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Salt Tolerance and Canopy Reflectance of Kentucky Bluegrass Cultivars

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***Abstract*. Six cultivars or selections of kentucky bluegrass (*Poa pratensis* L.) were grown outdoors from vegetative clones in a gravelly sand medium from Apr. to Sept. 2005 in Riverside, CA, at soil water salinities ranging from 2 to 22 dS·m^{-1}. Cultivars Baron, Brilliant, Cabernet, Eagleton, Midnight, and the selection A01-856, a 'Texas' × kentucky bluegrass hybrid (*P.· arachnifera* × *P. pratensis*), were evaluated for salt tolerance based on relative and absolute cumulative biomass production, growth rates, leaf chloride concentration, and hyperspectral ground-based remote sensing (RS) canopy reflectance measurements. Remotely sensed indices were linearly correlated with absolute biomass production. Three variations of a Normalized Difference Vegetation Index (NDVI*red*, NDVI*protein*, and NDVI*infra*) decreased with increasing salinity-induced changes in grass canopies. An index based on the red-edge inflection point increased (became less negative) with increasing salinity. A Floating Water Band Index decreased with decreased leaf moisture content related to increasing salinity but did not discriminate between cultivars. Shoot spreading rate and NDVI*infra* were both related to shoot chloride concentration differences among the kentucky bluegrass (*Poa pratensis* L) (KBG) cultivars or selections. In theory, non-destructive RS monitoring of above-ground turf development, including NDVI*infra*, coupled with measurement of leaf chloride concentrations could be useful in turf salt tolerance breeding programs. Salt tolerance rankings among the KBG cultivars varied depending on the evaluation methods and selection criteria used. Based on absolute and relative biomass, growth rate, and RS, cultivars Baron, Brilliant, and Eagleton were rated as more salt-tolerant than 'Cabernet', 'Midnight', and AO1-856.**

Cultivar-specific salinity stress evaluations are of continued interest as fresh water supplies for irrigation diminish in quantity and quality and turfgrass managers seek the best varieties for a multitude of conditions and desired outcomes. Irrigation management of turf with recycled water requires additional considerations that will decrease certain problems associated with degraded waters in turf operations (Devitt et al., 2004, 2005). Matching cultivars or species selection with irrigation water quality is critical for the development of strategies to conserve fresh water supplies. Although not the most salt-tolerant of grasses, kentucky bluegrass (KBG) is a popular cool-season grass that can remain green throughout the year in arid climates with supplemental irrigation. Kentucky bluegrass genotypes with increased salt tolerance would benefit many turf operations.

Increased evaporative demand, however, can potentially lead to significant salt loading. Proper irrigation management and drainage conditions may mitigate the potentially negative impacts of recycled water on plant response (Lockett et al., 2008), but the upper salt limit can be dictated by the salt tolerance of the turfgrass cultivar. Local wastewater supplies are in greater demand by golf courses and other turf-intensive recreation facilities as potable water supplies diminish. Municipal wastewaters are invariably higher in salinity than are the original potable sources (Feigin et al., 1991). Some chemical components (calcium, sodium, magnesium, for example) of reclaimed water can vary in quantity by 15% to 20% within a cropping season (Friedman et al., 2007).

Kentucky bluegrass is a widely used cool-season turfgrass that is considered sensitive to moderate levels of drought and salinity (Marcum, 2006). Salt tolerance rankings based on both relative and absolute biomass accumulation as a function of soil salinity (Grattan et al., 2004) are important tools needed to assess salt tolerance differences of KBG selections. In recreational settings, the need for more tolerant, slower-growing cultivars might need to be balanced with vigor to provide plant characteristics better suited for reducing operation and maintenance costs.

Leaf water content differences are related to leaf water potential and plant turgor maintenance and have been attributed to salt tolerance differences among KBG cultivars (Qian et al., 2001). Minimum leaf water content appears to be an important estimate of turf growth and development (Turgeon, 2008).

Screening newly developed KBG cultivars for salt tolerance has not kept pace with efforts of plant breeders to exploit the inherent variability among KBG cultivars and their genotype × environment interaction (Suplick-Ploense et al., 2002). This variability in KBG germplasm is also evident in the broad salt tolerance range (very sensitive to moderately tolerant) reported for this species (Carrow and Duncan, 1998).

The performance of some of the KBG and 'Texas' × kentucky bluegrass hybrid (*P. arachnifera* × *P. pratensis*) (TBG) selections that are the focus of the present study have recently been evaluated under drought conditions (Abraham et al., 2004; Wang et al., 2003a, 2003b). These evaluations were primarily based on physiological parameters and biomass production was not emphasized. The TBG hybrids and KBG cultivar Midnight were reported as highly drought-resistant, whereas 'Brilliant' was reported as drought-susceptible. Mid-Atlantic-type cultivars, including Cabernet and Eagleton, typically exhibit good performance under summer conditions of heat and drought stress (Bonos and Murphy, 1999; Shortell et al., 2004) and are thought to avoid drought by producing deep roots. The cultivar Baron normally exhibits poor summer performance in the field in the temperate areas of the United States (Bonos and Murphy, 1999; Shortell et al., 2004).

Horst and Taylor (1983) evaluated 'Baron' for salt tolerance and observed that growth at 11.6 dS·m^{-1} was reduced by 50%. Others rated 'Baron' as less tolerant than two other KBG cultivars, Aldelphi and Ram I (Torello and Symington, 1984), and noted significant variability in KBG cultivar salt tolerance. To explore the effects of growth rate on salt tolerance rankings, Qian et al. (2001) compared the growth of two KBG cultivars, Limousine and Kenblue, at salinities approaching 14 dS·m^{-1}. The higher absolute growth rate (0.43 g clipping/week compared with 0.29 g clipping/week for 'Limousine') of 'Kenblue' in the low salinity treatment (2 dS·m^{-1}) was reduced to a greater extent as salinity was increased to ≈8.2 dS·m^{-1} than was the rate of

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growth for 'Limousine' (0.17 g clipping/week for both 'Limousine' and 'Kenblue'). A reduction in leaf firing of 'Limousine' at salinities greater than 5.2 $dS \cdot m^{-1}$ was associated with a slower growth rate and greater relative salt tolerance than 'Kenblue'. In an independent study, 'Kenblue' was also rated as moderately salt-tolerant (Suplick-Ploense et al., 2002).

Turfgrass development assessed with multispectral radiometers (Fitz-Rodriguez and Choi, 2002) as alternatives to visual rankings have proven successful. Turfgrass salinity screening trials can potentially benefit from remote sensing (RS) by providing a simple and effective basis for characterizing salinity stress response among turfgrass cultivars. Non-destructive, RS canopy reflectance in the near-infrared (980 nm) has been reported by Thenkabail et al. (2000) as sensitive to leaf water content.

The use of RS in selection of plants in natural environments may complement molecular efforts to enhance plant tolerance to naturally occurring environmental conditions (Mittler, 2006), but more research is needed to determine the effectiveness of RS as a measure of water and nitrogen stress (Fitz-Rodriguez and Choi, 2002).

Under management scenarios, RS estimates of turfgrass performance can provide useful information if calibrated equations with acceptable correlations are determined for the physiological parameters of interest (Jiang et al., 2009). Soil matric and salinity stress interactions on the growth of tall wheatgrass [*Thinopyrum ponticum* (Host.) Beauv. Var 'Jose'] were correlated with RS measurements (Poss et al., 2006) and a two-Vegetative Index (VI) multiple linear regression model was developed that predicted absolute yield under varying levels of drought and salinity stress.

Canopy reflectance measurements under carefully controlled conditions may provide a tool to accurately characterize differences in KBG selections. The objective of this study was to evaluate the salt tolerance of five KBG selections and one TBG hybrid with traditional methods such as growth rate and relative or absolute biomass production and to compare the effectiveness of ground-based hyperspectral canopy reflectance measurements for ranking salt tolerance.

Materials and Methods

Plant material and culture. Six bluegrass cultivars were obtained as plugs from the Turfgrass Research Center, Rutgers University, New Brunswick, NJ. 'Baron' and 'Brilliant' are two KBG selections identified as drought-sensitive. 'Cabernet', 'Eagleton', and 'Midnight' are KBG cultivars rated as drought-tolerant; and A01-856 is a 'Texas' × KBG hybrid (TBG) identified as drought-resistant (Abraham et al., 2004).

The trial was conducted in outdoor lysimeters at the U. S. Salinity Laboratory, Riverside, CA. The facility consisted of 24 tanks ($1.5 \times 3 \times 2$ m deep) filled with washed river sand having an average bulk density of 1.4 $Mg \cdot m^{-3}$. The sand particle size ranged from 0.085 mm to 4.5 mm with 60% greater than 0.5 mm. At saturation, the sand had an average volumetric water content of 0.28 $m^3 \cdot m^{-3}$ (Wang, 2002). Each tank was flood-irrigated with solutions prepared in individual reservoirs (1.5 m diameter × 2.2 m deep) having a volume of 4000 L. Irrigation solutions were pumped from the reservoirs to the tanks and then returned through a subsurface drainage system at the bottom of each sand tank. Before planting, the tanks were irrigated with a complete nutrient solution. Tanks were divided into six equal sections separated by plastic partitions extending ≈20 cm below the surface of the sand. Details of an analogous but smaller volumetric lysimeter system developed for plant–water relations studies are described by Poss et al. (2004).

On 15 Mar. 2005, 11 plugs per cultivar were planted in separate 0.75-m^2 sections of each of the 24 sand tanks. Plants were allowed to establish under nonsaline conditions for 3 weeks. Salinization was initiated on 5 Apr. 2005, and irrigation applications of all plots were at rates exceeding five times baseline evapotranspiration (ET) for Riverside, CA, according to California Irrigation Management Information System station No. 44. High leaching fractions (LFs greater than 0.90) were possible with the coarse sand media with no signs of aeration problems (ponded water drained completely within 2 min). The high LF imposed throughout the course of the study avoided any soil matric stress and maintained a uniform salinity gradient in the root zone. Irrigation water salinity treatments of 2, 6, 8, 10, 12, 14, 18, and 22 $dS \cdot m^{-1}$ were replicated three times in a randomized design. Salinizing salts (Table 1) were added to the nutrient solutions in the reservoirs. The resulting irrigation waters simulated typical saline wastewaters present in the Coachella Valley of California and from predictions based on appropriate simulations of what the long-term composition of the water would be on further concentrations by evaporation and plant–water extraction (Suarez and Simunek, 1997). Tanks were flood-irrigated daily for sufficient duration to completely saturate the sand and completely submerge the shoots in irrigation water to simulate shoot contact similar to sprinkler irrigation. Water lost by ET was replenished automatically to maintain constant volumes and osmotic potential in each reservoir. Irrigation waters were routinely analyzed by inductively coupled plasma optical emission spectrometry to confirm that target ion concentrations of calcium, magnesium, sodium, potassium, total phosphorus, and total sulfur were maintained. The pH was not controlled and ranged between 7.8 and 8.4. Chloride in the solutions and plant tissue was determined by coulometric–amperometric titration.

Calculations, accounting for maximum ET, soil water-holding capacity, and intervals between irrigations, indicate that the salinity of the irrigation water was generally equivalent to that of the sand water. Previous soil-water dynamic studies (Wang, 2002) show that the electrical conductivity (EC) of the sand water is ≈2.2 times the EC of the saturated soil extract, the salinity parameter used to characterize salt tolerance in most turfgrass studies (Carrow and Duncan, 1998).

Standard meteorological measurements were made with a Class 1 agrometeorological station adjacent to the sand tanks. Ambient daytime air temperatures during the experiment ranged from 6.1 to 38.6 °C (mean, 23.4 °C); nighttime temperatures ranged from 6.1 to 30.8 °C (mean, 16.4 °C). Relative humidity ranged from 10.3% to 96.5% with a mean of 72.4% during the night and 49.9% during the day.

During the saline treatment period (23 May to 9 Sept. 2005), turf performance was evaluated by biomass production. Clippings were cut with scissors and collected at ≈2-week intervals. Shoot tissues were sampled for chloride ion analysis on 20 June 2005, then weighed, washed in deionized water, dried in a forced-air oven at 70 °C for 72 h, reweighed, and ground to pass a 60-mesh screen. Chloride was determined on nitric–acetic acid extracts by coulometric–amperometric titration. Percentage moisture of the tissue was determined after drying samples for 72 h at 100 °C. Relative moisture content (RMC) was calculated as: RMC = (FW – DW)/FW for each cutting period, in which FW and DW represent fresh and dry weights of tissue, respectively.

To minimize turf height influence, hyperspectral radiometer measurements of canopy reflectance were taken within 1 or 2 d after harvests on two (20 June and 4 Aug. 2005) of five cuttings (from 1 June to 4 Sept. 2005). Because of the number of treatments and cultivars in this study, ground-based RS measurements were labor-intensive and more frequent reflectance measurements were not feasible. The canopy reflectance of the grass

Table 1. Composition of salinizing salts in solutions used to irrigate bluegrass cultivars grown in outdoor lysimeters.

Electrical conductivity ($dS \cdot m^{-1}$)	Ca^{2+}	Mg^{2+}	Na^+ ($mmol_c \cdot L^{-1}$)	SO_4^{2-}	Cl^-
2	5	5	9.5	5.6	10.3
6	11.4	18.7	32.2	20.2	42.4
8	15.1	25.3	43.6	27.2	57.2
10	18.9	32.1	55.2	34.5	72.5
12	22.7	38.8	66.9	41.8	87.8
14	27.0	40.7	81.0	50.5	107
18	35.2	62.3	107	66.4	141
22	40.7	77.8	134	80.0	176

surface was measured at 350 to 2500 nm with a peak-to-peak bandwidth of ≈1.5 nm with an ASD FieldSpec Pro spectroradiometer (Analytical Spectral Devices, Inc., Boulder, CO). Before each measurement, the instrument was optimized for integration time to allow for maximum allowable signal without saturation and calibrated to a white reference panel (99% Spectralon; Labsphere, North Sutton, NH) for percent reflectance through an automated optimization and white reflectance panel routine (RS^3; Analytical Spectral Devices, Inc.). During each measurement, three scans, each consisting of internal averages of 10 scans by the capturing software, were obtained.

Three randomly selected clones of the 11 planted for each cultivar within each plot under full canopy were measured at a distance of 35 cm from the 8° foreoptic accessory to the canopy surface at an obtuse 45° angle from the canopy surface for a spot size of ≈5 cm diameter (19-cm^2 area). Special attention was made to avoid shadows and minimize the effect of glare by positioning the foreoptic between the sun and the plot. Measurements were made as quickly as possible at similar times of day (midday) under full sun. The foreoptic was focused on individual clumps of grass and was not influenced by bare areas between clone plugs as would have been true if the field of view was from a greater distance. The measurement routine consumed a minimum of 5 min per measurement, including changing locations and resetting equipment or nearly a full manweek to measure all 432 (144 × 3) samples. The RS indices used in this study (Table 2) and wavelengths that comprised calculating the various vegetative indices are indices that were previously demonstrated to be sensitive to biomass (Poss et al., 2006) and water content (Strachan et al., 2002).

Relative salt tolerance was estimated based on results of a non-linear least squares fit of the salt tolerance equation: relative yield (RY) = $Y_{max}/[(1 + (c/C_{50})^p]$, in which Y_{max} is the fitted maximum relative yield, c is the salinity in $dS\cdot m^{-1}$, C_{50} is the salinity where RY is reduced by 50%, and p is an empirical shaping parameter (a greater p increases the rate of yield reduction per unit salinity) proposed by van Genuchten and Hoffman (1984). As input for the model when analyzing the cumulative dry weight of the six selections, the average cumulative yield of the control salinity (2 $dS\cdot m^{-1}$) was divided into each cumulative dry weight for a relative yield input. As input for the relative reduction of the four-VI as a function of salinity, to compare salt tolerance parameters with those fitted based on relative dry weight, a technique successful in basing *Eucalyptus camaldulensis* salt tolerance parameters with this same equation using relative stable carbon isotope discrimination data was used (Poss et al., 2000) where each VI is scaled based on the range of VI values with the formula: $VI_{Relative} = (VI_{treatment} - VI_{min}/VI_{max} - VI_{min})$.

To evaluate differences in the turf growth rate, an empirical model approach (Grieve et al., 2008) was used in this study to fit the expansion rate of representative turf plugs of each cultivar clone. The model was used to estimate changes in the growth rate (β), based on time-course measures of the canopy area (cm^2), of each cultivar. Clone sward area development was measured periodically [length × width (cm^2)] from the same four clones initially selected at random for each clone in each tank. Measurements were taken on 10 May, 12 May, 17 May, 20 May, 24 May, 27 May, 2 June, 6 June, 9 June, and 14 June 2005. Turf plug area increase (cm^2) over time (day), with 10 May representing t = 0, was then fitted to estimate β.

At the end of the trial, root mass was evaluated from one (2.5 cm i.d.) soil core taken per plot from the 0- to 30-cm sand depths. Roots were washed in tap water and collected in a series of screens ending with a 150-μm mesh, then dried at 60 °C, and weighed.

Analysis of variance was performed with the general linear models (GLM procedure) and regression analysis with the (REG procedure) in SAS Institute (1997). Non-linear least squares analysis was used to fit the relative salt tolerance data to the C_{50} equation and the phasic growth equation for parameter estimates (NLIN procedure; SAS Institute, 1997). Parameter initial estimates were varied until the final residual sum of squares was minimized in the analysis that implemented the Gauss-Newton iterative method for convergence.

Results and Discussion

Visual turf quality. No visual deterioration of turf color quality was noticeable up to16 $dS\cdot m^{-1}$ for all cultivars relative to the respective non-saline control plots. This is remarkable considering that other studies have observed dramatic decreases in growth at lower salinity levels (Qian et al., 2001). At 18 and 22 $dS\cdot m^{-1}$, premature senescence of leaves (browning) was evident in all cultivars and at 22 $dS\cdot m^{-1}$, the rate of growth was insufficient to completely cover the plot area (0.75 m^2) for all cultivars at the end of the study. One plot of 'Brilliant' suffered from a slight rust infestation toward the end of the study.

Table 2. Vegetative indices used in this study to estimate biomass, relative leaf moisture content (RMC), and leaf percent nitrogen in kentucky bluegrass selections.^{z}

Estimated	Index
Biomass	NDVI*red* = (R695 – R670)/(R695 + R670)
Biomass	REP = log (1/R) red edge inflection point within 600:800
Biomass	NDVI*protein* = (Kumproteinavg – R670)/(Kumproteinavg + R670), where Kumproteinavg = [(R1500 + R1680 + R1740 + R1940 + R2050 + R2170 + R2290 + R2480)/8]
Biomass	NDVI*infra* = (R2200 – R660)/(R2200 + R660)
RMC	FWBI = (R900)/min(R930:R980)

^{z}The reflectance at a given wavelength is represented by R followed by the wavelength in nanometers. NDVI = Normalized Difference Vegetation Index; REP = red-edge inflection point; FWBI = Floating Water Band Index.

Absolute biomass production. Growth of each cultivar significantly decreased with increasing salinity, and KBG selections differed in response to salinity as indicated by the analysis of variance (ANOVA) for both cumulative dry and fresh biomass production. Cultivar type (P < 0.0001), salinity treatment (P < 0.0001), and the interaction of cultivar × salinity (P < 0.052) on the cumulative fresh weight were significant (ANOVA full model r^2 = 0.94). Evaluating cumulative dry yield per plot yielded similar significance for cultivar (P < 0.0001) and salinity (P < 0.0001) effects and a significant interaction between cultivar and salinity (P = 0.002) was observed (ANOVA full model r^2 = 0.96).

The cumulative average dry weight over the five harvest periods indicated the six cultivars were generally divided into two distinct yielding groups of three. Cultivars Eagleton, Baron, and Brilliant dry weights ranged from 220 ('Eagleton') to 262 ('Baron') g/plot across salinity levels with non-saline treatments averaging over 415 g/plot, whereas similarly averaged cultivars Cabernet, Midnight, and AO1-856 dry weights ranged from 119 (AO1-856) to 151('Cabernet') g/plot with non-saline treatments less than 350 g/plot for each cultivar. For five of the six cultivars, yields began to decline near 6 $dS\cdot m^{-1}$. The exception was 'Baron' whose cumulative biomass declined ≈10 $dS\cdot m^{-1}$ and at 8 $dS\cdot m^{-1}$ was similar to that observed at 2 $dS\cdot m^{-1}$ (Table 3). Absolute dry weight yield reductions at 10 $dS\cdot m^{-1}$ were between 54% and 65% for higher growth rate or drought-tolerant cultivars (Table 3), but yield reductions resulting from salinity were less than 50% for low growth rate cultivars (Table 4) indicating that cultivars exhibiting high growth rates under the experimental conditions of this study are affected by salinity to a greater extent than cultivars exhibiting a lower growth rate.

The absolute growth rates based on sward area development in this salt tolerance study were contrasting to growth rates expected based on pedigree, mature plant height, and plant spread measurements collected in New Jersey (Shortell et al., 2006, 2009) under non-saline field conditions. However, our trial was conducted in Riverside, CA, under optimal growth conditions for cool-season grasses and biomass was collected from plants at regular intervals throughout the 4-month study period and plants were not permitted to flower. These conditions may have influenced the differences in observed versus expected growth rates.

Table 3. Cumulative dry clipping weights and values of four individual vegetative indices sensitive to biomass for three higher growth rate kentucky bluegrass selections irrigated with saline waters.[z]

Electrical conductivity (dS·m^{-1})	∑DW ± SE (g)	NDVI*red*	REP	NDVI*protein*	NDVI*infra*
Eagleton					
2	418 ± 30	0.320 ± 0.017	–0.081 ± 0.004	0.675 ± 0.029	0.635 ± 0.028
6	324 ± 7.6	0.315 ± 0.031	–0.077 ± 0.007	0.642 ± 0.047	0.598 ± 0.048
8	288 ± 47	0.362 ± 0.043	–0.087 ± 0.007	0.712 ± 0.035	0.650 ± 0.034
10	195 ± 21	0.376 ± 0.051	–0.091 ± 0.011	0.721 ± 0.057	0.690 ± 0.047
12	199 ± 18	0.309 ± 0.039	–0.079 ± 0.009	0.675 ± 0.055	0.634 ± 0.051
14	163 ± 11	0.273 ± 0.016	–0.075 ± 0.004	0.663 ± 0.034	0.618 ± 0.033
18	91.1 ± 6.5	0.223 ± 0.025	–0.063 ± 0.005	0.584 ± 0.051	0.548 ± 0.044
22	83.8 ± 14	0.269 ± 0.037	–0.069 ± 0.009	0.607 ± 0.066	0.575 ± 0.063
Baron					
2	495 ± 10	0.331 ± 0.020	–0.087 ± 0.006	0.716 ± 0.035	0.667 ± 0.038
6	374 ± 51	0.344 ± 0.040	–0.093 ± 0.011	0.729 ± 0.053	0.689 ± 0.052
8	422 ± 17	0.279 ± 0.026	–0.079 ± 0.007	0.671 ± 0.058	0.634 ± 0.053
10	230 ± 26	0.271 ± 0.020	–0.078 ± 0.003	0.688 ± 0.025	0.623 ± 0.024
12	214 ± 23	0.221 ± 0.025	–0.069 ± 0.007	0.642 ± 0.049	0.608 ± 0.045
14	172 ± 34	0.202 ± 0.036	–0.061 ± 0.010	0.541 ± 0.077	0.510 ± 0.076
18	95.7 ± 17	0.176 ± 0.025	–0.057 ± 0.007	0.496 ± 0.059	0.445 ± 0.069
22	95.1 ± 6.7	0.167 ± 0.016	–0.051 ± 0.004	0.481 ± 0.033	0.442 ± 0.033
Brilliant					
2	440 ± 44	0.333 ± 0.024	–0.082 ± 0.005	0.678 ± 0.036	0.638 ± 0.031
6	381 ± 43	0.385 ± 0.046	–0.092 ± 0.011	0.708 ± 0.062	0.673 ± 0.058
8	270 ± 45	0.322 ± 0.028	–0.082 ± 0.006	0.672 ± 0.034	0.627 ± 0.029
10	222 ± 34	0.304 ± 0.014	–0.082 ± 0.004	0.714 ± 0.022	0.681 ± 0.020
12	204 ± 17	0.283 ± 0.034	–0.077 ± 0.009	0.679 ± 0.066	0.635 ± 0.067
14	202 ± 22	0.289 ± 0.017	–0.081 ± 0.005	0.719 ± 0.035	0.676 ± 0.027
18	112 ± 10	0.250 ± 0.039	–0.068 ± 0.009	0.621 ± 0.056	0.593 ± 0.049
22	54.6 ± 16	0.149 ± 0.035	–0.046 ± 0.009	0.442 ± 0.103	0.403 ± 0.096

[z]Values represent average of three replications and se for each of six selections grown at salinities ranging from 2 to 22 dS·m^{-1}.
NDVI = Normalized Difference Vegetation Index; REP = red-edge inflection point.

Table 4. Cumulative clipping dry weights and values of four individual vegetative indices sensitive to biomass for three lower growth rate kentucky bluegrass selections irrigated with saline waters.[z]

Electrical conductivity (dS·m^{-1})	∑DW ± SE (g)	NDVI*red*	REP	NDVI*protein*	NDVI*infra*
Cabernet					
2	346 ± 13	0.306 ± 0.045	–0.080 ± 0.009	0.691 ± 0.052	0.646 ± 0.041
6	208 ± 16	0.335 ± 0.054	–0.085 ± 0.013	0.677 ± 0.083	0.644 ± 0.087
8	201 ± 7.6	0.296 ± 0.032	–0.081 ± 0.005	0.676 ± 0.035	0.630 ± 0.030
10	155 ± 15	0.227 ± 0.034	–0.064 ± 0.009	0.585 ± 0.068	0.541 ± 0.068
12	116 ± 24	0.211 ± 0.036	–0.059 ± 0.007	0.534 ± 0.057	0.492 ± 0.049
14	96.8 ± 20	0.232 ± 0.022	–0.067 ± 0.005	0.614 ± 0.055	0.568 ± 0.055
18	37.2 ± 5.4	0.190 ± 0.027	–0.054 ± 0.005	0.481 ± 0.040	0.451 ± 0.040
22	52.8 ± 12	0.177 ± 0.021	–0.049 ± 0.005	0.439 ± 0.045	0.388 ± 0.043
Midnight					
2	347 ± 33	0.263 ± 0.021	–0.075 ± 0.005	0.713 ± 0.023	0.688 ± 0.022
6	261 ± 34	0.278 ± 0.033	–0.083 ± 0.008	0.733 ± 0.043	0.703 ± 0.044
8	154 ± 40	0.257 ± 0.037	–0.075 ± 0.009	0.679 ± 0.067	0.649 ± 0.066
10	123 ± 46	0.206 ± 0.014	–0.064 ± 0.004	0.632 ± 0.036	0.612 ± 0.034
12	110 ± 8.1	0.229 ± 0.028	–0.068 ± 0.006	0.659 ± 0.044	0.614 ± 0.046
14	85.6 ± 14	0.215 ± 0.033	–0.066 ± 0.006	0.643 ± 0.035	0.598 ± 0.039
18	45.5 ± 6.3	0.169 ± 0.013	–0.056 ± 0.004	0.564 ± 0.036	0.539 ± 0.033
22	33.6 ± 4.5	0.144 ± 0.009	–0.045 ± 0.002	0.454 ± 0.026	0.419 ± 0.020
A01-856					
2	335 ± 27	0.254 ± 0.023	–0.069 ± 0.005	0.598 ± 0.041	0.557 ± 0.039
6	169 ± 19	0.300 ± 0.040	–0.085 ± 0.009	0.688 ± 0.055	0.622 ± 0.053
8	150 ± 38	0.239 ± 0.036	–0.072 ± 0.008	0.569 ± 0.077	0.504 ± 0.088
10	97.2 ± 2.9	0.222 ± 0.017	–0.064 ± 0.006	0.565 ± 0.035	0.498 ± 0.031
12	75.1 ± 9.7	0.208 ± 0.023	–0.062 ± 0.006	0.536 ± 0.052	0.474 ± 0.044
14	64.6 ± 3.2	0.179 ± 0.030	–0.059 ± 0.005	0.483 ± 0.060	0.454 ± 0.050
18	30.6 ± 5.8	0.194 ± 0.033	–0.056 ± 0.010	0.457 ± 0.083	0.405 ± 0.078
22	27.1 ± 11	0.169 ± 0.030	–0.048 ± 0.006	0.398 ± 0.062	0.343 ± 0.048

[z]Values represent average of three replications and standard error for each of six selections grown at salinities ranging from 2 to 22 dS·m^{-1}.
NDVI = Normalized Difference Vegetation Index; REP = red-edge inflection point.

The performance of these selections under salinity was not related to the performance of selections rated for drought tolerance. The AO1-856 TBG (Abraham et al., 2004) previously identified as drought-tolerant with greater biomass produced under recovery from drought stress had the poorest biomass production under salinity stress. Also, a previously identified drought-sensitive cultivar, Brilliant, with lower biomass production (Wang et al., 2003a, 2003b) exhibited the second highest biomass production when exposed to salinity stress in the absence of any soil matric stress during the present study.

The correlation of VI to absolute biomass varied between cultivars. The VIs were generally less sensitive to increasing salinity than was biomass. The trends appeared independent of the VI type and wavelength domain. The segregation of reflectance values resulting from salinity stress was similar to that for biomass. Absolute reflectance values for Normalized Difference VI (NDVI) tended to be higher for higher growth rate selections than for low growth rate selections. Some higher VI values observed in the intermediate salinity treatments were not different from the VI values of the controls primarily in the higher-growth rate selections (see $NDVI_{protein}$; Table 3). By convention, the red-edge inflection point index became more positive with increasing salinity (red shift) but was less variable when comparing high- and low-growth rate selection VI values at the high and low salinity treatments (Tables 3 and 4). Absolute yield, although important in some situations (i.e., forage production), is confounded by the inherent growth rate of individual cultivars, which make determining differences in salinity tolerance between cultivars difficult. In turfgrasses, low growth rate is not necessarily a negative characteristic. In fact, breeders have been selecting for low growth habit in breeding programs for years (Meyer and Funk, 1989). Therefore, in turfgrasses, relative yield may be a more useful measurement of salinity tolerance because genetic differences between cultivars are accounted for.

Relative salt tolerance. Interestingly, the relative yield indicated that the EC related to 50% relative biomass reduction (C_{50} parameter) generally separated the six cultivars into the same two distinct groups. A high-growth rate group based on biomass production included 'Baron', 'Brilliant', and 'Eagleton' with C_{50} parameter values near 10 dS·m^{-1} in each case (Table 5), and the lower-growth rate group based on biomass production included 'Cabernet', 'Midnight', and AO1–856 with C_{50} values of 8, 8, and 6 dS·m^{-1}, respectively (Table 6). For a direct cultivar comparison, Horst and Taylor (1983) observed the salinity of irrigation water for a 50% yield reduction in 'Baron' was 11.6 dS·m^{-1} and in this experiment, the 50% clipping dry weight reduction occurred at irrigation water salinity of 10.9 ± 0.9 dS·m^{-1}. The maximum relative yield parameter was 1.0 to 1.1 for all cultivars. The shaping parameter, p, an indication of how steep the decline in biomass production occurs in response to salinity, revealed that all cultivars had a P value close to 2 but that the steepest declines occurred for 'Baron', 'Midnight', and 'Brilliant' (three greatest P values of 2.6, 2.3, and 2.2, respectively; Tables 5 and 6), respectively, indicating that these cultivars suffered the steepest decline in response to salinity. The biomass reduction found for the higher growth rate selections ('Baron', 'Brilliant', and 'Eagleton') of ≈50% of the control salinity (2 dS·m^{-1}) at 10 dS·m^{-1} was similar to findings of Qian et al. (2001) for KBG cultivars Kenblue and Limousine.

The correlations between cumulative relative dry weight and those VIs sensitive to biomass were similar for both the high and low growth rate cultivars. The best relationship for VI as a function of relative biomass was found for the high growth rate 'Baron' (r^2 = 0.71; Table 7) with $NDVI_{red}$. The correlations with $NDVI_{red}$ were slightly improved for each KBG selection when compared with the other VIs tested that were sensitive to biomass (Table 7). For any given cultivar, significant linear correlations of VI with biomass tended to be independent of the type of VI used in the regression. Following 'Baron', the best relationship overall of VI with relative biomass yield as a function salinity were 'Midnight' > 'Brilliant' > 'Cabernet' > AO1-856. For 'Eagleton', a weaker yet significant relationship (P = 0.0302) with relative yield was found only with the $NDVI_{red}$ index.

Shoot relative moisture content. Salinity (P < 0.0001) and cultivar (P < 0.0001) significantly influenced the shoot tissue RMC (ANOVA model r^2 = 0.85, P < 0.0001), but no interaction between salinity and cultivar was found. Similarly, salinity (P < 0.0001) and cultivar (P < 0.0001) differences in the Floating Water Band Index (FWBI; Strachan et al., 2002) were observed (ANOVA model r^2 = 0.70, P < 0.0001) without a significant cultivar × salinity interaction. Tissue RMC was found to be significantly correlated with FWBI for each cultivar (Table 8). For most cultivars, the RMC decreased 10% to 15% as salinity increased from 2 dS·m^{-1} to 22 dS·m^{-1}, but the FWBI exhibited a narrow range of values over salinity treatments and produced a ≈5% reduction in FWBI (Table 8). The linear relationship between increasing salinity and decreasing RMC was significant for each cultivar (Table 8) and when the FWBI was averaged across the cultivars and correlated with average cultivar tissue RMC (r^2 = 0.37, P > F ≤ 0.0001). The highest correlation observed between RMC and FWBI was for AO1-856 (r^2 = 0.46, P = 0.0002; Table 8).

Rankings of cultivars based on FWBI were not consistent with rankings of absolute or relative biomass. For example, the FWBI values were similar for the high growth rate, 'Baron', and the lower growth rate, AO1-856 (Table 8), yet biomass production for the two selections was significantly different (Tables 3 and 4). When averaged across salinity, the ratio of FWBI:cumulative dry weight for low-biomass AO1-856 (0.073) was higher than for high-biomass 'Baron' (0.029) reflecting differences in shoot growth efficiency independent of shoot water status. Similarly, when averaged across salinity, the ratio of the FWBI: $NDVI_{infra}$ for AO1-856 (2.23) was higher than for 'Baron' (1.85).

Abraham et al. (2004) and Bonos and Murphy (1999) observed different responses to drought and heat stress among KBG cultivars. The drought-tolerant cultivars had deeper rooting systems that maintained higher leaf relative water content or transpiration potential as soil matric stress progressed than sensitive KBG cultivars. In our evaluation, cultivar effects and salinity significantly influenced root:shoot ratio. Root dry weight showed trends for cultivar differences but were not significant. Root dry mass from the 147-cm^3 soil volume was the greatest for AO1-856 (0.157 g) followed by 'Cabernet' (0.154 g), 'Baron' (0.140 g), 'Eagleton' (0.128 g), 'Brilliant' (0.128 g), and 'Midnight' (0.113 g). The drought-tolerant cultivar AO1-856 had a greater root:shoot ratio (Fig. 1) and also higher RMC than the other cultivars (Table 8), but unlike drought in which rooting extent helps maintain shoot growth and presumably RMC, this greater proportion of root mass under salinity stress continued to reduce shoot

Table 5. Mathematical salt tolerance model parameters for three higher growth rate kentucky bluegrass selections irrigated with saline waters based on relative dry clipping weight and four scaled relative vegetative indices.[z]

Salt tolerance parameter	Relative dry wt	Scaled relative vegetative index			
		NDVI*red*	REP	NDVI*protein*	NDVI*infra*
		Eagleton			
C50	10.3 ± 0.95	17.1 ± 2.9	20.1 ± 3.0	23.4 ± 4.1	24.0 ± 4.4
Ym	1.04 ± 0.07	0.91 ± 0.14	0.88 ± 0.11	0.85 ± 0.08	0.79 ± 0.07
p	2.0 ± 0.32	4.0 ± 2.7	3.9 ± 2.8	4.1 ± 3.5	3.9 ± 3.4
		Baron			
C50	10.9 ± 0.88	11.2 ± 0.8	12.8 ± 1.01	14.0 ± 0.92	14.2 ± 1.07
Ym	1.00 ± 0.08	0.94 ± 0.06	0.84 ± 0.07	0.83 ± 0.06	0.83 ± 0.06
p	2.6 ± 0.45	3.5 ± 0.7	3.5 ± 0.8	4.4 ± 1.1	4.3 ± 1.2
		Brilliant			
C50	10.7 ± 1.2	18.1 ± 1.6	19.8 ± 0.96	21.0 ± 0.79	21.0 ± 0.68
Ym	1.03 ± 0.1	0.95 ± 0.07	0.91 ± 0.05	0.93 ± 0.04	0.94 ± 0.05
p	2.2 ± 0.4	3.8 ± 1.4	7.5 ± 3.0	10.4 ± 4.4	11 ± 4.4

[z] Salt tolerance model values represent nonlinear least squares estimates and estimated SES for eight salinities ranging from 2 to 22 dS·m^{-1} and three replications. NDVI = Normalized Difference Vegetation Index; REP = red-edge inflection point.

Table 6. Mathematical salt tolerance model parameters for three lower growth rate kentucky bluegrass selections irrigated with saline waters based on relative dry weight and four scaled relative vegetative indices.[z]

Salt tolerance parameter	Relative dry wt	Scaled relative vegetative index			
		NDVI*red*	REP	NDVI *protein*	NDVI*infra*
		Cabernet			
C50	7.94 ± 0.85	11.5 ± 2.0	12.5 ± 2.1	14.5 ± 2.32	14.9 ± 2.2
Ym	1.06 ± 0.08	0.73 ± 0.12	0.75 ± 0.11	0.78 ± 0.11	0.84 ± 0.10
p	1.9 ± 0.28	3.1 ± 1.4	2.9 ± 1.3	2.7 ± 1.2	2.6 ± 1.1
		Midnight			
C50	7.87 ± 0.96	13.7 ± 1.8	14.9 ± 1.6	17.7 ± 1.18	16.6 ± 1.3
Ym	1.05 ± 0.10	0.88 ± 0.11	0.92 ± 0.09	0.89 ± 0.06	0.89 ± 0.06
p	2.3 ± 0.49	3.5 ± 1.4	3.7 ± 1.4	4.8 ± 1.5	3.9 ± 1.1
		A01–856			
C50	5.68 ± 1.04	13.6 ± 2.9	15.8 ± 2.6	15.5 ± 1.84	16.7 ± 1.9
Ym	1.05 ± 0.13	0.91 ± 0.17	0.96 ± 0.13	0.88 ± 0.09	1.01 ± 0.10
p	1.9 ± 0.35	2.8 ± 1.5	2.8 ± 1.3	3.3 ± 1.2	2.6 ± 1.1

[z] Values represent nonlinear least squares estimates and estimated SEs for eight salinities and three replications fitted for selections grown at salinities ranging from 2 to 22 dS·m^{-1}.

REP = red-edge inflection point; NDVI = Normalized Difference Vegetation Index.

Table 7. Regression analysis of relative (to non-saline control) cumulative dry weights of six kentucky bluegrass selections as a linear function of four vegetative indices sensitive to biomass for three replications at eight levels of salinity (n = 24 for each selection).

VI	Selection	Slope	Intercept	r^2	$P > F$
NDVI*red*	Eagleton	1.78	–0.02	0.20	0.0302
	Baron	3.73	–0.40	0.71	<0.0001
	Brillant	2.66	–0.23	0.48	0.0002
	Cabernet	2.39	–0.15	0.39	0.0012
	Midnight	4.16	–0.50	0.51	<0.0001
	A01-856	2.67	–0.31	0.31	0.0047
REP	Eagleton	–8.55	–0.01	0.14	NS
	Baron	–15.20	–0.56	0.59	<0.0001
	Brillant	–11.90	–0.37	0.41	0.0007
	Cabernet	–10.60	–0.27	0.38	0.0014
	Midnight	–16.80	–0.70	0.49	<0.0001
	A01-856	–11.20	–0.36	0.29	0.0067
NDVI*protein*	Eagleton	1.25	–0.30	0.09	NS
	Baron	2.10	–0.77	0.53	<0.0001
	Brillant	1.20	–0.29	0.22	0.0206
	Cabernet	1.50	–0.44	0.40	0.001
	Midnight	2.31	–1.05	0.48	0.0002
	A01-856	1.59	–0.49	0.35	0.0022
NDVI*infra*	Eagleton	1.40	–0.34	0.09	NS
	Baron	2.06	–0.66	0.52	<0.0001
	Brillant	1.37	–0.31	0.24	0.0162
	Cabernet	1.57	–0.41	0.41	0.0007
	Midnight	2.35	–1.00	0.51	<0.0001
	A01-856	1.74	–0.48	0.39	0.0012

VI = Vegetation Index; NDVI = Normalized Difference Vegetation Index; NS = nonsignificant.

growth in the absence of drought. Differences in salt and drought sensitivity of AO1-856 may be the result of decreased carbon fixation and transpiration rates that would be proportional to lower biomass production when water for transpiration is unlimited. Similar findings of greater total root length in a hybrid bluegrass coupled with lower ET and biomass production when compared with non-hybridized KBG selections (Suplick-Ploense and Qian, 2005) indicate differences in cultivar responses between soil matric and salinity stress (rooting patterns and water use efficiency) are important. Obviously, RS measurements cannot quantify the rooting extent, but the combination of canopy analysis as a surrogate for biomass and leaf moisture content coupled with root observations gives similar interpretations of salinity response between KBG selections, indicating that RS technology may be a better estimate of overall salinity tolerance than total biomass production alone.

Shoot chloride accumulation and Vegetation Index. Differences among the cultivars in shoot chloride accumulation were significant even under control conditions, ranging from 205 (‘Midnight’) to 300 mmol·kg^{-1} dry weight (dw) (‘Brilliant’ and ‘Eagleton’). As salinity increased, however, shoot chloride accumulation by ‘Midnight’ became stronger. At the highest salinity level, the cultivars, ranked by decreasing shoot Cl, were ‘Brilliant’, ‘Midnight’, ‘Cabernet’, ‘Eagleton’, ‘Baron’, and A01-856 with concentrations of 835, 760, 645, 580, 450, and 415 mmol·kg^{-1} dw, respectively.

The relationship between growth rate and shoot chloride concentration in this study indicates chloride uptake appears to be influenced by both shoot, rhizome, and root growth rates and the effects of shoot morphology-related differences on transpiration. Chloride uptake would be expected to be proportional to transpirational increases as a result of biomass of shoots; however, in this study, the low biomass-producing cultivar, A01-856, and higher biomass-producing ‘Baron’ both maintained lower shoot chloride. Shortell et al. (2009) reported that KBG × ‘Texas’ hybrids as well as mid-Atlantic turf types have aggressive rhizome spread and intermediate height characteristics compared with compact types like ‘Baron’, ‘Midnight’, and ‘Brilliant’ that tend to be shorter plants and have less aggressive spreading. In this study, however, a low β (intrinsic canopy area growth rate parameter) together with less aggressive spread was observed for both A01-856 and ‘Baron’ at high salinity (Fig. 2). Biomass differences between the hybrid and ‘Baron’ indicate that an increase in canopy area in ‘Baron’ may have resulted from increased growth, thereby diluting tissue Cl^- concentration. This could be the result of improved water use efficiency in ‘Baron’ reducing the potential for water flux related Cl^- uptake and ion exclusion through differences in mass flow at the root level while optimizing carbon fixation. The lower Cl^- concentration in A01-856 may be explained in part by a reduction in biomass-related transpirational mass flow exclusion at the root level but not as a result of dilution in the tissue.

The use of RS NDVI$_{infra}$ as a surrogate for the intrinsic growth rate also gave similar results; however, the correlations were not as high and one selection, ‘Eagleton’, showed no significant relationship of chloride as a function of increasing growth rate (Fig. 3). Salinity tolerance in KBG has been associated with the ability to restrict accumulation of sodium and chloride in shoot (Qian et al., 2001; Torello and Symington, 1984) and A01-856 and ‘Baron’ in this study would meet these criteria to a greater extent than the other cultivars. If low growth habit is a selection criteria (Meyer and Funk, 1989), then A01-856 would be a better selection for both low growth rate and low Cl^- accumulation rates than would ‘Baron’.

Deeper or more extensive roots may increase shoot water content when salts are absent. When salinity is present, however, increased surface area for potential salt loading through diffusion and mass flow may counter the advantage of greater exploitation of soil moisture under drought. This study did not measure ET directly and the plants were not subjected to drought, but Suplick-Ploense and Qian (2005) demonstrated that not only growth was proportional to ET ($r^2 > 0.94$) but that ET was less for the hybrid bluegrass ‘Reveille’ than for non-hybridized KBG selections.

Conclusions

Collection of near-canopy (within 35 cm) reflectance spectra from 350 to 2500 nm for calculating VI of KBG and TBG cultivars

Table 8. The relative moisture content (RMC) of five kentucky bluegrass selections and one 'Texas' × kentucky bluegrass hybrid selection and corresponding floating water band index value (FWBI).[z]

Electrical conductivity (dS·m^{-1})	High growth rate selections		Electrical conductivity (dS·m^{-1})	Low growth rate selections	
	Eagleton: $r^2 = 0.28$, $P = 0.0108$			Cabernet: $r^2 = 0.32$, $P = 0.0040$	
	RMC ± SE	FWBIstr ± SE		RMC ± SE	FWBIstr ± SE
2	0.751 ± 0.005	1.083 ± 0.008	2	0.761 ± 0.003	1.062 ± 0.007
6	0.735 ± 0.006	1.063 ± 0.008	6	0.733 ± 0.004	1.065 ± 0.007
8	0.732 ± 0.007	1.072 ± 0.008	8	0.733 ± 0.006	1.076 ± 0.008
10	0.708 ± 0.014	1.070 ± 0.014	10	0.706 ± 0.005	1.056 ± 0.005
12	0.716 ± 0.007	1.066 ± 0.008	12	0.704 ± 0.008	1.053 ± 0.015
14	0.700 ± 0.004	1.071 ± 0.006	14	0.690 ± 0.002	1.057 ± 0.002
18	0.662 ± 0.014	1.053 ± 0.003	18	0.642 ± 0.002	1.042 ± 0.009
22	0.656 ± 0.031	1.044 ± 0.007	22	0.630 ± 0.002	1.040 ± 0.004
	Baron: $r^2 = 0.42$, $P = 0.0080$			Midnight: $r^2 = 0.39$, $P = 0.0015$	
2	0.735 ± 0.005	1.081 ± 0.010	2	0.732 ± 0.002	1.084 ± 0.013
6	0.717 ± 0.007	1.091 ± 0.009	6	0.715 ± 0.003	1.063 ± 0.008
8	0.714 ± 0.010	1.081 ± 0.004	8	0.711 ± 0.005	1.055 ± 0.011
10	0.687 ± 0.008	1.076 ± 0.006	10	0.682 ± 0.008	1.041 ± 0.009
12	0.694 ± 0.002	1.064 ± 0.003	12	0.683 ± 0.004	1.060 ± 0.009
14	0.690 ± 0.012	1.060 ± 0.008	14	0.659 ± 0.003	1.048 ± 0.006
18	0.655 ± 0.012	1.072 ± 0.005	18	0.654 ± 0.019	1.041 ± 0.008
22	0.650 ± 0.005	1.037 ± 0.006	22	0.610 ± 0.024	1.025 ± 0.001
	Brillant: $r^2 = 0.45$, $P = 0.0030$			A01-856: $r^2 = 0.46$, $P = 0.0002$	
2	0.732 ± 0.004	1.074 ± 0.013	2	0.744 ± 0.008	1.089 ± 0.012
6	0.718 ± 0.012	1.057 ± 0.009	6	0.722 ± 0.009	1.105 ± 0.014
8	0.716 ± 0.011	1.085 ± 0.005	8	0.723 ± 0.005	1.102 ± 0.013
10	0.674 ± 0.005	1.060 ± 0.010	10	0.705 ± 0.009	1.071 ± 0.010
12	0.673 ± 0.010	1.041 ± 0.005	12	0.711 ± 0.004	1.071 ± 0.006
14	0.676 ± 0.005	1.054 ± 0.004	14	0.679 ± 0.003	1.074 ± 0.002
18	0.631 ± 0.010	1.043 ± 0.008	18	0.691 ± 0.019	1.050 ± 0.006
22	0.613 ± 0.026	1.017 ± 0.004	22	0.657 ± 0.014	1.045 ± 0.017

[z]Both RMC and FWBI decreased significantly with increasing salinity, but differences between cultivars were not significant.

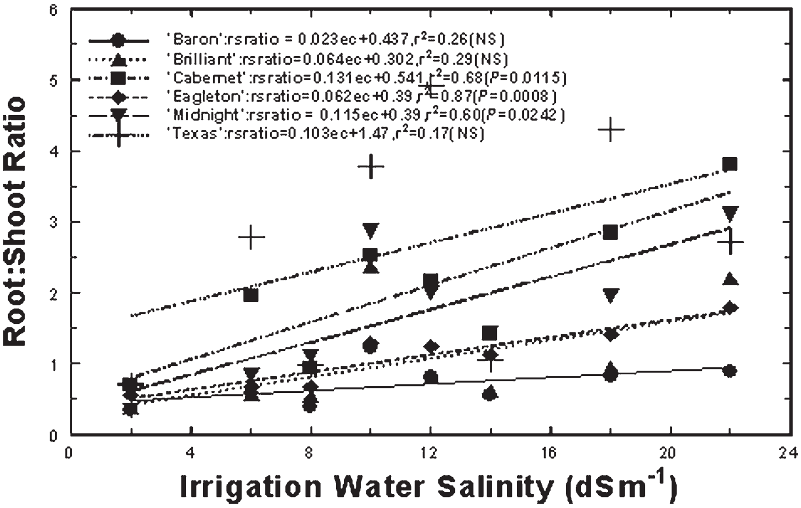

Fig. 1. The root:shoot ratio of six kentucky bluegrass selection as a function of electrical conductivity of the soil solution. The equations represent the root:shoot ratio of each cultivar with increasing salinity. Based on least squares mean comparison when averaged across salinity, the overall ratio was significantly different between A01-856 and 'Baron' ($P = 0.017$) with the remaining ratios ranked as 'Cabernet' > 'Midnight' > 'Eagleton' = 'Brilliant'.

grown in outdoor plots provided a strong, non-destructive, complimentary response measurement in this salinity tolerance study under controlled conditions.

Despite significant relationships between biomass and salinity stress observed in this study, one-to-one correlation of traditional salt tolerance parameters with RS techniques may not be possible or may require greater effort than traditional direct measures of salt tolerance (yield, biomass, etc.). As a complement to any plant salt tolerance examination, RS can aid investigators as a real-time indirect monitor of biomass accumulation and leaf water status.

The estimated salinities for a relative yield reduction of 50% based on canopy reflectance (C_{50} parameter) in this study were much greater than similarly fitted parameters based on relative biomass reduction, indicating a reduced sensitivity in reflectance data as salinity stress increases. Nevertheless, RS data were able to discriminate generally between the high-growth rate selections and the lower-growth rate selections.

The traditional approach of assessing salt tolerance based on yield or plant vigor may not directly apply to turf selections for recreational purposes. Decreased growth rates and the associated reductions in transpiration appear to control salt loading to the shoots as well as reduce the need for more frequent clipping. Based on selection of lower growth rates and minimizing chloride uptake, the tolerance ranking would appear to be A01-856 > 'Baron' > 'Eagleton' > 'Midnight' > 'Cabernet' > 'Brilliant', whereas the tolerance ranking based on relative or absolute cumulative yield would be 'Baron' = 'Brilliant' = 'Eagleton' > 'Midnight' = 'Cabernet' = A01-856. It should be noted that conflicting rankings for KBG cultivar salt tolerance have been reported and that these discrepancies may be attributed to a narrow range of salt tolerance within this species (Marcum, 2008). In theory, for other similar assessments, these results could be achieved by measuring $NDVI_{infra}$ and shoot chloride over time, indicating that including RS measurements may be more useful for salinity tolerance evaluations in cool-season turfgrasses than biomass information alone.

Additional research is needed to evaluate if the effects of changes in soil moisture in the presence of significant salinity stress are detectable with RS. Baghzouz et al. (2007) noted that at best only 40% to 60% of the nitrogen and tissue moisture content variability was explained by RS indices and emphasized that new approaches are needed to explain the large temporal variability that precludes using these techniques with a single functional relationship. Turf selection for salt tolerance by RS may also be applied at the field-scale provided assessments of soil salinity ground truth are simultaneously coupled with canopy reflectance estimates of biomass or the harvestable product to provide statistically reliable data. Lesch et al. (2006) related electromagnetic induction (EM) estimates of soil salinity to lettuce yields in Yuma, AZ. RS measurements in a field with no matric stress (soon after an irrigation event) coupled with EM may provide canopy reflectance information that primarily reflects salinity plant growth reductions.

These results indicate changes in turf reflectance at a small spatial scale measured with RS technology can provide useful information on turf canopy development as affected by salinity. In addition to biomass changes and potential inferences on transpiration rates, RS coupled with tissue ion analysis provided information on shoot-related responses that could be related to rooting differences. Decreases in VI in this study may have partially been the result of increased shoot senescence associated with the two highest salt treatments (18 and 22 dS·m^{-1}) in addition to reductions in leaf area or biomass.

With RS measurements, it may be possible to non-destructively estimate or quantify turf development rates based on area or biomass and plant tissue moisture status. Remotely

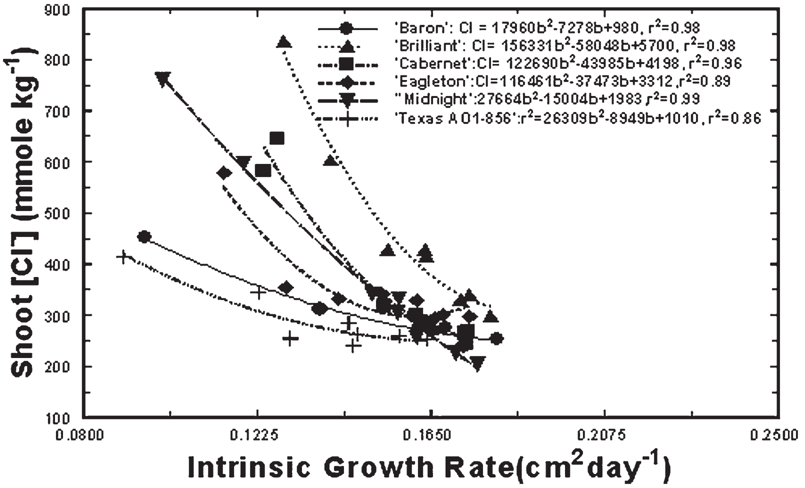

Fig. 2. The average shoot chloride concentrations of three replications for six kentucky bluegrass selections as a function of the average intrinsic shoot area increase rate. The relationship was significant for all cultivars ($P \leq 0.0074$).

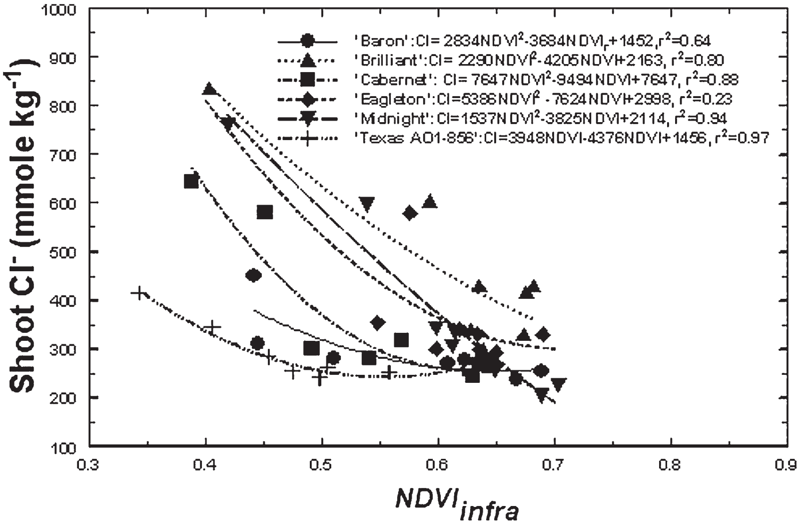

Fig. 3. The average shoot chloride concentrations of three replications for six kentucky bluegrass selections as a function of the vegetative index NDVI$_{infra}$. The relationship was significant for all cultivars ($P \leq 0.0191$) except 'Eagleton'.

sensed canopy reflectance provided VI as indicators of multiple stressors that are important and typically occur simultaneously in practical turf situations. These observations were shown to significantly characterize KBG cultivar adaptive response differences.

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