KENTUCKY BLUEGRASS ESTABLISHMENT UNDER SALINE, WATERLOGGING, AND SALINE-WATERLOGGING CONDITIONS

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Kevin Paul Rue

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Plant Science

October 2022

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Kentucky bluegrass (*Poa pratensis* L.) (KBG) is commonly used for golf fairways, however, it is sensitive to salinity and waterlogging. The objectives of this research were to determine (1) KBG growth response to saline, waterlogging, and saline-waterlogging conditions and (2) efficacy of seed priming in stress enhancement. Nine KBG cultivars were subjected to the aforementioned stresses at the seedling stage for four weeks. The combined saline-waterlogging caused more severe damage than individual stress. ‘Sudden Impact’, ‘Award’, ‘Limousine’, and ‘Kenblue’ were relatively tolerant to the stresses based on results from tissue biomass, root length, and specific root length stresses, while ‘Moonlight’ and ‘Blue Note’ were relatively sensitive. Seeds primed with abscisic acid, glycinebetaine, polyethylene glycol, and water performed better or similar to the non-primed grasses. Use of relatively tolerant cultivars, alone or in combination with priming, may be a better management practice when establishing a turfgrass stand under stress.

ACKNOWLEDGMENTS

I would like to thank my Advisor and Supervisor Dr. Qi Zhang for her guidance, encouragement, and expertise in this study.

I would like to also thank my committee members Drs. Deying Li, Alan Zuk and Tom DeSutter for their encouragement, and direction.

Lastly, I want to thank my wife and family for the encouragement and reminding me that you’re never too old to learn.

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INTRODUCTION

Saline, waterlogging, and saline-waterlogging

High soil salinity is a major problem in irrigated lands, including turfgrass areas (Carrow and Duncan, 1998) and by the 1990's approximately 50% of all irrigated lands worldwide were affected (Carrow and Duncan, 1998). Currently, nearly 2.3 million ha of land in North Dakota are salt-affected (Franzen et al., 2014). Saline conditions may be caused by many factors, such as deficient precipitation, water percolation from high water tables, low quality water (e.g. recycled water, well water, and salt water from sea water intrusion), and salts from fertilizers and deicer (Wu and Lin, 1993; Barrett-Lennard, 2003). The most common cations and anions in salt-affected soils include Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^- (Grattan and Grieve, 1999); however, the relative concentrations of each ion vary from site to site (Butcher et al., 2016). For example, chloride salts (e.g. NaCl and $MgCl_2$) are dominant in the saline soils of Eastern Grand Forks County, while sulfate salts (e.g. Na_2SO_4 and $MgSO_4$) are more commonly detected in the rest of the state (Franzen, 2013; Zuk et al., 2012).

Excessive salt causes reduced water potential in soil, resulting in low water availability to plants (i.e. osmotic stress or physiological drought) (Marcum, 2007a). Osmotic stress begins once salt concentration in a growing medium is above a threshold level, which varies in plant species/cultivars (Munns and Tester, 2008). Leaf water potential, evapotranspiration, and stomatal conductance are negatively affected immediately once plant roots are surrounded by saline conditions (Aronson, 1989).The symptoms of osmotic stress are primarily observed as a decrease in growth and expansion of new leaves and shoots with delayed development (Munns and Tester, 2008). Another major stress induced by salintiy is ion toxicity and imbalance, which occurs at a later stage and has less severe effects (especially at low to moderate salinity levels) on plant growth and developement than osmotic stress (Munns and Tester, 2008). Salinity also causes other stresses in plants and soils, such as oxidative stress (Munns and Tester, 2008). Reactive oxygen species (ROS), such as O_2 and H_2O_2, by-products of various metabolic processes such as mitochondrial electron transport chain and photorespiration, accumulates under stress conditions (Møller et al., 2007). Excessive ROS cause oxidative stress on proteins, polynucleic acids, and lipids, resulting in cell dysfunction. Salt-damaged plants are more likely to be infected by other stresses, such as insects and pathogens, further increasing stress severity and management costs.

Large interspecific and intraspecific differences in salinity tolerance exist in turfgrass. For example, salinity level causing 50% shoot reduction in alkaligrass (*Puccinellia* spp.) and Kentucky bluegrass (*Poa pratensis* L.) (KBG) is 25 and 4 dS m^{-1}, respectively (Marcum, 2007a). Wang and Zhang (2010) reported that NaCl concentrations causing 50% reduction in daily germination rate ranged from 6.3 to 11.0 g NaCl L^{-1} when evaluating salinity tolerance in 26 commercial creeping bentgrass (*Agrostis palastris* L.) (CB) cultivars. Salt tolerant plants have shown higher capability of osmotic adjustment than the sensitive ones, either by accumulating compatible solutes [e.g., carbohydrates, proline, and glycinebetaine (GB)] and/or compartmentalizing inorganic ions (e.g., Na^+) in vacuoles (Marcum, 2007b). Other salt tolerant mechanisms include ion exclusion and excretion, thereby minimizing the ion toxic effects induced by salts (Marcum, 2007b).

Waterlogging (i.e. excessive water) is another obstacle in turfgrass management, which occurs due to over-irrigation (particularly during establishment and summertime when frequent irrigation is needed to prevent drought stress) and/or after intense rainfall. Waterlogging may also be seen in sodium-affected soils that are prone to swelling, dispersion, and crusting, resulting in a reduced infiltration rate and increased surface runoff but can retain greater volumes of water than non-sodium affected soils (He et al., 2015). Under waterlogging conditions, air exchange between soil and the atmosphere is reduced, causing an O_2 deficiency. Plants revert to fermentation under waterlogging, resulting in reduced energy production (Alam et al., 2011). Similarly, waterlogging elevates ROS production, resulting in oxidative stress (Jiang, 2007). These responses, in turn, contribute to inefficient metabolic activities including nutrient uptake, photosynthesis, protein synthesis, and poor membrane stability (Alam et al., 2011).

Large variations in waterlogging tolerance exist in turfgrass species and cultivars. Buffalograss [*Buchloë dactyloides* (Nutt.) Englem.], bermudagrass (*Cynodon* spp.), and CB have excellent tolerance to waterlogging, KBG and perennial ryegrass (*Lolium perenne* L.) (PR) are moderately tolerant, while red fescue (*Festuces rubra* L.) and centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.] are waterlogging sensitive (Beard, 1973). Among CB, tolerant cultivars of G-6 and L-93 showed higher root dry weight, chlorophyll content, and antioxidant activities than the sensitive cultivars of Penncross and Pennlinks under waterlogging (Jiang and Wang, 2006; Wang and Jang, 2007a).

Investigating the co-factors of saline and waterlogging conditions on plant growth and development are not as common within the literature compared to individual saline and waterlogging studies. However, higher growth reduction was observed in wheat (*Triticum aestivum* L.), soybean (*Glycine max* L. Merr.), and legumes under the combined saline-waterlogging conditions compared to salinity and waterlogging (Alam et al., 2011; Teakle et al., 2006; Zheng et al., 2009), which is concerning for turfgrass managers, especially those utilizing gray waters (Harivandi, 2012) or within areas prone to salinity. In contrast to the observations of field crops, the highest reduction of KBG and tall fescue (*F. arundinacea* Schreb) (TF) seedlings was observed under salinity, followed by saline-waterlogging, whereas waterlogging had minimal impact during germination and seedling growth (Zhang et al., 2013a). Zhang et al. (2013b) reported a similar result when the salinity level reached 5 g NaCl L^{-1}. However, at lower salinity (2.5 g NaCl L^{-1}), no difference in turfgrasses growth was observed between saline and saline-waterlogged conditions, both lower than that of those under waterlogging conditions. Such results indicate that plant responses to saline-waterlogging conditions are influenced by the salinity level. The discrepancy between the observations made of turfgrasses and field crops needs to be explored to identify the causes. The ranking of plant tolerance to saline-waterlogging conditions may differ from the ranking of tolerance to salinity or waterlogging stress alone (Noble and Rogers, 1994). Zhang et al. (2013b) reported that KBG, which is salt sensitive but moderately tolerant to waterlogging, performed similarly to TF, which is a moderately salt tolerant and waterlogging tolerant turfgrass species (Beard, 1973; Rogers and Davies, 1973), under saline-waterlogging conditions. To date, tolerances to saline-waterlogging conditions have not been widely evaluated, especially in turfgrasses.

Kentucky bluegrass

Kentucky bluegrass is native to Eurasia and was introduced for turfgrass use throughout cool and humid climates throughout the world (Beard, 1973). Kentucky bluegrass is one of the most preferred turfgrass species in the cooler climates of the United States (e.g. ND) because of its dark green color, rhizomatous growth habit and high freezing tolerance; however, it requires frequent irrigation, fertilization, and pesticide inputs to maintain functionality and its aesthetic qualities (Christians, 2004). With increasing government regulations and public pressure to reduce management inputs, the implementation of turfgrass materials tolerant to stresses is in high demand.

Kentucky bluegrass is considered as salt sensitive compared to other common cool-season turfgrass (Harivandi et al., 1992). For example, Friell et al. (2012) evaluated salinity tolerance of 75 cool-season turfgrasses (14 species) under roadside conditions. Their results showed that alkaligrass , slender creeping red fescue (*F. rubra* L. spp. *Litoralis*) and strong creeping red fescue (*F. Rubra* L. spp. *rubra*) were among the most salt tolerant plants, while KBG cultivars were among the most sensitive. Among the 13 KBG cultivars included in a saline study conducted by Friell et al. (2013), 'Park' and 'Diva' KBG had the highest salt tolerance with tissue damage < 50% when saline concentration was < 14 dS m^{-1} and 'Moonshine' had the lowest tolerance. Yang and Zhang (2019) evaluated 'Kenblue' and 'Moonlight' KBG growth under salinity at different growth stages. 'Kenblue' outperformed 'Moonlight' during germination and seedling growth when evaluated based on plant growth. However, the reversed trend was observed at the vegetative growth stage when aesthetical performance plays a more important role than growth for turfgrass evaluation. Information on the interspecific differences of waterlogging tolerance in KBG is largely scarce. Wang and Jiang (2007b) studied visual quality, electrolyte leakage, and root dry weight (RDW) of 10 KBG cultivars under waterlogging. The results showed that 'Moonlight', 'Serene', and 'Champagne' were tolerant, whereas 'Kenblue' and 'Eagleton' were sensitive. Limited information is available on KBG tolerance to saline-waterlogging conditions.

Priming

Plant responses to stresses including soil salinity and waterlogging are growth stage dependent. Plants are usually more sensitive to stresses during the germination and seedling stages compared with the mature stage (Zhang and Rue, 2012). Quick and uniform seed germination is critical for a healthy plant stand, especially for perennial crops such as turfgrass.

Seed priming is the process of soaking seed allowing imbibition and metabolic processes but preventing radical protrusion through dehydration (Paparella et al., 2015) and is a proven and effective technique for rapid and uniform seed germination (Jisha et al., 2013). There are various types of seed priming, including hydropriming (i.e. priming with water) and osmopriming [i.e. priming in low-water-potential solutions such as polyethylene glycol (PEG), NaCl, KNO_3, abscisic acid (ABA)] that are the most common priming methods. Kaya et al. (2006) reported a faster germination and better seedling growth in KNO_3- and hydroprimed sunflower (*Helianthus annuus* L.) seeds than unprimed ones under drought and saline conditions. Chilling tolerance was improved in maize (*Zea mays* L.) primed with GB (Farooq et al., 2008). Similarly, Zhang and Rue (2012) reported enhanced osmotic and salinity tolerance in GB-primed turfgrass seeds. The mechanisms of seed priming are still under investigation. Generally seed priming induces physiological and biochemical changes (e.g. increased α–amylase activity, hormonal changes, and DNA/RNA repair) during imbibition and lag phase, which gives the primed seeds a faster start than the non-primed seeds during germination (Chen and Arora, 2013). The priming agents other than water, like PEG and ABA, and or the drying process that prevent radical emergence stimulate stress memory in the primed seeds, which may result in enhanced stress tolerance (Chen and Arora, 2013). Compared to other environmental conditions, such as drought and salinity, the effects of seed priming on waterlogging tolerance have not been fully investigated. Vwioko et al. (2019) primed okra (*Abelmoschus esculentus* L.) seeds with sodium azide (NaN_3) (0 %, 0.02%, and 0.05%) and then subjected to waterlogging four weeks after planting. Final germination percentage decreased with increasing NaN_3 concentration when evaluated nine days after planting. However, NaN_3 improved the survival rate, adventitious roots, and fruits production of okra under waterlogging conditions (1 or 2 weeks) compared to the plants grown from unprimed seeds, when the experiment was terminated 10 weeks after planting. To our knowledge, no research has been conducted to determine the efficacy of seed priming on plant tolerance to combined saline-waterlogging conditions.

OBJECTIVES

The objectives of this research were to (1) determine the response of nine KBG cultivars to saline and waterlogging, alone and in combination during the germination and seedling stages when plants are the most vulnerable to stressful environmental conditions and (2) evaluate the efficacy of seed priming on KBG enhancement to saline, waterlogging, and saline-waterlogging conditions.

MATERIALS AND METHODS

Experiment 1 – Early growth of KBG under saline, waterlogging, and combined saline-waterlogging conditions

Nine KBG cultivars were included in this experiment (Table 1). These KBG cultivars are commercially available and have shown high turfgrass quality in the 2005 Kentucky bluegrass National Turfgrass Evaluation Program, except Kenblue (NTEP, 2011). 'Moonlight' is tolerant to saline and waterlogging conditions, 'Limousine' is salt-tolerant but only moderately tolerant to waterlogging, while 'Kenblue' is sensitive to both stresses when evaluated at the vegetative growth stage (Qiang, 2003; Wang and Jiang, 2007b).

Table 1. Seed source of Kentucky bluegrass cultivars included in the stress evaluation study.

Kentucky bluegrass cultivar	Seed Source
Sudden Impact	Jacklin Seed (Post Falls, ID)
Award	Jacklin Seed (Post Falls, ID)
Limousine	Jacklin Seed (Post Falls, ID)
Kenblue	Landmark Turf and Native Seeds (Albany, OR)
America	DLF Pickseed (Halsey, OR)
Legend	Mountain View Seeds (Salem, OR)
Arrowhead	Mountain View Seeds (Salem, OR)
Moonlight	Landmark Turf and Native Seeds (Albany, OR)
Blue Note	Mountain View Seeds (Salem, OR)

Each grass was seeded at 245 kg pure live seed (PLS) ha^{-1} in 1.1 kg washed mason sand (Knife River, Fargo, ND) and reed sedge peat mixture (The Tessman Company, Fargo, ND) at 9:1 volume ratio in plastic bags held in 10 cm x 10 cm x 10 cm plastic pots. This seeding rate was higher than the recommended rate for new turfgrass establishment (49 – 98 kg PLS ha^{-1}) (Christians, 2004) to ensure enough tissue for sampling, especially under stressful environments. The plastic bags were used to avoid potential leaching when watering the plants. Fertilizer, 18N-24P_2O_5-5K_2O (The Anderson Lawn Fertilizer Division, Inc., Maumee, OH), was applied at 49 kg N ha^{-1} at seeding. Grasses were exposed to four growing conditions: (1) non-stress (i.e. the control treatment); (2) salinity; (3) waterlogging; and (4) salinity-waterlogging conditions during the germination and seedling growth stage for six weeks.

Experimental pots were treated with stored tap water (control and waterlogging) or including a Na_2SO_4 + $MgSO_4$ mixture (1:1, w:w, 6.1 dS m^{-1}) (salinity and salinity-waterlogging) at field capacity before seeding. The field capacity volume was determined following the method of Yang and Zhang (2018). Briefly, three reference pots of each treatment (i.e. experimental pots without plastic bags) were soaked with tap water or the salt solution for 10 mins. The reference pots were weighed before soaking (PW0) and at 3 h (PW1) and 3 ½ h (PW2) after soaking when no leaching from the bottom of the pot was observed. A minimal weight change (≤ 2g) between PW1 and PW2 indicated that all gravitational water had leached out. The field capacity volume of water was calculated as [(PW1+PW2)/2 – PW0], which was approximately 210 mL. Additional 50 mL of tap water and salt solution was added to the waterlogging and salinity-waterlogging pots (total 260 g), respectively, to stimulate waterlogged conditions (i.e. solution level was ~ 0.5 cm above the soil surface). Initial soil salinity levels (ECe) and pH were determined from reference pots. The control and waterlogging pots had an ECe and pH readings of 0.5 dS m^{-1} and 6.3, respectively, whereas the salinity and salinity-waterlogging treated pots had ECe readings of 6.0 dS m^{-1} and pH of 6.6. Pots were kept in a greenhouse at 25/15 ºC (day/night) with a 16-hr. photo period for six weeks. Tap water was added to the experimental pots once daily to maintain the required water level as described previously.

Plants were harvested when the experiment was terminated by Day 42. Soil mixtures were carefully hand-washed off the roots and the longest root length was measured with a ruler. Shoots and roots were then separated, shoot and root dry weights (SDW, RDW) were recorded after being oven-dried at 65 ºC for 48 hr. Specific root length (SRL) was calculated as root length (RL) to RDW ratio (Ostonen et al., 2007). The experiment was set up as a 9 (cultivar) x 4 (growing condition) factorial combination, arranged in a randomized complete block design with four replicates. Data were subjected to analysis of variance using the PROC MIXED procedure (SAS Institute Inc., Cary, NC) and means were separated with Fisher's protected least significant difference at $P \leq 0.05$.

Experiment 2 - Effects of seed priming on the early growth of KBG under saline, waterlogging, and combined saline-waterlogging conditions

Two KBG cultivars, Moonlight and Award, were included in this experiment. 'Award' was tolerant to saline, waterlogging, and saline-waterlogging at the germination and seedling growth stage while 'Moonlight' was determined sensitive based on the results from Experiment 1.

The KBG seeds were either non-primed (i.e. NP) or primed with 7 solutions (Table 2), which had shown enhanced stress tolerance in various crops, except the Na_2SO_4 + $MgSO_4$ mixture (i.e. SS). Sargeant et al. (2006) reported that NaCl priming improved the survival rate and growth of *Distichlis spicata* (L.) when exposed to NaCl-induced salinity at low to moderate saline conditions. As saline and saline-waterlogging conditions were induced by a Na_2SO_4 + $MgSO_4$ (SS) mixture in the present study, SS was included as a priming treatment. Seeds were primed following the method of Zhang and Rue (2012). Briefly, seeds were aerated in the priming solutions for 24 hr at room temperature. The ratio of seed weight to volume of the priming solutions was 1:5 for maximum seed absorption of the priming solutions. Seeds were rinsed three times with distilled and deionized water (DD) after priming and air-dried to the original weight under a laminar-flow hood for approximately 12 hr in the dark.

Table 2. Priming solutions that showed enhanced stress tolerance in previous research.

Priming solution	Stress	Plant	Reference
Deionized, distilled water (DD)	Saline, drought, low temperature	Rice (*Oryza sativa* L.)	Zheng et al., 1994
KNO_3 (500 ppm)	Saline, drought	Sunflower	Kaya et al., 2006
Polyethylene glycol -6000 (PEG, 20%)	Drought	Rice	Sun et al., 2010
Glycinebetaine (GB, 100 mM)	Saline, drought	Turfgrass	Zhang and Rue, 2012
Abscisic acid (ABA, 50 ppm)	Drought	Tall wheat grass (*Agropyron elongatum* Host)	Eisvand et al., 2010
Gibberellic acid (GA, 100 ppm)	Drought	Tall Wheat grass	Eisvand et al., 2010
Na_2SO_4 + $MgSO_4$ (SS, 1:1, w:w, 3 dS m^{-1})			

Grasses were seeded, managed, and exposed to the stressful conditions in a greenhouse as described in Experiment 1 with modifications. Growing medium used in Experiment 2 was a topsoil:sand (1:2, v:v) mixture, 1 kg per pot, to improve plant biomass. The topsoil was native to Fargo, ND (S&S Landscaping). The sand was the same washed mason sand which was used in experiment 1. Each stress condition (i.e. salinity, waterlogging, and saline-waterlogging) was applied individually to determine the effects of seed priming on enhancement of individual stressful environment. Two hundred mL of water and salt solution was applied to each pot for the non-stressed and salinity pots, respectively. An additional 50 mL of appropriate agents were added to the waterlogging and saline-waterlogging pots. Fertility remained the same as described in Experiment 1. Plant samples were collected following the same procedure as described in Experiment 1. The experimental design was a 2 (cultivar) x 8 (priming treatment) x 2 (growing condition) factorial combination, arranged in a randomized complete block design with four replicates, under each stressful environment. Data were subjected to analysis of variance using the PROC MIXED procedure (SAS Institute Inc., Cary, NC) and means were separated with Fisher's protected least significant difference at $P \leq 0.05$.

RESULTS AND DISCUSSION

Experiment 1 – Early growth of KBG under saline, waterlogging, and combined saline-waterlogging conditions

The SDW was highest in the control treatment (1.30 g pot^{-1}), followed by the waterlogging (0.92 g pot^{-1}) and salinity treatments (0.91 g pot^{-1}), and the combined salinity-waterlogging stress showed the lowest SDW (0.56 g pot^{-1}) (Tables 3 and 4). Similarly, RDW decreased in the following order: control > waterlogging and salinity > salinity-waterlogging (Table 4). The RDW/SDW ratio of the control plants was 52.9%, similar to that of the waterlogged and saline-waterlogged plants, but 20% higher than that of the salinity-treated ones ($P = 0.0017$). RL for the plants germinated under the control and waterlogging conditions was 16.1 cm and 17.8 cm, respectively, significantly higher than those under the saline and saline-waterlogging conditions. The highest SRL was observed in the plants exposed to salinity-waterlogging, followed by waterlogging and salinity, whereas non-stressed plants had the lowest SRL.

Table 3. Probability value of the main factors (growing condition and cultivar) and their interaction on Kentucky bluegrass growth during the germination and seedling growth stage.

Source of variance	Shoot dry weight	Root dry weight	Root to shoot ratio	Root length	Specific root length
Growing condition (G)	<0.0001[†]	<0.0001	0.0169	<0.0001	<0.0001
Cultivar (C)	<0.0001	<0.0001	0.0548	0.9953	<0.0001
G × C	0.6234	0.7704	0.1765	0.8828	0.3176

[†]Probability value ≤ 0.05 indicates significant difference.

Table 4. Kentucky bluegrass seedling growth as affected by non-stress (i.e. control), saline, waterlogging, and saline-waterlogging conditions. Data were pooled across nine Kentucky bluegrass cultivars.

Growing condition	Shoot dry weight ($g\ pot^{-1}$)	Root dry weight ($g\ pot^{-1}$)	Root to shoot ratio (%)	Root length (cm)	Specific root length ($cm\ g^{-1}$)
Control	1.30a†	0.69a	52.9a	16.1a	35.3c
Waterlogging	0.92b	0.45b	49.6ab	17.8a	59.1b
Saline	0.91b	0.40b	44.1b	12.5b	56.8b
Saline-waterlogging	0.56c	0.27c	47.9ab	10.4b	86.4a

†Means in a column followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

The combined salinity-waterlogging stress resulted in a higher reduction in tissue biomass compared to salinity and waterlogging alone in the present study (Table 4), consistent with previous findings of Alam et al. (2011), Teakle et al. (2006), and Zheng et al. (2009). Barrett-Lennard (2003) reported a higher Na^+ and Cl^- content in plants under saline-waterlogging conditions compared to saline conditions alone, which may be caused by a higher inhibition in ion regulation under the combined stress. Akhtar et al. (1998) suggested that higher reduction of aerenchyma, a mechanism of waterlogging tolerance, under saline-waterlogging conditions contributed to the higher damage in wheat under the combined stress compared to salinity or waterlogging alone. Zhang et al. (2013) reported that salinity caused the highest damage in turfgrass germination and shoot and root fresh weight, followed by salinity-waterlogging, and waterlogging resulted in the least damage. Their results were partially consistent with our findings in that waterlogging was less detrimental to turfgrass compared to saline and saline-waterlogging conditions. Zhang et al. (2013) suggested that high waterlogging tolerance in turfgrass was likely due to its shallow root system. Differences in salt application methods and salt concentrations between Zhang et al. (2013) (~ 11.1 dS m^{-1} NaCl applied through hand-watering) and the current study (6.0 dS m^{-1} of a Na_2SO_4 and $MgSO_4$ mixture, amended into the soil mixture) may contribute to the discrepancy between the two experiments. Furthermore, Zuk et al. (2012) and Yang and Zhang (2018) suggested that SO_4^{2-} salt was less detrimental to turfgrass than Cl^- salts.

All grasses showed a similar level of RL (Tables 3 and 5). Genetic variations were observed in SDW and RDW, RDW/SDW ratio, and SRL (Table 3). Among the nine cultivars, ‘Sudden Impact’, ‘Award’, ‘Limousine’, ‘Kenblue’, and ‘America’ had a similar level of shoot growth when data were pooled across growing conditions (Table 5). ‘Legend’ and ‘Arrowhead’ showed lower shoot biomass compared to the aforementioned grasses, but higher than 'Moonlight' and 'Blue Note'. Excluding 'America', the Ranking of root biomass in Kentucky bluegrass cultivars was identical to shoot biomass. 'America' had a higher SDW than 'Arrowhead' and 'Legend', but a similar level of RDW as the two cultivars. The highest and lowest RDW/SDW ratio was observed in 'Kenblue' and 'America', respectively. 'Blue Note' had the highest SRL, 120.0 cm g^{-1}. 'Moonlight' had a similar level of SRL as 'Blue Note' and 'Arrowhead', but significantly higher than the other cultivars. Previous research showed that the plants with high SRL were more efficient in water and nutrient acquisition under stress if the increased SRL was primarily contributed by enhanced RL (Rubio and Lavado, 1999; Almansouri et al., 2001; Lovelli et al., 2012). High SRL observed in 'Moonlight' and 'Blue Note' in the current study was not caused by extended RL, rather at the expense of root longevity (i.e. reduced RDW) (Table 5); thus, 'Moonlight' and 'Blue Note' showed low SDW and RDW under the stressful conditions despite having high SRL.

Table 5. Growth response of Kentucky bluegrass seedlings under non-stress (i.e. control), saline, waterlogging, and saline-waterlogging conditions. Data were pooled across the growing conditions.

Cultivar	Shoot dry weight ($g\ pot^{-1}$)	Root dry weight ($g\ pot^{-1}$)	Root to shoot ratio (%)	Root length (cm)	Specific root length ($cm\ g^{-1}$)
Sudden Impact	1.20a[†]	0.62a	51.1ab	14.5a	40.7cd
Award	1.15a	0.58a	49.2a-c	14.3a	41.7cd
Limousine	1.12a	0.60a	52.9ab	14.8a	36.6cd
Kenblue	1.06a	0.58a	54.5a	14.2a	33.7d
America	1.05a	0.41b	41.1c	14.4a	54.1cd
Legend	0.85b	0.41b	46.2bc	14.0a	51.5cd
Arrowhead	0.84b	0.44b	50.5ab	14.0a	64.2bc
Moonlight	0.56c	0.25c	46.6bc	14.5a	92.2ab
Blue Note	0.49c	0.20c	45.8bc	13.1a	120.0a

[†]Means in a column followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

Our results were contradictory to the observations of Qiang (2003) and Wang and Jiang (2007b) that concluded at the vegetative growth stage in which 'Moonlight' was tolerant to saline and waterlogging conditions, 'Limousine' was salt-tolerant but only moderately tolerant to waterlogging, while 'Kenblue' was sensitive to both stresses. Dai et al. (2007), Zhang et al. (2012), and Wang and Zhang (2011) reported that relative ranking of stress tolerance in turfgrass species and cultivars may vary between growth stages. Such discrepancy of stress tolerance at different plant growth stage is, at least partially, due to different defense mechanisms (Rose-Fricker and Wipff, 2001). Different screening criteria may also contribute to the contradictory results between the current study (germination and seedling stage) and past research of Qiang (2003) and Wang and Jiang (2007b) (vegetative growth stage). For example, visual quality is more important than other characteristics when evaluating stress tolerance at the vegetative growth stage in turfgrass, while tissue biomass is more important at germination and seedling growth stage (Mintenko and Smith, 2001). Cultivars such as Sudden Impact, Award, Limousine, and Kenblue, which maintained a high growth rate may be considered tolerant to salinity and waterlogging during the germination and seedling growth stage; while, Moonlight and Blue Note were relatively sensitive. Similar to the present study, Yang and Zhang (2018) reported a faster growth rate of 'Kenblue' than 'Moonlight' at the initial growth stage (6 weeks after germination) (1.13 g pot^{-1} vs. 0.85 g pot^{-1} for SDW; 0.53 g pot^{-1} pot vs. 0.39 g $pot^{-1}$for RDW).

Experiment 2 - Effects of seed priming on early growth of KBG under saline, waterlogging, and combined saline-waterlogging conditions

Among the main factors, SDW was only affected by cultivar in which 'Award' outperformed 'Moonlight' (Tables 6 and 7). Two two-way interactions, cultivar x priming and salinity x priming, were detected in SDW (Table 6). GA and KNO_3- treated 'Award' had a higher SDW than ‘Moonlight’ under the same priming treatments when data were pooled across saline conditions (Figure 1). In contrast, hydroprimed ‘Moonlight’ grew better than hydroprimed ‘Award’. No differences were observed in other priming treatments between the cultivars. The highest and lowest SDW was ABA and DD treatments, respectively, in ‘Award’. Hydroprimed ‘Moonlight’ had a higher level of SDW than GB, GA, and KNO_3 treatment of the same cultivar, but were not significantly different from other treatments. Salinity did not affect SDW within each priming treatment when data were pooled across cultivars, except PEG (Figure 2). The SDW ranged from 2.93 g pot^{-1} in the ABA treatment to 1.82 pot^{-1} in PEG treatment at 0 dS m^{-1}, and from 2.89 pot^{-1} in the ABA treatment to 1.77 g pot^{-1} in GA treatment at 6 dS m^{-1}. Shoot dry weight was also influenced by the three-way interaction, saline condition x cultivar x priming (Table 6). The highest and lowest SDW was observed in ABA-treated ‘Award’ at 0 dS m^{-1} and GA-treated ‘Moonlight’ at 6 dS m^{-1}, respectively (Figure 3). As salinity increased from 0 to 6 dS m^{-1}, ABA-treated ‘Award’ and non-primed ‘Moonlight’ showed decreased shoot biomass, while GB- and PEG-treated and non-primed ‘Award’ and PEG-treated ‘Moonlight’ showed increased SDW. The SDW of other priming treatments in either cultivar was not affected by salinity.

Table 6. Probability value of the main factors (saline concentration, cultivar, and priming) and their interactions on Kentucky bluegrass growth during the germination and seedling growth stage.

Source of variance	Shoot dry weight	Root dry weight	Root to shoot ratio	Root length	Specific root length
Saline concentration (S)	0.0980[†]	0.8459	0.1257	0.0018	0.7816
Cultivar (C)	0.0410	0.0599	0.4329	0.1477	0.9442
Priming (P)	0.0615	0.0489	0.0088	0.1032	0.1112
C x P	0.0059	0.0279	0.2326	0.5691	0.2758
C x S	0.5937	0.6507	0.6426	0.2639	0.5344
P x S	0.0237	0.1572	0.4936	0.5199	0.8952
C x P x S	0.0100	0.1921	0.5530	0.6035	0.3261

[†]Probability value ≤ 0.05 indicates significant difference.

Table 7. Growth response of Kentucky bluegrass seedlings as affected by saline concentration, cultivar, and priming solutions.

The priming treatments are: abscisic acid at 50 ppm (ABA), glycinebetaine at 100 mM (GB), no priming (NP), deionized and distilled water (DD), gibberellic acid at 100 ppm (GA), KNO_3 at 500 ppm (KNO_3), polyethylene glycol-6,000 at 20% (PEG), and a Na_2SO_4 + $MgSO_4$ (1:1, w:w) at 3 dS m^{-1} (SS).

Treatment	Shoot dry weight ($g\ pot^{-1}$)	Root dry weight ($g\ pot^{-1}$)	Root to shoot ratio (%)	Root length (cm)	Specific root length ($cm\ g^{-1}$)
Salt concentration (dS m^{-1})					
0	2.20a†	0.86a	37.3a	20.6a	42.1a
6	2.40a	0.84a	33.6a	18.6b	39.6a
Cultivar					
Award	2.43a	0.92a	36.4a	20.1a	40.5a
Moonlight	2.18b	0.78a	34.5a	19.2a	41.1a
Priming					
ABA	2.80a	1.00a	36.7a-c	19.2a	23.9a
GB	2.05a	0.69bc	33.1bd	19.8a	37.0a
NP	2.10a	0.97ab	43.0a	20.8a	30.4a
DD	2.26a	0.90ab	37.4a-c	20.1a	40.4a
GA	2.09a	0.59c	26.2d	17.6b	74.6a
KNO_3	2.39a	0.74a-c	28.6cd	19.9a	53.8a
PEG	2.36a	0.91ab	37.9ab	21.0a	29.1a
SS	2.35a	0.99a	40.6ab	18.6a	37.5a

†Means in a column followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

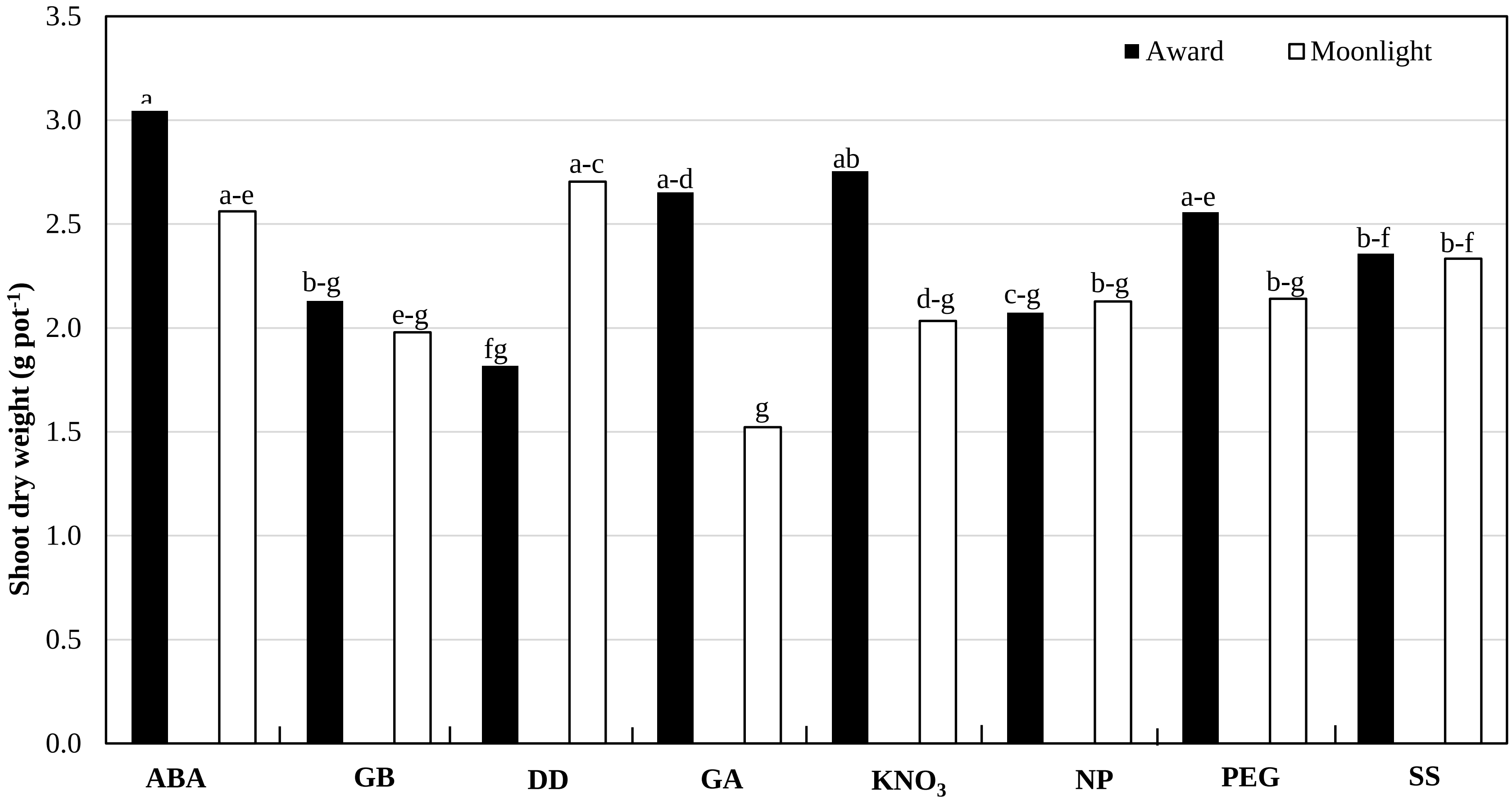

Figure 1. Shoot dry weight (g pot-1) of Kentucky bluegrass seedlings as affected by the cultivar x priming interaction when data were pooled across salinity.

The priming treatments are: abscisic acid at 50 ppm (ABA), glycinebetaine at 100 mM (GB), deionized and distilled water (DD), gibberellic acid at 100 ppm (GA), KNO_3 at 500 ppm (KNO_3), no priming (NP), polyethylene glycol-6,000 at 20% (PEG), and a Na_2SO_4 + $MgSO_4$ (1:1, w:w) at 3 dS m^{-1} (SS). Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

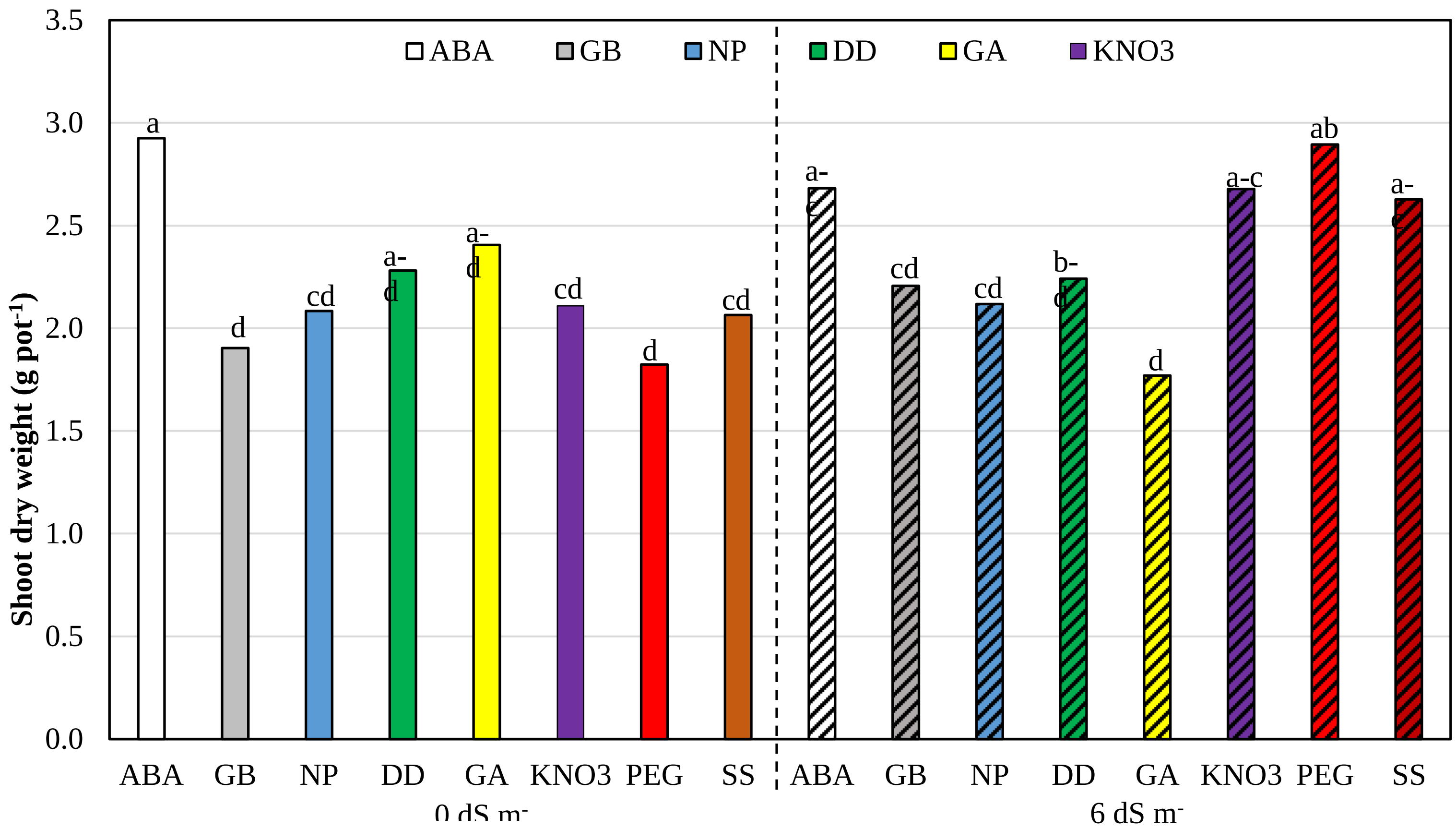

Figure 2. Shoot dry weight (g pot-1) of Kentucky bluegrass seedlings as affected by the salinity x priming interaction when data were pooled across cultivars.

The priming treatments are: abscisic acid at 50 ppm (ABA), glycinebetaine at 100 mM (GB), no priming (NP), deionized and distilled water (DD), gibberellic acid at 100 ppm (GA), KNO_3 at 500 ppm (KNO_3), polyethylene glycol-6,000 at 20% (PEG), and a Na_2SO_4 + $MgSO_4$ (1:1, w:w) at 3 dS m^{-1} (SS). Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

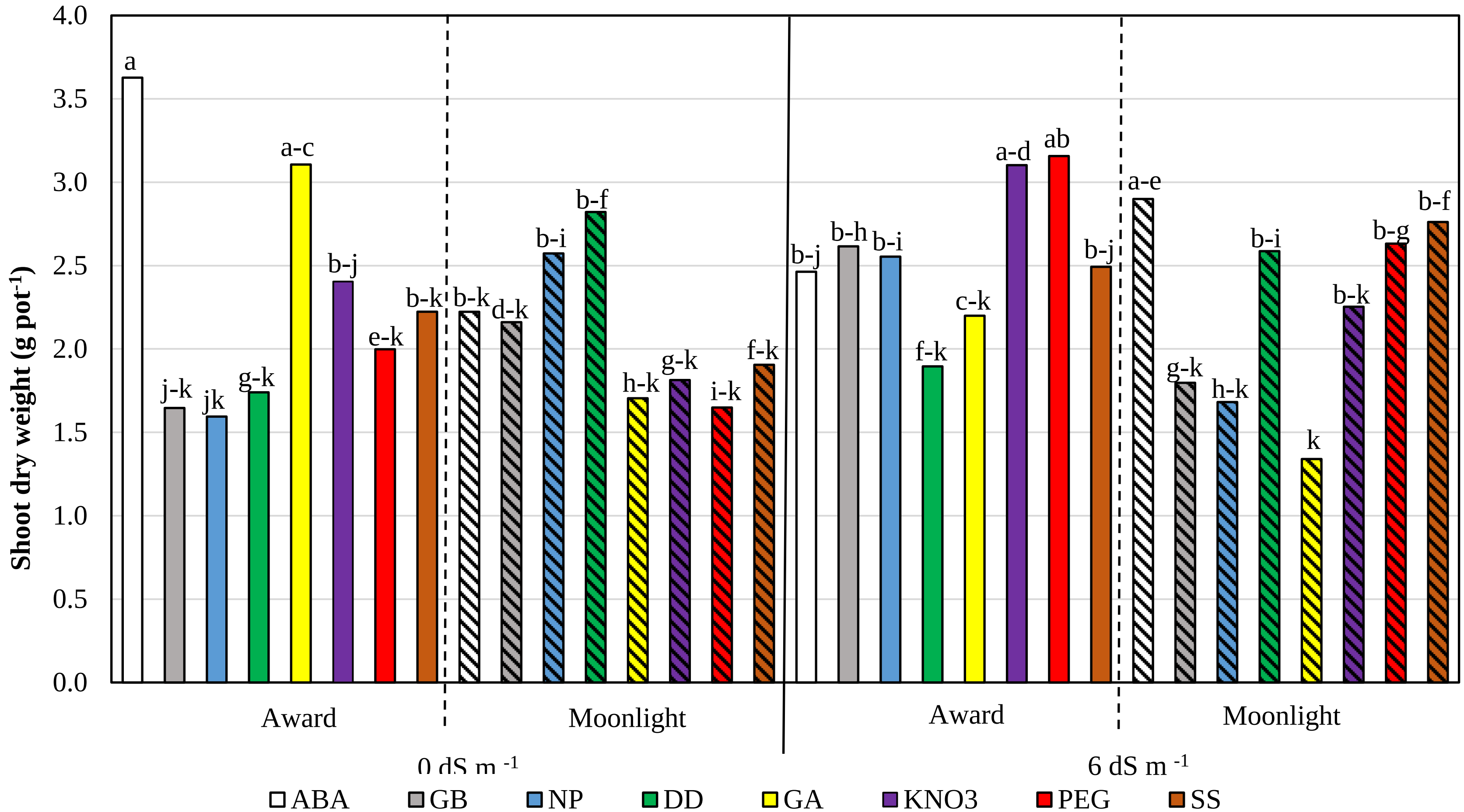

Figure 3. Shoot dry weight (g pot-1) of ‘Award’ and ‘Moonlight’ (hashed) Kentucky bluegrass seedlings as affected by the cultivar x growing condition x priming interaction.

The priming treatments are: abscisic acid at 50 ppm (ABA), glycinebetaine at 100 mM (GB), no priming (NP), deionized and distilled water (DD), gibberellic acid at 100 ppm (GA), KNO_3 at 500 ppm (KNO_3), polyethylene glycol-6,000 at 20% (PEG), and a Na_2SO_4 + $MgSO_4$ (1:1, w:w) at 3 dS m^{-1} (SS). Means followed by the same letter are not significantly different according to Fisher’s protected least significant difference test ($P \leq 0.05$).

The RDW was influenced by one of the main factors, priming (Table 6). Root dry weight of GA treatment was 0.59 g pot^{-1}, similar to that of GB and KNO_3 treatments, but significantly lower than that of the other treatments (average = 0.94 g pot^{-1}) (Table 7). A two-way interaction, cultivar x priming, was observed in RDW (Table 6). No priming differences were observed in 'Award' (Figure 4). 'Moonlight', however, responded more favorably to the DD treatment compared to GB, GA and KNO_3. Cultivar differences were only observed in GA and KNO_3 treatments in which 'Award' had a higher RDW than 'Moonlight'.

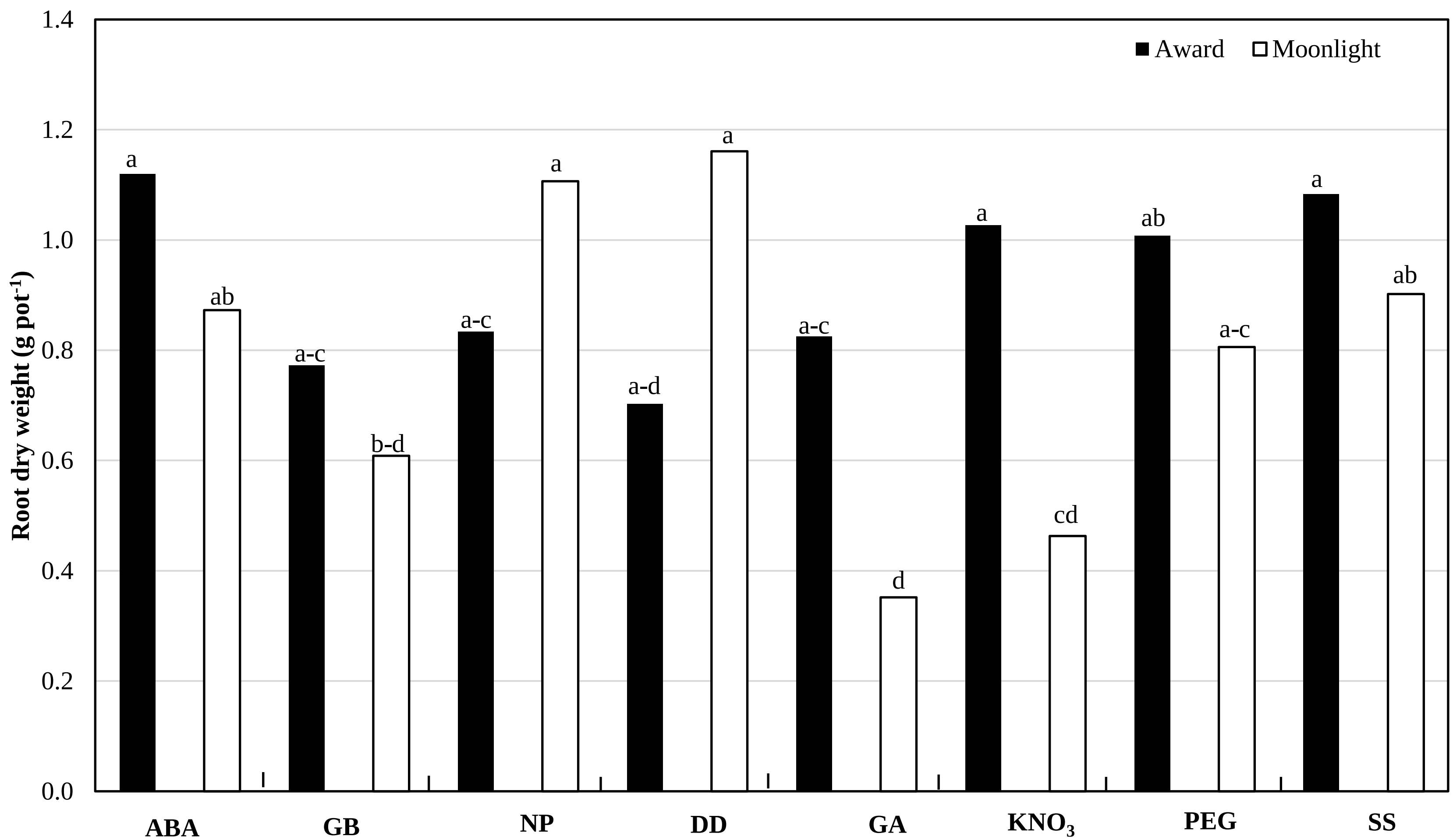

Figure 4. Root dry weight (g pot^{-1}) of Kentucky bluegrass seedlings as affected by the cultivar x priming interaction when data were pooled across salinity.
The priming treatments are: abscisic acid at 50 ppm (ABA), glycinebetaine at 100 mM (GB), no priming (NP), deionized and distilled water (DD), gibberellic acid at 100 ppm (GA), KNO_3 at 500 ppm (KNO_3), polyethylene glycol-6,000 at 20% (PEG), and a Na_2SO_4 + $MgSO_4$ (1:1, w:w) at 3 dS m^{-1} (SS). Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

Effects of seed priming on early growth of KBG under saline conditions

The RDW/SDW ratio showed no differences between the two cultivars nor saline conditions (Tables 6 and 7). Non-primed plants had a RDW/SDW ratio of 43.0%, higher than those treated with GB, KNO_3, and GA (average = 29.3%). Salinity reduced RL from 20.6 cm at 0 dS m^{-1} to 18.6 cm at 6 dS m^{-1} (Table 7). Cultivar and priming did not show influence on RL (Table 6). SRL was not affected by either of the three main factors nor their interactions (Table 6).

Effects of seed priming on early growth of KBG seedlings under waterlogging conditions

The SDW was influenced by waterlogging conditions and cultivar (Table 8). The SDW decreased by 11.6% when exposed to waterlogging conditions (Table 9). 'Award' had a higher level of SDW than 'Moonlight' when data were pooled across growing conditions and priming treatments.

Table 8. Probability value of the main factors (waterlogging, cultivar, and priming) and their interaction on Kentucky bluegrass growth during the germination and seedling growth stage.

Source of variance	Shoot dry weight	Root dry weight	Root to shoot ratio	Root length	Specific root length
Waterlogging (W)	0.0226[†]	<0.0001	0.0030	0.1959	0.0009
Cultivar (C)	<0.0001	0.0374	0.0154	0.9087	0.2446
Priming (P)	0.0953	0.1445	0.5966	0.1892	0.9354
C x P	0.2496	0.0717	0.4548	0.5344	0.4621
C x W	0.7027	0.0240	0.0076	0.5288	0.9766
P x W	0.2654	0.1540	0.1044	0.1297	0.1992
C x P x W	0.9049	0.8584	0.4559	0.4829	0.6143

[†]Probability value ≤ 0.05 indicates significant difference.

Table 9. Growth response of Kentucky bluegrass seedlings as affected by waterlogging, cultivar, and priming solutions. The priming treatments are: abscisic acid at 50 ppm (ABA), glycinebetaine at 100 mM (GB), no priming (NP), deionized and distilled water (DD), gibberellic acid at 100 ppm (GA), KNO_3 at 500 ppm (KNO_3), polyethylene glycol-6,000 at 20% (PEG), and a Na_2SO_4 + $MgSO_4$ (1:1, w:w) at 3 dS m^{-1} (SS).

Treatment	Shoot dry weight (g pot^{-1})	Root dry weight (g pot^{-1})	Root to shoot ratio (%)	Root length (cm)	Specific root length (cm g^{-1})
Waterlogging					
Non-waterlogged	2.41a[†]	1.28a	52.8a	22.0a	19.8b
Waterlogged	2.16b	0.94b	46.2b	20.9a	26.2a
Cultivar					
Award	2.53a	1.17a	46.8b	21.4a	21.9a
Moonlight	2.04b	1.05b	52.1a	21.5a	24.1a
Priming					
ABA	2.33a	1.28a	54.8a	22.8a	22.4a
GB	2.27a	1.12a	50.9a	22.3a	24.9a
DD	2.57a	1.09a	44.6a	22.8a	24.3a
GA	2.27a	1.08a	49.2a	21.6a	24.4a
KNO_3	2.46a	1.15a	49.0a	22.6a	20.9a
NP	1.86a	0.90a	48.8a	19.8a	23.7a
PEG	2.31a	1.15a	49.6a	20.5a	22.0a
SS	2.21a	1.08a	49.0a	19.4a	21.5a

[†]Means in a column followed by the same letter are not significantly different at according to Fisher's protected least significant difference test ($P \leq 0.05$).

A two-way interaction, cultivar x waterlogging, was observed in RDW and RDW/SDW ratio (Table 8). The RDW of 'Award' was higher than that of 'Moonlight' under the non-waterlogging condition (Figure 5). However, the differences between the two cultivars diminished under waterlogging stress. Waterlogging inhibited RDW in both cultivars with a higher reduction in 'Award' (49.2%) compared to 'Moonlight' (20.8%). In contrast, the cultivar differences were not observed in RDW/SDW ratio under the regular growth conditions (Figure 6). And 'Award' had a lower RDW/SDW ratio than 'Moonlight' when subjected to waterlogging. Waterlogging reduced RDW/SDW ratio in 'Award', but not in 'Moonlight'. The RL and SRL were not affected by the main factors nor their interactions, except that waterlogging increased SRL (Tables 8 and 9).

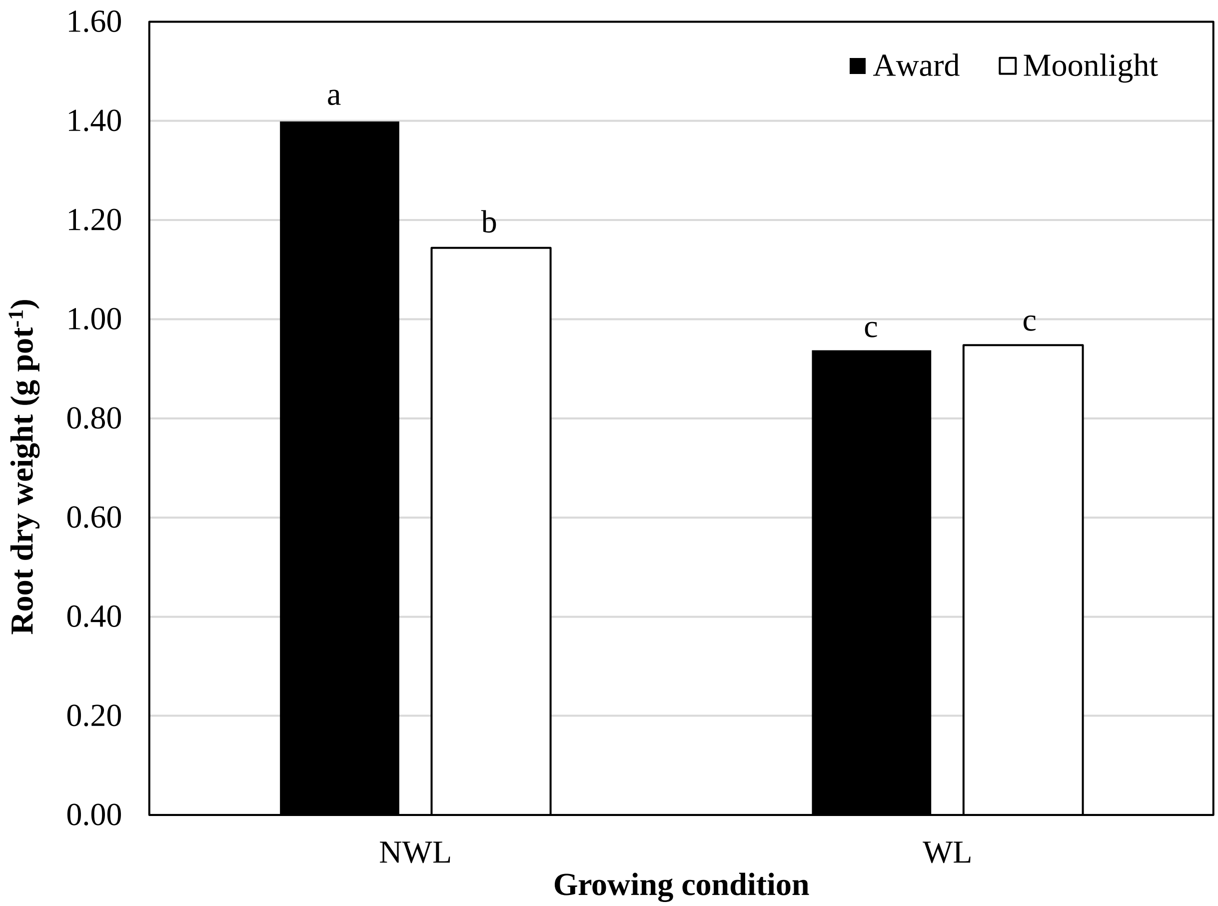

Figure 5. Root dry weight (g pot-1) of Kentucky bluegrass seedlings as affected by the cultivar x waterlogging (NWL = non-waterlogging; WL = waterlogging) interaction when data were pooled across priming treatments.
Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

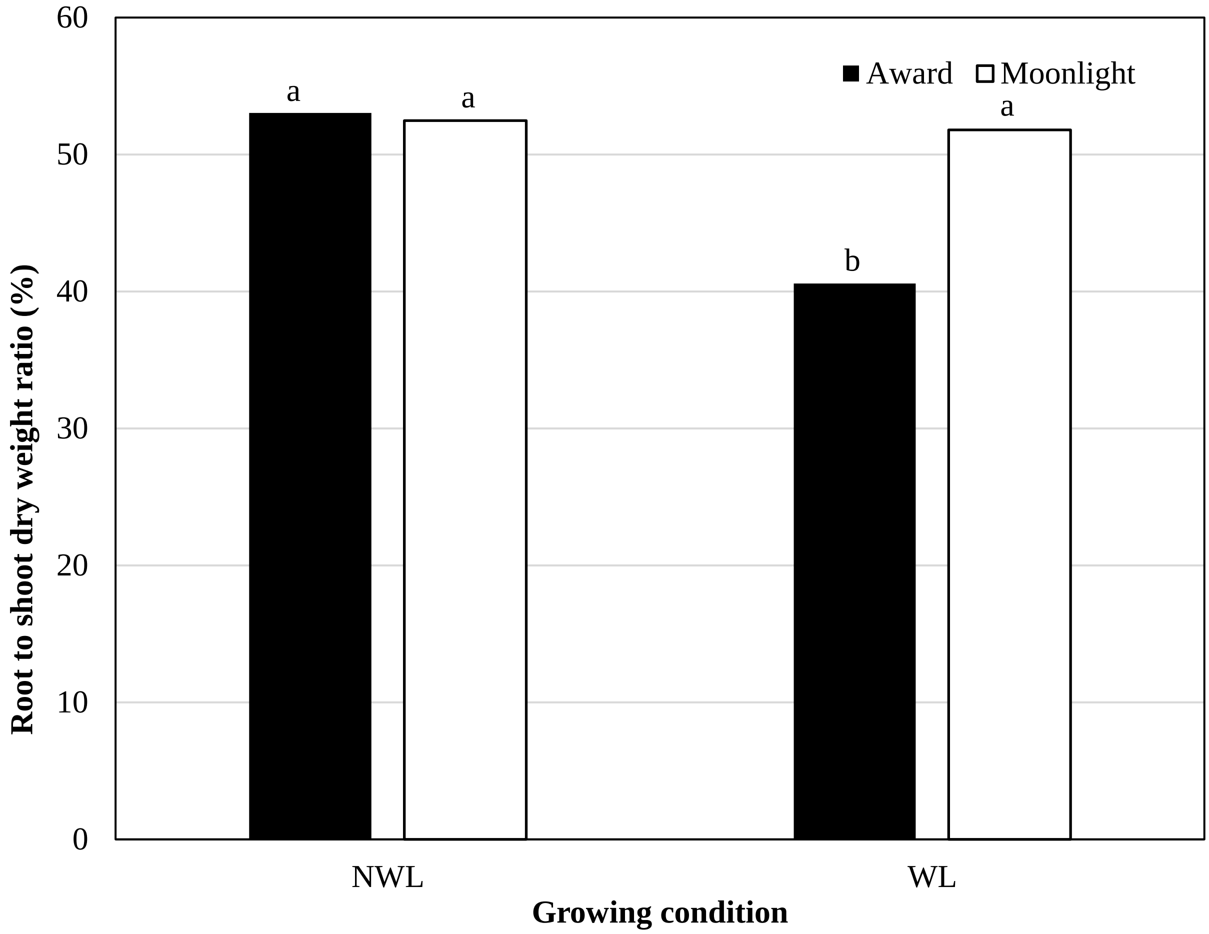

Figure 6. Root to shoot dry weight ratio (%) of Kentucky bluegrass seedlings as affected by the cultivar x waterlogging (NWL = non-waterlogging; WL = waterlogging) interaction when data were pooled across priming treatments.
Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

Effects of seed priming on early growth of KBG seedlings under the combined saline-waterlogging conditions

'Award' outperformed 'Moonlight' in shoot and root biomass (Tables 10 and 11). The cultivar differences were more pronounced in SDW than RDW; thus, RDW/SDW ratio was higher in 'Moonlight' than in 'Award'. The stress condition, saline-waterlogging, reduced SDW and RDW by 28.9% and 46.8%, respectively. As RDW was more influenced by the stress than SDW, RDW/SDW ratio was lower under saline-waterlogging than the non-stressed condition.

Significant differences were observed in SDW and RDW/SDW ratio in the priming treatments (Table 10). The SDW in KNO_3- or SS-primed plants was higher than those primed with DD, GA, or PEG (Table 11). The grasses that were not primed or primed with ABA, KNO_3, or SS had a lower level of RDW/SDW ratio than other priming treatments.

Table 10. Probability value of the main factors (saline-waterlogging, cultivar, and priming) and their interaction on Kentucky bluegrass growth during the germination and seedling growth stage.

Source of variance	Shoot dry weight	Root dry weight	Root to shoot ratio	Root length	Specific root length
Saline-waterlogging (SW)	<0.0001†	<0.0001	<0.0001	0.2823	<0.0001
Cultivar (C)	<0.0001	0.0469	<0.0001	0.5192	0.0758
Priming (P)	0.0103	0.6674	<0.0001	0.2974	0.6499
C x P	0.5152	0.2286	0.6507	0.7454	0.7989
C x SW	0.7635	0.7745	0.7114	0.2672	0.7549
P x SW	0.2998	0.1488	0.4421	0.0680	0.0252
C x P x SW	0.4603	0.6687	0.2423	0.9116	0.7833

†Probability value ≤ 0.05 indicates significant difference.

Table 11. Growth response of Kentucky bluegrass seedlings as affected by saline-waterlogging, cultivar, and priming solutions.

The priming treatments are: abscisic acid at 50 ppm (ABA), glycinebetaine at 100 mM (GB), no priming (NP), deionized and distilled water (DD), gibberellic acid at 100 ppm (GA), KNO_3 at 500 ppm (KNO_3), polyethylene glycol-6,000 at 20% (PEG), and a Na_2SO_4 + $MgSO_4$ (1:1, w:w) at 3 dS m^{-1} (SS).

Treatment	Shoot dry weight (g pot^{-1})	Root dry weight (g pot^{-1})	Root to shoot ratio (%)	Root length (cm)	Specific root length (cm g^{-1})
Saline-waterlogging					
Non-saline-waterlogged	1.86a[†]	0.81a	47.0a	19.8a	27.8b
Saline-waterlogged	1.32b	0.43b	36.5b	18.8a	52.3a
Cultivar					
Award	1.87a	0.66a	38.0b	19.6a	37.1a
Moonlight	1.31b	0.58b	45.5a	19.0a	43.0a
Priming					
ABA	1.64ab	0.58a	37.5b	18.0a	33.9a
GB	1.61a-c	0.70a	44.8a	19.2a	36.8a
NP	1.76ab	0.61a	37.2b	19.4a	43.9a
DD	1.41bc	0.68a	49.6a	20.4a	41.3a
GA	1.17c	0.56a	47.5a	17.9a	41.4a
KNO_3	1.88a	0.59a	34.6b	18.5a	41.6a
PEG	1.31bc	0.60a	47.7a	22.1a	45.3a
SS	1.936a	0.63a	35.1b	18.9a	36.2a

[†]Means in a column followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

Both cultivars performed similarly in regard to SRL, averaging 40.1 cm g^{-1}, when data were pooled across growing conditions and priming treatments (Tables 10 and 11). The SRL was influenced by the priming x saline-waterlogging interaction (Table 10). Grasses exposed to the saline-waterlogging conditions had a higher level of SRL than the non-stressed plants, except those primed with ABA (Figure 7). Grasses showed no differences among priming treatments under the non-stress condition. However, the plants primed with ABA had a similar level of SRL as those primed with GB and SS, but significantly lower than other priming treatments. The RL showed no differences regardless of stress, cultivar, and priming treatments (Table 10).

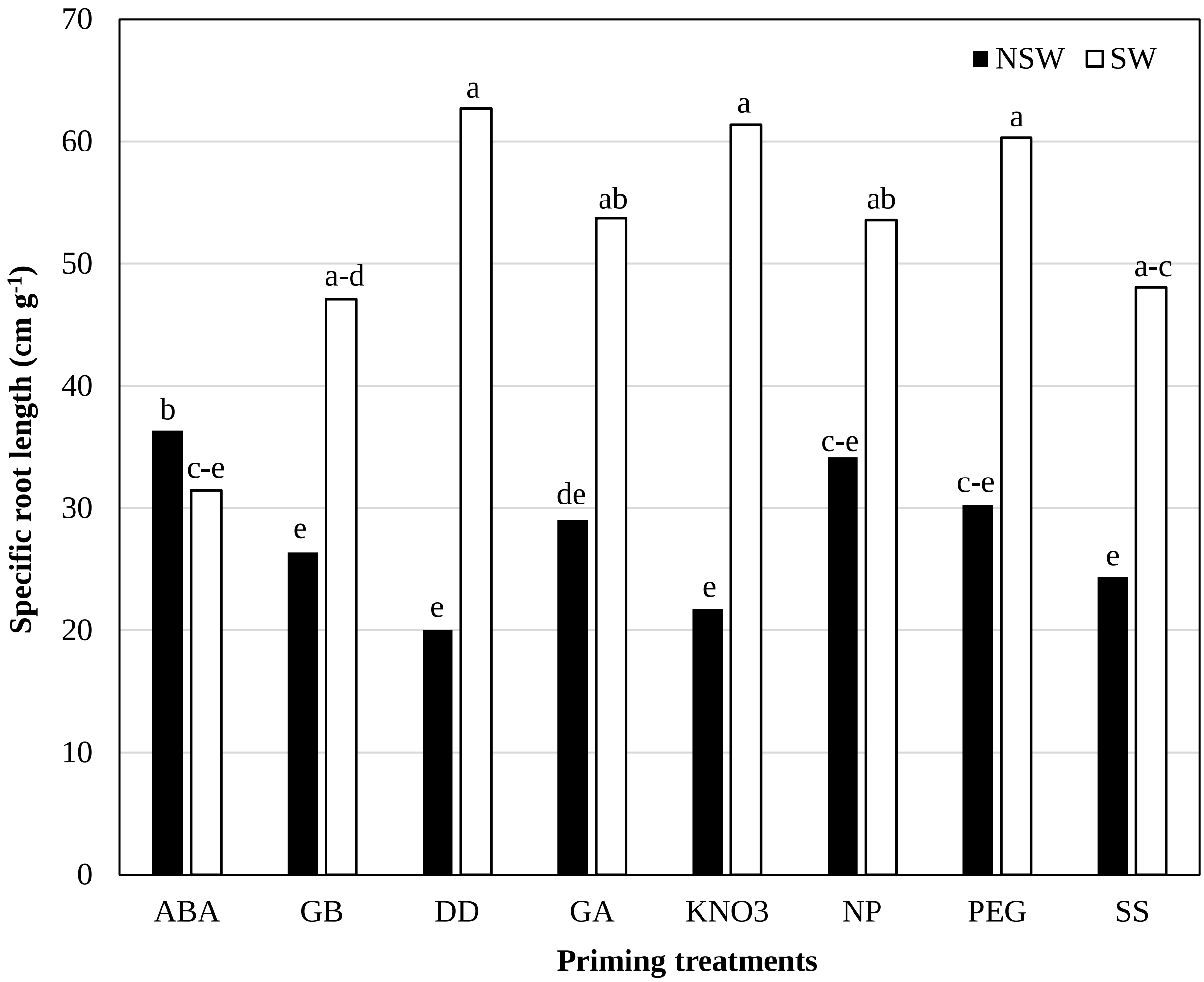

Figure 7. Specific root length (cm g-1) of Kentucky bluegrass seedling as affected by the growing condition (NSW = no saline-waterlogging, SW = saline-waterlogging) x priming interaction when data were pooled across cultivars.

The priming treatments are: abscisic acid at 50 ppm (ABA), glycinebetaine at 100 mM (GB), no priming (NP), deionized and distilled water (DD), gibberellic acid at 100 ppm (GA), KNO_3 at 500 ppm (KNO_3), polyethylene glycol-6,000 at 20% (PEG), and a Na_2SO_4 + $MgSO_4$ (1:1, w:w) at 3 dS m^{-1} (SS). Means followed by the same letter are not significantly different according to Fisher’s protected least significant difference test ($P \leq 0.05$).

Previous research has shown improved plant growth and stress tolerance through seed priming in various field crops (Jisha et al., 2013; Paparella et al., 2015). Compared to the field crops, information about priming on turfgrass performance is largely scarce and the results are not always consistent. Brede et al. (1985) observed KBG primed with NaCl and PEG germinated as fast as PR, faster than the water-primed KBG, while KNO_3 priming caused toxicity. Shim et al. (2008), however, reported that mean germination time and uniformity of seashore paspalum (*Paspalum vaginatum* Swartz) were improved by KNO_3 priming at 0.2% or 0.5% at 30 °C for 48 – 72 h. Zhang and Rue (2012) primed six turfgrass species with GB (50 – 200 mM) before osmotic and salinity exposure. They found that GB treatments improved final germination rate, seedling fresh weight, and absolute water content, but not daily germination when data were pooled across stresses. When the same six turfgrass species were primed with GB (5 – 50 mM) and germinated under drought, salinity, or sub-optimal temperatures, final and/or daily germination rate varied by grass, concentration, germination conditions (Zhang et al., 2014). Jia et al. (2020) conducted one of the few studies comparing efficiency of various priming agents. In their study, CB from two seed lots were primed with water, ABA (0.05 – 0.2 μM), GA (100 – 300 mg L^{-1}), GB (50 – 150 mM), H_2O_2 (0.1 – 100 mM), and PEG (100 – 300 g L^{-1}) before subjecting to optimal (30 °C for 10 d) or sub-optimal temperature (10 °C for 22 d). They observed different results from the two seed lots in the study. To enhance germination (maximum germination rate and/or days to reach 50% germination), the overall efficacy of priming agents decreased in the following order: GB and PEG > GA and ABA > H_2O_2 with variations in concentrations of each priming agent. Jia et al. (2020) concluded that in addition to plant, priming concentration, and stress, the effects of seed priming was also related to seed lot and the priming agent.

The complexity of seed priming was also detected in this present study. For example, effects of priming and/or its interaction with other main factors were detected under saline and saline-waterlogging conditions, but not waterlogging (Tables 6, 8 and 10). We also compared the efficacy of the seven priming agents, but no consistent results were observed. Only ABA and GA improved SDW in 'Award' (tolerant to saline, waterlogging, and saline-waterlogging), but not in 'Moonlight' (sensitive to the aforementioned stress), at 0 dS m^{-1} (Figure 1). Under the stress condition (i.e. 6 dS m^{-1}) though, ABA, DD, PEG, and SS enhanced shoot biomass in 'Moonlight', but not in 'Award'. Glycinebetaine, GA, and KNO_3 inhibited root growth in 'Moonlight' compared to NP, but not in 'Award', under saline conditions (Figure 4). Glycinebetaine, DD, GA, and PEG treated KBG had a higher RDW/SDW ratio than the NP grasses under saline-waterlogging (Table 11). The differences between our findings and Jia et al. (2020) may have been a result of concentrations applied, turfgrass used, stress condition, alone or in combination. Furthermore, Jia et al. (2020) studied germination responses to priming, while we quantified seedling growth. Yamamoto et al. (1997) noted that emergence and growth of PEG-primed and non-primed seedlings were evaluated in 4 KBG cultivars. Priming with PEG improved growth of 'Marquis' and 'Rugby' but showed no influence in 'Estate' and 'Limousine'. Similarly, cultivar differences in response to seed priming were observed in this study. Yamamoto et al. (1997) concluded that higher growth of primed seedling was related to the rapid emergence of the coleoptile and its longer growth period, rather than seedling growth itself. The emergence and seedling size of the 2^nd^ and 3^rd^ leaf were similar between the primed and non-primed KBG seeds. Brede (1992) also suggested that the effects of priming on turfgrass may be diminished after 6 weeks of growth under optimal conditions. The longer evaluation time, 42 days after seeding, applied in this study may partially explain why limited differences detected in priming agents in this study as noted by Brede (1992) and Yamamoto et al. (1997).

CONCLUSIONS

Saline, waterlogging, and saline-waterlogging conditions adversely affected Kentucky bluegrass seedling growth, with the highest reduction observed under the combined conditions. There were interspecific differences in the growth responses to saline, waterlogging, and saline-waterlogging conditions in Kentucky bluegrass at the germination and seedling stages. ‘Sudden Impact’, ‘Award’, ‘Limousine’, and ‘Kenblue’ were relatively tolerant to salinity and waterlogging stresses, having high tissue biomass, while ‘Moonlight’ and ‘Blue Note’ were relatively sensitive. ABA, GB, PEG, and DD performed better or similar to the NP, suggesting their potential to improve KBG growth and stress tolerance during the early growth period. Use of relatively tolerant cultivars, alone or in combination with priming, may be a better management practice when establishing a turfgrass stand under saline, waterlogging and saline-waterlogging conditions.

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