Salinity Effects on Seed Germination and Vegetative Growth of Greens-Type *Poa annua* Relative to Other Cool-Season Turfgrass Species

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ABSTRACT

Seed germination and vegetative growth studies were conducted to determine relative salinity tolerance of greens-type *Poa annua* L. compared with other cool-season turfgrass species. Effects of increasing salinity stress on final germination percentage (FGP), germination rate (GR), clipping yield dry weight (CYD), verdure dry weight (VD), root dry weight (RD), and the longest root length (LRL) were evaluated for nine experimental lines of greens-type *P. annua*, two cultivars of Kentucky bluegrass (*P. pratensis* L.), three cultivars of creeping bentgrass (*Agrostis stolonifera* L.), and one cultivar of perennial ryegrass (*Lolium perenne* L.). Generally, FGP, GR, CYD, VD, and RD declined with increasing salinity; LRL increased at lower salinity levels but decreased at higher levels. Perennial ryegrass 'Charger II' and creeping bentgrass 'Mariner' exhibited the most salinity tolerance while Kentucky bluegrass cultivars exhibited the least. Salinity tolerance of greens-type *P. annua* was intermediate; however, some experimental lines exhibited nearly equal salinity tol erance to that of Mariner. Our data suggest greens-type *P. annua* possesses moderate to good salinity tolerance during seed germination and vegetative growth relative to other cool-season turfgrass species and has potential to be used on golf courses with moderate salt problems affecting turf establishment and maintenance.

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Abbreviations: CYD, clipping yield dry weight; FGP, final germination percentage; GR, germination rate; LRL, the longest root length; RD, root dry weight; VD, verdure dry weight.

Salt problems on golf courses are increasing in both frequency and severity primarily due to the decreasing availability of fresh water resources. Driven by local water conservation plans, more and more golf courses are irrigated with effluent water, which is usually high in salinity and rich in detrimental salts (Marcum et al., 1998; Suplick-Ploense et al., 2002). Salt can have adverse effects on turfgrass growth including physiological drought, ion toxicity, and ion imbalances (Carrow and Duncan, 1998; Carrow et al., 2001). Most cool-season turfgrass species are particularly susceptible to salinity stress during seed germination with the possible exception of perennial ryegrass (Lolium perenne L.) (Dudeck and Peacock, 1985; Harivandi et al., 1992). Therefore, soils and irrigation water with high salinity levels are often more of an obstacle to turf establishment than to the maintenance of mature turfgrass (Qian and Suplick, 2001). As salt problems become one of the most complex management challenges, screening and breeding cool-season turfgrass cultivars that are salt-tolerant during both seed germination and vegetative growth becomes important.

Poa annua L. (annual bluegrass), a member of the Poaceae (Gramineae) family (Mabberley, 1989; Tutin, 1957), has historically

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Table 1. Seed sources of creeping bentgrass, Kentucky bluegrass, tall fescue, and perennial ryegrass used in seed germination and vegetative growth studies.

Species	Cultivar	Seed lot no.
Creeping bentgrass	Penncross	M39-6-302
Creeping bentgrass	Seaside II	M65-4-DF-1
Creeping bentgrass	Mariner	L79-0-M56
Kentucky bluegrass	Moonlight	M65-2-MNLT-R
Kentucky bluegrass	Northstar	Z1-3-1571
Perennial ryegrass	Charger II	M147-9-67

been considered an obstinate weed on golf courses because of its invasiveness, prolificacy, rapid germination, and wide distribution, as well as tolerance to traffic and soil compaction (Huff, 2004). Under selection pressures caused by frequent and intensive mowing management on golf course putting greens, however, greens-type *P. annua* has evolved as a morphologically and physiologically distinct biotype that possesses desirable turfgrass traits including tolerance to close mowing (even as low as 2.0 mm) and extremely high shoot density, especially in shady, temperate environments (Huff, 1998, 1999). In regions and climates that favor *P. annua*'s growth, turfgrass professionals utilize greens-type *P. annua* as an alternative to creeping bentgrass (*Agrostis stolonifera* L.) on putting surfaces. Cultivars of greens-type *P. annua* are being developed at The Pennsylvania State University (Huff, 1998).

Literature suggests that among cool-season turfgrass species, *P. annua* is very sensitive to salinity stress during vegetative growth, while perennial ryegrass is tolerant, creeping bentgrass moderately tolerant, and Kentucky bluegrass (*P. pratensis* L.) moderately sensitive (Carrow and Duncan, 1998; Turgeon, 2008). However, recent greenhouse studies indicate that substantial variation in salinity tolerance exists among greens-type *P. annua* experimental lines and that some lines were nearly unaffected by chronic salinity stress (12 wk at 8 dS m^{-1}) (Dai et al., 2008). However, the salinity tolerance of greens-type *P. annua* has not been compared to that of other cool-season turfgrass species. Moreover, relative salinity tolerance during vegetative growth does not necessarily correlate with that during germination (Marcar, 1987). Therefore, further research is needed to address salinity tolerance of greens-type *Poa annua* relative to other cool-season turfgrass species during both seed germination and vegetative growth. Thus the main objective of the present study was to evaluate salinity tolerance of greens-type *Poa annua* during seed germination and vegetative growth relative to the following cool-season turfgrass species: creeping bentgrass, Kentucky bluegrass, and perennial ryegrass.

MATERIALS AND METHODS

Plant Materials

Nine greens-type *P. annua* experimental lines (PSU 96-1-9, PSU 98-3-30, PSU 98-4-21, PSU 99-2-5, PSU 99-3-19, PSU 99-9-21, PSU 99-11-6, PSU 01-1-46, and PSU 05-1-14) were chosen to represent the high to low range of salinity tolerance observed in a previous long-term salinity stress study (Dai et al., 2008). Inclusion of other cool-season turfgrass cultivars was based on published salt studies: three creeping bentgrass cultivars (Mariner, Seaside II, and 'Penncross') (Marcum, 2001), two Kentucky bluegrass cultivars (Moonlight and Northstar) (Qian et al., 2004; Rose-Fricker and Wipff, 2001), and one perennial ryegrass cultivar (Charger II) (Rose-Fricker and Wipff, 2001) (Table 1).

Seed Germination Study

Two separate experiments were conducted under aseptic conditions from 13 July 2006 to 11 Aug. 2006 or from 17 July 2006 to 15 Aug. 2006. Seeds were disinfected following the protocol of 95% alcohol for 1 min and 2.0% (v/v) calcium hypochlorite [$Ca(OCl)_2$] for 20 min (Stephenson, 1942). Germination was conducted with 36 seeds placed on 1% agar (A7921; Sigma-Aldrich, Inc., St. Louis, MO) in 100 by 15 mm Falcon integrid petri dishes (Becton, Dickinson and Co., Franklin Lakes, NJ) sealed with parafilm. The agar media were salinized with NaCl solutions prepared by dissolving NaCl in deionized water to obtain salinity levels of 5, 10, 15, or 20 dS m^{-1} (0 dS m^{-1} for the control), measured with a temperature-adjusted conductivity meter (model CDB-430; Omega Engineering, Inc., Stamford, CT). Petri dishes were incubated in a germinator (model 1500; Cleland International, Inc., Rogers, MN) programmed to maintain alternating 8 h light at 25°C with irradiance of 10 W m^{-2} and 16 h dark at 15°C for 30 d for both experiments (Copeland, 1978). No contamination was observed during either experiment.

Both experiments were arranged in a randomized complete block design with three replications. Each block contained a complete factorial treatment set of 15 entries and five salinity levels. The positions of petri dishes within each block were rotated three times weekly to minimize possible shelf effect within a block. Data were collected for germination rate (GR, % d^{-1}) based on seedling counts three times weekly and final germination percentage (FGP, %) based on the final counts after 30 d (Maguire, 1962). A seed was considered germinated when an emerged shoot was visible under ×2 magnification (McCarty and Dudeck, 1993). Final germination percentage is described by FGP (%) =

$$100\frac{\sum n}{36}$$

and germination rate by GR (% d^{-1}) =

$$\frac{100}{36}\sum\left(\frac{n}{D}\right),$$

where n is the number of seeds that had germinated at each counting and D is the number of days accumulated up to that counting.

All data were subjected to analysis of variance using PROC GLM (SAS Institute, 2001). To meet the constant variance assumption of ANOVA, data for FGP and GR were subjected to arc sine and square root transformations, respectively. The relationship between salinity level and FGP or GR was described by linear or quadratic regressions for all entries. Mean separations were performed using Fisher's LSD (SAS Institute, 2001).

Vegetative Growth Study

The vegetative growth study was conducted over two separate experiments from 14 April to 28 July 2006 (Exp. I) or from 6 May to 20 Aug. 2006 (Exp. II) in a greenhouse at The Pennsylvania State University, University Park, PA 16802. Mean canopy temperatures ranged from 15.3 to 36.4°C in Exp. I and from 15.9 to 36.1°C in Exp. II. Mean photosynthetically active radiation in the greenhouse ranged from 295.4 to 326.3 μmol m^{-2} s^{-1} in Exp. I and from 300.6 to 326.3 μmol m^{-2} s^{-1} in Exp. II.

Greens-type *Poa annua* experimental lines were collected as sod from an experimental sand putting green (80/20% [w/w] coarse sand/sphagnum peat moss) at the Valentine Turfgrass Research Center, University Park, PA, and transplanted into the same sand mix (80/20% vol.). Cultivars of other cool-season turfgrass species (Table 1) were established from seed sown into 46 by 61 cm flats containing the same sand mix. Grasses were maintained at mowing heights recommended by Turgeon (2008); greens-type *P. annua* and creeping bentgrass were maintained at 6.4 mm, perennial ryegrass at 12.7 mm, and Kentucky bluegrass at 25.4 mm. To ensure establishment and adaptation, all plants were maintained in the greenhouse for 3 mo before the initiation of salinity treatments.

Tillers were randomly chosen from flats of each species and transplanted to foam plates with 20 by 20 mm wells filled with round-shaped USGA specification sand. Each cultivar or experimental line was represented by four tillers per well and six wells per plate. Nylon screen was glued to the bottom of each plate to hold the sand and allow roots to grow through. The hydroponic system was comprised of 12 (four salinity levels and three replications) tanks (33 by 44 by 32 cm) each containing 32 L of constantly aerated half strength Hoagland's no. 1 solution, which was replaced weekly (Hoagland and Arnon, 1939). Sodium chloride was added to treatment tanks gradually over a 3-d period to allow for salinity acclimation. Each of the four levels of salinity treatments (1.2 [control], 5, 10, or 15 dS m^{-1}) was measured with a lab conductivity meter (model CDB-430; Omega Engineering, Inc., Stamford, CT). After the 3-d acclimation period, all roots were clipped at the base of the foam plates to satisfy a uniform 2-cm starting length. Data collection began at this point.

Tillers were hand mowed three times per week at recommended mowing heights and clippings were collected for a period of 3 wk. Clippings were immediately oven-dried (72 h at 60°C) and weighed. Nine of these clippings were combined to determine clipping yield dry weight (CYD) for each entry. At the end of week 3, data were collected on the longest root length (LRL) for each entry. Verdures and roots were also collected at this point, oven-dried (72 h at 60°C), and weighed to determine verdure dry weight (VD) and root dry weight (RD).

Both experiments were arranged in a split plot design with three replications, salinity levels being the whole plot factor and entries the split plot factor. All data were subjected to analysis of variance using PROC GLM (SAS Institute, 2001). Data for CYD and RD were transformed (logarithm) to meet the constant variance assumption of ANOVA. Means were separated using Fisher's LSD (SAS Institute, 2001).

Table 2. Salinity main effect on final germination percentage (FGP) and germination rate (GR).

	dS m^{-1}					$LSD_{0.05}$
	0	5	10	15	20	
FGP, %	80.70	75.43	53.73	32.49	8.94	5.97
GR, % d^{-1}	20.63	18.68	9.83	4.93	1.05	1.78

RESULTS

Seed Germination Study

Salinity levels significant affected FGP and GR ($\alpha = 0.05$). Significant interactions were detected between salinity level and entry for both FGP and GR ($\alpha = 0.05$). Interaction between experiment and salinity level was not significant for FGP or GR, supporting presentation of simplified data pooled across both experiments.

Final germination percentage and GR pooled across entries decreased with increasing salinity (Table 2). Generally, salinity stress had a greater impact on GR than on FGP. The salinity level of 5 dS m^{-1} had a significant adverse effect on pooled GR but not on pooled FGP. When salinity approached 15 dS m^{-1}, pooled FGP was reduced by about 60% while pooled GR by more than 75%. Predicted salinity levels causing 25 and 50% reduction of GR were also lower than those of FGP for most of the entries (Table 3).

For all entries, FGP decreased linearly or quadratically with increasing salinity (Table 3). Perennial ryegrass Charger II was relatively the most salt-tolerant among all the entries in terms of maintaining FGP in saline environments. To reduce FGP by 25%, Charger II required a salinity level of 15.25 dS m^{-1}, which was significantly higher than that for any other entry. Creeping bentgrass cultivars Mariner, Penncross, and greens-type *Poa annua* lines PSU 99-11-6, PSU 99-3-19, PSU 98-4-21, PSU 99-9-21, and PSU 01-1-46 were intermediate, requiring an average of about 8.62 dS m^{-1} to reduce FGP by 25%. Kentucky bluegrass Northstar and Moonlight required the lowest salinity levels (averaging about 2.31 dS m^{-1}) and hence were the least salt tolerant. Similar trends were found on predicted salinity levels to reduce FGP by 50%. Charger II required the highest salinity level (18.16 dS m^{-1}). Mariner, PSU 99-11-6, PSU 98-4-21, and PSU 99-3-19 were intermediate (averaging about 15.27 dS m^{-1}), while Northstar and Moonlight required the lowest (averaging about 5.68 dS m^{-1}).

Linear or quadratic decreases in GR were observed with increasing salinity levels for all entries (Table 3). To reduce GR by 25%, Charger II, PSU 99-9-21, PSU 99-11-6, and the three creeping bentgrass cultivars required the highest salinity levels (averaging about 7.14 dS m^{-1}).

Table 3. Linear/quadratic regressions of final germination percentage (FGP, %) or germination rate (GR, % d^{-1}) vs. salinity levels and predicted salinity levels causing 25 and 50% reduction in FGP and GR of nine greens-type *Poa annua* experimental lines (PSU 96-1-9, PSU 98-3-30, PSU 98-4-21, PSU 99-2-5, PSU 99-3-19, PSU 99-9-21, PSU 99-11-6, PSU 01-1-46, and PSU 05-1-14), three creeping bentgrass cultivars (Mariner, Seaside II, and Penncross), two Kentucky bluegrass cultivars (Moonlight and Northstar), and one perennial ryegrass cultivar (Charger II).

Entry	FGP				GR			
	Regression	R^2	Reduction		Regression	R^2	Reduction	
			25%	50%			25%	50%
			— dS m^{-1} —				— dS m^{-1} —	
Charger II	$Y = 83.03 + 3.39X - 0.31X^2$	0.99*	15.25	18.16	$Y = 21.97 - 0.90X$	0.86*	8.94	14.07
Mariner	$Y = 91.11 - 3.32X$	0.82*	9.34	15.36	$Y = 27.98 - 1.13X$	0.91*	7.93	13.55
Moonlight	$Y = 62.37 - 8.89X + 0.29X^2$	0.99*	1.77	3.97	$Y = 6.92 - 0.97X - 0.03X^2$	0.99*	1.85	4.09
Northstar	$Y = 83.06 - 5.04X$	0.82*	2.84	7.39	$Y = 9.01 - 0.55X$	0.81*	3.01	7.51
Penncross	$Y = 85.19 - 3.53X$	0.92**	8.01	13.39	$Y = 24.04 - 1.15X$	0.97**	6.31	11.16
PSU 01-1-46	$Y = 97.87 - 4.30X$	0.89*	8.15	13.03	$Y = 26.49 - 1.36X$	0.91*	6.12	10.55
PSU 05-1-14	$Y = 93.61 - 3.80X$	0.96**	7.74	13.38	$Y = 27.65 - 1.37X$	0.95**	5.91	10.69
PSU 96-1-9	$Y = 102.50 - 5.45X$	0.92**	5.62	10.01	$Y = 22.04 - 1.26X$	0.90*	3.69	8.28
PSU 98-3-30	$Y = 76.39 - 3.67X$	0.98**	6.16	11.05	$Y = 14.75 - 0.78X$	0.97**	5.07	9.70
PSU 98-4-21	$Y = 96.02 - 3.31X$	0.89*	8.46	15.32	$Y = 23.89 - 1.10X$	0.99**	5.05	10.58
PSU 99-11-6	$Y = 108.06 - 3.89X$	0.88*	9.12	15.35	$Y = 32.57 - 1.55X$	0.95**	6.34	11.21
PSU 99-2-5	$Y = 102.50 - 5.04X$	0.96**	6.22	10.93	$Y = 26.44 - 1.47X$	0.93**	4.07	8.70
PSU 99-3-19	$Y = 100.37 - 3.66X$	0.85*	8.84	15.04	$Y = 28.38 - 1.35X$	0.99**	5.73	10.86
PSU 99-9-21	$Y = 110.65 - 4.44X$	0.91*	8.43	13.94	$Y = 31.70 - 1.54X$	0.93**	6.60	11.26
Seaside II	$Y = 76.48 - 3.29X$	0.92**	7.63	12.85	$Y = 21.10 - 0.99X$	0.96**	6.75	11.57
$LSD_{0.05}$			1.38	0.87			2.67	1.78

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

Northstar and Moonlight required the lowest (averaging about 2.43 dS m^{-1}). The other seven greens-type *P. annua* lines were intermediate, requiring an average salinity level of about 5.10 dS m^{-1} to reduce GR by 25%. To reduce GR by 50%, Charger II and Mariner required the highest salinity levels (averaging about 13.8 dS m^{-1}) among all the entries. Seaside II, Penncross, and all greens-type *P. annua* lines except PSU 98-3-30, PSU 99-2-5, and PSU 96-1-9 were intermediate, requiring an average salinity level of about 11.0 dS m^{-1}, which was significantly higher than those required by Northstar and Moonlight.

Among the nine greens-type *P. annua* experimental lines, PSU 98-3-30, PSU 99-2-5, and PSU 96-1-9 were observed to be less salt tolerant than others during seed germination while PSU 99-11-6 and PSU 99-9-21 were observed to be the most salt tolerant. Direct comparisons were performed between these most salt-tolerant greens-type *P. annua* lines (PSU 99-11-6 and PSU 99-9-21) and perennial ryegrass Charger II, creeping bentgrass Mariner, and Kentucky bluegrass Northstar. At 0 dS m^{-1}, all five entries performed similarly with FGP ranging from 80% (Mariner) to 98% (PSU 99-9-21) (Fig. 1). Separation was observed at 5 dS m^{-1} with the highest FGP 97% (PSU 99-9-21) and the lowest 69% (Northstar). Greatest separation in FGP was observed at 10 dS m^{-1} with Charger II maintaining 89% and Northstar only 3%. Separation became less evident when salinity approached 20 dS m^{-1}. Greens-type *P. annua* PSU 99-11-6 and PSU 99-9-21 had lower FGP than Charger II only at 10 and 15 dS m^{-1}, respectively. Compared to Mariner, these *P. annua* lines had higher FGP at 0, 5, and 10 dS m^{-1} and equal FGP at 15 and 20 dS m^{-1}.

Separation in GR among the five entries was observed at 0 dS m^{-1}, ranging from 10% d^{-1} (Northstar) to 30% d^{-1} (PSU 99-11-6) (Fig. 1). Separation among entries increased at 5 dS m^{-1} and decreased when salinity levels increased to 10 dS m^{-1}. At 20 dS m^{-1}, the five entries were clustered in a narrow range from 0 (Northstar) to 3% d^{-1} (Charger II) due to excessive salinity stress. Greens-type *P. annua* lines PSU 99-11-6 and PSU 99-9-21 germinated more rapidly than Charger II at 0 and 5 dS m^{-1} and as rapidly at 10, 15, and 20 dS m^{-1}. Both greens-type *P. annua* lines germinated more rapidly than Mariner at 0 and 5 dS m^{-1}, as rapidly at 10 and 20 dS m^{-1}, and less rapidly at 15 dS m^{-1}.

Vegetative Growth Study

Salinity treatments had significant effects on CYD, VD, RD, and LRL ($\alpha = 0.05$). Significant interactions existed between salinity level and entry for CYD, VD, RD, and LRL ($\alpha = 0.05$). Interaction between experiment and salinity level was nonsignificant for all growth parameters and therefore data were pooled across both experiments.

Salinity had an adverse effect on CYD and reduced CYD pooled across entries by approximately 25, 44, and 54% when salinity increased from 1.2 (the control) to 5, 10, and 15 dS m^{-1}, respectively (Table 4). When salinity increased from 1.2 to 5 dS m^{-1}, greens-type *P. annua* PSU 01-1-46 increased slightly in CYD compared to the control; PSU 99-2-5 and PSU 99-3-19 maintained over 90% CYD relative to the control; PSU 96-1-9, PSU 98-3-30, creeping bentgrass Penncross, and Kentucky bluegrass Moonlight declined significantly more than other entries (Table 5). The relative CYD rankings were similar at 10 and 15 dS m^{-1} with perennial ryegrass Charger II, creeping bentgrass Mariner, PSU 99-9-21, and PSU 99-2-5 ranking the highest and Moonlight, PSU 96-1-9, and PSU 98-3-30 the lowest.

Salinity significantly reduced VD pooled across entries by approximately 28, 36, and 37% when salinity increased from 1.2 (the control) to 5, 10, and 15 dS m^{-1}, respectively (Table 4). Interestingly, three entries including Northstar, Charger II, and Penncross did not exhibit any noticeable declines in VD with increasing salinity levels. Mariner, PSU 01-1-46, PSU 99-9-21, and PSU 99-2-5 each declined across salinity treatment levels but maintained more than 70% VD at 15 dS m^{-1}, relative to the control (Table 5). Moonlight and PSU 98-3-30 experienced the most reduction in relative VD at every salinity treatment level. Substantial variation was observed among nine greens-type *P. annua* experimental lines in their ability to maintain shoot growth in saline environments.

Generally, RD pooled across entries was significantly affected by salinity stress (Table 4). At 5 dS m^{-1}, RD increased relative to the control for PSU 01-1-46, PSU 99-9-21, PSU 99-3-19, and PSU 98-3-30 (Table 5); however, RD declined for all entries when salinity increased to 10 dS m^{-1}. Charger II, Mariner, PSU 99-9-21, PSU 01-1-46, and PSU 99-2-5 maintained relative RD above 80% at 15 dS m^{-1} and again Moonlight and PSU 98-3-30 had the most reduction in RD among all entries.

The LRL pooled across entries was significantly increased by 16 and 14% relative to the control at 5 and 10 dS m^{-1}, respectively (Table 4). All entries except Northstar and Moonlight increased in LRL at 5 and 10 dS m^{-1}, relative to the control (Table 5). At 15 dS m^{-1}, Northstar and Moonlight showed the most reduction in relative LRL. All other entries were at or near 100% relative LRL except for PSU 99-2-5 (124.8%), Penncross (142.5%), Mariner (150%), and Charger II (225.0%).

Greens-type *Poa annua* PSU 99-2-5 and PSU 99-9-21 were observed to be more salt-tolerant than other seven experimental lines during vegetative growth. Direct comparisons were performed between these lines (PSU 99-2-5 and PSU 99-9-21) and perennial ryegrass Charger II, creeping bentgrass Mariner, and Kentucky bluegrass Northstar. Significant interactions

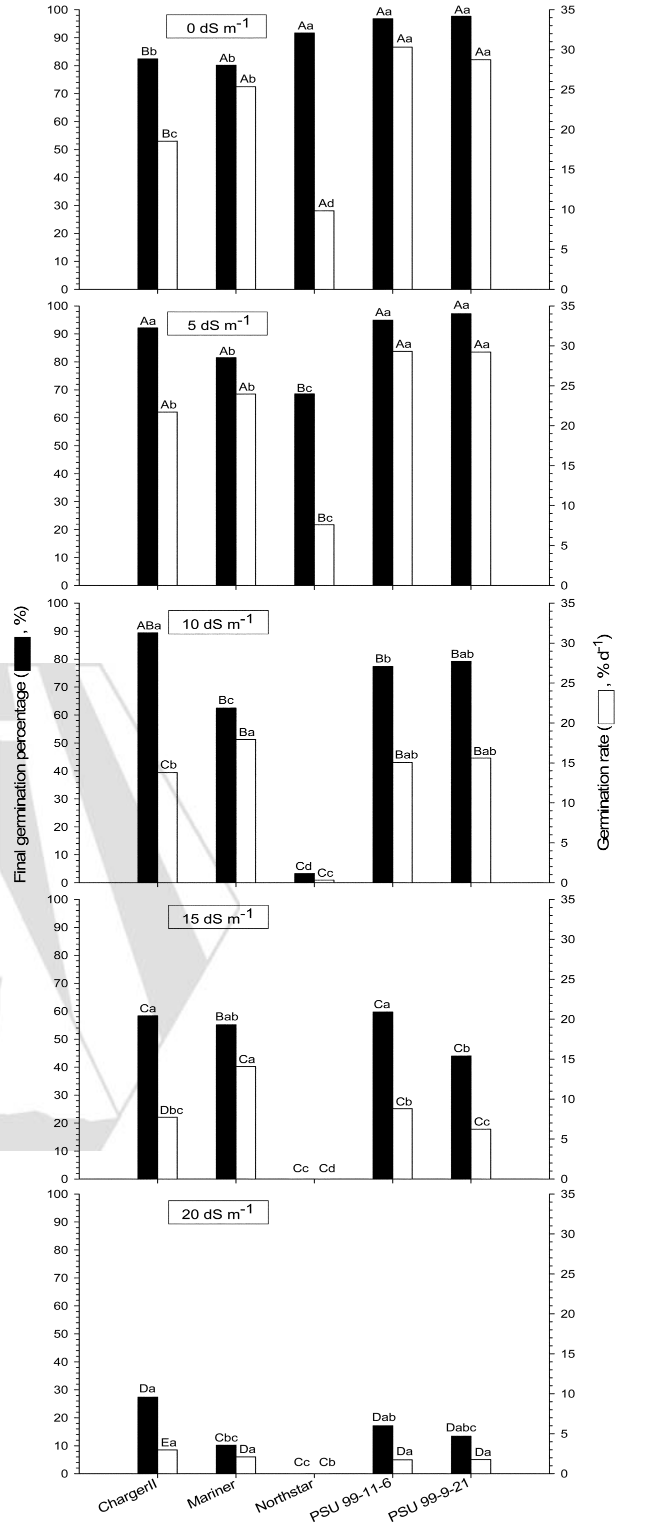

Figure 1. Salinity effects on (■) final germination percentage (FGP) and (□) germination rate (GR) of five representative entries: perennial ryegrass 'Charger II', creeping bentgrass 'Mariner', Kentucky bluegrass 'Northstar', and greens-type *Poa annua* experimental lines PSU 99-11-6 and PSU 99-9-21. Mariner, Northstar, PSU 99-11-6, and PSU 99-9-21 were considered relatively more salt tolerant during seed germination compared with entries within their own species in the present studies. Different uppercase letters denote significant differences between salinity levels for a specific entry; different lowercase letters denote significant differences between entries at a specific salinity level (α = 0.05).

Table 4. Salinity main effect on clipping yield dry weight (CYD), verdure dry weight (VD), root dry weight (RD), and the longest root length (LRL).

	dS m^{-1}				$LSD_{0.05}$
	1.2	5	10	15	
CYD, mg	8.7	6.2	4.7	3.9	1.4
VD, mg	27.0	19.7	16.9	16.9	4.9
RD, mg	9.1	7.2	5.7	5.8	1.2
LRL, cm	7.2	8.4	8.2	7.1	0.7

were detected between entry and salinity level on VD, RD, and LRL, but not on CYD. At 5 dS m^{-1}, the VD of Mariner, PSU 99-2-5, and PSU 99-9-21 were unaffected (Table 6). Only Mariner was unaffected at 10 dS m^{-1}. PSU 99-2-5 and PSU 99-9-21 declined more rapidly in VD than Mariner but less rapidly than Charger II and Northstar. The RD of Mariner and PSU 99-9-21 were unaffected at any salinity treatment level and PSU 99-2-5 experienced reduction in RD only at salinity levels beyond 5 dS m^{-1}. Charger II and Northstar, however, exhibited reduction in RD at each salinity treatment level. Generally, Mariner and Charger II increased in LRL as salinity stress increased. Greens-type *P. annua* PSU 99-2-5 and PSU 99-9-21 increased in LRL at 5 and 10 dS m^{-1} but declined at 15 dS m^{-1}. Northstar, however, showed a consistent trend in decreasing LRL with increasing salinity stress.

Table 5. Salinity effects on clipping yield dry weight (CYD), verdure dry weight (VD), root dry weight (RD), and the longest root length (LRL) of nine greens-type *Poa annua* experimental lines (PSU 96-1-9, PSU 98-3-30, PSU 98-4-21, PSU 99-2-5, PSU 99-3-19, PSU 99-9-21, PSU 99-11-6, PSU 01-1-46, and PSU 05-1-14), three creeping bentgrass cultivars (Mariner, Seaside II, and Penncross), two Kentucky bluegrass cultivars (Moonlight and Northstar), and one perennial ryegrass cultivar (Charger II). Relative values are presented as percent of control (1.2 dS m^{-1}) at three salinity levels.

Entry	Relative CYD			Relative VD			Relative RD			Relative LRL		
	dS m^{-1}											
	5	10	15	5	10	15	5	10	15	5	10	15
	%											
PSU 01-1-46	100.2	57.6	49.5	102.1	69.8	73.7	126.6	85.8	88.4	130.5	125.2	103.4
PSU 99-2-5	94.1	65.9	59.7	83.4	71.1	75.8	94.2	78.7	88.3	124.6	135.6	124.8
PSU 99-3-19	90.1	54.0	46.9	88.9	69.2	60.4	109.8	74.7	79.4	141.1	146.2	106.7
PSU 99-9-21	86.8	69.5	51.7	85.8	82.5	77.8	113.7	88.9	95.1	127.6	133.3	103.4
PSU 05-1-14	83.1	60.9	42.6	90.2	69.7	60.8	90.0	75.0	74.5	136.7	141.4	109.5
Seaside II	83.0	53.2	48.6	80.8	72.7	59.8	91.1	56.1	65.9	135.5	132.1	94.4
Mariner	81.7	71.2	61.4	82.9	79.6	70.9	87.6	97.7	80.2	143.0	143.0	150.8
Northstar	79.6	51.3	50.0	70.6	67.2	77.2	60.7	56.9	57.1	81.7	69.7	70.8
Charger II	78.5	76.7	68.9	68.3	64.8	69.8	76.7	82.7	96.7	160.1	218.1	225.0
PSU 98-4-21	76.5	65.6	38.2	74.7	67.6	61.2	83.2	82.3	67.8	128.8	132.2	107.5
PSU 99-11-6	70.9	43.5	36.9	80.3	63.6	59.3	95.2	77.8	66.6	120.7	118.0	101.6
PSU 96-1-9	68.9	38.5	23.1	93.6	67.6	58.7	99.4	76.7	74.6	113.8	103.5	101.1
Penncross	68.5	56.2	47.3	87.1	70.2	86.2	83.0	48.7	65.3	170.7	147.8	142.5
Moonlight	58.6	43.9	32.9	58.8	55.0	53.2	42.2	32.8	31.2	68.3	45.3	31.0
PSU 98-3-30	34.8	30.3	34.9	62.2	54.4	53.9	102.0	59.7	58.2	103.7	109.1	97.1
$LSD_{0.05}$	30.8	22.6	19.8	20.7	21.1	24.4	39.4	25.8	37.0	33.5	47.7	41.7

DISCUSSION

Literature suggests that *P. annua* is very sensitive to salt stress (Carrow and Duncan, 1998). However, we speculate this conclusion is likely based on empirical observations as indicated by a scarcity of supporting data and/or is based on information solely derived from the annual weedy type *P. annua* f. *annua*. As a spectrum of biotypes including greens-type *P. annua* f. *reptans* is known to exist within this species, we found it inappropriate to consider *P. annua* as a homogeneous population in terms of salinity tolerance.

Research indicates that greens-type *P. annua* possesses a wide range of variation in salinity tolerance. Among the nine experimental lines used in the present studies, a previous long-term vegetative growth study indicated that PSU 99-9-21, PSU 01-1-46, and PSU 99-2-5 were the most salt-tolerant, PSU 98-3-30 and PSU 96-1-9 the least, according to data on relative percent cover (Dai et al., 2008). In the present studies, the experimental lines of greens-type *P. annua* were intermediate in the range of predicted salinity levels causing 25 and 50% reduction in FGP and GR, relative to the other turfgrass species examined. Lines PSU 99-11-6 and PSU 99-9-21 exhibited nearly equal salinity tolerance to that of perennial ryegrass Charger II and creeping bentgrass Mariner during seed germination. During vegetative growth, the salt tolerance ranking of the nine *P. annua* lines was found to be consistent with our previous 12-wk chronic salt stress study (Dai et al., 2008). PSU 99-2-5 and PSU 99-9-21, though not as salt tolerant as Charger II, were nearly as salt tolerant as Mariner; and most greens-type *P. annua* experimental lines were more tolerant than Kentucky bluegrass Moonlight during vegetative growth. As perennial ryegrass (Butler et al., 1985), creeping bentgrass (Madison, 1971), and Kentucky bluegrass (Butler et al., 1985) were considered as salt-tolerant, moderately salt-tolerant, and moderately salt-susceptible species, respectively (Carrow and Duncan, 1998), our data suggest that greens-type *P. annua* possesses moderate to good salinity tolerance during seed germination and vegetative growth relative to these other cool-season turfgrass species.

Salinity stress was observed to exert a greater impact on GR than on FGP in the present studies. Similar results were reported by Camberato and Martin (2004) and Marcar (1987). Almansouri et al. (2001) also found that moderate osmotic stress

Table 6. Salinity effects on verdure dry weight (VD), root dry weight (RD), and the longest root length (LRL) of five representative entries: perennial ryegrass 'Charger II', creeping bentgrass 'Mariner', Kentucky bluegrass 'Northstar', and greens-type *Poa annua* experimental lines PSU 99-2-5 and PSU 99-9-21. Mariner, Northstar, PSU 99-2-5, and PSU 99-9-21 were considered relatively more salt tolerant during vegetative growth compared with entries within their own species in the present studies.

Entry	VD					RD					LRL				
	dS m^{-1}				$LSD_{0.05}$	dS m^{-1}				$LSD_{0.05}$	dS m^{-1}				$LSD_{0.05}$
	1.2	5	10	15		1.2	5	10	15		1.2	5	10	15	
	mg										cm				
Charger II	49.5	33.4	31.7	34.5	5.5	12.3	9.0	9.4	10.9	2.0	5.1	7.9	9.4	10.3	3.0
Mariner	11.0	9.0	8.6	7.2	2.7	3.4	3.0	3.3	2.6	1.0	5.2	7.0	7.1	7.4	1.5
Northstar	63.1	44.6	40.0	45.4	12.1	17.2	9.6	8.1	8.1	5.0	9.3	7.5	5.8	5.8	2.4
PSU 99-2-5	21.6	17.5	13.5	15.0	5.9	9.1	8.8	6.8	8.1	1.9	7.9	9.8	10.5	9.7	1.6
PSU 99-9-21	15.7	13.6	12.6	11.2	2.9	6.1	6.6	4.9	5.8	2.0	7.6	9.5	9.9	7.5	1.9

delayed seed germination while high osmotic stress reduced total germination percentage. Germination rate has been considered as a more sensitive indicator of seed vigor than FGP, and higher salinity levels corresponding to 50% reduction in GR suggest higher germination vigor during NaCl stress (Marcar, 1987).

The predicted salinity levels to reduce FGP by 50% for creeping bentgrass Penncross were slightly lower in the present studies than in McCarty and Dudeck's study (1993). This might be primarily caused by different salinity sources. McCarty and Dudeck (1993) used a mixture of salt species to simulate seawater compositions while we used NaCl as the sole salinity source. It was reported that salinity-induced declines in seed germination were mainly caused by osmotic stresses for halophytes while glycophytes were more likely to exhibit additional ion toxicity (Dodd and Donovan, 1999). Creeping bentgrass, a glycophyte, might thus be less sensitive to salinity stress induced by a mixture of salt species than solely by NaCl, the most detrimental salt species for plant growth (Suplick-Ploense et al., 2002). Furthermore, Wu (1981) found that creeping bentgrass possesses tolerance to magnesium, a major salt ion in seawater.

Qian et al. (2004) studied salinity tolerance of three Kentucky bluegrass cultivars using hydroponics and reported that Northstar and Moonlight were relatively more salt tolerant than 'P105'. Additionally, Northstar was found to be more salt tolerant than Moonlight based on salt damage ratings in field studies (Rose-Fricker and Wipff, 2001). Charger II was reported as a relatively susceptible perennial ryegrass cultivar according to salt damage ratings and survivor percentages in field studies (Rose-Fricker and Wipff, 2001). Marcum (2001) investigated salinity tolerance of 35 modern creeping bentgrass cultivars using hydroponics and found that Mariner and Seaside II were relatively more tolerant to salinity stress than Penncross. Results of the present studies were consistent with those of Rose-Fricker and Wipff's (2001). Our data showed that Mariner was generally more salt tolerant than Penncross but did not show that Seaside II significantly differed from Penncross in salinity tolerance as Marcum (2001) did.

In the present studies, the RD of several greens-type *P. annua* experimental lines increased at 5 dS m^{-1}, relative to the control. The LRL of most entries increased at 5 and 10 dS m^{-1}, relative to the control, except the two Kentucky bluegrass cultivars. Qian et al. (2000) and Dudeck et al. (1983) published similar results in zoysiagrass (*Zoysia japonica* Steud.) and bermudagrass [*Cynodon dactylon* (L.) Pers.] that root mass increased to a maximum point and then declined with increasing salt concentrations. Marcum (1999) studied the salinity tolerance mechanisms of Chloridoideae turfgrasses/forages and reported the LRL of seashore paspalum (*Paspalum vaginatum* Sw.), alkali sacaton [*Sporobolus airoides* (Torr.) Torr.], and bermudagrass increased with NaCl concentrations. Increased rooting depth and stimulated root growth under saline conditions have been considered adaptive mechanisms to the osmotic stress and nutrient deficiencies associated with salinity stress (Rozema and Visser, 1981).

Relative salt tolerance rankings for seed germination compared with those for vegetative growth were consistent for Kentucky bluegrass and creeping bentgrass cultivars but not for some greens-type *P. annua* lines such as PSU 99-2-5. Marcar (1987) reported similar inconsistency in perennial ryegrass cultivars, of which relative salt tolerance rankings during seed germination and vegetative growth were not closely correlated. Rose-Fricker and Wipff (2001) speculated that salinity tolerance during seed germination might be governed by a different mechanism of resistance from that of mature plants.

During both seed germination and vegetative growth, greens-type *P. annua* was intermediate in relative salinity tolerance rankings for cool-season turfgrass species. Some experimental lines displayed nearly equal salinity tolerance to that of perennial ryegrass Charger II and creeping bentgrass Mariner. Based on the results of the present studies in combination with our previous 12-wk salt stress study (Dai et al., 2008), we conclude that the greens-type *P. annua* experimental lines that we examined possess moderate to good salinity tolerance and particular experimental lines have potential to be used on golf courses with moderate salt problems affecting turf establishment and maintenance.

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