Morphological and Physiological Responses of Ornamental Grasses to Saline Water Irrigation

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Abstract. Reclaimed water provides a reliable and economical alternative source of irrigation water for landscape use but may have elevated levels of salts that are detrimental to sensitive landscape plants. Landscape professionals must use salt-tolerant plants in regions where reclaimed water is used. Ornamental grasses are commonly used as landscape plants in the Intermountain West of the United States due to low maintenance input, drought tolerance, and unique texture. Six ornamental grass species, including *Acorus gramineus* (Japanese rush), *Andropogon ternarius* (silver bluestem), *Calamagrostis ×acutiflora* (feather reed grass), *Carex morrowii* (Japanese sedge), *Festuca glauca* (blue fescue), and *Sporobolus heterolepis* (prairie dropseed), were evaluated for salinity tolerance. Plants were irrigated every 4 days with a fertilizer solution at an electrical conductivity (EC) of 1.2 dS·m⁻¹ (control) or with a saline solution at an EC of 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10). At 47 days, most species in EC 5 exhibited good visual quality with averaged visual scores greater than 4.6 (0 = dead, 5 = excellent). In EC 10, most *A. gramineus* plants died, but *C. ×acutiflora*, *F. glauca*, and *S. heterolepis* had no foliar salt damage. At 95 days, *C. ×acutiflora*, *F. glauca*, and *S. heterolepis* in EC 5 had good visual quality with averaged visual scores greater than 4.5. *Acorus gramineus*, *A. ternarius*, and *C. morrowii* showed foliar salt damage with averaged visual scores of 2.7, 3.2, and 3.4, respectively. In EC 10, *A. gramineus* died, and other grass species exhibited moderate to severe foliar salt damage, except *C. ×acutiflora*, which retained good visual quality. Plant height, leaf area, number of tillers, shoot dry weight, and/or gas exchange parameters also decreased depending on plant species, salinity level, and the duration of exposure to salinity stress. In conclusion, *A. gramineus* was the most salt-sensitive species, whereas *C. ×acutiflora* was the most salt-tolerant species. *Festuca glauca* and *S. heterolepis* were more tolerant to salinity than *A. ternarius* and *C. morrowii*. *Calamagrostis ×acutiflora*, *F. glauca*, and *S. heterolepis* appear to be more suitable for landscapes in which reclaimed water is used for irrigation. Plant responses to saline water irrigation in this research could also be applied to landscapes in salt-prone areas and coastal regions with saltwater intrusion into aquifers and landscapes affected by maritime salt spray.

Saline soils affect more than 800 million ha of land worldwide, which equates to more than 6% of total arable land area (Muchate et al., 2016; Munns, 2005). This trend continues as new fertile and productive soils are heavily cropped and irrigated with highly alkaline irrigation water, a major cause of increasing soil salinity over time (Ghassemi et al., 1995). As competition for and cost of

potable water increase in the southern and western United States, reclaimed water has become more common in landscape irrigation. Although reclaimed water contains nutrients essential for plant growth (Niu and Rodriguez, 2006), it also possesses chemicals [e.g., sodium chloride (NaCl)] that accumulate in the soil and can be detrimental to some taxa. The salt content of reclaimed

water is typically 2 to 3 times higher than in potable water (Khurram and Miyamoto, 2005; Wu et al., 2001). Salts accumulated in the soil affect the productivity (biomass production) and visual quality of salt-sensitive species (Mane et al., 2011). Saline water decreases water potential, which in turn reduces the ability of plants to uptake water, thereby slowly imposing salinity stress on the plants. The continued use of reclaimed water in landscape irrigation makes it essential and meaningful to assess the salinity tolerance of landscape plants. It is also imperative to select the most salt-tolerant plant species for use in salt-prone areas.

Plant salt tolerance is often evaluated and classified by morphological and physiological characteristics. In response to salinity stress, plants exhibit slower shoot and root growth, smaller leaves, increased foliar injury, and premature leaf senescence (Muchate et al., 2016; Munns 2005). Salinity stress also inhibits photosynthesis, decreases stomatal conductance (g_s), and causes nutrient deficiencies (Munns and Tester, 2008) that ultimately affect crop productivity (Muchate et al., 2016). Overall plant morphological appearance and physiological response to salinity stress are important considerations when determining salt tolerance of individual taxa (Hasegawa et al., 2000; Munns, 2002).

Some researchers have postulated that ornamental plants are less salt-tolerant than forage or other field crops (Amacher et al., 2000), and cool-season grasses are usually more salt-sensitive than warm-season ones (Schiavon et al., 2012, 2014). However, ornamental grass species and/or cultivars have a wide range of responses to salinity that effect growth and physiological characteristics (Sun and Palmer, 2018; Wang et al., 2019). Most grasses cannot survive in more than 200 to 300 mM (≈ 14.6 to 21.9 dS·m⁻¹) NaCl (Gulzar et al., 2003; Pearen et al., 1997). However, *Urochondra setulosa* can grow well when irrigated with 600 mM NaCl (≈ 43.8 dS·m⁻¹) solution (Gulzar et al., 2003). Amacher et al. (2000) summarized the salt tolerance of nearly 100 species grown in Utah including field crops, forages, vegetables, fruit and nut crops, flowers, and turfgrasses. They classified *Poa pratensis* (kentucky bluegrass) and *Poa annua* (annual bluegrass) as salt-sensitive grasses, whereas observations indicated *Puccinellia nutkaensis* (Nootka alkaligrass), which can thrive at an EC of 9.0 to 12.0 dS·m⁻¹, is a highly tolerant species. *Muhlenbergia capillaris* (pink muhly grass) can grow when irrigated with 10,000 mg·L⁻¹ NaCl (≈ 12.5 dS·m⁻¹) solution (LeCompte et al., 2016). Similarly, Wang et al. (2019) reported that *Eragrostis spectabilis* (purple love grass), *Miscanthus sinensis* (maiden silvergrass), *Panicum virgatum* (switchgrass), and *Schizachyrium scoparium* (little bluestem) performed well even when irrigated with a saline solution at an EC of 10.0 dS·m⁻¹ for 9 weeks. However, *Briza media* (quaking grass) is very sensitive to salt, and its morphological characteristics such as shoot dry weight, plant height, and visual quality

deteriorate at an EC as low as 2.5 dS·m⁻¹ (McKenney et al., 2016).

Cities and suburbs are emphasizing the creation and maintenance of appealing public and private landscapes using ornamental plants. Ornamental grasses are often used in landscapes in Utah and the Intermountain West due to their drought tolerance and low maintenance requirements (Gunnell et al., 2015). Although ornamental grasses have been evaluated for their salinity tolerance, more research-based information is needed to enable landscape professionals to choose the right grass species for regions where reclaimed water is used. *Acorus gramineus* 'Minimus Aureus', *Andropogon ternarius* 'Black Mountain', *Calamagrostis × acutiflora* 'Karl Foerster', *Carex morrowii* 'Ice Dance', *Festuca glauca* 'Elijah Blue', and *Sporobolus heterolepis* are popular in landscapes in the United States due to low maintenance input, strong drought tolerance, and unique texture and pattern, but their salt tolerance remains largely unknown. The objective of this study was to determine the effect of saline solution irrigation on the growth and physiology of six aforementioned ornamental grasses and to evaluate each species' tolerance to saline conditions.

Materials and Methods

Plant materials and greenhouse conditions. On 14 June 2019, rooted plugs of six ornamental grasses in 32-cell trays (5.5 × 5.5 × 10.5 cm) were received from Hoffman Nursery (Rougemont, NC). Plants (≈10 cm tall) were

placed in a single-gable glass greenhouse at Utah State University (lat. 41°45'28"N, long. 111°48'47"W, elevation 1409 m) and watered with tap water (EC = 0.31 dS·m⁻¹; pH = 7.3). During the experiment, greenhouse temperatures were maintained at 25 °C during the day and 20 °C at night using a fan-and-pad evaporative cooling system. Light intensities were recorded hourly using a heated silicon chip pyranometer (SP-230; Apogee Instruments, Logan, UT) mounted to a weather station at the Utah Agricultural Experiment Station's Greenville Research Farm (North Logan, UT), ≈1000 m away from the greenhouse. A light transmission rate of 68% was used when calculating the daily light integral (DLI) inside the greenhouse, and the DLI was 28.8 ± 10.8 mol·m⁻²·d⁻¹ (mean ± SD) from 14 June to 12 Nov. 2019. Supplemental lights at an averaged intensity of 337 ± 55 μmol·m⁻²·s⁻¹ at plant canopy level were provided using 1000-W high-pressure sodium lamps (Hydrofarm, Petaluma, CA) from 9 Sept. to 12 Nov. 2019 when light intensity inside the greenhouse was less than 544 μmol·m⁻²·s⁻¹ from 0600 to 2200 HR.

On 5 July 2019, plants were potted in 7.6-L injection-molded polypropylene containers (No. 2B Nursery Supplies, Orange, CA) filled with a growing substrate consisting of 75% peatmoss (Canadian sphagnum peatmoss; Sun Gro Horticulture, Agawam, MA), 25% vermiculite (Therm-O-Rock West, Chandler, AZ), 0.89 kg·m⁻³ gypsum (92% calcium sulfate dihydrate, 21% calcium, 17% sulfur, Athletic White Sports Field Marking Gypsum, Western Mining and Minerals, Bakersfield, CA), 1.57 kg·m⁻³ dolomitic lime (Lhoist North America, Salinas, CA), and 0.65 kg·m⁻³ wetting agent (AquaGro G; Aquatrols, Paulsboro, NJ). On 9 Aug. 2019, plants were pruned to uniform height (≈15 cm), except *A. gramineus*, a nearly stemless groundcover that averaged 9.4 cm tall.

Treatments. A nutrient solution (control) at an EC of 1.2 dS·m⁻¹ with a nitrogen concentration of 120 mg·L⁻¹ was prepared by adding 0.8 g·L⁻¹ water-soluble fertilizer 15N-2.2P-12.5K (Peters 15-5-15 Cal-Mag Special; Scotts, Marysville, OH) to tap water. Sodium chloride (NaCl; Fisher Scientific, Waltham, MA) and dihydrate calcium chloride (CaCl₂·2H₂O; Hi Valley Chemical, Centerville, UT) were added to the nutrient solution to create two saline solution treatments at an EC of 5.0 or 10.0 dS·m⁻¹ (Table 1). The pH of the nutrient and saline solutions was maintained at 6.42 ± 0.05 using 1 mol·L⁻¹ nitric acid. From 9 Aug. to 9 Nov. 2019, grasses were irrigated every 4 d with 1.5 L of nutrient solution or saline solution, resulting in a leaching fraction of 50 ± 10%. After each irrigation event, the EC of the leachate generated from the pour-through method described by Gibson et al. (2007) was determined using an EC meter (LAQUA Twin; Horiba, Kyoto, Japan). One plant per treatment per species was chosen for measurement, and EC values were averaged across six species at each irrigation event.

Plant harvest and data collection. Grasses were harvested twice during the experiment. The first harvest was done for all six grass

species with five plants per treatment per species destructively harvested on 25 Sept. 2019 (47 d after the initiation of treatments, 12 irrigation events). The second harvest of the remaining five plants was conducted on 12 Nov. 2019 (95 d after the initiation of treatments, 24 irrigation events) for all grass species with the exception of *A. gramineus*, which was harvested on 10 Oct. 2019 (62 d after the initiation of treatments, 16 irrigation events) because all plants died at an EC of 10.0 dS·m⁻¹.

Relative chlorophyll content was recorded for all grass species using a soil plant analysis development (SPAD) chlorophyll meter (SPAD-502; Minolta Camera Co., Osaka, Japan) before harvest. Five mature leaves from each plant were measured, and the averaged SPAD value was recorded. Ten and five plants were recorded for SPAD reading at the first and second harvest, respectively. Leaf net photosynthetic rate (P_n), g_s , transpiration rate (E), and water use efficiency (WUE) of grasses were measured 1 d before each harvest date using a portable photosynthesis system with an automatic universal PLC3 universal leaf cuvette (CIRAS-3; PP Systems, Amesbury, MA). Fully expanded leaves of five plants in each treatment were used for the measurement. Environmental conditions in the cuvette were controlled at 25 °C, 1000 μmol·m⁻²·s⁻¹ photosynthetic photon flux and 400 μmol·mol⁻¹ CO₂. Data were recorded once the environmental conditions and gas exchange parameters in the cuvette became stable. All plants were well watered before measurement to avoid water stress. Measurements were taken on sunny days generally between 1100 and 1400 HR. Relative chlorophyll content and gas exchange were not taken for *A. gramineus* and *F. glauca* because of their narrow leaves.

Visual score was assigned to each plant at each harvest date by giving a score from 0 to 5 where, 0 = dead; 1 = severe foliar salt damage (more than 90% leaves with burn and necrosis at the top part of leaf blade); 2 = moderate foliar salt damage (50% to 90%); 3 = slight foliar salt damage (less than 50%); 4 = good quality with minimal foliar salt damage (less than 10%); and 5 = excellent without foliar salt damage (Sun et al., 2015). Plant size was not considered when assigning the visual score. At each harvest date, plant height (centimeters) was recorded from the surface of growing media to the tip of the tallest leaf. Ten and five plants were recorded for visual score and plant height at the first and second harvest, respectively. The number of tillers was counted, and leaf area (square centimeters) was measured using a leaf area meter (LI-3100; LI-COR Biosciences, Lincoln, NE). In addition, shoot dry weight was measured after grasses were dried in an oven at 80 °C for 5 d. The final substrate EC (ECe) was determined using a saturated soil paste technique (Gavlak et al., 1994) with some modification (Sun et al., 2020a). At each harvest date, three containers per treatment per species were randomly selected and left for drying in the greenhouse for at least 2 weeks,

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Table 1. Mineral contents, sodium absorption ratio (SAR), and electrical conductivity (EC) of nutrient solution and saline solution used in the study.

Item ^z	Nutrient solution ^y	Saline solution ^x	
		5.0 dS·m ⁻¹	10.0 dS·m ⁻¹
Ca ²⁺ (mg·L ⁻¹)	80.6	371.2	897.3
Mg ²⁺ (mg·L ⁻¹)	29.6	27.3	27.2
Na ⁺ (mg·L ⁻¹)	1.6	322.2	773.2
SO ₄ ²⁻ (mg·L ⁻¹)	9.8	10.6	11.8
Cl ⁻ (mg·L ⁻¹)	1.5	1340	3260
B (mg·L ⁻¹)	0.2	0.18	0.18
SAR	0.04	4.34	6.93
Adjusted SAR	0.08	7.97	17.5
EC (dS·m ⁻¹)	1.21 ± 0.05	5.04 ± 0.04	10.2 ± 0.05

^zCalcium (Ca²⁺), magnesium (Mg²⁺), sodium (Na⁺), sulfate (SO₄²⁻), chloride (Cl⁻), and boron (B) ions.

^yWater-soluble fertilizer 15N–2.2P–12.5K (Peter Excel 15–5–15 Cal–Mag Special) at 0.8 g·L⁻¹ was added to tap water to make the nutrient solution at an EC of 1.2 dS·m⁻¹.

^xSodium chloride (NaCl) and dihydrate calcium chloride (CaCl₂·2H₂O) were used to prepare saline solution. NaCl at 0.92 g·L⁻¹ and CaCl₂·2H₂O at 1.17 g·L⁻¹ were added to the nutrient solution to make the saline solution at an EC of 5.0 dS·m⁻¹, whereas 2.27 g·L⁻¹ NaCl and 2.88 g·L⁻¹ CaCl₂·2H₂O were added to make the saline solution at an EC of 10.0 dS·m⁻¹.

Table 2. Visual score of six ornamental grass species irrigated with a nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse.^z

Taxa	Visual score ^y					
	First harvest (n = 10)			Second harvest (n = 5)		
	Control	EC 5	EC 10	Control	EC 5	EC 10
<i>Acorus gramineus</i>	4.8 a ^x A ^w	2.9 bC	0.3 cD	4.7 a	2.7 b	0 c
<i>Andropogon ternarius</i>	4.9 aA	4.6 aA	3.7 bB	3 aB	3.2 aB	2.7 aB
<i>Calamagrostis × acutiflora</i>	5 aA	5 aA	5 aA	5 aA	5 aA	5 aA
<i>Carex morrowii</i>	4 aB	3.4 bB	2.9 cC	3.8 aB	3.4 aB	1.7 bC
<i>Festuca glauca</i>	5 aA	5 aA	5 aA	5 aA	4.5 aA	3.2 bB
<i>Sporobolus heterolepis</i>	5 aA	5 aA	5 aA	5 aA	4.9 aA	3.3 bB

^zGrasses were harvested at 47 d (12 irrigation events, first harvest) and 95 d (24 irrigation events, second harvest) after the initiation of treatments except *A. gramineus* that was harvested at 62 d (16 irrigation events, second harvest) after the initiation of treatments because *A. gramineus* was dead when irrigated with saline solution at an EC of 10.0 dS·m⁻¹.

^y0 = dead; 1 = severe foliar salt damage (more than 90% leaves with burn and necrosis); 2 = moderate foliar salt damage (50% to 90%); 3 = slight foliar salt damage (less than 50%); 4 = good quality with minimal foliar salt damage (less than 10%); and 5 = excellent without foliar salt damage (Sun et al., 2015).

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

^wMeans with the same uppercase letters within a harvest date and column are not significantly different among species by Tukey's method for multiplicity at $\alpha = 0.05$. *A. gramineus* at the second harvest date is excluded for means separation.

and the top substrate (≈2 to 3 cm) from the pot was collected for soil extraction.

Experimental design and data analyses. The experiment was conducted using a randomized complete block design with 10 blocks. There were 18 plants in each block (six species and three treatments). Although there were significant interactions between grass species and salinity levels, an analysis of variance was conducted separately for individual species due to various plant growth habits. Visual score was considered as multinomial data, whereas tiller number as negative binomial data. The most appropriate transformation (log) of data were also conducted for all parameters before statistical analyses. Means separation among treatments (or species for visual score) was adjusted using Tukey's

method for multiplicity at $\alpha = 0.05$. All statistical analyses were performed using GLIMMIX procedures of SAS/STAT 14.3 in SAS (SAS Institute, Cary, NC).

Results and Discussion

Visual quality. At the first harvest, all grass species irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ survived except *A. gramineus* that had 70% mortality at an EC of 10.0 dS·m⁻¹ (data not shown). *Acorus gramineus* also displayed moderate to severe foliar salt damage with a visual score of 2.9 and 0.3, respectively, when irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ (Table 2). *Andropogon ternarius* and *C. morrowii* had minimal to slight foliar salt damage when irrigated with saline solution at an EC

of 5.0 dS·m⁻¹ but had slight to moderate foliar damage with a visual score of 3.7 and 2.9, respectively, when irrigated with saline solution at an EC of 10.0 dS·m⁻¹. No foliar salt damage was observed on *C. ×acutiflora*, *F. glauca* and *S. heterolepis* plants when irrigated with saline solutions at an EC of 5.0 or 10.0 dS·m⁻¹.

All *A. gramineus* plants died when irrigated with saline solution at an EC of 10.0 dS·m⁻¹ for 62 d (16 irrigation events) (Table 2). At an EC of 5.0 dS·m⁻¹, *A. gramineus* had moderate foliar salt damage with a visual score of 2.7. Therefore, *A. gramineus* plants were harvested earlier than anticipated. At the second harvest, *A. ternarius* and *C. morrowii* exhibited slight foliar salt damage with visual scores ranging from 3.0 to 4.0 when irrigated with saline solution at an EC of 5.0 dS·m⁻¹ (Table 2). Moderate foliar salt damage was observed on *A. ternarius* and *C. morrowii* plants with a visual score of 2.7 and 1.7, respectively, when they were irrigated with saline solution at an EC of 10.0 dS·m⁻¹. *Andropogon ternarius* and *C. morrowii* plants in the control also exhibited symptoms similar to salt damage with a visual score of 3.0 and 3.8, respectively. However, this may not have been a salt response because *A. ternarius* blooms in the fall, which causes deterioration of foliage (Hoffman Nursery, 2020). Additionally, *C. morrowii* is not an evergreen near the northern edge of its growing range (Missouri Botanical Garden, 2020) and was likely entering fall dormancy at the end of the trial, despite the use of supplemental lights in this study. *Calamagrostis × acutiflora* did not exhibit any foliar salt damage when irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹. *Festuca glauca* and *S. heterolepis* had slight foliar salt damage with a visual score of 3.2 and 3.3, respectively, when irrigated with saline solution at an EC of 10.0 dS·m⁻¹, and minimal salt damage was observed on plants irrigated with saline solution at an EC of 5.0 dS·m⁻¹.

Salinity is known to cause plant foliar damage such as leaf burn, necrosis, and premature discoloration (Sun and Palmer, 2018; Sun et al., 2020a, 2020b). In this study, salinity levels in the leachate increased over time with the irrigation of saline solution (Fig. 1). The average leachate EC of plants irrigated with nutrient solution at an EC of 1.2 dS·m⁻¹ increased from 0.96 to 2.34 dS·m⁻¹. When plants were irrigated with saline solution at ECs of 5.0 or 10.0 dS·m⁻¹, the average leachate EC values increased from 1.87 to 7.95 dS·m⁻¹ and from 3.92 to 14.01 dS·m⁻¹, respectively. These results were further confirmed using a saturated soil paste technique at both harvest dates ($P < 0.0001$; Fig. 2). Compared with the control, substrate ECe in the treatment of 5.0 or 10.0 dS·m⁻¹, collected at the first harvest date, increased by ≈2 and 3 times, respectively. At the second harvest, substrate ECe in the treatment of 5.0 or 10.0 dS·m⁻¹ were 3 and 4 times greater than that in the control, respectively. The leachate and substrate EC values obtained in the

Fig. 1. Electrical conductivity (EC) of leachate solution collected after irrigating ornamental grasses with a nutrient solution at an EC of $1.2 \text{ dS}\cdot\text{m}^{-1}$ (control) or a saline solution at an EC of $5.0 \text{ dS}\cdot\text{m}^{-1}$ (EC 5) or $10.0 \text{ dS}\cdot\text{m}^{-1}$ (EC 10) over the course of experiment. Treatment solutions were applied from 9 Aug. to 9 Nov. 2019 (24 irrigation events). Vertical bars represent SEM of 12 and 11 measurements, respectively, before and after *Acorus gramineus* was harvested on 10 Oct. 2019 (16 irrigation events).

Fig. 2. Electrical conductivity (EC) of soil extraction for ornamental grasses irrigated with a nutrient solution at an EC of $1.2 \text{ dS}\cdot\text{m}^{-1}$ (control) or a saline solution at an EC of 5.0 or $10.0 \text{ dS}\cdot\text{m}^{-1}$. Treatment solutions were applied from 9 Aug. to 22 Sept. 2019 (12 irrigation events) before first harvest. Treatment solutions were applied to all grass species from 9 Aug. to 9 Nov. 2019 (24 irrigation events) before second harvest, with the exception of *Acorus gramineus*, which was irrigated from 9 Aug. to 8 Oct. 2019 (16 irrigation events). Vertical bars represent SEM of three measurements. Same letters above columns within species represent no significance among treatments as determined by Tukey's method for multiplicity at $\alpha = 0.05$.

current study were relatively lower than those reported in our previous research on ornamental grasses (Wang et al., 2019). This discrepancy is caused by the high leaching fraction applied in this study. However, in nursery production, it is becoming increasingly difficult to reconcile the high leaching fraction practice in light of our concerns over diminishing water supplies and groundwater quality. Foliar salt damage is an important parameter to assess when measuring salt tolerance (Niu and Cabrera, 2010), and plant species showing severe salt injury early in the study are less tolerant to salinity stress. Therefore, *A. gramineus* was the most salt-sensitive species, while *C. × acutiflora* was the most tolerant species. *Festuca glauca* and *S. heterolepis* are more tolerant than *A. ternarius* or *C. morrowii* to salinity levels in this study. *Sporobolus virginicus* (seashore dropseed), a halophytic turfgrass, had no visible salt damage when treated with 1500 mM NaCl ($\approx 110 \text{ dS}\cdot\text{m}^{-1}$) for 6 weeks (Tada et al., 2014). Plant species in *Andropogon* are probably moderately salt-tolerant as Redmann (1972) reported that *Andropogon scoparius* (little bluestem) and *Andropogon gerardii* (big bluestem grass) are found naturally in wet locations with non-saline surface soil ($\approx 2.1 \text{ dS}\cdot\text{m}^{-1}$ for 0 to 10 cm soil) and moderately saline subsoil ($\approx 7.7 \text{ dS}\cdot\text{m}^{-1}$ for 40 to 50 cm soil).

Plant growth. Irrigation with saline solution treatments significantly inhibited plant growth ($P < 0.0001$) for both harvest dates (Table 3). At the first harvest, all grass species irrigated with saline solution at an EC of 5.0 or $10.0 \text{ dS}\cdot\text{m}^{-1}$ were 9% to 20% and 16% to 39% shorter than those in the control, respectively, with the exception of *F. glauca* plants that had similar height among three treatments. At the second harvest, *A. gramineus*, *A. ternarius*, *C. × acutiflora*, and *C. morrowii* irrigated with saline solution at an EC of 5.0 or $10.0 \text{ dS}\cdot\text{m}^{-1}$ had 16% to 20% and 27% to 45% reductions in height, respectively, compared with the control. *Festuca*

glauca plants were 14% shorter than the control when they were irrigated with saline solution at an EC of 10.0 dS·m⁻¹. Similarly, Sun and Palmer (2018) documented that ornamental grass and grass-like plants had a 10% to 38% reduction in height compared with the control when irrigated with saline solution at an EC of 10.0 dS·m⁻¹ for 9 weeks. Plant height of *S. heterolepis* was the same among three treatments (Table 3), which is similar to a previous report of a 20-week greenhouse study by Hunter and Wu (2005) in which plant height of *Sporobolus airoides* (alkali sacaton) was not significantly impacted by increasing NaCl concentration in irrigation water applied via sprinkler system. Conversely, in a 12-week study, *S. virginicus* had significant reductions in plant height with increasing salinity levels (Naidoo and Naidoo, 1998). This contrast might suggest that salinity tolerance of *Sporobolus* is species-dependent.

Saline irrigation affected plant leaf area ($P < 0.0001$) for both harvest dates with different responses among grass species (Table 4). At the first harvest, compared

with the control, *A. gramineus* and *C. ×acutiflora* irrigated with saline solution at an EC of 5.0 dS·m⁻¹ had 43% and 39% reductions in leaf area, respectively. In the same treatment, no statistical difference was observed in the leaf area of *C. morrowii*, compared with the control, despite a decrease of 30%. Compared with the control, leaf area was decreased by 48% to 60% for *A. gramineus*, *C. ×acutiflora*, and *C. morrowii* irrigated with saline solution at an EC of 10.0 dS·m⁻¹. In the same treatment, no statistical difference was observed in leaf area of *A. ternarius*, despite a decrease of 35% compared with the control. Additionally, no differences were observed in the leaf area of *F. glauca* and *S. heterolepis* among treatments. At the second harvest, all grass species irrigated with saline solution at an EC of 5.0 dS·m⁻¹ had 35% to 53% smaller leaf area than those in the control, with the exception of *A. ternarius* and *F. glauca*. When irrigated with saline solution at an EC of 10.0 dS·m⁻¹, leaf area of all grass species decreased by 32% to 76% compared with the control. This is in line

with previous reports that decreased leaf area of ornamental grasses was observed in response to salinity stress (Sun and Palmer, 2018; Wang et al., 2019).

Saline irrigation also influenced the number of tillers of ornamental grasses ($P < 0.0001$) measured at both harvest dates (Table 5). At the first harvest, the number of tillers decreased by 26% to 33% when *A. gramineus*, *C. ×acutiflora*, *C. morrowii*, and *S. heterolepis* were irrigated with saline solution at an EC of 5.0 dS·m⁻¹, but these values were not significantly different from the control. *Acorus gramineus* developed 51% fewer tillers than the control when irrigated with saline solution at an EC of 10.0 dS·m⁻¹. In the same treatment, there was a 25% to 42% reduction in the number of tillers for *A. ternarius*, *C. ×acutiflora*, *C. morrowii*, *F. glauca*, and *S. heterolepis*, but these values did not statistically differ from the control. At the second harvest, *A. gramineus*, *C. ×acutiflora*, and *S. heterolepis* plants irrigated with saline solution at an EC of 5.0 dS·m⁻¹ had 39%, 20%, and 26% fewer tillers than the control, respectively. There were 24% to 70% reductions in the number of tillers when grass species were irrigated with saline solution at an EC of 10.0 dS·m⁻¹. Elevated salinity levels in irrigation water have been observed to negatively affect tiller formation of *E. spectabilis* and *S. scoparium* (Wang et al., 2019). There was a slight reduction in the number of tillers of *Bouteloua gracilis* (blue grama), *Chasmanthium latifolium* (Indian seaoats), *Leymus arenarius* (sand ryegrass), *Juncus effusus* (common rush), and *M. capillaris* with increasing salinity levels. *Carex vulpinoidea* (fox edge) and *Pennisetum alopecuroides* (fountain grass) irrigated with saline solution at an EC of 10.0 dS·m⁻¹ for 18 weeks had 26% and 23% fewer tillers compared with the control, respectively (Sun and Palmer, 2018). Ruess et al. (1997) also reported that the number of tillers significantly reduced in *Carex ramenskii* (Ramensk's sedge) treated for 12 weeks with 19,500 mg·L⁻¹ (≈ 24.4 dS·m⁻¹) NaCl compared with the control.

Irrigation with saline solution affected shoot dry weight ($P < 0.0001$) for both harvest dates, with varying responses among grass species (Table 6). At the first harvest, *C. ×acutiflora* and *C. morrowii* produced 37% and 34% less shoot dry weight, respectively, than the control when they were irrigated with saline solution at an EC of 5.0 dS·m⁻¹. In the same treatment, no statistical difference was observed in shoot dry weight of *A. gramineus*, despite a decrease of 23%. Compared with the control, shoot dry weight of *A. gramineus*, *C. ×acutiflora*, and *C. morrowii* irrigated with saline solution at an EC of 10.0 dS·m⁻¹ was reduced by 37%, 52%, and 47%, respectively. In the same treatment, no statistical difference was observed in shoot dry weight of *A. ternarius*, despite a decrease of 27%. No significant changes, in comparison with the control, were observed in shoot dry weight of *F. glauca* and *S. heterolepis* when they were irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹. At the second harvest, shoot

Table 3. Plant height of six ornamental grasses irrigated with a nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse.^z

Taxa	Plant ht (cm)					
	First harvest (n = 10)			Second harvest (n = 5)		
	Control	EC 5	EC 10	Control	EC 5	EC 10
<i>Acorus gramineus</i>	12.6 a ^y	10.7 b	8.8 c	13.4 a	11.1 b	— ^x
<i>Andropogon ternarius</i>	65.8 a	52.5 b	39.9 c	69.4 a	55.6 b	40.9 c
<i>Calamagrostis ×acutiflora</i>	78.6 a	68.0 b	55.8 c	89.2 a	74.9 b	65.2 c
<i>Carex morrowii</i>	36.2 a	28.8 b	22.0 c	44.8 a	37.2 b	24.5 c
<i>Festuca glauca</i>	17.7 a	17.9 a	16.7 a	20.0 ab	22.8 a	17.3 b
<i>Sporobolus heterolepis</i>	75.0 a	68.4 ab	62.7 b	83.9 a	79.5 a	75.8 a

^zGrasses were harvested at 47 d (12 irrigation events, first harvest) and 95 d (24 irrigation events, second harvest) after the initiation of treatments except *A. gramineus*, which was harvested at 62 d (16 irrigation events, second harvest) after the initiation of treatments because *A. gramineus* was dead when irrigated with saline solution at an EC of 10.0 dS·m⁻¹.

^yMeans 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*A. gramineus* was dead.

Table 4. Leaf area of six ornamental grasses irrigated with a nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse.^z

Taxa	Leaf area (cm ²)					
	First harvest (n = 5)			Second harvest (n = 5)		
	Control	EC 5	EC 10	Control	EC 5	EC 10
<i>Acorus gramineus</i>	654 a ^y	372 b	259 b	899 a	423 b	— ^x
<i>Andropogon ternarius</i>	1530 a	1328 a	990 a	1870 a	1626 ab	1270 b
<i>Calamagrostis ×acutiflora</i>	1391 a	844 b	573 b	3074 a	1722 b	1136 c
<i>Carex morrowii</i>	640 a	450 ab	334 b	1372 a	892 b	325 c
<i>Festuca glauca</i>	193 a	249 a	171 a	633 a	476 a	283 b
<i>Sporobolus heterolepis</i>	253 a	271 a	262 a	1837 a	1175 b	660 c

^zGrasses were harvested at 47 d (12 irrigation events, first harvest) and 95 d (24 irrigation events, second harvest) after the initiation of treatments except *A. gramineus*, which was harvested at 62 d (16 irrigation events, second harvest) after the initiation of treatments because *A. gramineus* was dead when irrigated with saline solution at an EC of 10.0 dS·m⁻¹.

^yMeans 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*A. gramineus* was dead.

Table 5. Number of tillers of six ornamental grasses irrigated with a nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse.^z

Taxa	Tiller (no.)					
	First harvest (n = 5)			Second harvest (n = 5)		
	Control	EC 5	EC 10	Control	EC 5	EC 10
<i>Acorus gramineus</i>	182 a ^y	134 ab	90 b	222 a	135 b	— ^x
<i>Andropogon ternarius</i>	177 a	155 a	133 a	121 a	104 ab	89 b
<i>Calamagrostis ×acutiflora</i>	127 a	85 a	77 a	133 a	107 b	101 b
<i>Carex morrowii</i>	12 a	8 a	7 a	30 a	25 a	9 b
<i>Festuca glauca</i>	138 a	149 a	88 a	95 a	78 a	61 b
<i>Sporobolus heterolepis</i>	65 a	44 a	41 a	69 a	51 b	37 c

^zGrasses were harvested at 47 d (12 irrigation events, first harvest) and 95 d (24 irrigation events, second harvest) after the initiation of treatments except *A. gramineus*, which was harvested at 62 d (16 irrigation events, second harvest) after the initiation of treatments because *A. gramineus* was dead when irrigated with saline solution at an EC of 10.0 dS·m⁻¹.

^yMeans 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*A. gramineus* was dead.

Table 6. Shoot dry weight of six ornamental grasses irrigated with a nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse.^z

Taxa	Shoot dry wt (g)					
	First harvest (n = 5)			Second harvest (n = 5)		
	Control	EC 5	EC 10	Control	EC 5	EC 10
<i>Acorus gramineus</i>	7.3 a ^y	5.6 ab	4.6 b	13.3 a	11.4 a	— ^x
<i>Andropogon ternarius</i>	31.5 a	29.3 a	22.9 a	64.6 a	54.9 ab	40.9 b
<i>Calamagrostis ×acutiflora</i>	30.9 a	19.4 b	15.0 b	110.7 a	58.1 b	38.6 c
<i>Carex morrowii</i>	9.2 a	6.1 b	4.9 b	33.4 a	21.4 b	6.9 c
<i>Festuca glauca</i>	6.6 a	8.5 a	6.9 a	18.2 a	16.8 a	10.6 b
<i>Sporobolus heterolepis</i>	9.3 a	8.5 a	9.6 a	75.7 a	47.8 b	30.2 c

^zGrasses were harvested at 47 d (12 irrigation events, first harvest) and 95 d (24 irrigation events, second harvest) after the initiation of treatments except *A. gramineus*, which was harvested at 62 d (16 irrigation events, second harvest) after the initiation of treatments because *A. gramineus* was dead when irrigated with saline solution at an EC of 10.0 dS·m⁻¹.

^yMeans 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*A. gramineus* was dead.

dry weight of *C. ×acutiflora*, *C. morrowii*, and *S. heterolepis* decreased by 48%, 36%, and 37%, respectively, when irrigated with saline solution at an EC of 5.0 dS·m⁻¹. All grass species except *A. gramineus* had 37% to 79% reductions in shoot dry weight when irrigated with saline solution at an EC of 10.0 dS·m⁻¹, compared with the control. Similarly, with increasing salinity levels, there was a decrease in biomass production of *Andropogon glomeratus* (bushy bluestem) (Bowman and Strain, 1988). This also aligns with previous work documenting that *Carex rigescens* (rigescent sedge), *Carex rostrata* (beaked sedge), and *Carex pilosa* (hairy sedge) had reduced growth under salinity stress (Choo et al., 2001; Li et al., 2018). Likewise, there was a 40% reduction in total plant mass of *C. ramenskii* when treated with 19,500 mg·L⁻¹ NaCl (≈24.4 dS·m⁻¹) compared with the control (Ruess et al., 1997). LeCompte et al. (2016) also reported that shoot dry weight of *M. capillaris* decreased with increasing concentrations of NaCl from 2000 to 10,000 mg·L⁻¹ (≈3.1 to 12.5 dS·m⁻¹). On the other

hand, shoot dry weight of *S. airoides* was unaffected by salt treatment at 1500 mg·L⁻¹ NaCl (≈2.4 dS·m⁻¹) (Hunter and Wu, 2005).

These results indicate that responses of ornamental grasses to salinity stress were dependent on species, salinity levels of the irrigation water, and the length of exposure to salinity stress. In a previous study, *L. arenarius*, *M. capillaris*, and *P. alopecuroides* had minimal foliar salt damage. However, *C. latifolium* showed slight to moderate foliar salt damage when irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ for 18 weeks (Sun and Palmer, 2018). Wang et al. (2019) also reported that *P. virgatum* and *S. scoparium* did not show any foliar salt damage, but *E. spectabilis* and *M. sinensis* had a visual score of 3.0 or greater when grasses were irrigated with saline solution at an EC of 10.0 dS·m⁻¹ for 9 weeks. In the present study, *A. gramineus* was sensitive to saline irrigation, and most plants died when irrigated for 47 d with saline solution at an EC of 10.0 dS·m⁻¹. This is in contradiction to some texts that list *A.*

gramineus as a moderately salt-tolerant plant and describe it as a species that “can tolerate some salt spray, but grow best when protected by other plants, structures or dunes” (Rockaway, Inc., 2020). *Calamagrostis ×acutiflora* did not show any foliar salt damage during this 95-d experiment, although saline solution irrigation inhibited plant growth and development (Tables 3–6). This research-based information supports the anecdotal observation made by Jull (2009) that *C. ×acutiflora* ‘Karl Foerster’ is considered tolerant of high soil-salinity. Saline irrigation had little effect on plant growth and visual quality of *F. glauca* and *S. heterolepis* at the first harvest, but at the second harvest, slight foliar salt damage occurred and plant growth and development were significantly affected, especially with saline solution at an EC of 10.0 dS·m⁻¹ (Tables 3–6). Massahi et al. (2018) reported that lawn quality of *Festuca arundinacea* (tall fescue) was unaffected by saline irrigation at an EC of 12.0 dS·m⁻¹ for 7 months. *Andropogon ternarius* and *C. morrowii* exhibited slight foliar salt damage and reduced plant growth at the first harvest and moderate foliar salt damage and further reduced plant growth at the second harvest (Tables 3–6). *Carex rigescens*, a turfgrass species, had decreased turf quality rating when irrigated for 7 d with NaCl concentration greater than 300 mM (≈21.9 dS·m⁻¹) (Li et al., 2018). *Carex vulpinoidea* showed slight to moderate foliar salt damage when irrigated with saline solution at an EC of 5.0 or 10.0 dS·m⁻¹ for 18 weeks (Sun and Palmer, 2018).

Leaf greenness (SPAD reading) and gas exchange. Saline irrigation had significant effects on the leaf greenness of ornamental grasses as inferred by SPAD readings ($P < 0.0001$) at both harvest dates (Fig. 3). There was no difference among the three treatments in SPAD readings of *C. ×acutiflora* at both harvest dates, *S. heterolepis* at the first harvest, and *A. ternarius* at the second harvest (Fig. 3). Compared with the control, SPAD readings of *C. morrowii* irrigated with saline solution at an EC of 5.0 dS·m⁻¹ were reduced by 12% for both harvest dates. At the first harvest, compared with the control, SPAD readings of *A. ternarius* and *C. morrowii* irrigated with saline solution at an EC of 10.0 dS·m⁻¹ decreased by 29% and 31%, respectively. At the second harvest, SPAD readings of *C. morrowii* and *S. heterolepis* were reduced by 36% and 20%, respectively, compared with the control, when they were irrigated with saline solution at an EC of 10.0 dS·m⁻¹. These results are in line with previous research by Li et al. (2018) that reported *C. rigescens* experienced chlorophyll degradation with increasing salinity levels in irrigation water. In addition, SPAD readings of *A. ternarius* were significantly higher at the first harvest than the second harvest ($P < 0.0001$), regardless of treatments. This might be associated with plant growth stage because *A. ternarius* blooms in the fall (Hoffman Nursery,

Fig. 3. Relative chlorophyll content [soil plant analysis development (SPAD) reading] of ornamental grasses irrigated with a nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse. Treatment solutions were applied from 9 Aug. to 9 Nov. 2019 (24 irrigation events). All grasses were harvested at 47 d (12 irrigation events, first harvest) and 95 d (24 irrigation events, second harvest) after the initiation of treatments. SPAD was not taken for *Acorus gramineus* and *Festuca glauca* because of narrow leaves. Vertical bars represent SES of 10 and 5 measurements for the first and second harvest, respectively. Same letters above columns within species represent no significance among treatments as determined by Tukey's method for multiplicity at $\alpha = 0.05$.

2020), which can draw resources from the foliage and hence reduce foliar quality.

Saline irrigation had significant effects on P_n ($P < 0.0001$) and g_s ($P < 0.001$) for both harvest dates (Fig. 4). At the first harvest, compared with the control, saline solution at an EC of 5.0 dS·m⁻¹ reduced P_n of *C. x acutiflora* by 36%. The P_n of *A. ternarius*, *C. x acutiflora*, *C. morrowii*, and *S.*

heterolepis decreased by 75%, 60%, 60%, and 37%, respectively, when irrigated with saline solution at an EC of 10.0 dS·m⁻¹. At the second harvest, compared with the control, *A. ternarius*, *C. morrowii*, and *S. heterolepis* had 56%, 69%, and 83% reductions in P_n , respectively, when irrigated with saline solution at an EC of 10.0 dS·m⁻¹. Yet no difference was observed

for *C. x acutiflora* under these same conditions. Similarly, Vitt et al. (2020) observed a 41% decline in P_n in *C. aquatilis* (water sedge) at the 2354 mg·L⁻¹ sodium treatment compared with 14 mg·L⁻¹ sodium treatment after 15 weeks. At the first harvest, compared with the control, the g_s of *A. ternarius* and *C. x acutiflora* was reduced by 40% and 55%, respectively,

Fig. 4. Net photosynthetic rate (P_n) and stomatal conductance (g_s) of ornamental grasses irrigated with a nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse. Treatment solutions were applied from 9 Aug. to 9 Nov. 2019 (24 irrigation events). All grasses were harvested at 47 d (12 irrigation events, first harvest) and 95 d (24 irrigation events, second harvest) after the initiation of treatments. Gas exchange was not taken for *Acorus gramineus* and *Festuca glauca* because of narrow leaves. Vertical bars represent SES of five measurements. Same letters above columns within species represent no significance among treatments as determined by Tukey's method for multiplicity at $\alpha = 0.05$.

when irrigated with saline solution at an EC of 5.0 dS·m⁻¹ (Fig. 4). When irrigated with saline solution at an EC of 10.0 dS·m⁻¹, the g_s of *A. ternarius*, *C. ×acutiflora*, and *C. morrowii* was reduced by 34%, 65%, and 45%, respectively, compared with the control. Although the g_s of *S. heterolepis* decreased, there was no statistical difference. At the second harvest, when irrigated with saline solution at an EC of 10.0 dS·m⁻¹, the g_s of *C. morrowii* and *S. heterolepis* was reduced by 50% and 57%, respectively. There was no difference in the g_s of *A. ternarius* and *C. ×acutiflora* among the three treatments. Corroborating these results, Bowman (1987) reported that net CO₂ uptake and g_s of *A. glomeratus* decreased with increasing salinity levels in irrigation water. Similarly, Vitt et al. (2020) observed a 55% decrease in g_s in *C. aquatilis* at a 2354 mg·L⁻¹ sodium treatment compared with 14 mg·L⁻¹ sodium treatment after 15 weeks. Finally, NaCl application at 250 mM (≈18.3 dS·m⁻¹) over 24 d reduced the net CO₂ assimilation and g_s of *F. arundinacea* (Pawlowicz et al., 2018).

Saline irrigation influenced E ($P < 0.001$) and WUE ($P < 0.01$) at both harvest dates

(Fig. 5). At the first harvest, *C. ×acutiflora* irrigated with saline solution at an EC of 5.0 dS·m⁻¹ had a 40% reduction in E compared with the control. *Andropogon ternarius*, *C. ×acutiflora*, and *C. morrowii* exhibited 25%, 53%, and 41% reductions in E when they were irrigated with saline solution at an EC of 10.0 dS·m⁻¹. There was no difference in E of *S. heterolepis*. At the second harvest, when they were irrigated with saline solution at an EC of 10.0 dS·m⁻¹, *C. morrowii* and *S. heterolepis* had 43% and 53% reductions in E , respectively. No difference in E was recorded for *A. ternarius* and *C. ×acutiflora*. In line with these results, *C. aquatilis* subjected to a 15-week 2354 mg·L⁻¹ sodium irrigation treatment had a 47% reduction in E when compared with 14 mg·L⁻¹ sodium treatment (Vitt et al., 2020). At the first harvest, there were no differences in the WUE of *C. ×acutiflora* and *C. morrowii* (Fig. 5). However, *A. ternarius* and *S. heterolepis* had 44% and 23% reductions in the WUE when they were irrigated with saline solution at an EC of 10.0 dS·m⁻¹. At the second harvest, *A. ternarius*, *C. morrowii*, and *S. heterolepis* irrigated with saline solution at an EC of 10.0 dS·m⁻¹ had 44%, 50%,

and 69% reductions in WUE, compared with the control. There was no difference in the WUE of *C. ×acutiflora*.

In conclusion, ornamental grasses in this study exhibited varying responses to saline irrigation over a 95-d study. Among the six grass species, *A. gramineus* was the most sensitive species with high mortality and poor visual quality. *Andropogon ternarius* and *C. morrowii* were less tolerant to salinity levels in the irrigation water than *F. glauca* and *S. heterolepis*. *Andropogon ternarius* and *C. morrowii* showed moderate foliar salt damage, whereas *F. glauca* and *S. heterolepis* had slight foliar salt damage at the end of the experiment. Plant growth and development of these four grass species were inhibited, to some extent, because of saline solution irrigation. *Calamagrostis ×acutiflora* was the most tolerant species, not exhibiting any foliar salt damage, although plant growth and development were impaired. Overall, *C. ×acutiflora*, *F. glauca*, and *S. heterolepis* are more suitable for landscapes in which reclaimed water is used for irrigation as well as landscapes in salt-prone areas and coastal regions.

Fig. 5. Transpiration rate (E) and water use efficiency (WUE) of ornamental grasses irrigated with a nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; control] or a saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse. Treatment solutions were applied from 9 Aug. to 9 Nov. 2019 (24 irrigation events). All grasses were harvested at 47 d (12 irrigation events, first harvest) and 95 d (24 irrigation events, second harvest) after the initiation of treatments. Gas exchange was not taken for *Acorus gramineus* and *Festuca glauca* because of narrow leaves. Vertical bars represent SES of five measurements. Same letters above columns within species represent no significance among treatments as determined by Tukey's method for multiplicity at $\alpha = 0.05$.

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