Responses of Ornamental Grass and Grass-like Plants to Saline Water Irrigation

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ADDITIONAL INDEX WORDS. salt tolerance, reclaimed water, blue grama, fox sedge, indian seaoats, common rush, sand ryegrass, pink muhly grass, fountain grass.

SUMMARY

Ornamental grasses are popular in urban landscapes in Utah and the Intermountain West, one of the driest and fastest growing regions in the United States. This experiment evaluated the responses of five ornamental grass species [blue grama (*Bouteloua gracilis*), indian seaoats (*Chasmanthium latifolium*), 'Blue Dune' sand ryegrass (*Leymus arenarius*), pink muhly grass (*Muhlenbergia capillaris*), and 'Foxtrot' fountain grass (*Pennisetum alopecuroides*)] and two ornamental grass-like species [fox sedge (*Carex vulpinoidea*), and common rush (*Juncus effusus*)] to saline irrigation water in a greenhouse. Plants were irrigated weekly with a nutrient solution at an electrical conductivity (EC) of 1.2 $dS \cdot m^{-1}$ (control) or saline solutions at EC of 5.0 or 10.0 $dS \cdot m^{-1}$. At the first harvest (9 weeks after the initiation of treatment), sand ryegrass, pink muhly grass, and fountain grass irrigated with solutions at EC of 5.0 and 10 $dS \cdot m^{-1}$ had good visual quality with no or minimal foliar salt damage; however, the remaining species exhibited slight or moderate foliar salt damage. There were no significant differences in shoot dry weight (DW) among treatments within any species, except fox sedge and fountain grass. At the second harvest (18 weeks after the initiation of treatment), sand ryegrass, pink muhly grass, and fountain grass still had no or minimal foliar salt damage, and indian seaoats and fox sedge exhibited slight or moderate foliar salt damage. Compared to control, all species irrigated with solutions at EC of 10.0 $dS \cdot m^{-1}$ had reduced shoot DWs with the exception of blue grama. However, only common rush and pink muhly grass irrigated with solutions at EC of 5.0 $dS \cdot m^{-1}$ had lower shoot DWs than the control. These results demonstrated that seven ornamental grass or grass-like species had a very strong tolerance to the salinity levels used in the 4-month experiment. Although plant growth was inhibited as a result of saline irrigation, plant visual quality of sand ryegrass, pink muhly grass, and fountain grass was still acceptable. These three species appear to be more

suitable for landscapes where saline irrigation water is used. Further research is needed to evaluate more ornamental grasses for landscapes in salt-prone areas and nearby coastal regions.

Introduction

Water scarcity is a major concern in Utah and the Intermountain West, one of the driest and fastest growing regions in the United States (U.S.). Climate and human-driven changes in water quantity and quality could result in more restrictions on agricultural and landscape irrigation, a segment of water use that accounts for 82% of freshwater resources in Utah (Strong et al., 2010). Therefore, water conservation is becoming critically important throughout Utah and the Intermountain West. Alternative water sources such as treated and reclaimed sewage effluent (reclaimed water) are important for landscape irrigation with an established use record on golf courses in Utah and a handful of large corporate and municipal parks and landscapes in the arid to semiarid urban areas across the southwestern U.S. (Tanji et al., 2008). However, these water sources are still underutilized. This may be attributed to the high level of salinity and undesirable specific ions in reclaimed water that can potentially stress and damage landscape plants (Grieve, 2011). Proper management is needed to reduce salinity stress, for example, monitoring salt concentration in reclaimed water, improving drainage, maintaining a leaching fraction, and using salt tolerant species (Niu and Cabrera, 2010). Selecting and utilizing salt-tolerant plants are one of the best practices for preventing salt damage on landscape plants and maintaining aesthetically appealing landscapes. Previous research has consistently documented that landscape plant species and/or cultivars show different responses to salinity stress (Niu and Cabrera, 2010; Niu et al., 2011; Wu and Dodge, 2005). There is an urgent need for research-based information on the salinity tolerance of landscape plants for use in landscapes irrigated with reclaimed water or in salt-prone areas.

Ornamental grasses have recently received considerable attention in the U.S. green industry. Their production and landscape use has expanded in the last two decades. An estimated $158 million worth of ornamental grasses are sold annually in the U.S. (U.S. Department of Agriculture, 2015). Ornamental grasses are also popular in urban landscapes in Utah and the Intermountain West. Their use is expected to further increase due to the unique textures and patterns they contribute to the landscape, high drought tolerance, and low maintenance input (Gunnell et al., 2015). Blue grama is a warm-season perennial grass with low-growing habit, drought tolerance, and limited maintenance requirements (Wynia, 2007). It is grown in perennial gardens and used for native plant landscaping, habitat restoration, and erosion control projects. Indian seaoats is also a warm-season perennial grass that thrives in partial shade throughout most of its range and is used as ground cover in shady areas (Neill, 2007). Sand ryegrass is a bright blue, cool-season ornamental grass with straw-colored seed heads on stalks 8 to 12 inches above the foliage. It is a sand-loving grass species and can easily adapt to a highly salinized area (St. John et al., 2010). Pink muhly grass is a warm-season, hedge-like perennial with green leaves in dense clumps and pink flowers held above the foliage. It is an excellent garden plant because of its hardiness and drought tolerance, low maintenance needs, and general beauty (Kirk and Belt, 2010). Fountain grass is a warm-season, fine-textured, mounding perennial grass with narrow, medium-to-deep-green leaves and showy, silvery to pinkish-white, bristly, bottlebrush-like flower spikes. It typically grows in spreading clumps and needs full sun to light shade (Gilman, 1999). These five species belong to the grass family (Poaceae). Fox sedge is a grass-like species in sedge family (Cyperaceae) with an inflorescence consisting of a dense, tangled cluster of flower spikes. It tolerates fluctuating water levels and periods of drying (Wennerberg, 2004). Common rush is a grass-like perennial in rush family (Juncaceae) with a smooth, cylindrical stem. It is cultivated as an ornamental plant for use in water gardens, native plant and wildlife gardens, and for larger designed natural landscaping and habitat restoration projects (U.S. Department of Agriculture, 2002).

Salt tolerance has been evaluated on many grasses used for turf and forage (Bushman et al., 2016; Miyamoto, 2008; Tomar et al., 2003). Warm-season grasses are usually more salt tolerant than cool-season grasses when irrigated with impaired waters (Schiavon et al., 2012, 2014). The salinity tolerance of ornamental grasses has also been reported in extension articles. For example, blue grama exhibited moderate tolerance to salinity levels at a saturated soil extract (EC_e) of 4-8 $dS{\cdot}m^{-1}$ (Kratsch et al., 2008). Indian seaoats, 'Glaucus' sand ryegrass, and fountain grass have high levels of tolerance to soil salinity (Jull, 2009). Sand ryegrass and pink muhly grass are highly tolerant to salt spray, and fountain grass is slightly tolerant to salt spray (Glen, 2004). However, these reports are usually based on anecdotal observations. Furthermore, there are only a few ornamental grasses being investigated systematically for salinity tolerance. Zhang et al. (2012) reported that salinity tolerance of blue grama varied within ecotypes and was higher at the germination stage than the mature stage. Pink muhly grass was tolerant of saline irrigation with 100% of plants surviving even at sodium chloride (NaCl) irrigation rates of 10,000 $mg{\cdot}L^{-1}$, which is up to 20 times higher than what could be expected from greywater (Christova-Boal et al., 1996; LeCompte et al., 2016). 'Hameln' fountain grass appears to be slightly more tolerant of salt spray than 'Gracillimus' maiden grass [*Miscanthus sinensis* (Alvarez, 2006)]. Kikuyugrass (*Pennisetum clandestinum*) is salt tolerant with a threshold EC_e of 8.0 $dS{\cdot}m^{-1}$ (Grieve et al., 2012) and shows promise as a suitable candidate for the saline-sodic water reuse system (Grieve et al., 2004). Due to the vast number of ornamental grass and grass-like plants commercially available in the green industry and a diversified salinity tolerance in ornamental grasses commonly planted in urban landscapes, there is a need to further evaluate ornamental plants for salt tolerance for landscape use. This study was designed to compare the growth of seven ornamental grass and grass-like species in response to irrigation with saline solutions.

Materials and methods

PLANT MATERIALS AND GROWING CONDITIONS. On 5 Oct. 2017, rooted cuttings in 32-cell trays (5.5 × 5.5 × 10.5 cm) of five ornamental grass species (blue grama, indian seaoats, 'Blue Dune' sand ryegrass, pink muhly grass, and 'Foxtrot' fountain grass) and two grass-like species (fox sedge, common rush) were received from Hoffman Nursery (Rougemont, NC). Plants (~ 4 inches tall) were potted in 1-gal, injection-molded, polypropylene container (PC1D-4, Nursery Supplies, Inc., Orange, CA) filled with a soilless growing substrate consisting of 75% peat moss (Canadian sphagnum peat moss, SunGro Horticulture, Agawam, MA), 25% vermiculite (Therm-O-Rock West, Inc., Chandler, AZ), and 24.3 g/ft^3 white athletic field marking gypsum (92% calcium sulfate dihydrate, 21% calcium, 17% sulfur; Western Mining and Minerals, Inc., Bakersfield, CA). The water capacity of the substrate mixture was 74%.

All plants were grown in a greenhouse in Logan, UT (lat. 41°45'28"N, long. 111°48'47"W, elevation 1409 m) and well irrigated with tap water (EC = 0.37 $dS \cdot m^{-1}$, pH = 8.25) until treatments started. The sodium adsorption ratio (SAR) of the tap water is 0.04, and the major ions in the tap water were calcium (Ca^{2+}), magnesium (Mg^{2+}), silicate (SiO_3^{2-}), sulfate (SO_4^{2-}), boron (B^{+}), copper (Cu^{2+}) at 48.1, 14.6, 11.4, 5.8, 4.3, and 3.2 $mg \cdot L^{-1}$, respectively. The average air temperature in the greenhouse was 22.5 ± 4.9 °C during the day and 20.8 ± 5.3 °C at night.

The average daily light integral inside the greenhouse was 11.8 ± 6.2 $mol \cdot m^{-2} \cdot d^{-1}$ during the experiment. When light intensity inside the greenhouse was below 544 $\mu mol \cdot m^{-2} \cdot s^{-1}$, supplemental light at light intensities of 223 ± 37 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at the canopy level was provided using 1000-W high-pressure sodium lamps (Hydrofarm, Petaluma, CA) from 600 to 2200 HR.

TREATMENTS. A nutrient solution at EC of 1.2 $dS \cdot m^{-1}$ was prepared by adding 0.8 $g \cdot L^{-1}$ 15N-2.2P-12.5K water-soluble fertilizer (Peters Excel 15-5-15 Ca-Mag Special; ICL Specialty Fertilizers, Dublin, OH) to the tap water and used as the control. Saline solution at an EC of 5.0 $dS \cdot m^{-1}$ was prepared by adding 0.92 $g \cdot L^{-1}$ NaCl and 0.88 $g \cdot L^{-1}$ calcium chloride ($CaCl_2$) to the aforementioned nutrient solution, and saline solution at an EC of 10.0 $dS \cdot m^{-1}$ was prepared by adding 2.27 $g \cdot L^{-1}$ NaCl and 2.18 $g \cdot L^{-1}$ $CaCl_2$ to the nutrient solution. The SARs were 4.88 and 8.42 for the saline solutions with ECs of 5.0 and 10.0 $dS \cdot m^{-1}$, respectively. This mixture was used because NaCl is the common salt in reclaimed water (Niu and Cabrera, 2010) and $CaCl_2$ is used to forestall potential calcium deficiencies (Carter and Grieve, 2006). The pH of all solutions were adjusted to 6.5 ± 0.2 using nitric acid. Both control and saline solutions were prepared in 100-L tanks with EC confirmed using an EC meter (LAQUA Twin; Horiba, Ltd., Kyoto, Japan) before irrigation.

Five weeks after transplanting (10 Nov. 2017), plants were fully established with roots observed visually at the root ball's periphery, and uniform plants were chosen for the experiment. From 10 Nov. 2017 to 3 Jan. 2018, treatment solutions were applied once per week for 8 weeks. At each irrigation, plants were irrigated with 1 L treatment solution per plant, resulting in a leaching fraction of approximately 35.0% ± 9.9%. Between treatment solution irrigations, plants were irrigated with 300 mL nutrient solution whenever the substrate surface (~ 1 inch) became dry. Irrigation frequency varied with environmental conditions and treatment solution. Plants at higher salinity need less irrigation because of lower water use resulting from reduced transpiration and leaf area. On 12 Jan. 2018 (9 weeks after the initiation of treatment), five plants of each species were harvested (first harvest). On 24 Jan., the remaining five plants were repotted into 2-gal, injection-molded, polypropylene containers (No. 2B; Nursery Supplies, Inc., Orange, CA) with fresh substrate mentioned above, because they outgrew the 1-gal containers. Four vertical cuts were made along the root ball whenever circling roots had formed. From 27 Jan. to 16 Mar. 2018, treatment solutions were then applied once per week for eight weeks. A total of 1.5 L treatment solution irrigated each plant each time, resulting in a leaching fraction of approximately 13.4% ± 7.8%. On 24 Mar. (18 weeks after the initiation of treatment), all plants were harvested (second harvest). Abamectin (Avid® 0.15EC; Syngenta Crop Protection Inc., Greensboro, NC) was sprayed to control aphids (Aphidoidea) as needed.

LEACHATE EC. The pour-through method described by Cavins et al. (2008) and Wright (1986) was used to determine leachate EC. In brief, a saucer was placed under the container which has drained for at least 30 min right after treatment solution was applied. A total of 100 mL distilled water was poured on the surface of the substrate to obtain leachate in the saucer. The leachate solution was tested using an EC meter. One plant per treatment per species was chosen for measurement. Leachate EC readings were averaged across species.

PLANT GROWTH. Plant height (centimeters) from the soil surface to the tip of the tallest leaf and the number of inflorescences were recorded at both harvest dates (12 Jan. and 24 Mar.). At each harvest date, plant shoots of five plants per treatment per species were severed at the substrate surface, and leaf area was determined using an area meter (LI-3100; LI-COR® Biosciences, Lincoln, NE). Plant shoots were dried in an oven at 70 °C for 3 d, and shoot DW was determined. At the second harvest date, tillers were counted. In addition, roots were cleaned and dried in the oven at 70 °C for 3 d, and root DW was taken.

FOLIAR SALT DAMAGE EVALUATION. Foliar salt damage was rated by giving a visual score based on a reference scale from 0 to 5, where 0 = dead; 1 = over 90% foliar damage (salt damage: leaf edge burn, necrosis, and discoloration); 2 = moderate (50% to 90%) foliar damage; 3 = slight (less than 50%) foliar damage; 4 = good quality with minimal foliar damage; and 5 = excellent with no foliar damage (Sun et al., 2015). The foliar salt damage rating did not consider plant size.

CHLOROPHYLL CONTENT. Relative chlorophyll content [Soil-Plant Analysis Development (SPAD) reading] was measured using a handheld chlorophyll meter (SPAD 502 Plus; Minolta Camera Co., Osaka, Japan) 1 week before each harvest date. Ten healthy and fully expanded leaves of each plant of all species were chosen for measurements with the exception of common rush. Instead, a protocol described by Lichtenthaler and Buschmann (2001) was used to determine the chlorophyll content of common rush. In brief, fresh leaves (1 g) were ground with 10 mL ethanol (ethyl alcohol 190 proof, 95%, Pharmco-AAPER, Greenfield Global USA Inc., Brookfield, CT). The extract was centrifuged at 1300 gn using a centrifuge (Marathon 21K; Thermo Fisher Scientific, Waltham, MA) for 20 min. The supernatant (~ 6 mL) was then collected and stored overnight in the dark at room temperature. Samples were loaded into plastic cuvettes (PMMA; VWR International LLC., Radnor, PA), and spectrophotometric readings at wavelengths of 470, 648.6, and 664.1 nm were made using a spectrophotometer (BioMate™ 3; Thermo Fisher Scientific, Waltham, MA). The chlorophyll a and b contents were estimated using the formula: C_a (micrograms per milliliter) = 13.36 $A_{664.1}$ – 5.19 $A_{648.6}$; C_b (micrograms per milliliter) = 27.43 $A_{648.6}$ – 8.12 $A_{664.1}$. The concentration of carotenoids was calculated as follows:

$C_{(x+c)}$ (micrograms per milliliter) = (1000 A_{470} – 2.13 C_a – 97.64 C_b) /209. SPAD readings are positively correlated with destructive chlorophyll measurements in st. augustinegrass (*Stenotaphrum secondatum*) (Rodriguez and Miller, 2000).

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS. All plants were arranged in the greenhouse following a split-plot experimental design with salinity levels as the main plot factor and seven species as the subplot factor. Ten plants per treatment per species were used. Due to different plant growth habits, data was analyzed separately for each species following a completely randomized experimental design with three salinity levels. Visual score was analyzed as multinomial data, whereas number of inflorescences and tillers were analyzed as negative binomial data. Means separation among treatments was adjusted using Tukey's method for multiplicity at $\alpha = 0.05$. Means separation among species was also conducted for visual score. All statistical analyses were performed with the GENMOD and GLIMMIX procedures of SAS/STAT 14.3 in SAS (Version 9.4, SAS Institute, Cary, NC).

Results and discussion

Salts gradually built up in the plant root zone when plants received saline water irrigation, as indicated by increased salinity level in the leachate solution (Fig. 1). From 10 Nov. 2017 to 3 Jan. 2018, the EC of the leachate solution ranged from 4.1 to 8.4 $dS \cdot m^{-1}$ and from 5.9 to 13.8 $dS \cdot m^{-1}$ when irrigated with solutions at EC of 5.0 and 10.0 $dS \cdot m^{-1}$, respectively. However, the EC of the leachate solution stayed around 2.0 $dS \cdot m^{-1}$ for the control. From 27 Jan. to 16 Mar. 2018, the EC of the leachate solution for control was from 2.4 to 3.8 $dS \cdot m^{-1}$ with an average of 3.0 $dS \cdot m^{-1}$. The EC of the leachate solution ranged from 6.1 to 13.5 $dS \cdot m^{-1}$ and from 8.6 to 20.9 $dS \cdot m^{-1}$ when irrigated with solutions at EC of 5.0 and 10.0 $dS \cdot m^{-1}$, respectively. These results are similar to previous reports (Sun et al., 2015; Wu et al., 2016) that consistently documented that the salinity level in the leachate solution increased when irrigated with saline solution and the EC of leachate was higher than that of the treatment solution after two or three irrigation events.

At the first harvest, sand ryegrass, pink muhly grass, and fountain grass exhibited no foliar salt damage when irrigated with solutions at EC of 5.0 $dS \cdot m^{-1}$, and they had minimal foliar salt damage with visual scores of 4.4 or above when irrigated with solutions at EC of 10.0 $dS \cdot m^{-1}$ (Table 1). Common rush experienced minimal foliar salt damage with an average visual score of 4.5 and 3.9 when irrigated with solutions at EC of 5.0 and 10.0 $dS \cdot m^{-1}$, respectively. Blue grama, indian seaoats, and fox sedge had slight foliar salt damage with average visual scores ranging from 3.0 to 3.8 when irrigated with solutions at EC of 5.0 and 10.0 $dS \cdot m^{-1}$. At the second harvest, fountain grass and pink muhly grass still showed no foliar salt damage using solutions at EC of 5.0 $dS \cdot m^{-1}$ and had minimal or slight damage using solutions at EC of 10.0 $dS \cdot m^{-1}$. Sand ryegrass and indian seaoats experienced minimal foliar salt damage when irrigated with solutions at EC of 5.0 and 10.0 $dS \cdot m^{-1}$. Fox sedge plants had moderate foliar salt damage with an average visual score of 3.0 using solutions at EC of 5.0 $dS \cdot m^{-1}$ and 2.4 using solutions at EC of 10.0 $dS \cdot m^{-1}$. Visual scores were not taken at the second harvest date for blue grama and common rush due to aphid infestation. McKenney et al. (2016) observed that the visual quality of blue muhly grass (*Muhlenbergia lindheimeri*), indian seaoats, and foothill sedge (*Carex tumulicola*) plants were hardly affected by increasing salinity until EC of 5.0 $dS \cdot m^{-1}$, but declined sharply at EC of 10.0 $dS \cdot m^{-1}$. They also found that blue muhly grass irrigated with solutions at EC of 10.0 $dS \cdot m^{-1}$ still had acceptable visual quality, but indian seaoats and foothill sedge exhibited poor visual quality.

The relative chlorophyll content (SPAD reading) of all ornamental grass and grass-like plants irrigated with solutions at EC of 5.0 dS·m^{-1} was similar to that in the control at the first harvest (Table 1). Blue grama, sand ryegrass, and fountain grass irrigated with solutions at EC of 10.0 dS·m^{-1} also had similar SPAD readings to those in the control. However, fox sedge and pink muhly grass irrigated with solutions at EC of 10.0 dS·m^{-1} had lower SPAD readings than that in the control. At the second harvest, blue grama, sand ryegrass, pink muhly grass, and fountain grass irrigated with solutions at EC of 5.0 and 10.0 dS·m^{-1} had similar SPAD values to those in control. However, the SPAD readings of fox sedge irrigated with solutions at EC of 5.0 and 10.0 dS·m^{-1} were less than that in the control. Interestingly, all indian seaoats had yellowish foliage during the entire experiment. This might be attributed to high light levels in the greenhouse because indian seaoats usually thrives in partial shade throughout most of its range and is planted in shady areas (Neill, 2007). Norcini et al. (2001) found that the foliage of indian seaoats was more yellowish when grown under full sun than when grown in the shade. The SPAD readings of indian seaoats were greater than that in the control when plants were irrigated with a saline solution, which might be caused by increased specific leaf weight (the weight per unit area of a leaf) under osmotic stress (Acosta-Motos et al., 2017; Caudle et al., 2014; García-Valenzuela et al., 2005). In common rush, the chlorophyll and carotenoid contents determined by chemical extraction and spectrophotometer were not significantly different among treatments (data not shown). These results are in line with a previous report that increasing salinity stress did not change the SPAD reading of blue muhly, indian seaoats, and foothill sedge (McKenney et al., 2016).

At the first harvest, blue grama, fox sedge, common rush, and sand ryegrass plants irrigated with solutions at EC of 5.0 dS·m^{-1} had a similar height to those in control (Table 2).

Nevertheless, indian seaoats, pink muhly grass, and fountain grass irrigated with solutions at EC of 5.0 dS·m^{-1} were 26%, 22%, and 18%, respectively, shorter than those in the control. All ornamental grass and grass-like plants irrigated with solutions at EC of 10.0 dS·m^{-1} had a reduction of 10% to 38% in height compared to the control. At the second harvest, compared to the control, blue grama, fox sedge, pink muhly grass, and fountain grass irrigated with solutions at EC of 5.0 dS·m^{-1} reduced their height by 18%, 12%, 29%, and 12%, respectively. The height of the remaining three species irrigated with solutions at EC of 5.0 dS·m^{-1} did not differ from the control. Except sand ryegrass, all ornamental grass and grass-like plants irrigated with solutions at EC of 10.0 dS·m^{-1} had a 13% to 36% reduction in height compared to the control. McKenney et al. (2016) documented in their research that blue muhly and foothill sedge plants irrigated with solutions at EC of 10.0 dS·m^{-1} were much shorter than those at lower EC levels, but indian seaoats exhibited similar height among salinity treatments.

At the first harvest, all ornamental grass and grass-like plants irrigated with solutions at EC of 5.0 dS·m^{-1} had similar leaf area to those in control with an exception of indian seaoats, which had a 38% reduction (Table 2). The leaf area of indian seaoats, common rush, and fountain grass irrigated with solutions at EC of 10.0 dS·m^{-1} was 48%, 31%, and 67% less than in the control, respectively. At the second harvest, there was no significant difference in the leaf area of all ornamental grass and grass-like plants irrigated with solutions at EC of 5.0 dS·m^{-1} and control. Indian seaoats, fox sedge, common rush, and fountain grass irrigated with solutions at EC of 10.0 dS·m^{-1} had 52%, 29%, 55%, 46% smaller leaf area, respectively, than those in the control. Similarly, reduction in leaf area has been observed in many plant species under salinity stress (Sun et al., 2015; Wu et al., 2016). This could be considered a first line of defense strategy against salt-induced drought conditions. Salinity lowers the water potential of the soil solution, thereby making water less available to plants, and reducing leaf surface area with fewer stomata could significantly reduce water loss as an adaptation to a saline environment.

Fox sedge and pink muhly grass plants did not produce any inflorescences during the entire experiment (Table 3). At the first harvest, all common rush and fountain grass did not form inflorescences. Indian seaoats produced less inflorescences when saline water irrigation was applied. Although the remaining two plant species produced inflorescences, there were no significant differences among treatments. At the second harvest, the number of inflorescences of blue grama, indian seaoats, and sand ryegrass also did not change; however, irrigation with solutions at EC of 5.0 $dS{\cdot}m^{-1}$ reduced the number of inflorescences of common rush by 50%, and irrigation with solutions at EC of 10.0 $dS{\cdot}m^{-1}$ lowered the number of inflorescences of common rush and fountain grass by 89% and 48%, respectively. Hunter and Wu (2005) observed no significant effect of salinity on flowering in native California grass species that received moderate salt spray. However, decreased flowering on ‘Gracillimus’ maiden grass and ‘Hameln’ fountain grass occurred at 100% seawater salt spray, whereas no difference in flowering was observed at 50%, 25%, or 0% seawater salt spray (Scheiber et al., 2008). Additionally, fox sedge and fountain grass irrigated with solutions at EC of 10.0 $dS{\cdot}m^{-1}$ had 26% and 23% fewer tillers, respectively, compared to their respective control. Saline water irrigation slightly reduced the number of tillers of other tested species (Table 3).

At the first harvest, saline solutions at EC of 5.0 and 10.0 $dS{\cdot}m^{-1}$ did not affect the shoot growth of all species except fox sedge and fountain grass. Fox sedge irrigated with solutions at EC of 5.0 $dS{\cdot}m^{-1}$ and 10.0 $dS{\cdot}m^{-1}$ had 16% and 17%, respectively, less shoot DW than in the control, whereas fountain grass irrigated with solutions at EC of 10.0 $dS{\cdot}m^{-1}$ produced 54% less shoot DW than in the control (Table 4). At the second harvest, saline solutions at EC of 5.0 and

10.0 dS·m^{-1} had no influence on the shoot growth of blue grama (Table 4). The solution at EC of 10.0 dS·m^{-1} lowered the shoot DW of indian seaoats, fox sedge, sand ryegrass, and fountain grass by 55%, 29%, 19%, and 41%, respectively, but this was not the case for plants irrigated with solutions at EC of 5.0 dS·m^{-1}. Both saline solutions at EC of 5.0 and 10.0 dS·m^{-1} reduced the shoot DW of common rush by 30% and 49%, respectively, and that of pink muhly grass by 28% and 43%. Saline water irrigation also inhibited the root growth of fox sedge, common rush, and pink muhly grass with reductions of 35%, 69%, and 64% for plants irrigated with solutions at EC of 5 dS·m^{-1} and of 71%, 77%, and 80% for plants irrigated with solutions at EC of 10 dS·m^{-1}, respectively (Table 4). Saline irrigation water at EC of 10 dS·m^{-1} hindered the root growth of indian seaoats and fountain grass by 57% and 59%, respectively. The total DW of blue grama, indian seaoats and fountain grass irrigated with solutions at EC of 5.0 dS·m^{-1} was not different from that in controls. However, a reduction of 12% to 37% in total DW was recorded for fox sedge, common rush, sand ryegrass, and pink muhly grass plants irrigated with solutions at EC of 5.0 dS·m^{-1}. All plant species except blue grama had a reduction of 22% to 53% in total DW when irrigated with solutions at EC of 10.0 dS·m^{-1}. These results are in agreement with a previous report (Alvarez, 2006) that the root, shoot, and whole plant biomass gain of 'Hameln' fountain grass and 'Gracillimus' maiden grass decreased as the seawater concentration increased from 0% to 100%. Shoot DW of buffalograss (*Buchloe dactyloides*) and blue grama also declined with salinity level increasing from 0 to 10 g·L^{-1} (Zhang et al., 2012). LeCompte et al. (2016) observed that the root and shoot DW of muhly grass decreased with high NaCl concentrations increasing from 2000 to 10,000 mg·L^{-1}, but there was no significant effect of low NaCl concentrations (0-1000 mg·L^{-1}) on its root and shoot DW.

This research evaluated seven ornamental grass and grass-like species for their tolerance to saline irrigation water containing NaCl and $CaCl_2$ salts that could be expected from reclaimed water. Unlike many ornamental herbaceous and woody shrub species screened in the past, these ornamental grass and grass-like plants showed a very strong tolerance to the salinity levels in the 4-month greenhouse experiment. Sand ryegrass, pink muhly grass, and fountain grass plants were still of high visual quality and marketable, although their plant growth reduced as a result of saline water irrigation. These three species had minimum foliar salt damage, but the remaining tested species exhibited slight or moderate foliar salt damage. Sand ryegrass, pink muhly grass, and fountain grass appear to be more suitable for landscapes where saline irrigation water is used. Plant responses to saline water in this research could also be applied to landscapes in salt-prone areas and nearby coastal regions.

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Table 1. Visual score and relative chlorophyll content [soil plant analysis development (SPAD reading) of seven ornamental grass or grass-like species irrigated with nutrient solution [Electrical conductivity (EC) = 1.2 $dS \cdot m^{-1}$; Control] or saline solution [EC = 5.0 $dS \cdot m^{-1}$ (EC 5) or 10.0 $dS \cdot m^{-1}$ (EC 10)] in a greenhouse. Plants were harvested after the eighth (first harvest, 9 weeks after the initiation of treatment) and sixteenth irrigation (second harvest, 18 weeks after the initiation of treatment). [z]

Species	Visual score (0 to 5 scale)[y]						SPAD reading					
	First harvest			Second harvest			First harvest			Second harvest		
	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10
Blue grama	5.0 aA[x]	3.8 bC	3.8 bE	-[w]	-	-	33.4 a	33.0 a	33.4 a	32.0 a	31.9 a	31.0 a
Indian seaoats	4.2 aB	3.7 bC	3.0 cF	4.6 aAB	4.0 abB	3.8 bA	17.1 b	19.6 ab	23.6 a	30.9 b	36.9 a	33.0 b
Fox sedge	5.0 aA	3.0 bD	3.0 bF	4.0 aB	3.0 bC	2.4 cB	45.6 a	45.3 a	43.9 b	47.2 a	44.4 b	42.8 c
Common rush	5.0 aA	4.5 bB	3.9 cD	-[w]	-	-	-[v]	-	-	-[v]	-	-
Sand ryegrass	5.0 aA	5.0 aA	5.0 aA	5.0 aA	4.4 abB	4.0 bA	55.8 ab	54.9 b	57.0 a	59.3 a	57.7 a	59.1 a
Pink muhly grass	5.0 aA	5.0 aA	4.4 bC	5.0 aA	5.0 aA	3.6 bA	39.5 a	38.4 ab	37.5 b	38.3 a	39.0 a	37.7 a
Fountain grass	5.0 aA	5.0 aA	4.7 bB	5.0 aA	5.0 aA	4.0 bA	46.2 a	44.6 a	44.5 a	44.3 a	44.9 a	44.9 a

[z] 1 $dS \cdot m^{-1}$ = 1 mmho/cm.

[y] 0 = dead; 1 = more than 90% foliar salt damage (salt damage: leaf burn, necrosis, and discoloration); 2 = moderate (50% to 90%) foliar salt damage; 3 = slight (less than 50%) foliar salt damage; 4 = good quality with minimal foliar salt damage; and 5 = excellent without foliar salt damage.

[x] Means with same lowercase letters within a row and harvest date are not significantly different among treatments by Tukey's method for multiplicity at $\alpha = 0.05$. For visual score, means with same uppercase letters are not significantly different among species by Tukey's method for multiplicity at $\alpha = 0.05$.

[w] Plants infested with aphids (Aphidoidea), and visual scores were not taken.

[v] SPAD 502 Plus chlorophyll meter (Minolta Camera Co., Osaka, Japan) did not work on this species.

Table 2. Height and leaf area per plant of seven ornamental grass or grass-like species irrigated with nutrient solution [Electrical conductivity (EC) = 1.2 dS·m^{-1}; Control] or saline solution [EC = 5.0 dS·m^{-1} (EC 5) or 10.0 dS·m^{-1} (EC 10)] in a greenhouse. Plants were harvested after the eighth (first harvest, 9 weeks after the initiation of treatment) and sixteenth irrigation (second harvest, 18 weeks after the initiation of treatment). [z]

Species	Height (cm)[z]						Leaf area (cm^2)[z]					
	First harvest			Second harvest			First harvest			Second harvest		
	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10
Blue grama	76.1 a[y]	74.1 a	66.1 b	75.0 a	61.4 b	58.4 b	1165 a	1192 a	1041 a	2138 a	1761 a	1730 a
Indian seaoats	56.0 a	41.3 b	40.2 b	76.8 a	68.4 a	52.8 b	1274 a	785 b	668 b	2919 a	2450 ab	1406 b
Fox sedge	85.3 a	82.4 a	76.9 b	92.4 a	81.8 b	80.0 b	4367 a	4008 a	3775 a	6793 a	6003 ab	4859 b
Common rush	93.0 a	87.7 a	77.5 b	93.0 a	87.5 ab	75.3 b	2944 a	2855 ab	2030 b	4497 a	2876 ab	2027 b
Sand ryegrass	91.2 a	88.1 a	77.6 b	85.2 a	85.0 a	76.4 a	2764 a	2441 a	2027 a	4731 a	3997 a	3323 a
Pink muhly grass	58.0 a	45.6 b	41.9 b	81.2 a	57.6 b	52.0 b	1021 a	897 a	901 a	1863 a	1417 a	1106 a
Fountain grass	87.0 a	71.3 b	53.9 c	91.2 a	80.0 b	74.6 b	2634 a	2010 a	875 b	3964 a	3729 a	2152 b

[z] 1 dS·m^{-1} = 1 mmho/cm, 1 cm = 0.3937 inch, 1 cm^2 = 0.1550 inch^2.

[y] Means with same lowercase letters within a row and harvest date are not significantly different among treatments by Tukey's method for multiplicity at $\alpha = 0.05$.

Table 3. Number of inflorescences and number of tillers per plant of seven ornamental grass or grass-like species irrigated with nutrient solution [Electrical conductivity (EC) = 1.2 $dS \cdot m^{-1}$; Control] or saline solution [EC = 5.0 $dS \cdot m^{-1}$ (EC 5) or 10.0 $dS \cdot m^{-1}$ (EC 10)] in a greenhouse. Plants were harvested after the eighth (first harvest, 9 weeks after the initiation of treatment) and sixteenth irrigation (second harvest, 18 weeks after the initiation of treatment). [z]

Species	Inflorescences (no.)						Tillers (no.)		
	First harvest			Second harvest			Second harvest		
	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10
Blue grama	20.2 a[y]	15.7 a	21.4 a	41 a	38 a	36 a	450 a	420 a	366 a
Indian seaoats	3.4 a	1.8 b	1.8 b	21 a	18 a	14 a	47 a	46 a	35 a
Fox sedge	-[x]	-	-	-	-	-	370 a	332 ab	275 b
Common rush	-	-	-	53.3 a	26.5 b	6 c	655 a	502 a	482 a
Sand ryegrass	0.1 a	0.2 a	0 a	2 a	1 a	1 a	46 a	44 a	43 a
Pink muhly grass	-	-	-	-	-	-	422 a	350 a	351 a
Fountain grass	-	-	-	22 a	19 a	12 b	100 a	90 ab	78 b

[z] 1 $dS \cdot m^{-1}$ = 1 mmho/cm.

[y] Means with same lowercase letters within a row and harvest date are not significantly different among treatments by Tukey's method for multiplicity at $\alpha = 0.05$.

[x] No plants flowered during the entire experimental period.

Table 4. Shoot, root, and total dry weight (DW) of seven ornamental grass or grass-like species irrigated with nutrient solution [Electrical conductivity (EC) = 1.2 $dS \cdot m^{-1}$; Control] or saline solution [EC = 5.0 $dS \cdot m^{-1}$ (EC 5) or 10.0 $dS \cdot m^{-1}$ (EC 10)] in a greenhouse. Plants were harvested after the eighth (first harvest, 9 weeks after the initiation of treatment) and sixteenth irrigation (second harvest, 18 weeks after the initiation of treatment). [z]

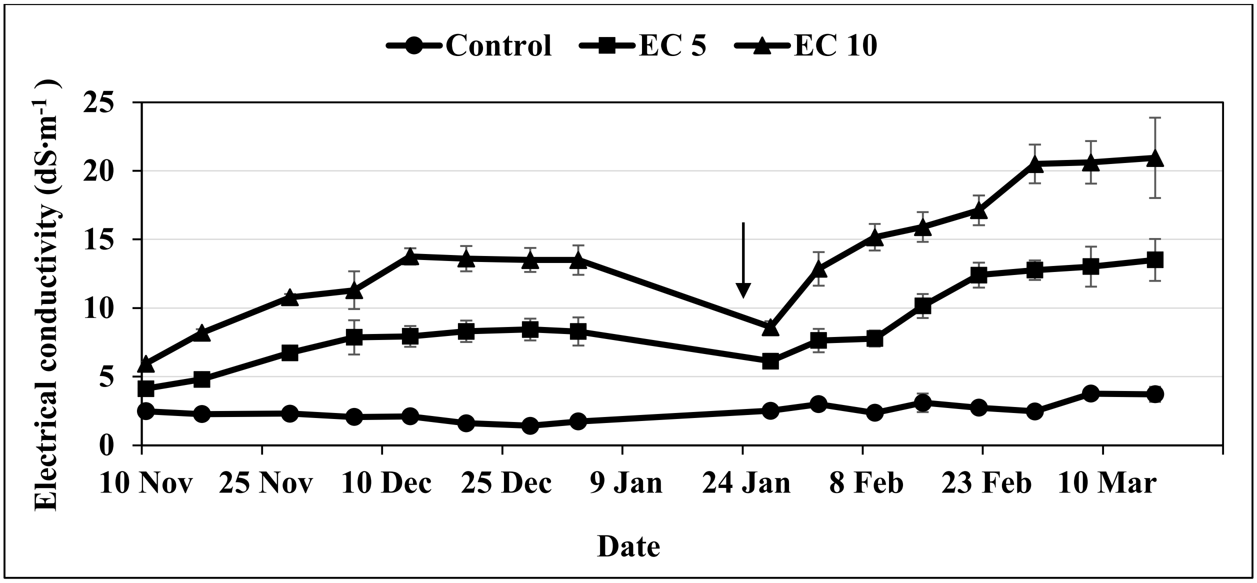
Species	Shoot DW (g)[z]						Root DW (g)			Total DW (g)		
	First harvest			Second harvest			Second harvest			Second harvest		
	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10
Blue grama	27.6 a[y]	21.8 a	21.8 a	74.0 a	68.0 a	64.8 a	17.8 a	12.0 a	11.8 a	91.8 a	79.9 a	76.6 a
Indian seaoats	16.2 a	12.4 a	11.0 a	57.1 a	47.0 ab	25.7 b	16.6 a	13.6 ab	7.1 b	73.6 a	60.5 a	32.8 b
Fox sedge	66.9 a	56.4 b	55.5 b	173.4 a	165.1 a	123.3 b	50.9 a	33.0 b	14.8 c	224.3 a	198.1 b	138.2 c
Common rush	62.7 a	59.1 a	47.7 a	185.6 a	130.7 b	95.4 b	15.7 a	4.9 b	3.6 b	201.3 a	135.6 b	99.0 b
Sand ryegrass	48.4 a	45.3 a	41.4 a	146.7 a	132.4 ab	118.7 b	61.3 a	47.7 a	43.0 a	208.1 a	180.1 b	161.6 b
Pink muhly grass	24.1 a	25.7 a	20.9 a	122.3 a	88.3 b	69.3 b	42.7 a	15.3 b	8.4 b	165.0 a	103.6 b	77.7 b
Fountain grass	40.9 a	30.9 ab	19.0 b	169.7 a	158.2 a	100.8 b	60.4 a	50.0 a	24.5 b	230.1 a	208.1 a	125.3 b

[z] 1 $dS \cdot m^{-1}$ = 1 mmho/cm, 1 g = 0.0353 oz.

[y] Means with same lowercase letters within a row and harvest date are not significantly different among treatments by Tukey's method for multiplicity at $\alpha = 0.05$.

Fig. 1. Time course of the electrical conductivity (EC) of leachate solution collected after ornamental grass or grass-like species irrigated with a nutrient solution at EC of 1.2 $dS \cdot m^{-1}$ (Control) or a saline solution at EC of 5.0 $dS \cdot m^{-1}$ (EC 5) or 10.0 $dS \cdot m^{-1}$ (EC 10) in a greenhouse. One plant per treatment per species was chosen for measurement. Leachate EC readings were averaged across seven ornamental grass and grass-like species. Vertical bars represent standard errors of seven measurements. Arrow denotes that plants grown in 1-gal containers were repotted into 2-gal containers. 1 $dS \cdot m^{-1}$ = 1 mmho/cm, 1 gal = 3.7854 L.

Figure 1.


Control
EC 5
EC 10
Electrical conductivity (dS·m-1)
25
20
15
10
5
0
10 Nov
25 Nov
10 Dec
25 Dec
9 Jan
24 Jan
8 Feb
23 Feb
10 Mar
Date