KENTUCKY BLUEGRASS GROWTH AND PERFORMANCE AS AFFECTED BY SALINITY AND SALT COMPOSITION

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ABSTRACT

Turfgrass growth, development, and functionality are adversely affected by high soil salinity. Most of the previous salinity tolerance research involved NaCl-induced saline conditions. However, there are regions such as California and North Dakota where the predominant cation and anion is Mg^{2+} and SO_4^{2-}, respectively. The objective of this research was to determine the salinity tolerance of 'Kenblue' and 'Moonlight' Kentucky bluegrass as affected by NaCl, Na_2SO_4, $MgCl_2$, and $MgSO_4$ at four saline levels at early growth and vegetative stages. The results showed that shoot and root dry weight, root length, and turfgrass performance decreased with increasing salinity levels at both stages. Specific root length increased during saline exposure at the germination and seedling stage but decreased at the vegetative growth stage. The plants subjected to the Na_2SO_4 and $MgSO_4$ treatments performed better than those under the NaCl and $MgCl_2$ treatments when data were pooled across cultivars and salt concentrations.

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LITERATURE REVIEW

Salinity

Salinity is a major problem that adversely affects plant growth, development, and functionality (Fahad et al., 2015; Francois and Maas, 1999). Approximately 60% of the world's 9 x 10^9 ha of cultivated land is affected by salinity (Francois and Maas, 1999), including 8.5 x 10^6 ha in the United States (Massoud, 1977). Due to global climate change, irrigation practices, and increasing food demand, salt-affected soil has expanded (Joshi et al., 2016; Munns and Gillham, 2015). For example, salt-affected soil in North Dakota had increased from 1.05 million ha in 1987 to 2.35 million ha in 2010 (Brennan and Ulmer, 2010; Seelig, 2000).

High soil salinity may be caused by natural weathering, seawater intrusion, irrigation water, fertilizers, and road deicers (Carrow and Duncan, 1998). The U.S. Salinity Laboratory classified soils into four categories: (1) normal soil with electrical conductivity from saturated soil paste (EC_e) < 4 dS $m^{-ß1}$ and sodium adsorption ratio (SAR) < 13; (2) saline soil with EC_e > 4 dS m^{-1}, SAR < 13; (3) sodic soil with EC_e < 4 dS m^{-1}, SAR > 13; and (4) saline-sodic soil with EC_e > 4 dS m^{-1} and SAR > 13 (Richards, 1954). In saline soils, plants are mostly subjected to osmotic effects (Francois and Maas, 1999). Specific ion effects are rather minimal in saline soils as they contain a mixture of various salts (Francois and Maas, 1999). In sodic soils, Na^+ can occupy 15% or more of the cation exchange sites (Francois and Maas, 1999). Replacement of Ca^{2+} and Mg^{2+} by Na^+ in sodic soils causes reduced hydraulic conductivity and permeability of both water and air, resulting in deterioration of the soil physical structure. Therefore, plants in sodic soils are prone to combined saline-waterlogging conditions (Barrett-Lennard, 2003). Plants grown in sodic soils are also likely to experience nutrient deficiencies, particularly Ca^{2+} and Mg^{2+}. High salt concentration in saline-sodic soils helps elevate nutrient deficiencies commonly

seen in sodic soils; thus, salinity effects are predominant in saline-sodic soils (Francois and Maas, 1999).

Salinity effects on plants

Excessive salt lowers the water potential in soil, which may limit water availability to plants (i.e. osmotic stress or physiological drought) (Marcum, 2007). Osmotic stress begins once salt concentration in a growing medium is above a threshold level (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 leaf and shoot, and delayed development (Munns and Tester, 2008).

The other major stress induced by soil salintiy is ion toxicity and imbalance, which occurs at a later growth stage and not as detrimental to plant growth and developemnt (especially at low to moderate salinity levels) than osmotic stress (Munns and Tester, 2008). The most common cations and anions in salt-affected soils are Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, and HCO_3^- and the relative concentrations of different ions may vary between individual sites (Grattan and Grieve, 1999).

Sodium

Sodium is not an essential, but a beneficial (i.e. functional) nutrient for plants (Hopkins and Hüner, 2004). It is involved in the transport of pyruvate, a critical intermediate compound between the bundle-sheath and mesophyll cells in the C4 photosynthetic pathway. Sodium may stimulate plant growth, particularly when K is deficient, by maintaining cell turgor (Gorham, 2007). Excessive Na also causes reduced absorption of K, Ca, and Mg. Halophytes, such as dwarf saltwort (*Salicornia bigelovii* Torr.) and salt marsh grass (*Spartina foliosa* Trin.), produce

maximum growth under moderate to high salinity due to their ability to compartmentalize Na in vacuoles for osmotic adjustment.

Calcium

Calcium is abundant in most soils and rarely deficient under natural conditions (Pilbeam and Morley, 2007). It is taken up as Ca^{2+} by plants. Calcium is primarily involved in membrane stability and permeability, formation of primary cell walls, cell division, cell elongation, and stomatal movement (Pilbeam and Morley, 2007). Calcium is also used as a secondary messenger regulating plant growth and development and stress responses (Hepler, 2005). For example, Ca^{2+} activates the Salt Overly Sensitive (SOS) pathway, protecting plant cells from excessive ion accumulation (Ji et al., 2013). Kaplan et al. (2006) reported that Ca^{2+} in cytosol regulates abscisic acid (ABA) response in *Abrbidopsis* seedlings.

Magnesium

Magnesium is absorbed as Mg^{2+} by plants. It is an integral component of chlorophyll structure; thus, chlorosis is the first and most pronounced symptom of Mg deficiency (Merbaut, 2007). Magnesium is also essential for other plant physiological functions, such as being a cofactor in various enzymatic processes, regulating membrane channels and receptor proteins, and playing a structural role in stabilizing proteins and the configurations of DNA and RNA strands (Merhaut, 2007). Limited information is available on Mg toxicity; however, Mg may inhibit uptake of other cations, such as Ca, K, and occasionally Fe. Therefore, deficiency of other nutrients, rather than the initial Mg toxicity, is more likely an issue in plants grown under high Mg contents (Merhaut, 2007).

Chloride

Chloride is ubiquitous in nature; thus, Cl deficiency is rarely observed. Chloride, taken up as Cl^-, is required to counter balance cations maintaining electrical neutrality across membranes, one of the principal osmotically active solutes in the vacuole, an essential cofactor for the activation of the oxygen-evolving enzyme associated with photosystem II, and participates in regulation of stomatal movement (Heckman, 2007; Hopkins and Hüner, 2004).

Sulfur

Sulfur may exist in different forms in soil, but it is absorbed as SO_4^{2-} by plants (Hopkins and Hüner, 2004). Sulfur forms disulphide bonds, key structure for the tertiary structure or folding of proteins. Iron-sulfur proteins, such as ferredoxin, are important components in electron transfer reactions (Hopkins and Hüner, 2004). Chlorosis resulting from a sulfur deficiency is due to reduced protein synthesis, required to form stable chlorophyll-protein complexes for light harvest, rather than a direct impairment of chlorophyll synthesis.

Bicarbonate

Hydrogen, C, and O are also essential nutrients and primarily taken up as H_2O, CO_2, and O_2. Bicarbonate contributes to high soil pH which causes reduced availability of certain nutrients, such as P and Fe (Hopkins and Hüner, 2004).

Salinity tolerance mechanisms

Plants have multiple salinity defense mechanisms. Plants may undergo osmotic adjustment, lowering sap osmolarity to compensate for external osmotic stress in order to maintain cell turgor required for cell expansion (Marcum, 2007). Osmotic adjustment can be achieved by ion compartmentation (i.e. isolating ions in vacuole) or accumulation of compatible solutes (i.e. organic compounds) such as prolines, proteins, and carbohydrates (Leigh and Storey,

1993; Marcum, 2007; Munns and Tester, 2008). Decreased stomatal conductance under saline conditions reduces water loss through transpiration, helping elevate osmotic stress as well (Munns and Tester, 2008).

Plant actively controls ion influx and efflux between cytoplasm and growing medium (Jacoby, 1999). Ion exclusion, particularly Na, has been observed in some plant species including *Poaceae* to minimize toxicity effects (Marcum, 2007; Munns and Tester, 2008). The SOS pathway has been shown in regulating Na^+ exclusion and compartmentation (Ji et al., 2013; Munns and Tester, 2008). It has been suggested that salt tolerant plants have the capability of excluding most salts, yet maintaing adequate concentrations for osmotic adjustment (Marcum, 2007). In contrast, salt sensitive plants accumulate ions well above the concentrations for osmotic adjustment, resulting in ion toxicity (Marcum, 2007). Plants, such as *Frankeniaceae*, *Plumbaginaceae*, and *Poacea*e have salt glands or bladders, reducing excessive ions by excretion (Marcum, 2007).

Accumulation of reactive oxygen species (ROS) is a common physiological change in plants under stresses, including salinity (Marcum, 2007). Hu et al. (2012) reported higher activity of antioxidant enzymes, including superoxide dismutase, catalase, and ascorbate peroxidase in the salt-tolerant bermudagrass (*Cynodon dactylon* (L.) Pers) cultivar, C43, than in the sensitive cultivar, C198. Similar results were also reported by Veerasamy and Huang (2013) in which antioxidant activity and lipid peroxidation were associated with salinity tolerance in cool-season turfgrasses.

Salinity management

Use of tolerant plants

Variations in species, cultivars, and growth stages

Large interspecific differences exist in turfgrass salinity tolerance. Alshammary et al. (2004) evaluated the growth response of saltgrass (*Distichlis spicata* L.), alkaligrass (*Puccinellia distans* (Jacq.) Parl.), tall fescue (*Festuca arundinacea* Schreb.), and Kentucky bluegrass (*Poa pratensis* L.) to salinity. The growth rate decreased in the following order under saline conditions: saltgrass > alkaligrass > tall fescue > Kentucky bluegrass. Dai et al. (2009) reported that perennial ryegrass (*Lolium perenne* L.) and creeping bentgrass (*Agrostis stolonifera* L.) exhibited the highest tolerance to salinity, the greens-type (*Poa annua* L.) behaved intermediate, while Kentucky bluegrass showed the lowest tolerance. The predicted salinity level causing 50% reduction in germination in Kentucky bluegrass, fescues (*Festuca* spp.), alkaligrass, and creeping bentgrass was 10.4, 15.2, 17.0 and 18.7 g L^{-1} NaCl, respectively (Zhang et al., 2011). Chen et al. (2009) irrigated four warm-season turfgrasses, 'Diamond' zoysiagrass (*Zoysia metrella* (L.) Merr.), 'Z080' zoysiagrass (*Z. japonica* Steud.), 'C291' bermudagrass, and 'Adalayd' seashore paspalum (*Paspaslum vaginatum* Sw.) with saline water for nine months. Percentage green leaf canopy decreased in the following order: 'Diamond' > 'Adalayd' > 'C291' > 'Z080' (Chen et al., 2009).

Horst and Beadle (1984) examined salinity tolerance of tall fescue at the germination stage. Their results showed that the germination rate varied from 60% to 27% among the 16 cultivars when exposed to a saline solution at 23.4 dS m^{-1}. Horst and Dunning (1989) reported significant differences in germination rate and seedling growth in 48 perennial ryegrass cultivars under salinity stress. Wang and Zhang (2010) evaluated germination of 23 creeping bentgrass

cultivars under saline conditions, in which NaCl concentration causing 50% reduction in daily germination rate ranged from 11.0 g NaCl L^{-1} in 'Declaration' to 6.3 g NaCl L^{-1} in 'Kingping'. Intraspecific differences in salinity tolerance have also been observed in other turfgrass species, such as annual bluegrass (Dai et al., 2009), Kentucky bluegrass (Horst and Taylor, 1983; Poss and Russel, 2010), bermudagrass (Dudeck and Peacock, 1985; Marcum and Pessarakli, 2006), and zoysiagrass (Dudeck and Peacock, 1985).

Plant responses to salinity may vary in growth stages (Harivandi et al., 1982). Dai et al. (2009) reported a consistent relative salt tolerance between the germination and seedling growth stage and vegetative growth stage in Kentucky bluegrass and creeping bentgrass. However, ranking of relative salt tolerance varied between the two growth stages in greens-type *P. annua* lines and perennial ryegrass. Zhang et al. (2012) evaluated salinity tolerance of buffalograss (*Bouteloua dactyloides* L.) and blue grama (*Bouteloua gracilis* L.). Their results showed that blue grama exhibited higher salt tolerance than buffalograss during the germination and seedling growth, while buffalograss had better performance at the mature stage (i.e. vegetative growth). Rose-Fricker and Wipff (2001) suggested that different mechanisms of stress tolerance might be applied depending on growth stage.

Cultural practices

Salinity management usually includes soil amendment, leaching, and drainage (Carrow and Duncan, 1998). High Na^+ in salt-affected soils reduces soil permeability and increases the potential of Na^+ toxicity in plants. Amendments, such as gypsum and phosphogypsum, provide Ca^{2+} to replace Na^+, resulting in reduced Na^+ to Ca^{2+} ratio. Sulfur compounds, such as elemental S and sulfuric acid, provide Ca^{2+} indirectly by reacting with limestone. The most common amendments used to treat soil and water, which have high salt content, are gypsum and sulfuric

acid; while, elemental S is only used for soil treatment. Rahayu et al. (2011) evaluated the efficiency of five soil amendment mixtures (90% sand + 10% peat moss, 80% sand + 10% soil + 10% bottom ash, 80% sand + 20% soil, 90% sand + 5% peat most + 5% zeolite, and 80% sand + 20% bottom ash), either with or without gypsum, in salinity management of Kentucky bluegrass. Little differences were observed in the five amendment mixtures; however, gypsum reduced EC_e and SAR. Higher shoot and root growth were seen in the grasses under the gypsum treatments (Rahayu et al., 2011). Abdi et al. (2010) reported that zeolite amendment (15%) increased turf quality, tissue biomass, and water use efficiency in Kentucky bluegrass when exposed to salinity in a sand medium. However, the beneficial effects of zeolite were short-lived (three months) due to high accumulation of Na^+ and K^+ and high retention of Ca^{2+} and Mg^{2+} in the long-term.

Excessive salts and Na need to be leached out of the root zone to minimize salinity damage. Leaching should be provided prior to turfgrass establishment if initial soil salinity is sufficiently high to adversely affect turfgrass germination through ponding or a sprinkler system (Carrow and Duncan, 1998). Leaching can also be used after establishment through irrigation. Amount and frequency of irrigation required for leaching are mostly depending on grass species and water and soil salt content (Carrow and Duncan, 1998). A minimum of 0.10 leaching fraction (i.e. the fraction of water that infiltrates the soil surface and then passes through the rootzone) is recommended for turfgrass when the irrigation source, such as recycled water, contains a high level of soluble salt (Thomas et al., 2006). EI-Haddad and Noaman (2001) irrigated six halophyte species, including saltgrass and seashore paspalum, with saline solutions (10, 20, and 40 g L^{-1} of diluted seawater) to evaluate the relationship between leaching fraction (0.25 and 0.5) and plant growth under saline conditions. A 0.25 leaching fraction was needed to maintain an adequate biomass when irrigated at 20 g L^{-1}; however, a leaching fraction of 0.50 was preferred

when salinity increased to 40 g L^{-1}. The results indicated that leaching fraction is largely depending on total salinity level in irrigation water. Drainage water is the water that has moved past the rootzone (Carrow and Duncan, 1998). The necessity of installing a drainage system should be evaluated in conjunction with a water management plan, which includes irrigation practices and salt disposal options. Surface and subsurface drainage are important practices if water infiltration through soil is difficult (Carrow and Duncan, 2011). Limited cultural practices can be done to improve drainage post-establishment due to the soil depth.

Shahba et al. (2012) evaluated the effects of mowing height on salinity damage in seashore paspalum. 'Salam' (a salt-tolerant cultivar) provided acceptable quality (quality ≥ 6.0) at 44.0 dS m^{-1} if mowed at 45 mm, compared to a quality rating of 4.0 and 5.2 (0-9 scale) at 25 and 35 mm mowing height, respectively (Shabha et al., 2012). Increasing mowing height contributed to a higher photosynthetic rate, shoot sugar content, shoot proline level, and K^+/Na^+ ratio, resulting in enhanced salinity tolerance (Shabha et al., 2012). Similar results have also been reported in other turfgrass species, such as creeping bentgrass (Fu et al., 2005; Qian and Fu, 2005), Kentucky bluegrass (Krans and Beard, 1975), and bermudagrass (Shabha et al., 2012).

Langdale and Thomas (1971) investigated clipping yield and protein synthesis of bermudagrass as affected by N (0 - 200 mg kg^{-1} of soil), P (0 - 60 mg kg^{-1} of soil), and soil salinity (0 - 14.4 dS m^{-1}). Bermudagrass showed no responses to P fertilization regardless of soil salinity and N levels. Nitrogen and soil salinity had a synergistic effect on bermudagrass performance. Nitrogen application enhanced clipping yield and N-protein content at 4.8 dS m^{-1}. Nitrogen fertilization helped alleviate salinity damage at 9.6 dS m^{-1}, but not at the highest salinity level of 14.4 dS m^{-1}. Nitrogen fertilization offsets the negative effects of salinity up to 15 dS m^{-1} in bermudagrass, zoysiagrass, and seashore paspalum (Pompeiano et al., 2014). However,

a dramatic reduction was observed in verdure and clipping dry weight, proline content and chlorophyll content as salinity increased to 30 dS m^{-1} (Pompeiano et al., 2014). Large variations in salinity tolerance were also detected among the three aforementioned turfgrass species (Pompeiano et al., 2014). The results suggested that the potential of using N fertilization in salinity management was dependent upon salt concentration and species (perhaps even cultivars).

Salinity causes declines in metabolic activities, such as antioxidant pathways and photosynthesis (Krishnan and Merewitz, 2015). Doak et al. (2005) reported reduction in salinity damage (4.7 or 9.4 dS m^{-1}) in creeping bentgrass treated with metabolic enhancers, propiconazole (3 kg ha^{-1}) and seaweed (*Kappaphycus alvarezii*) extract (3.5 g m^{-2}) plus humic acid (0.7 kg ha^{-1}). The positive results in the treated bentgrass were due to reduced Na^+ uptake and increased proline content which was responsible for osmotic adjustment and cleavage of ROS (Doak et al., 2005). In contrast, humic acid applications (400 mg L^{-1}) did not improve salinity tolerance in creeping bentgrass which was grown hydroponically in salt solutions (8.0 or 16.0 dS m^{-1}) (Liu and Cooper, 2002). Esmaeili and Salehi (2016) observed higher proline content and better turfgrass performance in silicon-treated Kentucky bluegrass grown under saline conditions. Bae et al. (2012) suggested that silicon improved shoot and root growth, relative water content, chlorophyll content and membrane stability in NaCl-treated Kentucky bluegrass by reducing salinity-induced oxidative stress. Salinity tolerance was enhanced in perennial ryegrass by foliar application of glycinebetaine, a compatible solute with similar biological functionalities as proline (Hu et al., 2012). Similar results were reported in alkaligrass and tall fescue (Scalia et al., 2014). Zhang and Rue (2012) and Zhang et al. (2014) suggested that glycinebetaine had the potential to improve drought and salinity tolerance in turfgrass through seed priming.

Trinexapac-ethyle (TE), a plant growth regulator that inhibits gibberellic acid (GA) biosynthesis, has shown the ability of improving tolerance to environmental stresses, including salinity. For example, NaCl-treated bermudagrass showed improved visual quality and shoot and root biomass when TE was applied at 0.02 kg ha^{-1} (Baldwin et al., 2006). Arghavani et al. (2012) reported that foliar application of TE at 0.1 kg ha^{-1} enhanced salinity tolerance in Kentucky bluegrass by reducing oxidative stress and inhibiting shoot Na^+ accumulation. However, higher TE dosage, 0.17 kg ha^{-1}, resulted in more severe damage especially under high salinity levels (60 and 80 mM NaCl) (Arghavani et al., 2012). Abdi et al. (2010) reported conflicting results stating that paclobutrazol (0.4% active ingredient) which is also a GA inhibitor reduced Kentucky bluegrass growth under saline conditions. Therefore, the efficacy of plant growth regulators on enhancing salinity tolerance are dependent upon growth regulator, dosage, and salinity level.

The ability of plant growth-promoting microorganisms (PGPM) in stress enhancement has been proved in field crops, such as drought tolerance in citrus (*Ponicirus trifoliate* L.) (Wu et al., 2006) and salinity tolerance in maize (*Zea mays* L.) and cucumber (*Cucumis sativus* L.) (Egamberdieva et al., 2011; Rojas-Tapias et al., 2012). Turfgrass stress responses under PGPM application were studied in recent years. Coy (2014) and Coy et al. (2014) demonstrated that PGPM improved root and shoot growth and reduced insect damage in 'Tifway' bermudagrass (*C. dactylon* x *C. transvaalensis* Burtt-Davey). Kentucky bluegrass seeds inoculated with *Bacillus* and *Pantoea* showed a higher seed germination rate and seedling growth at 100 mM NaCl than non-inoculated seeds (Chen et al., 2015). Cheng et al. (2016) inoculated perennial ryegrass with two bacteria, *Burkholderia pytofirmanns* PsJN and *B. gladioli* RU1, which contain deaminase enzymes breaking down ethylene precursor, 1-aminocyclopropane-1-1carboxylate (ACC). Higher biomass and leaf water content, lower cell membrane damage, and better turf quality

were observed in the inoculated plants compared to non-inoculated ones when subjected to salinity (Cheng et al., 2016). Although plant-PGPM interaction is not been fully understood, some mechanisms of PGPM enhancing plant resistance to stresses have been discovered including influencing resource acquisition (e.g. water and nutrient), modulating plant hormone levels, regulating source-sink relations, energetic metabolism, and inducing systemic resistance (Glick, 2012).

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KENTUCKY BLUEGRASS GROWTH AND PERFORMACE AS AFFECTED BY SALT CONCENTRATION AND SALT TYPE

Kentucky bluegrass (*Poa pratensis* L.) is a dense, cool-season turfgrass with smooth, upright stems and sod forming rhizomes (Christians, 2011). It is widely used for home lawns, parks and gardens, as well athletic fields, golf course fairways, tees, and roughs in the northern regions and the turfgrass transition zone because of its ability to remain high turf quality under a cool and arid environment during the growing season (Huff, 2003). However, it is sensitive to salinity stress. Zhang et al. (2011) evaluated salinity tolerance of creeping bentgrass (*Agrostis stolonifera* L.), fescues (*Festuca* spp), Kentucky bluegrass, and alkaligrass (*Puccinellia distans* (Jacq.) Parl.) during the germination stage. The salinity level causing a 50% reduction in the daily germination rate was 9.6 g NaCl L^{-1} for Kentucky bluegrass, compared to 11.8 g L^{-1} for the other three species. During a 35-day saline exposure, alkaligrass and tall fescue (*F. arundinacea* Schreb.) had the highest turfgrass quality, followed by perennial ryegrass (*Lolium perenne* L.), and Kentucky bluegrass, while colonial bentgrass (*A. capillaris* L.) and velvet bentgrass (*A. canina* L.) showed the lowest quality (Veerasamy and Huang, 2013).

Horst and Taylor (1983) reported intraspecific differences in salinity tolerance of 44 Kentucky bluegrass cultivars during the initial growth stages (seed germination and seedling growth). Among the bluegrass cultivars subjected to five-weeks of saline exposure, the germination rate and leaf blade length ranged from 117% of control (i.e. non-saline conditions) to 4% of the control and 46% of the control to 7% of the control, respectively, Poss and Russel (2010) evaluated the salinity tolerance of six Kentucky bluegrass cultivars, ‘Baron’, ‘Brilliant’, ‘Cabernet’, ‘Eagleton’, ‘Midnight’, and ‘A01-856’ (a ‘Texas’ x Kentucky bluegrass hybrid, *P. arachnifera* Torr. x *P. pratensis* L.) at the vegetative growth stage in the field. ‘Baron’,

'Brilliant', and 'Eagleton' had a higher tissue biomass and Normalized Difference Vegetative Index than the other three cultivars, suggesting a higher salinity tolerance.

Much of the prior research that evaluated salinity tolerance in plants was conducted using Cl^- salts to stimulate saline conditions, particularly NaCl. However, in many regions around the world including parts of India, Egypt, and California, SO_4^{2-} salts are at a higher level than Cl^- salts (Rogers et al., 1998). In North Dakota, most salinity problems are caused by SO_4^{2-} salts (primarily $NaSO_4$ and $MgSO_4$), while Cl^- salts are more prevalent in the saline soils of eastern Grand Forks County (Franzen, 2003). Plants respond to Cl^- and SO_4^{2-} salts differently. For instance, soybean (*Glycine max* (L.) Merr.) is more sensitive to Cl^-, while, corn (*Zea mays* L.) is more sensitive to SO_4^{2-} (Butcher et al., 2015). Datta et al. (1994) reported higher shoot and root biomass, chlorophyll content, and photosynthetic rate in barley (*Hordeum vulgare* L.) exposed to NaCl compared to those treated with Na_2SO_4 at the same salinity level, 8.1 dS m^{-1}. In wheat (*Triticum aestivum* L.), a higher growth reduction was observed in NaCl-treated plants than the Na_2SO_4-treated ones (Zahoor et al., 2007). Information on turfgrass responses to Cl^- and SO_4^{2-} salts is scarce. The objective of this study was to determine Kentucky bluegrass growth and performance as affected by salt type and salt concentration.

Materials and methods

Plant material

'Kenblue' and 'Moonlight' Kentucky bluegrass were included in this study. 'Moonlight' and 'Kenblue' is tolerant and sensitive to NaCl-induced salinity, respectively, at the vegetative growth stage (Qian, 2003; Rose-Fricker and Wipff, 2001).

Soil medium preparation

A sand and topsoil (clay loam) mixture, 1:1 (v:v), was used to mimic field conditions. The soil mixture consisted of 7 ppm P, 110 ppm K, a salinity level of 0.8 dS m^{-1}, and a pH of 7.1. Bulk density of the soil medium was 1.59 g cm^{-3}. The soil medium was amended with NaCl, Na_2SO_4, $MgCl_2$, or $MgSO_4$ to achieve salinity levels of the saturated paste (EC_e) at 5, 10, 15, and 20 dS m^{-1} (Table 1). A non-saline control was also included in the experiment.

Table 1. Salt amendments to achieve the targeted salinity levels.

Salt source	Target EC_e (dS m^{-1})	Real EC_e (dS m^{-1})	g of salt for 1 kg of soil mixture
Na_2SO_4	5	4.4±0.3[†]	1.2601
Na_2SO_4	10	8.9±0.8	3.3498
Na_2SO_4	15	14.1±1.7	5.4394
Na_2SO_4	20	18.9±1.1	7.5291
$MgCl_2$	5	5.5±1.4	1.2256
$MgCl_2$	10	8.2±1.7	2.8770
$MgCl_2$	15	14.2±2.1	4.5283
$MgCl_2$	20	20.0±1.5	6.1797
$MgSO_4$	5	5.3±0.7	2.4223
$MgSO_4$	10	9.3±0.9	6.0428
$MgSO_4$	15	15.4±0.4	9.6633
$MgSO_4$	20	21.0±1.3	13.2838
NaCl	5	5.4±0.5	0.6738
NaCl	10	10.8±0.3	1.5143
NaCl	15	14.5±1.5	2.3547
NaCl	20	20.7±0.7	3.1951

[†]Mean
±Standard Deviation

Germination and seedling development

On Sept. 30, 2015, a germination study was initiated. Each grass was seeded at 147 kg pure live seed ha^{-1} in plastic bags containing the aforementioned soil mixture and held in 10 x 10 x 10 cm plastic pots.. Plastic bags were used to prevent leaching. Each pot held 1 kg of soil mixture. Pots were saturated with tap water before seeding. Saturation volume was calculated with three reference pots. Briefly, the reference pots (1 kg of soil mixture/pot, no plastic bag)

were soaked with tap water for 10 mins . The reference pots were weighted before soaking (PW0) and 3 hrs (PW1) and 3 ½ hrs (PW2) after leaching. There were limited weight changes between PW1 and PW2 (difference ≤ 2g), indicating that all gravitational water had leached out. Saturation volume was calculated as [(PW1+PW2)/2 – PW0], approximately 200 g. Fertilizer, 18N-11P-4K (The Anderson Lawn Fertilizer Division, Inc., Maumee, OH), was applied at 49 kg N ha^{-1} at seeding. Pots were kept in four mist chambers (one replication per chamber) at 25º C with an 8-hr photoperiod for two week (Week 1 and 2) for germination, during which pots were irrigated under automatic mist systems (8 secs. per 10 mins.) for approximately 3 mL H_2O d^{-1} pot^{-1}. Pots were then removed from the mist chambers and kept in a greenhouse at 25 ºC for another four weeks (Week 3 to 6). Pots were hand-watered with tap water every other day at 100% evapotranspiration (ET) determined volumetrically (Yu et al., 2013).

When the experiment was terminated at Week 6, plants were harvested. Soil was gently hand washed off from the roots with tap water. Root length was measured. Shoot and root were separated and shoot and root dry weight (oven-dried at 65 ºC for 48 hr) were recorded. Specific root length was calculated as root length to root dry mass ratio (Ostonen et al., 2007). The experiment was repeated from 17 Dec. 2015 to 14 Jan. 2016 (Run 2).

Vegetative growth

'Moonlight' and 'Kenblue' were seeded at 147 kg pure live seed ha^{-1} in 25 cm x 50 cm x 7 cm flats, filled with a non-saline top soil and sand mixture (3 cm soil depth) as described previously the greenhouse study initiated on 30 Oct. 2015. Flats were fertilized with a 18N-11P-4K fertilizer (The Anderson Lawn Fertilizer Division, Inc., Maumee, OH) at 49 kg N ha^{-1} at seeding and with another fertilizer, 22N-0P-8K (The Anderson Lawn Fertilizer Division, Inc., Maumee, OH), at 98 kg N ha^{-1} on 24 Nov. 2015. Flats were hand watered with tap water once

daily during germination (~ four weeks) and watered as needed to prevent stress. Grasses were hand-mowed at 4 cm once weekly after germination. The flats were maintained in the greenhouse for a total of two and a half months before saline exposure.

Mature plants (two and a half months old) were cut into 4 cm diam. plugs and then sodded into sixteen salt-amended soil media (four salt types x four salt concentrations) held in plastic bags in 10 x 10 x 10 cm pots as previously described. Eight hundred g of each soil medium was placed in individual pots. Pots were saturated before sodding and the saturation volume (160 g) was determined as previously described. Fertilizer, 22N-0P-8K (The Anderson Lawn Fertilizer Division, Inc., Maumee, OH), was applied at 24.5 kg N ha^{-1} at sodding. Pots were hand-watered with tap water every other day at 100% ET, determined volumetrically (Yu et al., 2013), for six weeks. Grasses were mowed at 4 cm every other week.

Data were collected on visual quality on a 1 - 9 scale, where 1 = dead grass, 6 = acceptable, and 9 = best quality based on color, texture, and uniformity once weekly for six weeks (Morris, 2008). Clippings were combined and weighted after oven-dried at 65 ºC for 24 hrs. When the experiment was terminated on 25 Feb. 2016 (Week 6), soil was gently hand-washed from the roots with tap water. Root length, root dry weight, and specific root length were measured as previously described. Verdure was harvested with green and yellow shoots separated. Green, yellow, and total verdure were recorded after oven-drying at 65 ºC for 48 hrs. The experiment was repeated from 9 Feb. to 22 Mar. 2016 (Run 2).

Statistical analysis

The experiment was set up as a 2 (cultivar) x 4 (salt concentration) x 4 (salt type) factorial design arranged in a RCBD with four replicates (pots) at each growth stage. All data were subjected to analysis of variance (ANOVA) using PROC MIXED (SAS, 2013). Week was

included as a fixed factor when analyzing visual quality data to allow 'time' to be modeled as a repeated measure because quality was determined from the same pots once weekly over the 6-week experimental period. Visual quality was further analyzed separately by week because significant interactions ($P \leq 0.05$) with week were observed (data not shown).. Treatment means were separated using Fisher's protected least significant difference (LSD) at the 0.05 probability level. PROC REG with a linear model was performed to determine plant responses to salt concentration (SAS, 2013). Data points which were higher than three times of standard deviation were considered as outliers and removed from regression analysis (SAS, 2013). The slopes and the intercepts were compared when significant differences were observed (SAS, 2013).

Results

Germination and seedling development

The two runs of the experiment were homogenous; therefore, data were combined before further analysis (data not shown).

A cultivar x salt concentration interaction was observed in shoot dry weight (Table 2). 'Moonlight' and 'Kenblue' both showed decreased shoot biomass with an increase of salinity level (Figure 1). Although the reduction rate was higher in 'Kenblue' (-44.7 mg per dS m^{-1}) than in 'Moonlight' (-31.1 mg per dS m^{-1}), 'Kenblue' outperformed 'Moonlight' under the saline conditions due to its higher shoot dry weight under the non-saline conditions (Figure 1). Shoot dry weight decreased with increasing salt concentrations regardless of salt type with an average slope of -37.4 mg per dS m^{-1} (Table 3). Na_2SO_4- and $MgSO_4$-treated plants had an average shoot dry weight of 553.7 mg when data were pooled across salinity levels (5 - 20 dS m^{-1}), 27% higher than the NaCl- and $MgCl_2$-treated ones (Table 4).

Table 2. Analysis of variance of Kentucky bluegrass grown under the saline conditions at the germination and seedling development stage.

Source of variance	*df*	Shoot dry weight	Root dry weight	Root length	Root dry weight to shoot dry weight	*df*	Specific root length†
Cultivar	1	*	*	*	*	1	*
Salt type	3	*	*	*	ns	3	*
Salt concentration	3	*	*	*	*	2	*
Cultivar x salt type	3	ns	ns	ns	ns	3	*
Cultivar x concentration	3	*	*	ns	ns	2	ns
Salt type x concentration	9	ns	ns	ns	ns	6	ns
Cultivar x salt type x concentration	9	ns	ns	ns	ns	6	ns

* and ns represent significant differences and no significant differences respectively at $P \leq 0.05$.

†Specific root length was quantified at 5, 10, and 15 dS m^{-1}, but not at 20 dS m^{-1} due to limited root biomass harvested at this concentration.

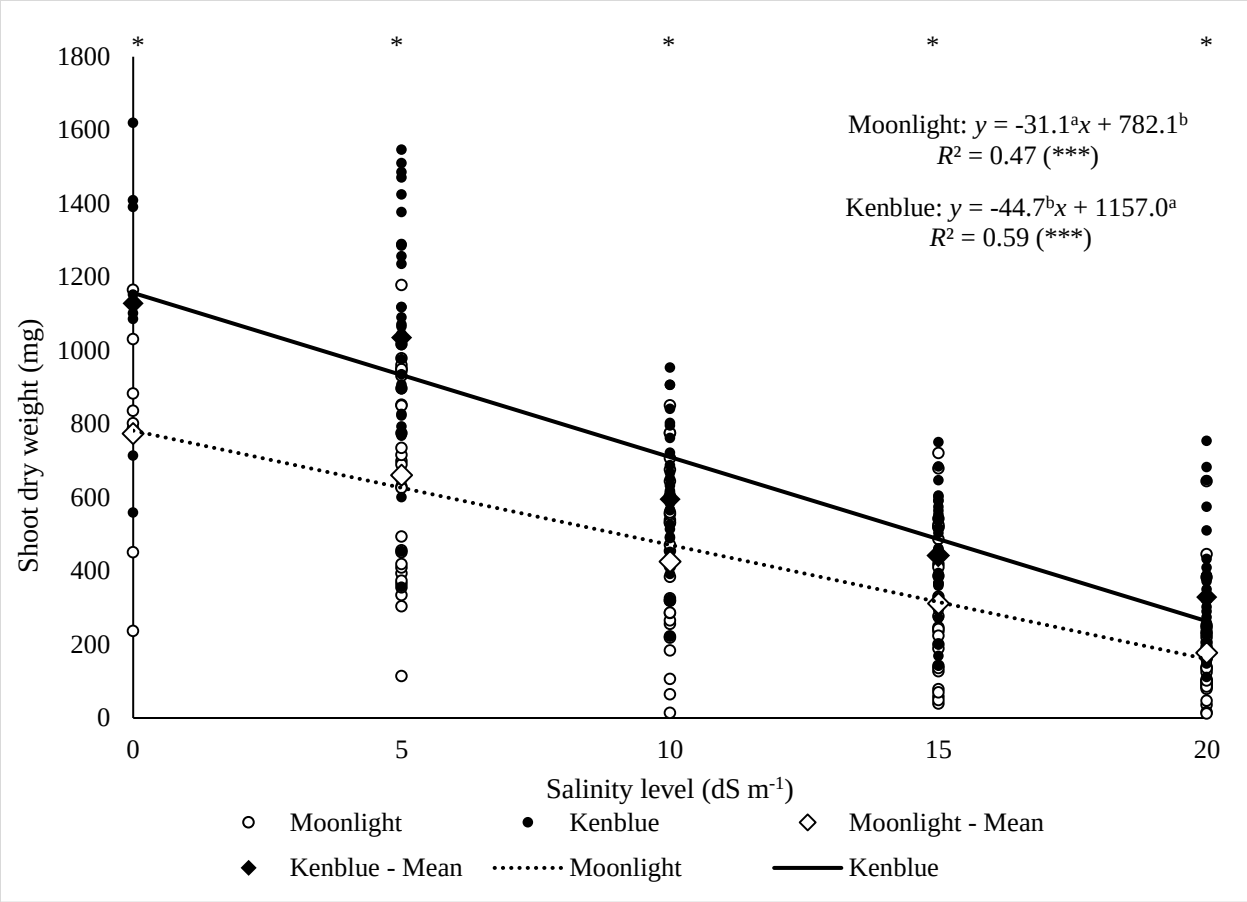

Figure 1. Shoot dry weight (mg) of 'Moonlight' and 'Kenblue' Kentucky bluegrass as affected by salt concentration at the germination and seedling development stage. An asterisk (*) above each individual salinity level indicates significant differences between the two cultivars at $P \leq 0.05$. Slopes and intercepts followed by the same letters are not significantly different between the two cultivars at $P \leq 0.05$.

Table 3. Regression of five Kentucky bluegrass growth indices as affected by NaCl, Na_2SO_4, $MgCl_2$, and $MgSO_4$ at the germination and seedling development stage. Data were pooled across cultivar and salt concentration.

	Shoot dry weight (mg)		Root dry weight (mg)	
	Equation	R^2	Equation	R^2
NaCl	y=-39.1$^{a\dagger}x$+916.6^{a}	0.48 (***)	y=-20.9^{a}x+375.6^{a}	0.60 (***)
Na_2SO_4	y=-35.8^{a}x+1013.3^{a}	0.50 (***)	y=-21.4^{a}x+422.9^{a}	0.63 (***)
$MgCl_2$	y=-38.7^{a}x+941.3^{a}	0.52 (***)	y=-21.6^{a}x+390.0^{a}	0.58 (***)
$MgSO_4$	y=-35.9^{a}x+975.8^{a}	0.52 (***)	y=-21.6^{a}x+402.1^{a}	0.62 (***)
	Root length (cm)		Root dry weight to shoot dry weight (%)	
	Equation	R^2	Equation	R^2
NaCl	y=-0.7^{a}x+15.4^{a}	0.72 (***)	y=-2.1^{a}x+46.7^{a}	0.68 (***)
Na_2SO_4	y=-0.6^{a}x+15.7^{a}	0.77 (***)	y=-2.0^{a}x+46.7^{a}	0.65 (***)
$MgCl_2$	y=-0.7^{a}x+14.6^{a}	0.75 (***)	y=-2.1^{a}x+45.3^{a}	0.65 (***)
$MgSO_4$	y=-0.7^{a}x+14.7^{a}	0.81 (***)	y=-2.1^{a}x+44.9^{a}	0.70 (***)
	Specific root length‡ (cm g^{-1})			
	Equation	R^2		
NaCl	y=5.7^{a}x+47.9^{a}	0.10 (*)		
Na_2SO_4	y=1.6^{a}x+45.4^{a}	0.01 (ns)		
$MgCl_2$	y=2.6^{a}x+53.8^{a}	0.32 (ns)		
$MgSO_4$	y=1.9^{a}x+46.7^{a}	0.05 (ns)		

*, **, and *** represent significant differences at $P \leq 0.05$, 0.01, and 0.001, respectively.
ns represents no significant differences at $P \leq 0.05$.
†Slopes and intercepts followed by same letter within each growth parameter are not significantly different at $P \leq 0.05$.
‡Regression of specific root length was determined based on the data from 0 to 15 dS m^{-1}. Limited root biomass was collected at 20 dS m^{-1}; therefore, specific root length was calculated at 20 dS m^{-1}.

Table 4. Shoot dry weight (mg), root dry weight (mg), root length (cm), root dry weight to shoot dry weight (%), and specific root length (cm g^{-1}) of Kentucky bluegrass as affected by cultivar, salt type, and concentration at the germination and seedling development stage. Numbers in parenthesis represent percentage of the control (i.e. non-saline condition).

Main factor	Shoot dry weight	Root dry weight	Root length	Root dry weight to shoot dry weight	Specific root length
Cultivar					
Moonlight	394.0b[†]	89.4b	6.3b	18.9b	96.4a
Kenblue	600.0a	155.9a	7.6a	21.6a	57.7b
Salt type					
NaCl	419.6b	106.7b	7.0b	21.4a	103.8a
Na_2SO_4	581.3a	152.3a	8.1a	21.8a	59.7c
$MgCl_2$	455.2b	108.2b	6.2c	19.1a	80.4ab
$MgSO_4$	533.1a	123.3b	6.4c	18.7a	64.2bc
Concentration					
5	848.3a (88.7%)	280.1a (64.3%)	11.8a (76.3%)	33.2a (72.8%)	54.3b (107.4%)
10	510.5b (53.6%)	136.2b (31.2%)	8.0b (51.6%)	27.3b (60.0%)	88.9a (175.9%)
15	376.8c (39.6%)	74.2c (17.1%)	4.7c (30.4%)	20.6c (44.4%)	87.8a (173.4%)
20	253.3d (26.6%)	0d (0.0%)	3.3d (21.3%)	0d (0.0%)	NA

[†]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[‡]Specific root length was not calculated at 20 dS m^{-1} due to limited root biomass harvested at this concentration.

Salinity adversely affected root dry weight in both cultivars; however, a faster reduction was observed in ‘Kenblue’ compared to ‘Moonlight’ when data were pooled across salt types (Figure 2). ‘Moonlight’ had a significantly lower root dry weight than ‘Kenblue’ from 0 to 10 dS m^{-1} (Figure 2). As salinity level increased to 20 dS m^{-1}, limited root growth was observed in both cultivars, averaged 0.0 mg (Figure 2). Root dry weight declined at a similar rate, averaged -21.4 mg per dS m^{-1}, under different salt type treatments (Table 3). When data were pooled across cultivar and salt concentration the Na_2SO_4 treatment resulted in a root dry weight of 152.3 mg, 35.1% higher than the other three treatments (average = 112.7 mg) (Table 4).

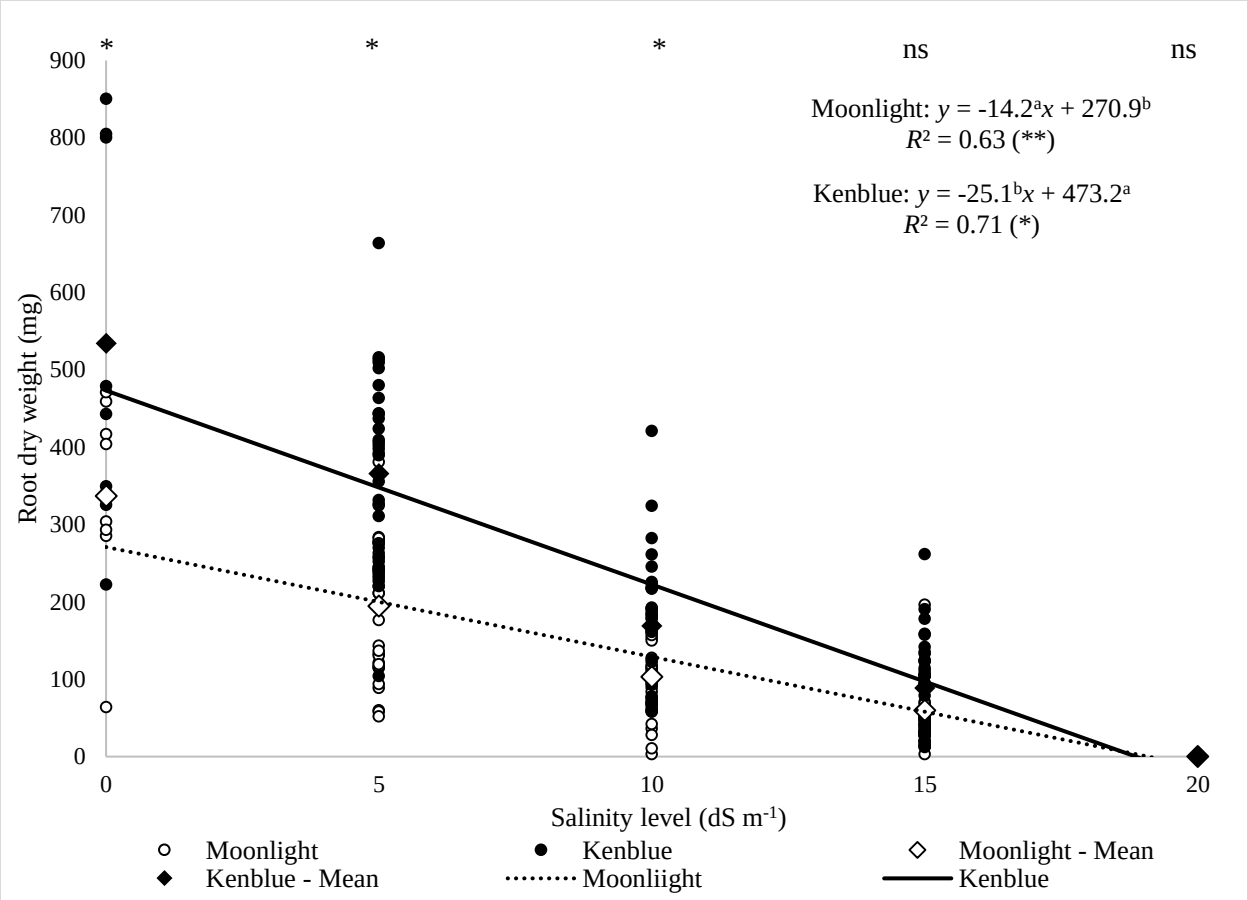

Figure 2. Root dry weight (mg) of 'Moonlight' and 'Kenblue' Kentucky bluegrass as affected by salt concentration at the germination and seedling development stage. An asterisk (*) or "ns" above indicates significant differences and non-significant differences between the two cultivars at $P \leq 0.05$. Slopes and intercepts followed by the same letters are not significantly different between the cultivars at $P \leq 0.05$.

The longest root length of 'Kenblue' and 'Moonlight' was 15.9 and 15.0 cm, respectively, at 0 dS m^{-1}, with no significant difference between the cultivars (data not shown). The longest root length in the salt-treated plants was affected by the three main factors, cultivar, salt type, and salt concentration (Table 2). 'Kenblue' had a root length 22% longer than 'Moonlight' when data were pooled across salt type and concentration (Table 4). Root length decreased linearly significantly along salt concentration, with no differences in the regression slopes among the salt types (Table 3). Plants treated with Na_2SO_4 had the longest root length,

followed by NaCl-treated ones, and $MgCl_2$- and $MgSO_4$-treated plants had the shortest root length (average = 6.3 cm) under the saline conditions (Table 4).

Root dry weight to shoot dry weight decreased linearly with increasing salinity level, with no significant differences in the slopes among the salt types (average = -2.1) (Table 3). 'Kenblue' and 'Moonlight' had a similar level of root dry weight to shoot dry weight at 0 dS m^{-1} (i.e. the control treatment), averaged 45.3% (data not shown); however, 'Kenblue' showed a higher root to shoot ratio than 'Moonlight' when exposed to salinity stress (Table 4).

'Kenblue' and 'Moonlight' had the same level of specific root length under the control treatment, averaged 50.6 cm g^{-1} (data not shown). A cultivar x salt type interaction was observed under the saline condition (Table 2). In 'Moonlight', NaCl treatment had a specific root length 91.8% higher than the other three salt treatments (average = 78.4 cm g^{-1}) (Figure 3). In contrast, salt type had limited effects on the specific root length in 'Kenblue', averaged 57.7 cm g^{-1}. Specific root length was higher in 'Moonlight' than in 'Kenblue' under the NaCl- and $MgCl_2$-treatments. No differences were observed between the two cultivars when the other two types of salt were applied. No linear relationship between specific root length and salt concentration was observed in any type of salt, except NaCl in which specific root length increased at 5.7 cm g^{-1} per dS m^{-1} from 0 to 15 dS m^{-1} (Table 3).

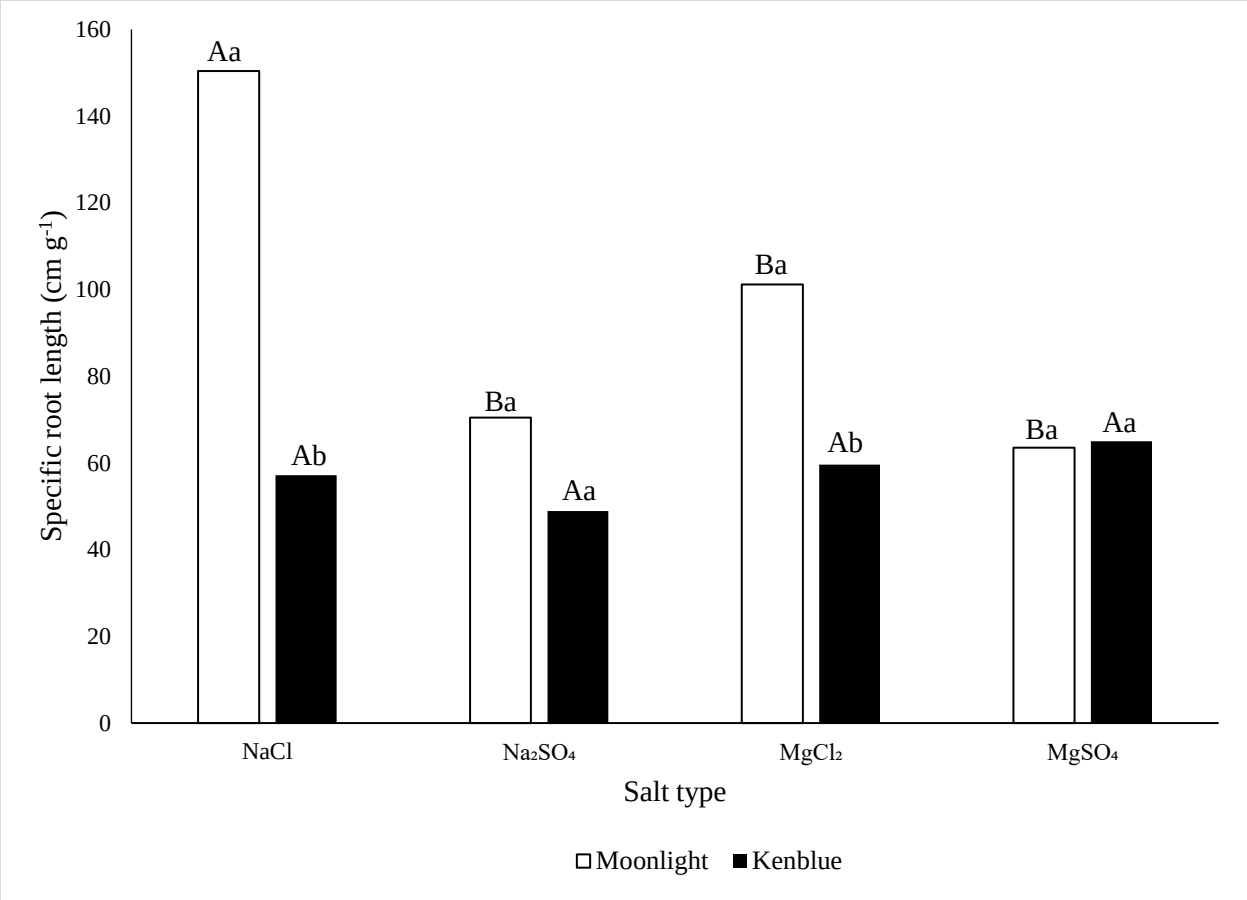

Figure 3. Specific root length (cm g^{-1}) of 'Moonlight' and 'Kenblue' Kentucky bluegrass grown under saline conditions (5 - 15 dS m^{-1}) at the germination and seedling development stage. Upper case letters indicate significant differences among salt types within the same cultivar at $P \leq 0.05$. Lower case letters indicate significant differences between cultivars within the same salt type at $P \leq 0.05$.

Vegetative growth

Total, yellow, and green verdure were influenced by cultivar, salt type, and salt concentration (Table 5). Total and green verdure showed a linear reduction with limited differences in the slopes among the salt types (averaged -17.7 mg per dS m^{-1} for total verdure and -16.8 mg per dS m^{-1} for green verdure) (Table 6). For yellow verdure, however, the linear relationships were only observed in the Na_2SO_4 and $MgSO_4$ treatments, averaged -3.6 mg per dS m^{-1} (Table 6). The plants grown in SO_4^{2-} treated soil media had a higher total and green verdure than Cl^- treated media under the saline conditions (Table 7). A reverse trend was observed in

yellow verdure in which Cl^- salts resulted in a higher tissue dry weight than SO_4^{2-} salts (Table 7). Total, yellow, and green verdure for ‘Moonlight’ was 784.7, 197.6, and 587.1 mg, respectively, under non-saline conditions, with no significant differences compared to ‘Kenblue’ (686.6, 217.9, and 468.7 mg for total, yellow, and green verdure, respectively) (data not shown). When data were pooled across salt type and concentration, ‘Moonlight’ had a higher total and green verdure growth than ‘Kenblue’ but a lower yellow verdure (Table 7).

Table 5. Analysis of variance of Kentucky bluegrass grown under the saline condition at the vegetative growth stage.

Source of variance	*df*	Total verdure	Yellow verdure	Green verdure	Clipping	Root dry weight	Root length	Root dry weight to shoot dry weight[†]	Specific root length
Cultivar	1	*[‡]	*	*	*	*	*	*	*
Salt type	3	*	*	*	*	*	*	ns	*
Concentration	3	*	*	*	*	*	*	*	*
Cultivar x salt type	3	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar x concentration	3	ns	ns	ns	ns	*	*	ns	*
Salt type x concentration	9	ns	ns	ns	ns	ns	ns	*	ns
Cultivar x salt type x concentration	9	ns	ns	ns	ns	ns	ns	ns	ns

* and ns represent significant differences and no significant differences at $P \leq 0.05$.

[†]Shoot dry weight = total verdure + clipping

Table 6. Regression of Kentucky bluegrass growth indices as affected by NaCl, Na_2SO_4, $MgCl_2$, and $MgSO_4$ at the vegetative growth stage. Data were pooled across cultivar and salt concentration.

	Total verdure (mg)		Yellow verdure (mg)	
	Equation	R^2	Equation	R^2
NaCl	y=-18.8$^{a\dagger}x$+755.7^{a}	0.20 (***)	y=1.8^{a}x+266.9^{a}	0.01 (ns)
Na_2SO_4	y=-15.8^{a}x+742.6^{a}	0.13 (**)	y=-3.7^{b}x+207.5^{b}	0.08 (*)
$MgCl_2$	y=-20.1^{a}x+763.3^{a}	0.21 (***)	y=1.6^{a}x+256.5^{a}	0.01 (ns)
$MgSO_4$	y=-16.1^{a}x+775.4^{a}	0.12 (**)	y=-3.4^{b}x+212.9^{b}	0.06 (*)
	Green verdure (mg)		Clipping (mg)	
	Equation	R^2	Equation	R^2
NaCl	y=-20.7^{a}x+488.8^{a}	0.31 (***)	y=-32.6^{a}x+686.9^{a}	0.49 (***)
Na_2SO_4	y=-12.1^{a}x+535.0^{a}	0.11 (**)	y=-28.4^{a}x+721.5^{a}	0.38 (***)
$MgCl_2$	y=-21.7^{a}x+506.9^{a}	0.36 (***)	y=-33.3^{a}x+713.7^{a}	0.50 (***)
$MgSO_4$	y=-12.7^{a}x+562.5^{a}	0.11 (**)	y=-31.0^{a}x+746.6^{a}	0.43 (***)
	Root dry weight (mg)		Root length (cm)	
	Equation	R^2	Equation	R^2
NaCl	y=-19.6^{a}x+628.0^{a}	0.27 (***)	y=-0.7^{a}x+19.7^{a}	0.69 (***)
Na_2SO_4	y=-18.7^{a}x+665.5^{a}	0.27 (***)	y=-0.6^{a}x+20.1^{a}	0.66 (***)
$MgCl_2$	y=-20.8^{a}x+645.0^{a}	0.32 (***)	y=-0.6^{a}x+19.1^{a}	0.66 (***)
$MgSO_4$	y=-18.1^{a}x+686.7^{a}	0.21 (***)	y=-0.7^{a}x+19.8^{a}	0.80 (***)
	Root dry weight to Shoot dry weight (%)		Specific root length (cm g^{-1})	
	Equation	R^2	Equation	R^2
NaCl	y=1.1^{a}x+40.8^{a}	0.15 (***)	y=-0.4^{a}x+39.5^{a}	0.04 (*)
Na_2SO_4	y=0.5^{a}x+47.8^{a}	0.04 (ns)	y=-0.5^{a}x+38.1^{a}	0.01 (*)
$MgCl_2$	y=1.2^{a}x+41.4^{a}	0.21 (***)	y=-0.5^{a}x+38.4^{a}	0.05 (*)
$MgSO_4$	y=1.2^{a}x+42.5^{a}	0.18 (***)	y=-0.8^{a}x+38.0^{a}	0.14 (**)

*, **, and *** represent significant differences at $P \leq 0.05$, 0.01, and 0.001, respectively.
ns represents no significant differences at $P \leq 0.05$.
†Slopes and intercepts followed by same letter within each growth parameter are not significantly different at $P \leq 0.05$.

Table 7. Total verdure (mg), yellow verdure (mg), green verdure (mg), clipping (mg), root length (cm), root dry weight to shoot dry weight (%), and specific root length (cm g^{-1}) of Kentucky bluegrass as affected by cultivar, salt type, and concentration at the vegetative growth stage. Numbers in parenthesis represent percentage of the control (i.e. non-saline condition).

Main factor	Total verdure	Yellow verdure	Green verdure	Clipping	Root dry weight	Root length	Root dry weight to shoot dry weight†	Specific root length
Cultivar								
Moonlight	581.7a‡	195.2b	368.5a	340.1a	462.4a	11.8a	58.1a	29.8b
Kenblue	506.3b	268.0a	238.3b	311.0b	353.4b	10.9b	53.6b	35.2a
Salt type								
NaCl	525.4b	304.5a	220.9b	267.3b	363.4b	11.4b	54.1a	36.5a
Na_2SO_4	546.5ab	161.0b	385.5a	379.3a	442.6a	12.8a	55.5a	32.8b
$MgCl_2$	519.5b	288.9a	230.6b	293.1b	370.0b	10.8b	55.0a	32.9b
$MgSO_4$	584.5a	172.0b	412.5a	362.5a	455.7a	10.7b	56.9a	27.9c
Concentration								
5	690.1a (93.8%)	261.3a (125.8%)	428.8a (81.2%)	561.7a (76.6%)	541.7a (76.7%)	17.0a (84.5%)	45.2c (92.8%)	40.6a (111.4%)
10	603.0b (82.0%)	239.4ab (115.3%)	363.6b (68.9%)	385.3b (52.6%)	432.8b (61.4%)	12.3b (61.2%)	49.4c (101.0%)	33.4b (91.7%)
15	489.1c (66.5%)	220.3bc (106.1%)	268.8c (50.9%)	233.4c (31.8%)	336.5c (47.7%)	9.0c (44.8%)	54.8b (113.4%)	30.0c (82.3%)
20	393.8d (53.5%)	205.4c (98.9%)	188.4d (35.7%)	121.8d (16.6%)	320.6c (45.5%)	7.5d (37.3%)	72.0a (148.4%)	26.1d (71.6%)

†Shoot dry weight = total verdure + clipping

‡Means followed by the same letter are not significantly different at $P \leq 0.05$.

Similar to verdure growth, clipping dry weight was affected by cultivar, salt type, and salt concentration (Table 5). Clippings decreased linearly at a similar rate, averaged -31.3 mg per dS m^{-1}, in all types of salt (Table 6). The average clipping dry weight of Na_2SO_4 and $MgSO_4$ treatments was 372.3 mg under saline conditions, 32.9% higher than that of the NaCl and $MgCl_2$ treatments (Table 7). Clipping dry weight of 'Kenblue' and 'Moonlight' was 728.2 and 737.8 mg at 0 dS m^{-1}, respectively, with no significant differences between the two cultivars (data not shown). However, 'Moonlight' had a higher clipping dry weight than 'Kenblue' when data were pooled across salt types and concentrations (Table 7).

Linear relationships were observed in root dry weight in both cultivars, in which root dry weight decreased with an increase of salinity level (Table 6). There are no significant differences between Kentucky bluegrass cultivars, averaged -16.7 mg per dS m^{-1}, (Figure 4). 'Moonlight' had a higher root dry weight than 'Kenblue' at low to moderate high salinity levels (5 - 15 dS m^{-1}) due to its higher growth (i.e. intercept) (Figure 4). As salinity increased to 20 dS m^{-1}, the differences between the two cultivars diminished (average = 320.7 mg). The four types of salt also showed a similar reduction slope, averaged -19.3 mg per dS m^{-1} (Table 6). The plants grown in $MgSO_4$-amended soils had the same level of root dry weight as those under the Na_2SO_4 treatment when data were pooled across salinity levels, but higher than those under the NaCl- and $MgCl_2$-treated soil (average = 366.7 mg) (Table 7).

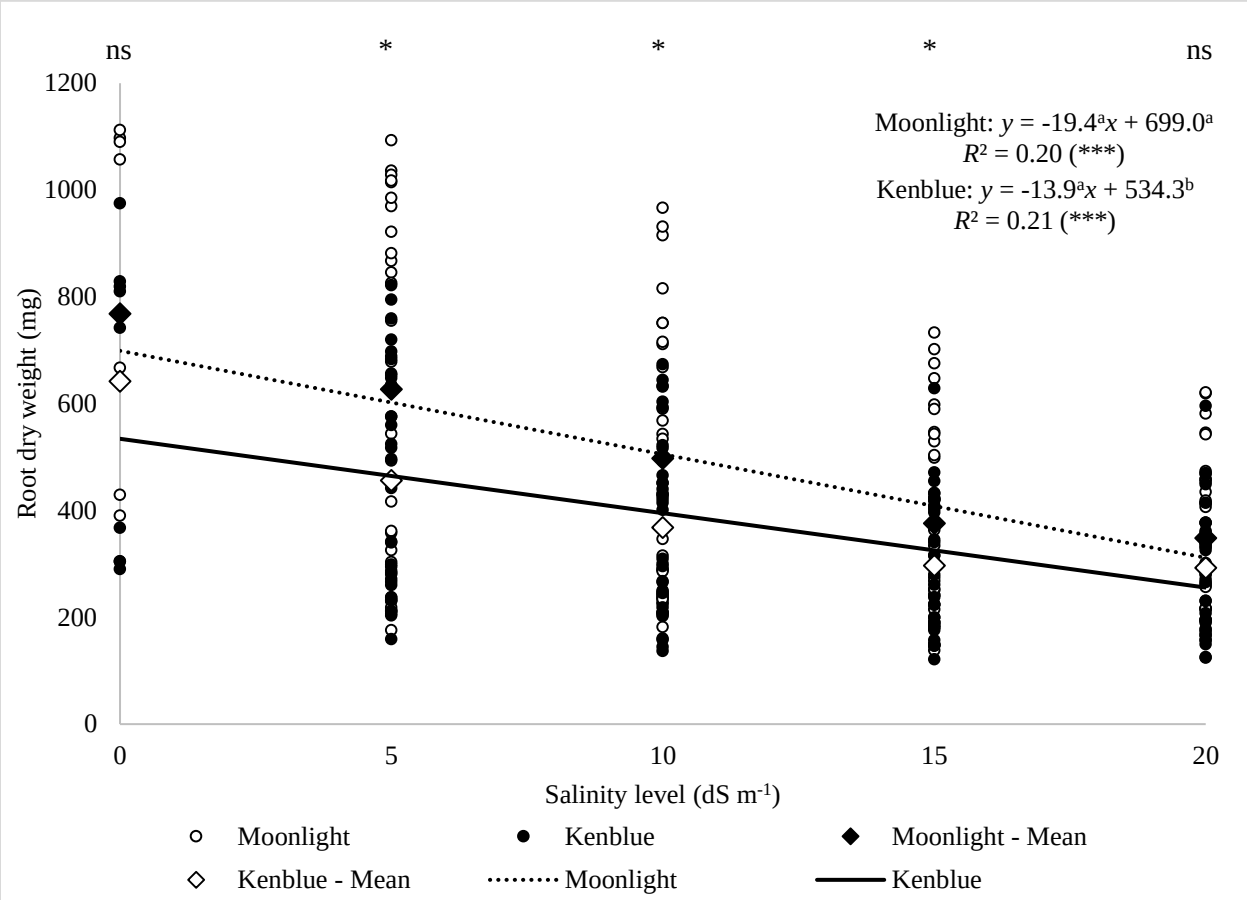

Figure 4. Root dry weight (mg) of 'Moonlight' and 'Kenblue' Kentucky bluegrass as affected by salt concentration at the vegetative growth stage. An asterisk (*) or "ns" above each individual salinity level indicates significant and non -significant differences between the two cultivars at $P \leq 0.05$. Slopes and intercepts followed by the same letters are not significantly different between the two cultivars at $P \leq 0.05$.

A cultivar x salt concentration interaction was observed in root length when the plants were exposed to salinity (Table 5). Root length decreased linearly with increasing salinity levels in all salt types, with an averaged slope of -0.66 cm per dS m^{-1} (Table 6). Although root length declined faster in 'Kenblue' (slope = -0.69) than in 'Moonlight' (slope = -0.57), only 'Kenblue' showed a significantly lower root length at 15 dS m^{-1} (Figure 5). Under saline conditions, plants grown in Na_2SO_4-treated soil mixture had a root length of 12.8 cm, significantly longer than those grown in the other three types of salt (average = 11.0 cm) (Table 7).

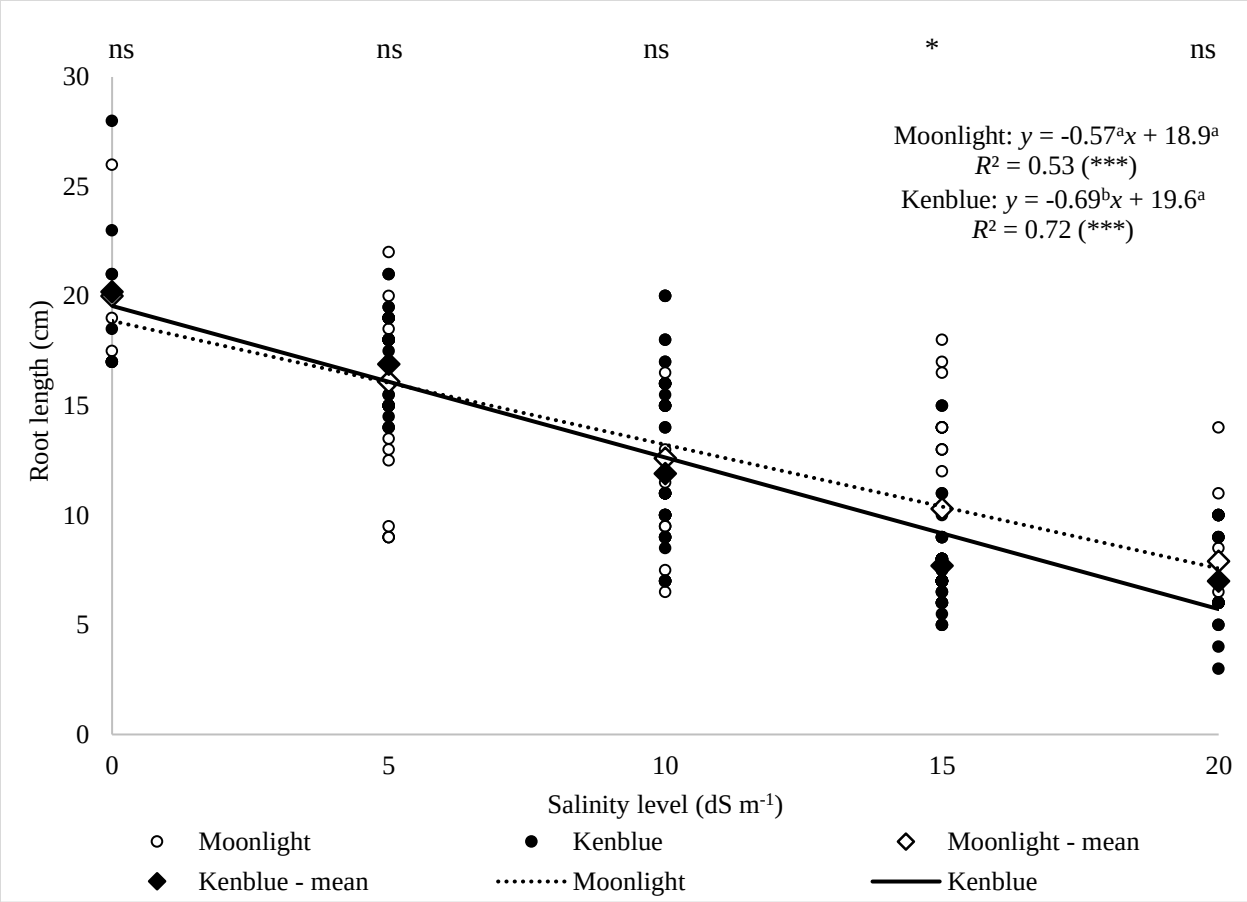

Figure 5. Root length (cm) of 'Moonlight' and 'Kenblue' Kentucky bluegrass as affected by salt concentration at the vegetative growth stage. An asterisk (*) or "ns" above each individual salinity level indicates significant and non -significant differences between the two cultivars at $P \leq 0.05$. Slopes and intercepts followed by the same letters are not significantly different between the two cultivars at $P \leq 0.05$.

A two-way interaction, salt type x salt concentration, was observed in root dry weight to shoot dry weight (i.e. total verdure + clipping) ratio (Table 5). No linear relationship was observed between root to shoot ratio and salt concentration under the Na_2SO_4 treatment (Table 6), while root to shoot ratio increased linearly under the other three salt types with a similar slope (average = 1.1% per dS m^{-1}) (Table 6). Averaged root to shoot ratio for Kentucky bluegrass was 48.8% under the non-saline condition, with no significant differences between the two cultivars (data not shown). However, 'Moonlight' had a higher root to shoot ratio than 'Kenblue' when exposed to salinity (Table 7).

Cultivar and salt concentration interactively affected specific root length under saline conditions (Table 5). ‘Moonlight’ and ‘Kenblue’ had a similar level of growth reduction in specific root length, averaged -0.70 cm g^{-1} per dS m^{-1} (Figure 6). Higher intercepts observed in ‘Kenblue’ may have contributed to its higher specific root length than ‘Moonlight’ at low to moderate salinity levels, ≤ 10 dS m^{-1} (Figure 6). Specific root length reduced linearly at -0.57 cm g^{-1} per dS m^{-1} across the salt types (Table 6). Averaged specific root length of the plants grown in Na_2SO_4- and $MgCl_2$-treated soil mixtures was 32.9 cm g^{-1} when data were pooled across cultivar and salt concentration, 10.9% lower than plants grown in NaCl-treated soil and 17.9% higher than plants grown in the $MgSO_4$-treated mixture (Table 7).

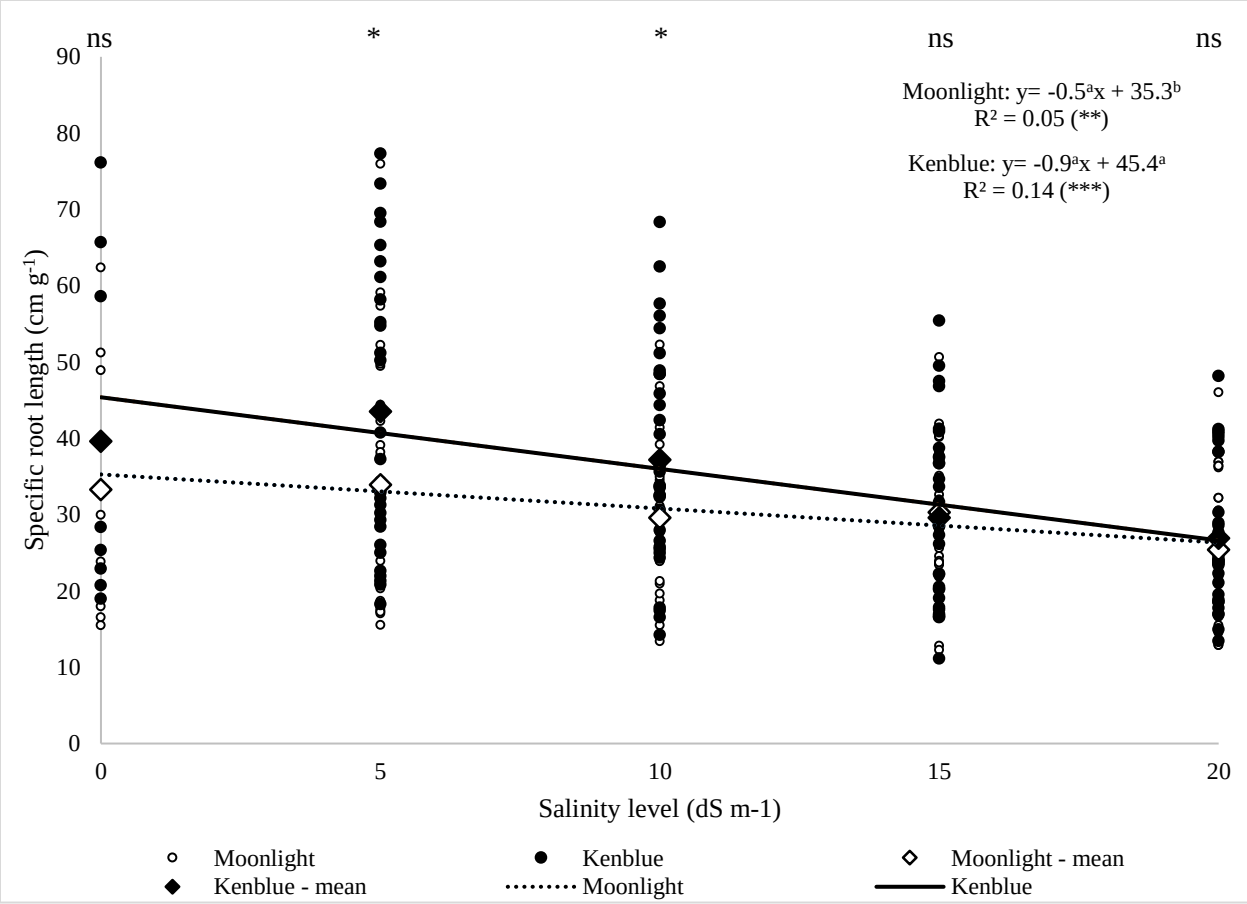

Figure 6. Specific root length (cm g^{-1}) of 'Moonlight' and 'Kenblue' Kentucky bluegrass as affected by salt concentration at the vegetative growth stage. An asterisk (*) or "ns" above each individual salinity level indicates significant and non -significant differences between the two cultivars at $P \leq 0.05$. Slopes and intercepts followed by the same letters are not significantly different between the two cultivars at $P \leq 0.05$.

Both cultivars showed similar and acceptable visual quality (Q ≥ 6) under the control treatment from W1 to W6 (data not shown). Visual quality was primarily affected by cultivar, salt type, and salt concentration during saline exposure treatment (Table 8). 'Moonlight' had a higher visual quality than 'Kenblue' from W1 to W6 when data were pooled across salt type and concentration (Table 9). 'Moonlight' provided acceptable quality at W1 and W2, while, 'Kenblue' did not provide adequate performance (i.e. Q < 6.0) at any week during saline exposure (Table 9). Visual quality decreased linearly along with increasing salt concentrations (Table 10) Overall, visual quality decreased in the following order among the four types of salt:

$Na_2SO_4 \geq MgSO_4 \geq MgCl_2 \geq NaCl$ (Table 10). A similar trend was observed when the two-way interaction, salt type x concentration, was observed at W2 and W3 (data not shown). When data were pooled across cultivar and salt concentration, the plants under Na_2SO_4 and $MgSO_4$ treatments had a higher visual quality compared to the NaCl and $MgCl_2$ treatments during the 6-wk experimental period (Table 10).

Table 8. Analysis of variance of visual quality of Kentucky bluegrass grown under saline conditions at the vegetative growth stage.

Source of variance	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Cultivar	*	*	*	*	*	*
Salt type	*	*	*	*	*	*
Concentration	*	*	*	*	*	*
Cultivar x salt type	ns	ns	ns	ns	ns	ns
Cultivar x concentration	ns	ns	ns	ns	ns	ns
Salt type x concentration	ns	*	*	ns	ns	ns
Cultivar x salt type x concentration	ns	ns	ns	ns	ns	ns

* and ns represent significant differences and no significant differences at $P \leq 0.05$.

Table 9. Visual quality of Kentucky bluegrass as affected by cultivar, salt type, and concentration at the vegetative growth stage.

Main factor	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Cultivar						
Moonlight	6.3a[†]	6.0a	5.4a	4.7a	4.4a	4.1a
Kenblue	5.3b	4.9b	4.1b	3.6b	3.3b	3.1b
Salt type						
NaCl	5.6b	5.2b	4.1b	3.4b	3.0b	2.9b
Na_2SO_4	6.1a	5.9a	5.4a	4.8a	4.6a	4.3a
$MgCl_2$	5.3b	4.9b	4.2b	3.6b	3.4b	3.1b
$MgSO_4$	6.0a	5.9a	5.2a	4.8a	4.5a	4.1a
Concentration						
5	6.7a	6.5a	6.2a	5.6a	5.1a	4.8a
10	6.2b	6.0b	5.3b	4.6b	4.2b	4.1b
15	5.5c	5.0c	4.1c	3.6c	3.4c	3.2c
20	4.7d	4.4d	3.4d	2.8d	2.7d	2.3d

[†]Means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 10. Regression of visual quality of Kentucky bluegrass as affected by NaCl, Na_2SO_4, $MgCl_2$, and $MgSO_4$ at the vegetative growth stage. Data were pooled across cultivar and salt concentration.

	Week 1		Week 2	
	Equation	R^2	Equation	R^2
NaCl	y=-0.13$^{ab\dagger}x$+7.2^{a}	0.42 (***)	y=-0.16^{bc}x+7.1^{a}	0.51 (***)
Na_2SO_4	y=-0.098^{a}x+7.3^{a}	0.37 (***)	y=-0.085^{a}x+7.0^{a}	0.22 (***)
$MgCl_2$	y=-0.17^{b}x+7.4^{a}	0.61 (***)	y=-0.20^{c}x+7.4^{a}	0.59 (***)
$MgSO_4$	y=-0.12^{a}x+7.4^{a}	0.45 (***)	y=-0.12^{ab}x+7.4^{a}	0.50 (***)
	Week 3		Week 4	
	Equation	R^2	Equation	R^2
NaCl	y=-0.23^{b}x+7.0^{a}	0.72 (***)	y=-0.23^{bc}x+6.4^{a}	0.70 (***)
Na_2SO_4	y=-0.13^{a}x+7.1^{a}	0.43 (***)	y=-0.16^{a}x+6.8^{a}	0.54 (***)
$MgCl_2$	y=-0.25^{b}x+7.3^{a}	0.69 (***)	y=-0.24^{c}x+6.7^{a}	0.74 (***)
$MgSO_4$	y=-0.18^{a}x+7.4^{a}	0.63 (***)	y=-0.19^{ab}x+7.1^{a}	0.66 (***)
	Week 5		Week 6	
	Equation	R^2	Equation	R^2
NaCl	y=-0.19^{b}x+5.6^{b}	0.63 (***)	y=-0.21^{a}x+5.6^{b}	0.73 (***)
Na_2SO_4	y=-0.14^{a}x+6.3^{a}	0.39 (***)	y=-0.16^{a}x+6.3^{a}	0.53 (***)
$MgCl_2$	y=-0.20^{c}x+6.0^{ab}	0.61 (***)	y=-0.21^{a}x+5.8^{ab}	0.62 (***)
$MgSO_4$	y=-0.17^{ab}x+6.5^{a}	0.54 (***)	y=-0.18^{a}x+6.3^{a}	0.64 (***)

*, **, and *** represent significant differences at $P \leq 0.05$, 0.01, and 0.001, respectively.
ns represents no significant differences at $P \leq 0.05$.
†Slopes and intercepts followed by same letter with each week are not significantly different at $P \leq 0.05$.

Discussion

Salinity adversely affects plant growth, development, and performance, including turfgrass. Severity of salinity stress is highly influenced by salt concentration. All growth indices (except specific root length at the germination and seedling development stage) and turfgrass visual quality decreased with an increase of salt concentration in the present study (Tables 4, 7 and 9). However, sensitivity to salinity stress varies among growth indices (Zhang et al, 2011). For example, shoot dry weight at the germination and seedling development stage decreased 11.3%, 46.4%, and 60.4% at 5, 10, and 15 dS m^{-1} compared to 33.7%, 68.8%, and 82.9% in root dry weight at the same salinity levels (Table 4). Plants were still able to produce shoot growth at 20 dS m^{-1}; however, limited root growth was observed at the same concentration (Table 4). Therefore, root growth was more sensitive to salinity compared to shoot growth at the germination and seedling growth stage based on dry weight (Table 4). Among all the growth indices evaluated, root and leaf growth were the most sensitive to salinity at the germination and seedling growth stage (Table 4) and the vegetative growth stage (Table 7), respectively, and can be used as a growth index to screen salinity tolerance in turfgrass in the aforementioned stages.

Specific root length is negatively associated with root diameter (Comas et al., 2013; Lovelli et al., 2007). Snapp and Shennan (1992) suggested that the thinner roots were efficient in osmotic adjustment as it had limited effects on the carbon partitioned to root tips. As the main organ for water absorption, a root system with a high specific root length is considered an adaptive mechanism that allows plants to thoroughly explore the soil volume, avoiding drought stress (Almansouri et al., 2001; Lovelli et al., 2012; Maggio et al., 2007). Huang and Fry (1998) reported increased specific root length under drought conditions. The drought tolerant tall fescue

variety, K-31, had a higher specific root length than the sensitive cultivar, MIC18 (Huang and Fry, 1998). Similarly, Huang (2001) observed a positive relationship between specific root length and relative drought tolerance in three tall fescue cultivars, Falcon II, Rebel Jr., and Houndog V. In contrast, 'Tifblair' centipedegrass (Eremochloa Büse (Poaceae)) and seashore paspalum (four ecotypes), which were more drought tolerant than common bermudagrass and 'Emerald' zoysiagrass, showed a lower specific root length compared to common bermudagrass and 'Emerald' zoysiagrass both under well-watered and drought conditions (Huang et al., 1997). Loveli et al. (2012) reported a higher specific root length in tomato (*Solanum lycopersium* L.) plants grown under 150 mM NaCl compared to non-stressed plants. Rubinigg et al. (2013) observed an increase of specific root length along with increasing salinity level in salt-treated *Plantago matritima* (L.). However, some research reported contrasting results. For example, Snapp and Shennan (1992) did not observe inhibited root growth in tomato plants under a relative low salinity level, 75 mM. Specific root length was at a similar level between tomato plants under the control (i.e. non-stress) and NaCl at100 mM (Lovelli et al., 2007). Faba bean (*Vicia faba* L.) plants showed reduced root length and biomass under saline conditions (Abdelhamid et al., 2010), while alfalfa (*Medicago sativa* L.) had increased root extension, particularly in the upper 30 cm of the high fibrous root population (Vaughan et al., 2002). These contradicting findings suggested that root morphological modification under drought and saline conditions may be affected by stress severity (e.g. salt concentration) and genotype (species and/or cultivar). In the present study, specific root length increased along with increasing salinity levels (0 to 15 dS m^{-1}) at the germination and seedling growth stages (Tables 3 and 4). A reverse trend was observed at the vegetative growth stage, in which specific root length decreased with

increasing salinity levels (Tables 6 and 7). Our results indicated that specific root length might respond to salinity differently depending on the plant growth stage.

Most of the research evaluating salinity tolerance in plants were conducted using NaCl. There is comparatively limited information on plant responses to other salts. Gao et al. (2012) evaluated tall fescue performance under NaCl, Na_2SO_4, Na_2CO_3, and $CaCl_2$ salinity. Their results showed that Na_2CO_3 caused the most severe damage, followed by Na_2SO_4 and $CaCl_2$, with NaCl causing the least amount. Similar findings were reported by Yu et al. (2013) and Han et al. (2014). Salt solutions were applied at iso-molar concentrations in the aforementioned studies, in which NaCl had the lowest EC and highest osmotic potential among the salt solutions at the same iso-molar concentration (Gao et al., 2012). In the study of Rogers et al. (1998), lucerne (*Medicago sativa* L.) was exposed to NaCl and Na_2SO_4 at the same salinity level (i.e. EC), ranging from 2 to 17 dS m^{-1}. Higher growth reduction was detected in NaCl-treated plants compared to the Na_2SO_4-treated ones. In the present study, a similar trend was observed in which plants subjected to Na_2SO_4 and/or $MgSO_4$ had higher growth indices (except specific root length) and better visual performance than the plants under NaCl and/or $MgCl_2$ when significant differences were observed among salt types (Tables 4, 7, and 9). Sulfate, the sulfur absorption source for plants, is assimilated into organic molecules in thiol (-SH) groups in proteins (cysteine-residues) or non-protein thiols (glutathione) in plants (Nazar et al., 2011). The ratio of reduced glutathione and oxidized glutathione involved in scavenging of reactive oxygen species that are commonly accumulated under stressful conditions (e.g., salinity and drought) and cause oxidative stress (Kocsy et al., 2002; Kranner et al., 2002; Nazar et al., 2011). Furthermore, SO_4^{2-} improved photosynthesis and growth by enhancing the activity of nitrate reductase and the accumulation of N (Khan et al., 2005; Pal et al., 1976). Al-Hamzawi (2007) reported a

contradictory finding that Na_2SO_4 was more detrimental to faba-bean than NaCl at the same salinity level (EC = 3 - 6 dS m^{-1}). NaCl-treated faba-bean had a higher mineral uptake (Na, Cl, P, K, and Ca) and proline accumulation than Na_2SO_4-treated plants (Al-Hamzawi, 2007). Lee and Iersel (2008) and Kang et al. (2014) reported positive effects of NaCl on plant growth, particularly under moderate salinity levels. Similar trends were observed in *Atriplex halimus* (L.), *Suaeda salsa* (L.) *Pall, Kosteletzkya Virginia* (L.) Presl, and *Zygophyllum xanthoxylum* (Bunge) Maxim (Bajji et al., 1998; Martinez et al., 2005; Ghanem et al., 2008; Ma et al., 2012) in which plant biomass was positively correlated with leaf Na accumulation. Sodium isolated in vacuoles in photosynthesized stems and leaves may help in osmotic adjustment, increasing water absorption in plants subjected to salinity and drought (Kang et al. 2014; Wang et al., 2004; Yue et al. 2012). Chen et al. (2002) showed that some plants preferentially deposited Na in the apoplastic space rather than compartmentalizing it in the vacuole, minimizing salinity damage. Overall, plant sensitivity to chloride and sulfate salts varies between plant species and may be dependent on nutrient uptake and regulation.

There are large intraspecific differences in salinity tolerance and such differences maybe vary between growth stages. For example, Dai et al. (2009) reported that relative ranking of salinity tolerance in annual bluegrass (*Poa annua* L.) cultivars were not consistent between the germination and vegetative growth stages. ‘Bad River’ and ‘Lovington’ blue grama (*Bouteloua gracilis* (Kunth) Lag. ex Steud.) had a higher germination rate than ‘Hachita’ under saline exposure; however, the three blue grama ecotypes performed similarly during the vegetative growth stage (Zhang et al., 2012). Comparing the two cultivars in the present study, mature ‘Moonlight’ showed higher plant growth and better turf quality than ‘Kenblue’ at the vegetative growth stage (Tables 7 and 9). The results were consistent with the findings of Rose-Fricker and

Wipff (2001) and Qian (2003). However, a reversed trend was observed at the germination and seedling growth stage, in which ‘Kenblue’ had higher shoot dry weight, root dry weight, and longer root length than ‘Moonlight’ (Table 4). Higher tissue biomass of ‘Kenblue’ seedlings might be due to its faster growth rate. ‘Kenblue’ germinated 5 days after planting, compared to 7 days for ‘Moonlight’ (visual observation) and had a higher shoot and root biomass than ‘Moonlight’ under non-saline conditions (Figures 1 and 2). The relatively faster germination rate and higher seedling growth of ‘Kenblue’ is likely attributed to its better performance at the germination and seedling growth stage compared to ‘Moonlight.’

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APPENDIX

Table A1. Analysis of variance of soil salinity (EC_e) and evapotranspiration (ET) under the saline conditions at the germination and seedling development stage.

Source of variance	*df*	EC_e	ET
Cultivar	1	ns	ns
Salt type	3	*	*
Concentration	3	*	*
Cultivar x salt type	3	ns	ns
Cultivar x concentration	3	ns	ns
Salt type x concentration	9	ns	ns
Cultivar x salt type x concentration	9	ns	ns

* and ns represent significant differences and no significant differences at $P \leq 0.05$.

Table A2. Regression of soil salinity (EC_e) and evapotranspiration (ET) as affected by NaCl, Na_2SO_4, $MgCl_2$, and $MgSO_4$ at the germination and seedling development stage. Data were pooled across cultivar and salt concentration.

	EC_e (dS m^{-1})		ET (g)	
	Equation	R^2	Equation	R^2
NaCl	$y=1.0^{a\dagger}x+0.6^{a}$	0.96 (***)	$y=-9.2^{a}x+672.3^{a}$	0.41 (***)
Na_2SO_4	$y=1.0^{a}x+1.1^{a}$	0.98 (***)	$y=-9.8^{a}x+691.8^{a}$	0.46 (***)
$MgCl_2$	$y=0.9^{a}x+0.7^{a}$	0.97 (***)	$y=-9.9^{a}x+681.1^{a}$	0.39 (***)
$MgSO_4$	$y=1.0^{a}x+1.0^{a}$	0.96 (***)	$y=-10.7^{a}x+691.8^{a}$	0.56 (***)

*** represents significant differences at $P \leq 0.001$.

†Slopes and intercepts followed by the same letters within each parameter are not significantly different at $P \leq 0.05$.

Table A3. Soil salinity (EC_e, dS m^{-1}) and evapotranspiration (ET, g) as affected by cultivar, salt type, and concentration at the germination and seedling development stage. Number in parenthesis represents percentage of the control (i.e. non-saline condition).

Main factor	EC_e	ET
Cultivar		
Moonlight	12.6a†	552.4a
Kenblue	12.3a	560.2a
Salt type		
Nacl	12.4b	549.6b
Na_2SO_4	13.1a	567.3a
$MgCl_2$	11.6c	552.9b
$MgSO_4$	12.8ab	555.3ab
Concentration		
5	5.0a (414.9%)	629.9a (89.8%)
10	10.2b (975.6%)	563.6b (80.3%)
15	15.0c (1244.8%)	524.5c (74.8%)
20	19.6d (1626.6%)	507.1d (72.3%)

†Means followed by the same letter are not significantly different at $P \leq 0.05$.

Table A4. Analysis of variance of soil salinity (EC_e), pH, and evapotranspiration (ET) under saline condition at the vegetative growth stage.

Source of variance	*df*	EC	pH†	ET
Cultivar	1	ns†	*	*
Salt type	3	ns	*	ns
Concentration	3	*	*	*
Cultivar x salt type	3	ns	ns	ns
Cultivar x concentration	3	ns	ns	ns
Salt type x concentration	9	ns	*	ns
Cultivar x salt type x concentration	9	ns	ns	ns

* and ns represent significant differences and no significant differences at $P \leq 0.05$.
†Soil pH was measured in Run 2 only.

Table A5. Regression of soil salinity (EC_e), pH, and evapotranspiration (ET) as affected by NaCl, Na_2SO_4, $MgCl_2$, and $MgSO_4$ at the vegetative growth stage. Data were pooled across cultivar and salt concentration.

	EC_e (dS m^{-1})		pH	
	Equation	R^2	Equation	R^2
NaCl	y=0.9$^{a\dagger}x$+1.3^a	0.95 (***)	y=-0.01$^a x$+7.7^a	0.34 (***)
Na_2SO_4	y=0.8$^a x$+1.6^a	0.96 (***)	y=-0.02$^a x$+7.7^a	0.47 (***)
$MgCl_2$	y=0.8$^a x$+1.6^a	0.96 (***)	y=-0.02$^a x$+7.7^a	0.42 (***)
$MgSO_4$	y=0.9$^a x$+1.3^a	0.95 (***)	y=-0.02$^a x$+7.6^a	0.36 (***)

	ET (g)	
	Equation	R^2
NaCl	y=-20.0$^a x$+912.6^a	0.39 (***)
Na_2SO_4	y=-20.5$^a x$+931.9^a	0.33 (***)
$MgCl_2$	y=-21.4$^a x$+917.3^a	0.41 (***)
$MgSO_4$	y=-22.3$^a x$+956.6^a	0.32 (***)

*** represents significant differences at $P \leq 0.001$.

†Slopes and intercepts followed by same letters within each column are not significantly different at $P \leq 0.05$.

Table A6. Soil salinity (EC_e, dS m^{-1}), pH, and evapotranspiration (ET, g) as affected by cultivar, salt type, and concentration at the vegetative growth stage. Number in parenthesis represents percentage of the control (i.e. non-saline condition).

Main factor	EC_e (dS m^{-1})	pH	ET(g)
Cultivar			
Moonlight	11.9a[†]	7.48a	668.9a
Kenblue	11.6a	7.37b	639.2b
Salt type			
NaCl	11.7a	7.53a	646.3a
Na_2SO_4	11.9a	7.36b	663.3a
$MgCl_2$	11.8a	7.48a	634.6a
$MgSO_4$	11.7a	7.34b	671.9a
Concentration			
5	4.8d (203.8%)	7.48a (96.2%)	789.9a (80.6%)
10	9.3c (394.9%)	7.49a (96.3%)	672.3b (68.6%)
15	14.2b (602.9%)	7.36b (94.7%)	611.3c (62.4%)
20	18.7a (794.1%)	7.39b (95.1%)	542.6d (55.4%)

[†]Means followed by the same letter are not significantly different at $P \leq 0.05$.