

Responses of Creeping Bentgrass to Salinity and Mowing Management: Growth and Turf Quality

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Abstract. Salt problems in turfgrass sites are becoming more common. The effects of mowing management on salinity tolerance are not well understood. The objective of this study was to examine the effects of three mowing regimes on turf quality and growth responses of 'L-93' creeping bentgrass (*Agrostis palustris* L.) to salinity stress. Sods of 'L-93' creeping bentgrass were grown in containers (45 cm long and 10 cm in diameter) in a greenhouse. Treatments included three mowing regimes (clipping three times weekly at 25.4 mm, four times at 12.7 mm, and daily at 6.4 mm) and four levels of irrigation water salinity (control, 5, 10, and 15 dS·m⁻¹). The relationship of increasing soil salinity with increasing irrigation water salinity was linear in each soil layer. Increasing salinity reduced turf quality and clipping yield more severely and rapidly when mowed at 6.4 mm than at 12.7 or 25.4 mm. Regression analysis of soil salinity and turf quality suggested that turf quality of creeping bentgrass mowed to 6.4, 12.7, and 25.4 mm fell to an unacceptable level when soil salinity reached 4.1, 12.5, and 13.9 dS·m⁻¹, respectively. Data on turf quality, clipping yield, and verdure indicated that salinity damage becomes more severe under close mowing conditions and that a moderate increase in mowing height could improve salinity tolerance of creeping bentgrass.

Salt problems in turfgrass sites are becoming more common for many reasons: accelerated urban development in western states where saline soils are common; the use of wastewater or other irrigation waters containing sodium and other salts, seawater intrusion into turf facilities located on coastal sites, and road deicing. Drought and water shortages result in mandatory turf watering restrictions in many cities. Water conservation efforts can further increase soil salinity levels due to reduced leaching.

Creeping bentgrass, because of its high turf quality and recuperative ability, is one of the most widely used species on golf course putting greens, tees, and fairways in the United States. The salinity tolerance of creeping bentgrass has been ranked from moderately sensitive [tolerant of 3 to 6 dS·m⁻¹ salinity of saturated soil paste (ECe)] to moderately tolerant (tolerant of 8 to 16 dS·m⁻¹ ECe) (Beard, 1973; Carrow and Duncan, 1998; Harivandi et al., 1992). A decline in bentgrass quality is often observed under salinity stress and close mowing conditions on putting greens and tees (personal observation). In addition to varietal variations (Marcum, 2001), different mowing regimes may also contribute to the great variations in salinity tolerance reported for creeping bentgrass. Reduced mowing height has been found to reduce turf quality (Salaiz et al., 1995), root production (Krans and Beard, 1975; Salaiz et al., 1995), photosynthesis (Hull, 1987; Krans and Beard, 1975; Liu and Huang,

2003), and total nonstructural carbohydrate content (Huang and Fry, 1999).

No published information is available to address the influence of mowing height and frequency on creeping bentgrass salinity tolerance. Most studies comparing salinity tolerance among different grasses have been conducted under a single mowing regime or under un-mowed conditions (Qian et al., 2004; Youngner et al., 1967). We hypothesize that close mowing will reduce the salinity tolerance of turfgrass because mowing reduces rooting, thereby negating the plant's water extracting ability. Close mowing may also reduce energy reserves, thereby reducing the salt-coping ability of turfgrass. Studies with other plants have shown that many salt resistance mechanisms (salt exclusion, salt secretion, salt sequestration, synthesis of benign osmoprotectants, salt damage repair, etc) are energy dependent (Tester and Davenport, 2003).

Understanding the interactive effects of mowing and salinity on turfgrass growth will aid in the development of guidelines for effective mowing practices that promote maximum salt tolerance in turfgrass. The objective of this study was to examine the effects of three mowing regimes on turf quality and growth responses of 'L-93' creeping bentgrass to salinity stress.

Materials and Methods

Plant materials and growth conditions. Sod pieces (10 cm in diameter) of 'L-93' were collected from a putting green at the Horticulture Research Center, Fort Collins, Colo. After removing soil by hand washing, sod pieces were transplanted to polyvinyl chloride (PVC) tubes (45 cm long and 10 cm in diameter) that were packed with clay loam soil to a uniform bulk density and kept in a greenhouse.

Plants were grown in the PVC tubes for 2 months, allowing root and canopy to establish before treatments were imposed. During this period, plants were watered on alternate days until water drained freely from the holes at the bottom of each tube and fertilized weekly with Peters Excel solution (15N–2P–12K, Scotts-Sierra Horticultural Products Co., Marysville, Ohio) to provide 24 kg N/ha/month. Each turf was hand-clipped every 2 d at 6.4 mm. The daily maximal/minimal temperatures in the greenhouse were 22/18 °C. Photosynthetically active radiation on a horizontal plane just above the canopy at 10:00 HR averaged about 1000 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

Treatments. Salinity treatments were applied by irrigating with different concentrations of saline water. Irrigation waters of different salinity levels were prepared by the addition of ocean salts (Aquarium Systems, Mentor, Ohio) to tap water to obtain EC values of 0.2 (control), 5.0, 10.0, and 15.0 dS·m⁻¹, measured by an electrical conductivity meter (model CO150; Hach Co., Loveland, Colo.). Mowing treatments included clipping three times weekly at 25.4 mm, four times at 12.7 mm, and daily at 6.4 mm. Irrigation was applied every 2 d with an amount equal to 120% of evapotranspiration (ET), as measured with an extra PVC container (served as a lysimeter) of bentgrass mowed at 25.4 mm. The amount of water applied was the same for all salinity and mowing treatments.

Measurements. Data were collected on turf quality, clipping yield, verdure, root dry weight, and soil salinity level. Visual turf quality was rated biweekly based on color, density, and uniformity using a scale of 0 (brown, dead turf) to 9 (optimum color, density, and uniformity), with a rating of 6.0 or higher indicating acceptable quality. Clipping yield was determined once every two weeks by collecting clippings grown during the previous 1 or 2 days, determining oven-dried (at 70 °C for 48 h) mass, and then calculating daily growth.

Verdure, root mass at different depths, and soil salinity at different depths were determined at the termination of the experiment. Aboveground tissue (verdure) was harvested, freeze-dried immediately (Genesis 25LL lyophilizer; Virtis, Gardiner, N.Y.), and weighed. The PVC tubes containing soil were cut into four 10-cm deep sections. One-fourth of the soil within each section was air-dried for the measurement of soil salinity. Roots in the rest of the soil were washed free of soil, freeze-dried, and weighed.

To determine soil salinity, the air-dried soil was crushed and passed through a 2-mm soil sieve. Electrical conductivity of saturated soil paste was determined with the Hach soil salinity appraisal kit (model CO150; Hach Co.). The mean root zone salinity for each column was calculated using a method described by Devitt (1989).

Statistical analysis. A split-plot experimental design was used with salinity treatment being the main plot, and mowing regimes being the subplots. Each treatment had four replications. Effects of mowing, salinity, and their interaction were determined by analysis

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of variance (SAS Institute, 2001). Turf quality and clipping yield were analyzed on individual measurement dates to examine salinity and mowing effects over time. Because the significant interaction of mowing regime and salinity level was often observed, comparisons of salinity treatments within individual mowing regimes are presented and means were separated by least significant difference at the 0.05 level of probability. Regression analysis was performed to determine the relationship between the parameters measured at the termination of the study and the mean root zone salinity (integrated soil salinity), where salinity was the independent variable and each measured parameter was the dependent variable.

Results and Discussion

Soil salinity. Irrigation with 4 different concentrations of saline water caused dramatically different soil salinity levels (Fig. 1). A linear relationship of increasing soil salinity with increasing irrigation water salinity was achieved in each soil layer ($R^2 = 0.92$ to 0.99).

Different mowing regimes had little effect on soil salinity when turf was irrigated with non-saline water (Fig. 1). When irrigated with 5 to $15 \text{ dS}\cdot\text{m}^{-1}$ water, decreasing mowing height and increasing mowing frequency caused a reduction in soil salinity. Soil salinity was significantly higher for the 25.4 mm mowing regime than for the 6.4 mm mowing regime at all depths of the soil profile. When irrigated with $5 \text{ dS}\cdot\text{m}^{-1}$ water, soil salinity was higher for the 25.4 mm mowing regime than for 12.7 mm mowing regime at all depths. When irrigated with $10 \text{ dS}\cdot\text{m}^{-1}$ water, soil salinity was higher at 12.7 mm mowing height when compared to 6.4 mm mowing height. The higher soil salinity observed under higher mowing heights likely have occurred because turf mowed at higher heights possessed higher ET rates. Since we irrigated each treatment with the same amount of water, a higher mowing height likely resulted in a lower leaching fraction than the low mowing height. The leaching fraction was 20% for non-saline treatment at 25.4 mm mowing regime. The amount of water leached increased as salinity increased and mowing height reduced due to reduced ET. Considering the difference in soil salinity under different mowing regimes, the relationship between bentgrass quality and shoot growth vs. soil salinity presented in Table 1 provided good indications of the effect of soil salinity on creeping bentgrass at different mowing heights.

As the salinity increased in irrigation water, the trend of increasing soil salinity with depth became apparent under high mowing regime. This trend was not apparent under conditions of low irrigation water salinity and/or low mowing height (i.e., high leaching fraction) conditions.

Turf quality. At the starting point of mowing and salinity treatments, all tubes exhibited a desirable turf quality (turf quality = 9). Turf quality declined over time with increasing salinity (Fig. 2). However, the quality decline caused by increasing salinity was more severe

and more rapid when mowed at 6.4 mm than at 12.7 or 25.4 mm. When mowed to 6.4 mm, irrigation with saline waters at 5, 10, and $15 \text{ dS}\cdot\text{m}^{-1}$ resulted in quality decline to an unacceptable level at 73, 60, and 30 d after treatment, respectively.

When mowed to 12.7 and 25.4 mm and irrigated with saline water at 5 and $10 \text{ dS}\cdot\text{m}^{-1}$, creeping bentgrass maintained turf quality above 6 throughout the study period. Yet, irrigation with saline water at $15 \text{ dS}\cdot\text{m}^{-1}$ reduced turf quality to an unacceptable level beginning 73 d after treatment.

Regression analysis was conducted to generate the relationship between soil salinity and turf quality at 85 d after salinity treatment. The linear equation presented in Table 1 suggests that with each unit increase in soil salinity, the turf quality reduction slope was significantly high for the lowest mowing height. Using these equations, we predict that turf quality of creeping bentgrass mowed to 6.4, 12.7, and 25.4 mm will fall below 6 when soil salinity reaches 4.1, 12.5, and $13.9 \text{ dS}\cdot\text{m}^{-1}$, respectively, under these growing conditions. Turf quality data suggests that salinity damage becomes much more severe under shorter mowing heights.

Although creeping bentgrass is typically considered to have medium to good salt tolerance, the short mowing heights used on putting greens and tees will greatly increase the susceptibility of bentgrass to salt stress. In addition to varietal variations (Marcum, 2001), different mowing regimes may also contribute to the great variations in salinity tolerance reported for creeping bentgrass. Our results suggest that increasing mowing height could help improve bentgrass salinity tolerance.

Clipping yield. Clipping yield is one indicator of turf vigor. Clipping yield decreased over time with increasing salinity (Fig. 3). When

mowed at 6.4 mm, creeping bentgrass receiving irrigation water at 5, 10, or $15 \text{ dS}\cdot\text{m}^{-1}$ salinity exhibited significantly lower clipping yields than the control at 30 d after salinity treatment and at the end of the experiment.

When mowed at 12.7 mm, 5 and $10 \text{ dS}\cdot\text{m}^{-1}$ irrigation water had no significant effects on clipping yield during most of experimental period. Irrigation with $15 \text{ dS}\cdot\text{m}^{-1}$ water reduced clipping yield significantly by the end of the experiment (Fig. 3).

Bentgrass mowed at 25.4 mm and irrigated with 10 and $15 \text{ dS}\cdot\text{m}^{-1}$ water had reduced clipping yield beginning at 42 d after salinity treatment began while irrigation with $5 \text{ dS}\cdot\text{m}^{-1}$ water had no effect on clipping yield.

The linear relationships between average root zone salinity and clipping yield harvested at 84 d after the initiation of salinity treatments are presented in Table 1. The effect of salinity on bentgrass clipping yield was most severe at the 6.4 mm mowing height followed by 25.4 mm mowing regime. Salinity had the least effect on creeping bentgrass clipping growth when mowed at 12.7 mm. It is unclear why salinity had the least effect on clipping yield reduction at 12.7 mm rather than 25.4 mm mowing height.

In previous work, salinity levels that resulted in 25% clipping yield reduction have been used as an indicator of salinity tolerance (Qian et al., 2001, 2004; Suplick-Ploense et al., 2002). Using the regression equation in Table 1 and clipping yield for the control, 25% clipping yield reduction salinities were derived. Under the 12.7 mm mowing height, the salinity level that resulted in 25% clipping yield reduction was $14.0 \text{ dS}\cdot\text{m}^{-1}$ whereas a salinity level as low as $5.7 \text{ dS}\cdot\text{m}^{-1}$ would result in 25% clipping yield reduction of creeping bentgrass mowed to 6.4 mm. Our results with creeping bentgrass suggest that the salinity tolerance of

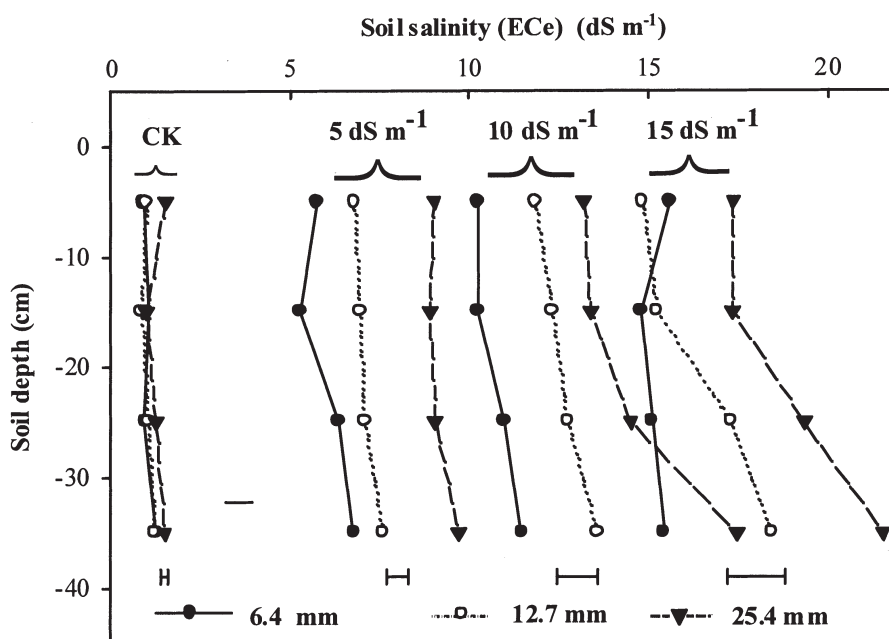


Fig. 1. Influence of mowing height and irrigation water salinity on soil salinity at 0 to 10, 10 to 20, 20 to 30, and 30 to 40 cm below soil surface. Horizontal bars indicate LSD value ($P = 0.05$) for mowing height comparison with each salinity treatment.

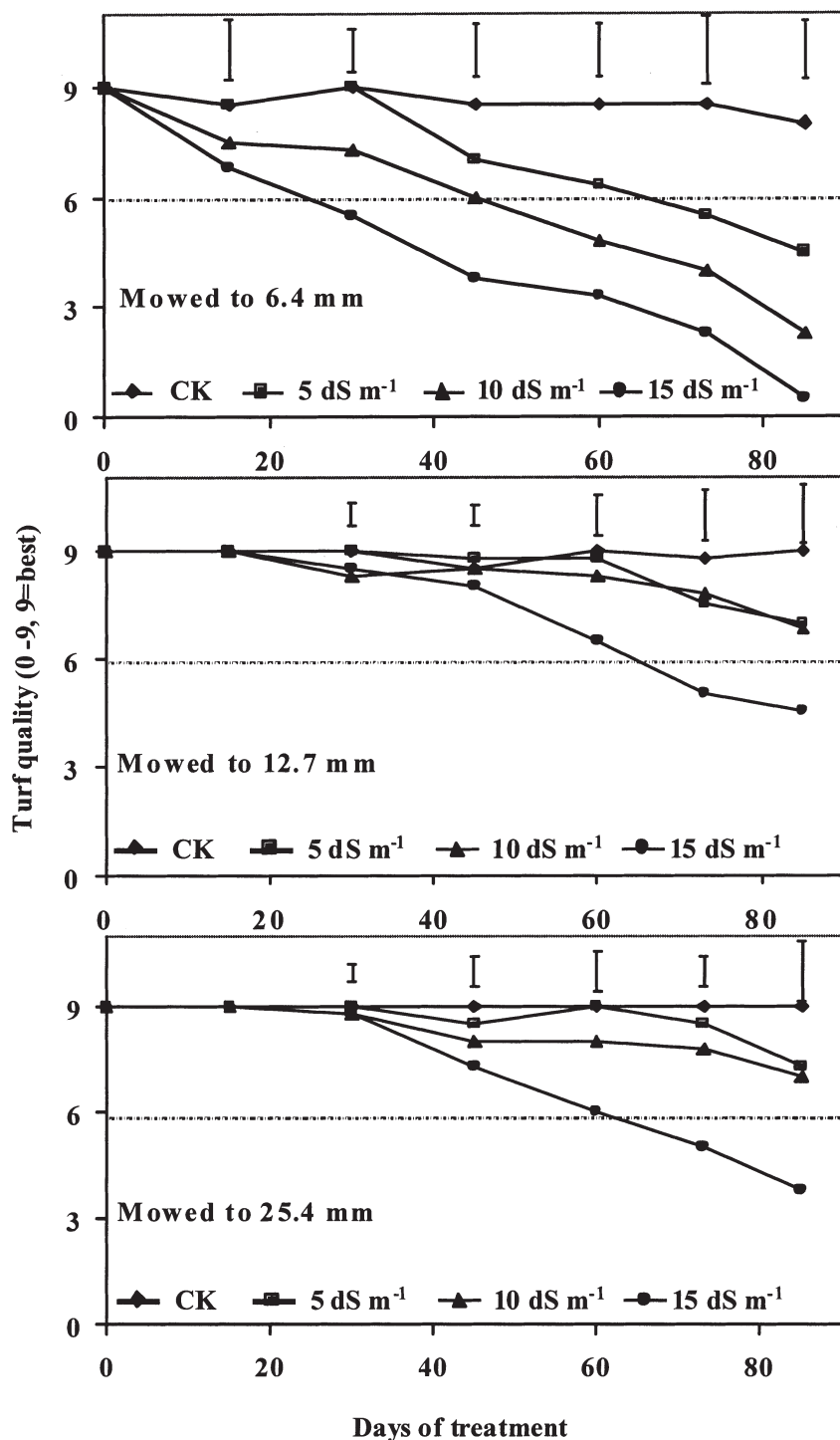


Fig. 2. Influence of irrigation water salinity on visual quality of creeping bentgrass mowed to 6.4, 12.7, and 25.4 mm, respectively. Vertical bars indicate LSD value ($P = 0.05$) for salinity treatment comparison with a mowing height at a given day of treatment.

turfgrass will be considerably lowered under short mowing heights.

Verdure and root mass. When mowed at 12.7 or 25.4 mm, verdure of creeping bentgrass was unchanged as salinity increased from control to 15 dS m⁻¹. However, when bentgrass was mowed at 6.4 mm, irrigation with 5 to 15 dS m⁻¹ water reduced verdure biomass by 33% to 42% when compared to the nonsaline control (Fig. 4). The reduction in verdure reflected reductions in shoot growth and turf density under close mowing and salinity stress conditions.

In agreement with previous studies (Krans and Beard, 1975; Salaiz et al., 1995), mowing height significantly affects total root mass of bentgrass (Fig. 4). When salinity of irrigation water was between the control level and 10 dS m⁻¹, total root mass was 30% to 66% and 39% to 89% greater at the 25.4 mm mowing height than at 12.7 and 6.4 mm mowing regimes, respectively. When salinity of irrigation water was 15 dS m⁻¹, the ranking of mowing heights for total root mass was 25.4 > 12.7 > 6.4 mm.

The highest root mass for all treatments occurred in the 0-10 cm depth, comprising 54% to 71% of the total root mass. In both the 0 to 10 cm and 10 to 20 cm depths, root mass increased with increasing mowing height. However, this trend was not as clear at 20 to 30 and 30 to 40 cm below the soil surface.

Root growth of bentgrass with different mowing regimes responded differently to increasing salinity. At 0 to 10 cm, bentgrass mowed at 12.7 mm exhibited higher root mass under the highest salinity level when compared to the nonsaline control. A relationship of increasing total root mass with increasing salinity was significant for the 12.7 mm mowing regime only (Table 2). Salinity stress generally increases root growth. Marcum (1999) reported an increase in root mass of several grasses mowed to 35 to 75 mm under saline conditions. Root growth stimulation under saline conditions has been reported in salt tolerant grasses (Dudeck et al., 1983; Meyer et al., 1989; Peacock and Dudeck, 1985). Increased rooting, and the associated increase in root absorbing area, is an adaptive mechanism to the osmotic and nutrient deficiency stresses present under saline conditions (Rozema and Visser, 1981.)

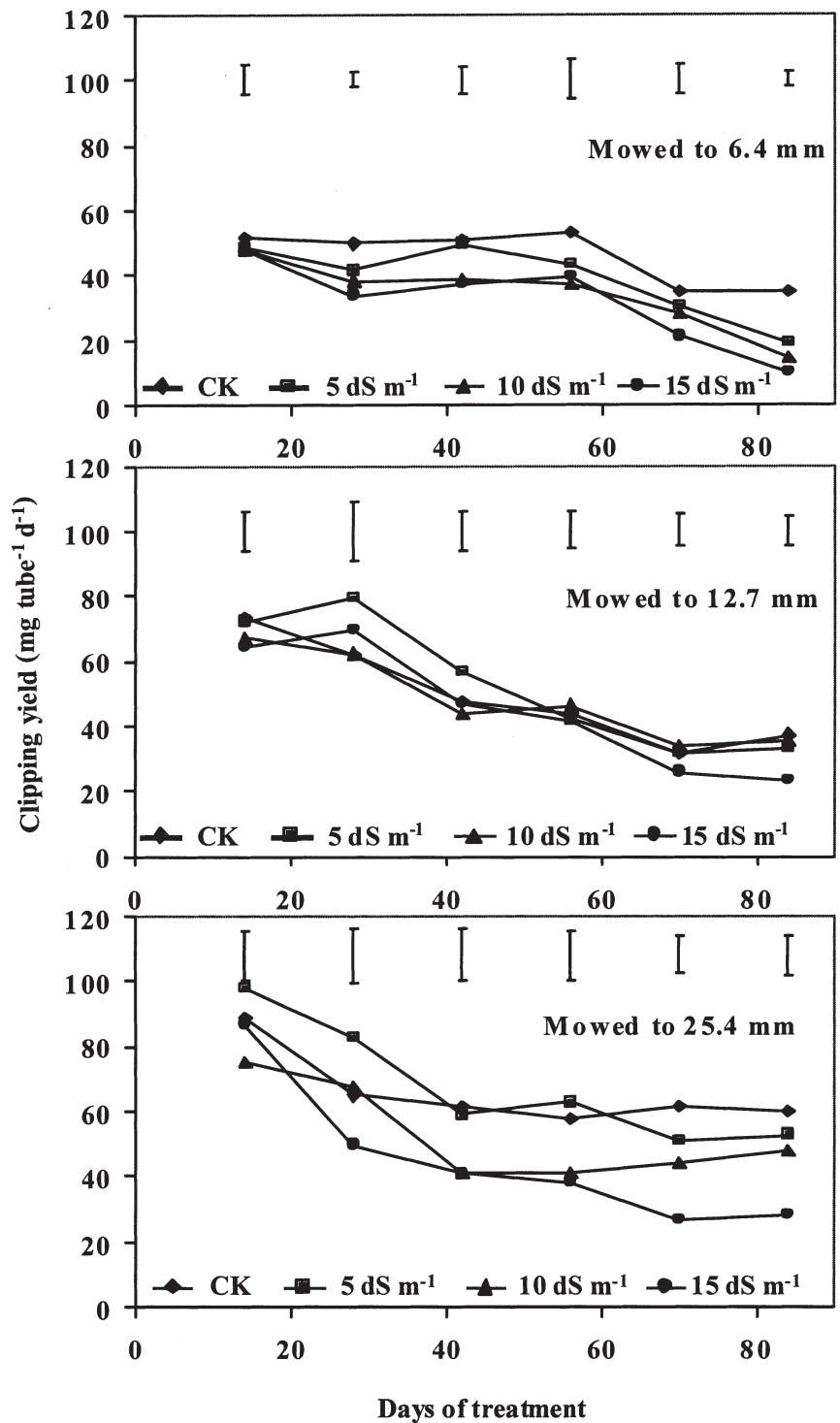
At the 30 to 40 cm depth, however, bentgrass mowed to 6.4 mm exhibited much reduced root mass as the level of salinity increased. The failure of close-cut bentgrass to maintain root mass at 30 to 40 cm with increasing salinity may have resulted from limited carbohydrate resources. Reduced root growth likely resulted in increased osmotic and nutrient deficiency stresses under saline conditions.

In summary, our data on turf quality, clipping yield, verdure, and root mass indicate that salinity damage becomes more severe as mowing height decreases. Moderately increas-

Table 1. Linear regression of creeping bentgrass parameters (measured at the end of experiment, 85 d after treatments) vs. soil salinity.

Parameter	Mowing ht (mm)	Regression	R ²
Quality (0-9 scale)	6.4	$Y = -0.52X + 8.15$	0.98**
	12.7	$Y = -0.26X + 9.23$	0.89**
	25.4	$Y = -0.26X + 9.65$	0.84**
Clipping yield (mg/tube/d)	6.4	$Y = -1.70X + 33.72$	0.91**
	12.7	$Y = -0.71X + 38.85$	0.61**
	25.4	$Y = -1.63X + 65.24$	0.84**
Verdure (g/tube)	6.4	$Y = -0.09X + 3.03$	0.23 ^{NS}
	12.7	$Y = 0.02X + 3.42$	0.21 ^{NS}
	25.4	$Y = 0.01X + 5.45$	0.01 ^{NS}
Root mass (mg/tube)	6.4	$Y = -1.02X + 245.98$	0.03 ^{NS}
	12.7	$Y = 5.92X + 0.21$	0.49**
	25.4	$Y = 2.75X + 368.68$	0.04 ^{NS}

NS, **Nonsignificant or significant at 0.05 and 0.01 levels, respectively.



ing mowing height could improve salinity tolerance of creeping bentgrass. The declining ability of bentgrass to tolerate salinity under close mowing may be associated with the effects of mowing height on photosynthesis and carbohydrate accumulation. Liu and Huang (2003) reported that low mowing significantly reduces the canopy photosynthetic rate of creeping bentgrass. Many salinity tolerance mechanisms require considerable amount of energy investment and are energy dependent. Further research is needed to determine photosynthetic rate, carbohydrate reserves, and other mechanisms that may attribute to the

Fig. 3. Influence of irrigation water salinity on clipping yield of creeping bentgrass at a given mowing height. Vertical bars indicate LSD value ($P=0.05$) for salinity treatment comparison with a mowing height at a given day of treatment.

changing salinity tolerance under different mowing regimes.

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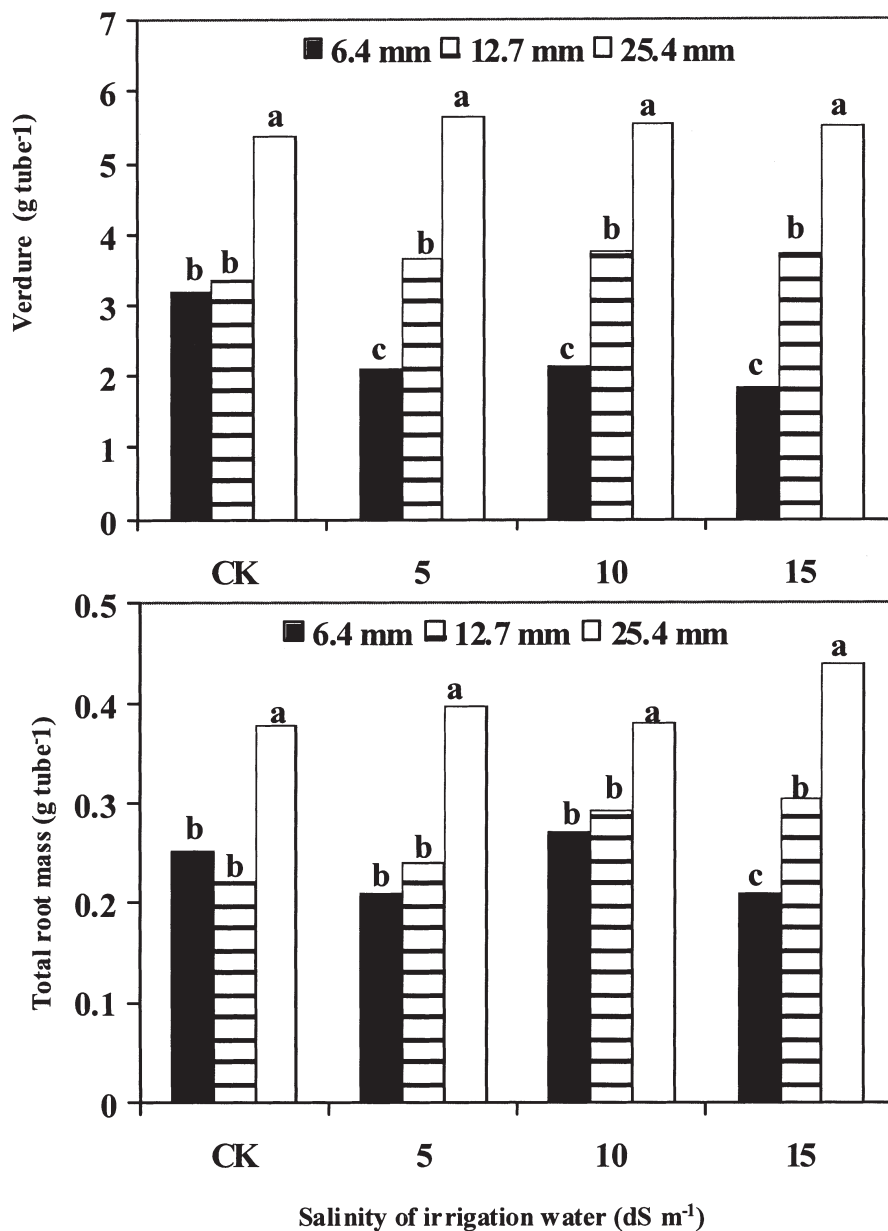


Table 2. Root mass at four depths for creeping bentgrass subjected to three mowing heights and irrigated by water at four different levels of salinity.

Soil depth (cm)	Mowing ht (mm)	Root mass (mg·dm ⁻³)			
		Salinity level (dS·m ⁻¹)			
		0	5	10	15
0–10	6.4	178.6 bA ^z	162.5 aA	180.4 bA	163.9 cA
	12.7	192.4 bB	190.7 aB	239.1 abAB	255.7 bA
	25.4	295.6 aA	287.0 aA	291.5 aA	334.9 aA
10–20	6.4	43.5 bA	41.3 bA	48.6 bA	51.8 bA
	12.7	54.1 abA	64.7 bA	57.1 abA	63.8 bA
	25.4	81.5 aA	98.7 aA	84.2 aA	113.4 aA
20–30	6.4	46.5 abB	39.5 abB	87.0 aA	35.1 bB
	12.7	20.2 bB	28.1 bAB	37.2 bA	32.3 abAB
	25.4	63.9 aA	49.7 aA	60.0 abA	54.2 aA
30–40	6.4	40.8 aA	13.9 bB	19.4 aB	7.0 bB
	12.7	8.1 bA	11.8 bA	26.0 aA	26.5 aA
	25.4	25.1 abA	53.3 aA	37.0 aA	40.3 aA

^zMeans in the same column followed by the small same letter within a column and means in the same row followed by the capital same letter are not significantly different at the 0.05 probability level.

Fig. 4. Influence of irrigation water salinity on verdure and total root mass of creeping bentgrass mowed to 6.4, 12.7, and 25.4 mm, respectively. Columns marked with the same letters within a salinity treatment are not significantly different at the 0.05 probability level.

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