EVALUATING THE SALINITY TOLERANCE OF BERMUDAGRASS CULTIVARS AND EXPERIMENTAL SELECTIONS

By

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Abstract: Bermudagrass is a highly productive, warm-season, perennial grass that has been grown in the United States for turfgrass, forage, pasture, rangeland, and roadside use. Many production and reclamation sites across the United States are affected by soil salinity issues. Identification of bermudagrasses with improved salinity tolerance is important for the successful implementation of bermudagrass production and reclamation of salt affected sites and/or with use of saline irrigation water. In this project, the relative salinity tolerance of seven clonal-type bermudagrasses and 10 seeded bermudagrasses, including industry standards and Oklahoma State University (OSU) experimental lines, were determined. The newly developed experimental lines and newly released cultivars by Oklahoma State University that had shown improved cold hardiness and improved spring dead spot tolerance were included in the study. The experiment was conducted under a controlled environment with six replications of each treatment. Four salinity levels (0, 15, 30 and 45 dS m^{-1}) were used to test the 17 bermudagrass entries, and the relative salinity tolerance among entries were determined by the normalized difference vegetation index (NDVI), digital image analysis (DIA), leaf firing (LF), turf quality (TQ), shoot dry weight (SW), shoot vertical growth (VG) and dark green color index (DGCI). Results indicated that there were variable responses to salinity stress amongst the entries studied. As salinity levels of the irrigation water increased, turf quality decreased and leaf firing increased. At the highest irrigation water salinity level (EC = 45 dS m^{-1}), the canopy green leaf area as measured using DIA ranged from 3.07% to 24.72% and 4.97% to 16.11% in the clonal and seeded trials, respectively. Overall, ‘Princess 77’ and experimental entry OKC1302 provided the highest level of performance in the seeded and clonal trials, respectively, at the 30 dS m^{-1} salinity level. The parameters LF, TQ, NDVI, DGCI, SW, VG, and DIA were all highly correlated with one another, indicating their usefulness as relative salinity tolerance measurements.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

LITERATURE REVIEW

Introduction

Bermudagrasses (*Cynodon* spp.) are native to Africa and are widely distributed and commonly found in tropical and subtemperate areas (Taliaferro et al., 2004). In the *Cynodon* genus, *Cynodon dactylon* (L.) Pers. var. *dactylon* (common bermudagrass) and *C. transvaalensis* Burtt-Davy (African bermudagrass) are well known species for turf cultivar development. Crosses between common bermudagrass and African bermudagrass have resulted in interspecific hybrids with high turf quality and fine leaf texture. Hybrid bermudagrasses are widely used on golf courses, sport fields, and other high-maintenance turf areas in the United States (Hanna et al., 2013).

General Adaptation Features of Bermudagrass

Bermudagrass is a highly productive, warm-season, perennial grass which reproduces through seeds, stolons, sprigs, tillers, and rhizomes. Bermudagrass grows best in areas with high sunlight and temperatures, mild winters, and moderate to high rainfall. It grows well in loamy sand, coarse sandy loam, and loam soil textures (Beard, 1973). The ideal temperature for bermudagrass growth ranges between 24-37^{o} C (75-99^{o} F), and when freezing temperature and short day length occurs, bermudagrass discolors and typically becomes dormant (Beard, 1973). Bermudagrass can grow well in hot arid climates and is tolerant to drought (Carrow, 1996). It is also tolerant to alkaline soil conditions and is moderately tolerant to salinity. Bermudagrass has been developed as an important grass for pasture, forage, and turfgrass and is used for the conservation of soil and water. Bermudagrasses with good traffic and drought tolerance, fast growth rates, and good recovery rates are popular grasses for golf and sports fields (Hanna et al., 2013). Bermudagrass is a major grass used in the southern United States, especially in the last six decades with newly released and improved cultivars for both forage and turf use (Wu and Anderson, 2011).

Plant Materials—Oklahoma State University Released Turf Bermudagrass Cultivars and Experimental Lines

After the release of the seed propagated bermudagrass cultivars 'Riviera' and 'Yukon' from Oklahoma State University (OSU), two newer vegetatively propagated cultivars 'Northbridge' and 'Latitude 36' were released. These two clonally propagated cultivars have very high quality, improved cold hardiness and improved spring dead spot disease tolerance (Wu et al., 2009). New experimental lines including both seed propagated and clonally propagated types from OSU, which showed good performance and improved cold hardiness in a previous test, have been included in this study. All of these grasses can provide high quality turf in the transition zone.

Soil Salinity

The concentration of all of the soluble salts in soil or water is defined as salinity. Total dissolved solids (TDS) and electrical conductivity (EC) are two primary methods to measure or estimate salinity (Brady and Weil, 2008). Electrical conductivity is an indirect measurement of salinity and is typically expressed as decisiemens per meter (dS m^{-1}) or millisiemens per centimeters (mS cm^{-1}).

Soils are considered saline when the saturation extract contains enough salt where the ECe value (conductivity of the solution extracted from a water-saturated soil paste) is greater than 4 dS m^{-1}, but the ESP (exchangeable sodium percentage) is less than 15 (Brady and Weil, 2008). Based on the ECe, Richard (1954) classed soil into non-saline (ECe 0-2 dS m^{-1}), very slightly saline (ECe 2-4 dS m^{-1}), moderately saline (ECe 8-16 dS m^{-1}), and strongly saline (ECe > 16 dS m^{-1}).

Salinity is becoming a critical environmental factor limiting crop production. Over 45 million hectares of irrigated land have been affected by saline soil issues around the world, and 1.5 million hectares are enervate due to soil salinity (Munns and Tester, 2008; Carillo et al., 2011).

Saline soil conditions can be caused by: (1) inherent saline soil conditions; (2) proximity to seawater; (3) application of saline water as irrigation; (4) restricted drainage due to a high water table; (5) low rainfall; and (6) high evaporation (Shahid and Rahman, 2011).

Plant Salinity Stress

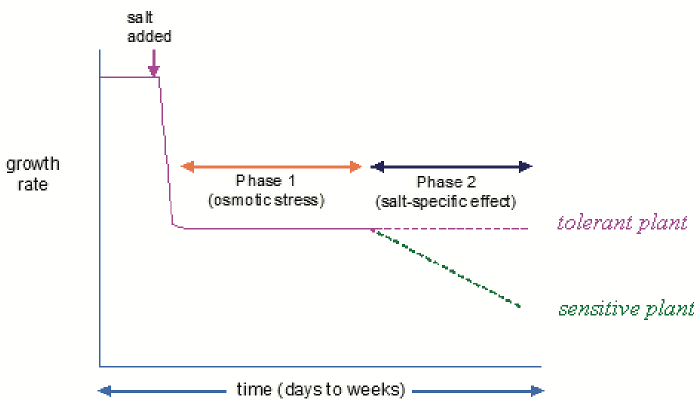
Salinity affects plant growth and production in several ways including: water stress, specific ion toxicity, nutritional disorder and imbalance, oxidative stress, alteration of metabolic processes, membrane disorganization, genotoxicity, and reduction of cell division and expansion (Carillo et al., 2011; Hasegawa et al., 2000; Munns, 2002; Zhu, 2007). The effects of salinity on plants are detected at the whole-plant level and may result in a reduction of plant growth and production, or death (Parida and Das, 2005).

During the onset and development of salinity stress within a plant, all the major processes, including photosynthesis, protein synthesis, as well as energy and lipid metabolism, are affected (Parida and Das, 2005). Plants experience water stress during the initial exposure of salt, followed by leaf expansion reduction (Carillo et al., 2011). The osmosis effects of salinity stress continue along with the duration of exposure, leading to inhibited cell expansion, cell division, and stomatal closure (Flowers, 2004; Munns, 2002; Carillo et al., 2011). Plants experience ionic stress when continuously exposed to salt, which can result in the premature senescence of older leaves; hence reducing photosynthetic activity (Cramer and Nowak, 1992;

Carillo et al., 2011). High Na^+ affects plants by disrupting protein synthesis and interfering with enzyme activity, which leads to premature senescence and toxicity symptoms in mature leaves (Hasegawa et al., 2000; Munns, 2002; Munns and Termaat, 1986; Carillo et al., 2011). Overall, high salts in the soil inhibits plant roots from extracting water, and the high salt inside of the plant cell can be toxic, leading to the prevention of many physiological and biochemical procedures (Hasegawa et al., 2000; Munns, 2002; Munns et al., 1995; Munns and Tester, 2008; Carillo et al., 2011).

Munns et al. (1995) proposed the two-phase model, which describes the osmotic and ionic effects of salt stress (Carillo et al., 2011) (Fig. 1). In this model, the salinity sensitivity and tolerant plants are grouped by the rate at which salt reaches toxic levels in leaves (Carillo et al., 2011). Phase 1 describes both salinity tolerant and sensitive plants experiencing growth reduction due to the osmotic effect of the saline solution outside of the roots (Carillo et al., 2011). Phase 2 describes the reduction of photosynthetic capacity of the sensitive plants due to the death of the old leaves (Carillo et al., 2011). Shoot growth, which is more sensitive than root growth when exposed to salt, is inhibited by the salt of symplastic xylem loading of Ca^{2+} in the root (Läuchli and Grattan, 2007).

Figure 1. Scheme of the two-phase growth response to salinity. Adapted from Munns (1995).



Several mechanisms have evolved in plants to acclimatize to salinity, such as the tolerance to osmotic stress, the Na^+ exclusion from leaf blades, and tissue tolerance (Munns and Tester, 2008; Carillo et al., 2011).

Statement of the Problem--Why Study the Salinity Tolerance of Bermudagrasses?

There are many influential environmental problems, especially salinity, by which plant productivity can be restricted (Uddin et al., 2011). The detrimental salinity effects on grass growth include osmotic stress, specific ion toxicity, imbalances of nutrition, excessive energy resulting in damaged photosynthetic systems, and structural disorganization (Shahba et al., 2012).

Water scarcity is a growing problem. Finding ways to satisfy the need of water for human activities while at the same time protecting the freshwater systems, now ranks among the 21st century's most critical challenges. Government-mandated water use restrictions are widely spreading, requiring use of reclaimed water due to the increasing demands on limited potable water resources (Marcum and Pessarakli, 2006).

Reclaimed water, in general, has a higher salinity level than fresh water. Saline tolerant plants can minimize saline stress effects by generating a series of processes at the morphological, physiological and biochemical levels (Jacoby, 1999; Uddin et al., 2011). Saline tolerant bermudagrass cultivars could be used in areas where reclaimed water is used as the irrigation source or where saline soil issues exist (Uddin et al., 2011).

Previous Salinity Tolerance of Bermudagrass Work

Cynodon spp. are ranked as having excellent salinity tolerance (Marcum, 2008). Marcum (2008) pointed out that the salinity tolerance of *Cynodon* spp. is highly variable, ranging from 8-18 dS m^{-1}. Studies from Ackerson and Younger (1975) showed that 'Santa Ana' had 50% shoot growth reduction when exposed to a 16 dS m^{-1} solution of 50/50 NaCl and $CaCl_2$ for 6 weeks (Marcum, 2008).

A number of studies have been conducted comparing the salinity tolerance of several bermudagrass cultivars. Dudeck and Peacock (1985 and 1993) conducted studies comparing 'Tifway' and 'Tifway II' with other warm-season turfgrasses. Their work showed that a 50% shoot growth reduction of both occurred at ECw (salinity level measure by the mixture of soil and water on the ratio of 1:2) levels of 33 and 24 dS m^{-1}, respectively, although Tifway was found to be more saline tolerant than Tifway II by Marcum (2008). Smith et al. (1993) pointed out that Tifway was slightly more salinity tolerant than Tifway II. The 50% shoot growth reduction occurred when the grass was exposed to an ECw at 12 dS m^{-1} and 11 dS m^{-1}, respectively, in solution culture (Marcum, 2008). Peacock et al. (2004) separated six cultivars into tolerant and sensitive salinity tolerance categories. ‘Navy Blue’, ‘GN-1’, and ‘Tifsport’ were grouped as salinity tolerant cultivars, and ‘Quickstand’, Tifway, and ‘Tifton 10’ were characterized as salinity sensitive cultivars (Marcum, 2008). There were other studies showing a narrower range of relative salinity tolerance with the 50% shoot growth reduction occurring from ECw 17.4 to 22.5 dS m^{-1} and from ECw 24 to 31 dS m^{-1} in a sand culture medium (Marcum, 2008). Dudeck et al. (1983) pointed out that ‘Tifdwarf’ and ‘Tifgreen’ had 50% shoot growth reduced at 21.6 dS m^{-1} compared with plants under no salt treatment (Marcum, 2008).

Marcum and Pessarakli (2006) compared the relative salinity tolerance of 35 *Cynodon* spp. The salinity treatments which caused 50% shoot growth reduction ranged from an ECw of 26 to 40 dS m^{-1}. They found the salinity level resulting in a 50% relative shoot growth reduction on Tifsport, Riviera, ‘Midlawn’, Yukon, ‘NuMex Sahara’, Princess 77 and Tifway was 35.7, 35.5, 33.8, 32.2, 32.2, 32.2 and 32 dS m^{-1}, respectively. Lee et al. (2004) compared Tifway and TifSport with other clonal bermudagrass cultivars. They found that Tifway had higher total growth (shoot, root and verdure) than TifSport at ECw of 24, 32 and 40 dS m^{-1}.

Goals

The goals of this research were to identify:

(1) the salinity tolerance of clonal-type bermudagrasses (including industry standards and OSU experimental lines) for turf use (Table 1).

(2) the salinity tolerance of seeded-type bermudagrasses (including industry standards and OSU experimental lines) for turf use (Table 2).

Objectives

This study represents two experiments designed to:

(1) determine the relative salinity tolerance of clonal-type and seeded-type bermudagrasses including industry standards and Oklahoma State University experimental lines;

(2) evaluate the response of 17 bermudagrass entries to salinity stress using GreenSeeker™ handheld NDVI sensor (Trimble Navigation LTD, CA), FieldScout® CM 1000 NDVI meter (N-Tech Industries Inc., Ukiah, CA), and the FieldScout® GreenIndex+ smartphone app compared with the traditional turfgrass visual ratings and digital image analysis (DIA).

Research Hypothesis

It was hypothesized that:

(1) there are differences in salinity tolerance among the 17 bermudagrasses;

(2) the normalized difference vegetation index (NDVI) measured by GreenSeeker™ handheld sensor and FieldScout® CM 1000 NDVI meter (N-Tech Industries Inc., Ukiah, CA), and dark green color index (DGCI) and visual reading measured by the FieldScout® GreenIndex+ smartphone app (VR) would be positively correlated with turf visual ratings and digital image analysis.

To evaluate this hypothesis, we set out to determine the following objectives:

(1) compare how the normalized difference vegetation index (NDVI) measured by GreenSeeker™ handheld sensor and FieldScout® CM 1000 NDVI meter (N-Tech Industries Inc., Ukiah, CA), dark green color index (DGCI) and visual readings (VR) as measured by the FieldScout® GreenIndex+ Turf app correlate with traditional visual ratings of greenhouse grown bermudagrasses;

(2) compare how the GreenSeeker™ handheld sensor, FieldScout® CM 1000 NDVI meter (N-Tech Industries Inc., Ukiah, CA), dark green color index (DGCI), and visual readings (VR)via the FieldScout® GreenIndex+ Turf app, correlate with a digital image analysis (DIA) of the greenhouse grown bermudagrasses;

(3) test the relative growth trend of the bermudagrass under different salinity levels; and

(4) compare how the eight parameters tested in this study correlate with one another.

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Table 1. Clonal-type bermudagrass cultivars and experimental selection tested for salinity tolerance.

Entry	Note
Celebration	Good salinity tolerance standard
Latitude 36	Sports field standard (OSU release)
Midlawn	Industry standard
Northbridge	Sports field standard (OSU release)
OKC1302	OSU experimental
TifSport	Sports field standard
Tifway	Golf course standard

Table 2. Seeded-type bermudagrass cultivars and experimental selections tested for salinity tolerance.

Entry	Note
NuMex Sahara	Poor salinity tolerance standard†
OKS 2009-3	OSU experimental
OKS 2011-1	OSU experimental
OKS 2011-4	OSU experimental
Princess 77	Industry standard
Pyramid 2	Industry standard
Riviera	Good salinity tolerance standard†
Royal Bengal	Industry standard
Southern Star	Industry standard
Yukon	Industry standard

†Marcum. K.B., and M. Pessarakli. 2006. Salinity tolerance and salt gland excretion efficiency of bermudagrass turf cultivars. Crop Sci. 46:2571–2574.

CHAPTER II

EVALUATING THE SALINITY TOLERANCE OF BERMUDAGRASS CULTIVARS AND EXPERIMENTAL SELECTIONS

Abbreviations: DIA, digital image analysis; LF, leaf firing; NDVI, normalized difference vegetation index; TQ, turf quality; SW, shoot dry weight; VG, vertical shoot growth rate; DGCI, dark green color index; GSNDVI, NDVI readings by GreenSeeker™ handheld sensor; FSNDVI, NDVI readings by FieldScout® CM 1000 NDVI meter; VR, visual reading by FieldScout® GreenIndex+ Turf smartphone app; SW50, 50% shoot dry weight reduction; and VG50, 50% shoot vertical growth reduction.

Introduction

Bermudagrasses (*Cynodon* spp.) are native to Africa and are widely distributed and commonly found in tropical and subtemperate areas (Taliaferro et al., 2004). They have been developed as important grasses for pasture, forage and turfgrass use and are used for the conservation of soil and water. Bermudagrasses are used in the southern United States, especially in the last six decades, with newly released and improved cultivars for both forage and turf use (Wu and Anderson, 2011). As a warm season grass, bermudagrass traditionally has limited use in the U.S. transition zone due to poor winter hardiness. In 2011, scientists at Oklahoma State University developed and released bermudagrass ‘Latitude 36’ and ‘Northbridge’ cultivars with improved cold hardiness. However, the relative salinity tolerance of these grasses has not been studied.

Water scarcity is a growing problem, and finding ways to satisfy the need of water for human activities, while at the same time protecting the freshwater systems, now ranks among the 21st century’s most critical challenges. Government-mandated water use restrictions are widely spreading, requiring use of reclaimed water due to increasing demands on limited potable water resources (Marcum and Pessarakli, 2006).

Saline tolerant plants can minimize saline effects by generating a series of processes at the morphological, physiological, and biochemical levels (Jacoby, 1999; Uddin et al., 2011). Saline tolerant bermudagrass cultivars could provide acceptable quality turf in areas where reclaimed water is used as the irrigation source or where saline soil issues exist (Uddin et al., 2011). In this study, the relative salinity tolerance of bermudagrasses was determined based on various salinity tolerance indicators.

This work represents two experiments designed to:

(1) determine the relative salinity tolerance of clonal-type and seeded-type bermudagrasses including industry standards and Oklahoma State University experimental lines;

(2) evaluate the response of 17 bermudagrass entries to salinity stress using GreenSeeker™ handheld sensor (Trimble Navigation LTD, CA), FieldScout® CM 1000 NDVI meter (N-Tech Industries Inc., Ukiah, CA), and the FieldScout® GreenIndex+ Turf smartphone app compared with the traditional visual ratings and digital image analysis (DIA).

Methods

Plant Materials and Growth Conditions

The responses of seven clonal-type bermudagrasses and 10 seeded-type bermudagrasses were evaluated, based on four salinity level treatments with six replications. Seeded cultivars were selected based on the National Turfgrass Evaluation Program (NTEP) data (industry standards), which includes ‘Princess 77’, ‘NuMex Sahara’, ‘Pyramid 2’, ‘Royal Bengal’, ‘Southern Star’, ‘Yukon’, and ‘Riviera’, and Oklahoma State University experimental lines, including OKS 2009-3, OKS 2011-1 and OKS 2011-4. Clonal bermudagrass entries include OKC1302, Latitude 36, Northbridge, ‘Tifway’, ‘Celebration’, ‘TifSport’ and ‘Midlawn’. ‘SeaStar’ Seashore Paspalum (*Paspalum vaginatum* Swartz), which is known as a highly salt tolerant turfgrass, was included in the seeded trial as the standard.

This study was conducted in a controlled environment at the Oklahoma State University (OSU), Department of Horticulture and Landscape Architecture greenhouse facility located in Stillwater, OK. Air temperatures were maintained at 25 to 37°C during the day, and at 21 to 30°C at night. A 14 hour photoperiod was provided by supplemental high pressure sodium (HPS) light from 07:00 AM to 21:00 PM, bringing daily maximum photosynthetically active radiation (PAR) levels ranging from 700 to 1150 mol m^{-2} s^{-1}. Experiments were conducted from Jan. through Nov. 2014.

The seeded-type bermudagrass entries were seeded into several individual flat greenhouse trays (27.9 cm x 54.6 cm x 6.35 cm) at 0.4-0.8 gram (at 9.88 to 17.56 kg per ac) pure live seed depending on coated or uncoated seed sources during Jan. 2014. Grasses were established under a mist system scheduled to water 10 sec every 20 min until all entries reached uniform germinations. The grasses were established in sand (particle size met the USGA topmix specification) mixed with gypsum at the rate of 3 grams per liter of sand to avoid Ca deficiency (USGA Green Section Staff, 2004). Fertilizer was applied three times a week at 250 mg N L^{-1} using a solution of 20-20-20 N-P_2O_5-K_2O (20-8.6-16.6 NPK) general purpose fertilizer (J.R Peters Inc., Allentown, PA).

Clonal-type bermudagrass entries and SeaStar were collected as six-inch diameter sod plugs from the field nursery at OSU Turfgrass Research Center during July 2014. Plugs were washed to remove all soil particles, separated individually, roots were trimmed to 3 cm, and 10 uniform sprigs were transplanted to the 11.14 cm x 11.14 cm pots. Seeded-type bermudagrasses were transplanted on 15 Aug. at the rate of 10 seedlings per pot.

Two ebb and flow benches were used in each trial to provide daily sub-irrigation with solution tanks (189 L) containing soluble fertilizer. Excel water soluble fertilizer, 13-2-13+6Ca+3MG plug special (Scotts-Sierra Horticultural Products Company, Marysville, OH 43041), was added to the tank at the rate of 0.53 grams per liter and modified with 0.04 grams per liter MgSO4 was mixed as the nutrient source to reach the salinity level of 1.5 dS m^{-1}.

The presence of mealy bugs (*Pseudococcus* spp.) and eriophyid mites (*Eriophes cynodoniensis)* were found on the TifSport entry during establishment. All grasses were immediately treated with imidacloprid (Merit 2F insecticide, Bayer Environmental Science, Research Triangle Park, NC 27709) or bifenthrin (Talstar lnsecticide, FMC Corporation Agricultural Products Group 1735 Market Street Philadelphia, PA 19103) with Agrisolutions (Aduro Winfield Solutions, LLC, 64589, St. Paul, MN 55164) at labeled rates and was repeated at 7 days intervals.

Shoots were clipped every 5 days at 4 cm for the clonal-type entries and at 5 cm for seeded-type entries, separately. The turfgrasses were established for 2.5 months under this mowing height. Before starting the salt treatment, pots were evaluated in several ways: for turf quality (TQ) and leaf firing (LF) by the human evaluator; the normalized difference vegetation index (NDVI) as measured by a GreenSeeker™ handheld sensor (GSNDVI) (Trimble Navigation LTD, 935 Stewart Dr, Sunnyvale, CA 94085) and a FieldScout® CM 1000 NDVI meter (FSNDVI) (Spectrum Technologies Inc., 3600 Thayer Court Aurora, IL 60504); dark green color index (DGCI) and visual reading (VR) as measured by the FieldScout® GreenIndex+ Turf mobile application (Spectrum Technologies Inc., 3600 Thayer Court Aurora, IL 60504); and digital image analysis (DIA) via a digital SLR camera. To provide uniform starting conditions, shoots were clipped 1 day prior to initiation of salinity treatment (Marcum, 1999). Clippings were collected and shoot dry weight (SW) was measured within the clonal-type bermudagrass trial; vertical shoot growth rate (VG) was measured within the seeded-type bermudagrass trial.

Treatments

On 25 Sept. and 29 Oct. 2014, day 0 data was collected, then an Instant Ocean Synthetic Sea Salt mix (Aquarium System, mentor, Ohio 44060) was gradually added to the salinity treatment tanks of the clonal-type bermudagrass trial and seeded bermudagrass trial separately. The salt concentration was increased by 5 dS m^{-1} daily in the treatment tank until 15 dS m^{-1} total salinity was reached (Marcum and Pessarakli, 2006). Treatment grasses were held at 15 dS m^{-1} for 1 week. Then all the pots were visually rated for TQ and LF; and GSNDVI, FSNDVI, DGCI, and VR were measured. Also, digital photographs were taken and digital image analysis (DIA) were conducted via SigmaScan software. Shoot dry weights were collected for the clonal-type bermudagrasses, and shoot vertical growths were measured for the seeded bermudagrasses. Following clipping, the increasing salt dosage was resumed until 30 dS m^{-1} was reached (Marcum and Pessarakli, 2006). Salinity was again held at 30 dS m^{-1} for one week, followed by ratings and clippings (Marcum and Pessarakli, 2006). This cycle was repeated one more time to reach 45 dS m^{-1}. Data collection began 1 day before the initiation of the treatment and was repeated one week right after the salinity reached each scheduled level (15, 30 and 45 dS m^{-1}).

Fertilizer levels were monitored daily by measuring the EC level of the control treatment tank with an EC portable meter (HI 9033, Hanna Instruments, Inc. Carrollton, TX). When the EC levels of the control treatment tanks dipped below 1 dS m^{-1}, Excel fertilizer was added at the rate of 0.27 grams of fertilizer per liter of solution to all tanks (Personal Communication, Dr. Paul Raymer, Nov., 2013). Salt levels in the tanks were measured daily, adjusted when necessary, and solutions were changed every 10 days to avoid changes in nutrient ion concentrations.

Two benches (one for control treatment and one for salinity treatments) in each trial were sub-irrigated daily simultaneously with a timer. To avoid an excess of salt in the growth media, the treatment irrigation solution at 300 ml was applied overhead every 5 days to regularly flush the pots.

Parameters

Eight parameters were collected to evaluate the performance of bermudagrasses in each trial, which included TQ, LF, FSNDVI, GSNDVI, DGCI, VR, SW, and DIA in the clonal bermudagrass trial and TQ, LF, FSNDVI, GSNDVI, DGCI, VR, VG, and DIA in the seeded bermudagrass trial.

TQ

Turf quality (TQ) ratings, which are not based on any single parameter alone, but on a combination of color, density, uniformity, texture, and disease or environmental stress was rated on a scale of 1 to 9 based on the National Turfgrass Evaluation Program criteria, where 1 = dead or dormant turf, 6 = acceptable turf, and 9 = outstanding or ideal turf (Morris, 2007).

LF

Leaf firing (LF), visual browning and wilting of the leaves, was rated on a scale of 1 to 9, where 1 = complete leaf firing and 9 = no wilting and no firing (Morris, 2007).

DIA

Digital photographs were taken via Canon PowerShot G16 12.1 MP CMOS (Melville, N.Y.) over the pots with a controlled light bucket painted black inside. DIA was analyzed via Sigma Scan Pro 5 software (Systat Software, Inc., San Jose, CA 95100) to calculate percent green cover (Richardson, 2001; Karcher and Richardson, 2003). The software was utilized to determine the percentage green cover of 200×200 pixel cropped picture with the setting of hue threshold at 40 to 140, and saturation set at 0 to 100. Mean separation was calculated based on LSD after ASIN (DIA/100) transformation.

GSNDVI

The normalized difference vegetation index (NDVI) is a parameter correlated with leaf area index, and correlated with plant quality or yield in turfgrasses (Crain et al., 2012; Shaver et al., 2011; Raun et al., 2005). NDVI is calculated by the equation list below:

$$\text{NDVI} = \frac{NIR - VIS}{NIR + VIS}$$

where NIR = spectral reflectance measurements acquired in the near-infrared for a given pixel and VIS = spectral reflectance measurements acquired in the visible (red) range for a given pixel (Deering, 1975).

The GreenSeeker^{TM} handheld sensor is a non-destructive, affordable, and simple to use NDVI sensor, with values ranging from 0 to 1 (Basyouni and Dunn, 2013). The larger the NDVI value, the healthier the plant. According to Basyouni (2014), the hooded GreenSeeker^{TM} handheld sensor provides a smaller field of view, which is an applicable choice for the greenhouse study by avoiding background noise caused by the small canopy area. The black hood was attached to the bottom and matched the diode viewing window. A black funnel was put on top of the greenhouse pot to make the bottom of the funnel and the top of the pot match and avoid background noise. The hooded GreenSeeker^{TM} handheld sensor was placed 35.5 cm above the grass canopy with the parameter sampled 3 times and averaged.

FSNDVI

Similar to the GreenSeeker^{TM} handheld sensor, the FieldScout® CM 1000 NDVI chlorophyll meter is another effective way to estimate plant health by instantly measuring red (660 nm) and near infrared (840 nm) spectral bands (Spectrum Technologies, Inc, 2013).

The NDVI is calculated by the equation of

$$\text{NDVI} = \frac{\%\text{Near Infrared} - \%\text{Red}}{\%\text{Near Infrared} + \%\text{Red}}$$

The lens was held 49 cm above the grass canopy. All the samples were taken between 12-1 PM under natural sun light with the same background, sampled three times, and averaged.

DGCI &VR

The most common objective method to assess the heath of turf is measuring the NDVI via an NDVI sensor. However, these devices require specialized light emitters and/or filters to conduct these measurements (Spectrum Technologies, Inc, 2014). FieldScout® GreenIndex+ Turf offers digital image analysis of the turf via smartphone app, which provides a low-cost method for managing turf quality and appearance. The image captured by the digital camera on the smartphone was standardized by the green and yellow reference, and white balance was adjusted by the gray area in the target board (Spectrum Technologies, Inc. Aurora, IL; Spectrum Technologies, Inc, 2014). The turf greenness was measured by converting the red, green, and blue (RGB) color scheme in the series of pixels into hue, saturation, and brightness (HSB). DGCI was then calculated from the HSB values as follows:

$$\mathrm{DGCI} = \frac{1}{3}\left[\frac{\mathrm{Hue} - 60}{60} + (1 - \mathrm{Saturation}) + (1 - \mathrm{Brightness})\right]$$

A default visual rating is computed by the app based on the DGCI data (Spectrum Technologies, Inc, 2014).

Data was collected at 10 AM in the morning to minimize environment light noise. An iPhone 5 (Apple, Cupertino, CA, 95014) with the FieldScout® GreenIndex+ Turf app was held 25 cm above the grass canopy, three pictures of the grass canopy were taken via the smartphone camera, the target board was included in the picture, and the average of DGCI was calculated by the app. Based on the DGCI, a default visual reading (VG) was calculated in decimal form. Different from the traditional visual rating, it provided a more precise data.

SW

Shoots were clipped at 4 cm for the clonal-type bermudagrasses and 5 cm for the seeded-type bermudagrasses, separately, every 5 days. Clippings were collected in paper envelopes for the clonal trial and dried at 80^{o}C for 48 hour, and shoot dry weight (SW) was recorded. According to Marcum and Pessarakli (2006), compared to absolute growth, relative shoot dry weight (SW/SW control) is a better indicator of plant vigor under salinity stress. The shoot growth response of each entry was determined by comparing the shoot dry weight with the control following the formula proposed by Ashraf and Waheed (1990).

$$\text{Relative growth (\%)} = \frac{\text{DW of salinized treatment of a species}}{\text{DW of the control treatment of that species}} \times 100$$

Grass shoot growth response of each cultivar to salinity was determined by calculating the salinity level resulting in 50% shoot dry weight (SW50), compared with control (Marcum and Pessarakli, 2006).

VG

The vertical growth rates (VG) were measured by the method developed by Bremer et al. (2006) after slight modification. The canopy was measured by placing a lightweight circular shaped cardboard with a slightly smaller diameter, over the canopy, and four spots were evenly marked around the circumference. The cardboard was lightweight enough to avoid bending the canopy but rigid enough to hold its shape (Bremer et al., 2006). The cardboard was randomly placed on the canopy, and the height of the canopy was measured at the four perpendicular spots marked on the cardboard every 5 days right before mowing. Daily vertical growth rates were calculated by dividing the number of days between mowing.

Experiment Design and Statistical Analysis

Separate trials were conducted for seeded as opposed to clonally propagated trials. The experimental design was a split plot design with six replications where cultivar/entry was the main plot factor and EC was the subplot factor. Analyses were conducted on TQ, LF, FSNDVI, GSNDVI, DGCI, VR, DIA and SW for the clonal trial and TQ, LF, FSNDVI, GSNDVI, DGCI, VR, DIA and VG for the seeded trial. General Linear Model Procedure (Proc GLM) was used to conduct ANOVA with SAS 9.4 (SAS Institute, 2013) [SAS Institute Inc., Cary, NC].

For the clonal trial, when treatment initiated, a significant entry × treatment (control and salinity treatment) interaction was detected ($p \leq 0.05$) with respect to most of the parameters including TQ, LF, FSNDVI, GSNDVI, DGCI, and DIA. Mean separations were conducted based on the LSD value at each of the treatment levels. Only the entry effect was detected at the salinity level of 15 dS m^{-1}, and significant interaction did not appear until the salinity level reached 30 dS m^{-1} in the parameter of VR.

For the seeded trial, significant entry × treatment (control and salinity treatment) interactions were detected ($p \leq 0.05$) in all the quantitative parameters after the initiation of the salt treatment, LF, TQ, FSNDVI, GSNDVI, DGCI, VR, and DIA included. Mean separations were conducted based on the LSD value at each treatment level.

Pearson's correlation coefficient was conducted to examine the relationships amongst the various response variables by using the Proc Corr procedure in SAS software (SAS, 2013) [SAS version 9.4, SAS Institute Inc., Cary, NC].

Results for the Clonal Bermudagrass Trial

LF

No leaf firing (LF) was found in any entry before initiating the salinity treatments (Table 3). Leaf firing increased in all entries as salinity levels increased. Leaf firing ranged from 6.2 to 7.8 at 15 dS m^{-1}. The experimental entry OKC1302 had the least LF, while TifSport had the most LF compared to other entries. However, no entries had LF less than 6.2, and all entries showed acceptable leaf firing at 15 dS m^{-1} (Table 3). When exposed to 30 dS m^{-1}, experimental entry OKC1302 had less LF than all other entries except Tifway, while Midlawn showed more leaf firing than all the entries. LF ranged from 1.0 to 2.7 at 45 dS m^{-1}, where Tifway outperformed all other entries (Table 3). All the entries showed significant differences (P = 0.01) for LF when comparing the control treatment with each of the salinity treatments (Table 4, Table 5, and Table 6). Overall, OKC1302 showed less leaf firing at 15 dS m^{-1} compared to other cultivars, while Tifway displayed the least leaf firing at 45 dS m^{-1}.

TQ

Turf quality of all the bermudagrass entries ranged from 7.7 to 8.8 (Table 7) before beginning the salinity treatments. Results demonstrated differences among entries (P = 0.05, Table 7) at EC = 1.5 dS m^{-1}, where Latitude 36 had better TQ than all other entries except OKC1302 (Table 7). Turf quality decreased as salinity level increased. When exposed to 15 dS m^{-1}, all the entries showed TQ declination, but TQ was acceptable and ranged from 6.0 to 7.7. Turf quality of all entries dropped down below the acceptable value thereafter. The entry OKC1302 out performed others at 15 dS m^{-1}. Turf quality was highest in OKC1302 and Tifway at 30 dS m^{-1}. At 45 dS m^{-1}, Latitude 36 and Midlawn had lower turf quality compared to OKC1302, Tifway, and Celebration, but no difference were found when compared to TifSport. After initiating the salinity treatment, all entries showed significant differences in TQ when compared under the control versus salinity treatment ($P = 0.001$) (Table 4, Table 5, and Table 6). Overall, means separation results of TQ were very similar to LF. The entry OKC1302 had high TQ at 15 dS m^{-1} and 30 dS m^{-1}, while Tifway out performed all others at 45 dS m^{-1}.

GSNDVI

The NDVI readings as determined by the GreenSeeker™ handheld sensor under the various salinity treatments are presented in Table 8. Before salt was added to the treatment tank, differences among entries were detected, where Latitude 36 had higher GSNDVI than all other entries except OKC1302. At 15 dS m^{-1}, the GSNDVI was found to be highest in OKC1302, besides Latitude 36, Tifway and Northbridge. The NDVI declined substantially as the salinity level went up to 30 dS m^{-1}. Tifway and OKC1302 exhibited the highest GSNDVI followed by Northbridge, TifSport, Latitude 36, and Celebration at 30 dS m^{-1}. At 45 dS m^{-1}, the GSNDVI reading was highest in Tifway, while lowest in Midlawn. Values for GSNDVI slightly increased as the salinity dose increased to 15 dS m^{-1} (Table 8), which indicated NDVI was not negatively impacted in the entries. However, based on Table 4, despite entries, the GSNDVI declined when comparing performance under the control treatment with the salinity treatment of 15 dS m^{-1} (P = 0.001).

FSNDVI

Table 9 provides the NDVI readings determined by the FieldScout® CM 1000 NDVI meter. The FSNDVI values declined as salinity levels increased. Before the initiation of the salinity treatments, Latitude 36 obtained the highest FSNDVI value. As the salinity increased to 15 dS m^{-1}, FSNDVI was higher in OKC1302 when compared to other entries with the exception of Latitude 36 and Northbridge. At 30 dS m^{-1}, FSNDVI was highest in Tifway and OKC1302, and was lowest in Midlawn. Tifway had the highest FSNDVI value at 45 dS m^{-1}. Significant declinations were found in all the entries under various levels of salt stress, when comparing the control to salinity treatment (P = 0.001) (Table 4, Table 5, and Table 6).

DGCI

Before the salinity treatment, Celebration had higher DGCI than other entries, except OKC1302 and Tifway, while DGCI was lowest in Midlawn, which indicated its lighter green color naturally (Table 10). When the salinity levels went up to 15 dS m^{-1}, the DGCI was higher in Tifway than all other entries besides OKC1302. Significant declination was found in all entries after the salinity level reached 30 dS m^{-1} (Table 5 and Table 6). At 30 dS m^{-1}, Tifway showed higher DGCI value than all other entries besides OKC1302. At 45 dS m^{-1}, DGCI was highest in Tifway compared with all other entries with the exception of Celebration.

VR

Because the VR reading was calculated based on DGCI by the application, results were similar for both parameters (Table 10, Table 11). At 15 dS m^{-1}, the lowest visual reading was detected in Midlawn. The average VR ranged from 3.9 to 5.9 at 30 dS m^{-1}, and Tifway was higher than all other entries with the exception of OKC1302. At 45 dS m^{-1}, VR was highest in Tifway and Celebration, and it was lowest in Midlawn.

DIA

The percentage of live green cover (pixels) was determined by DIA (Table 12). Before the conduction of the salinity treatment, Latitude 36 showed better DIA than all other entries. Minor declination was found in all entries at 15 dS m^{-1}. The DIA declined at 30 and 45 dS m^{-1}, respectively. OKC1302 had higher DIA than all other entries except Tifway at 30 dS m^{-1}. At 45 dS m^{-1}, Tifway had higher DIA than all other entries except Celebration.

SW

For all entries, the relative shoot dry weight declined linearly with increasing salinity levels with $r \geq 0.88$ (Figure 2-Figure 8). Regression analysis shows that the 50% relative (to control) shoot growth reduction (SW50) ranged from 22.9 to 24.5 dS m^{-1} (Table 13). Tifway needed relatively higher predicted salinity level than all other entries to reach SW50. The predicted salinity level lead to SW50 was showed in order: Tifway > Midlawn > Northbridge > Celebration > OKC1302 = TifSport = Latitude 36.

Correlation

All the turf quality factors, including LF, TQ, FSNDVI, GSNDVI, DGCI, VR and DIA, were highly positively correlated with one another ($r > 0.9$, $P < 0.0001$, Table 14), which indicated their mutual usefulness as salinity tolerance indicators. Amongst these seven parameters, TQ and LF both had the highest correlation coefficient with all others, ranked as the best criterion of turfgrass evaluation under salinity stress. Shoot dry weight as a physiological factor, was similar to but less correlated, with the other parameters.

Results for the Seeded Bermudagrass Trial

LF

No LF was detected in any entry before initiating the salinity treatments (Table 15). Despite entries, leaf firing increased as salinity levels increased. Leaf firing in the entries ranged from 7.3 to 8.7 at 15 dS m^{-1}. Princess 77 had less LF than all other entries except Riviera and Yukon, when exposed to 15 dS m^{-1}. Differences in the salinity treatment were only found in Southern Star, Yukon and experimental entry OKS 2011-1 ($P = 0.05$) at 15 dS m^{-1}, when comparing their performance with control treatment (Table 16). Significant declinations were found in all entries thereafter (Table 17 and Table 18). At 30 dS m^{-1}, less LF was displayed in Princess 77 than other entries with the exception of Yukon. At 45 dS m^{-1}, LF ranged from to 2.0 to 4.0, and SeaStar had the least LF. Overall, Princess 77 and Yukon showed less LF at 15 and 30 dS m^{-1}, while SeaStar displayed the least LF at 45 dS m^{-1}.

TQ

Before initiating the salinity treatment, turf quality ranged from 7.0 to 8.7 (Table 19). Results demonstrated significant differences among entries. At 15 dS m^{-1}, all entries had acceptable TQ, and TQ was higher in Princess 77 compared with other entries, except Riviera and Yukon. TQ ranged from 3.7 to 5.2 at 30 dS m^{-1}, and Princess 77 again displayed better TQ when compared with other entries besides Riviera and Yukon. At 45 dS m^{-1}, TQ ranged from 2.0 to 4.0, and SeaStar had higher TQ than other entries, with the exception of Princess 77. At 15 dS m^{-1}, comparing all entries under salinity to control treatment, declination in TQ was found only in experimental entry OKS 2009-3 (P = 0.05), Southern Star (P = 0.05), and Yukon (P = 0.01) (Table 16). Significant declinations were found in all entries thereafter (Table 17, Table 18).

GSNDVI

The NDVI readings determined by the GreenSeeker™ handheld sensor under various salinity treatments are shown in Table 20. Before conducting the salinity treatment, GSNDVI differed by entries. Values for GSNDVI ranged from 0.757 to 0.848, and GSNDVI was higher in Princess 77 and Yukon with the exception of Riviera, when comparing with other entries. A comparison between control and salinity treatment at different salinity levels is presented in Tables 16, 17, and 18. Differences between control and salinity treatment at 15 dS m^{-1} was found for Princess 77 (P = 0.05), Royal Bengal (P = 0.05), Southern Star (P = 0.05), Yukon (P = 0.05) and experimental entry OKS 2009-3 (P = 0.01) (Table 16). Amongst the entries in the salinity treatment trial, the GSNDVI was highest in Yukon, Princess 77, and Riviera, and lowest in SeaStar at 15 dS m^{-1}. Significant differences between the control and salinity treatment were found in all entries at 30 and 45 dS m^{-1} (Table 17 and Table 18). At 45 dS m^{-1}, the GSNDVI of SeaStar, the salinity tolerant standard, was the highest, and the GSNDVI was the lowest for Southern Star.

FSNDVI

NDVI readings as determined by the FieldScout® CM 1000 NDVI meter under various salinity treatments are presented in Table 21. Before giving the salinity treatment, the FSNDVI ranged from 0.635 to 0.707. The FSNDVI was higher for Princess 77 and Yukon when compared to all other entries, with the exception of Riviera. The declination of FSNDVI was only found in Southern Star, Yukon, and experimental entry OKS 2009-3, when comparing the control versus the salinity treatment at 15 dS m^{-1} (Table 16). Significant differences between control and salinity treatment was found for all entries when the salinity level reached 30 and 45 dS m^{-1} (Table 17 and Table 18). Values for FSNDVI were high for Princess 77 and Yukon, and low for NuMex Sahara and OKS 2009-3 at 30 dS m^{-1}. At 45 dS m^{-1}, SeaStar had higher FSNDVI than other entries except for Princess 77 and Yukon.

DGCI

Table 22 presents the dark green color index (DGCI). The DGCI of Yukon was higher compared to all entries, except for Princess 77 and Riviera, before conducting the salinity treatment. As the salinity level increased to 15 dS m^{-1}, all the entries showed significant darker color under salinity stress when compared with the control (P = 0.001) (Table 16). DGCI was higher in Yukon than all other entries, besides Princess 77 and Riviera, and lowest for NuMex Sahara at 15 dS m^{-1}. Despite entries, significant declination of DGCI was detected at 30 and 45 dS m^{-1}, when comparing the salinity treatment to the control treatment (Table 17 and Table 18). At 45 dS m^{-1}, DGCI was found higher in SeaStar and Princess 77 compared to all other entries besides Yukon (Table 22).

VR

The results of visual readings were default readings based on the DGCI, and very similar VR results are shown in Table 23.

DIA

The DIA data are presented in Table 24, and they ranged from 85.71% to 98.70% before initiating salinity treatments. Digital image analysis showed percentage green cover was highest in Princess 77 and Yukon. Minor declination of DIA was detected at 15 dS m^{-1}, where Princess 77, besides Yukon, had higher DIA than all others. At 30 dS m^{-1}, Princess 77, SeaStar, and Yukon displayed higher DIA. The DIA was detected to be highest for the salinity standard SeaStar at 45 dS m^{-1}.

VG

Similar to shoot dry weight (SW) for the clonal-type entries, vertical growth (VG) was measured for the seeded entries by comparing with control for relative shoot vertical growth. The relative vertical growth declined linearly ($R^2 > 0.88$) with increasing salinity (Figure 9-Figure 19). Regression analysis shows that 50% relative (to control) shoot vertical growth reduction (VG50) ranged from 21.7 to 22.5 dS m^{-1} for bermudagrass entries (Table 25). SeaStar had the VG50 at the highest salinity level of 23 dS m^{-1}. The predicted salinity level for VG50 was shown in order to be: Southern Star > Yukon > Princess 77 > OKS 2009-3 > Southern Star > OKS 2011-4 > OKS 2011-1 > Royal Bengal > Pyramid 2 > Riviera > NuMex Sahara.

Correlation

All the turf quality related parameters, including LF, TQ, FSNDVI, GSNDVI, DGCI, VR and DIA were highly positively correlated with one another ($r > 0.74$, $P < 0.0001$, Table 26), which indicated their mutual usefulness as salinity tolerance indicators. Amongst these seven parameters, LF had the highest correlation coefficient with all others, and ranked as the best criterion of turfgrass evaluation under salinity stress. When comparing all the sensors and the smartphone application, FSNDVI, compared with GSNDVI and DGCI/VR, the FieldScout® CM 1000 NDVI meter showed higher correlation in the seeded bermudagrass study. Shoot vertical growth as a physiological factor, was similar to but less correlated, compared to the other parameters.

Discussion

Eight parameters were evaluated to test the diversity in salinity tolerance among bermudagrass industry standards and OSU experimental lines. Differences among the seven clonal-type and 10 seeded-type bermudagrass entries were demonstrated based on the ranking of all parameters except SW and VG in the clonal and seeded trial, respectively.

The entries in the clonal trial were ranked in order from the most salinity tolerant to the least: Tifway, OKC1302, Celebration, Latitude 36, Northbridge, TifSport, and Midlawn (Table 27) based on the number of times an entry appeared in the top LSD group over the course of the entire study. The entry OKC1302 showed the best performance under 15 and 30 dS m^{-1}, and Tifway outperformed all others at 45 dS m^{-1}. Latitude 36 showed high overall quality before receiving the salinity treatment, and was in the top LSD group for TQ, GSNDVI, and FSNDVI. All the salinity parameters, however, declined quickly under the salinity stress. Thus, Latitude 36 was ranked less salinity tolerant than Celebration, even though it appeared more times in the top LSD group.

The entries in the seeded bermudagrass trial were ranked in order from the most salinity tolerant to the least: Princess 77, Yukon, Riviera, OKS 2011-1, OKS 2011-4, Southern Star, Pyramid 2, Royal Bengal, OKS 2009-3 and NuMex Sahara (Table 28). Princess77, Yukon, and Riviera showed better salinity tolerance under all levels of salinity stress. At 45 dS m^{-1}, Seashore Paspalum (SeaStar) out performed all bermudagrasses. SeaStar suffered light injury caused by scalping, which might have had slightly negative impacts on all indicators. At 1.5 dS m^{-1}, SeaStar was the lowest in FSNDVI, GSNDVI, and DGCI/VR. These readings might differ between species due to the different leaf character, which might also help to explain why SeaStar ranked higher than some of the bermudagrass entries at 15 and 30 dS m^{-1}.

For both clonal and seeded trials, all the entries had acceptable turf quality at 15 dS m^{-1}. Minor declination in percentage cover was found in all the entries when exposed to 15 dS m^{-1}. However, severe declinations were found when the treatment reached 30 dS m^{-1}. These findings demonstrated that the bermudagrasses tested in this study can be managed in the moderately low salinity level effectively (below 15 dS m^{-1}), and greener color can be found in the seeded bermudagrasses at up to 15 dS m^{-1}.

Marcum and Pessarakli (2006) pointed out that TifSport can better tolerate salinity than Tifway. However, Lee et al. (2004a) and Lee et al. (2004b) demonstrated that Tifway has better shoot growth and total biomass growth than TifSport when exposed to different salinity stress treatments. The results of this study agree with Lee et al. (2004a) and Lee et al., (2004b). It should be noted, the minor injury of TifSport in this study might have occurred by the presence of mealy bugs (*Pseudococcus* spp.) and eriophyid mites (*Eriophes cynodoniensis)* during the establishment process. However, insect problems were well controlled by applying insecticides at seven day intervals.

Marcum and Pessarakli (2006) also found out that Riviera is relatively more salinity tolerant than Yukon, with green leaf canopy area of 20% and 18%, respectively, at 60 dS m^{-1}. However, this study shows that Yukon performed slightly better than Riviera. This can be explained by the genetic diversity that exists in each single seedling for any seed propagated bermudagrass. To better represent a seeded entry in this study, 10 individual seedlings from each entry were transplanted into each pot, i.e., a total of 60 individual plants representing each released or experimental cultivar.

Marcum and Pessarakli (2006) demonstrated that, Midlawn had 29% green leaf canopy area at 60 dS m^{-1}, whereas Tifway and Yukon only maintained 10% and 18% green leaf canopy area, respectively. However, in the mid-1990's, the golf course superintendent at the Jimmie Austin Golf Course, which is located in Norman, OK, found out that Midlawn performed poorly compared with common bermudagrass over several years when both were irrigated with a high saline irrigation source (Personal communication with Dr. Dennis Martin). This study found that Midlawn had poor salinity tolerance and shows general agreement with the observational information supplied from the Jimmie Austin Golf Course, Norman, OK.

Among all the parameters, LF had better correlation with other parameters, and LF has been considered an important criterion to evaluate saline tolerance in turfgrass (Uddin et al., 2011). We recommend that turf bermudagrass breeders use LF in selecting for salinity tolerance in segregating populations and subsequently developing salinity tolerant cultivars. Among the sensor-based parameters, DIA showed better accuracy than GSNDVI and DGCI/VR in the seeded trial. This is likely due to the fact DIA was conducted with a light bucket under a controlled light condition. On the other hand, the GSNDVI, DGCI, and VR were collected under natural light conditions. Even though white balance was adjusted by the FieldScout® GreenIndex+ Turf application, results can be improved by controlled light conditions such as present when using a light box. Unlike the findings concerning all other parameters, no significant treatment differences were observed in the VR as measured by the FieldScout® GreenIndex+ Turf app at 15 dS m^{-1}. This finding suggests less accuracy in assessing VR using this device/app as compared with other salinity tolerance assessment tools. This can be explained because visual readings predicted by the green color index are not the ideal way to collect data since TQ is not only related to the color but also on the combination of density, texture, uniformity, and disease or environmental stress. Differences were detected in GSNDVI for all entries under the non-treated control condition measured over time. Increases in GSNDVI were found in the clonal trial at 15 dS m^{-1}. It is speculated that the stability of the GreenSeeker™ handheld sensor might be affected by other environmental or mechanical factors, such as the percentage of the battery power level. At a low battery level, less light may be reflected back to the sensor due to less red and infrared light being emitted from the sensor to the canopy. Considering the variations created by the environment, instead of comparing data among different days, random errors can be minimized by comparing the control with the salinity treatment of each entry each day. We speculate that the

GreenSeeker™ handheld sensor and FieldScout® GreenIndex+ Turf application might be sensitive and easily affected by environmental factors, especially light conditions. The accuracy of GSNDVI might also be limited by the size of the measuring area. Considering the small canopy area from the greenhouse pots in this study, FSNDVI, compared with GSNDVI, showed higher correlations, which implies better suitability as the salinity tolerance parameter for the turf greenhouse research. FSNDVI is also the least time consuming and very simple to use, making it a very good parameter for a turfgrass greenhouse salinity study.

Results in this study showed that the salinity levels leading to SW50 and VG50 had a very narrow range. Compared with the other parameters, shoot dry weight and shoot vertical growth rate show similar results with some exceptions. Grass with high relative shoot growth, has less LF and better TQ should be expected. However, exceptions can be found such as in the clonal trial where Midlawn had 27.16% relative shoot growth with a 2.7 LF, while Tifway had 25.88% relative shoot growth with a 5.2 LF, both at 30 dS m^{-1}. Similar results were provided in the seeded trial. The experimental entry OKS 2011-4 had 15.97% relative shoot vertical growth with a 3.7 LF rating, while Yukon had a 5.0 LF rating and VG of 13.98%. These issues show that there are complicated mechanisms present when studying the salinity tolerance of bermudagrasses and that other factors that limit plant growth can be difficult to detect (Lee et al., 2004).

Compared with the linear function used in this study, a non-linear function may also be appropriate when comparing the relative shoot growth of bermudagrasses. For future research, it is recommend to use more salinity treatment levels with a smaller incremental scale to better discern the response of relative bermudagrass shoot growth as a function of EC level.

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Table 3. Effect of four salinity treatments on leaf firing of seven clonal-type bermudagrasses.

Entry	Leaf firing (LF)†			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
OKC1302	9.0a‡	7.8a	5.2a	2.0b
Latitude 36	9.0a	6.8b	3.8c	1.0d
Northbridge	9.0a	7.0b	4.2c	1.7bc
Tifway	9.0a	6.7b	4.8ab	2.7a
Celebration	9.0a	7.0b	4.2c	2.0b
TifSport	9.0a	6.2c	4.3bc	1.5c
Midlawn	9.0a	6.7b	2.7d	1.0d

† Leaf firing (LF) was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

‡ Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 4. Mean leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI), dark green color index (DGCI) and visual reading (VR) for clonal-type bermudagrasses under non-salinity control and salinity treatment of 15 dS m^{-1}.

Entry	TRT†	Salinity level (EC dS m^{-1})	LF‡	TQ§	FSNDVI¶	GSNDVI#	DGCI††	VR‡‡
Celebration	Control	1.5	9.0	9.0	0.753	0.858	0.783	8.37
Celebration	Salinity	15	7.0**§§	6.7***	0.675***	0.783***	0.721***	8.02
Latitude 36	Control	1.5	9.0	9.0	0.763	0.868	0.714	7.72
Latitude 36	Salinity	15	6.8***	6.8***	0.692***	0.802***	0.711	7.68
Midlawn	Control	1.5	9.0	8.3	0.752	0.853	0.639	7.03
Midlawn	Salinity	15	6.7***	6.3***	0.658***	0.767***	0.661	7.12
Northbridge	Control	1.5	9.0	9.0	0.757	0.857	0.697	7.57
Northbridge	Salinity	15	7.0***	7.0***	0.682***	0.800***	0.716	7.73
OKC1302	Control	1.5	9.0	9.0	0.770	0.860	0.759	8.13
OKC1302	Salinity	15	7.8***	7.7***	0.695***	0.810***	0.737	8.12
Tifsport	Control	1.5	9.0	8.2	0.747	0.835	0.717	7.77

Tifsport	Salinity	15	6.2***	6.0***	0.663***	0.760***	0.729	7.90
Tifway	Control	1.5	9.0	8.8	0.755	0.848	0.723	7.80
Tifway	Salinity	15	6.7***	6.2***	0.690***	0.802***	0.783*	8.37***
$LSD_{0.05}$ for entry at the same EC treatment			0.44	0.44	0.0174	0.0191	0.0465	0.302

† TRT refers to treatment, which includes control and salinity treatment.

‡ LF = Leaf firing, it was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

§ TQ = Turf quality, it was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

¶ FSNDVI = NDVI reading determined by FieldScout® CM 1000 NDVI meter.

GSNDVI = NDVI reading determined by GreenSeeker™ handheld sensor.

†† DGCI = Dark green color index determined by FieldScout® GreenIndex+ Turf app.

‡‡ VR = Visual reading determined by FieldScout® GreenIndex+ Turf app.

§§ NS, *, **, *** Not significant (NS) or significantly different from the control (1.5 dS m^{-1}) at 5% (*), 1% (**), or 0.1% (***) within entry and column by LSD.

Table 5. Mean leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI), dark green color index (DGCI) and visual reading (VR) for clonal-type bermudagrasses under non-salinity control and salinity treatment of 30 dS m^{-1}.

Entry	TRT†	Salinity level (EC dS m^{-1})	LF‡	TQ§	FSNDVI¶	GSNDVI#	DGCI††	VR‡‡
Celebration	Control	1.5	9.0	8.5	0.695	0.803	0.760	8.13
Celebration	Salinity	30	4.2***§§	4.2***	0.545***	0.413***	0.465***	5.38***
Latitude 36	Control	1.5	9.0	9.0	0.717	0.82	0.762	8.18
Latitude 36	Salinity	30	3.8***	3.8***	0.537***	0.417***	0.403***	4.80***
Midlawn	Control	1.5	9.0	8.0	0.690	0.782	0.703	7.60
Midlawn	Salinity	30	2.7***	2.3***	0.450***	0.260***	0.316***	3.95***
Northbridge	Control	1.5	9.0	9.0	0.680	0.795	0.690	7.50
Northbridge	Salinity	30	4.2***	4.2***	0.562***	0.423***	0.417***	4.90***
OKC1302	Control	1.5	9.0	9.0	0.700	0.803	0.751	8.07
OKC1302	Salinity	30	5.2***	5.3***	0.598***	0.495***	0.493***	5.63***

Tifsport	Control	1.5	9.0	8.2	0.693	0.777	0.749	8.03
Tifsport	Salinity	30	4.3***	4.2***	0.548***	0.428***	0.408***	4.85***
Tifway	Control	1.5	9.0	8.8	0.687	0.787	0.741	7.97
Tifway	Salinity	30	4.8***	4.8***	0.613***	0.517***	0.522***	5.92***
$LSD_{0.05}$ for entry at the same EC treatment			0.5	0.53	0.0271	0.0435	0.0561	0.520

† TRT refers to treatment, which includes control and salinity treatment.

‡ LF = Leaf firing, it was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

§ TQ = Turf quality, it was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

¶ FSNDVI = NDVI reading determined by FieldScout® CM 1000 NDVI meter.

GSNDVI = NDVI reading determined by GreenSeeker™ handheld sensor.

†† DGCI = Dark green color index determined by FieldScout® GreenIndex+ Turf app.

‡‡ VR = Visual reading determined by FieldScout® GreenIndex+ Turf app.

§§ NS, *, **, *** Not significant (NS) or significantly different from the control (1.5 dS m^{-1}) at 5% (*), 1% (**), or 0.1% (***) within entry and column by LSD.

Table 6. Mean leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI), dark green color index (DGCI) and visual reading (VR) for clonal-type bermudagrasses under non-salinity control and salinity treatment of 45 dS m^{-1}.

Entry	TRT†	Salinity level (EC dS m^{-1})	LF‡	TQ§	FSNDVI¶	GSNDVI#	DGCI††	VR‡‡
Celebration	Control	1.5	9.0	7.7	0.710	0.805	0.689	7.48
Celebration	Salinity	45	2.0***§§	2.0***	0.393***	0.245***	0.309***	3.92***
Latitude 36	Control	1.5	9.0	7.3	0.707	0.800	0.629	6.92
Latitude 36	Salinity	45	1.0***	1.0***	0.327***	0.153***	0.238***	3.23***
Midlawn	Control	1.5	9.0	7.0	0.678	0.770	0.595	6.60
Midlawn	Salinity	45	1.0***	1.0***	0.293***	0.110***	0.212***	2.98***
Northbridge	Control	1.5	9.0	7.7	0.695	0.793	0.636	6.97
Northbridge	Salinity	45	1.7***	1.7***	0.342***	0.182***	0.252***	3.38***
OKC1302	Control	1.5	9.0	7.8	0.711	0.822	0.683	7.43
OKC1302	Salinity	45	2.0***	2.0***	0.397***	0.217***	0.278***	3.62***

Tifsport	Control	1.5	9.0	7.0	0.680	0.768	0.648	7.10
Tifsport	Salinity	45	1.5***	1.5***	0.373***	0.192***	0.262***	3.47***
Tifway	Control	1.5	9.0	8.2	0.713	0.800	0.675	7.37
Tifway	Salinity	45	2.7***	2.7***	0.437***	0.280***	0.313***	3.95***
$LSD_{0.05}$ for entry at the same EC treatment			0.34	0.56	0.0346	0.0325	0.0314	0.29

† TRT refers to treatment, which includes control and salinity treatment.

‡ LF = Leaf firing, it was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

§ TQ = Turf quality, it was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

¶ FSNDVI = NDVI reading determined by FieldScout® CM 1000 NDVI meter.

GSNDVI = NDVI reading determined by GreenSeeker™ handheld sensor.

†† DGCI = Dark green color index determined by FieldScout® GreenIndex+ Turf app.

‡‡ VR = Visual reading determined by FieldScout® GreenIndex+ Turf app.

§§ NS, *, **, *** Not significant (NS) or significantly different from the control (1.5 dS m^{-1}) at 5% (*), 1% (**), or 0.1% (***) within entry and column by LSD.

Table 7. Effect of four salinity treatments on turf quality of seven clonal-type bermudagrasses.

Entry	Turf quality (TQ)†			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
OKC1302	8.5ab‡	7.7a	5.3a	2.0b
Latitude 36	8.8a	6.8b	3.8c	1.0c
Northbridge	8.0cd	7.0b	4.2bc	1.7b
Tifway	8.2bc	6.2d	4.8a	2.7a
Celebration	8.0cd	6.7bc	4.2bc	2.0b
TifSport	7.7d	6.0d	4.2bc	1.5bc
Midlawn	8.0cd	6.3cd	2.3d	1.0c

† Turf quality was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

‡ Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 8. Effect of four salinity treatments on the normalized difference vegetation index (NDVI) of seven clonal-type bermudagrasses as measured by GreenSeeker™ handheld sensor.

Entry	NDVI by GreenSeeker™ handheld sensor (GSNDVI)			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
OKC1302	0.747ab†	0.810a	0.495a	0.217bc
Latitude 36	0.765a	0.802ab	0.417b	0.153e
Northbridge	0.725c	0.800ab	0.435b	0.182de
Tifway	0.732bc	0.802ab	0.517a	0.280a
Celebration	0.737b	0.783bc	0.413b	0.245b
TifSport	0.723c	0.760d	0.428b	0.192cd
Midlawn	0.735b	0.767cd	0.260c	0.110f

† Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 9. Effect of four salinity treatments on the normalized difference vegetation index (NDVI) of seven clonal-type bermudagrasses as measured by the FieldScout® CM 1000 NDVI meter.

Entry	NDVI by FieldScout® CM 1000 NDVI meter (FSNDVI)			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
OKC1302	0.713b†	0.695a	0.598a	0.397b
Latitude 36	0.738a	0.692ab	0.537b	0.327de
Northbridge	0.709b	0.682ab	0.562b	0.342cd
Tifway	0.716b	0.690ab	0.613a	0.437a
Celebration	0.714b	0.675bc	0.545b	0.393b
TifSport	0.714b	0.663c	0.548b	0.373bc
Midlawn	0.714b	0.658c	0.450c	0.293e

† Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 10. Effect of four salinity treatments on the dark green color index of seven clonal-type bermudagrasses.

Entry	Dark green color index (DGCI)			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
OKC1302	0.795ab†	0.737ab	0.493ab	0.278bc
Latitude 36	0.752bc	0.711b	0.403c	0.238de
Northbridge	0.722c	0.716b	0.417c	0.252cd
Tifway	0.794ab	0.783a	0.522a	0.313a
Celebration	0.829a	0.721b	0.465b	0.309ab
TifSport	0.775b	0.729b	0.408c	0.262cd
Midlawn	0.706d	0.661c	0.314d	0.212e

† Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 11. Effect of four salinity treatments on visual reading of seven clonal-type bermudagrasses as measured by FieldScout® GreenIndex+ Turf.

Entry	Visual reading by FieldScout® GreenIndex+ Turf (VR)			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
OKC1302	8.5ab†	8.1ab	5.6ab	3.6b
Latitude 36	8.1bc	7.7d	4.8d	3.2cd
Northbridge	7.8cd	7.7cd	4.9cd	3.4bc
Tifway	8.5ab	8.4a	5.9a	3.9a
Celebration	8.8a	8.0bc	5.4bc	3.9a
TifSport	8.3b	7.9bcd	4.9d	3.5bc
Midlawn	7.6d	7.1e	3.9e	3.0d

† Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 12. Effect of four salinity treatments on live green cover of seven clonal-type bermudagrasses assessed through digital image analysis (DIA).

Entry	Live green cover (%) † Salinity treatments (dS m^{-1})			
	1.5	15	30	45
OKC1302	96.84b‡	95.52a	59.24a	15.71bc
Latitude 36	99.20a	93.61b	42.46cd	4.82d
Northbridge	95.65bc	93.26bc	47.14bc	9.41cd
Tifway	94.79c	91.27cd	55.88ab	24.73a
Celebration	96.84b	89.21de	49.82bc	19.83ab
TifSport	90.90d	83.68f	34.64d	5.79d
Midlawn	97.10b	86.97e	23.50e	3.08d

† Live green coverage is the result of digital image analysis (DIA) via SigmaScan software, results were presented as percentage, LSD grouping was presented after Arcsin transformation.

‡ Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 13. Predicted salinity level for 50% shoot growth reduction (SW50) of seven clonal-type bermudagrasses.

Entry	Predicted salinity level (dS m^{-1})
	Relative shoot growth
OKC1302	22.9†
Latitude 36	22.9
Northbridge	23.3
Tifway	24.5
Celebration	23.2
TifSport	22.9
Midlawn	23.7

† Numerical difference does not necessary mean statistically difference (n = 6).

Table 14. Pearson correlation coefficient for leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI), dark green color index (DGCI), visual reading (VR), shoot dry weight (DW) and digital image analysis (DIA) in the clonal bermudagrass trial.

Parameter	LF‡	TQ§	FSNDVI¶	GSNDVI#	DGCI††	VR‡‡	DW§§	DIA¶¶
LF	1	0.971 ***†	0.946 ***	0.936 ***	0.908 ***	0.907 ***	0.719 ***	0.954 ***
TQ		1	0.950 ***	0.939 ***	0.918 ***	0.917 ***	0.705 ***	0.965 ***
FSNDVI			1	0.961 ***	0.920 ***	0.92 ***	0.669 ***	0.953 ***
GSNDVI				1	0.907 ***	0.907 ***	0.735 ***	0.950 ***
DGCI					1	0.999 ***	0.596 ***	0.934 ***
VR						1	0.593 ***	0.934 ***
DW							1	0.712 ***
DIA								1

†***Indicates significant of correlations at p = 0.001 level.

‡ LF = Leaf firing, it was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

§ TQ = Turf quality, it was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

¶ FSNDVI = the NDVI reading determined by FieldScout® CM 1000 NDVI meter.

GSNDVI = NDVI reading determined by GreenSeeker™ handheld sensor.

†† DGCI = Dark green color index determined by FieldScout® GreenIndex+ Turf app.

‡‡ VR = Visual reading determined by FieldScout® GreenIndex+ Turf app.

§§ DW = Shoot dry weight.

¶¶ DIA = Digital image analysis.

Table 15. Effect of four salinity treatments on leaf firing of 10 seeded-type bermudagrasses and SeaStar.

Entry	Leaf firing (LF)†			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
Princess 77	9.0a‡	8.7a	5.2a	3.5b
Riviera	9.0a	8.5ab	4.7bc	2.8cd
Yukon	9.0a	8.2abc	5.0ab	3.2bc
Pyramid 2	9.0a	8.0bcd	4.3de	2.5de
OKS 2011-4	9.0a	7.8cde	3.7f	2.3ef
Royal Bengal	9.0a	7.8cde	4.0ef	2.0f
NuMex Sahara	9.0a	7.7cde	3.8f	2.0f
SeaStar	9.0a	7.5de	4.5cd	4.0a
Southern Star	9.0a	7.5de	4.0ef	2.2ef
OKS 2009-3	9.0a	7.5de	3.7f	2.0f
OKS 2011-1	9.0a	7.3de	4.3de	2.3ef

† Leaf firing (LF) was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

‡ Means accompanied by the same small letter in the same column are not significantly different at the $P = 0.05$ level (n = 6).

Table 16. Mean leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI), dark green color index (DGCI) and visual reading (VR) for seeded-type bermudagrasses and SeaStar under non-salinity control and salinity treatment of 15 dS m^{-1}.

Entry	TRT†	Salinity level (EC dS m^{-1})	LF‡	TQ§	FSNDVI¶	GSNDVI#	DGCI††	VR‡‡
Princess 77	Control	1.5	9.0	9.0	0.703	0.795	0.711	7.69
Princess 77	Salinity	15	8.7	8.5	0.685	0.733*§§	0.839***	8.90***
NuMex Sahara	Control	1.5	7.7	7.5	0.645	0.727	0.622	6.84
NuMex Sahara	Salinity	15	7.7	7.2	0.618*	0.683	0.698***	7.58**
OKS 2009-3	Control	1.5	8.0	7.8	0.658	0.737	0.643	7.06
OKS 2009-3	Salinity	15	7.5	7.2*	0.612***	0.672**	0.730***	7.85**
OKS 2011-1	Control	1.5	8.0	7.7	0.692	0.745	0.652	7.14
OKS 2011-1	Salinity	15	7.3*	7.5	0.648**	0.715	0.761***	8.15***
OKS 2011-4	Control	1.5	7.8	7.2	0.667	0.725	0.633	6.97
OKS 2011-4	Salinity	15	7.8	7.2	0.620***	0.663	0.724***	7.82***
Pyramid 2	Control	1.5	7.8	8.0	0.678	0.742	0.664	7.26
Pyramid 2	Salinity	15	8.0	7.8	0.657	0.730	0.753***	8.08***

Royal Bengal	Control	1.5	8.0	7.8	0.678	0.748	0.648	7.08
Royal Bengal	Salinity	15	7.8	7.5	0.617***	0.678*	0.741***	7.95***
Seastar	Control	1.5	7.0	7.0	0.642	0.697	0.607	6.71
Seastar	Salinity	15	7.5	6.8	0.605**	0.650	0.718***	7.77***
Southern Star	Control	1.5	8.2	7.7	0.671	0.735	0.611	6.73
Southern Star	Salinity	15	7.5*	7*	0.617***	0.670*	0.737***	7.93***
Yukon	Control	1.5	8.8	8.8	0.708	0.828	0.696	7.56
Yukon	Salinity	15	8.2*	8.0**	0.667**	0.747*	0.809***	8.62***
Riviera	Control	1.5	8.7	8.7	0.707	0.782	0.683	7.43
Riviera	Salinity	15	8.5	8.2	0.683	0.735	0.803***	8.53***
LSD0.05 for entry at the same EC treatment			0.57	0.6	0.026	0.049	0.050	0.47

† TRT refers to treatment, which includes control and salinity treatment.

‡ LF = Leaf firing, it was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

§ TQ = Turf quality, it was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

¶ FSNDVI = NDVI reading determined by FieldScout® CM 1000 NDVI meter.

GSNDVI = NDVI reading determined by GreenSeeker™ handheld sensor.

†† DGCI = Dark green color index determined by FieldScout® GreenIndex+ Turf app.

‡‡ VR = Visual reading determined by FieldScout® GreenIndex+ Turf app.

§§ NS, *, **, *** Not significant (NS) or significantly different from the control (1.5 dS m^{-1}) at 5% (*), 1% (**), or 0.1% (***) within entry and column by LSD.

Table 17. Mean leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI), dark green color index (DGCI) and visual reading (VR) for seeded-type bermudagrasses and SeaStar under non-salinity control and salinity treatment of 30 dS m^{-1}.

Entry	TRT†	Salinity level (EC dS m^{-1})	LF‡	TQ§	FSNDVI¶	GSNDVI#	DGCI††	VR‡‡
Princess 77	Control	1.5	9.0	8.0	0.715	0.877	0.631	6.93
Princess 77	Salinity	30	5.2***§§	5.2***	0.548***	0.693***	0.402***	4.82***
NuMex Sahara	Control	1.5	9.0	7.2	0.658	0.830	0.551	6.20
NuMex Sahara	Salinity	30	3.8***	3.8***	0.435***	0.563***	0.302***	3.85***
OKS 2009-3	Control	1.5	9.0	6.8	0.647	0.822	0.573	6.40
OKS 2009-3	Salinity	30	3.7***	3.7***	0.438***	0.592***	0.320***	4.02***
OKS 2011-1	Control	1.5	9.0	7.7	0.688	0.850	0.570	6.37
OKS 2011-1	Salinity	30	4.3***	4.3***	0.491***	0.683***	0.369***	4.47***
OKS 2011-4	Control	1.5	9.0	6.3	0.662	0.810	0.588	6.52
OKS 2011-4	Salinity	30	3.7***	3.7***	0.476***	0.623***	0.360***	4.40***
Pyramid 2	Control	1.5	9.0	7.8	0.693	0.847	0.612	6.75
Pyramid 2	Salinity	30	4.3***	4.3***	0.502***	0.643***	0.338***	4.18***

Royal Bengal	Control	1.5	9.0	7.5	0.680	0.840	0.572	6.40
Royal Bengal	Salinity	30	4.0***	4.0***	0.468***	0.632***	0.350***	4.30***
Seastar	Control	1.5	9.0	7.2	0.649	0.823	0.533	6.02
Seastar	Salinity	30	4.5***	4.5***	0.492***	0.668***	0.412***	4.87***
Southern Star	Control	1.5	9.0	7.3	0.673	0.833	0.577	6.43
Southern Star	Salinity	30	4.0***	4.0***	0.465***	0.625***	0.376***	4.53***
Yukon	Control	1.5	9.0	8.0	0.713	0.888	0.629	6.90
Yukon	Salinity	30	5.0***	5.0***	0.541***	0.690***	0.410***	4.85***
Riviera	Control	1.5	9.0	8.0	0.709	0.870	0.627	6.90
Riviera	Salinity	30	4.7***	4.7***	0.499***	0.665***	0.370***	4.48***
LSD0.05 for entry at the same EC treatment			0.37	0.51	0.024	0.040	0.069	0.644

† TRT refers to treatment, which includes control and salinity treatment.

‡ LF = Leaf firing, it was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

§ TQ = Turf quality, it was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

¶ FSNDVI = NDVI reading determined by FieldScout® CM 1000 NDVI meter.

GSNDVI = NDVI reading determined by GreenSeeker™ handheld sensor.

†† DGCI = Dark green color index determined by FieldScout® GreenIndex+ Turf app.

‡‡ VR = Visual reading determined by FieldScout® GreenIndex+ Turf app.

¶¶ NS, *, **, *** Not significant (NS) or significantly different from the control (1.5 dS m-1) at 5% (*), 1% (**), or 0.1% (***) within entry and column by LSD.

Table 18. Mean leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI), dark green color index (DGCI) and visual reading (VR) for seeded-type bermudagrasses and SeaStar under non-salinity control and salinity treatment of 45 dS m^{-1}.

Entry	TRT†	Salinity level (EC dS m^{-1})	LF‡	TQ§	FSNDVI¶	GSNDVI#	DGCI††	VR‡‡
Princess 77	Control	1.5	9.0	8.0	0.722	0.827	0.736	7.95
Princess 77	Salinity	45	3.5***§§	3.5***	0.407***	0.308***	0.351***	4.32***
NuMex Sahara	Control	1.5	9.0	7.2	0.688	0.767	0.619	6.82
NuMex Sahara	Salinity	45	2.0***	2.0***	0.340***	0.203***	0.282***	3.65***
OKS 2009-3	Control	1.5	9.0	6.8	0.682	0.747	0.663	7.23
OKS 2009-3	Salinity	45	2.0***	2.0***	0.350***	0.193***	0.298***	3.80***
OKS 2011-1	Control	1.5	9.0	7.7	0.708	0.797	0.690	7.50
OKS 2011-1	Salinity	45	2.3***	2.3***	0.362***	0.223***	0.303***	3.85***
OKS 2011-4	Control	1.5	9.0	6.3	0.690	0.760	0.660	7.22
OKS 2011-4	Salinity	45	2.3***	2.3***	0.357***	0.198***	0.293***	3.75***
Pyramid 2	Control	1.5	9.0	7.8	0.710	0.773	0.694	7.52
Pyramid 2	Salinity	45	2.5***	2.5***	0.362***	0.232***	0.303***	3.83***

Royal Bengal	Control	1.5	9.0	7.5	0.702	0.783	0.663	7.25
Royal Bengal	Salinity	45	2.0***	2.0***	0.367***	0.212***	0.307***	3.88***
Seastar	Control	1.5	9.0	7.2	0.665	0.773	0.636	7.00
Seastar	Salinity	45	4.0***	4.0***	0.428***	0.348***	0.359***	4.37***
Southern Star	Control	1.5	9.0	7.3	0.703	0.780	0.633	6.95
Southern Star	Salinity	45	2.2***	2.2***	0.384***	0.187***	0.304***	3.83***
Yukon	Control	1.5	9.0	8.0	0.725	0.832	0.728	7.83
Yukon	Salinity	45	3.2***	3.2***	0.407***	0.302***	0.320***	4.02***
Riviera	Control	1.5	9.0	8.0	0.722	0.818	0.733	7.90
Riviera	Salinity	45	2.8***	2.8***	0.390***	0.272***	0.296***	3.79
LSD0.05 for entry at the same EC treatment			0.5	0.55	0.026	0.0375	0.039	0.368

† TRT refers to treatment, which includes control and salinity treatment.

‡ LF = Leaf wilting and firing, it was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

§ TQ = Turf quality, it was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

¶ FSNDVI = NDVI reading determined by FieldScout® CM 1000 NDVI meter.

GSNDVI = NDVI reading determined by GreenSeeker™ handheld sensor.

†† DGCI = Dark green color index determined by FieldScout® GreenIndex+ Turf app.

‡‡ VR = Visual reading determined by FieldScout® GreenIndex+ Turf app.

§§ NS, *, **, *** Not significant (NS) or significantly different from the control (1.5 dS m-1) at 5% (*), 1% (**), or 0.1% (***) within entry and column by LSD.

Table 19. Effect of four salinity treatments on turf quality of 10 seeded-type bermudagrasses and SeaStar.

Entry	Turf quality (TQ)† Salinity treatments (dS m^{-1})			
	1.5	15	30	45
Princess 77	8.7a‡	8.5a	5.2a	3.5ab
Riviera	7.7b	8.2ab	4.7abc	2.8cd
Yukon	8.5a	8.0abc	5.0ab	3.2bc
Pyramid 2	7.7b	7.8bcd	4.3cd	2.5de
OKS 2011-4	7.2c	7.2def	3.7e	2.3de
Royal Bengal	7.3bc	7.5cde	4.0de	2.0e
NuMex Sahara	7.0d	7.2def	3.8e	2.0e
Sea Star	7.0d	6.8f	4.5bcd	4.0a
Southern Star	7.5bc	7.0ef	4.0de	2.2e
OKS 2009-3	7.0d	7.2def	3.7e	2.0e
OKS 2011-1	7.0d	7.5cde	4.3cd	2.3de

† TQ (Turf quality) was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

‡ Means accompanied by the same small letter in the same column are not significantly different at the $P = 0.05$ level (n = 6).

Table 20. Effect of four salinity treatments on the normalized difference vegetation index (NDVI) of 10 seeded-type bermudagrasses and SeaStar as measured by GreenSeeker™ handheld sensor.

Entry	NDVI by GreenSeeker™ handheld sensor (GSNDVI) Salinity treatments (dS m^{-1})			
	1.5	15	30	45
Princess 77	0.848a†	0.733ab	0.693a	0.308b
Riviera	0.828ab	0.735a	0.665abcd	0.272bc
Yukon	0.845a	0.747a	0.690a	0.302b
Pyramid 2	0.803b	0.730ab	0.643bcde	0.232cd
OKS 2011-4	0.800b	0.663d	0.623ef	0.198de
Royal Bengal	0.802b	0.678cd	0.632cdef	0.212de
NuMex Sahara	0.802b	0.683bcd	0.563g	0.203de
SeaStar	0.757c	0.650d	0.668abc	0.348a
Southern Star	0.807b	0.670cd	0.625def	0.187e
OKS 2009-3	0.807b	0.672cd	0.592fg	0.193e
OKS 2011-1	0.805b	0.715abc	0.683ab	0.223de

† Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 21. Effect of four salinity treatments on the normalized difference vegetation index (NDVI) of 10 seeded-type bermudagrasses and SeaStar as measured by FieldScout® CM 1000 NDVI meter.

Entry	NDVI by FieldScout® CM 1000 NDVI meter (FSNDVI)			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
Princess 77	0.707a†	0.685a	0.548a	0.407ab
Riviera	0.698ab	0.683a	0.499bc	0.390bc
Yukon	0.707a	0.667ab	0.541a	0.407ab
Pyramid 2	0.677bc	0.657b	0.502b	0.362de
OKS 2011-4	0.680abc	0.620c	0.476bcd	0.357de
Royal Bengal	0.673bc	0.617c	0.468cde	0.367cd
NuMex Sahara	0.665cd	0.618c	0.435f	0.340e
SeaStar	0.635d	0.605c	0.492bcd	0.428a
Southern Star	0.665c	0.617c	0.465e	0.348de
OKS 2009-3	0.655c	0.612c	0.438f	0.350de
OKS 2011-1	0.678bc	0.648b	0.491bcd	0.362de

† Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 22. Effect of four salinity treatments on the dark green color index of 10 seeded-type bermudagrasses and SeaStar.

Entry	Dark green color index (DGCI)			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
Princess 77	0.893ab†	0.839a	0.402ab	0.351a
Riviera	0.862abc	0.803abc	0.370abcd	0.296b
Yukon	0.900a	0.809ab	0.410a	0.320ab
Pyramid 2	0.850c	0.753cd	0.3380cd	0.303b
OKS 2011-4	0.780ef	0.724d	0.360abcd	0.293b
Royal Bengal	0.851bc	0.741d	0.350abcd	0.307b
NuMex Sahara	0.780ef	0.698e	0.302d	0.282b
SeaStar	0.750f	0.718d	0.412a	0.359a
Southern Star	0.780ef	0.737d	0.376abc	0.304b
OKS 2009-3	0.798de	0.730d	0.320cd	0.298b
OKS 2011-1	0.829cd	0.761bcd	0.369abcd	0.303b

† Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 23. Effect of four salinity treatments on visual reading of 10 seeded-type bermudagrasses and SeaStar as measured by FieldScout® GreenIndex+ Turf.

Entry	Visual Reading by FieldScout® GreenIndex+ Turf (VR)			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
Princess 77	9.4a†	8.9a	4.8ab	4.3a
Riviera	9.1ab	8.5abc	4.5abcd	3.8b
Yukon	9.5a	8.6ab	4.9a	4.0ab
Pyramid 2	9.0b	8.1cd	4.2bcd	3.8b
OKS 2011-4	8.3de	7.8de	4.4abcd	3.8b
Royal Bengal	9.0b	7.9de	4.3abcd	3.9b
NuMex Sahara	8.5cd	7.6e	3.9d	3.7b
SeaStar	8.1e	7.8de	4.9a	4.4a
Southern Star	8.3de	7.9de	4.5abc	3.8b
OKS 2009-3	8.5cd	7.9de	4.0cd	3.8b
OKS 2011-1	8.8bc	8.2bcd	4.5abcd	3.9b

† Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 24. Effect of four salinity treatments on live green cover of 10 bermudagrasses and SeaStar assessed through digital image analysis.

Entry	Live green cover (%)†			
	Salinity treatments (dS m^{-1})			
	1.5	15	30	45
Princess 77	98.70a‡	90.96a	57.14a	16.11b
Riviera	92.63bc	84.96bc	39.42bc	11.76bcd
Yukon	98.15a	89.10ab	53.95a	14.61bc
Pyramid 2	92.52c	79.82cd	40.01bc	10.27bcd
OKS 2011-4	85.71d	72.05e	25.24c	4.97d
Royal Bengal	86.72d	71.57e	41.26bc	7.65bcd
NuMex Sahara	95.52b	78.37de	35.91bc	4.61d
SeaStar	91.74c	85.83ab	57.42a	22.92a
Southern Star	93.13bc	71.746e	37.97bc	6.90bcd
OKS 2009-3	87.07d	72.31e	35.01c	6.60d
OKS 2011-1	90.41cd	78.61de	44.80b	10.02bcd

† Live green coverage is the result of digital image analysis (DIA) via SigmaScan software, results were presented as percentage, LSD grouping was presented after Arcsin transformation.

‡ Means accompanied by the same small letter in the same column are not significantly different at the P = 0.05 level (n = 6).

Table 25. Predicted salinity level for 50% reduction in vertical shoot growth (VG50) of 10 seeded-type bermudagrasses and SeaStar.

Entry	Predicted salinity level (dS m^{-1})
	50% reduction shoot vertical growth
Princess 77	22.4†
Riviera	21.8
Yukon	22.5
Pyramid 2	21.9
OKS 2011-4	22.2
Royal Bengal	22
NuMex Sahara	21.7
SeaStar	23
Southern Star	22.3
OKS 2009-3	22.3
OKS 2011-1	22.1

† Numerical difference does not necessary mean statistically difference.

Table 26. Pearson correlation coefficient for leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI), dark green color index (DGCI), visual reading (VR), relative shoot vertical growth (VG) and digital image analysis (DIA) in the seeded bermudagrass trial.

Parameter	LF‡	TQ §	FSNDVI¶	GSNDVI#	DGCI#	VR‡‡	VG§§	DIA¶¶
LF	1	0.932 ***	0.951 ***	0.894 ***	0.856 ***	0.856 ***	0.869 ***	0.929 ***
TQ		1	0.942 ***	0.866 ***	0.845 ***	0.845 ***	0.832 ***	0.928 ***
FSNDVI			1	0.899 ***	0.823 ***	0.824 ***	0.845 ***	0.928 ***
GSNDVI				1	0.741 ***	0.742 ***	0.718 ***	0.886 ***
DGCI					1	1	0.776 ***	0.836 ***
VR						1	0.776 ***	0.837 ***
VG							1	0.824 ***
DIA								1

***Indicates significant of correlations at p = 0.001 level.

‡ LF = Leaf firing, it was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.

§ TQ = Turf quality, it was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

¶ FSNDVI = the NDVI reading determined by FieldScout® CM 1000 NDVI meter.

GSNDVI = NDVI reading determined by GreenSeeker™ handheld sensor.

†† DGCI = Dark green color index determined by FieldScout® GreenIndex+ Turf app.

‡‡ VR = Visual reading determined by FieldScout® GreenIndex+ Turf app.

§§ VG = Relative shoot vertical growth rate.

¶¶ DIA = Digital image analysis.

Table 27. Rank of salinity tolerance of seven clonal-type bermudagrass entries.

Entry	Times in Top Statistical Group†	Times in Bottom Statistical Group‡
Tifway	21	3
OKC1302	19	1
Celebration	6	3
Latitude 36	7	6
Northbridge	3	5
TifSport	2	11
Midlawn	1	23

† Number of times that the entry's mean ranked in the top statistical ranking group (according to Fisher's least significant difference at the P=0.05 level) for the categories with a significant F-test in a total of 28 times. These include leaf firing (LF), turf quality (TQ), NDVI determined by GreenSeeker™ handheld sensor (GSNDVI), NDVI determined by FieldScout® CM 1000 NDVI meter (FSNDVI), dark green color index (DGCI) and visual reading (VR) determined by FieldScout® GreenIndex+ Turf, and digital image analysis (DIA).

‡ Number of times that the entry's mean appeared in the bottom statistical ranking group according to Fisher's least significant difference at the P = 0.05 level (n = 6).

Table 28. Rank of salinity tolerance of 10 seeded-type bermudagrass entries compared with SeaStar.

Entry	Times in Top Statistical Group†	Times in Bottom Statistical Group‡
Princess 77	25	0
Yukon	24	2
Riviera	15	6
SeaStar	13	10
OKS 2011-1	5	14
OKS 2011-4	4	21
Southern star	3	18
Pyramid 2	2	8
Royal Bengal	2	17
OKS 2009-3	1	22
NuMex Sahara	1	24

† Number of times that the entry's mean ranked in the top statistical ranking group (according to Fisher's Protected Least Significant Difference at the P=0.05 level) for the categories over a total of 28 times. These include leaf firing (LF), turf quality (TQ), NDVI determined by GreenSeeker™ handheld sensor (GSNDVI), NDVI determined by FieldScout® CM 1000 NDVI meter (FSNDVI), dark green color index (DGCI) and visual reading (VR) determined by FieldScout® GreenIndex+ Turf, and digital image analysis (DIA).

‡ Number of times that the entry's mean appeared in the bottom statistical ranking group according to Fisher's least significant difference at the P = 0.05 (n = 6).

Figure 2. Linear regression relating the relative shoot growth of Celebration bermudagrass as a function of four salinity treatment levels.

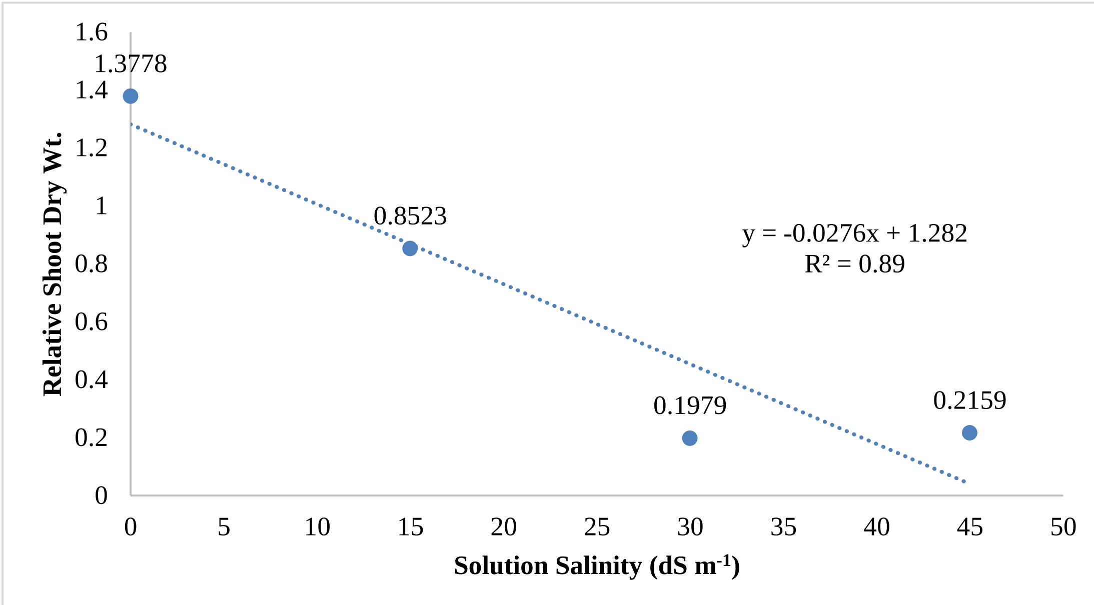


Figure 3. Linear regression relating the relative shoot growth of Midlawn bermudagrass as a function of four salinity treatment levels.

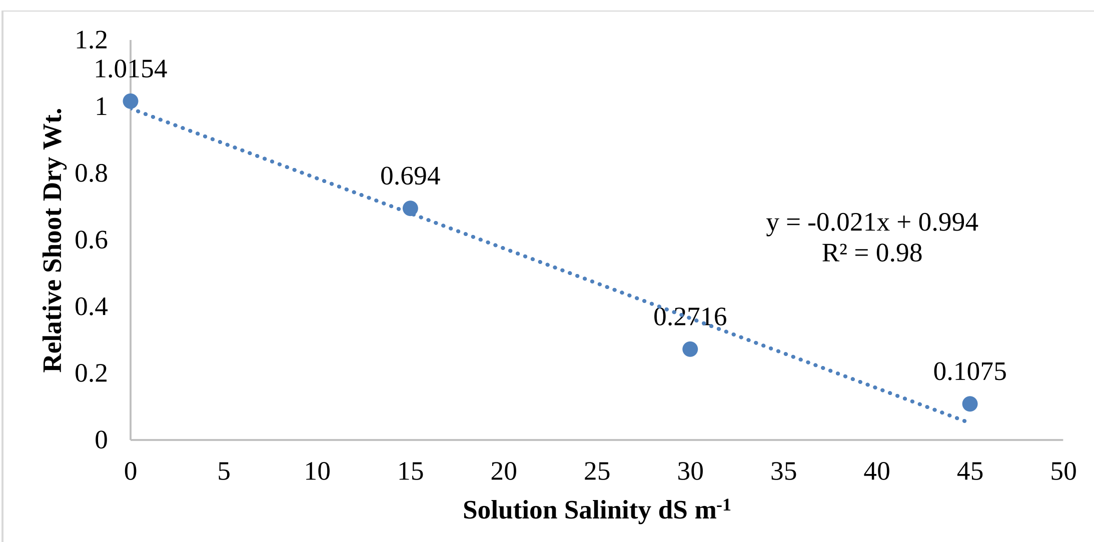


Figure 4. Linear regression relating the relative shoot growth of OKC1302 bermudagrass as a function of four salinity treatment levels.

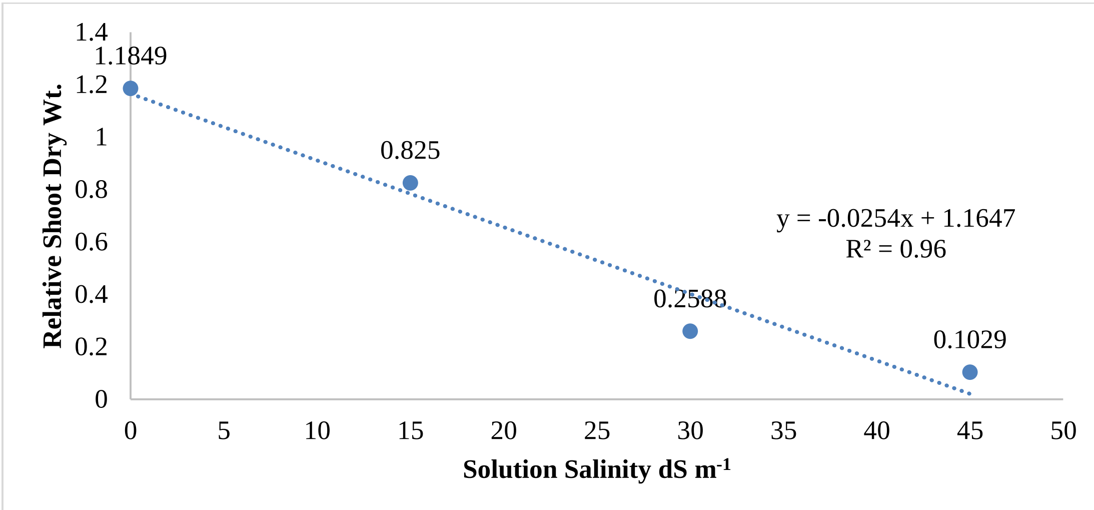


Figure 5. Linear regression relating the relative shoot growth of Latitude 36 bermudagrass as a function of four salinity treatment levels.

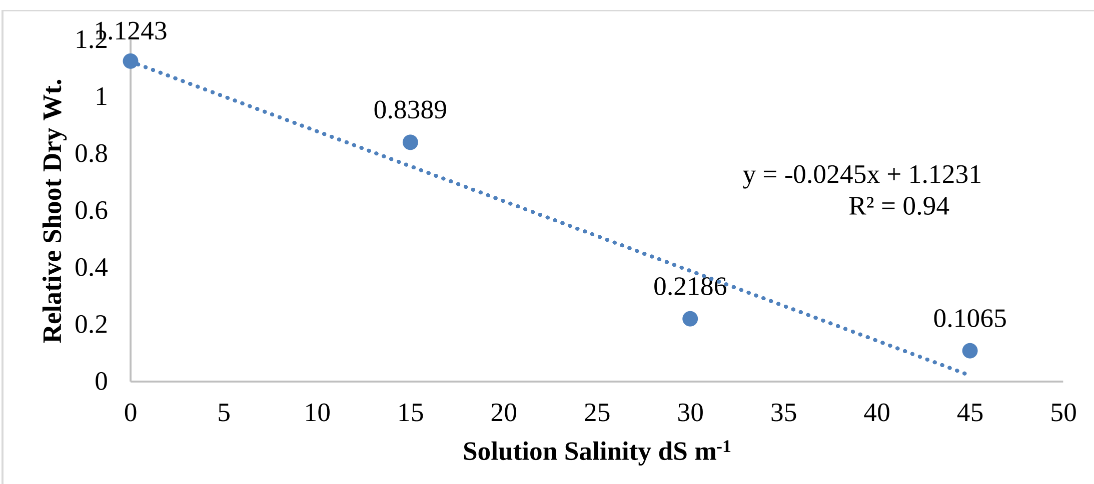


Figure 6. Linear regression relating the relative shoot growth of Northbridge bermudagrass as a function of four salinity treatment levels.

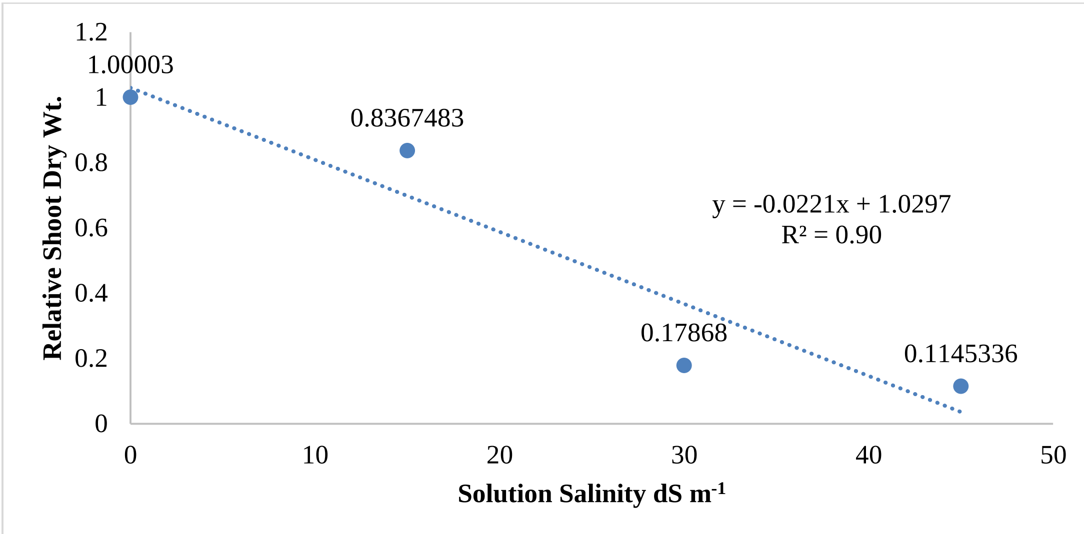


Figure 7. Linear regression relating the relative shoot growth of TifSport bermudagrass as a function of four salinity treatment levels.

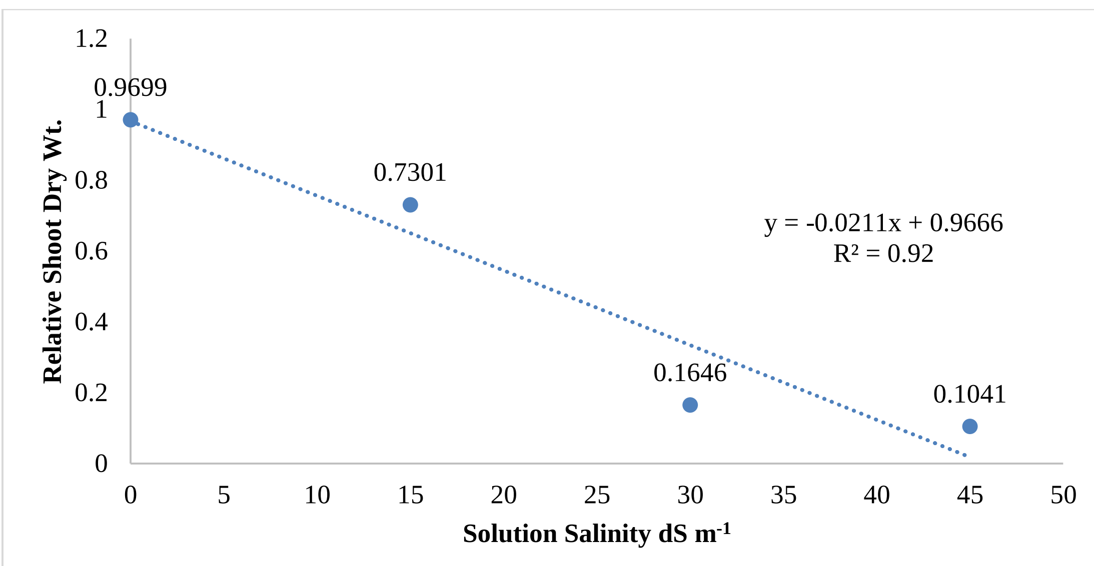


Figure 8. Linear regression relating the relative shoot growth of Tifway bermudagrass as a function of four salinity treatment levels.

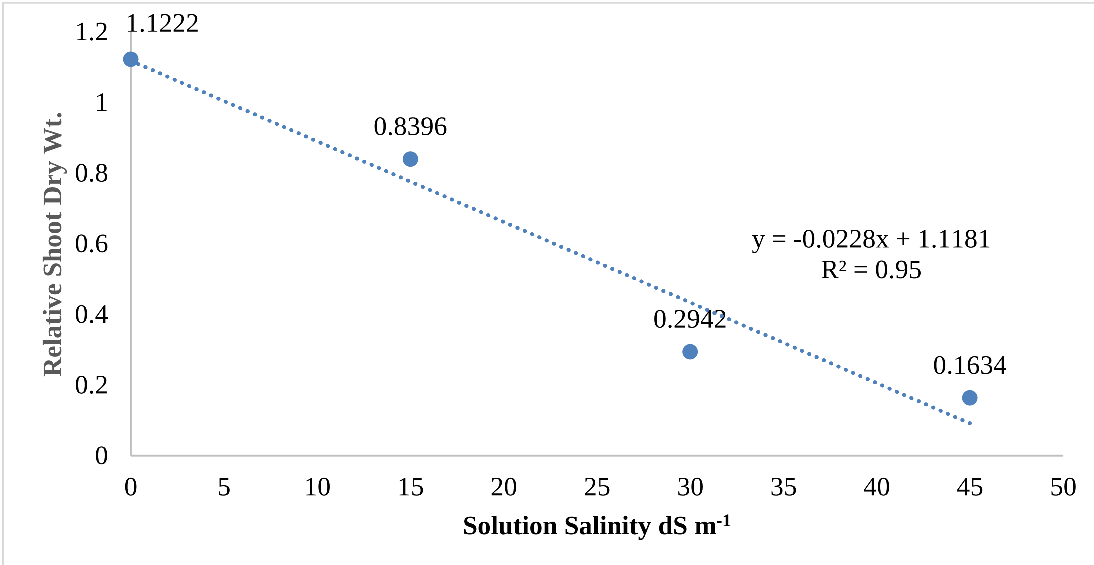


Figure 9. Linear regression relating the relative shoot vertical growth of Princess 77 bermudagrass as a function of four salinity treatment levels.

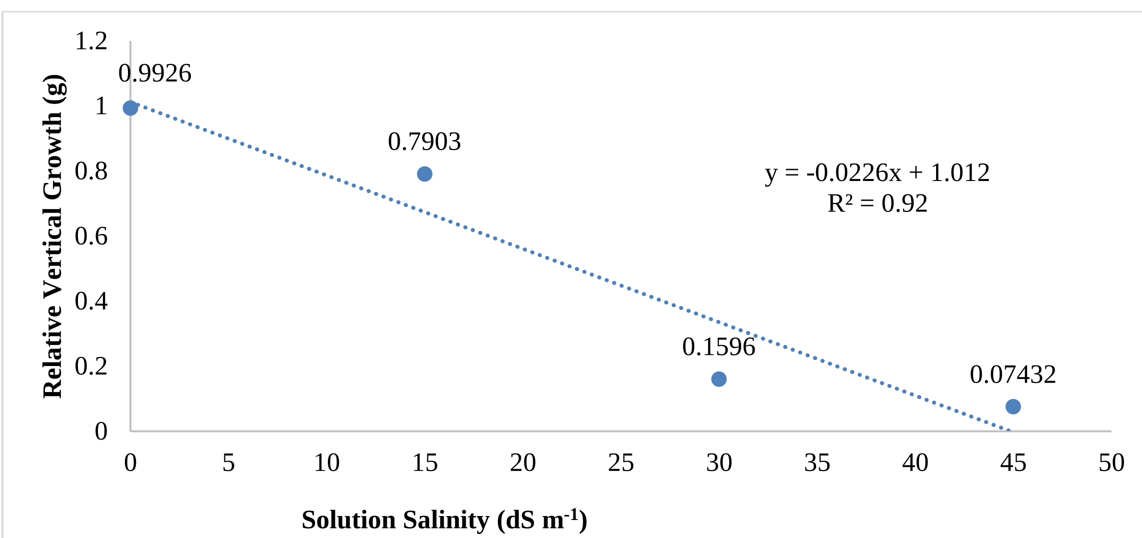


Figure 10. Linear regression relating the relative shoot vertical growth of NuMex Sahara bermudagrass as a function of four salinity treatment levels.

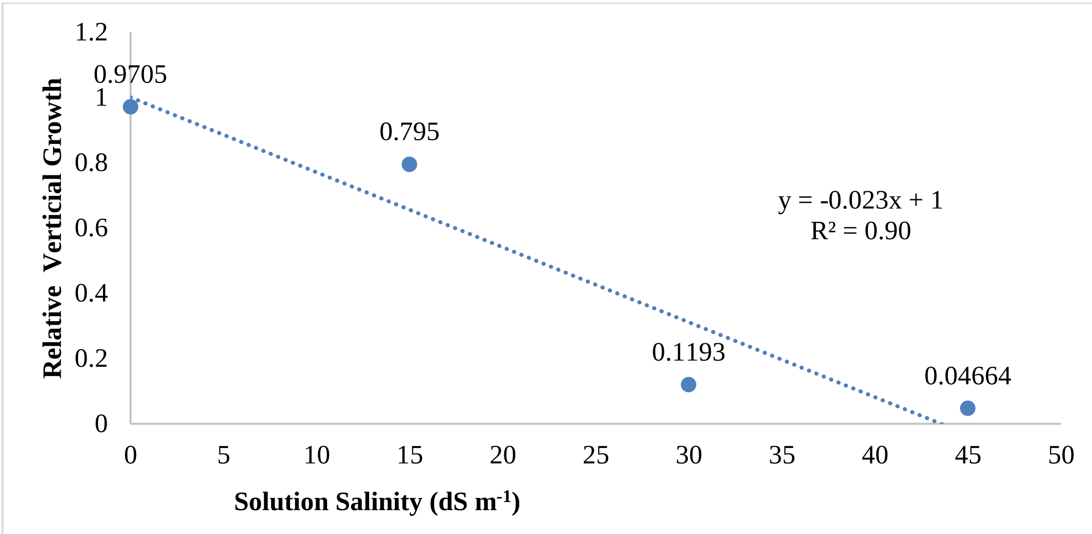


Figure 11. Linear regression relating the relative shoot vertical growth of OKS 2009-3 bermudagrass as a function of four salinity treatment levels.

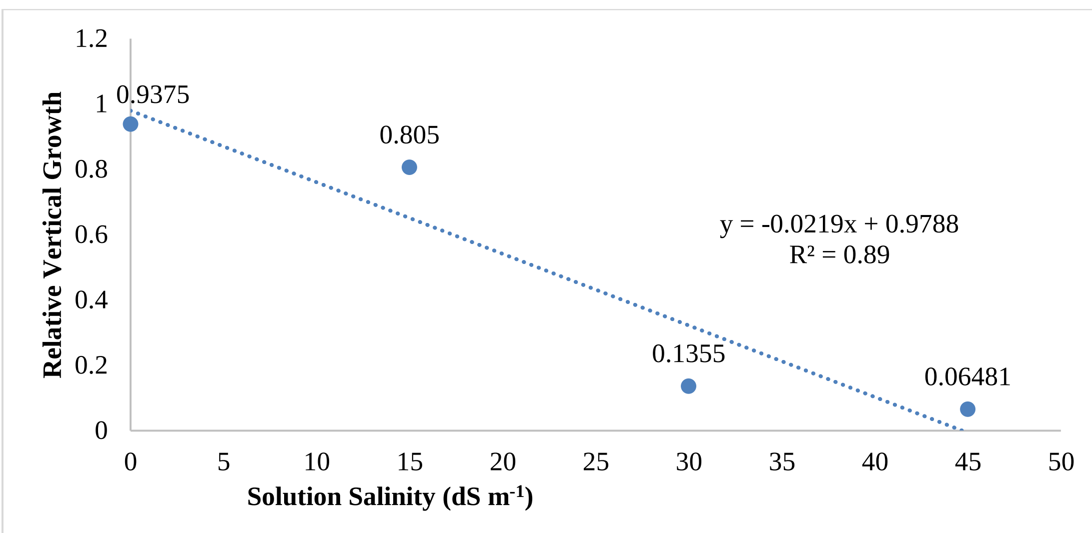


Figure 12. Linear regression relating the relative shoot vertical growth of OKS 2011-1 bermudagrass as a function of four salinity treatment levels.

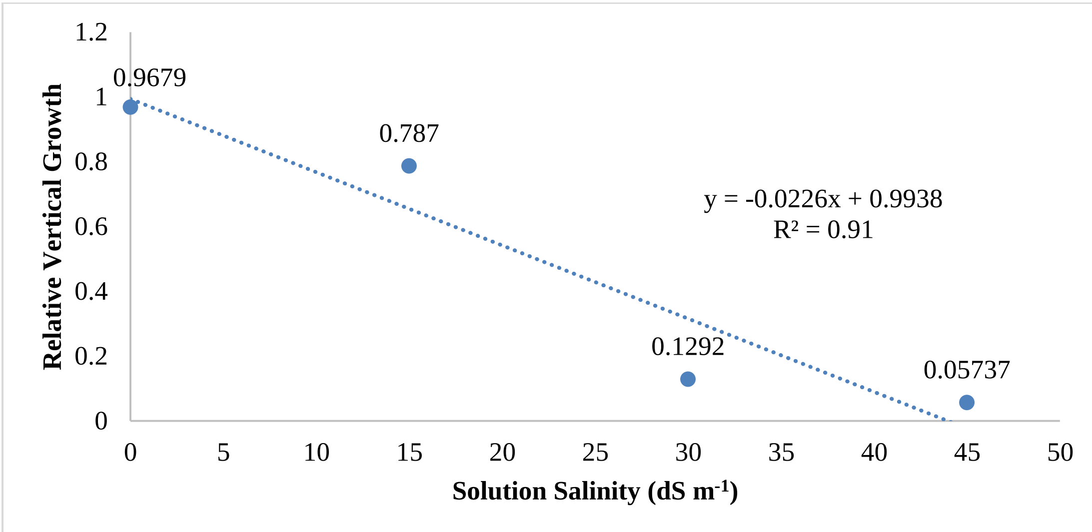


Figure 13. Linear regression relating the relative shoot vertical growth of OKS 2011-4 bermudagrass as a function of four salinity treatment levels.

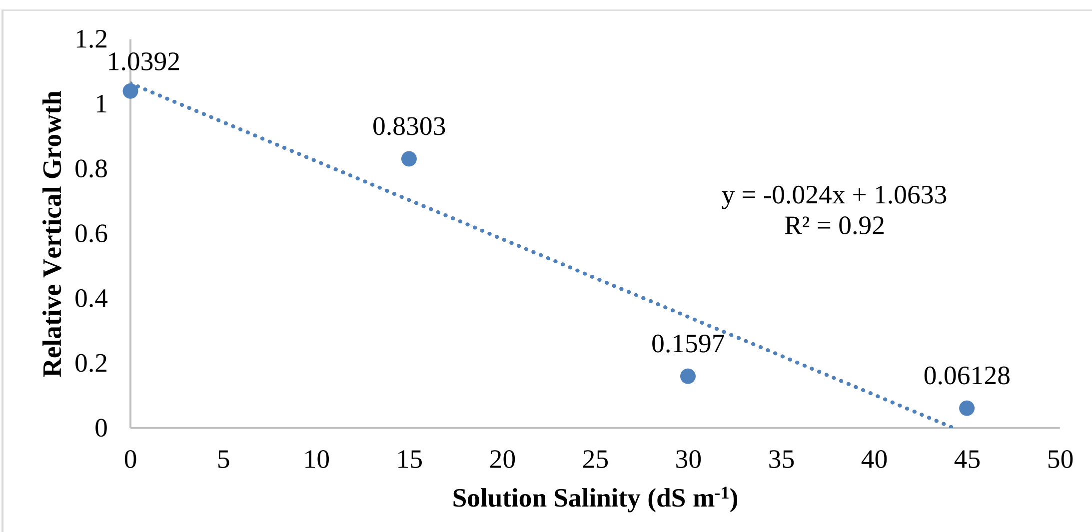


Figure 14. Linear regression relating the relative shoot vertical growth of Pyramid 2 bermudagrass as a function of four salinity treatment levels.

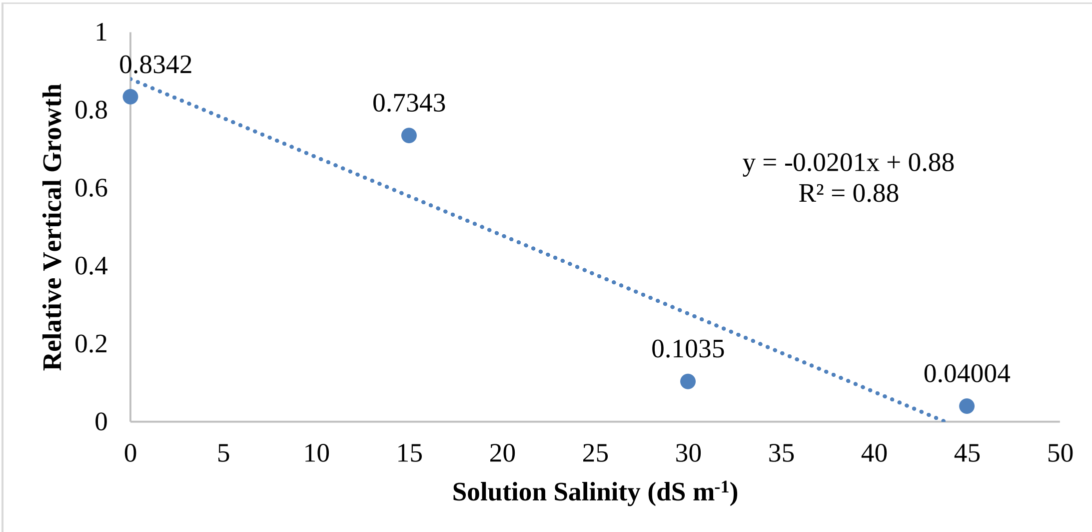


Figure 15. Linear regression relating the relative shoot vertical growth of Royal Bengal bermudagrass as a function of four salinity treatment levels.

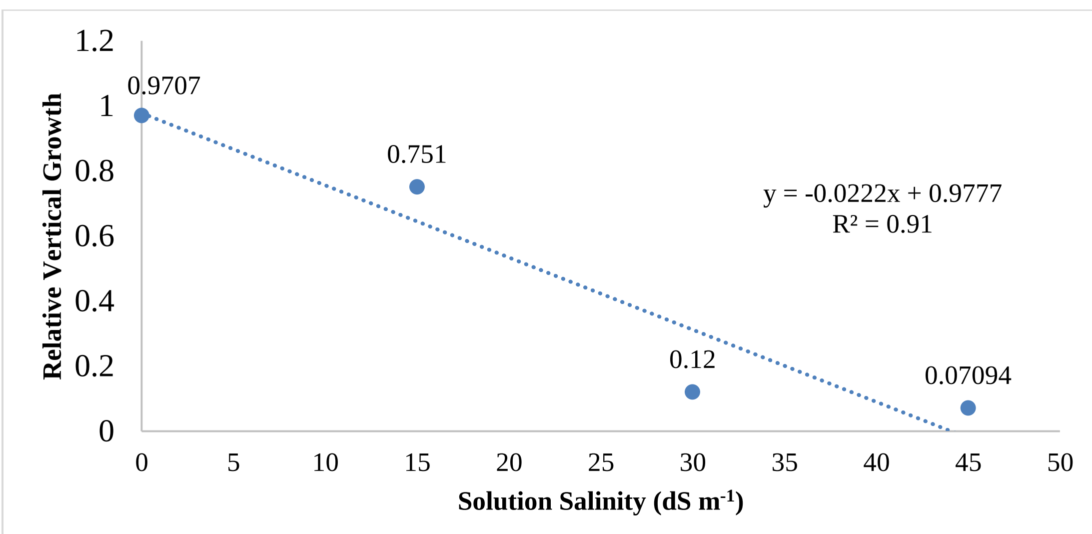


Figure 16. Linear regression relating the relative vertical growth of SeaStar as a function of four salinity treatment levels.

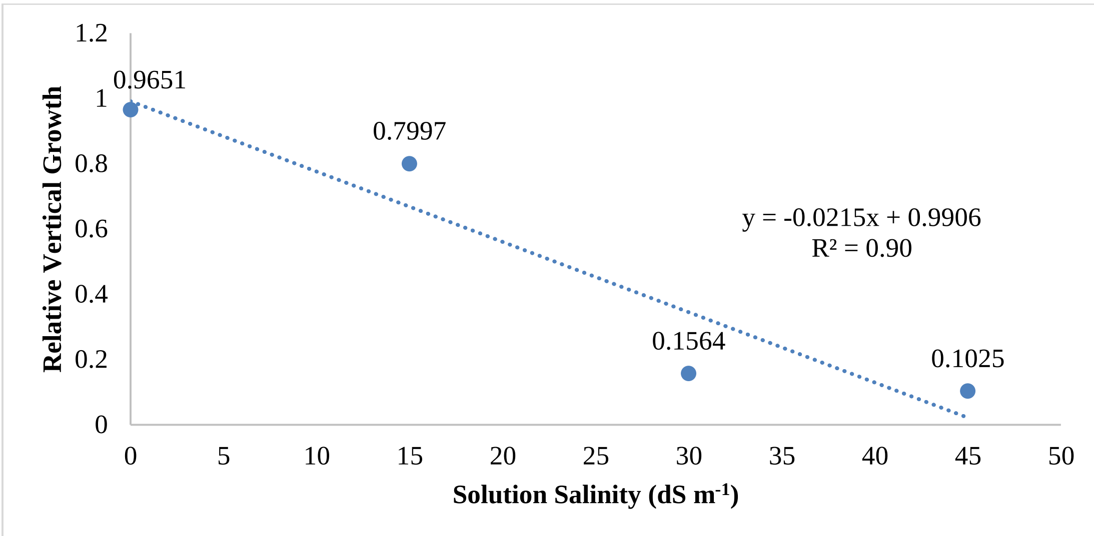


Figure 17. Linear regression relating the relative vertical growth of Southern Star bermudagrass as a function of four salinity treatment levels.

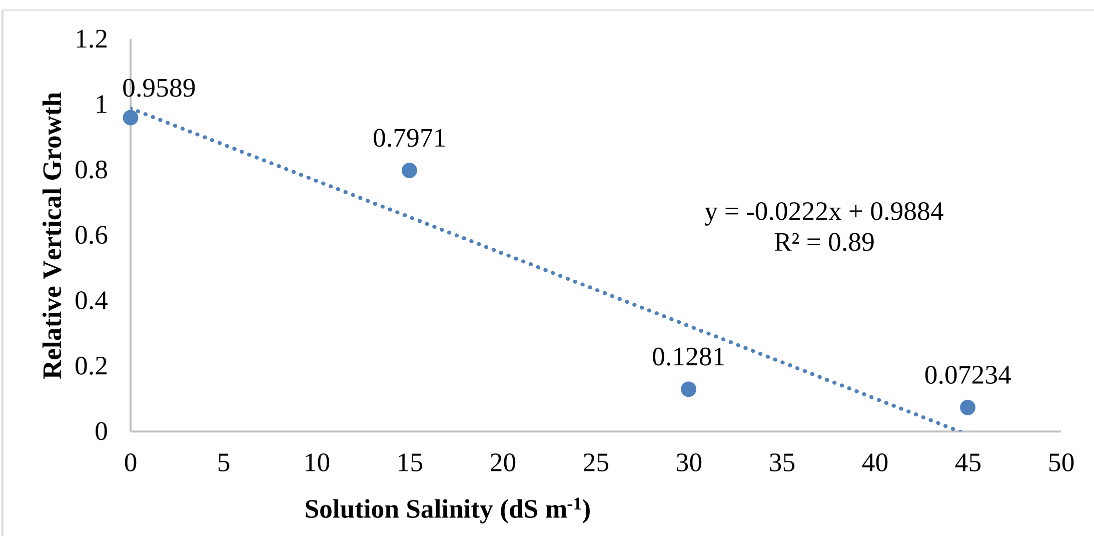


Figure 18. Linear regression relating the relative shoot vertical growth of Yukon bermudagrass as a function of four salinity treatment levels.

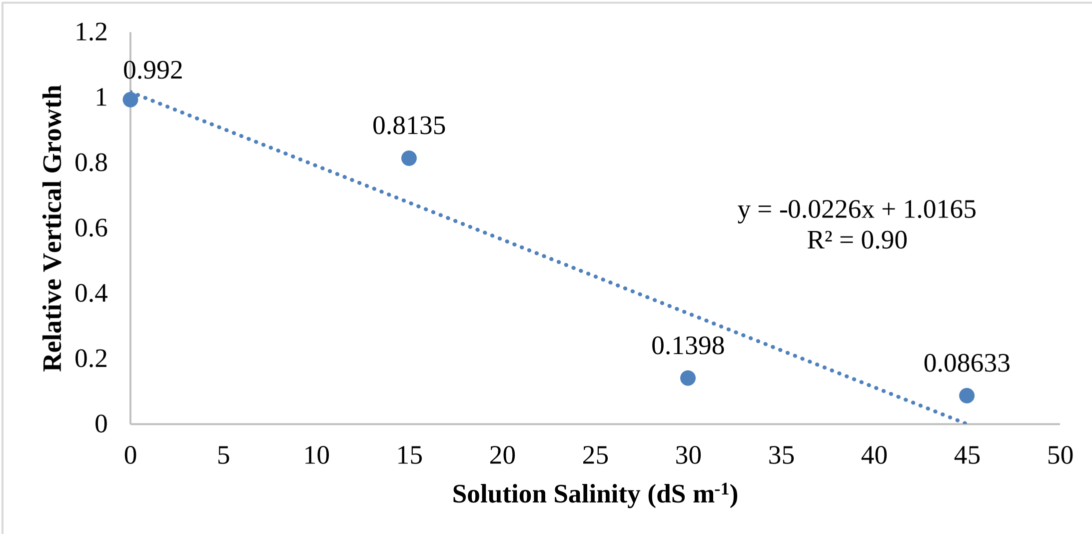
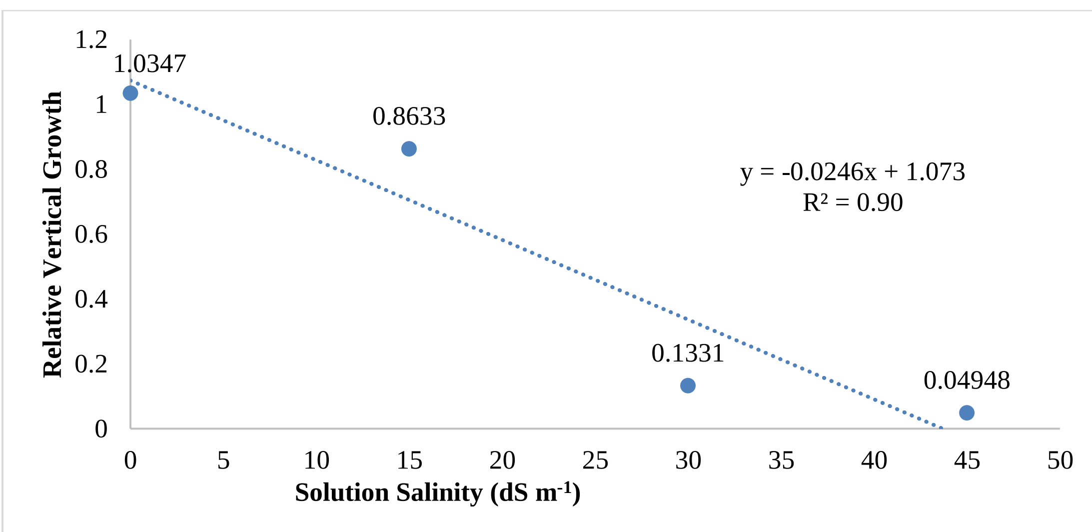


Figure 19. Linear regression relating the relative shoot vertical growth of Riviera bermudagrass as a function of four salinity treatment levels.



VITA

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