THESIS

DROUGHT AND SALINITY TOLERANCE OF COOL-SEASON TURFGRASSES

Submitted by

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ABSTRACT

DROUGHT AND SALINITY TOLERANCE OF COOL-SEASON TURFGRASSES

Due to the water scarcity and increased use of recycled water/saline water for turfgrass irrigation in arid and semi-arid climates, there is an increasing demand for drought and salt tolerant turfgrass. Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Schreb.), and perennial ryegrass (*Lolium perenne* L.) are the most commonly used cool season turfgrass species in the northern regions of the United States. The thesis includes two separate studies evaluating entries in National Turfgrass Evaluation Program (NTEP) trials. These two trials were conducted to identify the most drought tolerant lines of Kentucky bluegrass and tall fescue grown in a field study, and the most salt tolerant lines of perennial ryegrass grown in a greenhouse study, respectively.

The drought tolerance trial is presented in Chapter 1. In it, the drought tolerance of thirty-five cool-season turfgrasses, including 15 Kentucky bluegrass lines, 19 tall fescue lines, and 1 perennial ryegrass line were evaluated under three deficit irrigation treatments, 40%, 60% and 80% evapotranspiration (ETo) from 2018 to 2020. Overall turfgrass quality, minimum irrigation requirement for maintaining the acceptable quality, and length of time to maintain acceptable quality were determined for each entry. The amount of irrigation needed to maintain acceptable quality for tall fescue was 71% - 95% ETo, and for Kentucky bluegrass, it was 81% - 110% ETo under three-year deficit irrigation. Based on turf quality and irrigation requirement to maintain acceptable quality during the three-year deficit irrigation period, we have identified the most drought tolerant entries. Among Kentucky bluegrass entries, "PST-K13-141" has emerged as the top performer, demonstrating an 81% ETo rate to maintain acceptable quality. Among tall fescue

lines, the most drought-tolerant entries include "PST-5SDS," "Kingdom," "DLFPS 321/3679," and "Thor," requiring 71%, 74%, 74%, and 72% ETo, respectively, to uphold satisfactory turf quality. The results of this study suggest that selecting species and entries that use less water while maintaining acceptable quality could mitigate irrigation demands.

In Chapter 2, the salt tolerance of eighty-three perennial ryegrass lines was evaluated in two separate greenhouse experiments. Eighty-three lines were grown in cone-shaped containers that were soaked in increasingly saline nutrient solution for 1 hour per day. The solution began with an electrical conductivity (EC) of 6.0 $dS \cdot m^{-1}$ and was subsequently increased by 4.0 $dS \cdot m^{-1}$ (in Experiment I) or 6.0 $dS \cdot m^{-1}$ (in Experiment II) every 3 weeks until reaching the next targeted salinity level. The final targeted salinity level was 22 $dS \cdot m^{-1}$. Grasses were grown under each of the 4 or 5 targeted salinity levels for a period of 3 weeks. Clipping yield reduction, overall turf quality, leaf firing, and density were determined at each salinity level. Regression analysis was conducted to determine the relationship between clipping yield and salinity. The salinity level causing a 25% reduction in clipping yield was used as an indicator of salinity tolerance level in different entries. We found that entries “SGP4”, “PPG-PR 667”, “PVF-SGS5”, “BAR LP 22262”, “GO-RUS21”, “PPG-PR 610”, “DLF-PR 3727”, and “PPG-PR 639” were the most salt-tolerant, evidenced by the best turfgrass quality and the highest salinity levels at which there was a 25% clipping yield reduction in two experiments. We observed that the salinity levels that caused a 25% clipping yield reduction ranged from 5.0-8.8 $dS \cdot m^{-1}$ in experiment I and 5.7-10.7 $dS \cdot m^{-1}$ in experiment II. The entries with better salt tolerance identified in this study would hold the potential to be utilized on sites with marginally elevated saline soil. Additionally, they could be beneficial for locations where irrigation involves waters with elevated salinity, such as recycled water.

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CHAPTER 1 WATER USE AND DEFICIT IRRIGATION RESPONSE OF THIRTY-FIVE COOL SEASON TURFGRASSES

1.1 Overview

Located in a semi-arid climate as a headwater state, the topics of water use and drought response are ever present to the citizens of Colorado. This study focused on evaluating turfgrass quality and growth of 35 entries under variable irrigation treatments with the goal of identifying drought tolerant entries and determining the minimal amount of water required to maintain acceptable turf quality for each entry. Thirty-five cool-season turfgrasses, including 15 Kentucky bluegrass lines, 19 tall fescue lines, and 1 perennial ryegrass line were evaluated under three deficit irrigation treatments, 40%, 60% and 80% evapotranspiration (ETo) during the growing seasons from 2018 to 2020. We found that irrigation required to sustain acceptable quality fluctuated with time. With prolonged deficit irrigation, the cumulative effects of drought and the presence of salts in irrigation water influenced water requirement to sustain acceptable quality of the turfgrass. With the three-year drought stress cumulative effect, the required irrigation amount for tall fescue was 71% - 95% ETo, and for Kentucky bluegrass was 81% - 110% ETo. Among Kentucky bluegrass entries, "PST-K13-141" has emerged as the top performer, demonstrating an 81% ETo rate to maintain acceptable quality. Among tall fescue lines, the most drought-tolerant entries include "PST-5SDS", "Kingdom", "DLFPS 321/3679", and "Thor", requiring 71%, 74%, 74%, and 72% ETo, respectively, to uphold satisfactory turf quality. In summary, the results of this study suggest that selecting species and entries that use less water while maintaining acceptable quality could mitigate irrigation demands.

1.2 Introduction

Water resources are one of the most important resources in the world (Hadadin et al., 2010). By 2025, a quarter of the population in the world may face a water shortage problem, and this problem may be more serious in developing countries (Seckler, 2010). Essential for plant growth, water plays an important role in agricultural production (Farooq et al., 2009). However, with human activities and natural climate changes, water resources have become increasingly scarce (Farooq et al., 2009).

Turfgrass, a special kind of vegetation with numerous advantages, holds high value in various aspects, playing a crucial role in the city by providing aesthetic components, serving functionality in the urban ecosystem, and entertaining (Beard & Green, 1974; Monteiro, 2017). In recent decades, as cities in the United States have gradually expanded, the area of turfgrass landscapes has increased significantly. According to Thompson and Kao-Kniffin (2017), turfgrass has occupied at least 1.9% of the total land area of the United States and 60% of the urban area. Turfgrass can maintain the biodiversity of the urban ecosystem, produce oxygen, sequester carbon, and alleviate extreme temperatures in cities (Monteiro, 2017). From a psychological perspective, turfgrass can calm people, reduce stress and discomfort, promote health, and contribute to life satisfaction and happiness (Khachatryan et al., 2014).

However, the water consumption of urban and residential landscapes, including turfgrass, cannot be ignored. The outdoor irrigation water consumption exceeds 50% of the domestic water consumption of residents in some municipalities in arid American West, which turfgrass's water used as a major part (Mayer et al., 1999). This situation has caused some cities, such as Tampa, Florida to issue policies to limit turfgrass irrigation water (Ozan & Alsharif, 2013). The irrigation of turfgrass includes not only urban landscapes but also golf courses. The average annual water usage for golf courses during the years 2003, 2004, and 2005 is estimated to be 2,312,701 acre-feet in the United States (Trossell et al, 2009). According to Maupin et. al. (2014), golf courses are often criticized for the water demand of turfgrass.

Due to reduced precipitation in the cool semiarid zone and the likelihood of drought stress, irrigation becomes necessary in this area to achieve satisfactory turfgrass quality (Taleb et al., 2023). Different species of turfgrass employ various strategies to cope with drought conditions because of their different physiological structures. Kentucky bluegrass, tall fescue, and perennial ryegrass are three common species in this zone (Huang, 2008; Orta et al., 2023; PlantTalk Colorado, n.d.). Perennial ryegrass and tall fescue grow in bunches and spread via tillers (Nelson et al., 1977). They adapt to water-deficient conditions by adjusting stomata and leaf shape, developing smaller leaves, increasing stomatal density, reducing epidermal cell size, and forming deeper ridges on their adaxial surface (Jones et al., 1980). Kentucky bluegrass, on the other hand, utilizes rhizomes below-ground to achieve horizontal expansion (MYcaert, n.d.). Generally, turfgrass with a horizontal growth habit exhibits higher resistance to evapotranspiration, leading to reduced transpiration, making it more water-efficient compared to turfgrass with a vertical growth habit (Kim & Beard, 1988).

The National Turfgrass Evaluation Program (NTEP) is a non-profit organization that works with turf programs at universities across the United States to promote the evaluation of experimental and commercial turf for the turfgrass industry (Krans & Morris, 2007). In this study, NTEP protocol was followed to investigate quality changes in Kentucky bluegrass, tall fescue, and perennial ryegrass in response to deficit irrigation. The objectives of this project were to: 1) determine establishment rate among 15 Kentucky bluegrass entries and 18 tall fescue entries and 1 perennial ryegrass; 2) compare turfgrass quality and growth of these species and entries under different irrigation treatments [80% estimated turfgrass ET (ETo), 60% ETo, and 40% ETo] applied twice weekly for multiple growing seasons, and 3) select the entries that sustain acceptable quality with low irrigation water requirement for the Rocky Mountain region.

1.3 Methods & Materials

1.3.1 Study Duration and Location

A four-year study was conducted from 2017 to 2020 at the Colorado State University ARDEC South Research Center (40°36'41.9"N 104°59'54.6"W) in Fort Collins, Colorado. A total of 35 entries of turfgrasses were evaluated in this trial provided by NTEP, which included 15 Kentucky Bluegrasses (Barserati (BAR PP 110358), Barrari, Everest, Blue Note, Babe, NAI-13-132, NAI-13-14, Blue Devil, Dauntless, PST-K13-137, Orion (PST-K13-143), PST-K15-169, PST-K11-118, PST-K13-141, Midnight (standard entry), 1 perennial ryegrass (SR 4650 (standard entry), and 19 tall fescue entries (BarRobusto, BAR FA 121095, DLFPS 321/3677, DLFPS 321/3679, DLFPS 321/3678, Nonet, GO-AOMK, Supersonic, Titanium 2LS, Thor, Thunderstruck, RS4, Kingdom, MRSL TF15, Catalyst (standard entry), Stetson II, PST-5SDS, PST-R511, Matisse (LTP-SYN-A3)). The soil was a Nunn clay loam (fine, smectitic, mesic Aridic Argiustoll). The electrical conductivity (EC) of the soil saturation paste ranged from 2.5 to 4.5 $dS \cdot m^{-1}$, and soil pH was 7.6.

1.3.2 Experimental Design

The experiment was a split plot design with the irrigation treatment as whole plot and turfgrass entries as subplots. Nine whole plots (3 treatments with 3 blocks as replications) were arranged as completely randomized blocks. Within each whole plot consisted of 35 sub-plots (15 bluegrass entries, 18 fescues entries, and 1 perennial ryegrass entry). The 35 sub-plots (1m x 1m) in each whole plot were planted with 35 different turfgrasses, and there were no borders between sub-plots within each whole plot. A 0.6 m border separated whole plots from each other within each replication. Blocks were separated by a 3.7 meter border to avoid soil water movement from one replication to another.

1.3.3 Establishment

Turf was seeded in May 2017. The seeding rates for this study were 7.32g·m^{-2}, 39.06 g·m^{-2}, and 39.06g·m^{-2} for Kentucky bluegrass, tall fescue, and perennial ryegrass, respectively. All plots were uniformly irrigated with approximately 0.4 cm of irrigation water applied through an in-ground sprinkler irrigation system four times each day to prevent seeds from drying out.

1.3.4 Irrigation Water Analysis and Irrigation Treatment

The study site received underground well water for irrigation. The irrigation water was sampled and analyzed by the CSU Water Plant and Soil Testing Lab as shown in Table 1.1.

In this experiment, the responses of three species of turfgrasses to three irrigation treatments (40% ETo, 60% ETo, 80% ETo) were studied during deficit irrigation periods from 2018 to 2020 (year 2 to year 4). During years 2-4, irrigation at 100% ETo was applied during pre-deficit irrigation period (prior to May 31). Deficit irrigation period (irrigation at 40, 60, and 80% ETo) began on June 1st and ended on September 30th, which was followed by recovery period when plots were irrigated with 100 to 120% ETo. ET was calculated using the Penman-Monteith model with weather data including radiation, humidity, temperature, and wind speed obtained from the nearest weather station from CoAgMet of Colorado State University. The weather station was 4.6 km from the trial location. To maximize irrigation uniformity, plots were hand-watered twice a week. Irrigation treatments were applied through a spray nozzle attached to a garden hose. A hose-end water flow meter (Model No. ICS006, RainPoint, CA) was used to monitor the amount of water applied, and the flaw meter was calibrated before each use . During the three-year deficit irrigation period, the precipitation at this site is presented in Table 1.2. Rainfall amounts were factored into how much water was applied during the season by subtracting rainfall amount from replacement ET requirement.

1.3.5 Turfgrass Maintenance

All plots were mowed weekly during the growing season at a height of 6.3 cm using a rotary mower (Toro, MN) in a uni-directional regime. This was done to have the foliar tissue oriented in a common direction for improved consistent visual quality ratings. Mowing was performed 1 day prior to rating. Nitrogen as Urea (46-0-0) was applied once per month during the months of May and September at a rate of 1.22 - 1.46 g $N \cdot m^{-2}$.

1.3.6 Data Collection & Analysis

To evaluate turfgrass establishment, the percentage of ground covered by turfgrass at 23rd day, 33rd day, 69th day, 107th day, and 139th day after seeding was estimated by visual observation. Higher coverage percentages indicated better establishment. Data on ground coverage was subjected to analysis of variance to test the effects of species/entry on establishment on individual evaluation dates. Mean separations were performed at $P \leq 0.05$ by the Tukey adjusted pairwise comparisons.

Visual quality ratings based on overall color, uniformity and density were performed once weekly during the 4-month deficit irrigation period and the 1-month recovery period. A rating scale of 1-9 was used with 1 being straw brown or dormant turfgrass and 9 being dark green, dense turf. A rating of 6 indicated minimum quality that would be considered acceptable by most homeowners and industry professionals.

Data analysis of the data collected in 2018, 2019, and 2020 was performed separately using a linear mixed-effects model, with irrigation treatment, entry and collection date being the fixed factors whereas block and replication as the random factors. This analysis is aimed to test the effects of irrigation treatment, entry, species, collection date, and their interaction on turfgrass quality. Turfgrass quality data from July-August 2018, July-August 2019, and July-August 2020 was separately analyzed. For each month's data, linear regression was used to determine the relationship between the turfgrass quality and the irrigation level for each entry. Using the regression equation generated for each entry, the minimum amount of irrigation required to maintain the acceptable turf quality for each month was calculated. The means of minimum irrigation percentage for each month were separated by Fisher's least significant difference at $P \leq 0.05$. The overall three years minimum irrigation level to maintain acceptable quality was analyzed by a mixed effect model with entry being the fixed factor and collection date as the random factor. The difference of the minimum irrigation levels among entries were separated at $P \leq 0.05$ using the Tukey adjusted pairwise comparisons.

The count of weeks during which an entry maintained acceptable turf quality (above 6) was determined based on the weekly turf quality rating. ANOVA analysis was conducted for all entries throughout the entire deficit irrigation period. Data on the average numbers of weeks maintaining acceptable quality for all entries were separated by the Fisher's least significant difference.–All statistical analyses were performed using R version 4.0.3 and figures were created using Excel.

1.4 Results

1.4.1 Establishment Rate

Figure 1.1 shows the establishment rate of three species after seeding. During the first 23 days after seeding, perennial ryegrass had the fastest establishment rate compared to tall fescue and Kentucky bluegrass. Twenty-three days after seeding, the cover of perennial ryegrass, tall fescue, and Kentucky bluegrass reached 73%, 29%, and 3%, respectively. Tall fescue and Kentucky bluegrass began to establish rapidly during the 23rd to 33rd days after seeding. During the 33rd to 69th days after seeding and 69th to 107th days after seeding periods, the establishment rate of the three turfgrass species began to slow down. All species were fully established. Three species had a statistically significant difference from each other in 69 days after seeding ($P < 0.05$). In three species, "SR 4650" (perennial ryegrass) always showed the highest coverage among all entries. During the 23rd to 33rd days after seeding, the establishment rates of the three species differed greatly. However, during the 33rd to 69th days after seeding, the difference between the establishment rates of the three species gradually decreased.

Table 1.3 shows the comparison of establishment rates of 15 entries of Kentucky Bluegrass. "Midnight" was included as a standard entry in the experimental design. There was no significant difference in establishment rates between entries and the standard entry at 23 days after seeding ($P \geq 0.05$). At 33 days after seeding, the establishment rates of four entries "PST-K11-118", "PST-K13-137", "PST-K15-169", and "PST-K13-141" were lower than the standard entry. At 63 days after seeding, the establishment rates of "PST-K15-169", "DAUNTLESS", "PST-K11-118", "EVEREST", "PST-K13-137" were lower than the standard entry. Other entries had no significant difference in the establishment rate ($P \geq 0.05$). Entry "Barrari" had the highest establishment.

Table 1.4 shows the comparison of establishment rates of 19 entries of tall fescue. At 23 days after seeding, only "Titanium 2LS" had a significantly higher establishment rate than the standard entry, "Catalyst". For the next two dates recorded, there was no significant difference between the standard entry and the tested entries ($P \geq 0.05$).

There was no statistically significant difference between some of the fast-establishing Kentucky bluegrass entries and some of the slow establishing tall fescue entries ($P \geq 0.05$). For example, after 69 days of seeding, “Barrari”, a Kentucky bluegrass entry, had a similar establishment rate to some of the slowest establishing tall fescue entries, such as “RS4” and “Kingdom”.

1.4.2 Quality Analysis Between Species

According to Table 1.5 turfgrass quality was significantly affected by different irrigation level, entry, species, collection date, year, and their respective two-way interactions. However, the three-way interaction of irrigation level, entry, date was not significant. As shown in Figures 1.2-1.4, the quality of both Kentucky bluegrass and tall fescue gradually declined as deficit irrigation treatment progressed. The overall quality of the first year was better than that of the second and third years (Fig. 1.2-1.4). Turfgrass quality decreased in all three irrigation treatments. Turf quality decreased the most under the 40% irrigation treatment, followed by 60%, then 80%. Among the two species, tall fescue declined more than Kentucky bluegrass under 40% and 60% ETo treatments (Fig. 1.2-1.4).

Under the 40% irrigation treatment, the quality of tall fescue was better than Kentucky bluegrass in the first year of the experiment (Fig. 1.2). However, after July 2019, Kentucky bluegrass showed better quality in the second year of the deficit irrigation period. There was no statistically significant difference between the quality of Kentucky bluegrass and tall fescue in the third year deficit irrigation period. Under 60% ETo irrigation treatment, tall fescue had better turf quality than Kentucky bluegrass in the first year of drought stress (Fig. 1.3). However, Kentucky bluegrass demonstrated better quality than tall fescue between August of the second year and the end of the third year of deficit irrigation period. Under the 80% irrigation treatment, tall fescue always had better turf quality than Kentucky bluegrass except in September of the second year.

The turfgrass quality of the two species did not have a statistically significant difference in August of the first and third experimental years ($P \geq 0.05$).

It can be seen in Figures 1.2-1.4 that only in the 80% ETo irrigation treatment, the quality of the turfgrass had hardly changed in the first year of drought and the quality of both species remained above 6, the acceptable quality. The quality of both species in the irrigation treatments during the second and the third-year deficit irrigation periods decreased significantly. During these two deficit irrigation periods, the turfgrass quality of the three treatments was below the acceptable quality of 6.

1.4.3 Quality Analysis Between Entries

1.4.3.1 Minimum Irrigation Level to Maintain Acceptable Quality

The minimum amount of irrigation required to maintain acceptable turf quality for each month was calculated by the linear regression equation (Table 1.6). In July 2018, 15 entries of Kentucky bluegrass had irrigation requirements ranging from 43% ETo to 86% ETo. Among them, “PST-K13-141” had the lowest irrigation (43% ETo) requirement to maintain acceptable quality, while “PST-K15-169” required 86% ETo to achieve minimum acceptable quality. For the 19 entries of tall fescues, their water requirements ranged from 31% to 56% ETo. “Thor” required 31% ETo for acceptable quality, while “BAR FA 121095” needed 56% ETo. In August 2018, the irrigation water needed to maintain acceptable quality for 15 Kentucky bluegrass entries ranged from 55% to 78% ETo. “PST-K13-141” performed the best, requiring 55% ETo for minimum acceptable quality, whereas “PST-K15-169” needed 78% ETo. For the 19 tall fescue entries, the required ETo ranged from 52% to 72%. “Catalyst” required 52% ETo, while “BAR FA 121095” required 72% ETo.

In July and August 2019, the amount of water required to maintain acceptable quality increased for all entries. Among the best performers with the lowest irrigation requirements were "Thor", "PST-5SDS", "DLFPS 321/3679", and "SR 4650" (perennial ryegrass). They can maintain acceptable quality at irrigation levels around 80% ETo (Table 1.6). However, more than one-fourth of the entries required more than 100% ETo water to maintain acceptable quality.

Regarding the July 2020 data, the amount of water required for 15 entries of Kentucky bluegrass was between 87% and 130% ETo, with "Blue Devil" required 87% ETo and "PST-K15-169" required 130% ETo. For 19 tall fescue entries, the water amount needed was between 70% and 142% ETo. Among them, "PST-5SDS" and "Titanium 2LS" required 70% and 142% ETo, respectively. In the August 2020 data, the amount of water required for 15 Kentucky bluegrass entries was between 88% and 126% ETo, which "PST-K13-143" required 88% ETo and "PST-K15-169" required 126% ETo. For 19 tall fescue entries, the water amount needed was between 88% and 144% ETo. Among them, "DLFPS 321-3679" and "RS4" required 88% and 144% ETo, respectively.

For the overall three-year deficit irrigation, the minimum irrigation level for maintaining an acceptable turfgrass quality is presented in Table 1.7. The average minimum irrigation level of 19 tall fescue entries was 82% ETo, with the range between 71% ETo and 95% ETo. Kentucky bluegrass range was from 81% ETo to 110% ETo with average of 90% ETo, which was higher than tall fescue irrigation requirement. The ryegrass entry "SR 4650" showed 74% ETo required irrigation level to maintain acceptable quality.

In tall fescue entries, "PST-5SDS", "Kingdom" required the lowest irrigation to maintain an acceptable quality, namely 71% and 72% ETo, respectively. The irrigation requirements (ETo) of those two entries were significantly lower than the "BarRobusto" and "Titanium 2LS" which were the worst drought tolerance entry in tall fescue, both needed 95% ETo to maintain the acceptable quality.

Comparing the Kentucky bluegrass entries, seven entries, including “PST-K13-141”, “Midnight” had the better drought tolerance than “PST-K15-169”. “PST-K13-141” and “Midnight” Kentucky bluegrass required 81% and 85% of ETo, respectively, to maintain an acceptable quality. The irrigation levels were significantly lower than “PST-K15-169”, the least drought tolerance entry in Kentucky bluegrass which needed 110% ETo.

1.4.3.2 Length of Time to Maintain Acceptable Quality

During each deficit irrigation period, turf quality declined over time. The length of time that turfgrass can maintain acceptable quality is shown in Table 1.8. In 2018 deficit irrigation period, at 80% ETo level, tall fescue performed better than Kentucky bluegrass. Deficit irrigation treatments were carried out for 17 weeks in the first year. In tall fescue, turf quality of “Supersonic”, “Nonet”, “BAR FA 121095” and “GO-AOMK” declined to unacceptable in the 9th, 9th, 10th and 12th weeks after the beginning of drought, respectively (Table 1.8). All other 15 tall fescue entries maintained acceptable quality at 80% ETo irrigation for 17 weeks. Perennial ryegrass consistently maintained turf quality above 6 at 80% ETo irrigation for 17 weeks. In Kentucky bluegrass, only three entries, “BAR PP 110358”, “PST-K11-118”, and “Barrari”, consistently maintained turfgrass quality above the minimum acceptable rating of 6 throughout the first year of the deficit irrigation period. The rest of the entries maintained turfgrass quality above the minimum acceptable rating of 6 for 11.7 to 16.7 weeks. The entries that responded the most quickly to drought were “PST-K13-137”, “PST-K15-169”, and “NAI-13-132”, these three entries had turf quality below 6 in the 6th week in 2018. “PST-K13-137” and “Dauntless” were the worst performers, with quality below 6 most frequently after the 9th week.

In plots irrigated at 60% ETo, tall fescue, Kentucky bluegrass, and ryegrass had lower quality compared to plots irrigated at 80% ETo, but ryegrass and tall fescue maintained acceptable quality longer than Kentucky bluegrass. One instance of quality below 6 was recorded for ryegrass, which occurred after the 12th week of the deficit irrigation period. For the tall fescues, "Thunderstruck", "Kingdom", "MRSL TF15", "Catalyst", "PST-R511", were the five best performing entries and did not have a quality below 6 throughout the deficit irrigation period. Turf quality of tall fescue entries "LTP-SYN-A3", "Stetson II", "BAR FA 121095", "Titanium 2LS", "GO-AOMK" declined to below 6 at 12th week after the start of 60% ETo deficit irrigation. Kentucky bluegrass had the worst drought performance among species. In 2018, it was observed that many Kentucky bluegrass entries' turf quality become unacceptable after 6 weeks at 60% deficit irrigation treatment, and the performance worsened over time.

Within the 40% ETo irrigation treatment, the time of three species maintaining above acceptable quality was shorter. Most Kentucky bluegrasses entries could not be maintained above acceptable quality after the 6th week. "PST-K13-141" was slightly better than the other Kentucky bluegrasses, which maintained an average of 7.0 weeks for 17 weeks deficit irrigation (40% ET) period, but the mean of Kentucky bluegrasses was only 4.1 weeks. Tall fescue and ryegrass were able to maintain acceptable quality at the 40% ETo irrigation level for an average of 7.4 and 6.7 weeks for 17 weeks period, respectively.

In 2019, there were a total of 16 weeks in the deficit irrigation period in which turfgrass quality did not perform as well as in 2018. With 80% ETo, PST-K13-137 and "PST-K13-141" had more than 5 weeks of minimum acceptable quality. Tall fescue performed better than Kentucky bluegrass, with "Thor", "Kingdom", and "PST-5SDS" performing the best. They had more than 9 weeks in which they could maintain minimum acceptable quality. Ryegrass had 8 weeks of performance that was above acceptable. Turfgrass quality of all three species was low and varied little among the 60% ETo and 40% ETo irrigation levels. At 60% ETo irrigation, “BAR PP 110358” and “Kingdom” were the best performers among the 35 entries. They can maintain acceptable quality for 4.7 to 5.3 weeks. In the observations, almost all turfgrasses were of unacceptable quality after the fourth week of the experiment. Overall, turfgrass had large areas of bleached foliage, and some entries were completely brown/dormant.

In 2020, the third year of deficit irrigation treatment, the best entries in Kentucky bluegrass were “Everest” and “PST-K13-143” at 80% ETo irrigation and they maintained acceptable quality for more than 4 weeks. Tall fescue performed better compared to Kentucky bluegrass. “Kingdom”, “Thor”, “DLFPS 321/3679” and “DLFPS 321/3678” maintained acceptable quality for more than 7 weeks. “SR 4650” (perennial ryegrass) acceptable turf quality for more than four weeks. At 60% ETo and 40% ETo irrigation levels, turfgrass quality was unacceptable. Many entries went dormant under drought stress. Only an average of 2 weeks or one week was maintained above acceptable quality.

1.5 Discussion

According to the analysis of the results, tall fescue and perennial ryegrass performed better than Kentucky bluegrass in the first year of the entire experiment, especially at the irrigation level of 80% ETo, as evident in Figures 1.2, 1.3, and 1.4. This is further supported by the weeks of above-acceptable quality over time, as indicated in Table 1.8. However, as the deficit irrigation progressed, starting from the second year in August and September, the quality gap between tall fescue and Kentucky bluegrass gradually decreased. At the 40% ETo irrigation level, the performance of Kentucky bluegrass was better than tall fescue entries. These results may be because different species of turfgrass employ different strategies to cope with drought.

During establishment turf received 1.6 cm of water each day, over time this could add to the amount of water deep in the soil profile. Tall fescue avoids drought because it has a deeper root system, which is able to mine water, when present, from deeper in the soil profile (Ervin & Koski, 1998; Qian & Fry, 1997). Tall fescue grows more roots, maintaining turfgrass quality through longer root systems and higher root density. This feature also gives tall fescue better drought resistance (Qian & Fry, 1997). However, higher ET and more extensive root system may cause quick soil moisture depletion. This may be the reason for the suboptimal performance of tall fescue as the experiment progressed over time.

In general, with higher evapotranspiration resistance in Kentucky bluegrass resulting in a reduction in transpiration, a turfgrass with a horizontal growth habit is more water-efficient than a turfgrass with a vertical growth habit (Kim & Beard, 1988). Additionally, turfgrasses encounter many harsh environments during their life cycle. Kentucky bluegrass can avoid drought or heat damage by going dormant. This dormancy which can last for weeks or even months reduces turf quality. Rewatering and a drop in temperature will allow Kentucky bluegrass to break dormancy when the harsh conditions are gone (Huang, 2006; McCarty & Miller, 2002).

In the results, irrigation requirements (% ETo requirement) to maintain acceptable quality increased as deficit irrigation treatment progressed. In the second and third years of experimental data was different from the first year, many entries were below acceptable quality and many turfgrasses exhibited wilting and yellowing or dormancy. Every turfgrass has an optimal growing temperature. According to the suitable growth temperature of different kinds of turfgrasses, the best-growing temperature for cool-season turfgrasses is between 50°F to 75°F (10°C to 24°C) (Fu et al, 2004). At the experiment location, temperatures during the summer often exceed the mentioned range. For non-stressed turf, evapotranspiration has significant cooling effect, but deficit irrigation treatments can lead to stress from high temperatures on turfgrass growth.

The elevated salinity in the irrigation water could also have played a role in the finding. The well water on this site exhibits high salinity, elevated sodium content, and increased bicarbonate levels. Calcium and sulfate ions were found to be higher than normal, as indicated in Table 1.1. High sodium content can lead to soil compaction, making it challenging for water to penetrate and be absorbed by the roots (Qian & Mecham, 2005). Irrigation water with high salinity and alkalinity can subject turfgrass to osmotic stress, increasing drought stress on the turfgrass (Chen et al., 2015). Meanwhile, different species have different salinity tolerance. Previous study has demonstrated that perennial ryegrass and tall fescue have greater salinity tolerance than Kentucky bluegrass (Alshammary et al., 2004; Robins et al., 2009). The salinity problem interacted with drought treatment may affect our result and could potentially increase the water demand of the turfgrass in this experiment.

In this experiment, turfgrass quality varied significantly and decreased across the years. Our experiment was exposed to deficit irrigation for three years. Due to three years of prolonged exposure to drought, the cumulative effects of drought were observed. The cumulative effect prevented the turfgrass quality from fully returning to the levels observed in the previous year, resulting in significant differences between years.

1.6 Conclusions

In the study, different species of turfgrass exhibited significant variations in quality under different irrigation levels. In the first year of different irrigation treatments, tall fescue showed significantly better quality than Kentucky bluegrass across three irrigation levels. Tall fescue demonstrated a lower water demand to maintain acceptable quality compared to Kentucky bluegrass, and the duration that acceptable quality was maintained was longer. However, as the drought stress progressed, the significant differences between the two species decreased, and the quality of both declined. In the first year, as the short term of exposing to the drought stress, the minimum amount of irrigation required to maintain acceptable quality was 43%-64% ETo for tall fescue, 49%-82% ETo for Kentucky bluegrass. With the three-year drought stress cumulative effect, the required irrigation amount for tall fescue was 71%-95% ETo, and for Kentucky bluegrass was 81%-110% ETo. The ranges of irrigation requirements generated in this study are in agreement with findings from a previous study on the same site (Ervin and Koski, 1998). Based on the length of time to maintain acceptable quality, “DLFPS 321/3678”, “PST-5SDS”, “DLFPS 321/3679”, “Thor”, and “Kingdom” had superior drought tolerance under 80% of ETo irrigation level among tall fescue, “PST-K13-141”, had superior drought tolerance among Kentucky bluegrass under 80% of ETo irrigation level. Based on data on turf quality and irrigation requirement to maintain the acceptable quality, the best water saving tall fescue entries were “PST-5SDS”, “DLFPS 321/3679”, “Thor”, and “Kingdom”. The entry that had the least minimum irrigation requirement to maintain the acceptable quality in Kentucky bluegrass was “PST-K13-141”. The selected entries that showed superior drought tolerance in this study will be recommended for use in drought prone areas of the Rocky Mountain region.

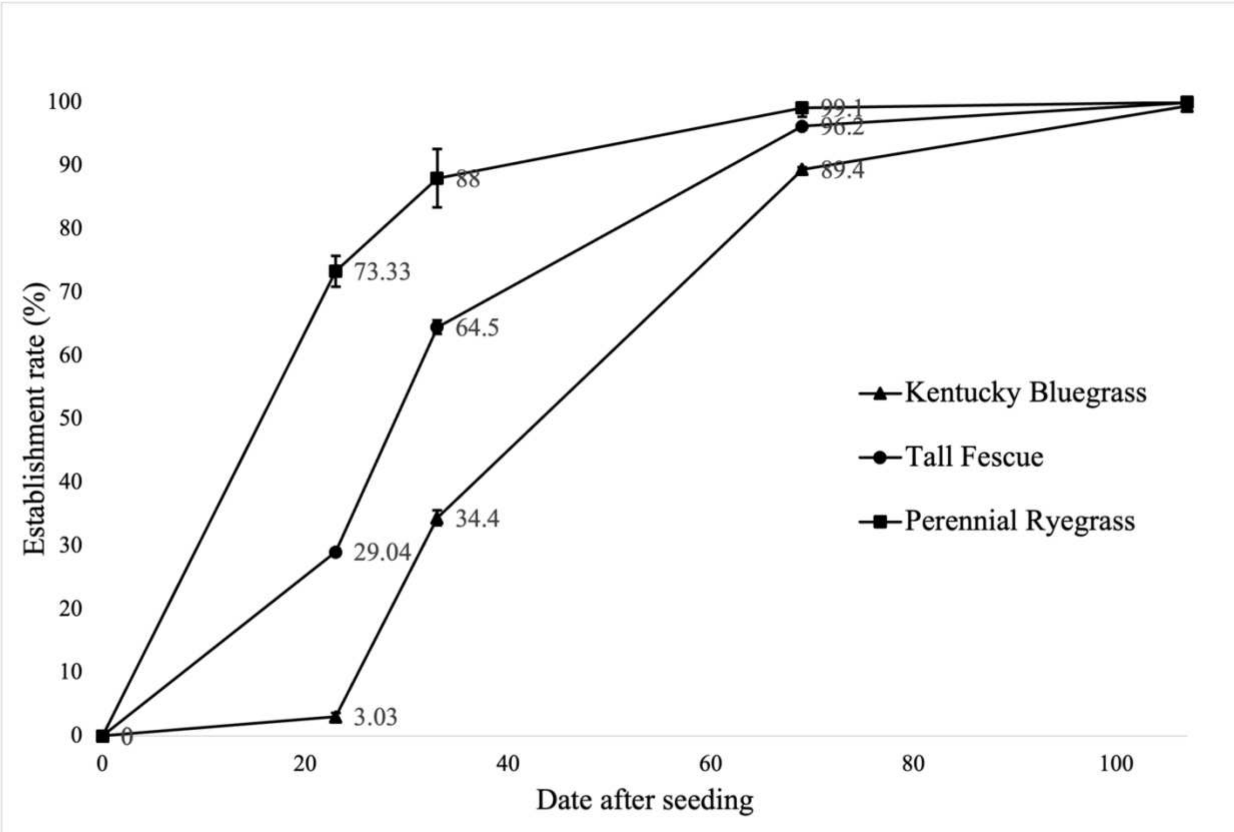

Figure 1.1. The relationship between establishment rate and days after seeding of three species. Error bars represent a 95% confidence interval ($P < 0.05$).

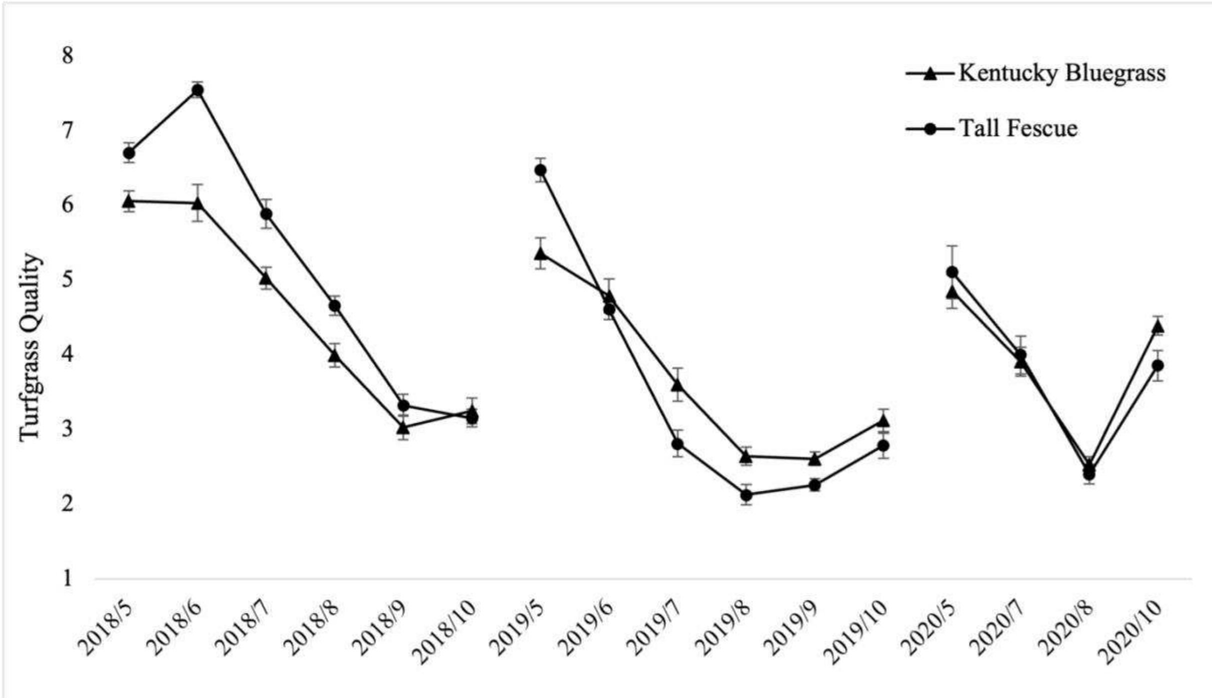

Figure 1.2. Turfgrass quality under 40% ETo irrigation treatment in three years for all entries of tall fescue and Kentucky bluegrass. Error bars represent a 95% confidence interval.

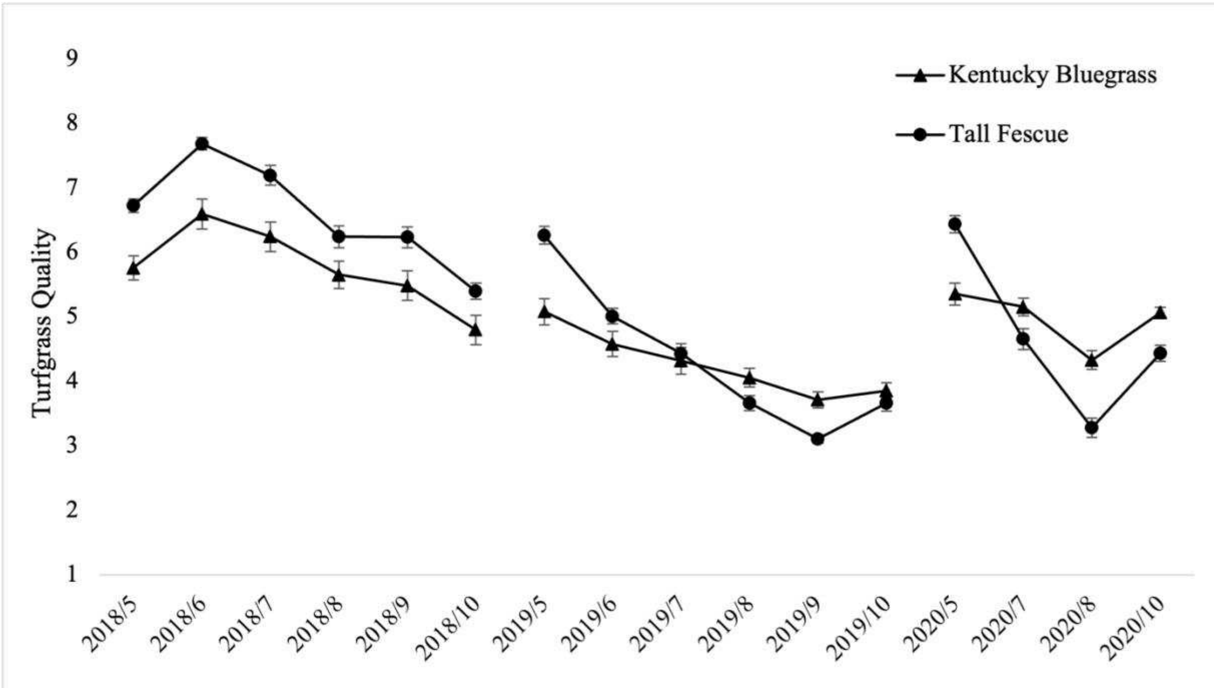

Figure 1.3. Turfgrass quality under 60% ETo irrigation treatment in three years for all entries of tall fescue and Kentucky bluegrass. Error bars represent a 95% confidence interval.

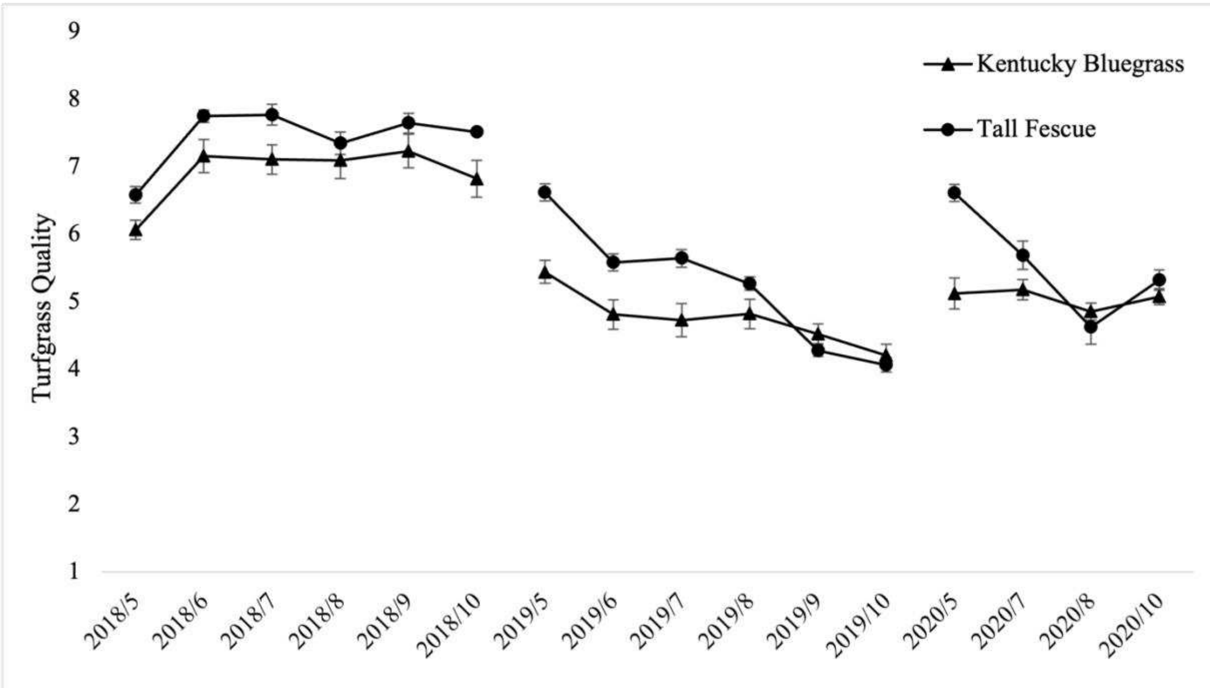

Figure 1.4. Turfgrass quality under 80% ETo irrigation ltreatment in three years for all entries of tall fescue and Kentucky bluegrass. Error bars represent a 95% confidence interval.

Table 1.1. Analysis of irrigation water from Colorado State University ARDEC South Research Center.

Parameters	Well water
pH	8.2
Cat^{++} (mg L^{-1})	417±12.9
Mg^{++} (mg L^{-1})	171.0±17.8
Na^{+} (mg L^{-1})	193.0±16.3
K^{+} (mg L^{-1})	6.0±0.80
B (mg L^{-1})	0.4±0.08
CO_3^{-} (mg L^{-1})	<0.01
HCO_3^{-} (mg L^{-1})	403.0±21.2
SO_4^{-} (mg L^{-1})	1679.0±80.5
CI^{-} (mg L^{-1})	43.0±6.00
NO_3^{-} (mg L^{-1})	42.0±6.80
EC (dS m^{-1})	3.1±0.15
SAR	2.1±0.14

Data is expressed as Mean±SE

Table 1.2. Estimated turfgrass ET (ETo), annual precipitation, water applied for each irrigation treatment in 2018, 2019, and 2020.

		2018	
ETo (mm)		552	
Precipitation (mm)		107	
Treatment level	80%	60%	40%
Applied (mm)	357	267	178
Deficit (mm)	89	178	267
		2019	
ETo (mm)		544	
Precipitation (mm)		126	
Treatment level	80%	60%	40%
Applied (mm)	334	251	167
Deficit (mm)	84	167	251
		2020	
ETo (mm)		589	
Precipitation (mm)		70	
Treatment level	80%	60%	40%
Applied (mm)	416	312	208
Deficit (mm)	104	208	312

Table 1.3. Establishment difference among 15 Kentucky Bluegrass entries.

	Day 23 (23-May)		Day 33 (2-Jun)		Day 69 (5-Jul)	
Entry name	EST.R Mean	Group	EST.R Mean	Group	EST.R Mean	Group
*Barrari	7.2	a	43.4	a	94.2	a
NAI-13-14	5.7	ab	33.6	abcd	90.8	abc
*Everest	4.5	abc	36.1	abcd	87.6	cd
*Midnight	4	abcd	40.3	abc	92.6	ab
NAI-13-132	3.9	abcd	43.3	ab	87.9	bcd
*BAR PP 110358	3.3	bcd	33.3	abcd	91.2	abc
*Blue Note	3.3	bcd	34.3	abcd	91	abc
*Blue Devil	2.5	bcd	35.7	abcd	89.2	bcd
PST-K13-141	2.1	cd	30.7	cd	85.6	d
PST-K15-169	2.1	cd	31.2	cd	88.8	bcd
*PST-K13-143	1.9	cd	32.1	bcd	91.3	abc
PST-K13-137	1.8	cd	27.2	d	87.6	cd
*Dauntless	1.3	cd	36	abcd	86.7	cd
*Babe	1	cd	32.8	abcd	90	abcd
PST-K11-118	0.8	d	25.3	d	86.8	cd

*Commercially available in the USA in 2021 or any other country
Midnight as standard entry
Significance level used: alpha = 0.05

Table 1.4. Establishment rate difference among 19 Tall Fescue entries.

	Day 23 (23-May)		Day 33 (2-Jun)		Day 69 (5-Jul)	
Entry name	EST.R Mean	Group	EST.R Mean	Group	EST.R Mean	Group
*Titanium 2LS	38.6	a	74.3	ab	97.1	abcd
*Supersonic	34.1	ab	74.8	a	97.7	a
*Kingdom	31.1	bc	68.2	abcde	97.6	ab
*LTP-SYN-A3	31.1	bc	64.8	abcdef	97.1	abcd
*Barrobusto	31.1	bc	61.2	bcdef	94	ef
PST-R511	30.8	bc	66.9	abcdef	96.6	abcde
MRSL TF15	29.6	bcd	71.1	abc	95	bcdef
PST-5SDS	29.3	bcd	63.6	abcdef	97.1	abcd
*Nonet	29	bcd	66.4	abcdef	96.3	abcde
*Stetson II	28.6	bcd	65.9	abcdef	97.9	a
BAR FA 121095	28.4	bcd	69.7	abcd	96.4	abcde
*Thunderstruck	28.2	bcd	54.6	f	97.3	abc
*Catalyst	27.9	bcd	67	abcdef	96.1	abcdef
DLFPS 321/3678	27.8	bcd	58	cdef	94.8	cdef
DLFPS 321/3677	26.4	cd	54.9	ef	96.7	abcd
*Thor	26.2	cd	64.8	abcdef	96.3	abcde
GO-AOMK	26.1	cd	63.7	abcdef	95.9	abcdef
DLFPS 321/3679	24.8	cd	57	def	94.6	def
RS4	22.7	d	57.9	cdef	93.7	f

*Commercially available in the USA in 2021 or any other country
Catalyst as standard entry
Significance level used: alpha = 0.05

Table 1.5. Analysis of variance for turfgrass quality during the deficit irrigation period for the irrigation level, entry, species, collection date, year, and their interactions.

Source	Degrees of Freedom	Mean Square	P Value
Irrigation Level	1	156.13	***
Entry	34	3.35	***
Species	2	10.29	***
Collection Date	27	59.22	***
Year	2	97.39	***
Irrigation Level* Entry	34	4.50	***
Irrigation Level* Collection Date	27	30.70	***
Entry* Collection Date	918	1.11	*
Irrigation Level* Entry *Collection Date	918	1.01	NS
Irrigation Level* Year	2	36.31	***
Entry* Year	68	4.99	***
Irrigation Level* Entry *Year	68	4.09	***

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001 respectively.

Table 1.6. The minimum amount of irrigation (%ETo) required to maintain the acceptable turf quality for each month.

Entry name	Specie	2018/7	2018/8	2019/7	2019/8	2020/7	2020/8
PST-K13-141	KBG	43%	55%	97%	88%	110%	98%
Barrari	KBG	48%	69%	124%	100%	94%	91%
PST-K11-118	KBG	53%	59%	104%	106%	97%	96%
Babe	KBG	53%	70%	108%	102%	90%	94%
Midnight	KBG	54%	60%	95%	95%	108%	103%
NAI-13-132	KBG	54%	60%	121%	104%	108%	102%
NAI-13-14	KBG	54%	60%	115%	99%	94%	94%
Blue Note	KBG	58%	68%	130%	122%	101%	92%
PST-K13-143	KBG	58%	68%	99%	106%	99%	88%
Dauntless	KBG	60%	74%	101%	104%	91%	92%
Blue Devil	KBG	61%	63%	130%	91%	87%	100%
Everest	KBG	62%	62%	≥140%	115%	113%	94%
BAR PP 110358	KBG	63%	65%	≥140%	107%	101%	97%
PST-K13-137	KBG	71%	76%	97%	93%	88%	101%
PST-K15-169	KBG	86%	78%	119%	120%	130%	126%
Thor	TF	31%	57%	77%	87%	88%	97%
Catalyst	TF	33%	52%	85%	93%	95%	98%
PST-5SDS	TF	33%	55%	81%	83%	70%	96%
RS4	TF	37%	56%	84%	95%	140%	≥140%
DLFPS 321/3678	TF	39%	56%	83%	90%	84%	107%
LTP-SYN-A3	TF	40%	58%	89%	91%	99%	107%
Supersonic	TF	40%	60%	84%	94%	104%	119%
PST-R511	TF	42%	53%	89%	92%	105%	109%
Kingdom	TF	42%	54%	79%	88%	78%	91%
Nonet	TF	42%	60%	87%	93%	101%	116%
Thunderstruck	TF	43%	57%	81%	89%	100%	103%
DLFPS 321/3677	TF	44%	57%	86%	89%	101%	128%
BarRobusto	TF	45%	60%	93%	93%	89%	101%
MRSL TF15	TF	46%	61%	84%	98%	93%	117%
DLFPS 321/3679	TF	47%	58%	79%	87%	83%	88%
Stetson II	TF	51%	60%	90%	91%	95%	120%
Titanium 2LS	TF	52%	60%	86%	90%	≥140%	≥140%
GO-AOMK	TF	52%	69%	90%	91%	89%	121%
BAR FA 121095	TF	56%	72%	85%	89%	87%	101%
SR 4650	RYE	52%	52%	80%	84%	86%	89%
KGB mean		59%	66%	116%	103%	101%	98%
TF mean		43%	59%	85%	91%	97%	111%
LSD (for entries)		19%	8%	19%	14%	18%	13%

Table 1.7. Minimum irrigation level (%ETo) required to maintain acceptable quality for three-year deficit irrigation treatment.

Species	Entry Name	Predicted Irrigation Level to Maintain Acceptable Turf Quality	Group
KBG	PST-K13-141	81%	abcd
KBG	Midnight	85%	abcd
KBG	NAI-13-14	86%	abcd
KBG	PST-K13-143	86%	abcd
KBG	PST-K11-118	86%	abcd
KBG	Babe	86%	abcd
KBG	Barrari	87%	abcd
KBG	Dauntless	87%	abcd
KBG	PST-K13-137	88%	abcd
KBG	Blue Devil	89%	abcde
KBG	NAI-13-132	91%	abcde
KBG	Blue Note	95%	bcde
KBG	BAR PP 110358	95%	cde
KBG	Everest	100%	de
KBG	PST-K15-169	110%	e
TF	PST-5SDS	71%	a
TF	Kingdom	72%	a
TF	DLFPS 321/3679	74%	ab
TF	Thor	74%	abc
TF	DLFPS 321/3678	77%	abc
TF	Catalyst	77%	abc
TF	Thunderstruck	79%	abc
TF	LTP-SYN-A3	81%	abcd
TF	PST-R511	82%	abcd
TF	BAR FA 121095	82%	abcd
TF	Nonet	83%	abcd
TF	MRSL TF15	84%	abcd
TF	Supersonic	84%	abcd
TF	Stetson II	85%	abcd
TF	DLFPS 321/3677	86%	abcd
TF	GO-AOMK	86%	abcd
TF	RS4	92%	abcde
TF	Titanium 2LS	95%	bcde
TF	BarRobusto	95%	bcde
RYE	SR 4650	74%	ab

Significance level used: alpha = 0.05

Table 1.8. Number of weeks during drought where acceptable quality was maintained.

		2018 (17 weeks)			2019 (16 weeks)			2020 (11 weeks)		
Species	Entry name	80% ETo	60% ETo	40% ETo	80% ETo	60% ETo	40% ETo	80% ETo	60% ETo	40% Eto
KBG	PST-K11-118	17.0	13.7	6.0	3.7	0.0	1.0	2.0	2.0	0.7
KBG	Barrari	17.0	10.7	4.7	3.3	0.0	0.7	2.0	2.0	0.3
KBG	BAR PP 110358	17.0	9.7	4.0	1.3	4.7	2.3	1.7	2.0	1.3
KBG	PST-K13-141	16.7	15.0	7.0	5.0	1.7	1.3	2.3	3.0	0.7
KBG	NAI-13-132	16.7	14.7	3.0	1.0	0.3	0.0	1.3	2.7	0.3
KBG	Everest	16.7	13.0	4.7	0.0	0.0	0.0	5.0	1.7	0.7
KBG	Blue Devil	16.7	11.3	4.0	4.0	0.3	0.3	2.3	3.3	1.0
KBG	Midnight	16.3	12.3	4.0	4.7	1.0	0.3	1.3	1.0	0.7
KBG	NAI-13-14	16.3	11.3	4.3	1.3	0.3	0.7	1.7	1.3	0.7
KBG	Blue Note	16.3	8.7	4.3	2.0	0.0	0.3	2.3	1.7	0.0
KBG	Babe	15.7	12.7	2.7	1.0	0.7	0.3	3.0	2.0	0.7
KBG	PST-K13-143	14.7	9.0	2.0	0.7	2.0	1.0	4.0	2.0	1.3
KBG	Dauntless	13.7	9.3	3.0	3.0	1.7	0.0	1.3	4.7	0.3
KBG	PST-K15-169	13.3	7.3	5.3	1.7	1.3	1.3	1.0	1.3	0.7
KBG	PST-K13-137	11.7	7.0	3.3	5.7	0.0	3.0	2.3	1.3	0.7
TF	Thunderstruck	17.0	17.0	7.0	6.3	2.0	0.3	2.0	2.0	1.3
TF	Kingdom	17.0	17.0	7.7	9.3	5.3	1.7	7.3	2.7	1.3
TF	MRSL TF15	17.0	17.0	6.0	4.7	0.7	0.7	3.3	3.0	0.3
TF	Catalyst	17.0	17.0	9.0	5.3	0.3	1.7	5.3	2.3	0.7
TF	PST-R511	17.0	17.0	7.3	4.3	0.3	2.3	3.7	2.0	1.3
TF	DLFPS 321/3679	17.0	16.7	6.7	8.0	0.3	1.3	7.7	1.7	0.3
TF	PST-5SDS	17.0	16.7	8.7	9.0	1.3	2.7	6.3	2.3	2.7
TF	Thor	17.0	16.3	8.0	10.3	1.0	2.3	7.0	2.0	1.0
TF	DLFPS 321/3677	17.0	15.7	8.0	8.0	1.7	1.7	4.3	2.7	2.7
TF	DLFPS 321/3678	17.0	15.7	8.7	8.3	1.0	2.3	7.0	1.7	1.7
TF	RS4	17.0	15.7	7.3	6.3	1.0	2.7	2.0	1.7	1.3
TF	LTP-SYN-A3	17.0	15.0	8.0	4.3	0.7	0.7	5.3	1.7	2.0
TF	Stetson II	17.0	14.7	6.7	4.0	0.3	0.7	4.0	2.3	1.3
TF	BarRobusto	17.0	14.0	8.0	5.0	0.0	1.3	5.7	2.0	1.3
TF	Titanium 2LS	17.0	14.0	6.0	4.3	1.0	1.3	1.3	1.7	0.7
TF	Supersonic	16.7	16.0	7.3	5.0	0.3	2.0	3.3	2.0	1.3
TF	Nonet	16.7	15.3	7.7	4.3	0.0	1.3	6.0	1.7	1.7
TF	BAR FA 121095	16.3	12.7	5.3	6.0	0.3	2.0	6.7	2.0	1.3
TF	GO-AOMK	15.7	13.3	6.3	3.0	1.0	1.0	4.0	1.7	0.7
Rye	SR 4650	17.0	16.7	6.7	8.3	0.0	0.0	4.7	2.3	0.0
KBG mean		15.7	11.0	4.1	2.6	0.9	0.8	2.2	2.1	0.7
TF mean		16.9	15.6	7.4	6.1	1.0	1.6	4.9	2.1	1.3
LSD		2.6	6.1	2.8	6.0	2.2	2.1	2.6	4.8	2.8

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CHAPTER 2 SALINITY TOLERANCE OF 83 PERENNIAL RYEGRASS LINES

2.1 Overview

There is an increasing demand for turfgrasses with enhanced salt tolerance due to increased use of recycled water/saline water for turfgrass irrigation. Two greenhouse experiments were conducted to assess salinity tolerance of eighty-three perennial ryegrass entries. Each of the eighty-three lines were grown in replicated cone-shaped containers. Treated grasses were soaked in salt + nutrient solution whereas the control groups were soaked in nutrient solution for 1 hour daily. The salt solution began with an electrical conductivity (EC) of 6.0 $dS \cdot m^{-1}$ and was subsequently increased by 4.0 $dS \cdot m^{-1}$ (in Experiment I) or 6.0 $dS \cdot m^{-1}$ (in Experiment II) every 3 weeks until reaching the next targeted salinity level. The final targeted salinity level was 22 $dS \cdot m^{-1}$. Grasses were grown under each of the 4 or 5 targeted salinity levels for a period of 3 weeks. Data on clipping yield, turf quality, leaf firing, and density were collected at each salinity level. Regression analysis was conducted to determine the relationship between clipping yield and the level of salinity. The salinity level causing a 25% reduction in clipping yield was used as an indicator of salinity tolerance level in different entries. The most salt-tolerant turfgrass entries were “SGP4”, “PPG-PR 667”, “PVF-SGS5”, “BAR LP 22262”, “GO-RUS21”, “PPG-PR 610”, “DLF-PR 3727”, and “PPG-PR 639” exhibiting the best turfgrass quality and the greatest 25% clipping yield reduction salinity in both Experiments. We observed that salinity level that caused 25% clipping reduction ranged from 5.0-8.8 $dS \cdot m^{-1}$ in experiment I and 5.7-10.7 $dS \cdot m^{-1}$ in experiment II. The entries with better salt tolerance identified in this study would hold the potential to be utilized on sites with marginally elevated saline soil or irrigated with recycled/saline water.

2.2 Introduction

Turfgrass is one of the world's most important vegetation types, used to beautify urban landscapes, provide a ground cover for outdoor recreational areas such as golf courses and soccer fields, and stabilize slopes (Uddin & Juarimi, 2013). However, with the scarcity of freshwater resources, many state and local governments have begun to restrict the use of freshwater resources for turfgrass and crops alike (Liu, et al., 2023). As a result, landscape managers have had to use lower-quality water sources, such as recycled or saline water, to irrigate turfgrass (Golf Course Superintendents Association of America, 2015; Liu, et al., 2023; Uddin et al., 2011; Uddin & Juarimi, 2013). The city of Denver uses about 314 million gallons of recycled water for parks and golf courses irrigation every year (City and County of Denver, 2016). In the western United States, saltwater intrusion into turfgrass areas in coastal cities and the use of salt to de-ice roads in the winter contribute to soil salinity (Carrow & Duncan, 1998; Chavarria et al., 2019; Qian et al., 2007).

Salinity is one of the environmental factors that can contribute to reduced vegetation growth (Liu et al., 2011; Uddin et al., 2011). Common salt elements in soil and saline water include sodium, potassium, calcium, magnesium, and anions (Marcum, 2006). High concentrations of sodium in the soil cause loss of structure and soil colloids, resulting in poor soil aeration, which can lead to hypoxia/anoxia soil environments (Marcum, 2006; Uddin et al., 2012). Turfgrass in high salinity environments can experience ionic toxicity (Ashraf et al., 2008; Munns, 2005; Uddin & Juarimi, 2013), cell damage (Sahar et al., 2007; Stoeva & Kaymakanova, 2008), and inhibition of mineral and water uptake due to osmotic stress. This can result in nutrient imbalances, leading to slow turfgrass growth or even death. (Uddin & Juarimi, 2013).

There is a great deal of species and cultivar variation in the salt tolerance of turfgrasses (Liu, et al., 2023; Marcum & Pessarakli, 2010). Perennial ryegrass is one of the most commonly used C_3 turfgrasses in cold climate regions (Christians, 2007; Duble, 1996; Marcum & Pessarakli, 2010). According to the research by Harivandi (1992), perennial ryegrass has an intermediate level of salt tolerance, tolerating soil ECe (saturated paste extract) in the range of 4 to 8 $dS \cdot m^{-1}$.

Salinity stress induces osmotic stress, reduces plant growth and the efficiency of photosynthesis, causes nutrient imbalance, etc. Plants usually adjust their metabolism to increase the accumulation of soluble sugars to improve osmotic regulation and protect biomolecules to avoid plant death, especially in C_3 grasses (Chatterton et al., 1989; Tang et al., 2013). High salt tolerance of turfgrass has been associated with saline ion exclusion including excretion at the root cortex and by salt glands (Leonard, 1983; Marcum & Murdoch, 1990; Marcum & Pessarakli, 2006). Specific characteristics of turfgrass salt damage include changes in root growth, increased leaf firing (Qian et al., 2005; Uddin & Juarimi, 2013), turfgrass quality, including color and density, and a reduction in clipping yield (Qian et al., 2005; Qian et al., 2007).

As new varieties of perennial ryegrass are developed and used provided by NTEP, studies on salt tolerance of new perennial ryegrass are needed. In this study, salt solution was used to examine the effects of different salinity levels on turfgrass, including quality, leaf firing, density, and clipping yield of newly developed perennial ryegrass cultivars at different salinity levels to select salt-tolerant perennial ryegrass for sites with salinity problems.

2.3 Material & Methods

2.3.1 Experimental Design

The experimental design was a split-plot with four replications, with salinity as the main factor and 83 different perennial ryegrass entries randomly assigned as subplot factors. The experiment was conducted at the Plant Growth Facility greenhouse at Colorado State University (CSU) located in Fort Collins, Colorado in December 2022 and repeated in June 2023.

The 83 perennial ryegrass entries were seeded individually in cone-shaped containers with dimensions of 6.4 cm in diameter and 25 cm in depth. The containers were filled to approximately 1 cm from the rim of the pot with an 80% sand and 20% organic matter mix as the growing media for the perennial ryegrass. The bottom of each container was plugged with a 15x15 cm geotextile fiber which confined sand to the container and regulated the flow of solution into the container when submerged in the salt solution (Peel et al., 2004). Each ryegrass entry was planted in 7 containers with 0.14 g of seeds that were evenly spread within each container. Among these, four containers were assigned to the salinity treatment group, while the remaining three were assigned to the control group. The seeds were covered with approximately 0.3 cm substrate, which helped to retain moisture in the seeds. Each group with 83 containers were separated into five racks randomly. After seeding, all racks were placed under an automated mist irrigation system that sprayed for five seconds every ten minutes. Greenhouse temperatures were 23.3 °C during the day and 18.3 °C at night.

2.3.2 Salt Screening

In the treatment group for Experiment I, the target salt concentration was gradually increased, which started at an EC of 6.0 $dS \cdot m^{-1}$and increased 4 $dS \cdot m^{-1}$ every 3 weeks until an EC level of 22 $dS \cdot m^{-1}$. In the treatment group for Experiment II, the four EC were 6, 12, 18, 22 $dS \cdot m^{-1}$. For the treatment, the racks were immersed (to the rim of the containers) into a complete nutrient and salt solution in five large tanks for 1.5 hours per day lasted three weeks at each EC level. The solution for the control group (tap water and nutrients) was maintained at an electrical conductivity level of 1.0 d $dS \cdot m^{-1}$. The treated racks and control racks were placed in solution concurrently.

Both control and salt treated containers received Miracle-Gro All Purpose Plant Food 24-8-16 (Scotts Company LLC, OH) at a N concentration of 120 ppm. Instant Ocean salt (58% NaCl with $MgCl_2$, Na_2SO_4, $CaCl_2$ and KCl) (Aquarium Systems, Mentor, OH) was used as the salt solution. Storage tanks for nutrient and salt solutions were covered with a light impermeable cover to prevent algae growth (Peel et al., 2004).

Turfgrass Maintenance

Racks were rotated to minimize the effects of varying light, ventilation, and other factors in the greenhouse environment in the experiment. During the experiment, all tanks were cleaned every two weeks to further prevent algae growth. The temperature in the greenhouse was maintained at 23.3°C (day)/18.3°C (night). The turfgrass was trimmed twice each week maintain a height of 3 cm. Insecticide was applied as needed by greenhouse staff to control aphids.

2.3.3 Data Collection & Analysis

Clipping yield was collected in the last week of each EC level treatment. Turfgrass was trimmed to a height of 3 cm one week prior to clipping collection. One-week-growth was collected and dried in an envelope at 70°C for 48 hours to obtain dry weights. The following formula was used to determine percentage of clipping yield reduction:

$$\text{Percent clipping yield reduction} = [(b - a)/b] * 100,$$

where a is the clipping yield for a given entry and replicate within a given salinity treatment, and b is the clipping yield for the same entry and replicate in the control treatment. Linear Regression analysis was used to generate the equation to describe the relationship between clipping yield reduction percentage and salinity level, and also to derive salinities at which there was a 25% clipping yield reduction.

Turf quality, density, and percentage of leaf firing data were collected for both treatment and control groups weekly by visual observation. Turf quality was evaluated using a 1 (dead) to 9 (best quality) scale, with a rating of 6 being minimum acceptable quality. Turfgrass density was also rated using a 1-9 scale, with 1 being bare soil (no turfgrass coverage), and 9 being optimally dense turf.

Linear regression was used to determine the relationship between EC level and overall turfgrass quality, and derive the salinity level to maintain acceptable quality. The linear regression equation was used to derive the EC value that can maintain acceptable quality. Leaf firing percentage was assessed visually by estimating the total percentage of bleached leaf area. Using control group in the same period time data as covariate, turfgrass quality, clipping yield, leaf firing percent, and turfgrass density, in each salinity level were subjected to Analysis of Covariance tests, and entries means were separated by Fisher's LSD (R version 4.0.3).

2.4 Results & Discussion

2.4.1 Leaf Clipping Yield

Leaf clipping yield reduction can occur when a turfgrass is exposed to salt stress (Qian et al., 2001). Clipping yield is one indicator of turf vigor. The percent reduction in clipping yield at each EC level are presented in Table 2.1 & 2.5.

In Exp. I, 72 entries showed a reduction in clipping yield at 6 $dS{\cdot}m^{-1}$. The overall average yield reduction was 13%, compared to the control. On the other hand, 11 entries did not show any yield reduction but rather showed some yield increase over the control group at this EC level. At 10 $dS{\cdot}m^{-1}$, the clipping yield decreased by an average of 33%. Twenty four entries had clipping yield reduction less than 25%, among which "BAR LP 22262" and "PPG-PR 647" showed no clipping yield reduction (Table 2.1). "PPG-PR 666", "PPG-PR 670", and "BAR LP 22256" showed the clipping yield reduction of more than 60%. At an EC value of 14 $dS{\cdot}m^{-1}$, all entries had a significant average reduction of 74%, compared to EC level of 10 $dS{\cdot}m^{-1}$ (P <0.001). "DLF-LGT-3066" showed with the least (46.0%) clipping yield reduction. Many entries stopped growing altogether at 18 $dS{\cdot}m^{-1}$ and 22 $dS{\cdot}m^{-1}$ concentrations. At EC 14 $dS{\cdot}m^{-1}$ in Exp. I, the clipping yield reduction for all entries was greater than 25%.

In Exp. II, at 6 $dS{\cdot}m^{-1}$, the average yield reduction of 83 entries was 10.0%. There were 71 entries that had clipping yield reduction and 12 entries, did not show reduction. At 12 $dS{\cdot}m^{-1}$, the mean of clipping yield reduction was 28.5%. Among them, 31 entries had less than 25% reduction. Four entries showed very little reduction in growth, namely "PST-2ADS", "RC20-020", "PPG-PR 611", "PVF-SGS5", with clipping yield reduction 2.2%, 2.2%, 2.7%, 2.7%, respectively. At an EC level of 18 $dS{\cdot}m^{-1}$, the average yield reduction of 83 entries was 47.7%. The average of clipping yield reduction was 90.4% at EC level of 22 $dS{\cdot}m^{-1}$.

As shown in Table 2.1 & 2.5, the EC_{25} demonstrated the EC value for the entry that can maintain ≤25% clipping yield reduction. The higher EC value, the better salt tolerance. In Exp. I, 83 entries maintain clipping yield less than 25% within the salinity range of 8.8 to 5.0 $dS{\cdot}m^{-1}$. In Exp. II, 83 entries maintain clipping yield reduction ≤ 25% within the salinity range of 10.7 to 5.7 $dS{\cdot}m^{-1}$.

Among the 83 entries, 12 were released to the market in 2022, and 5 of 12 entries were used as standard as shown in each table. In Exp. I, the best standard entry, "Stellar 4GL", can maintain clipping yield reduction ≤ 25% at EC level of 6.6 $dS{\cdot}m^{-1}$. 12 entries showed better salt tolerance than "Stellar 4GL" in Exp. I. This standard entry also showed as the best standard entry in Exp. II with threshold EC level of 8.0 $dS{\cdot}m^{-1}$. 33 entries demonstrated better performance than "Stellar 4GL" in Exp. II. In both experiments, "SGP4", "PVF-SGS5", "BAR LP 22262", "GO-

RUS21", and "PPG-PR 610" presented better 25% clipping yield reduction salinity than "Stellar 4GL".

Prior studies indicate that the salinity level causing a 25% reduction in clipping yield serves as a reliable indicator of salinity tolerance in the tested turfgrass lines (Fu et al., 2005; Qian et al., 2001; Qian et. al., 2004; Qian et al., 2007. As the result, in both Exp. I and II (Table 2.1 and 2.5), "SGP4", "PPG-PR667", "PVF-SGS5", "BAR LP 22262", "GO-RUS21", and "PPG-PR 610" can result in 25% clipping yield reduction at higher EC level than the best salt tolerance standard entry "Stellar 4GL". Comparing the five standard entries, "Linn" was the least salt tolerant as evidenced by demonstrating the lowest EC level resulting in 25% clipping yield reduction salinity in both Exp. I and II. Most of the 83 entries in this study showed better salinity tolerance than "Linn".

2.4.2 Turf Quality

In Exp. I, turf quality declined as salinity increased (Table 2.2). Entries maintained a high quality rating at the first two EC (6 and 10 $dS{\cdot}m^{-1}$) levels. At a salinity of 6 $dS{\cdot}m^{-1}$, the average quality of the turfgrasses was 8.2. At 10 $dS{\cdot}m^{-1}$, all entries remained above acceptable quality of 6, the average quality was same with 6 $dS{\cdot}m^{-1}$. The quality distribution of the 83 turfgrasses ranged from the lowest of 7.8 to the highest of 8.9 at 10 $dS{\cdot}m^{-1}$. After the EC level reached 14 $dS{\cdot}m^{-1}$, the quality of all the turfgrass entries had significantly declined ($P < 0.001$), with the average quality of the 83 entries being only 4.6, which was below acceptable turfgrass quality. None of the entries showed above acceptable quality. The entries showed more deviation from each other than at any other salt concentration. The entries ranged from the best, 5.6 for "BAR LP 22263", to the worst 3.4 for "Linn". As the EC level continued to increase to 18 $dS{\cdot}m^{-1}$ and 22 $dS{\cdot}m^{-1}$, the quality of the turfgrasses ranged from the best at 4.0 for "DLF-LGT-3066" to the worst at 2.2. This shows that the quality of all the turfgrasses was far below the acceptable quality of turfgrass with an average quality of 3.2 and 2.9 respectively. Most of the turfgrass blades had turned yellow and curled up.

In Exp. II (Table 2.6), at EC levels of 6 and 12 $dS \cdot m^{-1}$, all entries maintained above acceptable quality. At 6 $dS \cdot m^{-1}$, all entries scoring 8.7 or above. As the salinity increased to 12 $dS \cdot m^{-1}$, there was a significant decline in quality ($P<0.05$), dropping to a range of 6.0 to 7.2. All entries maintained minimum acceptable quality at this EC level. At 18 $dS \cdot m^{-1}$, the quality of all entries dropped below acceptable quality, with an average of 4.1. Some entries, namely "Alpha Centauri", "SGP4", "PPG-PR 639", and "BSG-PR22 had better quality at 5 than other entries. At 22 $dS \cdot m^{-1}$, the average quality of 83 entries was 2.5.

The results showed that in the Experiment I, the most salt tolerant perennial ryegrass maintained the acceptable turf quality at maximum 13.7 $dS \cdot m^{-1}$, and the least salt-tolerant turfgrasses maintained acceptable quality before EC value reaches 11.0 $dS \cdot m^{-1}$. This was also reflecting that entries can have acceptable quality at an EC value of 10 $dS \cdot m^{-1}$, but cannot maintain acceptable quality at a concentration of 14 $dS \cdot m^{-1}$. In Experiment II, all perennial ryegrass entries maintained at acceptable levels within the salinity range of 12.1 to 14.7 $dS \cdot m^{-1}$. The best released entry in both Exp. I and II was "Alpha Centauri". "BAR LP 22262", "SGP4", "DLF-PR 3727", and "PPG-PR 639". These entries performed better than "Alpha Centauri" in both experiments. They maintained acceptable quality at 13.7, 13.5, 13.0, and 13.2 $dS \cdot m^{-1}$, respectively, while "Alpha Centauri" was 12.8 $dS \cdot m^{-1}$ in Exp. I. In Exp.II, they could maintain acceptable quality at 14.7, 14.5, 14.7, and 14.7 $dS \cdot m^{-1}$, respectively, and "Alpha Centauri" was 14.5 $dS \cdot m^{-1}$. The exposure time to each of the salinity levels was only three weeks. The results could not accurately represent the true ability for these entries to maintain quality in long terms.

2.4.3 Leaf Firing

As the EC value increased, the percentage of turfgrass leaf firing progressively increased. In Table 2.3, the smaller the percentage of leaf firing, the better salt tolerance capacity.

In Exp. I, at 6 $dS{\cdot}m^{-1}$, all entries showed a low leaf firing percentage, with most of the entries having only leaf tip burn. According to Table 3, at this EC value, perennial ryegrass did not reflect much stress among entries. The leaf firing percentage of the different 83 perennial ryegrass at 6 $dS{\cdot}m^{-1}$ ranged from 0.2% to 1.5%, with a mean of 0.7%. When the EC value was increased to 10 $dS{\cdot}m^{-1}$, some entries started to show minor leaf bleaching and the overall average leaf firing percentage increased to 3.3%. The best performers were "PPG-PR 662" and "BAR LP 22256" with only 2% and the highest leaf firing percentage was "Linn", which is one of the standard entries, with 7.4%. There was not much difference between the other entries for this EC value. When the EC value reached 14 $dS{\cdot}m^{-1}$, the leaf firing percentage of the entries increased, and the difference between entries became larger ($p<0.05$). The worst entry was "Linn" with 54.7% leaf firing. The entry with the least amount of leaf firing was "SGP4" with 18.7% leaf firing. At 18 $dS{\cdot}m^{-1}$, the overall mean leaf firing percentage was 74.1%, with a range of 51.6 to 90.3%. At EC level of 22 $dS{\cdot}m^{-1}$, the mean leaf firing value was 83.8%. At this salinity level, most of the plants had stopped growing.

In Exp. II, entries at 6 $dS{\cdot}m^{-1}$ did not exhibit leaf firing, consistent with the performance in the first experiment. After increasing to 12 $dS{\cdot}m^{-1}$ EC value, some turfgrass entries displayed minor of leaf firing. As shown in Table 2.7, the average leaf firing percentage was recorded at 3.5%, ranging from 0.8 to 11.2%. Two entries "SGP4" and "BAR LP 22191" demonstrated leaf firing percentage values of less than 1%. At 18 $dS{\cdot}m^{-1}$, the leaf firing percentage for each turfgrass entry increased, culminating in an average leaf firing percentage of 47.6%, with a range from 26.0 to

70.8%. At 22 dS·m^{-1}, the mean of leaf firing percentage was 78.9%, with a range from 46.8 to 99.2%.

As shown in results, at EC value of 10 dS·m^{-1} of Exp. I and 12 dS·m^{-1} of Exp. II, many entries presented the superior salinity tolerance with the leaf firing lower than 3%. As observed during those EC levels, the leaf firing just had browning at the tips of the blades. This is not likely to significantly impact the aesthetic value of the turfgrass.

2.4.4 Density

Turf density decreased with increasing EC value. In Exp. I, as shown in Table 2.4, at EC value of 6 dS·m^{-1} and 10 dS·m^{-1}, the density ranges were 7.0 to 8.7 and 7.4 to 8.3, respectively. Turfgrass density was minimally affected and was maintained above the optimum levels at these two EC values. Turfgrass density values at 14 dS·m^{-1} showed a significant decrease ($p<0.001$), with the range dropping to 6.5 to 5.3. At this EC level, entries begin to exhibit densities below the rating of 6 with 30 out of 83 entries having ratings that exceed a density rating of 6. When the EC reached 18 dS·m^{-1} and 22 dS·m^{-1}, no entries achieve a density of 6. The turfgrass density range continued decreasing to 5.7 to 4.2 at 18 d S·m^{-1} and 5.4 to 3.7 at 22 dS·m^{-1}. It was observed that many entries at 18 dS·m^{-1} and 22 dS·m^{-1} stopped growing due to salt stress, but did not die completely, all of the entries had a density of 3.8 or greater by the end of this experiment.

In Exp. II, at 6 dS·m^{-1}, the mean turfgrass density was not significantly influenced by this concentration, as all entries had density readings above 7.3. However, within the increasing EC levels, the average density readings of turfgrass gradually declined with increasing salinity, as shown in Table 2.8, reaching 7.0 at 12 dS·m^{-1}, 4.8 at 18 dS·m^{-1}, and 4.3 at 22 dS·m^{-1}. As observed, all entries had acceptable density rating or above at 12 dS·m^{-1}. When EC level higher than 18 dS·m^{-}

^{1}, all entries density readings dropped below 6, which the density readings were no longer within an acceptable range.

In summary, based on EC level to result in 25% clipping yield reduction and EC level to maintain acceptable turfgrass quality, in two experiments, entries “SGP4” showed statistically significant higher 25% clipping yield reduction salinity and higher EC level to maintain acceptable quality than the other entries, demonstrating superior salinity tolerance. “SGP4”, “PVF-SGS5”, “BAR LP 22262”, “GO-RUS21”, “PPG-PR 610”, “DLF-PR 3727”, and “PPG-PR 639” presented better salt tolerance than the best standard entry, “Stellar 4GL” based on 25% clipping yield reduction and quality. The results obtained from the second experiment closely resembled those from the first experiment in terms of various parameters, but also showed some differences. Exp. II demonstrated better salt tolerance compared to Exp. I, as indicated by the greater EC values that caused 25% clipping yield reduction (Table 2.1 & 2.5). The targeted salinity levels were 6, 10, 14, 18, and 22 $dS{\cdot}m^{-1}$ in Exp. I, and the targeted salinity changed to 6, 12, 18 and 22 $dS{\cdot}m^{-1}$ in Exp. II, although the exposure time at each salinity was the same between Experiments, the total exposure time was different. Additionally, perennial ryegrass has an intermediate level of salt tolerance of 4-8 $dS{\cdot}m^{-1}$ (Harivandi et al., 1992), but in this experiment perennial ryegrass shown acceptable quality at higher level of salinity in greenhouse, which was attributed to the limited experimental exposure time. Mutlu et al. (2017) demonstrated that damage can occur at 6 $dS{\cdot}m^{-1}$. This study showed limited impact at 6 $dS{\cdot}m^{-1}$, it was likely related to the exposure time was very short which was three weeks for one salinity level.

2.5 Conclusion

In conclusion, the research collected and analyzed data on clipping yield reduction, turfgrass quality, leaf firing, and density of 83 perennial ryegrass entries. At the EC value range from 5.0-8.8 $dS \cdot m^{-1}$ in experiment I and 5.7-10.7 $dS \cdot m^{-1}$ in experiment II caused a 25% clipping yield reduction of perennial ryegrass entries. The level of salinity that results in 25% clipping yield reduction is a good indicator of the level of salinity tolerance for the tested turfgrass lines. Perennial ryegrass entries maintained acceptable quality at the EC value range from 11.0-13.7 $dS \cdot m^{-1}$ in experiment I and 12.1-14.7 $dS \cdot m^{-1}$ in experiment II. Density was less sensitive than quality and clipping yield reduction to salinity stress. "SGP4" showed significant better salt tolerance than other entries based EC level to result in 25% clipping yield reduction and EC level to maintain acceptable turfgrass quality in both experiments. Comparing with the best standard entry and released entry on 25% clipping yield reduction salinity and turfgrass quality, entries "SGP4", "PPG-PR 667", "PVF-SGS5", "BAR LP 22262", "GO-RUS21", "PPG-PR 610", "DLF-PR 3727", and "PPG-PR 639" demonstrated better salinity tolerance in this study.

Table 2.1. Clipping Yield Reduction Percentage (relative to control) of 83 perennial ryegrasses under different salinity levels (%) in Exp. I.

Entry	6 dS·m^{-1}	10 dS·m^{-1}	14 dS·m^{-1}	18 dS·m^{-1}	22 dS·m^{-1}	EC^{Y}
SGP4	17.9	44.9	59.6	73.8	23.5	8.8
DLF-LGT-3066	22.3	1.0	46.0	72.9	54.7	8.6
PST-2DRG	16.9	47.8	79.7	86.3	82.9	7.6
GO-RUS22	3.8	32.6	54.9	85.4	58.3	7.2
PVF-SGS5	-6.8	10.8	64.8	84.3	71.8	7.0
PST-2HAF20	2.4	29.1	74.5	83.2	56.1	7.0
PPG-PR 663	10.8	7.8	72.1	77.2	76.8	6.7
BAR LP 22262	28.8	-5.5	72.2	88.2	69.1	6.7
GO-RUS21	-12.9	54.7	66.8	72.3	70.4	6.7
DLF-PR-3737	30.4	45.6	55.4	78.0	66.7	6.7
PPG-PR 610	11.0	12.5	72.6	78.7	75.7	6.6
PPG-PR 647	1.8	-5.0	75.0	82.9	82.7	6.6
**Stellar 4GL	-16.7	16.4	63.7	80.5	87.4	6.6
PPG-PR 665	20.9	56.8	82.4	86.0	44.3	6.5
PPG-PR 662	15.0	27.5	76.1	82.6	70.9	6.5
DLF-PR-3726	18.8	-0.4	77.7	87.4	74.7	6.5
PPG-PR 642	13.2	38.2	76.0	81.1	65.2	6.4
DLF-PR-3738	11.7	27.9	67.5	76.1	81.0	6.4
PST-2SPF	23.5	20.9	66.8	85.4	74.0	6.4
SE-DK	0.8	30.8	63.9	87.1	76.3	6.4
DLF-PR-3727	10.9	9.9	68.7	83.7	82.8	6.4
*Siletz	-4.3	21.9	70.8	85.8	78.6	6.4
SEPR-2013	13.8	25.5	76.6	88.1	66.7	6.4
PPG-PR 667	23.3	40.9	58.2	72.7	82.7	6.3
*Alpha Centauri	6.8	27.4	71.5	84.1	75.8	6.3
PPG-PR 639	9.7	13.6	70.2	72.8	91.6	6.3
PPG-PR 668	14.8	38.7	72.2	79.8	71.9	6.3
PS4	2.5	6.3	69.0	81.4	90.8	6.3
DLF-PR-3728	-7.9	59.3	83.1	79.8	62.2	6.3
BAR LP 22263	38.8	25.3	66.0	79.3	77.8	6.3
20PR10	12.9	18.1	72.4	87.0	79.4	6.2
PPG-PR 606	12.0	46.1	80.2	82.9	65.3	6.2
GO-RUS20	1.6	36.1	57.7	86.6	84.3	6.2
BY-PS2	23.8	33.7	71.3	78.4	77.6	6.2
PST-2EGY	-3.9	28.5	78.0	87.3	76.1	6.2
TSC-CR5	-12.9	25.1	86.3	90.5	79.6	6.2
BAR LP 22191	2.5	51.3	71.6	84.9	70.9	6.2
PPG-PR 670	18.7	61.5	82.6	82.2	70.8	6.2
*Dark Matter	10.2	48.1	73.5	80.5	74.3	6.1
LTP-RPP4	7.4	31.3	78.5	79.8	82.2	6.1
PPG-PR 637	12.6	22.5	76.5	87.3	80.2	6.1
DLF-PR-3735	-0.5	36.1	71.0	85.6	82.9	6.0
PVF-RPP2	-6.8	44.2	62.3	81.1	90.1	6.0

DLF-PR-3730	17.6	23.6	81.2	91.1	73.6	6.0
**Karma	10.2	29.3	58.8	87.3	90.7	6.0
**Homerun LS	35.6	37.1	74.3	87.2	70.8	6.0
*Quasar	-2.1	37.7	74.2	83.4	84.2	6.0
PPG-PR 646	30.1	19.9	71.5	87.9	87.4	6.0
PPG-PR 602	6.0	39.1	78.1	86.1	77.0	6.0
PPG-PR 661	9.0	24.8	64.4	91.7	87.9	6.0
PPG-PR 643	1.9	32.8	75.5	87.0	83.0	6.0
PPG-PR 658	1.6	21.9	76.3	86.0	89.0	5.9
PR5	20.3	43.8	72.0	80.8	81.8	5.9
PST-2MEG	15.2	37.2	82.5	89.0	73.9	5.9
APS	-8.5	32.5	82.2	88.1	83.9	5.9
LTP-NR	28.4	17.4	75.8	87.8	85.2	5.9
CJP1R	3.3	16.9	74.0	93.0	90.6	5.8
PST-2MES1	35.2	32.1	78.2	86.0	78.2	5.8
DLF-PR-3729	25.0	53.2	78.0	82.4	75.7	5.8
PST-2HFM	25.0	51.5	66.1	84.1	83.3	5.8
BSG-PR22	4.8	56.0	87.7	89.1	69.0	5.8
*Greenback	10.6	38.4	84.1	90.3	77.2	5.8
DLF-PR-3736	9.9	17.6	75.7	88.5	93.8	5.8
PST-2ADS	17.2	29.2	81.5	88.2	83.6	5.7
PST-2GDS	13.4	24.7	84.7	90.2	84.7	5.7
MRSL-PR22	34.4	0.7	80.6	91.2	91.6	5.7
RPP3	15.0	36.6	61.8	88.4	95.3	5.7
BAR LP 22174	20.7	42.3	88.2	89.5	77.3	5.6
PPG-PR 611	25.7	45.6	80.9	88.1	80.7	5.6
**Brightstar SLT	23.0	52.4	79.7	80.0	86.6	5.6
*High Octane	24.8	55.0	69.6	89.3	86.3	5.5
PPG-PR 671	23.8	46.0	79.5	88.4	85.1	5.5
**Linn	21.0	57.9	71.6	90.4	85.8	5.5
PST-214	9.4	54.2	80.1	89.3	86.6	5.4
RC20-020	9.3	31.3	89.1	93.4	88.8	5.4
*Piston	17.4	46.7	80.3	86.3	91.8	5.4
PPG-PR 664	35.0	56.3	89.4	88.1	76.2	5.4
PPG-PR 666	24.4	62.6	78.7	87.3	86.3	5.3
PST-2E6	3.5	47.0	94.9	95.0	83.7	5.3
BAR LP 22256	26.2	60.0	81.4	91.2	88.1	5.2
PPG-PR 644	29.9	54.3	83.3	90.6	91.5	5.2
PST-2BGL	21.5	55.6	87.5	95.0	92.1	5.0
PPG-PR 620	32.0	54.8	85.7	93.5	94.3	5.0
Mean	13.3	34.0	74.4	85.2	78.7	6.1
LSD	28.0	44.8	28.2	14.9	28.4	

[Y]Salinity level (EC) cause 25% reduction.

*Commercially available entries

**Standard entries

Table 2.2. Turfgrass quality (scale of 1 to 9, with 9 = ‘‘best’’) of 83 perennial ryegrasses under different salinity levels of Exp. I. A rating of “6” indicates minimum acceptable quality.

Entry#	6 $dS{\cdot}m^{-1}$	10 $dS{\cdot}m^{-1}$	14 $dS{\cdot}m^{-1}$	18 $dS{\cdot}m^{-1}$	22 $dS{\cdot}m^{-1}$	EC^{Y}
BAR LP 22263	8.3	8.2	5.6	3.9	3.6	13.7
DLF-LGT-3066	8.0	8.2	5.3	4.0	3.9	13.6
PPG-PR 667	8.0	8.6	5.4	3.9	3.2	13.5
SGP4	8.1	8.1	5.3	3.8	3.8	13.5
PPG-PR 662	8.3	8.3	5.3	3.6	3.3	13.4
PST-2HAF20	8.1	8.9	5.0	3.6	3.2	13.4
DLF-PR-3737	8.1	8.1	5.1	3.8	3.4	13.2
PPG-PR 668	8.4	8.2	4.9	3.8	3.2	13.2
PPG-PR 639	8.2	8.3	4.8	3.7	3.7	13.2
GO-RUS22	8.2	8.1	5.2	3.7	3.2	13.1
BAR LP 22262	8.0	8.3	5.0	3.7	3.4	13.1
PPG-PR 663	8.1	8.2	5.0	3.8	3.3	13.1
PST-2MES1	8.4	8.4	4.9	3.3	3.0	13.1
DLF-PR-3727	8.1	8.0	5.2	3.7	3.3	13.0
PST-2HFM	8.2	8.2	4.8	3.4	3.6	13.0
PPG-PR 646	8.2	8.1	4.8	3.6	3.3	12.9
PST-2MEG	8.2	8.2	4.7	3.4	3.6	12.9
DLF-PR-3726	8.1	8.2	5.1	3.3	3.0	12.8
*Alpha Centauri	7.9	8.4	4.9	3.3	3.2	12.8
*Siletz	8.1	8.2	4.9	3.4	3.0	12.8
PPG-PR 665	8.2	8.3	4.7	3.3	3.2	12.8
DLF-PR-3735	8.2	8.3	4.7	3.4	3.1	12.8
PST-2SPF	8.3	8.3	4.6	3.3	3.0	12.8
DLF-PR-3729	8.2	8.1	5.1	3.1	2.9	12.7
*Quasar	7.9	8.4	4.9	3.4	3.0	12.7
PPG-PR 610	8.1	8.2	4.8	3.6	3.0	12.7
PPG-PR 647	8.1	8.4	4.8	3.2	3.0	12.7
PVF-SGS5	8.1	8.6	4.8	3.1	2.9	12.7
PS4	8.1	8.3	4.7	3.6	2.9	12.7
BAR LP 22256	8.4	8.4	4.6	2.9	3.0	12.7
PPG-PR 671	8.2	8.0	5.0	3.2	2.9	12.6
DLF-PR-3736	8.1	8.2	4.7	3.4	3.0	12.6
GO-RUS21	8.2	8.2	4.6	3.3	3.0	12.6
PPG-PR 606	8.1	8.1	4.4	3.4	3.3	12.6
PPG-PR 637	8.2	8.2	4.4	3.3	3.1	12.6
SE-DK	8.2	8.2	4.4	3.2	3.2	12.6
PPG-PR 658	8.1	8.3	4.9	3.0	2.7	12.5
PPG-PR 602	8.2	8.2	4.9	3.0	2.6	12.5
PST-2ADS	8.0	8.3	4.8	3.2	2.8	12.5
PPG-PR 661	8.2	8.0	4.8	3.1	2.9	12.5
BAR LP 22191	8.1	8.1	4.7	3.2	3.0	12.5
PPG-PR 611	8.2	8.3	4.6	3.1	2.8	12.5
PPG-PR 670	8.2	8.1	4.6	3.1	3.2	12.5

PVF-RPP2	8.1	8.4	4.4	3.2	2.8	12.5
*Piston	8.1	8.1	5.0	3.0	2.7	12.4
*Greenback	8.1	8.2	4.8	3.0	2.8	12.4
PPG-PR 666	8.1	8.0	4.8	3.2	2.9	12.4
SEPR-2013	8.3	8.4	4.8	2.4	2.4	12.4
**Karma	8.0	8.1	4.7	3.3	3.0	12.4
PST-2GDS	8.1	8.2	4.7	3.0	2.9	12.4
DLF-PR-3730	8.1	8.3	4.6	3.2	2.6	12.4
PPG-PR 664	8.1	8.2	4.4	3.0	3.1	12.4
DLF-PR-3728	8.2	8.2	4.3	3.2	2.8	12.4
PPG-PR 642	8.1	8.2	4.3	3.2	2.8	12.3
PR5	8.3	7.8	4.3	3.2	3.2	12.3
DLF-PR-3738	8.0	8.1	4.7	2.9	2.9	12.2
LTP-RPP4	8.1	8.1	4.6	2.9	2.8	12.2
PPG-PR 643	8.1	8.0	4.6	3.2	2.4	12.2
BY-PS2	8.2	8.0	4.6	3.0	2.4	12.2
LTP-NR	8.1	8.1	4.3	3.3	2.7	12.2
PST-2DRG	8.3	8.0	4.3	2.9	2.7	12.2
20PR10	8.2	8.6	4.0	2.8	2.8	12.2
BSG-PR22	8.4	8.6	4.0	2.4	2.4	12.2
RPP3	8.0	8.0	4.3	3.2	2.8	12.1
**Brightstar SLT	8.1	8.0	4.3	2.9	3.0	12.1
PST-2EGY	8.1	8.3	4.2	2.9	2.7	12.1
TSC-CR5	8.2	8.3	4.2	2.3	2.9	12.1
*Dark Matter	8.2	8.2	4.0	2.9	2.8	12.1
PPG-PR 620	8.3	7.9	4.0	3.1	3.0	12.1
MRSL-PR22	7.9	8.1	4.6	3.0	2.4	12.0
GO-RUS20	8.0	7.8	4.3	3.2	2.9	12.0
PPG-PR 644	8.1	8.1	4.1	3.1	2.6	12.0
PST-2BGL	8.0	8.0	4.6	2.8	2.2	11.9
APS	8.0	8.2	4.6	2.4	2.4	11.9
RC20-020	8.0	8.1	4.4	2.6	2.4	11.9
**Stellar 4GL	8.1	8.0	4.1	3.0	2.6	11.9
PST-214	8.2	8.1	4.1	2.4	2.6	11.9
BAR LP 22174	8.2	7.9	4.0	3.0	2.7	11.9
CJP1R	8.0	8.0	4.2	2.9	2.3	11.8
**Homerun LS	8.1	7.9	4.0	2.9	2.7	11.8
*High Octane	8.2	7.9	4.0	2.6	2.7	11.7
PST-2E6	8.2	7.9	3.8	2.3	2.4	11.5
**Linn	7.8	7.8	3.4	2.7	2.4	11.0
Mean	8.2	8.2	4.6	3.2	2.9	12.5
LSD	0.4	0.7	1.0	0.7	0.6	

Control group was used as the covariate in statistical analysis, so it is not shown in the table.
[Y]Salinity level (EC) maintain acceptable quality.
*Commercially available entries
**Standard entries

Table 2.3. Leaf Firing Percentage of 83 perennial ryegrass under different salinity levels (%) in Exp. I.

Entry	6 $dS \cdot m^{-1}$	10 $dS \cdot m^{-1}$	14 $dS \cdot m^{-1}$	18 $dS \cdot m^{-1}$	22 $dS \cdot m^{-1}$
SGP4	0.7	2.9	18.7	62.8	78.8
PST-2HAF20	1.0	2.1	21.2	73.9	85.3
PPG-PR 667	1.0	2.7	21.3	51.6	68.3
PPG-PR 662	0.7	2.0	21.4	63.8	76.4
DLF-LGT-3066	0.5	3.0	21.7	57.4	66.3
DLF-PR-3727	0.8	3.7	21.8	64.0	74.0
GO-RUS22	0.7	3.0	21.9	64.2	81.1
BAR LP 22263	1.3	3.3	21.9	57.1	73.4
DLF-PR-3737	0.8	2.9	22.9	73.3	76.4
PPG-PR 663	0.7	2.9	23.0	61.3	73.7
*Alpha Centauri	1.5	2.9	24.1	71.3	80.9
PPG-PR 602	0.3	3.4	24.7	79.2	90.6
DLF-PR-3729	1.0	3.3	24.8	75.4	83.7
*Quasar	1.2	3.1	25.0	69.0	82.1
DLF-PR-3726	1.0	3.1	25.2	66.9	82.3
PPG-PR 668	0.7	2.6	25.6	72.9	83.6
PST-2MES1	0.5	2.7	25.7	68.7	80.9
PPG-PR 637	0.2	2.8	26.2	75.4	78.9
PPG-PR 671	1.0	3.9	26.4	78.8	87.7
DLF-PR-3735	0.5	2.6	26.4	69.4	83.3
PPG-PR 665	0.5	2.6	26.7	64.1	81.3
BAR LP 22262	1.0	3.4	26.7	59.6	68.4
*Siletz	0.7	2.6	26.9	77.7	87.8
PVF-SGS5	0.3	3.3	27.4	69.3	82.3
PPG-PR 647	1.0	3.6	27.6	75.4	83.9
PPG-PR 658	0.8	3.8	27.8	83.7	89.4
DLF-PR-3730	0.7	3.0	28.2	80.8	88.4
DLF-PR-3738	0.8	2.3	28.2	77.0	90.3
BAR LP 22256	0.7	2.0	28.6	71.9	79.1
PPG-PR 646	0.3	3.6	28.7	62.0	75.7
DLF-PR-3736	0.7	2.9	28.7	66.4	79.8
PS4	0.2	2.9	28.9	66.4	82.1
SE-DK	0.7	3.7	28.9	61.9	78.3
PPG-PR 639	0.7	2.4	29.8	70.9	77.2
PPG-PR 610	0.2	3.2	29.9	65.4	75.9
PPG-PR 643	0.8	3.4	29.9	78.6	88.3
GO-RUS21	0.8	3.0	30.0	81.0	86.2
*Greenback	0.5	3.8	30.4	82.2	86.1
**Karma	0.5	2.6	30.6	76.9	84.0
PST-2BGL	0.7	3.0	30.9	85.9	91.1
PST-2SPF	0.7	2.8	30.9	72.8	80.3
PPG-PR 611	0.3	2.9	31.1	77.1	85.9

PST-2GDS	0.3	4.3	31.4	76.6	85.6
BAR LP 22191	1.2	3.1	31.9	75.9	81.9
PVF-RPP2	1.0	3.2	31.9	80.6	89.1
*Piston	0.8	3.0	32.1	83.7	90.6
PPG-PR 670	0.8	3.4	32.4	71.6	81.8
**Brightstar SLT	1.0	3.3	32.4	69.2	79.6
PST-2ADS	0.7	3.3	32.8	70.0	85.2
PST-2DRG	0.5	4.4	34.0	73.7	88.0
APS	0.7	3.7	34.0	77.9	89.7
DLF-PR-3728	0.2	3.1	34.0	73.3	85.4
PPG-PR 661	0.3	2.6	34.1	67.7	74.4
PST-2HFM	0.3	3.1	34.4	72.2	84.7
**Stellar 4GL	1.0	3.6	34.4	76.7	85.4
PPG-PR 642	0.5	2.7	34.7	73.2	86.8
PST-2MEG	0.7	3.2	34.8	62.8	76.2
RPP3	0.5	4.1	34.8	66.2	81.1
LTP-RPP4	0.8	2.7	36.2	86.6	88.3
PR5	0.8	3.7	36.4	80.2	81.9
PPG-PR 620	0.8	4.3	36.6	74.6	84.4
LTP-NR	1.0	4.0	36.8	76.3	85.8
CJP1R	0.8	4.9	36.9	81.6	91.4
PPG-PR 666	0.7	3.4	37.0	65.4	80.9
PPG-PR 606	0.7	2.7	37.2	69.9	85.1
PPG-PR 664	0.3	3.1	37.6	76.1	80.9
PST-2EGY	0.7	3.2	38.6	79.2	89.4
TSC-CR5	0.3	2.8	38.8	90.3	91.0
GO-RUS20	1.0	6.2	39.4	73.7	86.9
*Dark Matter	0.7	3.2	39.6	75.4	82.9
SEPR-2013	1.0	2.3	40.3	83.6	92.7
PST-214	1.5	3.6	41.1	88.8	91.4
*High Octane	0.7	3.6	41.1	82.3	89.4
RC20-020	0.7	5.2	41.2	88.6	94.9
PPG-PR 644	1.2	3.6	41.3	89.1	93.2
MRSL-PR22	1.2	3.0	41.6	85.7	89.9
BY-PS2	0.3	2.4	41.7	83.4	89.0
**Homerun LS	0.7	3.6	42.7	78.1	90.2
20PR10	0.7	2.8	47.1	77.6	84.8
BSG-PR22	0.3	3.3	48.8	85.8	90.6
PST-2E6	0.3	3.2	50.2	88.8	85.7
BAR LP 22174	0.8	2.6	52.3	78.6	89.7
**Linn	0.8	7.4	54.7	78.3	90.2
Mean	0.7	3.3	32.2	74.1	83.8
LSD	1.2	2.2	16.9	16.9	11.7

Control group was used as the covariate in statistical analysis, so it is not shown in the table.
*Commercially available entries
**Standard entries

Table 2.4. Turfgrass density (scale of 1 to 9, with 9 = ‘‘best’’) of 83 perennial ryegrasses under different salinity levels in Exp. I.

Entry	6 $dS \cdot m^{-1}$	10 $dS \cdot m^{-1}$	14 $dS \cdot m^{-1}$	18 $dS \cdot m^{-1}$	22 $dS \cdot m^{-1}$
PPG-PR 667	8.3	8.2	6.6	5.7	5.0
GO-RUS22	8.2	8.3	6.4	5.6	5.0
PST-2MEG	8.0	7.8	6.2	4.9	5.0
RC20-020	8.5	8.0	6.1	4.9	4.4
PPG-PR 637	8.0	8.0	6.1	5.4	4.9
PPG-PR 639	8.2	8.3	6.1	5.3	4.8
PPG-PR 658	8.5	8.2	6.1	4.8	4.9
PPG-PR 662	8.3	8.0	6.1	5.4	5.0
PPG-PR 671	8.2	8.1	6.1	5.1	4.9
PR5	8.2	7.9	6.1	5.1	5.1
APS	8.2	8.0	6.1	4.8	4.9
**Stellar 4GL	8.0	8.1	6.1	5.7	5.4
DLF-PR-3730	8.2	8.3	6.1	5.4	5.3
DLF-PR-3736	8.3	8.2	6.1	5.4	5.0
DLF-PR-3737	7.8	7.9	6.1	5.2	4.9
GO-RUS21	8.7	8.3	6.0	5.6	5.0
PST-2BGL	8.2	8.2	6.0	5.0	4.8
PPG-PR 610	8.2	8.2	6.0	5.3	5.0
PPG-PR 643	8.0	8.0	6.0	5.1	4.8
PPG-PR 644	8.2	7.8	6.0	5.2	5.0
PPG-PR 664	8.2	8.2	6.0	5.4	5.1
PPG-PR 665	8.5	7.9	6.0	5.3	5.1
PPG-PR 666	8.0	7.8	6.0	5.1	4.8
PPG-PR 668	8.3	8.3	6.0	5.6	5.2
PVF-SGS5	8.2	8.2	6.0	5.1	4.9
PS4	7.8	7.9	6.0	5.4	4.9
BAR LP 22191	8.2	7.8	6.0	5.6	5.0
BAR LP 22263	8.0	8.1	6.0	5.1	4.7
SEPR-2013	8.0	7.9	6.0	5.3	5.0
*Quasar	7.5	8.1	6.0	4.7	4.3
GO-RUS20	8.2	7.9	5.9	5.2	4.9
PST-2ADS	8.0	7.9	5.9	5.3	4.4
PST-2DRG	8.5	7.9	5.9	5.1	5.0
PST-2EGY	8.0	8.1	5.9	5.4	4.9
LTP-RPP4	8.2	8.1	5.9	5.2	4.8
PST-2HFM	8.0	8.0	5.9	5.0	4.7
PST-2MES1	8.5	8.1	5.9	5.2	4.8
PST-2SPF	8.0	8.1	5.9	5.3	4.8
PPG-PR 602	8.0	7.9	5.9	5.0	4.6
PPG-PR 642	8.2	8.1	5.9	4.9	4.6
PPG-PR 647	7.8	8.0	5.9	5.1	4.7

PPG-PR 661	8.3	8.3	5.9	5.2	4.8
BY-PS2	8.0	8.2	5.9	5.2	4.7
SGP4	8.0	8.1	5.9	5.3	4.9
*Piston	7.7	7.9	5.9	4.9	4.8
**Brightstar SLT	7.5	8.0	5.9	4.8	4.8
*Dark Matter	7.7	8.0	5.9	5.0	4.8
DLF-PR-3726	8.3	8.3	5.9	5.3	4.9
DLF-PR-3727	8.2	8.1	5.9	5.3	4.7
DLF-PR-3728	8.2	8.0	5.9	4.6	5.1
**Karma	8.2	8.1	5.9	5.2	4.9
DLF-PR-3738	7.5	8.1	5.9	5.2	4.6
DLF-LGT-3066	7.0	7.6	5.9	5.4	4.6
PST-214	8.0	8.1	5.8	4.9	5.0
PST-2HAF20	8.2	8.1	5.8	5.1	4.7
PPG-PR 606	8.2	8.0	5.8	5.0	4.4
*Greenback	8.2	8.0	5.8	5.1	4.7
PPG-PR 646	7.8	8.0	5.8	4.9	4.8
BAR LP 22174	8.2	8.1	5.8	4.9	4.4
RPP3	7.8	8.1	5.8	5.4	5.1
DLF-PR-3729	7.8	7.9	5.8	4.9	4.6
*Alpha Centauri	7.3	7.8	5.8	4.8	4.3
*Siletz	8.3	7.9	5.8	5.3	4.9
PPG-PR 611	8.5	8.1	5.7	4.9	4.6
PPG-PR 663	8.5	8.2	5.7	5.1	4.8
PPG-PR 670	8.0	7.9	5.7	4.6	4.3
*High Octane	7.8	7.8	5.7	4.9	4.2
LTP-NR	8.0	8.0	5.7	4.6	4.4
BAR LP 22256	8.5	8.1	5.7	5.2	4.4
SE-DK	7.3	7.7	5.7	5.0	4.4
CJP1R	7.8	7.7	5.7	4.7	4.3
DLF-PR-3735	8.2	7.9	5.7	5.1	4.8
**Homerun LS	8.2	7.9	5.7	4.8	4.4
**Linn	7.3	7.4	5.7	4.3	4.0
PST-2GDS	8.2	7.4	5.6	4.7	4.2
BAR LP 22262	7.2	7.6	5.6	4.9	4.4
PVF-RPP2	7.7	7.9	5.6	5.0	4.7
MRSL-PR22	7.5	7.4	5.4	4.2	4.0
20PR10	8.0	8.2	5.4	4.8	4.3
PST-2E6	8.0	8.0	5.4	4.4	4.2
BSG-PR22	8.0	7.8	5.4	4.7	4.2
PPG-PR 620	8.2	7.6	5.3	4.3	3.9
TSC-CR5	7.8	7.7	5.3	4.3	3.8
Mean	8.0	8.0	5.9	5.1	4.7
LSD	0.6	0.6	0.5	0.7	0.6

Control group was used as the covariate in statistical analysis, so it is not shown in the table.
*Commercially available entries
**Standard entries

Table 2.5. Clipping Yield Reduction Percentage (relative to control) of 83 perennial ryegrasses under different salinity levels (%) in Exp. II.					
Entry	6 dS·m^{-1}	12 dS·m^{-1}	18 dS·m^{-1}	22 dS·m^{-1}	EC^{Y}
SGP4	13.9	20.3	14.4	78.5	10.7
PPG-PR 667	1.4	18.3	23.6	83.4	9.9
PPG-PR 639	9.5	32.6	18.4	78.8	9.8
PPG-PR 671	3.2	9.2	21.3	94.2	9.6
PPG-PR 611	19.6	2.7	28.8	94.2	9.0
PR5	0.7	18.4	40.7	81.1	9.0
GO-RUS20	11.3	40.3	14.9	88.0	9.0
PVF-SGS5	-1.1	2.7	38.3	94.3	8.8
GO-RUS21	1.6	13.3	45.4	82.5	8.8
SE-DK	9.6	8.5	33.0	93.6	8.8
PS4	10.4	21.8	32.4	87.9	8.7
*Piston	7.5	25.1	32.2	87.5	8.7
*Dark Matter	20.2	6.3	50.9	80.1	8.6
BSG-PR22	15.2	15.5	39.4	86.5	8.6
BAR LP 22262	19.1	29.2	44.1	75.8	8.4
LTP-NR	-1.8	29.2	30.3	93.7	8.4
PPG-PR 658	9.9	28.9	44.5	80.5	8.3
PST-2HFM	6.1	27.2	38.8	87.2	8.3
PPG-PR 661	18.6	20.5	42.9	84.3	8.3
PPG-PR 668	-4.7	24.4	46.5	85.7	8.3
*Alpha Centauri	27.1	30.6	32.2	86.8	8.2
DLF-PR-3728	9.3	32.8	43.2	81.5	8.2
PPG-PR 610	4.4	23.8	36.4	93.7	8.2
DLF-PR-3726	-1.6	25.1	41.9	90.2	8.2
PPG-PR 642	0.4	52.3	27.7	87.2	8.1
DLF-PR-3730	1.7	28.2	38.5	91.8	8.1
PST-2MES1	5.1	37.0	39.2	86.0	8.0
PPG-PR 606	4.3	36.1	46.5	80.9	8.0
PPG-PR 666	19.6	21.0	41.5	89.2	8.0
**Stellar 4GL	9.4	15.0	43.8	93.5	8.0
*Siletz	8.8	34.2	32.5	92.9	8.0
PST-2GDS	16.1	35.8	28.5	93.3	8.0
DLF-PR-3738	22.0	24.4	28.7	97.8	8.0
DLF-PR-3729	10.2	18.4	42.5	93.2	8.0
PST-2EGY	11.6	27.7	47.3	84.8	7.9
APS	7.6	8.5	51.7	94.1	7.8
PPG-PR 663	-5.3	11.9	49.9	97.3	7.8
PPG-PR 646	15.1	19.7	48.8	89.0	7.8
PPG-PR 670	0.6	32.8	46.3	89.9	7.7
*Greenback	-9.1	32.2	46.9	92.9	7.7
PPG-PR 602	-3.3	28.2	45.6	94.9	7.7
RPP3	6.3	48.4	42.5	84.0	7.6

BAR LP 22256	11.0	38.9	44.2	87.0	7.6
BAR LP 22191	-8.0	12.0	64.0	90.7	7.6
PPG-PR 637	-0.1	35.2	49.2	88.4	7.6
DLF-PR-3727	24.0	44.0	40.8	84.5	7.6
PPG-PR 647	16.7	37.8	43.7	87.8	7.5
PPG-PR 643	-5.3	25.2	51.6	94.6	7.5
PST-2ADS	3.0	2.2	67.3	92.0	7.5
TSC-CR5	21.6	27.8	49.6	88.3	7.5
*High Octane	9.9	29.2	58.3	83.8	7.5
MRSL-PR22	15.1	16.5	50.0	96.1	7.5
RC20-020	7.9	2.2	60.8	97.3	7.5
PST-214	10.7	22.0	56.4	90.2	7.4
PPG-PR 665	0.9	46.5	52.9	83.8	7.4
DLF-LGT-3066	12.6	38.9	50.0	87.1	7.4
PPG-PR 664	5.1	46.5	45.4	89.3	7.3
*Quasar	22.0	43.1	42.8	88.9	7.3
DLF-PR-3736	23.5	38.3	41.5	92.2	7.3
PPG-PR 662	18.6	42.3	49.8	86.7	7.2
**Brightstar SLT	5.2	19.6	65.6	92.0	7.1
DLF-PR-3737	3.9	24.0	56.4	97.6	7.1
PPG-PR 620	21.8	42.1	42.5	94.6	7.1
PST-2HAF20	0.0	55.1	54.6	87.2	6.9
BY-PS2	2.7	8.3	70.5	99.0	6.9
PPG-PR 644	18.1	52.5	44.3	93.9	6.9
20PR10	6.8	28.9	58.9	98.1	6.8
SEPR-2013	19.7	21.4	65.7	94.0	6.8
PVF-RPP2	-0.4	33.6	63.1	95.9	6.8
PST-2E6	9.9	41.5	54.1	96.6	6.8
PST-2MEG	10.7	38.5	60.5	94.4	6.7
PST-2BGL	22.2	36.0	53.5	98.6	6.7
DLF-PR-3735	30.1	43.9	48.8	96.9	6.6
PST-2SPF	20.7	28.8	66.2	94.5	6.6
**Homerun LS	3.2	29.1	71.4	97.4	6.5
LTP-RPP4	20.2	33.5	63.5	96.9	6.5
**Linn	6.4	15.6	79.3	97.7	6.5
BAR LP 22263	22.1	32.8	69.7	93.9	6.4
CJP1R	16.8	44.5	69.8	90.0	6.4
**Karma	19.0	32.0	72.9	94.3	6.4
BAR LP 22174	21.3	31.2	74.6	94.2	6.3
GO-RUS22	8.5	52.0	78.1	97.5	5.8
PST-2DRG	22.6	53.7	76.5	99.0	5.7
Mean	10.0	28.5	47.7	90.4	7.7
LSD	24.0	39.9	36.0	16.0	

[Y]Salinity level (EC) cause 25% reduction.

*Commercially available entries

**Standard entries

Table 2.6. Turfgrass quality (scale of 1 to 9, with 9 = ''best'') of 83 perennial ryegrasses under different salinity levels of Exp. II. A rating of "6" indicates minimum acceptable quality.

Entry#	6 $dS{\cdot}m^{-1}$	12 $dS{\cdot}m^{-1}$	18 $dS{\cdot}m^{-1}$	22 $dS{\cdot}m^{-1}$	EC^{Y}
BAR LP 22262	9.0	6.7	4.6	4.0	14.7
DLF-PR-3727	9.0	6.7	4.8	3.8	14.7
PPG-PR 639	9.0	7.0	5.0	3.2	14.7
*Alpha Centauri	9.0	6.8	5.0	3.2	14.5
SGP4	9.0	7.0	5.0	3.0	14.5
PPG-PR 664	9.0	7.2	4.9	2.9	14.5
PPG-PR 658	9.0	6.8	4.6	3.2	14.2
BSG-PR22	9.0	7.0	5.0	2.4	14.1
PST-2HFM	9.0	6.8	4.6	3.0	14.1
PPG-PR 661	9.0	6.8	4.3	3.2	14.1
PST-2MES1	9.0	6.5	4.3	3.4	14.0
PPG-PR 644	9.0	6.7	4.7	2.9	14.0
PST-2SPF	9.0	6.7	4.8	2.7	13.9
PPG-PR 637	9.0	6.7	4.6	2.9	13.9
PPG-PR 611	9.0	6.8	4.6	2.7	13.9
DLF-PR-3726	9.0	6.5	4.4	3.1	13.9
*Siletz	9.0	6.5	4.6	2.9	13.8
BAR LP 22256	9.0	6.5	4.4	3.0	13.8
PPG-PR 667	9.0	6.8	4.4	2.6	13.8
APS	9.0	6.7	4.2	3.0	13.8
PPG-PR 602	9.0	6.5	4.6	2.8	13.7
PPG-PR 606	9.0	6.5	4.2	3.1	13.7
SE-DK	9.0	6.7	4.3	2.8	13.7
**Brightstar SLT	9.0	6.7	4.3	2.8	13.7
PPG-PR 610	9.0	6.8	4.3	2.6	13.7
*Piston	9.0	6.7	4.4	2.6	13.7
PPG-PR 642	9.0	6.5	4.3	2.9	13.7
PS4	9.0	6.8	4.3	2.4	13.7
RC20-020	9.0	6.8	4.4	2.2	13.6
**Stellar 4GL	9.0	6.7	4.2	2.7	13.6
PPG-PR 665	9.0	6.5	4.4	2.6	13.6
DLF-LGT-3066	9.0	6.3	4.2	3.0	13.5
GO-RUS20	9.0	6.5	4.4	2.4	13.5
DLF-PR-3738	9.0	6.5	4.4	2.4	13.5
LTP-NR	9.0	6.8	4.2	2.2	13.5
GO-RUS21	9.0	6.7	4.1	2.6	13.5
DLF-PR-3728	9.0	6.7	4.1	2.6	13.5
*Greenback	9.0	6.8	4.1	2.2	13.4
PST-214	9.0	7.0	4.0	2.1	13.4
PVF-SGS5	9.0	6.5	4.1	2.7	13.4
BY-PS2	9.0	6.8	4.0	2.3	13.4
PST-2EGY	9.0	6.7	4.2	2.2	13.4
DLF-PR-3729	9.0	6.7	4.0	2.4	13.4

PPG-PR 663	9.0	6.7	4.3	2.0	13.3
MRSL-PR22	9.0	6.7	4.2	2.1	13.3
PST-2MEG	9.0	6.3	4.2	2.6	13.3
PPG-PR 620	9.0	6.3	4.1	2.7	13.3
Dark Matter	9.0	6.7	3.9	2.4	13.3
PST-2BGL	9.0	6.7	4.1	2.1	13.3
DLF-PR-3730	9.0	6.5	4.1	2.3	13.3
PPG-PR 643	9.0	6.7	4.0	2.2	13.3
BAR LP 22191	9.0	6.8	4.4	1.4	13.3
DLF-PR-3736	8.7	6.5	4.0	2.9	13.2
PPG-PR 670	9.0	6.5	3.8	2.6	13.2
PST-2HAF20	9.0	6.3	3.8	2.8	13.2
PPG-PR 666	9.0	6.5	4.1	2.1	13.2
DLF-PR-3735	9.0	6.5	3.8	2.4	13.1
PPG-PR 668	9.0	6.3	3.8	2.7	13.1
GO-RUS22	9.0	6.8	3.4	2.2	13.1
BAR LP 22263	9.0	6.5	3.7	2.4	13.1
*High Octane	9.0	6.3	3.7	2.7	13.1
PST-2ADS	9.0	6.2	3.8	2.8	13.1
TSC-CR5	9.0	6.5	3.6	2.4	13.1
RPP3	9.0	6.5	3.9	2.1	13.0
*Quasar	8.7	6.5	4.0	2.6	13.0
PR5	9.0	6.2	3.9	2.6	13.0
SEPR-2013	9.0	6.5	3.9	1.9	13.0
PPG-PR 646	8.7	6.3	4.4	2.1	13.0
DLF-PR-3737	9.0	6.5	3.9	1.8	12.9
PVF-RPP2	9.0	6.8	3.7	1.4	12.9
PPG-PR 647	9.0	6.3	3.4	2.4	12.9
PST-2GDS	9.0	6.3	3.6	2.2	12.8
PPG-PR 671	9.0	6.2	3.6	2.4	12.8
PST-2DRG	9.0	6.7	3.4	1.7	12.8
20PR10	9.0	6.5	3.7	1.7	12.8
BAR LP 22174	9.0	6.3	3.8	1.7	12.7
**Karma	9.0	6.5	3.3	1.7	12.6
PPG-PR 662	9.0	6.3	3.1	2.1	12.6
CJP1R	9.0	6.5	3.0	1.4	12.4
PST-2E6	8.7	6.3	3.7	1.6	12.4
LTP-RPP4	9.0	6.2	3.0	1.7	12.3
**Homerun LS	9.0	6.0	3.2	1.7	12.3
**Linn	9.0	6.0	3.1	1.3	12.1
Mean	9.0	6.6	4.1	2.5	13.6
LSD	0.2	0.8	1.0	0.9	

Control group was used as the covariate in statistical analysis, so it is not shown in the table.
[Y]Salinity level (EC) maintain acceptable quality.
*Commercially available entries
**Standard entries

Table 2.7. Leaf Firing Percentage of 83 perennial ryegrass under different salinity levels (%) in Exp. II.

Entry	6 dS·m^{-1}	12 dS·m^{-1}	18 dS·m^{-1}	22 dS·m^{-1}
SGP4	0	0.8	26.0	66.7
*Alpha Centauri	0	1.3	26.4	55.3
DLF-PR-3726	0	2.3	30.9	69.7
PPG-PR 602	0	2.7	31.3	77.0
PST-2SPF	0	2.3	31.4	78.2
DLF-PR-3727	0	2.0	32.1	52.0
BSG-PR22	0	1.3	32.4	74.8
PPG-PR 611	0	3.3	33.9	75.3
*Piston	0	1.5	34.7	78.6
PPG-PR 637	0	2.5	34.9	69.1
PPG-PR 664	0	1.5	34.9	65.1
PPG-PR 639	0	2.2	35.4	64.3
DLF-PR-3738	0	2.8	35.8	78.1
PPG-PR 644	0	2.7	36.0	70.2
*Siletz	0	2.8	36.4	64.3
BAR LP 22256	0	2.3	37.0	65.9
APS	0	1.7	37.4	72.1
SE-DK	0	1.7	37.6	80.8
PS4	0	2.3	37.7	76.6
GO-RUS20	0	2.8	38.0	72.4
PPG-PR 658	0	2.0	38.8	63.9
BAR LP 22262	0	2.8	39.1	46.8
PST-2HFM	0	2.2	39.6	74.2
PPG-PR 667	0	2.2	39.7	72.8
**Stellar 4GL	0	2.2	39.7	75.4
MRSL-PR22	0	1.7	40.8	79.2
PPG-PR 610	0	2.3	40.9	75.8
PPG-PR 620	0	3.2	41.2	76.9
PPG-PR 646	0	5.5	41.3	84.8
DLF-PR-3736	0	10.2	41.6	73.4
**Brightstar SLT	0	2.2	41.8	71.4
PPG-PR 663	0	3.0	41.9	89.0
PST-2MES1	0	4.2	42.4	61.0
BAR LP 22191	0	0.8	43.1	93.9
PVF-SGS5	0	1.7	43.6	79.3
LTP-NR	0	3.5	44.6	88.9
DLF-PR-3730	0	2.2	44.8	83.9
RC20-020	0	2.8	45.2	84.8
DLF-LGT-3066	0	6.3	45.4	71.3
PST-2MEG	0	2.3	46.2	78.7
DLF-PR-3737	0	2.7	46.9	90.0
*Dark Matter	0	3.0	47.0	75.9

PST-2EGY	0	1.8	47.1	87.0
BY-PS2	0	2.5	47.2	79.6
PST-214	0	2.3	47.3	85.3
PPG-PR 661	0	2.8	48.3	75.3
PPG-PR 665	0	2.0	50.1	77.0
GO-RUS21	0	3.0	50.3	79.4
PPG-PR 642	0	2.2	50.3	68.3
PPG-PR 606	0	7.0	50.6	66.4
*Greenback	0	3.2	51.1	85.3
PST-2BGL	0	8.8	51.3	87.0
PST-2HAF20	0	7.0	51.3	70.4
DLF-PR-3729	0	3.2	51.3	87.2
RPP3	0	2.5	51.4	87.8
TSC-CR5	0	5.8	51.7	74.3
PPG-PR 643	0	2.8	52.0	81.6
PST-2ADS	0	6.0	52.8	71.4
SEPR-2013	0	2.8	53.1	88.7
BAR LP 22174	0	4.0	53.3	93.6
PR5	0	4.5	53.8	79.4
PST-2E6	0	3.2	53.9	97.2
PPG-PR 666	0	4.5	54.3	87.6
*Quasar	0	2.7	54.7	77.8
PPG-PR 647	0	2.5	56.0	81.6
PPG-PR 671	0	4.5	56.2	80.0
DLF-PR-3735	0	3.5	56.2	81.1
DLF-PR-3728	0	2.7	56.3	75.9
PVF-RPP2	0	4.0	59.0	94.6
BAR LP 22263	0	3.5	59.9	89.1
*High Octane	0	3.8	60.3	73.2
PST-2DRG	0	4.2	62.3	98.2
PPG-PR 668	0	11.2	62.6	73.9
20PR10	0	4.5	65.6	91.4
**Karma	0	1.7	65.6	97.4
**Linn	0	8.7	66.3	99.2
PPG-PR 670	0	3.5	66.4	77.1
PST-2GDS	0	2.8	67.7	88.8
CJP1R	0	2.5	68.2	98.2
LTP-RPP4	0	10.3	69.6	91.1
PPG-PR 662	0	8.7	69.8	84.6
**Homerun LS	0	6.3	70.7	96.9
GO-RUS22	0	5.7	70.8	89.4
Mean	0	3.5	47.6	78.9
LSD		7.0	20.5	20.8

Control group was used as the covariate in statistical analysis, so it is not shown in the table.
*Commercially available entries
**Standard entries

Table 2.8. Turfgrass density (scale of 1 to 9, with 9 = ‘‘best’’) of 83 perennial ryegrasses under different salinity levels in Exp. II.

Entry	6 $dS \cdot m^{-1}$	12 $dS \cdot m^{-1}$	18 $dS \cdot m^{-1}$	22 $dS \cdot m^{-1}$
PPG-PR 664	9.0	7.2	5.3	4.3
PPG-PR 639	7.7	7.0	5.2	4.7
PPG-PR 667	8.0	7.2	5.2	4.7
**Brightstar SLT	8.7	7.2	5.2	4.3
DLF-PR-3727	8.7	7.2	5.2	4.8
DLF-PR-3737	8.7	7.2	5.2	4.4
PPG-PR 610	8.3	7.5	5.1	4.4
PPG-PR 644	8.7	7.0	5.1	4.6
PPG-PR 658	8.7	7.3	5.1	4.7
PPG-PR 665	8.7	7.3	5.1	4.8
SGP4	8.7	7.3	5.1	4.7
RC20-020	8.3	6.8	5.0	4.3
GO-RUS20	8.7	7.0	5.0	4.7
GO-RUS21	8.0	6.8	5.0	4.3
PST-2ADS	9.0	7.2	5.0	4.4
PST-2SPF	8.0	6.8	5.0	4.2
PPG-PR 611	8.7	7.2	5.0	4.8
PPG-PR 620	8.7	7.0	5.0	4.4
PPG-PR 646	8.3	6.8	5.0	4.4
PPG-PR 661	8.3	7.2	5.0	4.4
*Piston	8.0	7.0	5.0	4.1
PST-2HFM	8.0	6.8	4.9	4.7
PPG-PR 637	8.0	7.3	4.9	4.4
*Greenback	9.0	7.3	4.9	4.1
PPG-PR 643	8.0	6.8	4.9	4.8
PPG-PR 647	8.3	7.2	4.9	4.7
PVF-SGS5	8.3	6.8	4.9	4.6
BAR LP 22174	8.3	7.0	4.9	4.3
RPP3	8.3	7.0	4.9	4.3
SEPR-2013	8.0	7.0	4.9	4.4
*Siletz	8.3	7.2	4.9	4.3
PST-2BGL	8.0	7.2	4.8	4.6
PPG-PR 602	8.3	7.3	4.8	4.7
BY-PS2	8.0	7.0	4.8	4.2
20PR10	8.7	7.0	4.8	4.1
BAR LP 22256	9.0	7.0	4.8	4.6
PVF-RPP2	7.7	6.8	4.8	4.1
PR5	8.3	6.8	4.8	4.3
*Dark Matter	8.3	7.2	4.8	4.1
DLF-PR-3726	8.3	7.0	4.8	4.2
DLF-PR-3728	8.0	7.2	4.8	4.2
DLF-PR-3735	8.3	7.2	4.8	4.4

*Alpha Centauri	8.0	6.8	4.8	4.4
**Homerun LS	8.3	6.8	4.8	4.3
DLF-PR-3738	8.0	7.0	4.8	4.3
PST-214	9.0	7.0	4.7	4.0
PST-2MES1	8.0	7.2	4.7	4.6
PPG-PR 666	8.3	6.8	4.7	4.7
LTP-NR	8.3	7.0	4.7	4.2
BAR LP 22191	8.7	7.0	4.7	4.1
TSC-CR5	8.7	7.0	4.7	4.6
PST-2MEG	8.0	6.8	4.7	4.3
DLF-PR-3729	9.0	7.2	4.7	4.2
DLF-PR-3730	8.0	6.8	4.7	4.3
*Quasar	8.0	6.8	4.7	4.2
GO-RUS22	8.3	6.8	4.6	4.2
PST-2EGY	8.3	7.0	4.6	4.2
PPG-PR 606	8.0	6.8	4.6	4.3
PPG-PR 642	8.7	7.0	4.6	4.3
PPG-PR 663	8.0	6.8	4.6	4.0
PPG-PR 668	8.7	7.2	4.6	4.7
*High Octane	8.0	7.0	4.6	4.0
PS4	8.3	7.2	4.6	4.7
BAR LP 22263	8.3	7.2	4.6	4.2
SE-DK	8.3	6.7	4.6	4.3
PST-2E6	8.0	7.2	4.6	4.3
APS	8.0	6.8	4.6	4.4
BSG-PR22	7.7	6.8	4.6	4.0
**Stellar 4GL	7.7	6.8	4.6	4.3
DLF-LGT-3066	8.3	6.8	4.6	4.1
PST-2DRG	8.7	7.0	4.4	3.9
PST-2GDS	8.3	6.8	4.4	4.1
PST-2HAF20	7.7	6.8	4.4	4.3
LTP-RPP4	8.3	6.8	4.4	4.1
PPG-PR 671	8.0	6.8	4.4	4.4
CJP1R	8.3	6.7	4.4	3.6
DLF-PR-3736	8.0	6.8	4.4	4.3
**Karma	8.7	7.0	4.4	3.9
PPG-PR 662	7.7	6.8	4.3	4.4
PPG-PR 670	8.0	7.0	4.3	4.3
MRSL-PR22	8.3	6.5	4.3	4.0
BAR LP 22262	7.3	6.8	4.3	4.3
**Linn	8.7	6.7	4.1	3.7
Mean	8.3	7.0	4.8	4.3
LSD	1.3	0.8	0.7	0.5

Control group was used as the covariate in statistical analysis, so it is not shown in the table.
*Commercially available entries
**Standard entries

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