bluegrasses is possible. More current information regarding the salt tolerance of KBG is needed. Nothing is known of the salt tolerance of TBG or HBG.

Therefore, the objective of this study was to examine the growth and turf quality responses to salinity within and among KBG cultivars, TBG accessions, and their hybrids.

MATERIALS AND METHODS

Plant Material

Five KBG cultivars were chosen for this study: 'Huntsville', 'Dellwood Fine', and 'H-86-386' because they served as the pollen source for the HBG examined in this study, and 'Kenblue' and 'Bensuns A-34' because of their contrasting growth characteristics. Dellwood Fine, Huntsville, and Kenblue represented three common KBG ecotypes (erect growth habit, narrow leaf blade) and Bensuns A-34 and H86-386 represented two aggressive ecotypes (aggressive lateral growth habit, high shoot density) as described by Murphy et al. (1997).

M.R. Suplick-Ploense and Y.L. Qian, Dep. of Hortic. and Landscape Architecture, Colorado State Univ., Fort Collins, CO 80523-1173; and J.C. Read, Texas A&M Univ. Res. and Ext. Center, 17360 Coit Rd., Dallas, TX 85252-6599. Funding was provided by Gardner Turfgrass, Inc. and the Colorado Agric. Exp. Stn. (project 780). Manuscript submitted by the senior author in partial fulfillment of the requirements for the Ph.D. degree from Colorado State Univ. Received 20 Sept. 2001. *Corresponding author (mploense@earthlink.net).

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Abbreviations: EC, electrical conductivity; HBG, hybrid bluegrass; KBG, Kentucky bluegrass; TBG, Texas bluegrass.

Table 1. Greenhouse mean minimum and maximum temperatures and irradiance during Exp. I and Exp. II in 2000.

	Mean min	Mean max	Mean PAR†
	°C		W m^{-2}
Exp. I			
January	**20.9**	**27.2**	**33.8**
February	**21.5**	**27.3**	**45.5**
March	**21.7**	**26.8**	**58.2**
April	**21.5**	**27.4**	**71.8**
May	**21.9**	**28.2**	**78.1**
Exp. II			
June	**23.3**	**31.3**	**80.6**
July	**24.9**	**36.1**	**70.9**
August	**22.8**	**33.6**	**63.7**
September	**20.8**	**32.7**	**52.9**
October	**20.9**	**27.4**	**35.7**

† PAR = photosynthetically active radiation.

Additionally, four unidentified Kentucky bluegrass plants discovered persisting on a highly sodic site at College Station, TX, which exhibit the appearance of compact ecotypes (low, compact growth habit) were collected and included in this study. Three TBG accessions, 20-11, 10-30, and 10-24, which served as the female parents of the released hybrid Reveille, and four HBG experimental lines (TXKY 96-260-6, TXKY 96-260-7, TXKY 96-260-22, and TXKY 94-8-8) were examined.

Plant Culture and Treatment Procedures

From 30 Dec. 1999 to 30 May 2000 (Exp. I) and from 1 June to 30 Oct. 2000 (Exp. II), plant material was screened for salinity tolerance in a greenhouse at the W.D. Holly Plant Environmental Research Center at Colorado State University, Fort Collins, CO, in a solution culture system (Qian et al., 2000). New sets of plants not previously subjected to salinity treatment were used at the initiation of each experiment. Greenhouse air temperatures ranged from 20.9 to 28.2°C in Exp. I and from 20.8 to 36.1°C in Exp. II. Because no supplemental light source was used during either experiment, mean photosynthetically active radiation in the greenhouse increased from 33.8 to 78.1 W m^{-2} in Exp. I (December to May) and decreased from 35.7 to 80.6 W m^{-2} in Exp. II (June to October) (Table 1). Sod pieces of each grass were planted into 7-cm diam. by 4-cm-deep plastic cups filled with a 1-cm layer of Isolite (Sundine Enterprises Inc., Arvada, CO). The cup bottom was removed and covered with nylon screen to hold the Isolite and allow roots to grow through. Seventeen cups consisting of one entry per cup were placed into holes of a 1.5-cm-thick wooden lid, with the lid suspended over a 38-L tank. A total of 15 tanks were used with each accommodating 17 cups. The tanks contained 36 L of constantly aerified full strength Hoagland solution, which was replaced weekly. This volume allowed the bottom of each cup to be submersed $\approx$2 cm into the solution.

When plants had fully established, $\approx$10 wk after planting, shoots and roots were clipped and discarded prior to initiation of salt treatments. Roots were clipped at the base of the cups and shoots were clipped to a 2.5-cm height. For salinity treatment, NaCl was gradually added daily, for a period of 5 d, to bring the tank solutions to their randomly assigned treatment level of 3, 5, 7, or 9 dS m^{-1}, which was measured using an EC meter (Hach Co., Model 50150). Sodium chloride was chosen because its presence in irrigation water produces the most detrimental effects on plant growth and soil structure. Electrical conductivity in the control tanks was maintained at 1.8 dS m^{-1} throughout the study. Twelve tanks were subjected to salinity treatments while three tanks were maintained as controls for 10 wk. Experimental design was a split plot with three replications, salt treatment (tank) as the main effect, and entries within each tank being the subplot effect.

Data Collection and Analyses

Data were collected on shoot and root growth and leaf firing percentage. After reaching the designated treatment level, shoots were clipped weekly to a 2.5-cm height and discarded. Beginning 4 wk after salinity treatment when grasses had fully exhibited response to the salt treatments, clippings were collected weekly for $\approx$6 wk. Clippings were immediately dried for 48 h at 70°C and weighed. Six of these harvests were combined to determine shoot growth. At the conclusion of each experiment, roots were harvested and dried for 48 h at 70°C, then weighed for dry mass. Leaf firing percentage was determined by visually estimating the total percentage of chlorotic leaf area at the conclusion of each experiment.

Analysis of variance indicated significant difference in all measured parameters between Exp. I and Exp. II (Table 2). Therefore, data on shoot and root growth and leaf firing percentage are presented separately. Linear and quadratic regression analysis was conducted to determine relationships between shoot and root growth vs. salinity level. By regression analysis, threshold EC (salinity level at which growth reduction began relative to control) and the slope of growth reduction were determined for each entry. The regression slopes were then used to derive salinity levels that caused 25 and 50% shoot and root growth reductions (EC$_{\text{shoot}}$ 25, EC$_{\text{shoot}}$ 50, EC$_{\text{root}}$ 25, and EC$_{\text{root}}$ 50) (Maas and Hoffman, 1977). Resulting data were then subjected to ANOVA tests, and cultivar means were separated by Fisher's LSD (SAS Institute, 1990). Pearson's correlation analysis between percentage leaf firing and threshold EC, EC$_{\text{shoot}}$ 25, and EC$_{\text{shoot}}$ 50 was conducted using the CORR procedure of SAS (SAS Institute, 1990). Group response comparisons were made using the TTEST procedure assuming both equal and unequal variance (SAS Institute, 1990). Using two factors, leaf firing percentage at 5 dS m^{-1} and EC$_{\text{shoot}}$ 50 as source data, cluster analysis was performed on all 17 entries using the nonhierarchical FASTCLUS procedure to place entries into groups not defined a priori (SAS Institute, 1990). Electrical conductivity of 50% shoot growth reduction values was transformed (max EC$_{\text{shoot}}$ 50 $-$ xEC$_{\text{shoot}}$ 50) so that a lower score indicated greater tolerance by both factors. Thus, both axis values increased with increasing distance from the point of origin.

Table 2. Analysis of variances with mean square, experiment, and treatment significance.

Parameters	Experiment	Salinity	Grass	Experiment × salinity	Experiment × grass	Salinity × grass
Leaf firing	**1151.9****	**6900.1†**	**7718.6†**	**648.4ns‡**	**4573.9†**	**229.5ns**
Shoot wt.	**27.9*****	**1.4†**	**0.266†**	**0.018ns**	**0.533****	**0.046ns**
Root wt.	**132.9†**	**12.4†**	**3.2**	**0.218ns**	**4.4†**	**0.238ns**

**** Significant at the 0.01 probability level.**
***** Significant at the 0.001 probability level.**
† Significant at the 0.0001 probability level.
‡ ns = not significant.

RESULTS

Leaf Firing

Experiment I

All entries exhibited increased leaf firing with increasing salinity (data not shown). Analysis of variance indicated that greater variability among entries in leaf firing was exhibited at 5 dS m^{-1} than other salinity levels; therefore, leaf firing at this salinity level is presented in Table 3. Leaf firing response at 5 dS m^{-1} ranged from 1.7 to 5.0% in the most tolerant group (CS-ST 1 KBG, CS ST 3 KBG, CS ST 4 KBG, H-86-386 KBG, and Bensuns A-34 KBG) to 97.7% in the least tolerant group (TBG 10-24). Interspecific comparisons revealed differences in leaf firing response at 5 dS m^{-1} among KBG, TBG, and their hybrids, with KBG as a group exhibiting less leaf firing than TBG and their hybrids (Table 4). No significant difference in leaf firing was found between TBG and HBG. Among ecotypes, compact types showed less leaf firing than common types.

Table 3. Leaf firing, threshold salinity levels, and salinity levels of 25 and 50% shoot and root growth reduction for three Texas bluegrasses (TXBGs), nine Kentucky bluegrasses (KBGs), and five hybrid bluegrasses (HBGs and TXKYs).

Entry	Type	Leaf firing (EC = 5 dS m^{-1})†	Growth reduction					
			Shoot			Root		
			Threshold	25%	50%	Threshold	25%	50%
		%	EC‡, dS m^{-1}					
			Exp. I					
Texas bluegrass								
TXBG 10-30	unknown	91.7ef§	1.6bc	3.3cd	6.5cdef	3.0cdef	7.4bcd	8.6bcd
TXBG 10-24	unknown	97.7f	1.0c	2.2cde	4.4efg	1.0f	2.5e	5.1cd
TXBG 20-11	unknown	46.7bcd	3.0a	5.6b	8.1bc	3.0cdef	7.3bcd	11.6ab
Kentucky bluegrass								
‘Dellwood Fine’ KBG	common	30.0abc	1.0c	3.1cde	6.2cdefg	1.06ef	2.4e	4.8cd
‘Huntsville’ KBG	common	18.3ab	2.3ab	2.8cde	5.5defg	5.0abc	9.3b	11.0ab
‘Kenblue’ KBG	common	58.3cd	2.3ab	5.5b	7.9bcd	1.0f	5.1de	7.1bcd
‘Bensuns A-34’ KBG	aggressive	1.7a	1.6bc	3.2cde	6.3cdef	5.0abc	6.7bcd	8.1bcd
‘H86-386’ KBG	aggressive	3.3a	1.0c	6.3b	9.5b	1.6ef	7.5bcd	9.0bcd
CS ST 1 KBG	compact	1.7a	1.0c	3.4c	6.7cde	7.0a	13.3a	15.8a
CS ST 2 KBG	compact	20.0ab	1.0c	2.3cde	4.7efg	1.0f	5.8cd	11.7ab
CS ST 3 KBG	compact	5.0a	1.0c	3.3cd	6.6cdef	3.7cde	8.4bc	10.8ab
CS ST 4 KBG	compact	5.0a	2.3ab	7.8a	12.6a	4.3bcd	8.4bc	9.9bc
Hybrid bluegrass								
TXKY 96-260-7	H-86-386 KBG × TXBG 10-30	89.3e	1.6bc	2.1de	4.2fg	1.0f	2.4e	4.7cd
TXKY 96-260-6	H-86-386 KBG × TXBG 20-30	41.7bcd	1.6bc	2.2cde	4.4efg	1.6ef	2.3e	4.7cd
TXKY 94-8-8	Dell. Fine KBG × TXBG 10-24	40.0bcd	3.0a	5.4b	7.9bcd	6.3ab	5.9cd	7.2bcd
TXKY 96-260-22	H-86-386 KBG × TXBG 10-30	68.3de	1.6bc	2.4cde	4.9efg	2.3def	8.3bcd	10.5ab
‘Reveille’ HBG	Huntsville KBG × TXBG 20-11	88.3ef	1.0c	2.0e	4.0g	1.6ef	2.2e	4.4d
LSD ($P < 0.05$)		29.0	1.3	1.2	2.5	2.1	3.3	5.4
F test		12.0¶	2.4**	16.4¶	6.9¶	7.3¶	8.2¶	3.2***
CV		42.0	46.5	20.1	22.7	42.3	29.4	34.7
			Exp. II					
Texas bluegrass								
TXBG 10-30	unknown	10.0a	1.6bc	5.2cdefg	10.5abcd	3.0a	7.2b	8.6b
TXBG 10-24	unknown	18.3abc	1.6bc	5.7cdefg	11.4abcd	1.6a	8.5a	12.1a
TXBG 20-11	unknown	16.7ab	1.6bc	4.4efg	8.8bcd	1.6a	3.1cdef	6.2cdef
Kentucky bluegrass								
‘Dellwood Fine’ KBG	common	35.0abcd	1.6bc	6.3bcdef	12.5abc	1.0a	2.6cdef	5.2defg
‘Huntsville’ KBG	common	93.3e	2.3bc	6.3bcdef	9.5abcd	1.0a	2.4ef	4.8defg
‘Kenblue KBG	common	38.3abcd	1.6bc	4.8defg	6.7cd	1.0a	2.9cdef	6.3bcdef
‘Bensuns A-34’ KBG	aggressive	15.0ab	3.0ab	10.0a	15.0a	1.6a	2.5def	5.0defg
‘H86-386’ KBG	aggressive	35.0abcd	4.3a	8.9ab	14.8ab	1.6a	3.4cde	6.9bcd
CS ST 1 KBG	compact	20.0abc	2.3bc	8.2abc	13.4ab	3.0a	3.8cd	7.6bc
CS ST 2 KBG	compact	53.3cd	1.0c	3.5fg	7.0cd	1.6a	2.4ef	4.8efg
CS ST 3 KBG	compact	5.0a	4.3a	5.6cdefg	11.2abcd	1.0a	8.6a	11.2a
CS ST 4 KBG	compact	10.0a	1.6bc	7.1abcde	14.2ab	1.6a	2.3ef	4.6fg
Hybrid bluegrass								
TXKY 96-260-7	H-86-386 KBG × TXBG 10-30	95.0e	1.0c	3.1g	6.2d	1.0a	1.9f	3.9g
TXKY 96-260-6	H-86-386 KBG × TXBG 10-30	46.7bcd	2.3bc	6.4bcdef	9.8abcd	1.0a	2.3ef	4.7fg
TXKY 94-8-8	Dell. Fine KBG × TXBG 10-24	65.0de	3.0ab	7.5abcd	10.0abcd	3.0a	6.9b	8.9b
TXKY 96-260-22	H-86-386 KBG × TXBG 10-30	63.3de	3.0ab	3.6fg	7.3cd	1.6a	3.1cdef	5.3defg
‘Reveille’ HBG	Huntsville KBG × TXBG 20-11	33.3abcd	2.3bc	5.9bcdefg	8.8bcd	2.3a	3.9c	6.8bcde
LSD ($P < 0.05$)		35.7	1.9	3.0	6.1	2.1	1.3	3.3
F test		4.9¶	2.1**	3.7***	2.0**	1.4***	22.7¶	9.7¶
CV		55.9	50.7	28.1	32.9	38.6	19.6	18.8

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† EC$_w$ = xx.

‡ EC = electrical conductivity.

§ Means followed by the same letter within a column are not significantly different at the 0.05 probability level using Fisher’s LSD test.

¶ Significant at the 0.0001 level of probability.

Table 4. Mean performance of bluegrass entries in three groups for leaf firing at 5 dS m^{-1}, threshold salinity level, and salinity level causing 25 and 50% shoot and root growth reductions.

				Growth reduction											
		Leaf firing (EC = 5 dS m^{-1})†		Shoot						Root					
				Threshold		25%		50%		Threshold		25%		50%	
Group	Entries	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II
	No.	%		EC, dS m^{-1}											
Texas bluegrass	9	78.7a‡	15.0b*	1.9a	1.6a	3.7a	5.1a	6.3a	10.2a*	2.3a	2.1a	5.7a	6.3a	8.4a	9.0a
Kentucky bluegrass	3	15.9b	33.9ab	1.5a	2.4a	4.2a	6.7a*	7.3a	11.6a*	3.3a	1.5a*	7.4a	3.4a*	9.8a	6.3a*
Hybrid bluegrass	5	65.5a	60.7a	1.8a	2.3a	2.8a	5.3a*	5.1a	8.4a*	2.6a	1.8a	4.2a	3.6a	6.3a	5.9a

* Significantly different from Exp. I at the 0.05 probability level.

† EC = electrical conductivity.

‡ Means in the same column followed by the same letter within a column are not significantly different at the 0.05 probability level using Fisher's protected LSD test.

Experiment II

In agreement with Exp. I, all entries showed increased leaf firing with increasing salinity. Greatest differences within and among *Poa* species and their hybrids were exhibited at 5 dS m^{-1} (Table 3). Leaf firing at 5 dS m^{-1} ranged from 5 to 10% in the more tolerant group (CS ST 3 KBG, CS ST 4 KBG, and TBG 10-30) to 93.3 to 95% in the more susceptible group (Huntsville KBG and TXKY 96-270-7 HBG). Hybrid bluegrass as a group exhibited greater leaf firing than TBG. Kentucky bluegrass had intermediate leaf firing percentage but was not statistically different from TBG or HBG. Unlike in Exp. I, there was no difference in leaf firing among KBG ecotypes at 5 dS m^{-1}. As a group, TBG exhibited a significantly lesser degree of leaf firing in Exp. II than Exp. I (78.7 vs. 15.0%) (Table 4).

Shoot Growth Reduction

Experiment I

Differences were found for threshold EC, $\mathrm{EC}_{\mathrm{shoot}}$ 25, and $\mathrm{EC}_{\mathrm{shoot}}$ 50 (Table 3). Threshold EC ranged from 1.0 to 3.0 dS m^{-1}. The highest threshold EC of 3.0 was observed in TBG 20-11, Kenblue, H-86-386 KBG, and TXKY 94-8-8 HBG. Salinity levels that caused 25% shoot growth reduction ranged from 2.0 dS m^{-1} in Reveille HBG to 7.8 dS m^{-1} in CS ST 4 KBG. Salinity levels that caused 50% shoot growth reduction ranged from 4.0 dS m^{-1} in Reveille HBG to 12.6 dS m^{-1} in CS ST 4 KBG. Variability in shoot growth reduction both within and among *Poa* species and their hybrids increased from $\mathrm{EC}_{\mathrm{sh}}4\mathrm{o}_{\mathrm{ot}}$ 25 to $\mathrm{EC}_{\mathrm{shoot}}$ 50, indicating the influence of slope on shoot growth reduction in response to increasing salinity. No differences were found in threshold EC, $\mathrm{EC}_{\mathrm{shoot}}$ 25, and $\mathrm{EC}_{\mathrm{shoot}}$ 50 between *Poa* species, their hybrids, or among KBG ecotypes as groups (Table 4).

Experiment II

Again, significant variability in shoot growth reduction parameters was found within and among *Poa* species and their hybrids (Table 3). Threshold EC ranged from 1.0 to 5.0 dS m^{-1}, with the highest threshold EC of 5.0 observed in Bensuns A-34 KBG, H-86-386 KBG, and TXKY 94-8-8 HBG. Values of EC 25 ranged from 3.1 dS m^{-1} in TXKY 96-260-7 HBG to 10.0 dS m^{-1} in Bensuns A-34 KBG. Both HBG and KBG significantly increased their mean $\mathrm{EC}_{\mathrm{shoot}}$ 25 from Exp. I to Exp. II. Among KBG ecotypes, aggressive types exhibited higher $\mathrm{EC}_{\mathrm{shoot}}$ 25 than both common and compact types (Table 4).

Salinity levels that caused 50% shoot growth reduction values ranged from 6.2 dS m^{-1} in TXKY 96-260-7 HBG to 15.0 in Bensuns A-34 KBG. Although the most and least tolerant entries were the same from $\mathrm{EC}_{\mathrm{shoot}}$ 25 to $\mathrm{EC}_{\mathrm{shoot}}$ 50, greater difference in $\mathrm{EC}_{\mathrm{shoot}}$ 50 was found between KBG and HBG than $\mathrm{EC}_{\mathrm{shoot}}$ 25, indicating influence of slope of reduction on decreased shoot growth. Both species and their hybrids increased their mean $\mathrm{EC}_{\mathrm{shoot}}$ 50 in Exp. II compared with Exp. I (Table 4). Among KBG ecotypes, aggressive types exhibited higher $\mathrm{EC}_{\mathrm{shoot}}$ 50 than common types.

Root Growth Reduction

Experiment I

Relationships between root growth and level of salinity were determined for each entry. Variability existed within and among *Poa* species and their hybrids for each measured or derived root growth reduction parameter (threshold EC, EC that caused 25 and 50% root growth reduction) (Table 3). Threshold EC ranged from 1.0 to 7.3 dS m^{-1}. The highest threshold EC of 7.3 was observed in CS ST 1 KBG. Salinity levels that caused 25% root growth reduction ranged from as low as 2.2 to 2.5 dS m^{-1} in Reveille HBG, TXKY 96-260-6 HBG, TXKY 96-260-7 HBG, Dellwood Fine KBG, and TBG to as high as 13.3 dS m^{-1} in CS ST 1 KBG. Electrical conductivity of 50% root growth reduction ranged from 4.4 dS m^{-1} in Reveille HBG to 15.8 in CS ST 1 KBG. No difference in $\mathrm{EC}_{\mathrm{root}}$ 25 was found between *Poa* species and their hybrids. No difference in any root growth reduction parameter was exhibited among KBG ecotypes.

Experiment II

Significant variability in all measured and derived root growth reduction parameters were found within and among *Poa* species and their hybrids (Table 3). Threshold EC ranged from 1.0 to 5.0 dS NaCl m^{-1}, with the highest threshold EC of 5.0 observed in TBG 10-

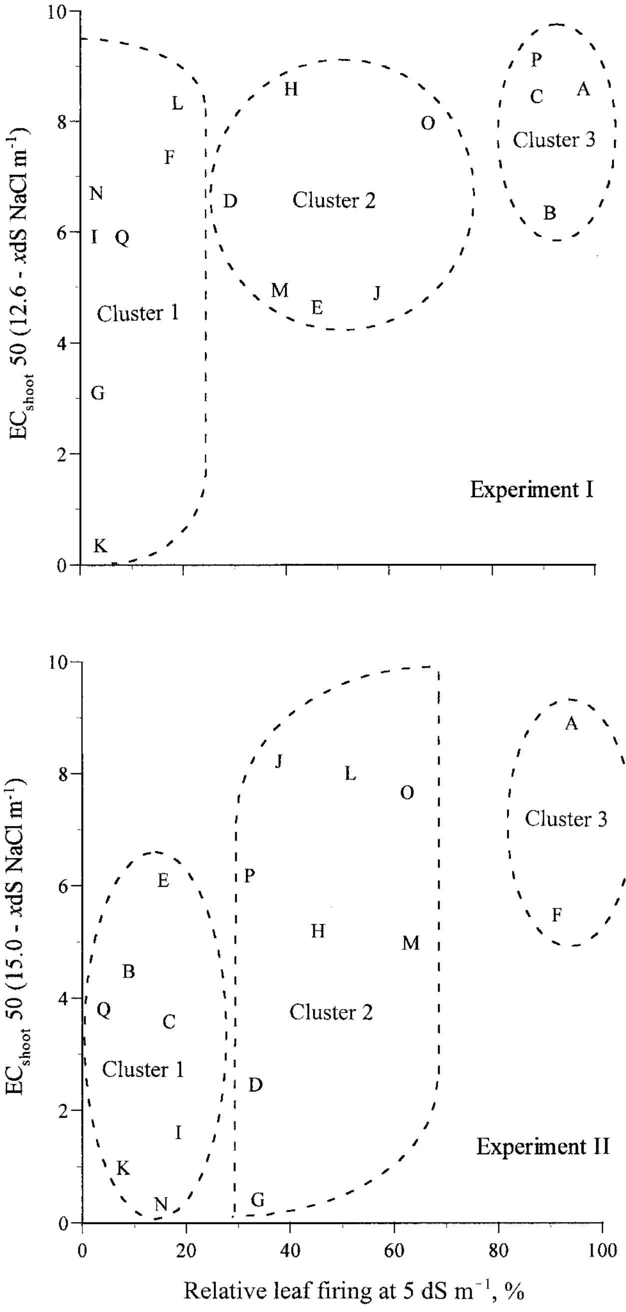

Fig. 1. Cluster analysis of Exp. I and Exp. II based on relative leaf firing at 5 dS m^{-1} and salinity level resulting in 50% shoot growth reduction (EC_{shoot} 50) for three Texas bluegrasses (TXBG), nine Kentucky bluegrasses (KBG), and five of their hybrids (HBG). A = TXKY 96-260-7 HBG, B = TXBG 10-30, C = TXBG 10-24, D = 'Dellwood Fine' KBG, E = TXBG 20-11, F = 'Huntsville' KBG, G = H-86-386 KBG, H = 96-260-6 HBG, I = CS ST 1 KBG, J = 'Kenblue' KBG, K = CS ST 4 KBG, L = CS ST 2 KBG, M = TXKY 94-8-8 HBG, N = 'Bensuns A-34' KBG, O = TXKY 96-260-22 HBG, P = 'Reveille' HBG, Q = CS ST 3 KBG.

Table 5. Correlation coefficients for turfgrass appearance (% leaf firing) and growth [threshold electrical conductivity (EC), EC of 25 and 50% shoot growth reduction] measurements of salt treated and control plants for 17 bluegrass grown in the greenhouse in solution culture.

	Threshold EC	EC_{shoot} 25	EC_{shoot} 50
		Exp. I	
% Leaf firing, 5 dS m^{-1}	−0.208	−0.412	−0.506*
		Exp. II	
% Leaf firing, 5 dS m^{-1}	0.111	−0.353	−0.578*

* Significant correlation at the 0.05 probability level.

24 and TXKY 94-8-8 HBG. Values of EC_{root} 25 ranged from a low of 1.9 dS m^{-1} in TXKY 96-260-7 HBG to 8.5 dS m^{-1} in TBG 10-24. No difference was found among KBG ecotypes for EC_{root} 25.

Although salinity levels that caused EC_{root} 50 ranged from 3.9 dS m^{-1} in TXKY 96-260-7 HBG to 12.1 dS m^{-1} in TBG 10-24, no difference in EC_{root} 50 was found between *Poa* species, their hybrids, or among KBG ecotypes. Even though the most and least tolerant entries ranked the same from EC_{root} 25 to 50, variability within and among *Poa* species and their hybrids was greater at EC_{root} 50 than at EC_{root} 25.

Kentucky bluegrasses exhibited a significantly lower (7.3 to 3.4 dS m^{-1}) EC_{root} 25 in Exp. II than in Exp. I because of poorer performance of the compact and aggressive ecotypes in Exp. II. The same occurred for EC_{root} 50; however, at this level it was primarily attributable to the poorer performance of only compact ecotypes.

Salt Tolerance Ranking

To assess the overall salt tolerance of all entries, cluster analysis was performed based on relative leaf firing and EC_{shoot} 50 (Fig. 1). These factors were chosen because turfgrass appearance and growth are two important factors influencing overall turf performance, and the highest correlation between relative leaf firing and shoot growth was found between EC_{shoot} 50 scores (Table 5).

Experiment I

The group with the highest salt tolerance ranking (Cluster 1) was composed only of KBG (CS ST 4 KBG, H-86-386 KBG, CS ST 1 KBG, CS ST 3 KBG, Bensuns A-34 KBG, Huntsville KBG, and CS ST 2 KBG) including four compact, two aggressive, and one common ecotypes (Fig. 1). The intermediate and least tolerant groups (Clusters 2 and 3, respectively) included KBG, TBG, and HBG.

Experiment II

In Exp. II, the most salt-tolerant group (Cluster 1) was composed of four KBG cultivars (Bensuns A-34, CS ST 1, CS ST 3, and CS ST 4), including three compact and one aggressive ecotype, and all three TBG accessions examined (10-24, 10-30, and 20-11) (Fig. 1). Again, the intermediate and least tolerant groups (Clusters 2 and 3, respectively) included KBG, TBG, and HBG.

DISCUSSION

Results indicate that significant variability in leaf firing and shoot and root growth responses to salinity exist within and among *Poa* species and their hybrids. The range of salinity tolerance among the nine KBG cultivars in relative leaf firing response at 5 dS m^{-1} in both Exp. I (1.7–58.3%) and Exp. II (5.0–93.3%) was considerably broad. Among the KBG examined in this study, greatest salt tolerance was seen in the aggressive and compact ecotypes. Qian et al. (2001) also reported that 'Limousine' KBG, an aggressive ecotype, was more salt-tolerant than 'Kenble', a common ecotype KBG. Nevertheless, KBG is still a salt-sensitive turfgrass species when compared with other species such as tall fescue (*Festuca arundinacea* Schreb.) and creeping bentgrass {*Agrostis palustris* Huds. [= *A. stolonifera* var. *palustris* (Huds.) Farw.]} (Carrow and Duncan, 1998). Selecting relatively salt-tolerant KBG cultivars is beneficial for sites where salinity level is only marginal.

Differences between Exp. I and Exp. II suggested that environmental conditions could substantially affect bluegrass salt tolerance (Table 4). In a previous study (Qian and Suplick, 2001), involving the interactive effect of temperature and salinity on KBG seed germination, the effect of salinity became more pronounced as temperature deviated from optimum growth range. Optimum temperature range for KBG shoot growth is 16 to 24°C, and 10 to 18°C for root growth (Beard, 1973). Optimum shoot and root growth temperature ranges have not been determined for TBG or HBG.

Texas bluegrass is distributed throughout several vegetative regions of Texas, where mean maximum summer temperatures range from 34 to 37°C (Gould, 1975; Northeast Regional Climate Center, 2000). This region of origin suggests that TBG may have a warmer optimum temperature range than KBG. Current and ongoing research (Suplick and Qian, 2000) suggests that HBG may have a broader temperature adaptation than those of KBG and TBG.

This speculation may be supported by the differences in performance from Exp. I to Exp. II of the three *Poa* groups examined in this study in many measured and derived parameters (Table 4). Experiment I was conducted during winter and spring. Experiment II was conducted throughout summer into fall when daily warm temperatures were higher, and their duration prolonged, possibly creating an environment more favorable to TBG but less favorable to KBG growth. This change in environment may explain several observations: (i) There was an 81% decrease in TBG mean leaf firing at 5 dS m^{-1} from Exp. I to Exp. II; (ii) KBG root threshold EC, EC_{root} 25, and EC_{root} 50 were significantly decreased from Exp. I to Exp. II, whereas no change was seen in TBG or HBG; and (iii) there was an improvement in overall salt tolerance for all three TBG accessions, demotion of several KBG cultivars, and relatively steady ranking of HBG from Exp. I to Exp. II.

This research supports that of Horst and Taylor (1983) and Grueb et al. (1983), in that significant variability in salt tolerance exists within and among *Poa* species, indicating that improvement in the salt tolerance of bluegrasses may be possible. Additionally, our findings, with respect to the effect of sub- and supraoptimum temperature regimes on the expression of that tolerance, are in agreement with previous research (Qian and Suplick, 2001), confirming the importance of temperature in evaluating the salt tolerance of *Poa* species.

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