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THE RESPONSE OF BERMUDAGRASSES [Cynodon dactylon (L.) Pers. x C. transvaalensis Burtt-Davy] AND CREEPING BENTGRASS [Agrostis Stoloniferi (L.)] TO A COMMERCIAL HUMECTANT AND WETTING AGENTS DURING SUMMER

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THE RESPONSE OF BERMUDAGRASSES [*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy] AND CREEPING BENTGRASS [*Agrostis stolonifera* (L.)] TO A COMMERCIAL HUMECTANT AND WETTING AGENTS DURING SUMMER

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ABSTRACT

Four field studies, one laboratory and one greenhouse study were conducted from April 2011 through August 2011 at Clemson University in Clemson, SC on 'L-93'creeping bentgrass (*Agrostis stolonifera* L.), 'Tifeagle' bermudagrass (*Cynodon dactylon* (L.) Pers. X C. *transvaalensis* Burtt-Davy), and a combination of 'Tifway' (*Cynodon dactylon* (L.) Pers. X C. *transvaalensis* Burtt-Davy) and common bermudagrass (*Cynodon dactylon* (L.)

The objectives of this research were: (i) evaluate bentgrass response to two irrigation regimes, light and frequent irrigation (replacing daily ET), verses deep and infrequent irrigation (watering at the sign of wilt); (ii) evaluate the combination of a humectant and a soil wetting agent under these two irrigation regimes; (iii) evaluate the efficacy of a humectant, various wetting agents and a fungicide on bermudagrass infected with fairy ring (*Lycopedon* spp.); (iv) evaluate a humectant and various wetting agents on localized dry spots (LDS) on a 'TifEagle' bermudagrass putting green; (v) evaluate a humectant and various wetting agents on non-irrigated common and 'Tifway' bermudagrass blend in a sports field; (vi) assess the changes in volumetric water content (VWC) of a soil treated with different water sources, a humectant and a wetting agent; and (vii) assess the fluctuations of volumetric water content over a 7 day period under two relative humidity levels.

The humectant, Hydretain ES Plus; two wetting agents, Cascade Plus and Primer Select; and Primer Select + the commercial fungicide, Prostar (flutolanil), were used during these studies. All field treatments were applied according to the label rate and plots were irrigated prior to application at 2.54 mm (0.10 inches) and following application at 6.35 mm (0.25 inches) to provide uniform soil moisture, except for the non-irrigated study.

All treatments provided a normal electrical conductivity (EC) of 0.01 dS/m for the bentgrass irrigation regimes. Also, the light and frequent irrigation (LF) plots had the highest EC while the dielectric constant increased by 6v (volts) throughout each study. Turf quality and turf color provided acceptable visual quality and color of ≥7, but did not differ from the control. Phytotoxicity provided a rating of >40% and suggests there was significant chemical burn. At 14 DAT, Cascade held the most moisture in the upper 0-5.7 cm rootzone at 30%. Cascade provided a 20% increase on the upper rootzone moisture verses the other treatments. Soil temperatures were maintained around 35°C for all studies on the bentgrass. All root diameter measurements provided a slight decrease from the beginning to the end from approximately 0.22 to 0.19 cm. Root length increased from 397 cm to 591 from the first sampling to 35 DAT, respectively. However, root length decreased from 35 to 42 DAT from 591 cm to 444 cm, respectively, Root volume also provided a similar trend decreasing after 35 DAT.

Localized dry spot and fairy ring treatments provided a wettable (water penetrating the soil in <5 seconds) to slightly wettable soil and all treatments, including the check plots passed the water droplet penetration test (WDPT) for hydrophobicity. The non- irrigated study provided no differences among treatments or treatment ratings.

However, Cascade provided the highest volumetric water content in the non-irrigated field study. Cascade also provided the highest volumetric water content in the greenhouse and laboratory studies with < 20% (20 g/cm^{-3}).

DEDICATION

I dedicate this thesis to my parents, Gil and Sandra Landry. Their love, patience, faith and understanding are my unlimited inspiration. They have been pillars of support throughout this entire journey. I also share this dedication to the "village" families (Murphys, Johnsons, and Raymers) in Griffin, GA; for their help, support, motivation and honesty.

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CHAPTER ONE

INTRODUCTION

Humectants and Wetting Agents

Growing populations throughout the world have created significant concerns regarding our future water supply. The book “Seashore Paspalum: the Environmental Turfgrass,” begins by stating the two domineering factors affecting turfgrass management in the twenty-first century will be water quality and water quantity/conservation (Duncan and Carrow, 2000). Turfgrasses provide many aesthetic and economically stimulating effects in areas throughout the world; most commonly for golf courses, athletic fields, and landscapes (McCarty 2011). Waltz (2003), similarly stated water quality and quantity are two of many factors turf managers often combat in order to maintain high quality turf areas. Therefore, proper water management is a major parameter in maintaining these surfaces.

These types of issues have increased interest in the use of various absorbent materials and humectants for agriculture, including turfgrass management. "Superabsorbers" have been used more recently throughout Germany as a possible approach to water conservation on golf courses and sports pitches due to irrigation restrictions (Paebens 2010). Mitra (2010) also reported that water shortage was becoming a major limiting factor in maintaining high quality turf areas (i.e. golf courses and athletic fields) worldwide. One possible means of maximizing the efficiency of water applied in turfgrass is utilizing artificial water retention materials. Water absorbent materials have become more prevalent in horticulture as efforts increase to conserve water while avoiding water stress. A “humectant” is a substance that promotes moisture retention (Merriam-Webster.com 2011) thus Hydretain® is defined by the manufacturer as a humectant due to its properties that aid in soil water retention.

Hydretain® ES Plus is a commercial “absorbent” that contains 54% humectants (sugar alcohols, polysaccharides and neutral salts of alpha-hydroxypropionic acid), 10% nonionic surfactants (NIS), and 36% inert ingredients (Ecologel, USA 2008). Based on previous greenhouse horticultural experiments, Ecologel Solutions (2008) describes Hydretain as a liquid blend of hygroscopic and humectant compounds designed to manage soil moisture between irrigation or rainfall events. It is stated to aid in seed germination, the elimination of dry spots and to reduce watering on greens and fairways.

Hydretain is also stated to aid in water uptake by plants and to decrease wilting in different crops (Ciardi et al., 1998). In a field transplant study, Ciardi et al. (1998) investigated Hydretain to increase establishment of tomato (*Lycopersicon esculentum* Mill.). Roots were soaked prior to transplant with Hydretain consisting of 35% hydrogenated simple sugars, 1.5% calcium lignosulfate, and 63% inert ingredients applied at a concentration of 7% Hydretain. Plants treated with Hydretain had 54% increased yield compared to the control in the first year with a rainfall of 6.4 cm. The second year with rainfall increasing to 24 cm, yield was not improved. Thus, Hydretain was reported to increase yield by water uptake during more arid conditions. With growing concerns about limited water quality and quantity, the objectives of this research were to:

(i) evaluate two irrigation regimes using a humectant, and a commercial wetting agent on a creeping bentgrass (*Agrostis stolonifera* L.) putting green; (ii) evaluate the efficacy of a humectant and various wetting agents and a fungicide on ‘TifEagle’ bermudagrass (*Cynodon dactylon)* (L.) Pers. X C. *transvaalensis* Burtt-Davy) as a control for fairy ring (*Lycoperdon* spp.); (iii) evaluate a humectant and various wetting agents on localized dry spots (LDS) on a TifEagle’ bermudagrass (*Cynodon dactylon)* (L.) Pers. X C. *transvaalensis* Burtt-Davy) putting green; and (iv) evaluate a humectant and various wetting agents on a non-irrigated common (*Cynodon dactylon* L.) and a ‘Tifway’(*Cynodon dactylon)* (L.) Pers. X C. *transvaalensis* Burtt-Davy) bermudagrass blend sports field at Clemson University.

Water Usage

Water conservation and drought continue to be one concern throughout the turfgrass industry, thus, turfgrass professionals should be aware of turf water use rates (WUR’s). Although water use rates vary for different turfgrass species and cultivars within a species, there has been significant research conducted on pinpointing exact water usage rates. The WUR of a turfgrass is defined as the total amount of water necessary for turfgrass growth and the quantity lost by evapotranspiration (ET) from the soil and plant surfaces (McGroary et al., 2011). However, many factors influence turfgrass ET rates such as: major climatic factors, (notably: wind speed, solar radiation, atmospheric vapor pressure, humidity, and temperature), and plant morphological and anatomical features. Previous research has shown various irrigation techniques, the water penetration droplet test, various equations and calculations (i.e. The modified Penman equation), soil sampling, and soil moisture probes to be effective when measuring ET, WUR's, and soil moisture (Fu, 2009; Karnok, 1989; McGroary, 2011; Waltz, 2001).

Irrigation Practices

Creeping bentgrass (*Agrostis stolonifera* L.) is a widely grown cool-season turfgrass species on golf greens in the mid-Atlantic region of the United States (Fu and Dernoenden 2009). Although bentgrass exhibits heat stress issues in summer months, it has become popular throughout the lower-Atlantic region due to a superior playing surface and year round green color.

Fu and Dernoenden (2009) stated irrigation management was directly related to root growth and longevity, therefore, root production and growth are essential components required for plant adaptation to environmental stresses. Light and frequent (LF) and deep and infrequent (DI) irrigation practices are often used in turfgrass management, especially among golf course managers. Light and frequent (LF) irrigation requires water to be applied prior to wilt, and as frequent as needed to maintain soil moisture at or close to field capacity. Deep and infrequent (DI) irrigation requires water to be applied at the first signs of leaf wilt to replenish the entire rootzone (Fu and Dernoeden 2009).

These two irrigation regimes are typically recommended for cool-season turfgrass species under summer stress, thus, Fu and Dernoeden (2009) conducted a field study on the effects of LF vs. DI irrigation regimes in relation to rooting development and longevity in creeping bentgrass under summer temperatures. The LF plots were irrigated daily to maintain field capacity (replaced daily ET loss) in the top 4 to 6 cm of the soil profile. The DI plots were irrigated to a depth of ≥24 cm at initial signs of leaf wilt. The DI irrigation regimes demonstrated greater total root count (TRC), longer total root length (TRL), and a larger total root surface area (TRSA), compared to the LF irrigation regime. Average root diameter of the DI irrigated plots decreased in the second year of the study. In September of the second summer, average root diameter decreased by 32% in the DI irrigated plots compared to the first summer. However, DI irrigation stimulated root growth throughout a 24 cm rootzone in May and June and supported root longevity throughout summer months (Fu and Dernoeden, 2009).

Soil moisture and temperature were also observed in both experimental years. DI irrigated plots provided an average soil moisture of 10% in the 0-15 cm rootzone. LF irrigated plots provided an average soil moisture of 19% in the 0 to 6.5 cm rootzone for both years. In the 0 to 15 cm rootzone the DI irrigated plots maintained lower soil moisture than the LF irrigated plots in both years suggesting the turf was removing water from this depth.

Minimal soil temperature differences occurred between irrigation regimes throughout both years. LF irrigated creeping bentgrass had a maximum temperature of 31°C where the DI irrigated creeping bentgrass provided nearly the same temperature of 31.5°C (Fu and Dernoeden 2009).

Water Repellency

Some soils can become water repellent or hydrophobic over time. These conditions occur primarily in the top 5 cm (2 in) of sandy soils and are caused by different sources. The waxy compound on the leaf surface and cuticle layer of turfgrass serves as a guard against penetration by insects and fungi, however, the waxy compound can be dislodged by rainfall and irrigation (Samples 2011). Due to waxes from the cuticle dislodging, soil pores become clogged, thus reducing the rate of infiltration and percolation of a soil. Infiltration and percolation can also be affected by decomposition of clippings and roots as the organic films from this can coat sand particles, causing hydrophobicity (Samples 2011).

Hydrophobins are produced by algae and contribute to water repellency as they develop around advancing tips of fungi strands (hyphae) during movement through soil. Several species of fungi, including basidiomycetes that cause fairy ring, are associated with soil hydrophobicity in sandy soils. In addition, sorgoleone, a water-repellent compound, which is produced by turfgrass roots, can be absorbed by soil particles causing them to repel water or become hydrophobic (Samples 2011).

Localized Dry Spot (LDS) appears as an irregular area of turfgrass showing visual signs of drought stress. Karnok (2001) notes many causes of LDS, such as thatch/mat buildup, soil compaction, hydrophobic soils and various fungi species, especially those of fairy ring.

Beard (1973) defines a wetting agent as a type of surfactant that increases the ability of water to moisten a solid substance such as soil. A wetting agent lowers surface tension of water, improving the wetting ability of the soil surface. Although wetting agents are not fully understood and remain fairly complex, they are used as a cultivation practice under drought stress situations, such as localized dry spots (LDS).

Soil Surfactants

A surfactant is primarily used on substances not having affinity for each other (such as water and leaf wax) thus, the tendency to repel increases (McCarty 2011). Increasing "binding" characteristics of two surfaces requires a lipophilic ("water hating") portion and a hydrophilic ("water loving") portion on the same molecule. Water droplets then spread out and contact a larger area of the leaf, aiding in penetration. The same principle applies to soil particles and the ability for water to penetrate the surface. In an ornamental container study, Leinauer (2001) screened two soil surfactants on water retention at various depths and concluded the commercial product, Primer 604, provided greater water content compared to the control and an additional surfactant. Greatest water retention from Primer 604 was found at depths of 150 mm (5.9 in) and 250 mm (9.8 in) in sand sampled from August to November. Soil water content at the 150 mm depth ranged from 12.9 kg kg^{-1} to 14.6 kg kg^{-1} in treated soil compared to 8.9 kg kg^{-1} and 12.5 kg kg^{-1} for untreated soil. Similarly soil water content in treated soil at 250 mm ranged from 22.0 kg kg^{-1} to 25.5 kg kg^{-1} compared to 14.6 kg kg^{-1} and 19.4 kg kg^{-1} for untreated soil. The 50 mm (1.96 in) depths provided the lowest water content from 7.9 kg kg^{-1} to 10.7 kg kg^{-1} in treated soil compared to 6.4 kg kg^{-1} and 10.3 kg kg^{-1} for untreated soil.

Cascade Plus (Precision Laboratories, Inc. Waukegan, IL) and Primer Select (Aquatrols, Paulsboro, NJ) are soil wetting agents commonly used to treat LDS. Cascade Plus is a non-ionic surfactant (NIS) which helps penetrate water through the soil to provide a more uniform infiltration rate (Karcher 2009). In a study screening various wetting agents including Cascade Plus, Karcher (2008) evaluated LDS and soil moisture characteristics. A range of irrigation regimes were applied from May through July following treatments to compare the wetting agents under different irrigation regimes. Volumetric soil moisture was evaluated at three sampling depths of 76, 127, and 203 mm (3, 5 and 8 in.) within each plot with time domain reflectrometry probes. Cascade Plus maintained LDS < 25% soil moisture from May through July. However, these treatments had an increase in LDS in the last two weeks of the study, possibly due to only one application in May, whereas the other treatments were applied in May, June and July.

CHAPTER TWO

CREEPING BENTGRASS [*Agrostis Stolonifera (L.*)] RESPONSE TO A HUMECTANT AND A COMMERCIAL WETTING AGENT UNDER TWO IRRIGATION REGIMES DURING THE SUMMER

Introduction

Maximizing irrigation efficiency and minimizing water used to irrigate turfgrass is desirable for many reasons. Water conservation is of high importance as energy cost, turf health and quality are among a few irrigation issues and efficacy is dependent on irrigation systems distribution uniformity (DU), irrigation scheduling, and the ability of soils to absorb and retain and release water for use by plants (Moore et al., 2010). Soil surfactants are then used to alleviate the soil water repellency and other issues that can cause inefficient water movement through the soil. In this experiment, a humectant and a wetting agent were evaluated under two irrigation regimes tested. The objectives of this study were to (i) evaluate bentgrass response to two irrigation regimes, light and frequent irrigation (replacing daily ET), and evaluate deep and infrequent irrigation (watering at the sign of wilt), and (ii) evaluate the combination of a humectant and a soil wetting agent under these two irrigation regimes.

Materials and Methods

The research green was maintained under typical golf course conditions with a mowing height of 3.18 mm (0.125 in.) and a mowing frequency of 6 days per week. This experiment was conducted twice. The first study was initiated May 26 and concluded July 10, 2011. The second study was initiated July 11 and concluded on August 25, 2011.

The study involved these factors: irrigation, wetting agents and day (s) combined to make 4 treatments observed over 45 days. The experimental units were plots. Plot size was 1.5 m x 1.5 m (4.9 x 4.9 ft) with three replications per the combination and a 0.5 m (1.6 ft) untreated buffer between plots. All treatments were applied with a CO_2 backpack sprayer calibrated at 151 L ha^{-1} (40 GPA). Application timings and treatments were similar to Karcher et al., 2008 and Karnok and Tucker, 2001 and are listed in Appendix B.

Irrigation strategies were similar to Fu (2009) and consisted of deep and infrequent (DI) and light and frequent (LF) irrigation. Each plot was individually irrigated between 0700 and 0800 h with a handheld hose equipped with a breaker fan spray nozzle (Robert Bosch Tool, Peoria, IL.). The quantity of water applied was calibrated through the nozzle using a pressure reducer at 28 kg^{-1} (40 psi). In the LF irrigation regime, water was applied daily to replace soil moisture lost due to evapotranspiration (ET). This ensured soil was moistened to a depth of approximately 4 to 6 cm each morning. ET rates were based on the modified Penman equation (Waddington et. al.1992) from a weather station located adjacent to the research plots. In the deep and infrequent (DI) irrigation regime, water was provided at the first visual sign of leaf wilt, such as foot printing or the appearance of a bluish-gray canopy. Frequency of DI irrigation was variable and depended on weather conditions, but could be as often as every 2 days or as infrequently as every 5 days. Fifty liters (12.7 mm or 0.5 in.) of water was applied to each DI plot. Using a soil probe and ruler, it was determined 50 L of water would wet the soil to a depth of 6 to 8 cm (2 to 3 in.) within 5 minutes and penetrated to a depth of 24 cm (9 in.) within 20 minutes.

On sunny days, the entire turf area was syringed 3 to 5 times daily depending on weather conditions to reduce leaf canopy temperatures. During syringing, water did not penetrate the thatch layer.

Statistical Design and Analysis

The statistical design was a completely randomized split plot design with repeated measures. Irrigation regimes of light and frequent (LF) and deep and infrequent (DI) defined as the whole plot treatment and wetting agents defined the sub plot treatment. Study was the whole-plot experimental unit while plots within replication were the sub-plot experimental unit and days were the repeated measures within a replication. A model was defined for this study as follows:

$$[\ Y_{ij}k = M + I + S(I) + R(SI) + WA + WA*I + WA*R(SI) + D + D*I + D*WA + D*I*WA + Error]$$

Where, *Yij*k is the response of soil moisture, temperature, dielectric constant/permittivity, electrical conductivity, turf quality, root growth, and turf color, respectively. M is the overall mean, IR is the effect of irrigation regime, S(I) is the effect of study within irrigation regime, which was the whole plot error. R is the effect of replication. R(SI) is the effect of replication within S and I, WA is the effect of wetting agent, WA* I is the effect of the interaction of WA and IR, WA and R(SI) is the effect of the interaction which is the sub plot error. D is the effect of date which incorporates the repeated measures aspect of the study, and E is the residual which is the repeated measures error (Appendix A).

An analysis of variance (ANOVA) based on this model was used to determine if irrigation regime, wetting agent, and day had significant effects on the mean responses and Fisher's protected LSD test was used to determine any significant differences among specific irrigation, wetting agent, and day means. All calculations were performed using JMP (SAS institute, 2011) and all significance test were performed with α=0.05. An example of the ANOVA table is shown in Table 1.

Table 1. Analysis of variance (ANOVA) of a split plot with repeated measures for soil moisture; evaluating irrigation, wetting agents, and day, interactions of a humectant and a soil wetting agent applied under light and frequent (LF) and deep and infrequent (DI) irrigation regimes on a 'L-93' creeping bentgrass research putting green in Clemson, SC, 2011.

Source	Degrees of Freedom	DFDen	F Ratio	Prob > F
Wetting Agent	2	9.851	0.6755	0.5310
Irrigation	1	9.85	3.0632	0.1111
WettingAgent*Irrigation	2	9.851	0.5335	0.6028
Day	5	166	3.1316	0.0100*
Day*Wetting Agent	10	166	1.6261	0.1031
Day*Irrigation	5	166	1.7120	0.1345
Day*Irrigation*Wetting Agent	10	166	1.9861	0.0377*

*Denotes interaction of two variables (JMP 2011)

Measurements

Turf quality was rated prior to application and every 7 d until the conclusion of the study. Root samples were collected prior to the initiation of the study and every 14 d from two soil cores at a depth of 15 cm (6 in.) randomly located in each plot. Roots were washed free of soil and scanned on a flatbed color scanner. Total root surface area (including root length and diameter) was quantified using similar software (WinRhizo, Regeants Instruments, Quebec, Canada) as Xu and Huang (2010).

Soil moisture (SM), dielectric constant/permittivity (DC), electrical conductivity (EC), and soil temperatures (T) were measured twice weekly typically 1 d prior to DI irrigation until the conclusion of the study. The readings were taken of the surface 0-5.7 cm using the soil sensor probe (POGO, Stevens water monitoring systems, Inc. Portland, OR). Turf quality and turf color, were evaluated similar to Xu and Huang (2010) as a visual rating based on turf color, density, and uniformity of each plot on a 0 to 9 scale (9 representing a lush green, dense turf and 0 representing an entirely necrotic turf area). Phytotoxicity was rated visually as the percentage of the plot showing chlorosis with (0 representing totally green turf and 100 representing totally chlorotic/necrotic). All ratings were made prior to irrigation and every 7 d until the conclusion of the study. Root samples were collected prior to the initiation of the study and every 14 d from two soil cores per plot to a depth of 15 cm (6 in.) randomly located in each plot. Roots were washed free of soil and scanned on a flatbed color scanner. Total root surface area (including root length and diameter) was quantified using similar software (WinRhizo, Regeants Instruments, Quebec, Canada) as Xu and Huang (2010).

Soil Moisture Probe

Volumetric water content, soil moisture (SM), soil temperature (T), electrical conductivity (EC), and dielectric constant (DC) were determined with a Coaxial Impedance Dielectric Reflectometry (CIDR) http://www.soilsensor.com/soilsensors.aspx, August 22, 2011). The probe (Figure 1) (POGO, Stevens water monitoring systems, Inc. Portland, OR) generates an electromagnetic signal transmitted through the unit by metal tines (5.7 cm long x 3 cm apart) and can be calibrated to specific soil types (i.e. sand, silt, clay); in this case for a sand profile.

Figure 1. Commercial probe used to determine volumetric water content, soil temperature, electrical conductivity, and dielectric constant/permittivity.

Results and Discussion

Total Root Surface Area

Treatment differences did not occur between studies, thus data were pooled. Mean total root surface area (TRSA) increased during the first study from 22.5 to 34.6 cm^2 in surface area. In the second study, TRSA decreased from 30 to 22.5 cm^2 (Table 2). This decline in total root surface area was probably due to increased plant stress from high summer temperatures. A decline in roots is typically what practitioners report during most summer months (Dernoeden 2000).

In the first study, Hydretain increased TSRA at 28 DAT (days after treatment) but this then reduced TSRA below the other treatments by 35 DAT. Also by 42 DAT (July 7) TRSA began to decline for all treatments which again agrees with most field observations of practioners. In the second study TRSA started out greater than the 42 DAT (July 7) results but then trended down at least until 35 DAT (August 17).

Root Length

Mean root length were different within sampling dates in the first study. Mean root length at the first sampling was 397 cm and increased to 591 cm by 35 DAT with a decline to 444 cm from 35 to 42 DAT (Table 3). However just like TRSA, total root length peaked at 35 DAT and then began to decline. In the second study, root length declined from 446 cm to 315 cm (35 DAT). These results again suggest summer stress had a negative effect on total root length as did TRSA.

Root Diameter

Mean root diameters were significantly different for sampling dates in the second study. Root diameter going into the heat of the summer was highest at 0.22 mm (data not shown) and decreased to 0.19 mm by the end of the study. This trend is similar to other root measurements previously reported.

Root Volume

Study 1 had a root volume of 0.10 cm^{-3} at 14 DAT and slowly increased to 0.17 cm^{-3} by 35 DAT and declined to 0.11 cm^{-3} by the end of the study (Table 4). The first study provided a lower root volume at the beginning of the study possibly due to lack of nutrients because the location was newly seeded. Root volume is consistent with the other measurements in terms of summer stress on bentgrass. The second study had the greatest root volume at 14 DAT but then declined from that point (data not shown).

Turf Quality and Turf Color and Phytoxicity

Study differences did not occur among treatments for turf quality, turf color, and phytotoxicity for either irrigation regime, thus, data was pooled. Both turf quality and turf color were visually rated and resulted in treatment means of 7.9 and 7.7, respectively (Table 4). All treatments provided acceptable turf quality and color with only slight phytotoxicity from the applications. Phytoxicity was acceptable at $\leq$3% for all treatments. The phytotoxicity ratings for the UTC's was probably due to heat and drought stress. Although, not statistically different it should be noted that agronomically TQ and TC was slightly higher in Study 2 for both irrigation regimes. Most bentgrass practitioners would report that TQ and TC would tend to decline in July and August. However, this was not the case in this study, even though the average temperature for June, July and August were 33°C and 34°C (Appendix C). Also, TRSA declined during July and August which is more typical of bentgrass performance. Improving TQ and TC from study 1 to study 2 while TRSA declined may indicate turf response to proper management under stressful environmental conditions. Even though roots declined, the water management and fertility treatments appeared effective enough to offset root decline.

Electrical Conductivity and Dielectric Constant

Electrical conductivity and dielectric constant were measured using a CIDR portable soil probe which provides an average reading in the surface 5.7 cm. In the first study, EC provided day within treatment differences for the untreated control at 35 and 42 DAT, having the highest EC at 0.03 dS/m (Table 6). All other treatments had an EC of < 0.00 dS/m. The light and frequent (LF) irrigation regime had the highest EC of 0.05 dS/m at 35 and 42 DAT. Dielectric constant provided day differences and irrigation differences in both studies.

The first study ranged from 5.3 to 7.3 with both (LF and DI) irrigation regimes maintaining a mean dielectric constant of ≥6.5. The second study had a dielectric constant between 11 and 13 for all rating dates. Dielectric constant increased by approximately 6 from the beginning of the first study to the end of the second study.

Electrical conductivity provided no differences in the second study but maintained an EC of approximately 0.01 for all treatments and irrigation regimes.

Soil Moisture and Temperature

Soil moisture and temperature readings were with a portable soil probe which provided an average reading for the surface 5.7 cm. In the first study, the deep and infrequent (DI) irrigation regime maintained the lowest amount of soil moisture at 8.9%. This is in close proximity to the findings of Fu and Dernoenden, 2009 as their DI irrigated plots provided average soil moisture of 10% for the duration of the experiment. In their study, the LF irrigated plots provided an average of 19% in the 0 to 5.7 cm rootzone whereas a mean soil moisture of approximately 11.5% was measured in our study. This suggests the light and frequent irrigation treatment maintained higher moisture content due to the frequency of wetting of the soil and turfgrass in the upper 0-6.5 cm rootzone.

The first study provided differences among day, irrigation, and treatments. Fourteen days after treatment (14 DAT), the LF regime with Cascade provided the highest mean at 30.8% (or g/cm^3). All other treatments provided a mean between 8.3 and 12.3%. This suggest Cascade Plus helped to maintain soil moisture better than the other treatments including the untreated control, however, this may be due to the second application of Cascade, whereas the other treatment did not receive a 7-10 sequential application.

In the second study, soil moisture differences occurred among dates and irrigation regimes. At forty-two DAT the LF regime had soil moisture of approximately 20% and the DI irrigation regime had only 15% soil moisture, nearly a 5% decrease between the two irrigation regimes at the end of the study.

Minimal soil temperature differences occurred between irrigation regimes. LF irrigated plots had a maximum temperature of 35°C where the DI irrigated plots was 0.2 °C lower. This similarity in temperatures between irrigation regimes was provided similar to Fu and Dernoeden 2009, except they reported a maximum soil temperature of 31 and 31.5°C, respectively.

In the second study, rating dates had differences in soil temperature. The first rating date had a mean soil temperature of 40.5°C. After application of treatments at 14 DAT, soil temperature decreased by approximately 5%, from 40 to 35 DAT, reaching its lowest temperature on the last rating date at 30°C.

Summary

Root diameter had similar differences to the previous root growth results by having differences between days. A slight decrease was observed from the start of the study until the end with diameters of 0.22 to 0.19 cm. This suggests summer stress decreased root growth. A slight decrease in root length occurred toward the end of the study. Overall, all variables had similar date differences among the studies.

EC was relatively high with an electrical conductivity of 0.08 dS/m during the last two rating dates (35 and 42 DAT) for the untreated control. All other treatments provided an EC of 0.01 dS/m. The light and frequent (LF) regime had the second highest EC of 0.05 dS/m. Dielectric constant increased over the summer months by 6. This suggests temperatures and rainfall probably influenced this as they increased and decreased, respectively.

Turf quality and turf color on the creeping bentgrass provided acceptable visual turf quality and color at ≥7, but did not differ from the untreated control, similar to Karcher et., al, 2007. Phytoxocity had a rating (>40%) and suggest there was chemical burn. The phytoxocity that was noted was probably due to leaf firing and turfgrass sensitivity especially on the untreated control.

Two weeks after treatment (14 DAT) Cascade held the most moisture in the upper 0-6.5 cm rootzone at approximately 30%, providing a 20% difference between it and the untreated control and other treatments. This is possibly due to Cascade's sequential application. Soil moisture, in the second study, provided a 5% difference between soil moisture and irrigation at the end of the study with LF having the highest soil moisture percentage of 20, and DI with only 15% (or g/cm^3).

Minimal soil temperature differences were found between irrigation regimes with almost the same at approximately 35°C.

Table 2. Mean effects of a humectant and a wetting agent on total root surface area (TRSA) for two studies on a 'L-93' creeping bentgrass putting green under two irrigation regimes in Clemson, SC, 2011.

Study	Treatment	Total root surface area (cm^2)			
		Day(s) after application			
		14 DAT	28 DAT	35 DAT	42 DAT
1	UTC†	25.2	30.3	35.3	27.7
	Hydretain	20.4	31.9*	33.5*	22.47
	Cascade	21.7	19.8	35.4	21.8
2	UTC†	25.3	25.2	17.0*	20.0
	Hydretain	33.1	22.0	20.0	24.0
	Cascade‡	33.2	23.7	19.41	22.9

*Denotes a significant difference between treatments according to Fisher's LSD (α=0.05) test.

† UTC= untreated control

‡ Cascade Plus requires a sequential application 7-10 days after initial treatment

Table 3. Mean effects of a humectant and a wetting agent on total root length for two studies on a 'L-93' creeping bentgrass putting green under two irrigation regimes in Clemson, SC, 2011.

Study	Total root length(cm^2)			
	Day(s) after application			
	14 DAT	28 DAT	35 DAT	42 DAT
1	397.07cd	484.50b	591.33a	444.90bc
2	446.17bc	389.61cd	315.82d	361.63cd

*Within columns means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.
†Treament data is did not occur, thus treatment data is not shown due to only study differences.

Table 4. Mean effects of a humectant and a wetting agent on total root volume (TRV) for two studies on a ‘L-93’ creeping bentgrass putting green under two irrigation regimes in Clemson, SC, 2011.

Study	Total root volume(cm^3)			
	Day(s) after application			
	14 DAT	28 DAT	35 DAT	42 DAT
1	0.10c*	0.14b	0.17a*	0.11b*
2	0.17a	0.12bc	0.09c	0.10c

*Within columns means followed by the same letter are not significantly different according to Fisher’s LSD (α=0.05) test.

Table 5. Mean effects of a humectant, and wetting agent in two studies under two irrigation regimes conducted May through August on ‘L-93’ bentgrass research putting green located in Clemson, SC 2011

Study	Treatment	Turf Quality		Turf Color		Phytotoxocity	
		0-9		0-9		0-100%	
		LF†	DI‡	LF	DI	LF	DI
1	UTC	7.3	7.0	7.3	7.1	1.4	3.1
	Hydretain ES Plus	7.0	7.3	7.0	7.2	5.1	2.9
	Cascade Plus‡‡	7.1	7.3	8.9	8.9	3.1	3.6
2	UTC	7.9	7.8	7.9	7.8	1.4	3.1
	Hydretain ES Plus	7.7	7.8	7.8	7.7	5.0	2.9
	Cascade Plus‡‡	7.8	7.8	7.8	7.7	3.1	3.6

† LF= Light and Frequent irrigation regime (replace daily ET rate).
‡ DI = Deep and Infrequent irrigation regime (watered with 50 L at first sign of wilt)
‡‡ Cascade Plus required a sequential application 7-10 days after initial treatment

Table 6. Mean soil moisture (SM), dielectric constant/permittivity (DC), temperature (T), and electrical conductivity taken with a soil moisture probe under two irrigation regimes with a humectant, and commercial wetting agent on ‘L-93’creeping bentgrass research putting green under summer stress conditions located in Clemson, SC, 2011

Treatment	SM	DC	T	EC
	g/cm^3	volts	°C	dS/m
UTC†	11.2	7.01	28.7	0.03
Hydretain ES Plus	9.0	6.61	28.6	0.00
Cascade Plus‡	10.6	6.49	28.7	0.00

† UTC= Untreated control

‡ Cascade Plus requires a sequential application 7-10 days after initial treatment

CHAPTER THREE

FAIRY RING (*Lycopedon spp.*) RESPONSE TO A HUMECTANT, SOIL WETTING AGENT, AND A FUNGICIDE AND SOIL WETTING AGENT COMBINATION ON 'TIFEAGLE' BERMUDAGRASS (*Cynodon dactylon* (L.) Pers. X C. *transvaalensis* Burtt-Davy)

Introduction

Circles of mushrooms and puff balls or circular bands of green rapidly growing turf are common symptoms of disease called Fairy Rings. The term Fairy Ring originates from the middle ages as it was widely believed these sites were the locations of dancing fairies. In Holland, the dead grass in the center was thought to be the place where the devil "churned his butter." Throughout other areas of the world, tales evolved as to why fairy rings occurred.

Couch (2000) states fairy rings are caused by several species of soil and thatch inhibiting fungi. Two basic types of fairy rings exist: (1) edaphic – rings produced by fungi that colonize mainly in the soil, and (2) lectophilic – rings produced by fungi that gather primarily from leaf litter and thatch. With lectophilic fairy rings, a hydrophobic condition develops within the soil, thatch and rooting mixtures previously mentioned in the introduction as localized dry spot in turfgrass.

All cultivated warm and cool season turfgrasses are susceptible to fairy ring, one of the fifty-four known species of mushrooms such as (*Agaricales spp.*) and puff balls such as (*Lycopedon spp.*). Fairy ring occurs primarily in spring, summer and fall. Signs

Type II fairy ring tend to be circular bands of turfgrass that are darker green and faster growing than adjacent plants of the same species (Figure 2). The “belts” of greener plants can range anywhere from 10 to 30 cm (4-12 in) in width, and circular areas vary from 0.9 to 3.7 m (3-12 ft) in length. This is caused by the breakdown of organic matter which produces the greener “belts” of actively growing turfgrass.

Figure 2. Fairy ring on the ‘TifEagle’ bermudagrass research golf green, approximately 10 m x 16 m (33 ft x 53 ft).

Control of fairy rings has proven difficult and expensive to achieve. Therefore, identification of the fairy ring can prove to be important as usually once there is one fairy ring, more tend to develop in the same areas (Couch 2000). Symptoms associated with *Tricholoma* species often develop additional fairy rings. Nitrogen fertilizer is often applied in an attempt to mask the darker circular bands associated with certain fairy rings. Saturation with irrigation for ≥ 48 hours is another cultural practice used. However, these practices rarely provide complete eradication. Experimental usage leads to discovery of ways of eradication or removal, along with prevention. The objectives of this research were: (i) evaluate the effectiveness of a humectant on Type II fairy ring; (ii) evaluate the effectiveness of a soil wetting agent, and a combination of a fungicide plus a soil wetting agent on fairy ring; and (iii) evaluate soil characteristics of a bermudagrass putting green with fairy ring.

Materials and Methods

Two studies were conducted on a ‘TifEagle’ bermudagrass (*Cynodon dactylon* (L.) Pers. X C. *transvaalensis* Burtt-Davy) research green to investigate the effects of various products and fungicides on a fairy ring. The green was constructed according to the United States Golf Association specifications (USGA, 1993). The green was maintained under typical golf course conditions with a mowing height of 3.17 mm (0.125 in.) and a mowing frequency of 6 days per week and irrigated with 38.1 mm (1.5 in.) per week.

The first study began May 23 and concluded July 7, 2011. The second study was initiated July 14 and concluded August 28, 2011. Fairy ring was present at the beginning of the study and the ring size was 10 m x 16 m (33 ft x 53 ft) (Figure 2). All treatments were applied with a CO_2 backpack sprayer calibrated at 40 GPA (151.4 L ha^{-1}). Products used included: a humectant, Hydretain® ES Plus (Ecologel Solutions, LLC, Ocala, FL); two wetting agents, Cascade Plus (Precision Laboratories, Inc. Waukegan, IL); and Primer Select (Aquatrols, Paulsboro, NJ); and a fungicide, Prostar (flutolanil) (Bayer

Environmental Science, Research Triangle Park, NC). All timings and treatments were similar to Karcher et al., 2008 and Karnok and Tucker, 2001 (Appendix B). Primer Select + flutolanil treatments were irrigated after the application dried with 1.25 cm (0.5 in.) and mowing was avoided for 24 hours, as directed by the flutolanil label (Bayer, 2005).

Turf quality (TQ), ring intensity (RI), and LDS/ Phytotoxicity were rated as described in the measurements section prior to application and every 7 d throughout each study. Water droplet penetration (WDPT), hydraulic conductivity/infiltration (HC), soil moisture (SM) and soil temperature (T) were assessed every 14 d for the duration of each study as described in the measurements section.

Statistical Design and Analysis

The statistical design was a completely randomized split plot design with repeated measures. Study was the whole-plot experimental unit while plot within replication was the sub-plot experimental unit, and days were the repeated measures within a replication. The study involved these factors: depth, wetting agents and day (s) combined to make 4 treatments observed over 45 days. A model was developed for this study. The form of the model was as follows:

[*Yij*k = +S+R(S)+WA+WA*R(S)+D+D*S+D*WA+S*WA+S*D*WA+Depth+Error]

Where, *Yij*k is the response of soil moisture, temperature, dielectric constant/permittivity, electrical conductivity, turf quality, and turf color, infiltration, and localized dry spot. M is the overall mean, WA is the wetting agent, R is the replication, R

(S) is replication within study. D is the date, and E is the residual which is the repeated measures error (Appendix A).

An analysis of variance (ANOVA) based on this model was used to determine if depth, wetting agent, and day had significant effects on the mean responses and Fisher's protected LSD test was used to determine any significant differences among specific depth, wetting agent, and day means. All calculations were performed using JMP (SAS institute, 2011) and all significance test were performed with α=0.05. An example of the ANOVA table is shown in Table 7.

Finally, an analysis was performed to measure the correlation between water penetration and the responses listed above. This analysis involved computing the partial correlation of water penetration with soil moisture, temperature, dielectric constant/permittivity, electrical conductivity, turf quality, infiltration, localized dry spot, and turf color after adjusting for the effects of wetting agent, day and depth.

Data were analyzed using analysis of variance (ANOVA) to determine if model effects were significant and Fisher's protected LSD test was used to determine any significant differences among treatment means. All calculations were performed using JMP (SAS institute, 2011) and all significance test were performed with α=0.05.An example of an ANOVA table is shown in Table 7.

Table 7. Analysis of variance (ANOVA) of a split plot with repeated measures for water penetration, evaluating treatment, day, and depth interactions of a humectant, soil wetting agent and a combination of a soil wetting agent and fungicide to fairy ring on a bermudagrass research putting green in Clemson, SC. 2011

Source	DFDen	Degrees of Freedom	F ratio	Prob > F
Wetting Agent	14.55	3	1.5110	0.2535
Day	39.24	2	8.4321	0.0009*
Day*Wetting Agent	31.87	6	2.2260	0.0661
Wetting Agent*Depth	300	15	2.3166	0.0039*
Day*Depth	300	10	1.8597	0.0504
Day*WettingAgent*Depth	300	30	1.0686	0.3743

Measurements

Soil hydrophobicity was determined by the water droplet penetration time test (WDPT). Water droplets were placed along the length of intact 7.62 cm (3 inch) soil cores at 12.7 mm (0.5 inch) intervals (Karnok and Tucker 1989). Time (seconds) required for the droplet to penetrate into the core was recorded. Water repellency was determined according to Waltz (2001) (Appendix D)

Field turfgrass quality was evaluated similar to Xu and Huang (2010) as a visual rating based on color, density, and uniformity of each plot on a 0 to 9 scale (9 representing a lush green, dense turf area and 0 representing an entirely necrotic turf area). A rating of 7 was considered as minimally acceptable turf quality (TQ).

Hydraulic conductivity/infiltration rate was measured using a double ring infiltrometers which were initially filled and allowed to reach a steady state before measurements were started (Canaway 1986). Infiltration was conducted within the center of the plot, but outside the fairy ring due to the amount of area and variability. Time (seconds) for water to infiltrate through the soil was recorded and was expressed as centimeters per hour (cm hr^{-1}). The POGO soil probe was used to determine soil moisture (SM), soil temperature (T), dielectric constant (DC) and electrical conductivity (EC) to a depth of 5.7 cm. Other measurements consisted of fairy ring intensity, localized dry spot percentage, WDPT for hydrophobicity, and soil volumetric and gravimetric water content.

Ring intensity was quantified using a 1.5 x 1.5 m grid (4.9 x 4.9 ft) consisting of 200 squares. The percentage of squares consisting of dark green turf located on the fairy ring determined ring intensity with 0 representing no fairy ring and 200 representing total fairy ring coverage. Phytotoxicity was rated as a percentage or the area within each plot on a 0-100% scale, 0 represented no phytotoxicity (full green turf) and 100 represented full phytotoxicity coverage (brown or dead turf).

Results and Discussion

Infiltration

Differences between studies did not occur, thus, data was pooled. The mean infiltration rate of each study was ≥7 cm/hr^{-1} and was based on three measurements per plot (Table 8). Infiltration rate ranged from 5.3 in the UTC to 11.7 in the Primer treated areas. All infiltration rates were above the suggested infiltration rates for golf course putting greens of 2.4 cm hr^{-1} (Waddington et al., 1974).

The Primer treatment had the greatest infiltration rate followed by Primer + Flutolanil. Cascade Plus, Hydretain ES Plus and the UTC were similar. Day differences in the infiltration rates did not occur; however 14, 28, and 42 DAT had a mean of 9.2, 7.8, and 5.9, respectively. This 35% decrease from 14 DAT to 42 DAT probably reflects increased compaction, thus slowing infiltration rates over time.

Table 8. Mean infiltration rates and water droplet penetration of a humectant, a wetting agent and a wetting agent + fungicide during the first study conducted on a fairy ring infected bermudagrass putting green in Clemson, SC. 2011

Treatment	Infiltration Rate	WDPT
	cm hr^{-1}	sec
UTC†	5.3c*	5.1a
Hydretain ES Plus	5.9c	3.2b
Cascade Plus††	6.5c	1.4c
Primer+ Flutolanil‡‡	8.8b	1.2c
Primer	11.7a	1.0c

*Within columns means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.

† UTC= untreated control

††Cascade Plus recieved a sequential application 7-10 days after initial treatment

‡‡ Flutolanil was applied 24 hrs after the Primer application and mowing was avoidedfor 24 hours avoided following after application.

Water Droplet Penetration

Differences were not seen between studies, thus, data was pooled. The WDPT had differences among treatments, although all treatments were between wettable and/or slightly wettable (Appendix D). The UTC provided the highest water penetration time of ≥5.1 seconds followed by Hydretain ES Plus at 3.2 seconds. All other treatments had soil water penetration times of ≤1.5 seconds.

Soil Moisture

Differences between studies did not occur thus, the data was pooled. Primer and Primer + Flutolanil had greatest soil moisture of ≥18%, while, all other treatments maintained lower soil moisture between 10.1% and 12.3% (Table 9). Leinauer et al. (2001) reported similar performance of Primer. Marginal day differences were reported from 21 DAT and 35 DAT (first and second rating dates) with soil moisture readings of >11% and 16%, respectively.

Dielectric Constant/Permittivity

Difference between days, and interactions between treatments were not seen, but there were some differences among treatments were seen (Table 9). Similar to the soil moisture results, Primer and Primer+Flutolanil maintained the highest dielectric constant at ≥12%, whereas, all other treatments provided a dielectric constant between 7.2 and 8%. Since the DC of a soil is the capacitive and conductive parts of a soil's electrical response, this suggests that differences were marginal.

Soil Temperature and Electrical Conductivity

Results between studies for temperature and EC were not seen. Differences were also not evident among treatments, days, or treatment and day interactions. Treatments means for temperature ranged from 32.2 to 33°C (Table 9). This correlates with typical soil temperatures at this time of year in the southeastern climate (McCarty 2011). Both studies provided an EC of 0.00, for treatment and day interactions.

Table 9. Mean water droplet penetration test (WDPT), soil moisture (SM), dielectric constant (DC), temperture (T), and electrical conductivity (EC) effects from a humectant, a wetting agent, and a wetting agent+fungicide on a fairy ring infested ‘TifEagle’ bermudagrass putting green located in Clemson, SC. 2011

Treatment	WDPT	SM	DC	T	EC
	seconds	cm^{-3}	volts	°C	dS/m
UTC	5.1a*	10.6b	7.5b	32.2	0.01
Hydretain ES Plus	3.2b	10.1b	7.2b	32.7	0.01
Cascade Plus	1.4c	12.3b	8.3b	32.8	0.01
Primer	1.3c	19.8a	12.9a	33.0	0.01
Primer +flutolanil‡‡	1.0c	18.2a	12.1a	33.0	0.01

*Within columns means followed by the same letter are not significantly different according to Fisher’s LSD (α=0.05) test.

† UTC= untreated control

††Cascade Plus requires a sequential application 7-10 days after initial treatment

‡‡ Flutolanil was applied 24 hrs after the Primer application and mowing was avoided

Turf Quality, Ring Intensity, and Localized Dry Spot

Treatments did not provide any differences in turf quality, which agrees with Karnok and Tucker, 2011. Differences were not seen between days, or treatments and day interactions. Treatment means for turf quality ranged from marginally unacceptable at 6.5 for the UTC to ≥7.4, marginally acceptable (Table 10). This suggest that ring intensity did not affect the quality of the turfgrass plot area during the study but maintained acceptable quality which is what would normally have been observed during the warm temperatures throughout most summers in the southeast United States.

Ring intensity provided treatment differences. The first study had a mean ring intensity of ≥35%, whereas, the second study had fairy ring intensity of 75%, however, no differences occurred between studies (Table 10). Less rainfall occurred during the second study which intensified the dark green areas as well as the ring itself. Fairy ring intensity could also have increased during the warmer part of the season. The UTC and Hydretain had ring intensities of ~42 with both being lower than Cascade Plus by 35%. Hydretain appeared as the only treatment with lowest ring intensity while the other treatments were above 50 (Table 10). This could be because the suppression was more toward the edges or end of the ring which is typically the case. However, it also suggests that the Primer treatments performed similar as the untreated control.

Localized dry spot data had treatment differences except for interactions between treatments and rating dates and studies (data not shown). The first study provided an LDS mean of ≤5% and the second study provided a mean of <15%. These differences are most likely related to higher temperatures during the second study and less rainfall. The most LDS was ≤30% for the untreated control at 42 DAT (Table 10).

Table 10. Turf quality, ring intensity (RI) and localized dry spot (LDS) treatment means for both studies conducted April through July 2011 on evaluating a humectant, two wetting agents and a wetting agent + fungicide on a Fairy ring infested bermudagrass research putting green located in Clemson, SC. 2011

Treatment	Turf Quality§	Ring Intensity	LDS
	0-9	0-100sq	0-100%
UTC†	6.5	42.7b*	23.9
Hydretain ES Plus	6.8	42.1b	16.1
Cascade Plus††	7.4	77.3a	2.5
Primer Select	7.3	58.0ab	2.8
Primer+ Flutolanil ‡‡	7.4	58.0ab	2.2

*Within columns means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.
† UTC= untreated control
††Cascade Plus requires a sequential application 7-10 days after initial treatment
‡‡ Flutolanil was applied 24 hrs after the Primer application and mowing was avoided

Summary

All infiltration rates were above the suggested infiltration rate for golf course putting greens of 2.5 cm hr^{-1} (Waddington et al., 1974). Primer had greatest infiltration rate followed by Primer + Flutolanil. These two treatments also had greatest soil moisture and highest dielectric constant (DC). Treatments did not produce any differences in turf quality which agrees with previously reported results. Ring Intensity increased from the first study to the second study by approximately 40% due to irrigation, and temperatures resulting in greater fungal activity.

Using the POGO probe for this type of work does present limitations as it measures conditions in the surface 5.7 cm and conditions in the top 1.5 cm can be dramatically different from the lower 3 cm or 1.5 cm.

Temperature differences were not seen. Electrical conductivity and turf quality also had no differences. The LDS ratings proved all treatments were commercially acceptable, displaying $\leq$25% LDS on each plot (Table 10).

CHAPTER FOUR

PERFORMANCE OF A HUMECTANT AND VARIOUS WETTING AGENTS ON LOCALIZED DRY SPOT OF A'TIFEAGLE' [*Cynodon dactylon* (L.) Pers. X C. *transvaalensis* Burtt-Davy] BERMUDAGRASS RESEARCH PUTTING GREEN

Introduction

Several studies have been performed to investigate the source and cause of localized hydrophobic soil conditions also called Localized Dry Spot. Leinauer et al. (2001), and Baird and Calhoun (1999) examined whether wetting agents could improve the rewetting of dry spot and observed differences in rewetting times between cores from plots treated with wetting agents and cores from untreated plots. Although previous studies have provided some insight into the nature of localized dry spots and the impact of wetting agents on the condition, conflicting findings remain in the literature. Ruemmele and Amador (1994), and Wiecko and Carrow (1992) reported increased infiltration and/or percolation rates of rootzones treated with wetting agents. Wiecko and Carrow (1992) also reported a decrease in water retention in plots treated with a wetting agent, while other studies (Blodgett et al,1993; Karnok et al.,1989; and Ruemmele and Amador, 1998) showed increases in soil moisture in plots treated with wetting agents. The objectives of this study were: (i) evaluate a humectant's performance on localized dry spot; (ii) evaluate other wetting agents performance on localized dry spot; and (iii) evaluate the development of localized dry spots under summer stress conditions.

Materials and Methods

Experiments were conducted on a 'TifEagle' bermudagrass (*Cynodon dactylon* (L.) Pers. X C. *transvaalensis* Burtt-Davy) research green to evaluate the impact of various products on localized dry spot (LDS) symptoms. The 'TifEagle' bermudagrass research green was constructed according to the United States Golf Association (USGA, 1993) and maintained under typical golf course conditions with a mowing height of 3.17 mm (0.125 in.), a mowing frequency of 6 times weekly, and irrigated with 38.1 mm (1.5 in.) of water per week.

This experiment was divided into three studies. The first was initiated on May 18 and concluded July 2, 2011. In the first study, irrigation was reduced to 19 mm (0.75 in.) per week to enhance/induce LDS severity. On day 21, irrigation was reduced to 15 mm (0.5 in.) per week. Products used in this study were similar to the non-irrigated field experiment, with the addition of the fungicide Prostar (flutolanil). All timings and treatments were similar to Karcher et al., 2008 and Karnok and Tucker, 2001 (Appendix B). All treatments were applied with a CO_2 backpack sprayer calibrated at 151 L ha^{-1} (40 GPA).

The second and third studies were conducted under a different irrigation regime than the first study therefore; the first study was not statistically comparable and was analyzed separately (data not reported). The second study was initiated July 6 and concluded August 20, 2011. The third study was initiated on July 11 and concluded August 25, 2011. Irrigation was not applied until 21 DAT of each study in order to induce LDS. Irrigation was then applied at 38 mm (1.5 in.) of water per week. Plot size and design were consistent with the previous study. Treatments and timings are listed in Appendix B.

Statistical Design and Analysis

The statistical design was a completely randomized split plot design with study as the whole-plot experimental unit while replication was the sub-plot experimental unit, and days were the repeated measures within a replication. Since both replications and treatments were nested within studies, the two studies were combined for analysis. Plots were 1.5 by 1.5 m with three replications per treatment combination.

A model was performed for this study consistent with the treatment and experiment design. The form of the model was:

$$[\ Y_{ij}k = M + S + R(S) + WA + WA*R(S) + D + D*S + D*WA + S*WA + S*D*WA + Depth + Error]$$

Where, *Yij*k is the response of soil moisture, temperature, dielectric constant/permittivity, electrical conductivity, turf quality, and turf color, localized dry spot, water penetration and infiltration. M is the overall mean, WA is the wetting agent, R is the replication, R (S) is replication within study. D is the date, and E is the residual which is the repeated measures error (Appendix A).

An analysis of variance (ANOVA) based on this model was used (Table 11) to determine if wetting agent, day, and depth had significant effects on the mean responses and Fisher's protected LSD test was used to determine any significant differences among specific treatment means. All calculations were performed using JMP (SAS institute,

2011) and all significance test were performed with α=0.05. An example of the ANOVA Table is shown in Table 11.

This model (Appendix A), was used to determine the effects of wetting agent and day on soil moisture, turf quality, and turf color, etc. An additional objective of the analysis was to determine how wetting, day, and depth affected water penetration.

Table 11. Analysis of variance (ANOVA) of water penetration on the localized dry spot study conducted on a 'TifEagle' bermudagrass research putting green in Clemson, SC, 2011.

Source	DFDen	Degrees of Freedom	F Ratio	Prob > F
Wetting Agent	14.55	3	1.5110	0.2535
Day	39.24	2	8.4321	0.0009*
Day*Wetting Agent	31.87	6	2.2260	0.0661
Wetting Agent*Depth	300	15	2.3166	0.0039*
Day*Depth	300	10	1.8597	0.0504
Day*Wetting Agent*Depth	300	30	1.0698	0.3743

* Denotes crossing of interactions, day x treatment, etc. (JMP, 2009)

Measurements

Measurements were consistent throughout each separate study. Turf quality, LDS and turf color were visually rated prior to application and every 7 d after until the conclusion of the study. Turf quality was rated from 1-9 with 1 representing brown turf or bare areas and 9 representing full turf color, vigor and density. Soil moisture/water content, temperature, electrical conductivity (EC), and dielectric constant were determined with Coaxial Impedance Dielectric Reflectometry (http://www.soilsensor.com/soilsensors.aspx, August 22, 2011). A portable soil moisture probe with four tines 5.7 cm long and 3 cm apart (POGO, Stevens water monitoring systems, Inc. Portland, OR) was inserted into the soil adjacent to where samples were taken to conduct a Water Droplet Penetration Time (WDPT). Soil moisture (volumetric water content), soil temperature, electrical conductivity, and dielectric constant were determined with a Coaxial Impedance Dielectric Reflectometry (http://www.soilsensor.com/soilsensors.aspx, August 22, 2011) unit. A portable soil moisture probe (POGO), (Stevens water monitoring systems, Inc. Portland, OR) was used for this measurement. An electromagnetic signal is reflected back to the unit by the soil thus measuring amplitude of reflectance and the incident signal in volts. The ratio of the voltages was used in a mathematical equation to calculate the impedance, and then both real and imaginary dielectric permittivity's to estimate soil water content (http://www.soilsensor.com/soilsensors.aspx, August 22, 2011). The probe was calibrated for a sand profile every 14 d prior to assessment of soil moisture, soil temperature, dielectric constant and electrical conductivity. The probe penetrated the top 5.2 cm of the profile and probes were 3 cm apart.

The water droplet penetration test (WDPT) for repellency was determined by placing water droplets on the extracted soil cores at 12 mm (0.5 inch) intervals from 0 to 7.6 cm (3 in). Time (sec) required for the droplet to penetrate into the core was recorded (Karnok and Tucker 1989).

As previously discussed the WDPT test was used to evaluate hydrophobic conditions. This process involves placing water droplets on an intact soil core at different depths. A stop watch was used to record the time (sec) it took for the droplet to penetrate the soil. A WDPT was conducted every 14 d until the conclusion of the experiment and results were compared to the five repellency ranges (Appendix C) (Logsdon 2008).

Infiltration rate was measured with double ring infiltrometers using a stop watch. The infiltration time was recorded and expressed in millimeters per hour (mm hr^{-1}) (Canaway 1986). Treatment effects were determined by analysis of variance.

LDS and phytotoxicity were rated as a percentage within each plot on a 0-100% scale, with 0 representing no LDS or phytotoxicity (green turf) in the plot and 100 representing full LDS or phytotoxicity (totally brown or showing leaf discoloration).

Turfgrass quality was evaluated similar to Xu and Huang (2010), for overall turf performance as a visual rating based on color, density, and uniformity of each plot on a 0 to 9 scale (0 representing all necrotic turf and 9 representing lush green, dense turf). A rating of 7 was considered to be minimally acceptable turf quality (TQ) for turfgrass areas. Turf density was based on a scale from 0-100% with 0 representing bare turf and 100 representing full turfgrass coverage. Acceptable turf density was ≥70%.

Hydraulic conductivity/Infiltration rate was measured using double ring infiltrometers placed in the center of each plot and initially flooded and allowed to reach a steady state before measurements were started (Canaway 1986). Upon a steady state, time for water to infiltrate through the soil was recorded (cm hr^{-1}).

Results and Discussion

Water Droplet Penetration Test (WDPT)

Differences did not occur between both studies, thus, data was pooled. Cascade treatments had lower water penetration time compared to the UTC at 14, 28, and 35 DAT. In both studies water penetration times decreased by 3 seconds from 14 DAT to 42 DAT. This suggests the entire area became more hydrophilic with time. Until 35 DAT the WDPT results remained similar. However, by 42 DAT all treatments were substantially lower. This was probably due to the scheduled core aerification on 36 DAT.

Infiltration

Infiltration rate had differences from the beginning to the end of the experiment. Infiltration rate was 6 cm hr^{-1} (14 DAT) and decreased to 4 cm hr^{-1}(42 DAT). The decrease is likely due to aerification at 32 DAT needed for regular maintenance of the putting green. However, treatment differences in infiltration rate did not occur in either study.

Localized Dry Spot

Differences did not occur between studies, therefore, data was pooled (Table 12). Mean LDS ratings for the study ranged from 11.4% (Hydretain) to 20.0% for Cascade Plus with the UTC being 17.5%. Hydretain and Primer Select had lowest LDS and the UTC and Cascade Plus had highest LDS. Cascade Plus and Primer had 42 and 36% localized dry spot while the untreated control (UTC) and Hydretain provided ≤ 30%. Hydretain demonstrated the least amount of LDS throughout the study with up to 23%

LDS. This suggests Hydretain controlled and prevented LDS more than any other treatment. LDS at 35 DAT was highest with a mean of 33%, while, 21 DAT and 42 DAT dates provided approximately 10%; at 21 DAT, irrigation decreased, thus, encouraging more LDS to be most expressed 35 DAT.

Electrical Conductivity provided marginal differences between sampling dates (data not shown), but all treatments provided an EC of 0.00. This could indicate a lack of nutrients (i.e. Ca, Mg, K, Na) for putting greens.

Turf Quality and Turf Color

Differences did not occur among treatments for turf quality and turf color. Mean turf quality ranged from 6.8 to 7.4. Turf color, like turf quality, was very similar with a range from 7.2 to 7.8 (Table 12). The research green never gained a lush green color through the summer and may partially be from skipping normal spring aerification due to this study.

Water Penetration and Depth

The various depths of water penetration times proved to be different. The longest time was at the 1.25 cm (0.5 in.) depth, with water infiltrating through the soil within approximately 3 seconds. All depths below 3.81 cm (1.5 in) were within approximately 1.5 seconds or less. This suggests the most hydrophobic portion of the soil is located in the top 5.08 cm (2 in) and it decreases by approximately 1 second per half inch (1.25 cm) (Karnok and Tucker, 2001).

Summary

All treatments provided a wettable soil with a penetration time of less than 5 seconds. Cascade provided lowest amount of penetration times at approximately 1 second. Infiltration decreased from 6 cm hr^{-1} to 4 cm hr^{-1} from 14 to 45 DAT, possibly due to time and weather conditions. No treatment differences were evident for infiltration measurements. All treatments rated for localized dry spot provided acceptable control with Cascade at 20%, UTC at 17%, Primer 15%, and Hydretain providing the most LDS control at 11%. All treatments provided turf quality rating of 7 compared to the untreated with approximately only 6 on the scale of 0 to 9. Turf color provided a marginally acceptable level of 7 due to lack of aerification and spring maintenance in order to induce LDS on the putting green.

Soil moisture was maintained approximately less than 10% and was not influenced by treatments. Soil temperature was maintained at approximately 32°C throughout the duration of the studies, suggesting this was unaffected by any of the treatments. Water penetration times varied among each depth. The most hydrophobic conditions were in the top 5.08 cm (2 in) of the soil suggesting that all areas were not hydrophobic according to (Karnok and Tucker 2001).

Table 12. Mean water droplet penetration test (WDPT) times for both studies on a 'TifEagle' bermudagrass putting green with localized dry spot in Clemson, SC, 2011.

Treatment	Date(s) after application			
	cm/hr^{-1}			
	14 DAT	28 DAT	35 DAT	42 DAT
UTC†	2.7a*	3.8ac	3.7ab	0.5ef
Hydretain	2.4ab	2.9abcd	2.6abcd	1.6d
Primer	1.9ab	2.9abcd	2.2cd	0.5f
Cascade	1.7b	2.4bd	2.1de	0.4f

*Denotes values in columns followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.
† UTC= untreated control (products were not applied to this area)

Table 13. Mean infiltration rates of the first study conducted on a ‘TifEagle’ bermudagrass putting green with localized dry spot in Clemson, SC, 2011.

Treatment	Infiltration Rate
	—cm hr^{-1}—
Cascade Plus	6.0 ns
Hydretain ES Plus	4.7
Primer	5.9
UTC†	4.3

*NS denotes a significant difference between infiltration rates according to Fisher’s LSD (α=0.05) test.

† UTC = Untreated Control (No treatments applied to this plot area).

Table 14. Mean water penetration (WP), soil moisture (SM), dielectric constant(DC), soil temperature (T), and electrical conductivity taken with a soil moisture probe in a 'TifEagle' bermudagrass putting green located in Clemson, SC. 2011.

Treatment	WP	SM	DC	T	EC
	seconds	g/cm^{-1}	volts	°C	dS/m
UTC†	2.7	8.7	6.6	32.5	0.00
Hydretain ES Plus	2.4	9.4	6.9	32.4	0.00
Cascade Plus	1.7	9.1	6.7	32.3	0.00
Primer	1.9	9.7	7.0	32.5	0.00

† UTC = Untreated Control (No treatments applied to this plot area).

Table 15.Turf quality, turf color and localized dry spot (LDS) treatment means for both studies conducted April through July 2011 on Fairy ring infested bermudagrass research putting green in Clemson, SC, 2011.

Treatment	Turf Quality†	Turf Color	LDS
	—0-9—	—0-9—	—0-100%—
UTC	6.8	7.3	17.5ab*
Hydretain ES Plus	7.1	7.2	11.4c
Cascade Plus	7.1	7.3	20.0a
Primer Select	7.4	7.8	15.0bc

* Denotes a significant difference according to Fisher's LSD (α=0.05) test.
† Turf quality and turf color rated from 0 – 9 where 9 = best turf and values 6.0 are unacceptable.

CHAPTER FIVE

INFLUENCE OF A HUMECTANT AND WETTING AGENTS ON A NON-IRRIGATED 'TIFWAY' AND COMMON BERMUDAGRASS [*Cynodon dactylon)* (L.)] SPORTS FIELD

Introduction

Among warm season turfgrasses, common and hybrid bermudagrass are popular throughout the southeastern climatic region of the United States on sports fields and golf courses. Their popularity is due to many attributes such as wear tolerance, recuperative potential and drought tolerance. Carrow (1993) reported zoysiagrass (*Zoysia japonica* (L.) and common and hybrid bermudagrass provide lowest water use rates among turfgrasses. Carrow (1993) also ranked bermudagrasses highest in drought resistance for warm season species.

Volumetric water content can be used for various reasons but mainly to estimate the amount of water in a field soil or the amount of water needed to wet the soil to a specified degree by rainfall or irrigation (Miller and Gardiner 1998). The objectives of this experiment were as follows: (i) determine if wetting agents and a humectant maintained a higher soil water content and (ii) determine if these treatments increased soil water retention.

Materials and Methods

An experiment consisting of two studies was conducted during the spring and summer of 2011 to evaluate the performance of a non-irrigated 'Tifway' bermudagrass [*Cynodon dactylon)* (L.) Pers. X C. *transvaalensis* Burtt-Davy] and common bermudagrass [*Cynodon dactylon* (L.)] mixture. The commercial humectant, Hydretain ES Plus, and commercial two wetting agents, Primer Select and Cascade Plus, were used in this experiment. The non-irrigated field was on a wateree soil series (Coarse-loamy, mixed, semiactive, thermic Typic Dystrudepts) sports field located in Clemson, SC and was sustained under natural traffic situations from April through July 2011.

The experiment was split into two studies. The first study began April 15 and concluded June 1. Plots were 3 m x 7 m (10 ft x 23 ft) replicated three times using a completely randomized block design. All treatments were tank mixed and applied with a sprayer calibrated at 151.4 L ha^{-1}(40 GPA). Application timings and treatments were similar to Karcher et al., 2008 and Karnok and Tucker, 2001 (Appendix B). Applications were applied immediately prior to predicted rainfall events as possible.

The second study began June 3 and concluded July 18. Plot size and design was consistent with those of the initial study. Treatments and timings are listed in Appendix B. Turf quality and density were rated every 14 days. Gravimetric water content was conducted using a soil probe to extract samples at a depth of 0-10 cm (0-4 in.) every 14 to 21 d after application depending on rain events. In case of rain events, soil samples were not extracted until 36 hours after rainfall ended. Samples were weighed following extraction and oven dried at ~ 80°C for 24 hours. Five soil samples were extracted from each plot and placed in an airtight plastic bag to reduce evaporation prior to weighing. Wet weight of each sample was taken and placed in a paper bag, then, into a forced-air dryer at 80°C for 24 hours before measuring dry weight of each sample. After all samples were weighed, gravimetric soil water content was calculated.

Statistical Design and Analysis

The treatment design for this study was a two factor (treatment and day) factorial. The experimental design was a split plot with repeated measures. Study was the whole-plot experimental unit while replication was the sub-plot experimental unit, and days were the repeated measures within a replication. A model was defined for this study consistent with the treatment and experiment design. The form of the model is as follows:

[*Yij*k = *M*+S+R(S)+WA+WA*R(S)+D+D*S+D*WA+S*WA+S*D*WA+Error]

Where *Yij*k is the response of soil moisture, turf quality, and turf density. M is the overall mean, S is Study, R is replication, R(S) is replication within study, WA is wetting agent, WA and R(S) is the interaction of wetting agent and replication within study. D is day.

Data were analyzed using analysis of variance (ANOVA) to determine if wetting agent, and day had significant effects on the mean responses and Fisher’s protected LSD test was used to determine any significant differences among specific wettings agent and day means. All calculations were performed using JMP (SAS institute, 2011) and all significance test were performed with α=0.05. An example of the ANOVA is shown in Table 16.

Table 16. Analysis of variance (ANOVA) of turf quality with a split plot with repeated measures for evaluating treatment, day, and treatment and day interactions for a humectant and two wetting agents on a bermudagrass sports fields located in Clemson, SC 2011.

Source	DFDen	Degrees of Freedom	F ratio	P > 0.05
Wetting Agent	3	3	0.93	0.52
Day	6	6	0.80	0.60
Day*WettingAgent†	18	18	0.51	0.91

†Day crossed with treatment (JMP, 2011)

Measurements

Field turfgrass quality was evaluated similar to Xu and Huang (2010), for overall turf performance as a visual rating based on color, density, and uniformity of each plot on a 0 to 9 scale (0 representing all necrotic turf and 9 representing lush green, dense turf). A rating of 7 was considered to be minimally acceptable turf quality (TQ).

Turf density was determined as a visual rating on a scale from 0-100% with 0 representing bare turf and 100 representing full turfgrass coverage.

Phytotoxicity was rated as a percentage within each plot on a 0-100% scale, with 0 representing no phytotoxicity (full green turf) and 100 representing full phytotoxicity coverage (brown or leaf discoloration) of the plot. Gravimetric water content was determined by extracting five soil samples every 14-21 days from each plot placing samples in an airtight plastic bag to reduce evaporation prior to weighing. Wet weight of each sample was measured following extraction and placed in a forced-air dryer at 80°C for 24 hours before measuring dry weight. Gravimetric soil water content was determined and is reported as a percentage of soil dry weight (Magni et al. 2005).

Results and Discussion

Turf Quality and Turf Density

Differences were not noted in turf quality and turf density in either study. However, turf quality differences occurred between studies. The first study (Apr-May 2011) had a commercially unacceptable turf quality of 5.5. (Table 17). The second study (May-July 2011) provided higher turf quality performance of 7.8 to 8.4. The low turf quality in the first study was indicative of bermudagrass quality during spring green-up while the second study was later in the year when environmental conditions were more conclusive to bermudagrass growth..

Turf density was commercially acceptable (≥70%) in both studies. The first study (Apr-May 2011) had a turf density at ≥85%. Study two (June through August) provided a turf density ≥9% (Table 17).

Table 17.Turf quality and turf density and phytotoxicity treatment means for two studies conducted April through July 2011 on non-irrigated bermudagrass sports field located in Clemson, SC. 2011

Study	Treatment	Turf Quality	Turf Density	Phytoxicity
		0-9	0-100%	0-100%
1	UTC	5.5e*	86.3	1.3b*
	Hydretain ES Plus	5.4be	85.3	2.9b
	Cascade Plus	5.5de	86.1	15.3a
	Primer Select	5.8ce	88.0	17.0a
2	UTC	8.4a	97.4	1.3b
	Hydretain ES Plus	8.0ab	97.8	10.6ab
	Cascade Plus	7.8ad	94.4	7.7ab
	Primer Select	7.9ac	96.3	3.9ab

* Denotes a significant difference between treatments receiving the same non-irrigated regime according to Fisher's LSD (α=0.05) test.

Phytotoxicity

Cascade Plus and Primer Select caused significant phytotoxicity from 7.7 to 15.3%, respectively. In combination with growth stage of turfgrass enough stress was observed to cause phytotoxcity in Study 1, where in study two there were no differences between products. Study 2 ranged from 3.9 to 10.6. In the first study, Cascade Plus and Primer Select produced the most phytoxicity (≤ 31% of the turf plot). While at 21 DAT Hydretain provided less than 10% injury symptoms. In the second study, all treatments provided less than 15% phytotoxicity, with Hydretain providing the least amount of injury (≤ 5) at 45 DAT. In the first study, symptoms appeared 7 DAT whereas in the second study initial symptoms did not occur until 21 DAT.

Water Content

Treatments did not affect volumetric water content at the 0-4 inch depth but ranged throughout the study from 0.17 kg kg^{-1} to 0.07 kg kg^{-1}. However, all treatments, including the control provided a slightly higher water content 14 DAT at 0.17 kg kg^{-1} compared to ≤ 0.10 kg kg^{-1} 45 DAT.

Summary

Differences observed in these two studies were probably due to spring green up of the bermudagrass. However, air temperatures (Appendix C) during both studies were in the ideal range for bermudagrass growth, which is between 15.5°C and 24°C (McCarty 2011). The first study was applied April to June during green-up. The second study was from June to August. This time difference probably affected and turf quality ratings as the turfgrass emerged from dormancy.

Under the non-irrigated conditions additional stress from some treatments resulted in mild phytotoxicity. However, care was taken to apply treatments when temperatures were relatively cool and as close to a forecasted rain event as possible. Gravimetric water content did not provide any differences.

CHAPTER SIX

SOIL VOLUMETRIC WATER CONTENT RESPONSE TO A HUMECTANT, A WETTING AGENT, AND TWO WATER SOURCES UNDER LABORATORY AND GREENHOUSE PROPAGATION CONDITIONS

Introduction

Roberts and Linder 2010, state that over the last 15-20 years humic acid-based root stimulants, hydrophilic gels and mycorrhizal-containing substrates have been evaluated to help relieve transplant shock, and the wilting cycle of drought stressed plants. These amendments have proved to be ineffective, partially because they do not account for post-plant root zone soil moisture stress, thus, encouraging the development of humectants. When applied to growing media, humectants are reported to have the potential of improving the proportion of water available for plant growth. This is extracting moisture from air spaces within the soil matrix and, in some instances, preventing evaporative loss of water out of porous soils (Roberts and Linder 2010).

Few studies have been conducted to understand the mechanism by which wetting agents and humectants improve water availability in agriculture. However, these compounds containing humectants or properties thereof, have gained widespread acceptance in pharmaceutical formulations, food, and personal care products, thus, probably leading into future research of agriculture.

The objectives of the experiments were (i) evaluate a native soil under controlled greenhouse propagation and laboratory conditions for volumetric water content (VWC)

(ii) assess the changes in volumetric water content (VWC) of a soil treated with water, de-ionized water (DI), and the commercial products Cascade Plus and Hydretain ES Plus; (iii) assess the fluctuations of volumetric water content over a 7 day period under two humidity levels.

Materials and Methods

A greenhouse and laboratory study was conducted to determine volumetric water content at various times following product use. Treatments included: Cascade Plus, de-ionized (DI) water, tap water, and Hydretain ES Plus®. One hundred grams of ground, homogenized sandy clay soil with a bulk density of 0.19 g cm^{-3} and a total porosity of 0.31 g cm^{-3} was placed in a dryer at 80°C until time of treatments. Thirty mL of each treatment was applied to glass jars measuring 5 x 4.5 mm. Jars were completely randomized statistical design, with four replications, for a total of 16 jars and were weighed daily for 7 days to determine the volumetric soil water content. Jars were placed under two humidity levels (40 and 80%) to determine moisture fluctuations over each 7 day experiment.

Miller and Gardiner (1998) express volumetric water content as a measure to express the volume of a soil as follows:

$$\theta_v = \text{volume of water/volume of soil} = \frac{\text{mass of water/density of water}}{\text{mass of oven-dried soil/soil bulk density}}$$

Statistical Design and Analysis

The experimental design was a split plot with repeated measures. Study was the whole-plot experimental unit while replication was the sub-plot experimental unit, and days were the repeated measures within a replication. A model was performed for this study consistent with the treatment and experiment design. The form of the model was:

$$[\ Y_{ij}k = M+S+R(S)+T+T*R(S)+D+D*S+D*T+S*T+S*D*T+Error]$$

Where, *Yij*k is the response of soil moisture and relative humidity. M is the overall mean, WA is the wetting agent, R is the replication, S is the Study, and D is the date and E is the error (Appendix A).

All factor levels within study were randomized to ensure the proper significance test for the treatment and experimental design. Data were analyzed using analysis of variance (ANOVA) to determine if model effects were significant and Fisher's protected LSD test were used to determine any significant differences among treatment means (Table 18). All calculations were performed using JMP (SAS institute, 2011) with significance tests performed at $\alpha=0.05$. An example of the ANOVA table is shown in Table 18.

Table 18. Analysis of variance (ANOVA) table of relative humidity on a split plot with repeated measures for evaluating study, wetting agent and day interactions for the laboratory studies conducted with a porous native soil in Clemson, SC. 2011

Source	Nparm	Degrees of Freedom	F ratio	P > 0.05
Study	1	1	0.8583	0.355
Treatment	3	3	0.0000	1.000
Day	7	7	38.8790	<.0001*

*, Significant at the 0.05 probability levels (JMP, 2009).

Results and Discussion

Relative Humidity

Differences did not occur between studies in the laboratory thus, data were pooled. The first study conducted in April 2011 had an average relative humidity (RH) of 45.1% and the second study had an average relative humidity of 46.6%. In the laboratory, RH ranged from 30.4 to 67% with 3 DAT having the highest RH (Table 19). This suggests RH fluctuated with temperatures.

Each study varied as as the first study had a laboratory RH between 30 and 67% while the greenhouse had a RH between 55 and 74%. In the greenhouse, the first study provided a mean of ≥50%; and the second study had a greenhouse RH of ≥70%. This could be due to the time of the studies, as the first study was conducted in March 2011 and the second study was conducted in July 2011. However, it also suggests that the amount of sunlight reflected in the greenhouse could contribute to the humidity changes (sunny vs cloudy days). The mean RH throughout the study was 64%. The mean relative humidity ranged from the lowest at 3 DAT of 56% and the highest at 6 DAT of 73%.

Water Content

Differences occurred between studies, thus data are discussed separately. The first study provided mean water content (WC) of 19.9 and the second study had a mean of 17.1. Treatments for both studies also provided differences between days, however no treatment differences occurred (Table 19 and Table 19.1). Cascade provided highest water content with a mean of 16.6 (Table 20). Hydretain and tap water had a mean water content of 15.9 and 14.4, respectively while De-ionized (DI) water provided a mean of 12.8. Days varied from 1 DAT to 7 DAT with a mean of 25 and 15, respectively, which provided a decrease of 10. This suggests that within 1 DAT approximately 5 ml of water loss occurred in the laboratory and slightly more in the greenhouse study. Over the course of both studies a total of approximately 15 ml of water loss occurred over the 7 day period. No increase in water holding capacity occurred during the 7 day period in any of the treatment. Suggesting, no treatment attracted moisture from the air into a porous soil under these greenhouse conditions.

The first study in the greenhouse provided a mean of 12.8% volumetric water content whereas, the second study provided 16.6% of water content. There were different means between the two studies; however each study is presented together due to similarities within the studies (Table 20). Water content differences occurred among treatments. Cascade and Hydretain had a mean ≥16%, whereas water provided a mean of 14%, and DI water provided ≥12% of volumetric water content percentage (Table 20). This suggests that the treatments of clay plus Hydretain or Cascade held more moisture/water than clay plus tap water or DI water. This correlates with literature, where these products help improve water retention, however, since no moisture was gained, humectants may not carry out all characteristics in all aspects of soils in the greenhouse. The analysis of multivariate correlations proved that there was a correlation between the residual water content, relative humidity and Cascade.

Water Content and Relative Humidity

Water content and relative humidity were analyzed as multivariate correlations to determine if there was a correlation of 0.0001 between these two and variables. Cascade provided a correlation between water content and relative humidity. No other treatments provided a correlation between the two. This agrees with the statements earlier stating that Cascade held the most water in the soil throughout the experiment.

Table 19. Relative humidity (RH) and volumetric water content (VWC) by day for a humectant, a soil wetting agent and different sources of water on a sandy clay native soil for the experiment conducted under laboratory humidity conditions for days 0-7 in Clemson, SC 2011.

Day	Relative Humidity	Water Content
	%	
0	30.55e*	30.00a
1	45.55d	25.09b
2	67.05a	21.62c
3	57.85b	19.54d
4	30.45e	16.39e
5	31.85e	13.92f
6	51.35cd	11.59g
7	52.35bc	9.52h

*Denotes values in columns followed by the same letter are not significantly different according to Fisher’s LSD (α=0.05) test.

Table 19.1 Relative humidity (RH) and water content for the greenhouse experiment conducted in a under controlled propagation and greenhouse humidity conditions for days 0-7 in Clemson, SC. 2011

Day	Relative Humidity	Water Content
	—————————————%—————————————	
0	59.85	30.00a*
1	59.50	23.75b
2	55.70	18.82c
3	64.25	15.07d
4	62.40	11.75e
5	73.70	8.90f
6	69.10	6.73g
7	67.10	4.41h

* Denotes a significant difference between water content and relative humidity according to Fisher's protected LSD α=0.05

Table 20. Mean volumetric water content (VWC) by treatment for a humectant, a soil wetting agent and different sources of water on a sandy clay native soil for the experiment conducted under laboratory humidity conditions for days 0-7 in Clemson, SC 2011.

Treatment	Water Content
Cascade Plus	20.18a*
Hydretain ES Plus	18.5b
Water	18.24b
DI Water	16.93c

*Denotes a significant difference between volumetric water content and treatments an values in columns followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.

Summary

Relative humidity can fluctuate based on weather conditions in a greenhouse environment which correlates with water content holding more or less for a day at a time suggesting that days can vary based on these observations. Although plant matter was not used in these greenhouse experiments we cannot directly state treatment effects, especially with Cascade where there are plant related relationships. However, if a porous soil does not attract water from the air, this suggests that it would not occur in the field.

APPENDIX A

Statistical Analysis Model Descriptions

Chapter 2: p. 9

[*Yij*k = *M*+T+I+T*I+R+T*I*R+D+D*T+D*I+D*I*T+Error]

Yijk=

T= Treatment

I=Irrigation Regimes

R= Replications

D= Days (Dates)

Error = amount of error in analysis

Chapter 3: p. 26

[*Yij*k = *M*+S+R(S)+T+T*R(S)+D+D*S+D*T+S*T+S*D*T+Error]

Yijk=

S= Study

R= Replications

R(S)= Replications nested with Study

T= Treatment

D= Days (Dates)

Error = amount of error in analysis

Chapter 4: p.41

[$Y_{ijk} = M$+S+R(S)+T+T*R(S)+D+D*S+D*T+S*T+S*D*T+Error]

Yijk=

S= Study

R= Replications

R(S)= Replications nested with Study

T= Treatment

D= Days (Dates)

Error = amount of error in analysis

Chapter 5: p.56

[$Y_{ijk} = M$+S+R(S)+T+T*R(S)+D+D*S+D*T+S*T+S*D*T+Error]

Yijk=

S= Study

R= Replications

R(S)= Replications nested with Study

T= Treatment

D= Days (Dates)

Error = amount of error in analysis

Chapter 6: p.65

[$Y_{ijk} = M$+S+R(S)+T+T*R(S)+D+D*S+D*T+S*T+S*D*T+Error]

Yijk=

S= Study

R= Replications

R(S)= Replications nested with Study

T= Treatment

D= Days (Dates)

Error= amount of error in analysis

Appendix B

Treatments, rates and timing of all applications

Appendix B. Treatments, rates, and timing of wetting agent and humectant applications applied to bermudagrass and bentgrass golf course putting greens, and bermudagrass athletic pitches for studies conducted April through August in Clemson, SC 2011.

Treatment	Application Rate (1000 sq ft)	Application Date	Application Interval
Non Irrigated Study	-	-	-
Hydretain ES Plus	266 ml	15 Apr	Initial
Cascade Plus†	237 ml	15 Apr	Initial + 7-10 day
Primer Select	237 ml	15 Apr	Initial
Localized Dry Spot Study	-	-	-
Hydretain ES Plus	266 ml	18 May	Initial
Cascade Plus	237 ml	18 May	Initial + 7-10 day
Primer Select	237 ml	18 May	Initial
Fairy Ring Study	-	-	-
Hydretain ES Plus	266 ml	23 May	Initial
Cascade Plus	237 ml	23 May	Initial + 7-10 day
Primer Select	237 ml	23 May	Initial
Primer Select +Prostar‡	237 ml+ 70 WP	23 May	Initital

Appendix B. Treatments, rates, and timing of wetting agent and humectant applications applied to bermudagrass and bentgrass golf course putting greens, and bermudagrass athletic pitches for studies conducted April through August in Clemson, SC 2011.

Treatment	Application Rate (1000sq ft)	Application Date	Application Interval
Irrigation Regime	-	-	-
Hydretain ES Plus	266 ml	26 May	Once
Cascade Plus†	237 ml	26 May	Initial + 7-10 day

† Cascade Plus requires a sequential application 7-10 days after initial treatment
‡ Flutalonil was applied 24 hrs after the Primer application and mowing was avoided.

Appendix C

Rainfall and Temperatures

Appendix C. Monthly total rainfall and average monthly temperature prior to application of the non-irrigated (NI) study on April 15, 2011 through August 30, 2011 during the fairy ring (FR), irrigation regimes (IR), and localized dry spot (LDS) studies.

2011	—Apr—	—May—	—June—	—July—	—August—
Rainfall (mm):	29.9	39.1	91.4	54.3	17.7
Temperature(°C):	25.0	27.8	33.4	34.0	34.3

Appendix D. Classification of water repellency based on the water droplet penetration time (WDPT) (Waltz, 2001)

WDPT (s)	Repellency
0-5	Wettable
5-60	Slight
60-600	Moderate to Severe
600-3600	Severe
>3600	Extreme

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