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Response of Four Warm-Season Grasses to Saline Irrigation Water Under Arid Climate

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Abstract: A 2 year field experiment was conducted to evaluate the growth response, proline and mineral content of four warm-season turfgrasses to saline water irrigation. Four salinity treatments were imposed on sandy soil by irrigation with waters at 2.0, 6.25, 12.5 and 18.8 dS m^{-1}. The local bermudagrass, Tifgreen bermudagrass, Nagisa zoysiagrass and saltgrass experienced a 25% shoot growth reduction at 7.9, 20.5, 10.2 and 26.0 dS m^{-1}, respectively. Although shoot Na^+ and Cl^- contents increased linearly with increasing salinity for all species, the extent of increase ranked as: local bermudagrass > Nagisa > Tifgreen > Saltgrass. Sodium and Cl exclusion likely contributed to the superior salinity tolerance of saltgrass and Tifgreen. The experiment demonstrated that at 2.5 dS m^{-1} irrigation water salinity, Tifgreen, local bermudagrass and Nagisa all performed very well in Saudi Arabia. At 6.25 to 12.5 dS m^{-1} salinity, Tifgreen exhibited better turf quality than local bermudagrass and Nagisa and saltgrass. However, at the highest salinity (18.8 dS m^{-1}), only saltgrass and Tifgreen showed acceptable turf quality which was significantly higher than the local bermudagrass and Nagisa.

Key words: Warm season grasses, arid climate, saline irrigation water, Na^+ and Cl^- contents

INTRODUCTION

Salinity is one of the major environmental and agricultural problems in many regions in the world. The freshwater resources available for agriculture are declining quantitatively and qualitatively. The high demands on limited freshwater resources has resulted in some governmental restrictions requiring use of low quality water sources for landscape irrigation (Arizona Department of Water Resources, 1999; California State Water Resources Control Board, 1994; Florida Department of Environmental Protection, 1999). High saline water has agricultural potential with proper irrigation management. Therefore, several countries have adopted the use of marginal quality water for irrigation to overcome water scarcity (Oron *et al*., 2002). Saudi Arabia has a climate which is characterized by long, hot, dry summer and mild, cool, short winter with a mean annual rainfall of 70 mm. The agricultural lands of Saudi Arabia contain salts to varying degrees and are often irrigated with groundwater. Large decreases (up to 200 m in some places) in groundwater levels have been observed due to over extraction (Bushnak, 2002). Typically, the soils are coarse textured with low organic matter, high percolation rate, high salinity, low water holding capacity and poor fertility.

Recently, the desire for green space in urban landscapes, such as home lawns, commercial landscapes, parks and greenbelts is increasing in Saudi Arabia. Turfgrass is used in landscapes and household lawns. Turfgrass contributes to our lifestyle through improved environmental conditions, safer playgrounds and more attractive settings for homes, parks, roads and other facilities. Considering the fresh water limitations, the best strategy for the development of landscape turfgrass in Saudi Arabia is to identify and use turfgrass species with enhanced salinity tolerance. Bermudagrass

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(*Cynodon* spp.) is widely used for turfgrass sites in warm regions worldwide and is recognized as being both drought and salt tolerant (Harivandi *et al*., 1992; Carrow, 1996; Duble, 1996). Marcum and Pessarakli (2006) studied the salinity response of thirty five bermudagrass turf cultivars and found a wide range in salinity tolerance within this genus. Marcum *et al*. (2005) evaluated the relative salt tolerance of 21 desert saltgrass (*Distichlis spicata* var. *stricta*) accessions and found a great range of salinity tolerance, but all 21 accessions of saltgrass were more salinity resistant than Midiron bermudagrass (*Cynodon dactylon* (L.)). Qian *et al*. (2007) studied the salt tolerance of 14 saltgrasses selections and found that saltgrass is one of the most salt-tolerant species that can be used as turf. Zoysiagrass in general is ranked as salt tolerant turfgrass (Harivandi *et al*., 1992; Marcum *et al*., 1998; Qian *et al*., 2000; Engelke *et al*., 2002a, b).

In arid Saudi Arabia, limited information is available on the utilization and management of turfgrasses with low quality water. Therefore, the main objective of this study is to evaluate the growth response, proline and mineral contents of four warm-season turfgrasses to saline irrigation water for the selection of the most salt tolerant and acceptable quality turfgrass for the development of landscapes in Saudi Arabia.

MATERIALS AND METHODS

Plant materials and growth conditions: The experiment was conducted from 2 May 2005 to 25 December 2006 at King Abdulaziz City for Science and Technology (KACST) research station in Al-Mozahmiyah, Saudi Arabia, on sandy soil. The physical and chemical properties of the soil is presented in Table 1. The experiment was laid out in an area of 46×11 m. The study area was divided into four blocks (10×11 m) and each block was divided into 12 separated plots with each measuring 2×2 m and the distance between blocks is one meter in all sides. Four grasses, a local bermudagrass (*Cynodon dactylon* L.), Tifgreen bermudagrass (*Cynodon dactylon*×*C. transvaalensis*), 'Nagisa' zoysiagrass (*Zoysia matrella*.) and a saltgrass (*Distichlis spicata* (Torr.) Beetle) line collected from the United States were sodded and randomly distributed to the plots of each block. Before planting, a fertilizer (18-9-18) was mixed into the top 10 cm of soil in each plot at the rate of 220 kg ha^{-1}. The grasses were grown for 8 weeks with non-saline irrigation water.

Table 1: Initial physical and chemical characteristics of experimental soil

Parameters	Values
Texture	Sand
Saturation (%)	20.00
ECe (dS m^{-1})	1.26
PH	7.85
TDS (mg L^{-1})	810.00
Ca (mg L^{-1})	101.00
Mg (mg L^{-1})	26.00
Na (mg L^{-1})	87.00
K (mg L^{-1})	12.00
Cl (mg L^{-1})	243.00
CO_3 (mg L^{-1})	4.00
HCO_3 (mg L^{-1})	113.00
SAR	1.99

Installation of tensiometers and salinity sensors: Two tensiometers and two salinity sensors (Soil Moisture Equipment Corp. Santa Barbara, CA, USA) were installed in each plot at 15 and 30 cm depths to monitor soil matric potential and soil salinity. In all, there were 48 sets of tensiometers and 48 sets of salinity sensors in 4-blocks.

Salinity treatment and irrigation water: Irrigation waters of different salinities were composed by mixing freshwater from a well having an EC of approximately 2.5 dS m^{-1} with water from an evaporation pond with EC between 23-42 dS m^{-1}. The fresh water and saline pond water were mixed in proper proportions to attain water EC of 6.25, 12.5 and 18.8 dS m^{-1} for T_2, T_3 and T_4 treatments, respectively. Fresh well water was kept as control treatment (T_1). Water samples were collected from the well, the evaporation pond (before composition) and irrigation tanks (after composition) and analyzed for pH, EC, Ca, Mg, Na, K, CO_3, HCO_3 and Cl. The chemical composition of the well water, pond water and the treatment waters is given in (Table 2).

Four water tanks, each having a capacity of 10 m^3, were placed near the blocks to apply water of desired salinity for different treatments. The mean soil water content at field capacity of the experimental soil (sandy) was 0.08 m^3 m^{-3}. Soil has a bulk density of 1.65 g cm^{-3}. The soil matric potential at field capacity was around -0.033 MPa. Twenty percent soil moisture depletion occurred when soil water potential reached ~ -0.06 MPa as measured with the tensiometer and confirmed with the gravimetric measurement in the laboratory by taking soil samples from the plots at the time of the tensiometer readings.

After 8 weeks with fresh water irrigation to ensure establishment, salinity treatments were initiated. To avoid salinity shock, salinity levels of T_2, T_3 and T_4 were gradually increased by daily increments of ~3.13 dS m^{-1}. After the targeted salinity levels were reached, salinity treatments were continued for a period of 17 months. The irrigation interval was every day in the summer months and 3-4 days in the winter months depending on the weather conditions. Water was applied until the soil matric potential as measured by tensiometer reached to

Table 2: Chemical composition of well, evaporation pond and treatments waters

Parameters	Pond water	T_1 (well water)	T_2	T_3	T_4
EC (dS m^{-1})	23.1	2.50	6.25	12.5	18.8
PH	7.4	7.70	7.80	8.1	7.8
TDS (mg L^{-1})	14,800.0	1,598.00	4,005.00	7,970.0	12026.0
Calcium (mg L^{-1})	1260.0	212.00	424.00	665.0	957.0
Magnesium (mg L^{-1})	665.0	59.00	216.00	336.0	497.0
Sodium (mg L^{-1})	3623.0	227.00	938.00	1755.0	2814.0
Potassium (mg L^{-1})	209.0	14.00	46.00	99.0	162.0
Chloride (mg L^{-1})	6995.0	653.00	2135.00	3926.0	5524.0
Carbonate (mg L^{-1})	15.0	0.00	9.00	15.0	7.0
Bicarbonate (mg L^{-1})	143.0	152.00	150.00	118.0	112.0
SAR	20.47	3.54	9.21	13.79	18.31

-0.03 MPa. The amount of water applied was approximately 158 L per irrigation to reach field capacity. Additionally 15% excess water (above field capacity) was included in the irrigation water to maintain stable soil salinity. In all 182 L of irrigation water per plot was applied per irrigation as measured by water flow meters (Delta irrigation water flow meter, RS Hydro, UK) installed at the beginning of the irrigation pipe.

Grasses were clipped weekly to 3 cm height for local bermudagrass, Tifgreen bermudagrass and Nagisa zoysiagrass and to 5 cm for saltgrass throughout the experiments.

Data collection: Data were collected on leaf firing, turf quality, shoot growth, root growth, shoot proline content and shoot and root mineral contents. Leaf firing and turf quality were visually estimated weekly. Leaf firing was estimated as the total percentage of chlorotic leaf area, with 0% corresponding to no leaf firing and 100% as totally brown leaves. Turf quality was estimated based on a scale of 1 to 9, with 9 as green, dense and uniform turf and 1 as thin and completely brown turf.

Shoots were clipped weekly, washed with deionized water and dried at 70°C for 24 h to determine dry weight. At the termination of the experiment shoots were harvested and roots were clipped. Both shoots and roots were washed with deionized water and dried at 70°C for 24 h to determine dry weight. Relative shoot and root growth data were calculated as a percentage of growth under each salinity treatment relative to the control. Root to shoot ratio was calculated based on root dry weight and cumulative shoot dry weight.

Shoot proline content was determined after the initiation of salinity treatment and at the end of the experiment. Based on the method described by Bates *et al*. (1973), about 0.5 g leaf tissue was homogenized in 10 mL of 3% aqueous sulfosalicylic acid. After filtration, 2 mL of extract was reacted with 2 mL glacial acetic acid and 2 mL acid-ninhydrin in a test tube for 1 h at 97°C. The reaction mixture was cooled in an ice bath, 4 mL toluene was added and it was mixed vigorously. The separated top toluene layer was used for proline measurement with a spectrophotometer (Beckman DU-50, Beckman Instruments, Inc. Fullerton, CA); proline concentration was presented as μmole proline/g FW.

Accumulated shoots and dried roots were ground in a Wiley mill to pass through a screen with 425 μm openings. Approximately 1 g screened and dried sample was weighed and ashed for 7 h at 500°C. Ash was dissolved in 10 mL of 1N HCl and diluted with deionized water. Solution aliquots were analyzed for Na^+, Ca^{++}, Mg^{++} and K^+ by inductively-coupled plasma atomic emission spectrophotometry (ICP-AES) (Model 975 plasma Atomcomp, Thermo Jarrell Ash Corp., Franklin, MA 02038). To determine Cl^- Content, shoot and root samples (200 mg) were dissolved in 50 mL of 2% acetic acid and filtered. Chloride was analyzed by a Cl-selective electrode (Orion Ionplus Chloride combination electrode).

Data analysis: Statistical design used was a split plot design with salt treatment (tank and block) being the main plot and grass species within each block being the subplot and each treatment had 3 replications. Data were analyzed by analysis of variance (SAS Institute, 1989). Treatment means were separated by Fisher's protected LSD. Regression analysis was used to determine the relationships between each variable and the salinity level.

RESULTS AND DISCUSSION

Development of soil salinity: Because irrigation provided sufficient leaching, soil salinity approached close equilibrium with irrigation water salinity 6 months after irrigation treatment began and maintained relatively stable salinity levels throughout the experiment. Depending upon different irrigation water treatments, mean soil salinity ranged between 3.59-18.26 dS m^{-1} in the upper 0-15 cm and 7.01-21.33 dS m^{-1} in the 15-30 cm depth of soil profile (Table 3). The results showed a significant increase in soil salinity due to the application of high salinity waters.

Plant responses: Plant responses, including shoot and root growth, leaf firing and turf quality have been reported to be excellent criteria to determine salinity tolerance among turfgrasses (Francois, 1988; Marcum and Murdoch, 1990; Dean *et al*., 1996; Marcum and Kopec, 1997; Marcum, 1999; Peacock *et al*., 2004; Marcum *et al*., 2005; Marcum and Pessarakli, 2006; Qian *et al*., 2007). In this experiment, relative shoot growth decreased significantly with increasing salinity for the local bermudagrass, Tifgreen bermudagrass and Nagisa zoysiagrass, whereas relative shoot growth of saltgrass was higher with salinity treatments than the control (Table 4). Regression analysis predicted that local bermudagrass, Tifgreen bermudagrass and Nagisa zoysiagrass experienced a 25% shoot growth reduction at 7.9, 20.5 and 10.2 dS m^{-1}, respectively. The salinity level that resulted in 25% shoot growth reduction for saltgrass was beyond the salinity range in this experiment. However, by extrapolating the results to levels beyond the salinity treatment range, the 25% shoot growth reduction salinity of saltgrass was predicted to be 26.0 dS m^{-1}. Previously, Qian *et al*. (2007) reported that salinity levels that caused 25% clipping yield reduction for 14 saltgrass accessions ranged from 21.2 to 29.9 dS m^{-1}.

Table 3: Mean soil salinity (dS m^{-1}) recorded by salinity sensors†

Salinity level of irrigation water	0-15 cm soil depth	15-30 cm soil depth
2.5	3.59	7.01
6.25	9.83	11.74
12.5	14.47	17.32
18.8	18.26	21.23

†Mean of weekly readings from 1 to 17 months after the initiation of the experiment

Root growth of saltgrass and Tifgreen were significantly enhanced as salinity increased from 2.5 to 18.8 dS m^{-1}, whereas Nagisa maintained a stable root mass across all salinity levels. The local bermudagrass showed a significant root growth reduction at 18.8 dS m^{-1} salinity (Table 4). Root growth stimulation of saltgrass and Tifgreen and the maintenance a stable root mass of Nagisa observed in our study may be adaptive mechanisms enabling these plants to maintain water balance. The greater reduction at high salinity in the root growth of local bermudagrass demonstrated the poorer salinity tolerance of the local bermudagrass when compared to Tifgreen bermudagrass. Root growth of all species was less adversely affected by salinity than that of shoots, leading to significant increase in root to shoot ratio of all grasses (Table 4). Across all salinity levels the local bermudagrass, Tifgreen and Nagisa exhibited higher root to shoot ratio than saltgrass. At 12.5 and 18.8 dS m^{-1} Nagisa and the local bermudagrass showed higher root to shoot ratio than Tifgreen and saltgrass (Table 4).

A linear relationship of increased leaf firing with increasing irrigation water salinity was observed for local bermudagrass, Tifgreen and Nagisa, reaching 65, 15 and 30%, respectively, at 18.8 dS m^{-1}.

However, there was no salinity injury noticeable in saltgrass at all levels of salinity (Table 4). Increasing irrigation water salinity significantly reduced turf quality of local bermudagrass, Nagisa and Tifgreen. In contrast, turf quality of saltgrass was unaffected under all salinity levels.

Table 4: Relative shoot and root growth, root/shoot ratio, leaf firing and turf quality of local bermudagrass, Tifgreen, Nagisa and saltgrass exposed to salinity stress

Salinity (dS m^{-1})	Relative shoot growth (%)	Relative root growth (%)	Root to shoot ratio	Leaf firing (%)	Turf quality (1-9, 9 = best)
Tifgreen					
2.5	100.00aA[Z]	100.00bA	0.086cA	0dA	9aA
6.25	93.94bB	128.04aB	0.117bA	5cB	9aA
12.5	86.68cB	126.94aB	0.127aB	10bC	8bA
18.8	79.97dB	121.00aB	0.133aB	15aC	7cA
Saltgrass					
2.5	100.00bA	100.00bA	0.050bC	0aA	7aB
6.25	111.30aA	159.60aA	0.073aC	0aC	7aC
12.5	110.57aA	154.40aA	0.071aC	0aD	7aB
18.8	110.04aA	160.60aA	0.074aC	0aD	7aA
Nagisa					
2.5	100.00a A	100.00aA	0.078cB	0dA	9aA
6.25	85.30bB	105.00aC	0.098bcB	10cA	8bB
12.5	66.20cC	1024.00aC	0.136aA	20bB	7cB
18.8	59.40dC	99.70aC	0.145aA	30aB	6dB
Local bermudagrass					
2.5	100.0aA	100.00a A	0.078cB	0dA	9aA
6.25	79.39bB	99.15aC	0.098bcB	10cA	8bB
12.5	55.61cD	97.39aC	0.136aA	25bA	6c C
18.8	33.80dD	62.70bD	0.143aA	65aA	3dC

[Z]lowercase letter(s) indicate significant differences (p = 0.05) among salinity treatments for each species. Uppercase letter(s) indicate significant differences (p = 0.05) among species within a given salinity level

Based on data on shoot and root growth, the salinity that caused 25% shoot growth reduction, leaf firing and turf quality, we ranked the salinity tolerance as: Saltgrass > Tifgreen > Nagisa > Local bermudagrass. Marcum *et al.* (2005) evaluated the relative salt tolerance of 21 desert saltgrass accessions and found a great range of salinity tolerance and all accessions were more resistant than Midiron b ermudagrass. Moreover, Pasternak *et al.* (1993) indicated that dry matter yields of saltgrass increased with increasing salinity ranging from 3 to 14 dS m^{-1} and that saltgrass was more salt tolerant than seashore paspalum (*Paspalum vaginatum* Swartz) and bermudagrass. Despite the superior salinity tolerance, saltgrass had a poorer turf quality at 2.5-12.5 dS m^{-1} salinity than Tifgreen bermudagrass, largely due to its poorer mowing quality and lower density. Research in needed to breed and select saltgrass for better mowing quality and high shoot density.

This experiment demonstrated that at 2.5 dS m^{-1} irrigation water salinity, Tifgreen, local bermudagrass and Nagisa zoysiagrass all performed very well and would be suited in Saudi Arabia. At 6.25-12.5 dS m^{-1} salinity, Tifgreen exhibited better turf quality than local bermudagrass, Nagisa zoysiagrass and saltgrass. However, at the highest salinity (18.8 dS m^{-1}), only saltgrass and Tifgreen showed an acceptable turf quality which was significantly higher than local bermudagrass and Nagisa zoysiagrass.

Proline content in plant tissues: All grasses exhibited an increased shoot proline content with increasing irrigation water salinity (Table 5). Across all salinity levels, Nagisa had higher mean proline content than all other grasses. Saltgrass produced the lowest proline content under salinity treatments. Proline is one of the most frequently reported organic solutes that accumulated in cytoplasm in salt stressed plants to counter balance the osmotic potential attributed to inorganic ions compartmentalized in cell vacuoles (Wyn Jones, 1984; Gorham *et al.*, 1985). However, the physiological significance of proline accumulation is controversial; some report that it represents a form of injury, while others suggest proline acts as a compatible solute. Our results indicated that shoot proline content of all grasses significantly increased with increasing salinity (Table 5). Furthermore, proline was positively correlated with leaf firing ($r = 0.88$) and negatively correlated with turf quality ($r = -0.75$) (Table 8) and the most salt tolerant saltgrass exhibited the lowest proline content in comparison with other grasses. These results suggest that proline accumulation may be a result of salt injury. However, Nagisa is an apparent exception in that salt injury was minimal under conditions leading to high proline content. Therefore, proline accumulation is a sign of a stress in Tifgreen, saltgrass and local bermudagrass, but may play a role as a compatible solute in Nagisa zoysiagrass.

Salt accumulation in shoots and roots: Information regarding differences in mineral accumulation among different species and the patterns of accumulation of minerals in various parts of a plant is very important in the evaluation of salinity tolerance and to understanding salinity tolerance mechanisms employed by plants. In this experiment, we found that Na, Cl and Ca concentrations in shoots and roots of all species increased linearly as salinity levels increased. Shoot Na, Cl and Ca concentrations in all grasses were lower than those in roots (Table 6, 7). Shoot and root Ca concentrations of Tifgreen were higher than other grasses at all salinity levels whereas, local bermudagrass had the lowest Ca concentrations (Table 6, 7).

The experimental grass species differed in their ability to exclude Na and Cl from their shoots. Local bermudagrass shoots and roots had higher Cl content than other grasses and saltgrass had the lowest Cl concentrations (Table 6, 7). Although shoot Na and Cl contents increased linearly with increasing salinity for all species, the extent of increase ranked as: Local bermudagrass > Nagisa >Tifgreen > Saltgrass. Shoot Na and Cl concentrations were positively correlated with leaf firing ($r = 0.84$ to 0.89) and negatively correlated with turf quality ($r = -0.92$ to -0.95), shoot growth ($r = -0.82$ to -0.89) and root growth ($r = -0.59$ to -0.61) (Table 8). Therefore, accumulation of Na and Cl under saline conditions was one of the major causes of growth reduction observed in our study. Salinity tolerance of these grasses was associated with their ability to exclude Na and Cl from the shoots, thus maintaining a moderate ion content. Similar results were observed in a number of

Table 5: Shoot proline contents (μmole g^{-1} FW) for of Local bermudagrass, Tifgreen, Nagisa and saltgrass exposed to salinity stress

Salinity (dS m^{-1})	Tifgreen	Saltgrass	Nagisa	Local bermudagrass
2.5	2.84dB	1.69dC	2.83dB	2.93dA
6.25	5.19cB	2.50cC	15.75cA	6.77cB
12.5	13.01bB	6.10bC	32.07bA	12.72bB
18.8	17.59aB	8.95aC	49.67aA	18.18aB

[Z]lowercase letter(s) indicate significant differences ($p = 0.05$) among salinity treatments for each species. Uppercase letter(s) indicate significant differences ($p = 0.05$) among species within a given salinity level

Table 6: Shoot mineral concentration (mg g^{-1}. dw) of local bermudagrass, Tifgreen, Nagisa and saltgrass exposed to salinity stress

Salinity (dS m^{-1})	Na^+	Cl^-	Ca^{++}	Mg^{++}	K^+	K^+/Na^+
Tifgreen						
2.5	0.96dB	1.25dA	0.63dA	4.08aA	8.10aB	8.44aB
6.25	5.45cB	10.17cA	5.69cA	1.39bB	6.75bA	1.24bB
12.5	7.89bB	11.95bC	7.05bA	1.23bB	6.15cB	0.78cB
18.8	9.08aB	13.53aC	8.65aA	0.87cB	6.04cB	0.67cB
Saltgrass						
2.5	0.66dC	0.87dC	0.55dB	2.73aB	11.38aA	17.24aA
6.25	4.39cC	6.78cC	3.30cC	1.99bA	7.92bA	1.80bA
12.5	5.22bC	7.85bD	4.14bC	1.92bcA	7.42bcA	1.42bcA
18.8	5.99aC	9.45aD	5.27aC	1.77cA	7.09cA	1.18cA
Nagisa						
2.5	1.06dA	1.07dB	0.47dC	1.53aC	6.86aC	6.47aC
6.25	7.41cA	9.81cB	5.25cB	1.16bC	4.78bB	0.65bC
12.5	9.05bA	12.55bB	6.36bB	1.09bC	4.32cC	0.48bC
18.8	10.22aA	14.43aB	7.67aB	0.94cB	4.26cC	0.42bC
Local bermudagrass						
2.5	0.98dB	1.11dB	0.34dD	1.35aD	6.73aC	6.87aC
6.25	7.89cA	9.96cB	2.89cD	0.89bD	4.28bB	0.54bC
12.5	10.67bA	13.17bA	3.96bD	0.66bcD	3.67cD	0.34bD
18.8	12.28aA	15.27aA	4.56aD	0.42cC	2.12dD	0.17bD

[Z]lowercase letter(s) indicate significant differences (p =0.05) among salinity treatments for each species. Uppercase letter(s) indicate significant differences (p = 0.05) among species within a given salinity level

Table 7: Root mineral concentration (mg^{-1} g. dw) of local bermudagrass, Tifgreen, Nagisa and saltgrass exposed to salinity stress

Salinity (dS m^{-1})	Na^+	Cl^-	Ca^{++}	Mg^{++}	K^+	K^+/Na^+
Tifgreen						
2.5	1.18dB	2.79dA	1.71dA	1.12aC	4.62aA	3.92aB
6.25	8.58cB	12.87cC	8.12cA	0.57bcC	3.14bB	0.37bB
12.5	10.32bB	16.02bB	9.32bA	0.41cC	2.47cC	0.24bB
18.8	11.67aB	17.81abB	11.07aA	0.20dC	1.67dC	0.14bC
Saltgrass						
2.5	0.75dC	1.38dB	0.98dB	1.15abC	4.52aA	6.03aA
6.25	3.07cC	8.28cD	5.98cB	0.96bcB	4.55aA	1.48bA
12.5	7.28bC	9.92bC	6.68bC	0.83cB	4.11aA	0.57bA
18.8	8.25aC	11.12aC	7.99aC	0.51dB	4.01aA	0.49bA
Nagisa						
2.5	1.22dB	2.54dA	0.78dC	1.28aB	3.70aB	3.03aC
6.25	8.70cB	13.45cB	5.39cC	0.96bB	3.15bB	0.36bB
12.5	10.53bB	15.64bB	8.21bB	0.92bA	2.86cB	0.27bB
18.8	12.29aB	18.03aB	8.98aB	0.70cA	2.31dB	0.19bB
Local bermudagrass						
2.5	1.93cA	1.58cA	0.54cD	1.82aA	4.01aB	2.08aD
6.25	12.03bA	18.42bA	5.28bC	1.52bA	2.22bC	0.19bC
12.5	14.14aA	19.88abA	5.88aD	0.91cA	2.11bD	0.15bC
18.8	15.84aA	20.93aA	6.12aD	0.56dB	1.81cD	0.11bC

[Z]lowercase letter(s) indicate significant differences (p =0.05) among salinity treatments for each species. Uppercase letter(s) indicate significant differences (p =0.05) among species within a given salinity level

other studies. When exposed to NaCl up to 400 mM (~ 36.56 dS m^{-1}), salt tolerant 'Tifway' bermudagrass (*Cynodon dactylon* L.), Manilagrass (*Zoysia matrella* L.), St. Augustinegrass (*Stenotaphrum secundatum* Walt.) and seashore paspalum (*Papsalum vaginatum* Swartz) restricted shoot Na and Cl accumulation relative to salt sensitive Japanese lawngrass (*Zoysia japonica* Steud.) and centipedegrass (*Eremochloa ophuriodes* (Munro) Hack.) (Marcum and Murdoch, 1994). Moreover, Marcum (1999) suggested that salt transport to the shoot reflects cytosolic ion concentrations, with a more salt sensitive species *Sporobolus cryptandrus*, *Buchloe dactyloides* and *Bouteloua curtipendula* having a higher Na and Cl concentration in its cytoplasm than a more salt tolerant species *Distichlis spicata* and *Sporobolus airoides*.

In this experiment, present results showed that, with increasing salinity, Mg and K concentrations in shoots and roots of all grasses were reduced (Table 6, 7). Saltgrass shoots and roots had higher K^+ content than other grasses and local bermudagrass shoots and roots had the lowest K^+ concentrations (Table 6, 7). Shoot K^+ content was positively correlated with shoot and root growth and turf quality and negatively correlated with leaf firing (Table 8). Results of K/Na ratio suggested that saltgrass had the highest selectivity of K^+ over Na^+ while local bermudagrass had the lowest selectivity of K^+ when Na^+ concentrations were high. Interestingly, K^+/Na^+ ratio in all species was higher in shoots than in roots, possibly because these plants achieve the K^+ selectivity via multiple processes in multiple locations.

Table 8: Pearson correlation coefficients for leaf proline (PR), relative shoot dry weight (SW), relative root dry weight (RW), leaf firing (LF), turf quality (TQ), shoot Na, Cl, Ca, Mg, K and K/Na ratio

Parameter	SW	RW	LF	TQ	Na	Cl	Ca	Mg	K	K/Na
PR	-0.78***	-0.51***	0.88***	-0.75***	0.76***	0.87***	0.80***	-0.51***	-0.42***	-0.38**
SW		0.92***	-0.96***	0.84***	-0.82***	-0.89***	-0.75***	0.69***	0.77***	0.42**
RW			-0.82***	0.66***	-0.59***	-0.61***	-0.42**	0.53***	0.87***	0.05ns
LF				-0.95***	0.84***	0.89***	0.83***	-0.69***	-0.65***	-0.32*
TQ					-0.92***	-0.95***	-0.81***	0.73***	0.41**	0.15ns
Na						0.95***	0.89***	-0.76***	-0.66***	-0.65***
Cl							0.92***	-0.78***	-0.62***	-0.58***
Ca								-0.77***	-0.54***	-0.56***
Mg									0.55***	0.39*

ns, *, ** and *** indicates non-significant or significant of correlations at $p = 0.05$, 0.01 and 0.001 level, respectively

Study results indicated that along with Na^+ and Cl^- exclusion, selectivity of K^+ over Na^+ is critical in turfgrass salinity tolerance. This is in agreement with many other studies. Marcum and Murdoch (1994) reported that among warm season turfgrass species, salt tolerant Manilagrass and seashore paspalum maintained higher shoot K^+ than salt sensitive Japanese lawngrass and centipedegrass. Salinity tolerance in several grass species is associated with exclusion of Na^+ and the capacity to maintain high shoot K^+/Na^+ ratio (Torello and Rice, 1986; Qian *et al*., 2000; Qian *et al*., 2001; Qian and Fu, 2005). Datta *et al.* (1996) suggested that restriction or exclusion of Na^+ and higher K^+/Na^+ ratio contributed to the higher degree of salt tolerance in Sudan grass (*Sorghum sudanese* Stapf.) compared to teosinte (*Euchlaena maxicana* Schard.) and maize. Flowers and Hajibagheri (2001) found that between two cultivars of barley the K^+/Na^+ ratio of salt resistant 'Gerbel' was twice of that in salt sensitive Triumph.

The difference in K^+/Na^+ ratio of Tifgreen, saltgrass, Nagisa and local bermudagrass may be associated with Ca^{++} concentrations in their roots. In this study, Ca^{++} content in roots ranked as Tifgreen > Nagisa > saltgrass > local bermudagrass. Higher Ca^{++} in roots may have benefited Tifgreen, Nagisa and saltgrass by helping to maintain the proper function of biological membranes under saline conditions (Hanson, 1984; Kent and Lauchli, 1985). Calcium is an important factor in the maintenance of membrane integrity and ion uptake and transport regulation; therefore, Ca^{++} is essential for K^+/Na^+ selectivity (Cramer *et al*., 1985, 1986, 1987; Cheeseman, 1988; Subbarao *et al*., 1990; Cachorro *et al*., 1994; Garg, 1998). He and Cramer (1992) indicated that changes in tissues Ca^{++} concentration in *Brassica* were correlated with the relative salt tolerance of the species.

In conclusion, this experiment demonstrated that at 2.5 dS m^{-1} irrigation water salinity, Tifgreen, local bermudagrass and Nagisa zoysiagrass all performed very well in Saudi Arabia. At 6.25-12.5 dS m^{-1} salinity, Tifgreen exhibited better turf quality than local bermudagrass and Nagisa zoysiagrass and saltgrass. However, at the highest salinity (18.8 dS m^{-1}), only saltgrass and Tifgreen showed acceptable turf quality which was significantly higher than the local bermudagrass and Nagisa zoysiagrass. Sodium and Cl exclusion likely contributed to the superior salinity tolerance of saltgrass and Tifgreen bermudagrass. At the highest salinity levels saltgrass showed a great promise for the development of landscapes in Saudi Arabia as well as in arid and semi arid regions. However, more research is needed to breed and select saltgrass for better turf quality.

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