EFFECTS OF EVAPOTRANSPIRATION BASED IRRIGATION, DOUBLE MOWING, AND WETTING AGENT ON AN *Agrostis stolonifera var. palustris* PUTTING GREEN

By

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ABSTRACT

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State of Michigan legislators recommend the amount of irrigation water should be equal to total evapotranspiration (ET) since the last irrigation. To the common citizen this recommendation makes sense and is good policy, however, the legislation makes no differentiation between turfgrass species, mowing height, and soil type. The demand for optimum *Agrostis stolonifera var. palustris* (creeping bentgrass) putting greens requires golf courses' to manage inputs closely. Challenges include low mowing heights, summer heat stress, traffic, along with limitations in viable irrigation sources in order to manage creeping bentgrass. A factorial field experiment was designed on a Crenshaw putting green during the summers of 2010-2012 in East Lansing, MI comparing irrigation and mowing frequencies with and without a wetting agent. Daily irrigation replenishment of 30, 60, and 90% evapotranspiration (ET) measurements were compared for irrigation use efficacy while maintaining quality playing conditions and turfgrass health. Daily single and double mowing frequencies were compared for long-term aesthetics, pest populations, and playability when mowed at 0.3175 cm (0.125 in). Monthly applications of a wetting agent (Revolution®) were compared to untreated plots. Playability and overall aesthetics were characterized by weekly measurements of ball roll distance, percent volumetric water content (%VWC), and visual quality ratings (1-9). Annual soil measurements included water drop penetration (WDP) test and total microbial biomass (TMB).

Cumulative effects were averaged at the conclusion of the study, and data presented no significant differences among irrigation or wetting agent treatments for ball roll distance. Three year ball roll distance averages were significantly increased from 284.5 to 317.5 cm (112 to 125 inches) for single versus double mowed plots, respectively. Values for percent volumetric water content (%VWC) averaged 23.3, 33.1, and 35.6 for 30, 60, and 90% ET levels, respectively. Data of 60 and 90% were statistically similar, and were significantly greater than 30% ET in %VWC. Overall, double mowing and wetting agent application data presented no significant differences among treatments for %VWC. Visual quality averaged 5.6, 7.9, and 8.1 for 30, 60, and 90% ET levels, respectively. 60 and 90% were statistically similar in visual quality, and were significantly greater than 30% ET. Visual quality increased significantly from 6.7 to 7.9 with use of a wetting agent. Double mowing data presented no significant difference among treatments for visual quality. No significant differences in TMB were observed in soils treated with 30, 60 , or 90% ET daily irrigation from 2010 to 2012, with levels ranging from 29.9 to 60.1 μg g dry soil $^{-1}$ (Table 26). Daily double mowing and wetting agent application did not significantly affect TMB. However, during the driest season of 2012, TMB was significantly increased with the use of wetting agent at 30% ET replenishment. Data obtained from water drop penetration (WDP) tests resulted in significantly lower hydrophobicity in soil at the 0-1 cm depth below plant and/or thatch with wetting agent applications in all years (8-18 seconds). No differences were observed at sampling depths below 1 cm, and in response to irrigation or mowing treatments. Soil hydrophobicity reductions were more responsive to wetting agent applications than irrigation or mowing treatment effects.

To the one percent… Here I come!
&
To my loving family… “¡Ci Siamo!”

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PREFACE

This dissertation is submitted for the degree of Doctor of Philosophy at Michigan State University in East Lansing, MI. The research described herein was conducted under the supervision of Dr. T.A. Nikolai in the Department of Plant, Soil, and Microbial Sciences, Michigan State University, between September 2009 and December 2014.

This work is to the best of my knowledge original, except where acknowledgements and references are made to previous work. Neither this nor any substantially similar dissertation has been submitted for any degree, diploma or qualification at any university.

Rodney V. Tocco Jr.

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INTRODUCTION

Public concerns of water use led to 'Michigan's Water Use Reporting Program', initially mandated by Public Act (P.A.) 148 of 2003. This act is now Part 327, Great Lakes Preservation, of the Natural Resources and Environmental Protection Act, 1994 P.A. 451, as amended. Industries with the capacity to withdraw over 100,000 gallons per day (70 gallons per minute) are required to report to the state the water withdrawals and water conservation practices of their pumps, which applies to most Michigan golf courses. Irrigation is defined as water withdrawn and artificially applied on lands to assist in the growing of crops, pastures or in the maintenance of recreational lands such as golf courses and parks. Irrigation is responsible for 3% of total water use in Michigan (Water Use Report, 2006), and irrigation on golf courses is often viewed negatively even though it is a small portion of total irrigation. In 2006, 619 registered Michigan golf courses were involved with the 'Water Use Reporting Program'. Due to varying soils, turfgrass species, management practices, and micro-environments, this program did not establish baseline irrigation levels for golf courses in Michigan.

Proper watering of golf course putting greens has been debated since their inception. The amount of water and frequency of application depend on weather and on the physical properties of the soil including drainage (USGA Green Section Staff, 1922). Each green has unique requirements that are dictated by grass species, soils and microclimates. Putting this all together makes proper turfgrass irrigation the most difficult day-to-day agronomic decision a golf course superintendent makes (Beard, 2001). Deciding when and how much water to use is a delicate problem, especially on bentgrass, which suffers frequently from being too wet or too dry (Engel, 1982).

To ensure sustainability, people must have conservation awareness, and continue to be efficient and wise when using water resources (Norman, 2009). Stewardship of water quantity means using water as efficiently as possible while providing for the crop/landscape water needs (MDA GAAMP's, 2010). Ideally, irrigation regimes should be based on scientific principles and research; however, in most instances, intuition and experience are used to replenish water through irrigation. Technological advances such as potential evapotranspiration and time domain reflectometry measuring devices are available, but their effective application requires research.

Summer decline of creeping bentgrass (*Agrostis stolonifera* L.) putting greens is a common problem attributed to environmental and mechanical stresses (Dernoeden, 2002; Fry and Huang, 2004). Excessive watering is thought to not only increase costs associated with water consumption, but also to reduce environmental stress tolerance, predisposing turf to injury from mechanical stresses, cyanobacteria, moss, and disease (Beard, 1973; Dernoeden, 2002; Turgeon, 2008). Superintendents often use daily irrigation combined with hand watering and syringing practices when managing creeping bentgrass in the summer (Fu and Dernoeden, 2009). Optimal water supply is crucial to growing turfgrass, but has for a long time been determined by experience and "feel" due to a lack of soil science fundamentals combined with simple and reliable soil moisture measurement devices.

Public acts in the state of Michigan recommend evapotranspiration (ET) technology, stating that the amount of irrigation water to apply generally should be equal to the total ET since the last irrigation, minus any precipitation that occurred during the period (MDA GAAMP's, 2010). ET is the loss of water from the soil by evaporation and from the plants by transpiration (Beard, 1973). As much as 80 to 85% of the soil moisture depletion can be attributed to ET (Anonymous, 1933). Remaining plant-available soil moisture is dependent on retention and transmittance properties of the soil. To create putting green watering schedules based on ET, data are required to validate irrigation amounts at individual sites.

Water replenishment on turfgrass is most often estimated by an individual's experience at a site. Two contrasting irrigation methodologies known as deep and infrequent (DI) or light and frequent (LF) are practiced with the merits of both debated for decades. It is accepted that optimum irrigation frequency varies with plant species, climatic conditions, and soil types (Pessarakli, 2008). In general, DI irrigation is applied at leaf wilting point, whereas LF involves maintaining soil at field capacity (Fry and Huang, 2004). DI irrigation of creeping bentgrass at 4-day intervals showed significantly increased turf quality compared with irrigation every 1 or 2 days on a USGA-type root zone mixture (Jordan et al., 2003). However, studies involving fairway height creeping, colonial, and velvet bentgrass varieties reported significant decreases in turfgrass quality when maintained in deficit irrigation 60% ET versus 100% ET replenishment three times per week in North Brunswick, NJ, however, 100%ET was found not necessary to sustain plant growth (DaCosta and Huang, 2006). Some research across multiple root zones has shown that moderate drought stress, incurred by ET based irrigation, does not significantly affect summer performance of turfgrasses (Gibeault et al., 1985; Jordan et al., 2003; Fu et al., 2004; DaCosta and Huang, 2006). Gibeault et al. (1985) showed that the quality of turf irrigated at 80% ET was not significantly reduced compared to that irrigated at 100% ET. Fu et al. (2004) on silt loam soil reported achieving the same turf quality at 60 or 80% ET compared to well-watered turfgrass. DaCosta and Huang (2006) also showed an increase in irrigation to 80% of ET in three bentgrass cultivars on sandy loam soil had similar or higher quality than turf replaced with 100% ET. Minor differences in results may be attributable to soil types, mowing heights, micro-environments, and cultivar differences. Results from these studies indicate that water replenishment up to 100% ET is not necessary, and may also be detrimental to the health of a putting green.

Conversely, it is believed that minimizing irrigation on putting surfaces creates significantly longer ball roll distance or green speed (Rist and Gaussoin, 1997). Considering public concerns over water use, conflicting results from past irrigation studies, and the methods turfgrass managers use to estimate irrigation, there is a need for research on light and frequent ET-based irrigation on Michigan putting greens over subsequent seasons.

Double mowing influences turfgrass physiology and disease. Double mowing has negative physiological effects on turfgrass water use rate (Beard, 1973). A reduction in the leaf area causes a decrease in total transpiration rate per plant, but the water loss rate per unit of leaf area actually increases (Beard, 1973). Research on double mowing effects on creeping bentgrass diseases, has brought contradicting results. Double mowing can increase severity of diseases such as basal rot anthracnose by creating greater mechanical abrasion wounds allowing the pathogen to enter the plant more readily, especially with mowing heights below 0.4 cm (0.156 inch) (Rimelspach and Boehm, 2006). However, double mowing at 0.36 cm (0.140 in) and rolling, to duplicate green speeds achieved by a lower mowing height at 0.28 cm (0.110 in), has led to less severe incidences of anthracnose (Rossi, 2008). Despite negative physiological and disease effects, double mowing is the primary mechanical practice for increased ball roll distance.

Playability is often determined by visual quality (aesthetics) and ball roll distance (Moeller, 2013). Both are ways to assess leaf growth habit and smoothness (playability). No consistently accurate quantitative method measuring turfgrass visual quality has been perfected. However, ball roll distance can be quantitatively measured using a Stimpmeter (Thomas, 2001), developed by Edward Stimpson, Sr., 1935 or a Pelz Meter (Pelz et al., 2002). Either tool creates a repeatable incline plane, on which gravity acts to force a golf ball to roll down and then across the turfgrass surface for a measure of speed. “Putting green speed” or “speed” is a term commonly used to describe playability as a condition of the putting surface related to ball roll distance (Throssel, 1981). The distance a ball travels on the putting surface after rolling down the incline is measured and reported in feet (USGA, 2004). A 3-day study showed that double mowing significantly increased ball roll distance (Throssel, 1981). However, a 5-week study showed that reducing mowing frequency to 3 times per week combined with rolling on alternate days of mowing significantly increased putting green speed (Nikolai, 2005). Double mowing alone, or in combination with a groomer, also significantly increased ball roll distance (Danneberger et al., 1988), but Stahnke and Beard (1981) found that double mowing resulted in a slight decrease in ball roll distance in three of five tests. Considering that most previous studies were short-term and resulted in mixed results it is apparent that a long-term double mowing study may contribute to our understanding the mechanical practice has on turfgrass disease, localized dry spot, irrigation use, and playability.

Double mowing stress and reduced irrigation quantity may lead to localized dry spots (LDS) (Beard, 1973; Karnok, 2003). LDS are irregularly shaped areas of wilted or dead turfgrass (Tucker, et. al., 1990). Soil surfactant or wetting agent, which refers to a canopy-applied nonionic chemical surfactant designed to wet the soil profile are often used to alleviate LDS (Zontek and Kostka, 2012). Wetting agents are a common and effective management tool for conserving water, combating LDS, and reducing sodium build up in putting greens (Mitra, S., et al., 2004; Danneberger, 2008.; Gelernter & Stowell, 1997; Throssel, 2006.). Wetting agents are used to avoid or alleviate soil water repellency and/or reduce the surface tension of water to uniformly wet the soil rootzone, increasing infiltration rate (Anonymous, 2011). Even with these considerations, few publications exist evaluating the efficacy of wetting agents on LDS in temperate climates (Lyons, et. al., 2009). Non-ionic wetting agents are the most widely used because of their efficacy and general safety on turfgrass. The products attach to hydrophobic soil particle coatings with a non-polar end, and provide a polar site for water to re-coat areas improving water distribution (Karnok, K. et. al., 2004). It is hypothesized that with proper irrigation and application of a wetting agent, daily double mowing to increase playability is plausible without detrimental effects to turfgrass physiology.

Specific objectives of this research were to evaluate combinations of ET-based irrigation, daily double mowing, and a wetting agent applied at label rate and frequency. It was hypothesized that turfgrass quality would be maintained with the correct combination of irrigation level, mowing, and wetting agent. It was hypothesized that percent organic matter and microbial biomass would significantly increase in irrigated plots as water inputs increased. WDPT were hypothesized to show no differences in soil hydrophobicity with application of the wetting agent.

CHAPTER ONE:

EFFECTS OF 'ET' BASED IRRIGATION, DOUBLE MOWING, AND A WETTING AGENT ON A 'CRENSHAW' *Agrostis stolonifera var. palustris* (CREEPING BENTGRASS) PUTTING GREEN PLAYABILITY & QUALITY

ABSTRACT

Proper watering of creeping bentgrass (*Agrostis stolonifera var. palustris*) golf course putting greens has been debated since their inception. The amount of water and frequency of application depend upon the weather and in a large part upon the soil type and drainage (USGA Green Section Staff, 1922). Increased public concern of water use has led to "Michigan's Water Use Reporting Program". Irrigation on golf courses is only a portion of total state water use, but often has a negative connotation in the public eye. State of Michigan legislation is embracing evapotranspiration (ET) technology, and recommends the amount of irrigation water needed generally is equal to the total ET since the last irrigation minus any precipitation that occurred during the period. ET is the loss of water from the soil by evaporation and by transpiration from the plants. This research follows state-suggested daily ET regimes, but addresses the Michigan Water Use reports not establishing baseline irrigation levels for golf course putting greens in Michigan. ET-based irrigation is hypothesized to be an effective water conservation solution. Double mowing influences turfgrass physiology and disease. Double mowing has negative physiological effects on turfgrass water use rate. Research results on double mowing effects on creeping bentgrass over long periods of time are contradictory.

Double mowing is practiced solely because it enhances playability through increased speed. Putting green speed is a term commonly used to describe playability in terms of ball roll distance. The distance a ball travels on the putting surface after rolling down an incline is measured and reported in terms of feet. Previous research results are mixed and have not evaluated the impact of long-term daily double mowing on the plant and soil. This research analyzes the effects of season-long daily double mowing over three-years. With proper irrigation and application of a wetting agent, daily double mowing was hypothesized to increase playability without detrimental effects to turfgrass physiology.

Wetting agent refers to a canopy-applied nonionic chemical surfactant intended to increase the amount of plant available water in a soil profile. Wetting agents are widely used to help re-wet or prevent an area known to be hydrophobic. Hydrophobicity occurs when soil particles are coated in microbial-produced ‘humic’ acid films, which prevent water adsorption. Wetting agents reduce the hydrophobicity of soil particles and restore soil structure by re-establishing a healthy water and air continuum. Repeated use produces good soil structure by creation of a surface on the hydrophobic soil particle for water to reattach. Often organic matter and clays can slow infiltration of previously open pores between larger soil particles. Water is proposed to be distributed more evenly throughout the soil profile by wetting agents, in essence becoming more plant available (Kostka, 2000). Research is limited on the interactions between wetting agents, irrigation regimes, and double mowing over multiple years. The effects of long term usage on potential water conservation, while retaining turfgrass quality and playability at acceptable levels were evaluated.

INTRODUCTION

Proper watering for golf course putting greens has been debated since their inception, and for turfgrass managers, irrigation is the most important daily decision (Beard, 1973). Deciding when and how much water to use is a delicate problem, especially on bentgrass that suffers frequently from being too wet or too dry (Engel, 1982). The amount of water and frequency of application depend upon the weather and in a large part upon the character of the soil and drainage. Increased public awareness of water use has led to “Michigan’s Water Use Reporting Program” (Water Withdrawal Reports, 2006). Irrigation on golf courses is only a portion of total state water use, but often has a negative connotation in the public eye.

The Michigan Department of Environmental Quality (MI DEQ) Water Reports estimates that 3% of Michigan total water usage is attributed to irrigation, some of which is attributed to the previously mentioned registered Michigan golf courses (Water Reports, 2006). In 2003, the Michigan Department of Agriculture (MDA) passed the irrigation water-use reporting program into law via Public Act 148, which contains Generally Accepted Agricultural and Management Practices (GAAMPs). The 2010 update of the GAAMPs states that stewardship of water quantity means using water as efficiently as possible while providing for the crop or landscape water needs (MDA GAAMPs, 2010). The current Michigan recommendation states “The amount of irrigation water to apply is generally equal to the total evapotranspiration (ET) since the last irrigation minus any precipitation that occurred during that period” (MDA GAAMPs, 2010). While well intentioned by not being overly restricted, this level of replenishment has not been evaluated for creeping bentgrass, and in some instances may lead to over-irrigated turfgrass. Over-irrigation can lead to numerous turfgrass problems, including infestations of weeds, diseases and algae, ball marks, and foot-printing (Moeller, 2013). Evaluation of the varying levels of irrigation used in this study will be beneficial for Michigan golf courses by providing insights into the impact irrigation has on the putting surface and underlying root zone.

State of Michigan legislation (Public Act 148 of 2003, now Part 327 of P.A. 451 of 1994) is embracing evapotranspiration (ET) technology, and suggests the amount of irrigation water needed generally is equal to the total ET since the last irrigation minus any precipitation that occurred during the period. ET is the loss of water from the soil by evaporation and by transpiration from the plants (Beard, 1973). ET-based irrigation is hypothesized to be an effective water conservation solution, however, this only holds true with an understanding of the factors used to determine ET. In turfgrass cropping systems ET is at best an “estimate” in regard to water replenishment via irrigation. An objective of this research is to demonstrate that using 100% ET may be wasteful in terms of sustainability, and may also have a negative impact on plant physiology and the playing surface. In contrast, it is believed that withholding irrigation to lower ET increases ball roll distance, however, we hypothesize this premise is only true if irrigation is withheld to the point of wilt or localized dry spot (LDS) formation. If LDS is allowed to form, the putting surface is put into jeopardy and turfgrass manager’s employment is in jeopardy.

Double mowing putting greens are common practice during tournament play for increasing ball roll distance, but long-term application is often relinquished due to known negative physiological plant stresses and mower wear (Beard, 2005; Blais, 2002; Sweeney et. al., 2000). The term putting green speed is commonly used to describe the distance a ball travels on the putting surface after rolling down an incline, and is measured and reported in terms of feet (USGA, 2004). Previous studies, the longest five weeks in duration, show mixed results and have not looked at long-term daily double mowing regimes (Danneberger et al., 1988; Nikolai, 2005; Stahnke and Beard, 1981; Throssel, 1981). Double mowing cultural practices are hypothesized to influence turfgrass physiology and disease, and are believed to have negative physiological effects on turfgrass water use rate (Beard, 1973 and Karnok, 2003). However, research results of double mowing effects on creeping bentgrass are contradictory. This research analyzes the effects of season-long daily double mowing over a three-year duration. With proper irrigation and/or application of a wetting agent, daily double mowing is hypothesized to increase ball roll distance without detrimental effects to turfgrass physiology.

Wetting agent refers to a canopy-applied nonionic chemical surfactant intended to retain moisture in the soil profile. Wetting agents are widely used to help wet an area known to be hydrophobic. Hydrophobicity occurs when soil particles are coated in microbial-produced humic acid films, which prevent water adsorption (Bond, 1968; Bond and Harris, 1964; Savage, 1969). Wetting agents reduce the hydrophobicity of soil particles and restore soil structure by re-establishing a water and air continuum. Repeated use produces good soil structure by creation of a surface on the hydrophobic soil particle for water to reattach. Organic matter and clays may slow infiltration of previously open pores between larger soil particles. Companies propose water is distributed more evenly throughout the soil profile by wetting agents, in essence becoming more plant available (Kostka, 2000). Research is limited on the interactions among wetting agents, irrigation regimes, and mowing frequencies for potential in conserving water over multiple years.

An objective of this study was to determine if irrigation volume could be decreased and turfgrass aesthetics and playability retained with the use of daily ET replenishment combined with a soil surfactant under two mowing regimes. Combining management practices of daily ET irrigation, double mowing, and use of a wetting agent may reduce irrigation inputs while maintaining turfgrass quality and ball roll distance.

MATERIALS & METHODS

Research was conducted at the Hancock Turfgrass Research Center (HTRC) at Michigan State University in East Lansing, Michigan, on a 1296-m^2 (36 x 36 m) owosso-marlette sandy loam native soil experimental putting green, seeded with creeping bentgrass (*Agrostis stolonifera var. palustris*) 'Crenshaw' in 2003. The area comprises nine 148-m^2 (12 x 12 m) plots. In each plot Hunter PGP™ (Hunter Industries Inc., San Marcos, CA USA) irrigation heads were installed on each corner. The nine plots were arranged in a randomized complete block design with three replications of main plot evapotranspiration (ET) replenishment levels (30,60, and 90% daily ET). Daily ET data were determined by the onsite Enviro-weather station (East Lansing / MSUHTRC) of the Michigan Agricultural Weather Network (MAWN). Each irrigation plot contained four 2.1 m by 9.8 m (20.6-m^2) sub-plots. Sub-plot treatments consisted of daily single mowing double mowing treatments with and without a wetting agent treatment.

From May to October daily irrigation replenishment at 30%, 60%, and 90% evapotranspiration (ET) were applied. The system utilized the Penman-Monteith equation to estimate potential ET (Penman, 1948; Monteith, 1965). Applicable rainfall was subtracted from ET to determine the overall daily replenishment for each treatment per current Michigan Department of Agriculture (MDA) recommendations (MDA GAAMP's, 2010). Project technology provided by Spartan Distributors (Sparta, MI) included a TORO Site Pro 'Central' computer control center running software v. 2.2 (1996-2006 TORO Irrigation Division, Bloomington, MN USA) and TORO NSN Connect© (The Toro Company, Bloomington, MN USA) computer software controls daily irrigation levels from an onsite computer and remotely via an iPhone 4© (Apple, Inc., Cupertino, CA USA) application. Irrigation audits were conducted throughout each of the growing seasons to ensure distribution of uniformity of 0.7 or greater and obtain data for scheduling accurate run-times (Leinauer and Smeal, 2012). Audits were conducted by placing six AcuRite™ Magnifying Rain Gauge 00850 (Chaney Instrument Company, Lake Geneva, WI USA) within each plot for three separate full-turns of the irrigation heads. Water amounts were averaged, and run-times adjusted accordingly.

The area was mowed six days per week with a Toro 1000 (The Toro Company, Bloomington, MN USA) greens mower at a bench setting height of 0.125 in (0.3175 cm). Mowing treatment sub-plots within each plot were double-mowed daily. The second cut immediately followed the initial cut always in a different direction. The entire area was lightly topdressed with sand weekly throughout the growing season and was rolled three days per week with a DMI Speed Roller (DMI/IPAC Group, Amherst, NY) throughout the growing season to simulate golf course putting green management practices. With the exception of preventative *Sclerotinia homeocarpa* (Dollar spot) treatments, pesticides were applied on a curative basis to allow disease, insect, and weed observations. To prevent total loss of the highly susceptible 'Crenshaw' creeping bentgrass putting green, the fungicides chlorothalonil (Bravo Weather Stik, Syngenta) and propiconazole (Banner MAXX, Syngenta) were applied to preventatively control *Sclerotinia homeocarpa* throughout 2011 and 2012. Treatments that warranted a monthly application of a wetting agent (Revolution®, Aquatrols, Paulsboro, NJ USA) were applied at the labeled rate of 168 mL/ 90 m^2 (6 oz/ 1000 ft^2) from May-October.

Qualitative visual ratings were taken as described by the National Turfgrass Evaluation Program (NTEP) based on a 1 to 9 scale (Morris and Shearman, 2005). At the same time soil moisture measurements were obtained with time domain reflectometry (TDR) with a

FieldScout TDR 300 Soil Moisture Meter (Spectrum Technologies, Plainfield, IL) at the 3.8 cm tine depth. On the same day, ball roll distance was measured with a Pelz-meter (Pelz Golf, Spicewood, TX). The same investigator took all visual ratings for the duration of the study. In the fall of each year, soil samples were obtained with a 2.54 cm diameter probe to monitor percent organic matter content (OM). OM content was determined by loss on ignition (Hummel, 1993). Additional data collected from these plots included pest and localized dry spot counts.

All statistical analysis was performed in SAS v. 9.3 (SAS institute, Inc., Cary, NC) using Proc Gli-Mix Procedure. The model statement for each response variable analyzed all main factors evaluated and all possible interactions with the main treatment factors. All data analysis utilized mean separation conducted at alpha = 0.05. All data were analyzed separately within years, because the number of ratings/sampling dates varied each year in addition to time frame between dates. All parameters included the random term Replication*Irrigation Level*Mowing Frequency*Wetting Agent. Evaluations for the entire study area on a single day were pooled if there was not a significant interaction. All parameters in this study were analyzed in this manner. Variables were additionally analyzed/imported into ARM v. 8.3.4© (Gylling Data Management 1982-2011, Brookings, SD) and/or GraphPad Prism (GraphPad Software, Inc., La Jolla, CA) for visual figure development.

RESULTS & DISCUSSION

Data for ball roll distance, %VWC, and visual quality were collected 43 times between May 2010 and August 2012. Plots were rated 12 times from 19 July to 6 Oct., 2010; 16 times from 9 May to 29 Aug., 2011; 15 times from 8 May to 22 Aug., 2012. Time between collections were weekly with an average of seven +/- two days. Consideration for correlation in data was made by all collections occurring on the same day within a two-hour time frame.

Total irrigation amounts applied each day were calculated based on weather data (Appendix A) from approximately May to October each season. In 2010, total daily irrigation applied for 30, 60, and 90% ET were 11.25, 22.63, and 33.91 cm, respectively. In 2011, total daily irrigation applied for 30, 60, and 90% ET were 15.44, 30.63, and 46.05 cm, respectively. In 2012, total daily irrigation applied for 30, 60, and 90% ET were 17.27, 34.29, and 51.56 cm, respectively.

Karcher et. al. (2001) found there was no significant difference in golfer green speed perception within six inches of one another. Irrigation level is often scrutinized for potential effects on ball roll distance. Analysis of variance means for each date of ball roll distance as affected by irrigation are shown in Tables 1.1 through 3.3. Interactions, if observed, are shown in Tables 4.1 and 4.2.

On one date in 2010, one date in 2011, and two dates in 2012, irrigation had a significant effect on ball roll distance (Tables 1.1 to 3.3). However, on all other dates from 2010 to 2012, the response to irrigation effects on ball roll distance were not significant. This suggests no significant differences in irrigation replenishment to 30, 60, and 90% ET effects on ball roll distance. Overall, average ball roll distance showed no significant differences between

30, 60, and 90% ET irrigation treatments (P=0.0756). Year significantly affected average ball roll distance (P<0.0001). The year difference is attributed to progression in application of treatments over time. 2010 was the year of experiment inception, whereas 2012 presented the culmination of three successive years of treatments. 2011 was average for results in comparison to 2010 and 2012, which is represented in observed ball roll distances.

Daily values shown in Figure 1 are averages of mowing and wetting agent for each irrigation treatment, and show the trend effects of irrigation on ball roll distance over each season.

Double mowing significantly increased ball roll distance for nearly all dates for the duration of the study. Analysis of variance means for each date of ball roll distance as affected by mowing are shown in Tables 1.1 through 3.3. Interactions, if observed, are shown in Table 4.1.

In 2010-2012, average ball roll distance showed significant increases when daily double (2X) mowing versus traditional single daily (1X) mowing (P<0.0001). Year significantly affected average ball roll distance (P<0.0001), with a steady increase in speeds as the study progressed. The year difference is most likely attributed to the management of the plots over time. An interaction between mowing and year was observed to be significant (P<0.0001), suggesting that mowing may not be the sole factor attributing to ball roll distance increases (Table 4.1).

Daily values shown in Figure 2 are averages of irrigation and wetting agent for each mowing treatment, and show the trend effects of mowing on ball roll distance over each season. Figure 2 emphasizes playability as determined by ball roll distance was effected frequently with daily double mowing, and suggests significant increases would continue.

Wetting agent had effect on ball roll distance on one, two, and one date(s) in 2010-12, respectively. Analysis of variance means for each date of ball roll distance as affected by wetting agent are shown in Tables 1.1 through 3.3. Interactions, if observed, are shown in Table 4.2.

In 2010-2012, average ball roll distance showed no significant differences between untreated and wetting agent treatments ($P=0.9460$). Year significantly affected average ball roll distance ($P<0.0001$). The year difference is most likely attributed to management over time. Daily or overall seasonal averages of ball roll distance did not differ with application of wetting agent. Ball roll distances are maintained in creeping bentgrass putting greens with long-term use of wetting agent.

Table 1.1. 2010 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on average ball roll distance in meters at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average Ball Roll Distance in Meters 2010					
Irrigation (IRR)	19 July	27 July	3 Aug	10 Aug	16 Aug	23 Aug
30% ET	2.06	1.94	2.39	2.45	2.50	2.42
60% ET	2.08	1.94	2.39	2.43	2.42	2.46
90% ET	2.05	1.93	2.71	2.37	2.42	2.41
Significance	NS	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS	NS
Mowing (MOW)						
1X daily	2.00b	2.02a	2.31	2.35b	2.39b	2.34b
2X daily	2.12a	1.85b	2.68	2.49a	2.51a	2.52a
Significance	***	***	NS	***	*	***
LSD (0.05)	0.05	0.06	NS	0.05	0.11	0.08
Wet-Agent (WA)						
Untreated	2.07	1.96	2.61	2.45a	2.45	2.44
1X monthly	2.06	1.91	2.39	2.39b	2.44	2.42
Significance	NS	NS	NS	*	NS	NS
LSD (0.05)	NS	NS	NS	0.05	NS	NS

		Mean Square and Pr>F											
Source	df												
Replication	2	0.34	0.1678	2.18	0.0029	15.46	0.4503	0.73	0.0407	0.28	0.7554	0.07	0.8699
IRR	2	0.12	0.2611	0.04	0.7570	16.21	0.4640	0.80	0.3170	0.93	0.3610	0.35	0.0731
Error for IRR	4	0.06	0.8384	0.12	0.7595	17.31	0.4666	0.52	0.0630	0.70	0.6036	0.06	0.9689
MOW	1	5.89	<.0001	10.26	<.0001	45.94	0.1329	6.37	<.0001	5.33	0.0335	10.57	0.0002
WA	1	0.02	0.7105	0.67	0.1300	15.77	0.3686	1.40	0.0144	0.06	0.8158	0.29	0.4497
IRRxMOW	2	0.08	0.6263	0.09	0.7107	17.83	0.4011	0.03	0.8665	0.54	0.5920	0.00	0.9987
IRRxWA	2	0.05	0.7663	0.55	0.1541	19.52	0.3694	0.39	0.1598	0.03	0.9736	0.36	0.4945
MOWxWA	1	0.02	0.7653	0.12	0.5021	18.97	0.3251	0.04	0.6644	0.10	0.7530	0.00	0.9039
IRRxMOWxWA	2	0.16	0.4196	0.13	0.6143	21.63	0.3338	0.54	0.0841	0.46	0.6423	0.45	0.4150
Error	18	0.17		0.27		18.54		0.19		1.00		0.49	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 1.2. 2010 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on average ball roll distance in meters at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Ball Roll Distance in Meters 2010											
Irrigation (IRR)		31 August		7 Sept		14 Sept		20 Sept		29 Sept		6 Oct	
30% ET		2.44		2.27a		2.21		2.17		2.32		2.16	
60% ET		2.38		2.18b		2.12		2.13		2.25		2.14	
90% ET		2.35		2.11c		2.14		2.09		2.27		2.11	
Significance		NS		*		NS		NS		NS		NS	
LSD (0.05)		NS		0.11		NS		NS		NS		NS	
Mowing (MOW)													
1X daily		2.27b		2.09b		2.08b		2.06b		2.14a		2.09b	
2X daily		2.50a		2.28a		2.24a		2.21a		2.42b		2.17a	
Significance		***		***		***		***		***		**	
LSD (0.05)		0.04		0.06		0.05		0.06		0.05		0.05	
Wet-Agent (WA)													
Untreated		2.39		2.19		2.19a		2.15		2.28		2.16a	
1X monthly		2.38		2.19		2.13b		2.12		2.28		2.11b	
Significance		NS		NS		*		NS		NS		*	
LSD (0.05)		NS		NS		0.05		NS		NS		0.05	
		Mean Square and Pr>F											
Source	df												
Replication	2	0.43	0.0923	2.48	0.0023	0.05	0.7602	0.20	0.5224	0.34	0.2048	0.11	0.6094
IRR	2	1.01	0.1477	2.80	0.0483	0.98	0.2860	0.65	0.2100	0.71	0.4171	0.31	0.4504
Error for IRR	4	0.31	0.1392	0.39	0.2786	0.57	0.0439	0.27	0.4689	0.65	0.0335	0.32	0.2702
MOW	1	18.54	<.0001	12.03	<.0001	8.51	<.0001	7.77	<.0001	26.78	<.0001	2.34	0.0047
WA	1	0.08	0.4810	0.00	0.9644	1.15	0.0230	0.36	0.2861	0.00	0.9683	1.03	0.0457
IRRxMOW	2	0.15	0.4111	0.18	0.5346	0.56	0.0743	0.02	0.9202	0.17	0.4296	0.08	0.7114
IRRxWA	2	0.04	0.7611	0.35	0.3123	0.01	0.9269	0.13	0.6442	0.40	0.1597	0.11	0.6173
MOWxWA	1	0.16	0.3261	0.03	0.7408	0.00	0.9048	0.03	0.7575	0.03	0.7233	0.39	0.2055
IRRxMOWxWA	2	0.04	0.7930	0.19	0.5303	0.35	0.1802	0.42	0.2658	0.24	0.3174	0.07	0.7237
Error	18	0.16		0.28		0.18		0.29		0.19		0.22	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 2.1. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on ball roll distance in meters at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Ball Roll Distance in Meters 2011											
Irrigation (IRR)		9 May		23 May		1 June		6 June		14 June		21 June	
30% ET		2.70		2.34		2.72		2.94		2.62		2.45	
60% ET		2.56		2.27		2.69		2.98		2.67		2.46	
90% ET		2.72		2.33		2.65		3.00		2.68		2.55	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
Mowing (MOW)													
1X daily		2.61		2.19b		2.56b		2.84b		2.50b		2.35b	
2X daily		2.71		2.43a		2.81a		3.10a		2.81a		2.62a	
Significance		NS		***		***		***		***		***	
LSD (0.05)		NS		0.10		0.13		0.06		0.09		0.04	
Wet-Agent (WA)													
Untreated		2.65		2.33		2.75		3.03a		2.68		2.47	
1X monthly		2.67		2.29		2.63		2.91b		2.64		2.50	
Significance		NS		NS		NS		**		NS		NS	
LSD (0.05)		NS		NS		NS		0.06		NS		NS	
		Mean Square and Pr>F											
Source	df												
Replication	2	0.31	0.7286	0.32	0.6570	1.56	0.3148	1.80	0.0140	0.32	0.6407	0.19	0.1903
IRR	2	3.60	0.4949	0.65	0.4944	0.66	0.3595	0.50	0.3795	0.47	0.1046	1.26	0.2525
Error for IRR	4	4.28	0.0113	0.76	0.4146	0.49	0.8128	0.40	0.3409	0.11	0.9551	0.64	0.0025
MOW	1	3.02	0.0931	21.41	<.0001	21.98	0.0006	22.81	<.0001	35.47	<.0001	25.69	<.0001
WA	1	0.09	0.7672	0.40	0.4706	4.94	0.0634	4.65	0.0014	0.37	0.4790	0.29	0.1101
IRRxMOW	2	5.20	0.0145	1.38	0.1814	0.97	0.4776	0.31	0.4090	0.17	0.7858	0.26	0.1029
IRRxWA	2	1.28	0.2895	1.50	0.1585	0.56	0.6489	0.21	0.5472	0.34	0.6284	0.11	0.3535
MOWxWA	1	0.70	0.4050	1.20	0.2161	0.00	0.9907	0.56	0.2086	1.34	0.1838	0.17	0.2107
IRRxMOWxWA	2	0.05	0.9517	1.80	0.1152	2.23	0.1991	1.12	0.0562	0.98	0.2722	0.56	0.0137
Error	18	0.96		0.74		1.26		0.33		0.70		0.10	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 2.2. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on ball roll distance in meters at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average Ball Roll Distance in Meters 2011					
Irrigation (IRR)	27 June	5 July	12 July	19 July	25 July	4 August
30% ET	2.09	2.46a	2.36	2.33	1.92	2.59
60% ET	2.17	2.41b	2.30	2.28	1.87	2.55
90% ET	2.15	2.37b	2.35	2.28	1.87	2.54
Significance	NS	*	NS	NS	NS	NS
LSD (0.05)	NS	0.04	NS	NS	NS	NS
Mowing (MOW)						
1X daily	2.02b	2.29b	2.26b	2.24b	1.82b	2.45b
2X daily	2.25a	2.54a	2.42a	2.36a	1.96a	2.68a
Significance	***	***	***	**	***	***
LSD (0.05)	0.04	0.06	0.08	0.08	0.04	0.05
Wet-Agent (WA)						
Untreated	2.14	2.39	2.34	2.31	1.89	2.57
1X monthly	2.13	2.44	2.33	2.29	1.89	2.56
Significance	NS	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS	NS

Source	df	Mean Square and Pr>F											
Replication	2	0.04	0.7796	0.20	0.5586	0.49	0.3962	1.50	0.0793	0.14	0.2775	0.20	0.3804
IRR	2	0.73	0.4731	0.92	0.0170	0.47	0.3989	0.32	0.4908	0.39	0.1285	0.36	0.5886
Error for IRR	4	0.81	0.0069	0.07	0.9301	0.40	0.5348	0.38	0.5786	0.11	0.3938	0.59	0.0488
MOW	1	18.86	<.0001	22.28	<.0001	8.68	0.0006	5.37	0.0046	7.66	<.0001	17.77	<.0001
WA	1	0.03	0.6629	0.82	0.1326	0.03	0.8266	0.06	0.7316	0.00	0.9474	0.04	0.6430
IRRxMOW	2	0.32	0.1668	0.00	0.9954	0.40	0.4622	0.00	0.9967	0.16	0.2243	0.01	0.9440
IRRxWA	2	0.09	0.5865	0.08	0.7989	0.06	0.8954	0.01	0.9804	0.06	0.5740	0.59	0.0773
MOWxWA	1	0.03	0.6818	0.05	0.6992	0.17	0.5664	2.03	0.0625	0.17	0.2143	0.02	0.7555
IRRxMOWxWA	2	0.00	0.9827	0.07	0.8205	0.04	0.9330	0.12	0.7880	0.15	0.2466	0.05	0.7657
Error	18	0.16		0.33		0.50		0.51		0.10		0.20	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 2.3. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on ball roll distance in meters at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Ball Roll Distance in Meters 2011							
Irrigation (IRR)		10 August		15 August		22 August		29 August	
30% ET		2.48		2.67		2.70		2.45	
60% ET		2.40		2.68		2.72		2.45	
90% ET		2.45		2.67		2.73		2.49	
Significance		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS	
Mowing (MOW)									
1X daily		2.34b		2.59b		2.61b		2.35b	
2X daily		2.55a		2.76a		2.82a		2.58a	
Significance		***		***		***		***	
LSD (0.05)		0.10		0.07		0.07		0.06	
Wet-Agent (WA)									
Untreated		2.47		2.69		2.70		2.47	
1X monthly		2.42		2.66		2.73		2.46	
Significance		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS	
		Mean Square and Pr>F							
Source	df								
Replication	2	2.01	0.0911	2.74	0.0033	2.17	0.0115	0.01	0.9582
IRR	2	0.87	0.7416	0.05	0.9630	0.09	0.8607	0.26	0.3375
Error for IRR	4	2.70	0.0232	1.18	0.0291	0.58	0.2324	0.18	0.6875
MOW	1	15.58	0.0002	10.55	<.0001	15.94	<.0001	19.72	<.0001
WA	1	0.94	0.2734	0.21	0.4478	0.21	0.4629	0.12	0.5488
IRRxMOW	2	0.51	0.5086	0.96	0.0879	0.09	0.7804	0.24	0.4905
IRRxWA	2	0.75	0.3809	0.13	0.6834	0.44	0.3292	1.28	0.0364
MOWxWA	1	0.04	0.8257	0.13	0.5477	1.23	0.0874	0.01	0.8602
IRRxMOWxWA	2	0.80	0.3575	0.45	0.2963	0.24	0.5338	0.05	0.8704
Error	18	0.73		0.34		0.38		0.32	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 3.1. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on ball roll distance in meters at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Ball Roll Distance in Meters 2012											
Irrigation (IRR)		8 May		17 May		24 May		30 May		6 June		13 June	
30% ET		2.84		2.78b		2.71		2.74		2.91		2.96	
60% ET		2.87		2.90a		2.69		2.80		2.96		3.04	
90% ET		2.90		2.85ab		2.74		2.84		2.97		3.07	
Significance		NS		*		NS		NS		NS		NS	
LSD (0.05)		NS		0.08		NS		NS		NS		NS	
Mowing (MOW)													
1X daily		2.70b		2.65b		2.59b		2.65b		2.78b		2.85b	
2X daily		3.03a		3.04a		2.84a		2.94a		3.12a		3.20a	
Significance		***		***		***		***		***		***	
LSD (0.05)		0.07		0.10		0.11		0.09		0.07		0.08	
Wet-Agent (WA)													
Untreated		2.90		2.84		2.75		2.80		2.97		3.04	
1X monthly		2.84		2.84		2.69		2.79		2.93		3.01	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
		Mean Square and Pr>F											
Source	df												
Replication	2	0.53	0.2587	1.63	0.1393	0.13	0.8736	1.22	0.2116	0.08	0.8249	0.15	0.7331
IRR	2	0.37	0.2858	1.99	0.0242	0.24	0.7176	1.23	0.4214	0.50	0.6182	1.53	0.4930
Error for IRR	4	0.21	0.6807	0.18	0.9073	0.67	0.5889	1.14	0.2230	0.92	0.0898	1.81	0.0220
MOW	1	39.13	<.0001	55.84	<.0001	21.53	0.0001	28.98	<.0001	40.70	<.0001	41.66	<.0001
WA	1	1.06	0.1044	0.02	0.8710	1.26	0.2600	0.01	0.9017	0.50	0.2715	0.35	0.4044
IRRxMOW	2	0.20	0.5896	1.09	0.2569	1.48	0.2312	0.13	0.8422	1.23	0.0652	0.38	0.4687
IRRxWA	2	0.06	0.8407	1.04	0.2696	0.64	0.5170	0.67	0.4137	0.05	0.8915	0.25	0.6039
MOWxWA	1	0.41	0.3013	3.79	0.0361	0.31	0.5711	1.63	0.1501	0.10	0.6088	0.09	0.6699
IRRxMOWxWA	2	0.27	0.4938	0.71	0.4044	0.74	0.4694	1.87	0.1014	0.05	0.8724	0.13	0.7640
Error	18	0.36		0.74		0.94		0.72		0.39		0.48	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 3.2. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on ball roll distance in meters at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Ball Roll Distance in Meters 2012											
Irrigation (IRR)		21 June		27 June		2 July		11 July		19 July		31 July	
30% ET		3.10		3.23		3.05		3.48		2.84		2.93a	
60% ET		3.25		3.26		3.10		3.11		2.87		2.70b	
90% ET		3.17		3.29		3.08		3.13		2.91		2.64b	
Significance		NS		NS		NS		NS		NS		**	
LSD (0.05)		NS		NS		NS		NS		NS		0.14	
Mowing (MOW)													
1X daily		3.00b		3.04b		2.93b		3.08b		2.73b		2.62b	
2X daily		3.35a		3.48a		3.23a		3.41a		3.02a		2.89a	
Significance		***		***		***		***		***		***	
LSD (0.05)		0.10		0.08		0.07		0.14		0.05		0.07	
Wet-Agent (WA)													
Untreated		3.17		3.27		3.11a		3.26		2.87		2.78	
1X monthly		3.18		3.26		3.04b		3.23		2.88		2.73	
Significance		NS		NS		*		NS		NS		NS	
LSD (0.05)		NS		NS		0.07		NS		NS		NS	
		Mean Square and Pr>F											
Source	df												
Replication	2	0.44	0.5845	0.20	0.6997	0.15	0.6501	5.95	0.0487	0.82	0.0284	0.51	0.2923
IRR	2	2.49	0.6238	0.43	0.2892	0.37	0.3359	21.08	0.1897	0.58	0.4225	11.49	0.0084
Error for IRR	4	4.67	0.0032	0.25	0.7675	0.26	0.5697	8.14	0.0074	0.54	0.0532	0.58	0.2395
MOW	1	42.76	<.0001	68.98	<.0001	31.21	<.0001	38.91	0.0001	29.10	<.0001	27.15	<.0001
WA	1	0.03	0.8480	0.09	0.6968	1.76	0.0357	0.35	0.6527	0.02	0.7587	1.12	0.1044
IRRxMOW	2	0.13	0.8473	0.30	0.5816	0.27	0.4669	1.59	0.4027	0.01	0.9368	0.29	0.4797
IRRxWA	2	0.19	0.7854	0.45	0.4521	0.25	0.4977	2.50	0.2477	0.84	0.0260	0.81	0.1496
MOWxWA	1	0.27	0.5669	0.14	0.6204	0.00	0.8931	3.18	0.1825	0.16	0.3722	0.38	0.3331
IRRxMOWxWA	2	0.56	0.5035	0.66	0.3209	0.17	0.6110	0.16	0.9084	0.07	0.6979	0.23	0.5591
Error	18	0.79		0.55		0.34		1.66		0.19		0.38	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 3.3. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on ball roll distance in meters at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Ball Roll Distance in Meters 2012					
Irrigation (IRR)		8 August		14 August		22 August	
30% ET		3.54		2.90		3.52	
60% ET		3.10		2.85		3.39	
90% ET		3.16		2.83		3.45	
Significance		NS		NS		NS	
LSD (0.05)		NS		NS		NS	
Mowing (MOW)							
1X daily		3.06b		2.75b		3.31b	
2X daily		3.47a		2.98a		3.59a	
Significance		***		***		***	
LSD (0.05)		0.17		0.05		0.09	
Wet-Agent (WA)							
Untreated		3.36a		2.87		3.43	
1X monthly		3.17b		2.86		3.47	
Significance		*		NS		NS	
LSD (0.05)		0.17		NS		NS	
		Mean Square and Pr>F					
Source	df						
Replication	2	2.39	0.3719	0.06	0.7697	1.56	0.1199
IRR	2	27.88	0.3890	0.62	0.1212	1.86	0.3057
Error for IRR	4	23.11	0.0002	0.17	0.5375	1.15	0.1803
MOW	1	57.51	<.0001	17.76	<.0001	28.51	<.0001
WA	1	13.15	0.0275	0.00	0.9082	0.28	0.5193
IRRxMOW	2	7.39	0.0630	0.89	0.0298	0.45	0.5184
IRRxWA	2	6.64	0.0805	0.50	0.1181	0.82	0.3102
MOWxWA	1	0.00	0.9654	0.00	0.9847	0.01	0.8883
IRRxMOWxWA	2	0.64	0.7589	0.36	0.1998	0.15	0.7987
Error	18	2.28		0.21		0.65	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 4.1. 2011-2012 green speeds (meters) as affected by irrigation and mowing† (MOW) at the Hancock Turfgrass Research Center in East Lansing, MI.

	9 May 2011		14 August 2012	
Irrigation	1X MOW	2X MOW	1X MOW	2X MOW
30% ET	2.59c	2.81ab	2.79c	3.02a
60% ET	2.63bc	2.48c	2.70c	3.00a
90% ET	2.62c	2.83a	2.77c	2.90b
LSD $_{(0.05)}$‡	0.19		0.09	
LSD $_{(0.05)}$§	0.27		0.12	

† Mowing was applied six days per week from May till September at 0.3175-cm

‡ Between mowing means at same irrigation level on the single date listed above.

§ Among irrigation level at the same or different mowing on the single date listed above.

Table 4.2. 2011-2012 green speeds (meters) as affected by irrigation and wetting agent† (WA) at the Hancock Turfgrass Research Center in East Lansing, MI.

	29 August 2011		17 May 2012		19 July 2012	
Irrigation	WA	No WA	WA	No WA	WA	No WA
30% ET	2.42b	2.48ab	2.80ab	2.75b	2.89a	2.79b
60% ET	2.40b	2.50ab	2.85ab	2.95a	2.84ab	2.90a
90% ET	2.54a	2.44ab	2.89ab	2.82ab	2.90a	2.92a
LSD $_{(0.05)}$ ‡	0.11		0.17		0.08	
LSD $_{(0.05)}$ §	0.15		0.24		0.12	

† Wetting agent was applied monthly from May till September with Revolution® from Aquatrols, Inc. (Paulsboro, N.J) at 1.87-ml/m^2.

‡ Between wetting agent means at same irrigation level on the single date listed above.

§ Among irrigation level at the same or different wetting agent on the single date listed above.

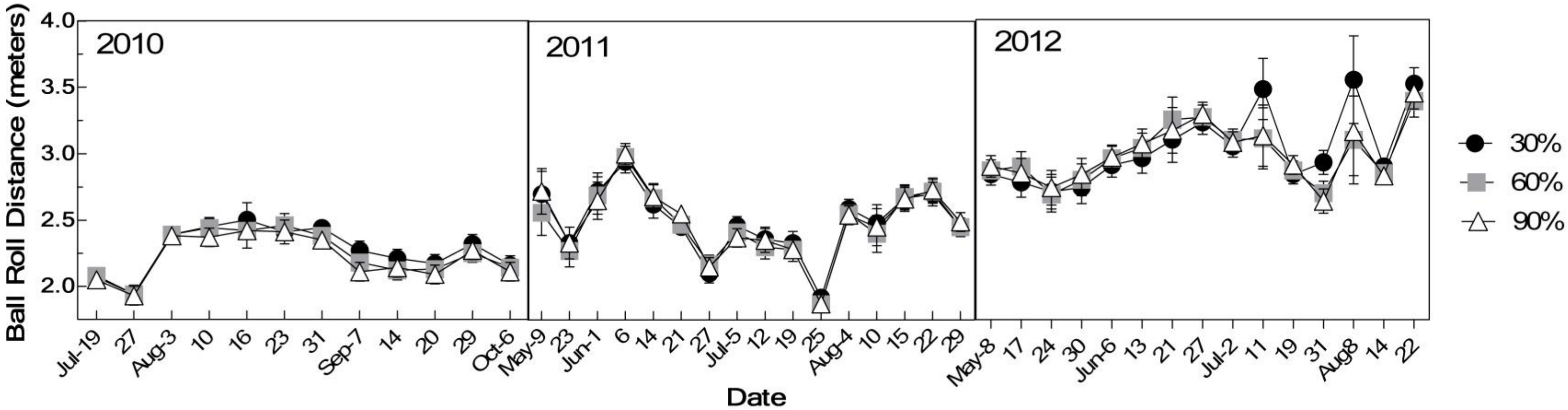

Figure 1. Irrigation effects on ball roll distance in 2010-12. Values are averages of mowing and wetting agent for each irrigation treatment. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at α=0.05. N=18.

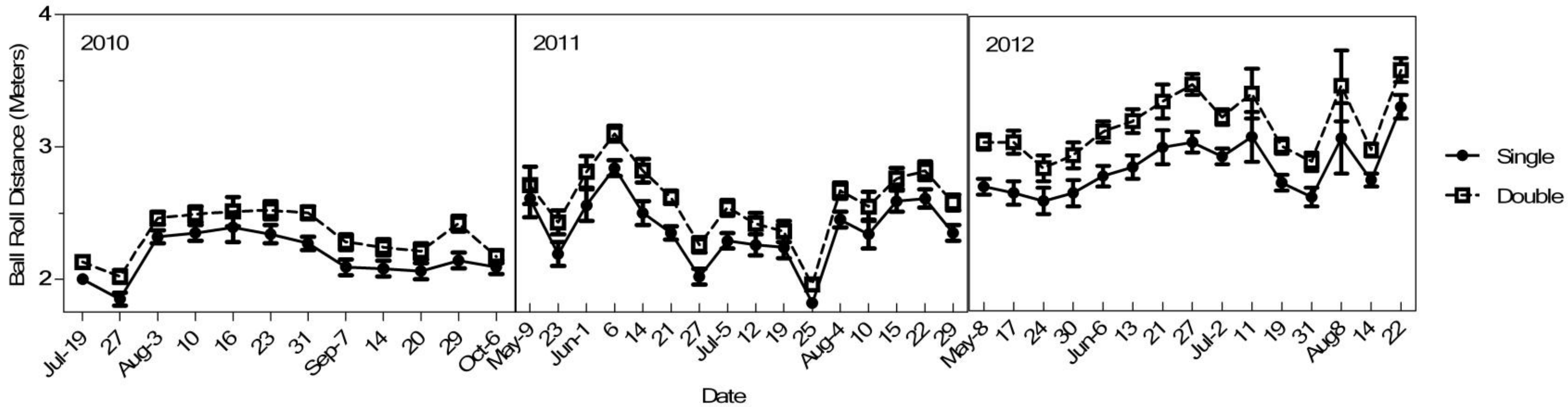

Figure 2. Mowing effects on ball roll distance from 2010-12. Values are averages of irrigation and wetting agent for each mowing treatment. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at α=0.05. N=18.

Technological advancements in time domain reflectometry (TDR) devices have given way to affordable means of measuring percent volumetric water content (%VWC). Analysis of variance means for each date of percent volumetric water (%VWC) as affected by irrigation are shown in Tables 5.1 through 7.3. On every date significance was observed, 60 and 90% ET were statistically similar, and greater in %VWC than 30% ET. Interactions, if observed, are shown in Tables 8.1 and 8.2.

In 2010-2012, %VWC showed significant differences between 30, 60, and 90% ET irrigation treatments ($P<0.0001$). 60 and 90% ET were statistically similar, and were greater than 30% ET each year.

Daily %VWC (Figure 3) numbers are averages of mowing and wetting agent values for each irrigation treatment. Irrigation had significant effects on %VWC over each season for all but one date in the three-year study. In 2012, 30% ET consistently showed significant reduction in overall %VWC; however, there was no significant difference between 60% ET and 90% ET in regards to %VWC. The use of time domain reflectometry to determine %VWC is an important technology to utilize for gauging water replenishment levels on putting greens each day (Kieffer and O'Connor, 2007).

For 2010-2012, mowing and wetting agent treatments had no significant effect on %VWC. Analysis of variance means for each date of percent volumetric water (%VWC) as affected by mowing or wetting agent are shown in Tables 5.1 through 7.3. %VWC values were statistically reduced with application of a wetting agent on two dates in 2010 and five dates in 2011, but then significantly increased on two dates in 2012 (Tables 5.1 to 7.3). Interactions, if observed, are shown in Tables 8.1 and 8.2. Interactions between irrigation and wetting agent in

Table 8.1 suggest the wetting agent helped the soil drain better at 90% ET, while holding more moisture at the 30% ET with no significant difference at 60% ET replenishment regimes.

Table 5.1. 2010 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on percent volumetric water content (%VWC) at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average Volumetric Water Content (%VWC) 2010					
Irrigation (IRR)	19 July	27 July	3 Aug	10 Aug	16 Aug	23 Aug
30% ET	28.81b	29.05	15.23b	18.08	13.42b	14.62b
60% ET	34.15a	31.49	18.33a	22.02	16.62ab	19.58a
90% ET	34.88a	31.44	20.09a	22.18	17.98a	21.05a
Significance	**	NS	*	NS	*	**
LSD (0.05)	2.98	NS	2.39	NS	3.38	2.95
Mowing (MOW)						
1X daily	33.05	30.80	18.02	21.22	16.38	18.71
2X daily	32.18	30.52	17.74	20.30	15.63	18.12
Significance	NS	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS	NS
Wet-Agent (WA)						
Untreated	32.63	30.61	18.20	20.76	16.07	18.75
1X monthly	32.60	30.71	17.56	20.76	15.94	18.07
Significance	NS	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS	NS

		Mean Square and Pr>F											
Source	df												
Replication	2	21.46	0.0105	9.84	0.0104	19.50	0.0082	6.22	0.1107	14.54	0.0204	20.35	0.0070
IRR	2	131.64	0.0090	23.19	0.2186	72.80	0.0119	64.60	0.1117	65.77	0.0453	136.26	0.0082
Error for IRR	4	6.92	0.1523	10.18	0.0027	4.45	0.2588	16.21	0.0020	8.89	0.0475	6.79	0.1088
MOW	1	6.86	0.1854	0.67	0.5319	0.73	0.6310	7.51	0.0998	4.96	0.2139	3.18	0.3225
WA	1	0.01	0.9587	0.08	0.8262	3.67	0.2887	0.00	0.9967	0.14	0.8284	4.18	0.2590
IRRxMOW	2	0.95	0.7730	0.42	0.7808	0.58	0.8306	0.55	0.8043	2.31	0.4757	2.40	0.4735
IRRxWA	2	4.90	0.2834	6.63	0.0364	2.62	0.4425	3.68	0.2553	1.61	0.5930	5.01	0.2238
MOWxWA	1	6.62	0.1930	1.60	0.3379	0.02	0.9298	1.39	0.4646	0.05	0.8971	3.25	0.3173
IRRxMOWxWA	2	0.76	0.8131	3.09	0.1833	1.00	0.7269	1.32	0.5984	1.43	0.6273	2.51	0.4580
Error	18	3.62		1.65		3.07		2.49		2.98		3.07	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 5.2. 2010 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on volumetric water content (%VWC) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Volumetric Water Content (%VWC) 2010											
Irrigation (IRR)		31 August		7 Sept		14 Sept		20 Sept		29 Sept		6 Oct	
30% ET		10.40b		14.72b		12.75b		17.27		15.19		14.54b	
60% ET		16.00a		18.10a		16.17a		19.37		20.94		18.08a	
90% ET		19.01a		19.68a		16.75a		24.34		18.91		18.86a	
Significance		*		*		*		NS		NS		**	
LSD (0.05)		4.91		2.51		2.85		NS		NS		1.33	
Mowing (MOW)													
1X daily		15.19		17.48		15.17		18.78		19.04		17.02	
2X daily		15.09		17.51		15.27		21.88		17.65		17.31	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
Wet-Agent (WA)													
Untreated		15.69		18.18		15.46		22.12		17.72		17.56a	
1X monthly		14.59		16.81		14.98		18.54		18.97		16.76b	
Significance		NS		*		NS		NS		NS		*	
LSD (0.05)		NS		1.04		NS		NS		NS		0.76	
		Mean Square and Pr>F											
Source	df												
Replication	2	27.76	0.0077	15.01	0.0063	11.90	0.0288	85.40	0.3333	79.19	0.0849	8.02	0.0060
IRR	2	229.29	0.0198	76.96	0.0127	56.13	0.0338	158.25	0.1875	102.03	0.1365	63.57	0.0017
Error for IRR	4	18.75	0.0123	4.89	0.1083	6.33	0.0972	60.42	0.5253	29.89	0.3997	1.37	0.3519
MOW	1	0.09	0.8866	0.01	0.9594	0.09	0.8613	86.43	0.2912	17.33	0.4409	0.75	0.4338
WA	1	10.93	0.1284	16.78	0.0130	2.13	0.3892	115.56	0.2246	14.16	0.4854	5.71	0.0398
IRRxMOW	2	9.67	0.1348	0.52	0.7923	0.60	0.8046	80.32	0.3545	20.35	0.4961	0.83	0.5037
IRRxWA	2	4.77	0.3518	0.79	0.7044	0.02	0.9910	103.98	0.2669	40.30	0.2620	2.46	0.1492
MOWxWA	1	0.01	0.9545	0.02	0.9313	2.29	0.3725	74.25	0.3268	20.28	0.4052	0.00	0.9732
IRRxMOWxWA	2	3.17	0.4924	2.02	0.4181	0.45	0.8497	84.75	0.3359	45.86	0.2211	2.42	0.1536
Error	18	4.31		2.21		2.74		73.07		27.91		1.16	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 6.1. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on volumetric water content (%VWC) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Volumetric Water Content (%VWC) 2011											
Irrigation (IRR)		9 May		23 May		1 June		6 June		14 June		21 June	
30% ET		14.54b		20.97b		18.10b		17.02b		14.33b		18.48b	
60% ET		16.33a		22.33a		20.03a		20.26a		17.80a		21.83a	
90% ET		16.85a		22.34a		20.17a		20.28a		17.89a		22.57a	
Significance		*		*		*		*		*		*	
LSD (0.05)		1.43		0.80		1.60		2.67		3.00		2.22	
Mowing (MOW)													
1X daily		15.63		21.46		18.73b		18.56b		16.47		20.51	
2X daily		16.17		22.30		20.12a		19.81a		16.87		21.41	
Significance		NS		NS		**		*		NS		NS	
LSD (0.05)		NS		NS		0.94		0.95		NS		NS	
Wet-Agent (WA)													
Untreated		16.36a		22.36		19.97a		19.61		17.04a		21.86a	
1X monthly		15.46b		21.39		18.89b		18.77		16.30b		20.06b	
Significance		*		NS		*		NS		*		**	
LSD (0.05)		0.90		NS		0.94		NS		0.73		1.17	
		Mean Square and Pr>F											
Source	df												
Replication	2	15.20	0.0017	18.19	0.0038	43.64	<.0001	25.81	0.0002	19.05	<.0001	13.12	0.0227
IRR	2	17.57	0.0237	7.47	0.0137	15.99	0.0401	42.36	0.0432	49.61	0.0488	56.78	0.0142
Error for IRR	4	1.60	0.4456	0.50	0.9292	2.00	0.3840	5.56	0.0448	7.04	0.0020	3.84	0.2808
MOW	1	2.67	0.2182	6.42	0.1163	17.50	0.0060	14.06	0.0126	1.44	0.2641	7.20	0.1255
WA	1	7.29	0.0492	8.41	0.0751	10.35	0.0279	6.33	0.0795	4.99	0.0458	29.34	0.0045
IRRxMOW	2	0.53	0.7299	0.08	0.9652	4.59	0.1070	1.06	0.5722	2.48	0.1301	1.35	0.6247
IRRxWA	2	2.73	0.2174	1.13	0.6279	1.20	0.5287	5.82	0.0659	6.42	0.0105	6.66	0.1202
MOWxWA	1	4.13	0.1296	1.21	0.4829	0.01	0.9513	2.01	0.3092	0.75	0.4160	1.03	0.5503
IRRxMOWxWA	2	0.35	0.8112	1.83	0.4748	1.38	0.4817	1.02	0.5822	2.39	0.1394	2.48	0.4289
Error	18	1.64		2.36		1.81		1.83		1.08		2.79	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 6.2. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on volumetric water content (%VWC) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Volumetric Water Content (%VWC) 2011											
Irrigation (IRR)		27 June		5 July		12 July		19 July		25 July		4 Aug	
30% ET		17.98b		13.29		13.33		10.54b		10.03b		27.73b	
60% ET		20.92a		19.01		19.06		16.68a		17.27a		31.76a	
90% ET		21.69a		18.98		19.11		16.30a		19.46a		32.14a	
Significance		*		NS		NS		*		*		**	
LSD (0.05)		2.37		NS		NS		4.40		4.81		1.29	
Mowing (MOW)													
1X daily		17.94		16.76		17.21		14.58		15.87		30.40	
2X daily		20.59		17.43		17.13		14.43		15.31		30.68	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
Wet-Agent (WA)													
Untreated		20.83		17.94a		17.08		14.53		15.43		31.03	
1X monthly		19.56		16.25b		17.26		14.48		15.74		30.05	
Significance		NS		*		NS		NS		NS		NS	
LSD (0.05)		NS		1.32		NS		NS		NS		NS	
		Mean Square and Pr>F											
Source	df												
Replication	2	7.19	0.2121	20.87	0.0108	18.85	0.0396	14.41	0.0149	22.93	0.0368	52.10	<.0001
IRR	2	46.14	0.0255	130.16	0.0597	132.45	0.0797	141.83	0.0308	291.91	0.0120	71.84	0.0012
Error for IRR	4	4.38	0.4181	21.03	0.0032	26.05	0.0050	15.09	0.0041	17.98	0.0406	1.29	0.6317
MOW	1	5.76	0.2594	4.13	0.2945	0.06	0.9109	0.22	0.7791	2.83	0.4916	0.72	0.5526
WA	1	14.44	0.0817	25.67	0.0150	0.30	0.8056	0.03	0.9201	0.90	0.6966	8.70	0.0500
IRRxMOW	2	1.77	0.6660	3.76	0.3672	13.56	0.0877	2.22	0.4534	12.15	0.1498	4.21	0.1471
IRRxWA	2	6.18	0.2595	1.92	0.5906	20.67	0.0306	1.74	0.5360	11.93	0.1545	3.72	0.1802
MOWxWA	1	0.09	0.8859	0.02	0.9443	1.40	0.5976	0.87	0.5762	2.95	0.4831	0.72	0.5526
IRRxMOWxWA	2	1.76	0.6675	1.36	0.6862	7.48	0.2409	2.08	0.4753	0.19	0.9678	10.22	0.0167
Error	18	4.24		3.54		4.85		2.69		5.75		1.97	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 6.3. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on volumetric water content (%VWC) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Volumetric Water Content (%VWC) 2011											
Irrigation (IRR)		10 August		15 August		22 August		29 August		8 Sept		12 Sept	
30% ET		27.58b		35.89		26.09b		20.05b		31.13b		27.83b	
60% ET		31.60a		33.84		30.40a		29.52a		34.98a		31.15a	
90% ET		31.23a		33.09		30.07a		30.53a		36.12a		31.60a	
Significance		*		NS		**		**		**		**	
LSD (0.05)		2.22		NS		2.07		2.59		2.26		1.45	
Mowing (MOW)													
1X daily		30.11		32.27		28.50		28.20		33.95		30.02	
2X daily		30.17		36.28		29.21		28.53		34.19		30.37	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
Wet-Agent (WA)													
Untreated		30.60		33.13		29.03		8.55		34.19		30.36	
1X monthly		29.68		35.42		28.67		8.44		33.96		30.03	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
		Mean Square and Pr>F											
Source	df												
Replication	2	12.43	0.0152	69.50	0.5429	7.20	0.0215	13.50	0.0171	7.84	0.0318	4.59	0.0737
IRR	2	59.18	0.0131	25.21	0.7955	68.95	0.0078	101.89	0.0086	82.09	0.0078	50.78	0.0036
Error for IRR	4	3.82	0.2081	104.00	0.4603	3.33	0.1078	5.22	0.1396	3.97	0.1195	1.63	0.3975
MOW	1	0.03	0.9143	145.20	0.2655	4.48	0.1014	0.97	0.5516	0.54	0.5979	1.14	0.3978
WA	1	7.65	0.0868	47.38	0.5198	1.17	0.3885	0.27	0.7535	0.49	0.6145	0.93	0.4427
IRRxMOW	2	6.00	0.1039	74.71	0.5194	3.76	0.1101	4.47	0.2106	2.66	0.2667	0.07	0.9564
IRRxWA	2	1.69	0.4973	148.07	0.2851	4.75	0.0665	2.74	0.3732	1.89	0.3836	4.45	0.0787
MOWxWA	1	0.13	0.8130	117.00	0.3159	0.20	0.7179	1.32	0.4870	1.28	0.4175	0.16	0.7491
IRRxMOWxWA	2	8.33	0.0493	149.25	0.2824	4.51	0.0750	6.38	0.1164	2.08	0.3495	0.21	0.8716
Error	18	2.33		109.95		1.50		2.63		1.87		1.52	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 7.1. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on volumetric water content (%VWC) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Volumetric Water Content (%VWC) 2012											
Irrigation (IRR)		8 May		17 May		24 May		30 May		6 June		13 June	
30% ET		37.53		33.27		25.90b		27.68		29.00b		23.13b	
60% ET		37.68		34.36		30.98a		28.79		34.63a		32.09a	
90% ET		37.07		35.35		32.79a		32.37		37.08a		35.09a	
Significance		NS		NS		**		NS		**		**	
LSD (0.05)		NS		NS		2.92		NS		3.10		4.48	
Mowing (MOW)													
1X daily		37.23		34.14		29.96		28.41		33.74		30.28	
2X daily		37.62		34.51		29.82		30.81		33.39		29.93	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
Wet-Agent (WA)													
Untreated		37.66		34.19		30.04		31.71		33.51		29.81	
1X monthly		37.19		34.46		29.74		27.51		33.63		30.40	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
		Mean Square and Pr>F											
Source	df												
Replication	2	10.13	0.0097	7.58	0.0276	13.14	0.0196	71.21	0.5062	26.67	0.0026	34.19	0.0153
IRR	2	1.22	0.7254	13.03	0.0697	153.21	0.0063	72.08	0.6781	206.05	0.0046	464.51	0.0040
Error for IRR	4	3.49	0.1242	2.34	0.2867	6.62	0.0807	168.09	0.2007	7.50	0.0913	15.65	0.0849
MOW	1	1.32	0.3851	1.25	0.4055	0.17	0.8015	51.84	0.4822	1.10	0.5625	1.14	0.6790
WA	1	2.01	0.2873	0.67	0.5411	0.78	0.5952	158.76	0.2253	0.12	0.8463	3.12	0.4949
IRRxMOW	2	0.60	0.7019	0.50	0.7530	0.83	0.7364	100.74	0.3872	2.40	0.4826	2.14	0.7216
IRRxWA	2	1.12	0.5235	0.02	0.9902	1.33	0.6158	78.77	0.4723	6.98	0.1392	2.48	0.6860
MOWxWA	1	0.06	0.8487	0.42	0.6260	1.48	0.4659	49.00	0.4943	0.12	0.8463	0.64	0.7560
IRRxMOWxWA	2	4.02	0.1182	3.63	0.1503	3.26	0.3182	64.49	0.5386	4.05	0.3022	4.07	0.5427
Error	18	1.67		1.72		2.67		100.68		3.17		6.43	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 7.2. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on volumetric water content (%VWC) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Volumetric Water Content (%VWC) 2012											
Irrigation (IRR)		21 June		27 June		2 July		3 July		5 July		6 July	
30% ET		22.93b		21.48b		21.15b		20.65b		23.03b		21.65b	
60% ET		34.12a		33.26a		34.25a		33.23a		34.82a		34.50a	
90% ET		37.03a		37.52a		37.85a		38.13a		38.67a		38.19a	
Significance		**		**		*		*		*		*	
LSD (0.05)		5.37		7.38		10.10		10.70		9.17		10.18	
Mowing (MOW)													
1X daily		31.54		31.22		31.33		30.86		32.71		31.58	
2X daily		31.17		30.28		30.84		30.48		31.63		31.32	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
Wet-Agent (WA)													
Untreated		31.49		30.85		31.08		30.67		32.24		31.58	
1X monthly		31.23		30.65		31.08		30.67		32.09		31.32	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
		Mean Square and Pr>F											
Source	df												
Replication	2	26.17	0.0606	43.10	0.0012	41.71	0.0152	50.61	0.0063	70.31	0.0007	100.17	0.0006
IRR	2	664.20	0.0040	828.63	0.0086	926.92	0.0214	975.29	0.0239	797.06	0.0199	904.76	0.0229
Error for IRR	4	22.47	0.0557	42.41	0.0002	79.36	0.0002	89.10	<.0001	65.46	0.0002	80.64	0.0003
MOW	1	1.25	0.6968	8.03	0.1891	2.15	0.6063	1.25	0.6872	10.35	0.2172	0.61	0.7920
WA	1	0.61	0.7844	0.36	0.7759	0.00	1.0000	0.00	0.9952	0.20	0.8600	0.61	0.7920
IRRxMOW	2	11.60	0.2590	5.44	0.3069	12.77	0.2229	10.36	0.2742	5.22	0.4544	18.96	0.1381
IRRxWA	2	16.00	0.1628	5.44	0.3068	1.70	0.8064	2.13	0.7547	0.21	0.9680	2.13	0.7827
MOWxWA	1	1.40	0.6798	1.78	0.5288	1.52	0.6644	0.10	0.9089	6.17	0.3366	0.27	0.8618
IRRxMOWxWA	2	9.16	0.3384	6.04	0.2717	5.00	0.5391	4.48	0.5589	7.13	0.3460	3.13	0.6990
Error	18	7.96		4.31		7.82		7.45		6.33		8.56	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 7.3. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on volumetric water content (%VWC) at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average Volumetric Water Content (%VWC) 2012					
Irrigation (IRR)	11 July	19 July	31 July	8 Aug	14 Aug	22 Aug
30% ET	13.70b	27.60b	19.48b	12.18b	24.42b	19.73b
60% ET	26.92a	37.14a	32.47a	28.84a	33.34a	31.65a
90% ET	32.87a	38.78a	34.82a	30.41a	34.08a	33.93a
Significance	*	*	*	*	*	**
LSD (0.05)	12.16	8.75	8.22	9.65	6.03	6.42
Mowing (MOW)						
1X daily	24.57	34.61	28.48	23.63	30.90	28.63
2X daily	24.42	34.40	29.36	23.99	30.32	28.24
Significance	NS	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS	NS
Wet-Agent (WA)						
Untreated	23.58b	34.62	27.82	22.98	29.80	27.64b
1X monthly	25.41a	34.39	30.02	24.64	31.42	29.23a
Significance	*	NS	NS	NS	NS	*
LSD (0.05)	1.71	NS	NS	NS	NS	1.44

		Mean Square and Pr>F											
Source	df												
Replication	2	73.40	0.0004	52.93	0.0040	28.25	0.0833	156.71	0.0008	19.79	0.0519	50.53	0.0005
IRR	2	1154.89	0.0276	437.18	0.0459	818.40	0.0130	1224.21	0.0112	346.95	0.0197	697.72	0.0071
Error for IRR	4	115.04	<.0001	59.58	0.0005	52.56	0.0052	72.54	0.0067	28.30	0.0068	32.05	0.0009
MOW	1	0.22	0.8504	0.40	0.8129	6.93	0.4129	1.21	0.7753	3.00	0.4752	1.36	0.5783
WA	1	29.88	0.0378	0.44	0.8033	43.56	0.0500	24.67	0.2072	23.68	0.0555	22.72	0.0327
IRRxMOW	2	27.04	0.0252	4.63	0.5260	2.03	0.8159	8.55	0.5629	2.60	0.6379	3.30	0.4744
IRRxWA	2	1.10	0.8330	0.14	0.9808	9.05	0.4175	6.50	0.6441	13.63	0.1179	0.80	0.8290
MOWxWA	1	0.09	0.9035	0.28	0.8420	4.99	0.4863	8.22	0.4599	2.15	0.5449	0.59	0.7142
IRRxMOWxWA	2	0.19	0.9686	6.81	0.3947	4.05	0.6696	10.01	0.5121	1.99	0.7080	1.67	0.6808
Error	18	5.95		6.95		9.87		14.41		5.65		4.25	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 8.1. 2010-2012 percent volumetric water content (%VWC) as affected by irrigation and wetting agent† (WA) at the Hancock Turfgrass Research Center in East Lansing, MI.

	27 July 2010		14 June 2011		12 July 2011	
Irrigation	WA	No WA	WA	No WA	WA	No WA
30% ET	29.96b	28.15c	14.3d	14.4d	14.5c	12.1c
60% ET	31.14ab	31.83a	17.9ab	17.7bc	19.5ab	18.7ab
90% ET	31.03ab	31.85a	16.7c	19.1a	17.8b	20.5a
LSD $_{(0.05)}$‡	1.56		1.26		2.67	
LSD $_{(0.05)}$§	2.21		1.79		3.77	

† Wetting agent was applied monthly from May till September with Revolution® from Aquatrols, Inc. (Paulsboro, N.J) at 1.87-ml/m^2.

‡ Between wetting agent means at same irrigation level on the single date listed above.

§ Between irrigation level at the same or different wetting agent on the single date listed above.

Table 8.2. 2012 percent volumetric water content (%VWC) as affected by irrigation and mowing† (MOW) at the Hancock Turfgrass Research Center in East Lansing, MI.

	11 July 2012	
Irrigation	1X MOW	2X MOW
30% ET	15.4c	12.0d
60% ET	26.8b	27.0b
90% ET	31.6a	34.2a
LSD $_{(0.05)}$ ‡	2.96	
LSD $_{(0.05)}$ §	4.18	

† Mowing was applied six days per week from May till September at 0.3175-cm.

‡ Between mowing means at same irrigation level on the single date listed above.

§ Among irrigation level at the same or different mowing on the single date listed above.

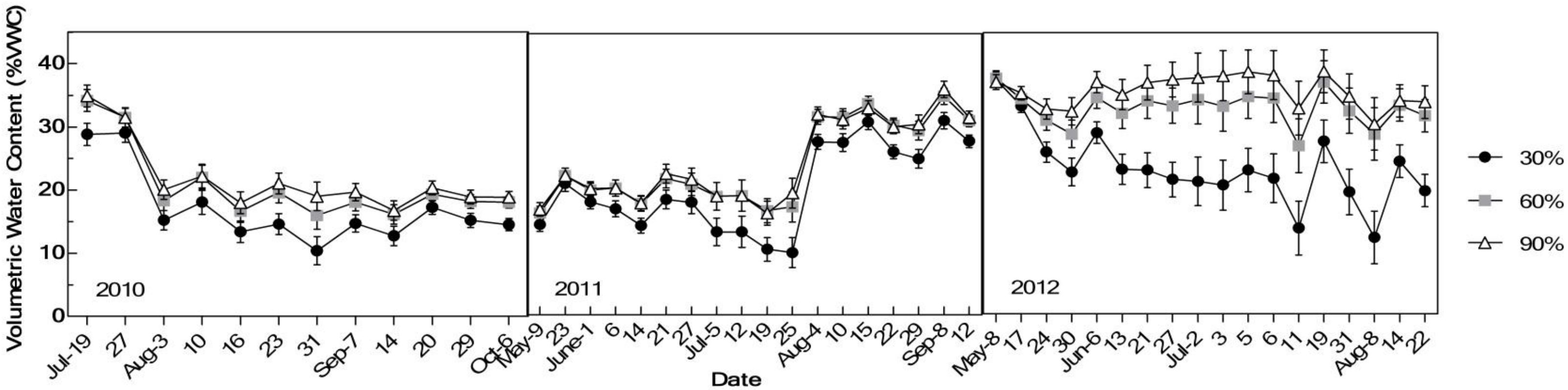

Figure 3. Irrigation Effects on percent volumetric water content (%VWC) in 2010-12. Values are averages of mowing and wetting agent for each irrigation treatment. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at α=0.05. N=15.

Analysis of variance means for each date of visual quality as affected by irrigation are shown in Tables 9.1 through 11.3. Irrigation had significant effects on visual quality (Figure 4 and Tables 9.1 to 11.3) on four dates in 2010 and nine dates in 2012. On each of these thirteen dates, 60 and 90% were statistically similar and significantly greater than 30% ET replenishment. Interactions, if observed, are shown in Tables 12.1 and 12.2. Table 12.1 shows wetting agent significantly improved visual quality at 30% ET irrigation replenishment in 2012. Table 12.2 shows a trend of increased turfgrass quality most often at the 90% ET irrigation replenishment.

In 2010-2012, average visual quality showed significant differences between 30, 60, and 90% ET irrigation treatments ($P<0.0001$). Year significantly affected average ball roll distance ($P<0.0001$). The year difference is most likely attributed to management over time. The irrigation x year interaction was significant ($P<0.0001$), suggesting irrigation alone is not entirely responsible for acceptable visual quality. Daily values shown in Figure 4 are averages of mowing and wetting agent for each irrigation treatment, and show the effects of irrigation on visual quality over each season. 2010-11 seasons visual quality separations based on irrigation were not observed. 60 and 90% ET replenishment were significantly higher in visual quality in 2012 compared to the 30% ET treatment. Effectively, the data shows no difference between 60 and 90% ET.

Long-term double mowing is rarely used as a mechanical practice because of the perceived negative physiological plant stress it puts on putting greens as well as it being labor intensive. Overall in our study, double mowing did not result in conclusive significant effects on visual quality. Visual quality was significantly reduced with double mowing on two dates in

2010, six dates in 2011, and eight dates in 2012 (Tables 9.1 to 11.3). In contrast, visual quality was significantly increased with double mowing on three dates in 2010 and four dates in 2011 (Tables 9.1 to 10.3). On eighteen dates from 2010-2012, double mowing has no significant effect on visual quality. Analysis of variance means for each date of visual quality as affected by mowing are shown in Tables 9.1 through 11.3. Interactions, if observed, are shown in Tables 12.1 and 12.2.

In 2010-2012, average visual quality showed no significant differences when daily double (2X) mowing versus single daily (1X) mowing ($P=0.3150$). Year significantly affected average visual quality ($P<0.0001$), and is most likely attributed to the same seasonal variations in weather mentioned previously. No interaction between mowing and year was observed to be significant ($P=0.3026$), suggesting that year may be the sole factor attributing to visual quality x mowing differences observed.

Daily values shown in Figure 5 are averages of irrigation and wetting agent for each mowing treatment, and show the effects of mowing on visual quality over each season. Figure 5 emphasizes visual quality was effected frequently with daily double mowing, but suggests significant decreases were temporary. The data shows daily 2X mowing for increased ball roll distance may be obtained without loss of turfgrass quality.

Wetting agent applications on golf course putting greens are scrutinized for efficacy and costs of applications. Analysis of variance means for each date of visual quality as affected by wetting agent are shown in Tables 9.1 through 11.3. Interactions, if observed, are shown in Tables 12.1 and 12.2. Table 12.2 shows wetting agent significantly improved visual quality at

30% ET replenishment on nine dates in 2012. Wetting agent effects on visual quality at 60 and 90% ET were statistically similar for these nine dates where interactions occurred (Table 12.2).

In 2010 and 2011 there was adequate precipitation to sustain visual quality without a wetting agent on the research site even at the 30% ET treatment, however, during the summer of 2012 there was statistical separation among ET treatments.

In 2010-2011, average visual quality showed statistically similar values between untreated and wetting agent treatments ($P=0.0496$). During the driest year, 2012, wetting agent resulted in significant increases in visual quality, especially on the 30% ET treatment. Year significantly affected average visual quality ($P<0.0001$), and is most likely attributed to management over time. A significant mowing x year interaction was observed ($P=0.0003$), and is hypothesized to be due directly to the weather of 2012. Daily averages of visual quality did not differ with wetting agent treatment in 2010 or 2011. Data shows visual quality is maintained in creeping bentgrass putting greens with long-term use of wetting agent, especially during periods of heat and drought stress.

Table 9.1. 2010 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on visual quality (1-9) at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average Visual Quality (1-9)					
	2010					
Irrigation (IRR)	19 July	27 July	3 Aug	10 Aug	16 Aug	23 Aug
30% ET	5.25	4.50	4.25b	4.25b	5.58	3.92
60% ET	5.92	5.58	5.50a	5.83a	6.42	5.17
90% ET	6.08	5.92	6.08a	6.17a	6.83	5.67
Significance	NS	NS	*	*	NS	NS
LSD (0.05)	NS	NS	1.19	1.01	NS	NS
Mowing (MOW)						
1X daily	6.39a	5.61a	5.39	5.28	6.22	4.61
2X daily	5.11b	5.06b	5.17	5.56	6.33	5.22
Significance	***	*	NS	NS	NS	NS
LSD (0.05)	0.61	0.48	NS	NS	NS	NS
Wet-Agent (WA)						
Untreated	6.06a	5.44	5.50	5.61	6.39	4.94
1X monthly	5.44b	5.22	5.06	5.22	6.17	4.89
Significance	*	NS	NS	NS	NS	NS
LSD (0.05)	0.61	NS	NS	NS	NS	NS

		Mean Square and Pr>F											
Source	df												
Replication	2	9.33	0.0004	6.08	0.0003	15.86	<.0001	9.33	0.0001	9.53	<.0001	2.08	0.0326
IRR	2	2.33	0.1634	6.58	0.2404	10.53	0.0304	12.58	0.0125	4.86	0.0984	9.75	0.1575
Error for IRR	4	0.79	0.4068	3.16	0.0017	1.11	0.1325	0.79	0.3020	1.11	0.0578	3.21	0.0022
MOW	1	14.69	0.0003	2.77	0.0260	0.44	0.3790	0.69	0.2969	0.11	0.6038	3.36	0.0184
WA	1	3.36	0.0485	0.44	0.3448	1.78	0.0880	1.36	0.1500	0.44	0.3047	0.03	0.8163
IRRxMOW	2	0.77	0.3747	0.53	0.3487	4.53	0.0028	1.19	0.1664	0.86	0.1440	0.36	0.4992
IRRxWA	2	3.11	0.0330	0.36	0.4800	0.19	0.7053	1.02	0.2094	1.02	0.1034	0.19	0.6834
MOWxWA	1	0.03	0.8495	0.11	0.6335	0.11	0.6574	0.03	0.8323	0.00	1.0000	0.03	0.8163
IRRxMOWxWA	2	0.44	0.5633	0.19	0.6686	0.19	0.7053	0.19	0.7280	0.25	0.5450	0.36	0.4992
Error	18	0.75		0.47		0.55		0.60		0.40		0.50	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 9.2. 2010 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on visual quality (1-9) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Visual Quality (1-9) 2010									
Irrigation (IRR)		31 August		7 Sept		14 Sept		20 Sept		29 Sept	
30% ET		5.33		6.50		6.08		5.33b		5.75b	
60% ET		7.17		7.25		7.00		6.50a		6.42a	
90% ET		7.50		7.50		7.67		6.75a		6.83	
Significance		NS		NS		NS		**		**	
LSD (0.05)		NS		NS		NS		0.60		0.46	
Mowing (MOW)											
1X daily		6.67		6.67b		6.83		5.89b		6.00b	
2X daily		6.67		7.50a		7.00		6.50a		6.67a	
Significance		NS		***		NS		***		**	
LSD (0.05)		NS		0.40		NS		0.29		0.40	
Wet-Agent (WA)											
Untreated		6.72		7.11		7.00		6.11		6.28	
1X monthly		6.61		7.06		6.83		6.28		6.39	
Significance		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS	
		Mean Square and Pr>F									
Source	df										
Replication	2	2.08	0.0292	3.00	0.0017	6.58	<.0001	0.53	0.0751	0.08	0.7761
IRR	2	16.33	0.0649	3.25	0.2870	7.58	0.0554	6.86	0.0056	3.58	0.0072
Error for IRR	4	2.79	0.0035	1.88	0.0036	1.17	0.0430	0.28	0.2228	0.16	0.7262
MOW	1	0.00	1.0000	6.25	0.0004	0.25	0.4277	3.36	0.0004	4.00	0.0025
WA	1	0.11	0.6367	0.03	0.7730	0.25	0.4277	0.25	0.2487	0.11	0.5655
IRRxMOW	2	0.33	0.5133	0.08	0.7761	1.75	0.0242	0.36	0.1574	0.25	0.4770
IRRxWA	2	2.11	0.0281	0.03	0.9182	0.08	0.8050	0.08	0.6302	0.36	0.3498
MOWxWA	1	0.11	0.6367	0.25	0.3913	0.03	0.7899	0.03	0.6958	0.11	0.5655
IRRxMOWxWA	2	0.11	0.7962	0.08	0.7761	0.36	0.4049	0.03	0.8551	0.36	0.3498
Error	18	0.48		0.32		0.38		0.18		0.32	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 10.1. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on visual quality (1-9) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Visual Quality (1-9) 2011									
Irrigation (IRR)		23 May		1 June		6 June		14 June		21 June	
30% ET		7.83		6.92		7.50		8.25		8.67	
60% ET		8.08		7.33		6.92		8.08		8.75	
90% ET		8.00		7.17		7.25		8.25		8.83	
Significance		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS	
Mowing (MOW)											
1X daily		8.61a		7.11		7.56a		8.61a		9.00a	
2X daily		7.33b		7.17		6.89b		7.78b		8.50b	
Significance		***		NS		**		**		**	
LSD (0.05)		0.30		NS		0.39		0.52		0.29	
Wet-Agent (WA)											
Untreated		7.72b		7.78		8.00a		8.33		8.78	
1X monthly		8.22a		6.50		6.44b		8.06		8.72	
Significance		**		***		***		NS		NS	
LSD (0.05)		0.30		0.42		0.39		NS		NS	
		Mean Square and Pr>F									
Source	df										
Replication	2	0.19	0.3704	1.19	0.0561	0.03	0.9135	0.86	0.2393	0.08	0.6302
IRR	2	0.19	0.5017	0.53	0.5071	1.03	0.1231	0.11	0.8646	0.08	0.6400
Error for IRR	4	0.24	0.3164	0.65	0.1623	0.28	0.4796	0.74	0.2986	0.17	0.4596
MOW	1	14.69	<.0001	0.03	0.7819	4.00	0.0020	6.25	0.0035	2.25	0.0022
WA	1	2.25	0.0026	14.69	<.0001	21.77	<.0001	0.69	0.2783	0.03	0.6958
IRRxMOW	2	0.03	0.8618	0.03	0.9244	0.08	0.7644	2.33	0.0318	0.08	0.6302
IRRxWA	2	0.25	0.2843	0.03	0.9244	0.53	0.2060	0.11	0.8205	0.03	0.8551
MOWxWA	1	0.25	0.2605	0.03	0.7819	0.44	0.2434	0.25	0.5109	0.03	0.6958
IRRxMOWxWA	2	0.08	0.6446	0.53	0.2497	0.03	0.9135	0.33	0.5594	0.03	0.8551
Error	18	0.19		0.35		0.31		0.56		0.18	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 10.2. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on visual quality (1-9) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Visual Quality (1-9) 2011											
Irrigation (IRR)		27 June		5 July		12 July		19 July		25 July		4 August	
30% ET		8.42		7.50		8.17		6.83		7.33		7.17	
60% ET		8.25		8.58		8.83		8.42		7.92		6.92	
90% ET		8.58		8.50		8.75		8.33		8.08		6.50	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
Mowing (MOW)													
1X daily		8.78a		8.11		8.83a		7.94		7.78		6.61	
2X daily		8.06b		8.28		8.33b		7.78		7.78		7.11	
Significance		***		NS		**		NS		NS		NS	
LSD (0.05)		0.31		NS		0.29		NS		NS		NS	
Wet-Agent (WA)													
Untreated		8.44		8.22		8.50		7.61b		7.50b		6.94	
1X monthly		8.39		8.17		8.67		8.11a		8.06a		6.78	
Significance		NS		NS		NS		*		*		NS	
LSD (0.05)		NS		NS		NS		0.49		0.47		NS	
		Mean Square and Pr>F											
Source	df												
Replication	2	1.00	0.0171	0.36	0.3294	0.58	0.0594	1.03	0.1473	2.53	0.0131	6.19	0.0005
IRR	2	0.33	0.7257	4.36	0.1139	1.58	0.1189	9.53	0.0565	1.86	0.3528	1.36	0.6026
Error for IRR	4	0.96	0.0073	1.11	0.0243	0.42	0.0913	1.49	0.0424	1.36	0.0464	2.36	0.0110
MOW	1	4.69	0.0001	0.25	0.3777	2.25	0.0022	0.25	0.4804	0.00	1.0000	2.25	0.0537
WA	1	0.03	0.7099	0.03	0.7665	0.25	0.2487	2.25	0.0444	2.78	0.0235	0.25	0.5001
IRRxMOW	2	0.11	0.5746	0.08	0.7644	0.08	0.6302	0.58	0.3209	0.58	0.3007	0.58	0.3526
IRRxWA	2	0.78	0.0365	0.53	0.2060	0.08	0.6302	0.25	0.6036	0.19	0.6579	0.08	0.8551
MOWxWA	1	0.03	0.7099	0.25	0.3777	0.03	0.6958	0.03	0.8129	0.11	0.6267	0.69	0.2664
IRRxMOWxWA	2	0.11	0.5746	0.25	0.4570	0.36	0.1574	2.19	0.0250	0.69	0.2433	0.86	0.2233
Error	18	0.19		0.31		0.18		0.48		0.45		0.53	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 10.3. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on visual quality (1-9) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Visual Quality (1-9) 2011							
Irrigation (IRR)		10 August		15 August		22 August		29 August	
30% ET		7.33		7.08		7.42		8.67	
60% ET		6.75		6.25		6.33		8.58	
90% ET		6.75		6.00		6.33		8.25	
Significance		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS	
Mowing (MOW)									
1X daily		6.39b		5.55b		5.61b		8.00b	
2X daily		7.50a		7.33a		7.78a		9.00a	
Significance		***		***		***		***	
LSD (0.05)		0.49		0.48		0.68		0.22	
Wet-Agent (WA)									
Untreated		7.17		6.78a		7.06a		8.55	
1X monthly		6.72		6.11		6.33b		8.44	
Significance		NS		**		*		NS	
LSD (0.05)		NS		0.48		0.68		NS	
		Mean Square and Pr>F							
Source	df								
Replication	2	0.78	0.2323	4.19	0.0021	0.19	0.8142	0.00	1.0000
IRR	2	1.36	0.1382	3.86	0.3648	4.69	0.2184	0.58	0.1736
Error for IRR	4	0.40	0.5287	2.94	0.0025	2.03	0.1140	0.21	0.1308
MOW	1	11.11	0.0002	28.44	<.0001	42.25	<.0001	9.00	<.0001
WA	1	1.78	0.0731	4.00	0.0093	4.69	0.0379	0.11	0.3101
IRRxMOW	2	0.36	0.4930	1.86	0.0381	1.58	0.2120	0.58	0.0119
IRRxWA	2	0.19	0.6786	0.08	0.8397	0.03	0.9708	0.19	0.1770
MOWxWA	1	1.00	0.1706	1.78	0.0682	0.25	0.6114	0.11	0.3101
IRRxMOWxWA	2	0.08	0.8452	0.19	0.6686	0.25	0.7684	0.19	0.1770
Error	18	0.73		0.47		0.94		0.10	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 11.1. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on visual quality (1-9) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Visual Quality (1-9) 2012											
Irrigation (IRR)		8 May		17 May		24 May		30 May		6 June		13 June	
30% ET		7.83		7.42		7.83		7.33		7.17		6.42	
60% ET		7.67		7.33		8.33		7.92		7.83		7.92	
90% ET		7.42		7.33		8.33		7.92		7.67		7.33	
Significance		NS		NS		NS		NS		NS		NS	
LSD (0.05)		NS		NS		NS		NS		NS		NS	
Mowing (MOW)													
1X daily		8.00a		7.56		8.39		7.89		8.06a		7.83a	
2X daily		7.28b		7.17		7.94		7.56		7.06b		6.61b	
Significance		**		NS		NS		NS		***		***	
LSD (0.05)		0.51		NS		NS		NS		0.39		0.52	
Wet-Agent (WA)													
Untreated		7.56		7.22		7.83b		7.50		7.50		6.83b	
1X monthly		7.72		7.50		8.50a		7.94		7.61		7.61a	
Significance		NS		NS		**		NS		NS		*	
LSD (0.05)		NS		NS		0.48		NS		NS		0.52	
		Mean Square and Pr>F											
Source	df												
Replication	2	0.11	0.8150	0.86	0.2445	0.08	0.8397	0.78	0.3242	2.03	0.0069	0.36	0.5284
IRR	2	0.53	0.1800	0.03	0.9512	1.00	0.3906	1.36	0.3120	1.44	0.2101	6.86	0.0667
Error for IRR	4	0.19	0.8323	0.69	0.3334	0.83	0.1800	0.86	0.2974	0.61	0.1377	1.19	0.1117
MOW	1	4.69	0.0084	1.36	0.1380	1.78	0.0682	1.00	0.2301	9.00	<.0001	13.44	0.0001
WA	1	0.25	0.5037	0.69	0.2821	4.00	0.0093	1.78	0.1150	0.11	0.5540	5.44	0.0055
IRRxMOW	2	0.19	0.7012	0.03	0.9521	0.11	0.7927	0.08	0.8802	0.33	0.3571	1.03	0.1811
IRRxWA	2	0.25	0.6352	0.53	0.4111	0.33	0.5068	0.36	0.5824	0.11	0.7001	2.53	0.0239
MOWxWA	1	0.03	0.8227	0.25	0.5143	0.11	0.6335	0.00	1.0000	0.00	1.0000	0.00	1.0000
IRRxMOWxWA	2	0.36	0.5228	0.08	0.8639	0.11	0.7927	0.08	0.8802	1.00	0.0613	0.58	0.3646
Error	18	0.54		0.56		0.47		0.65		0.31		0.55	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 11.2. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on visual quality (1-9) at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average Visual Quality (1-9) 2012					
Irrigation (IRR)	21 June	27 June	2 July	11 July	19 July	31 July
30% ET	5.50b	5.17b	5.00b	2.50b	3.58b	3.83b
60% ET	8.00a	8.33a	7.92a	7.67a	7.67a	7.75a
90% ET	7.83a	8.67a	8.42a	8.75a	8.25a	8.25a
Significance	*	**	**	***	***	***
LSD (0.05)	1.36	1.70	1.40	1.302	1.16	1.10
Mowing (MOW)						
1X daily	7.56a	7.72a	7.44a	6.78a	6.50	6.72
2X daily	6.67b	7.06b	6.78b	5.83b	6.50	6.50
Significance	**	*	*	**	NS	NS
LSD (0.05)	0.62	0.52	0.55	0.61	NS	NS
Wet-Agent (WA)						
Untreated	6.33b	6.67b	6.22b	5.72b	5.56b	5.44b
1X monthly	7.89a	8.11	8.00a	6.89a	7.44a	7.78a
Significance	***	***	***	***	***	***
LSD (0.05)	0.62	0.52	0.55	0.61	0.57	0.53

Source	df	Mean Square and Pr>F											
Replication	2	1.69	0.1451	0.53	0.4053	0.11	0.8353	0.19	0.7768	0.33	0.6106	1.19	0.1580
IRR	2	23.44	0.0120	44.78	0.0082	40.86	0.0048	133.86	0.0004	77.58	0.0007	70.19	0.0007
Error for IRR	4	1.44	0.1660	2.24	0.0167	1.53	0.0790	1.32	0.1856	1.04	0.2214	0.94	0.2127
MOW	1	7.11	0.0076	4.00	0.0152	4.00	0.0197	8.03	0.0044	0.00	1.0000	0.44	0.3942
WA	1	21.78	<.0001	18.78	<.0001	28.44	<.0001	12.25	0.0008	32.11	<.0001	49.00	<.0001
IRRxMOW	2	0.44	0.5783	0.33	0.5594	0.08	0.8734	1.69	0.1362	3.25	0.0194	0.19	0.7209
IRRxWA	2	8.44	0.0009	8.11	0.0002	11.19	<.0001	1.08	0.2660	4.19	0.0080	4.75	0.0030
MOWxWA	1	0.00	1.0000	1.78	0.0905	4.00	0.0197	0.03	0.8505	0.00	1.0000	1.78	0.0979
IRRxMOWxWA	2	0.33	0.6611	0.78	0.2722	1.75	0.0832	0.36	0.6291	0.08	0.8817	0.19	0.7209
Error	18	0.79		0.55		0.61		0.76		0.66		0.58	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 11.3. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on visual quality (1-9) at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average Visual Quality (1-9) 2012					
Irrigation (IRR)		8 August		14 August		22 August	
30% ET		2.92b		5.00b		5.75b	
60% ET		7.08a		7.08a		7.75a	
90% ET		8.08a		8.25a		8.50a	
Significance		**		**		*	
LSD (0.05)		1.71		1.22		1.91	
Mowing (MOW)							
1X daily		6.22		7.06a		7.39	
2X daily		5.83		6.50b		7.28	
Significance		NS		*		NS	
LSD (0.05)		NS		0.50		NS	
Wet-Agent (WA)							
Untreated		4.72b		5.61b		6.50b	
1X monthly		7.33a		7.94a		8.17a	
Significance		***		***		***	
LSD (0.05)		0.62		0.50		0.74	
		Mean Square and Pr>F					
Source	df						
Replication	2	3.44	0.0273	0.03	0.9480	1.58	0.2691
IRR	2	90.11	0.0023	32.53	0.0044	24.25	0.0359
Error for IRR	4	2.28	0.0500	1.15	0.1072	2.83	0.0766
MOW	1	1.36	0.2024	2.78	0.0327	0.11	0.7564
WA	1	61.36	<.0001	49.00	<.0001	25.00	0.0002
IRRxMOW	2	0.78	0.3874	0.53	0.3812	0.53	0.6318
IRRxWA	2	2.78	0.0494	7.58	0.0002	6.08	0.0143
MOWxWA	1	0.25	0.5778	0.44	0.3668	0.00	1.0000
IRRxMOWxWA	2	0.33	0.6579	0.36	0.5113	0.25	0.8022
Error	18	0.78		0.52		1.12	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 12.1. 2010-2012 visual quality as affected by irrigation and wetting agent† (WA) at the Hancock Turfgrass Research Center in East Lansing, MI.

	19 July 2010		31 Aug 2010		27 June 2011		13 June 2012	
Irrigation	WA	No WA	WA	No WA	WA	No WA	WA	No WA
30% ET	5.5bc	5.0c	5.7c	5.0c	8.7a	8.2ab	7.3a	5.5b
60% ET	5.5bc	6.3ab	6.7b	7.7a	8.0b	8.5ab	8.0a	7.8a
90% ET	5.3bc	6.8a	7.5ab	7.5ab	8.5ab	8.7a	7.5a	7.2a
LSD $_{(0.05)}$‡	1.05		0.84		0.53		0.90	
LSD $_{(0.05)}$§	1.49		1.19		0.76		1.27	
	21 June 2012		27 June 2012		2 July 2012		19 July 2012	
Irrigation	WA	No WA	WA	No WA	WA	No WA	WA	No WA
30% ET	7.2b	3.8c	6.8b	3.5c	7.0c	3.0d	5.2c	2.0d
60% ET	8.7a	7.3b	8.7a	8.0a	8.3ab	7.5bc	8.5a	6.8b
90% ET	7.8ab	7.8ab	8.8a	8.5a	8.7a	8.2ab	8.7a	7.8a
LSD $_{(0.05)}$‡	1.08		0.90		0.95		0.98	
LSD $_{(0.05)}$§	1.52		1.28		1.34		1.39	
	31 July 2012		8 Aug 2012		14 Aug 2012		22 Aug 2012	
Irrigation	WA	No WA	WA	No WA	WA	No WA	WA	No WA
30% ET	5.7d	2.0e	4.5c	1.3d	7.0b	3.0d	7.3bc	4.2d
60% ET	8.8a	6.7c	8.7a	5.5c	8.2a	6.0c	8.5ab	7.0c
90% ET	8.8a	7.7b	8.8a	7.3b	8.7a	7.8ab	8.7a	8.3ab
LSD $_{(0.05)}$‡	0.93		1.07		0.87		1.28	
LSD $_{(0.05)}$§	1.31		1.51		1.24		1.82	

† Wetting agent was applied monthly from May till September with Revolution® from Aquatrols, Inc. (Paulsboro, N.J) at 1.87-ml/m^2.

‡ Between wetting agent means at same irrigation level on the single date listed above.

§ Among irrigation level at the same or different wetting agent on the single date listed above.

Table 12.2. 2010-2012 visual quality as affected by irrigation and mowing† (MOW) at the Hancock Turfgrass Research Center in East Lansing, MI.

	3 Aug 2010		14 Sep 2010	
Irrigation	1X MOW	2X MOW	1X MOW	2X MOW
30% ET	4.8c	3.7d	4.8d	5.8c
60% ET	5.8ab	5.2bc	6.3bc	6.7ab
90% ET	5.5bc	6.7a	6.5ab	7.0a
LSD $_{(0.05)}$‡	0.90		0.75	
LSD $_{(0.05)}$§	1.27		1.06	

	14 June 2011		15 Aug 2011		29 Aug 2011	
Irrigation	1X MOW	2X MOW	1X MOW	2X MOW	1X MOW	2X MOW
30% ET	9.0a	7.5b	6.5b	7.7a	8.3b	9.0a
60% ET	8.7a	7.5b	5.5c	7.0ab	8.2b	9.0a
90% ET	8.2ab	8.3ab	4.7c	7.3ab	7.5c	9.0a
LSD $_{(0.05)}$‡	0.90		0.83		0.39	
LSD $_{(0.05)}$§	1.28		1.18		0.55	

	19 July 2012	
Irrigation	1X MOW	2X MOW
30% ET	4.2c	3.0d
60% ET	7.5b	7.8ab
90% ET	7.8ab	8.7a
LSD $_{(0.05)}$‡	0.98	
LSD $_{(0.05)}$§	1.39	

† Mowing was applied six days per week from May till September at 0.3175-cm.

‡ Between mowing means at same irrigation level on the single date listed above.

§ Among irrigation level at the same or different mowing on the single date listed above.

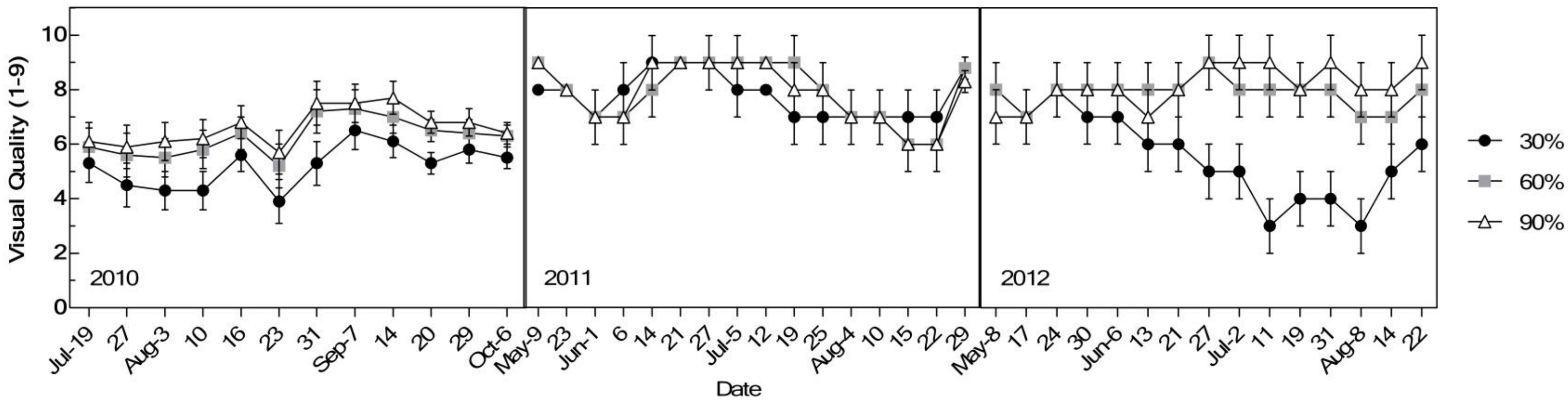

Figure 4. Irrigation Effects on Visual Quality in 2010-12. Values are averages of mowing and wetting agent for each irrigation treatment. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at α=0.05. N=3.

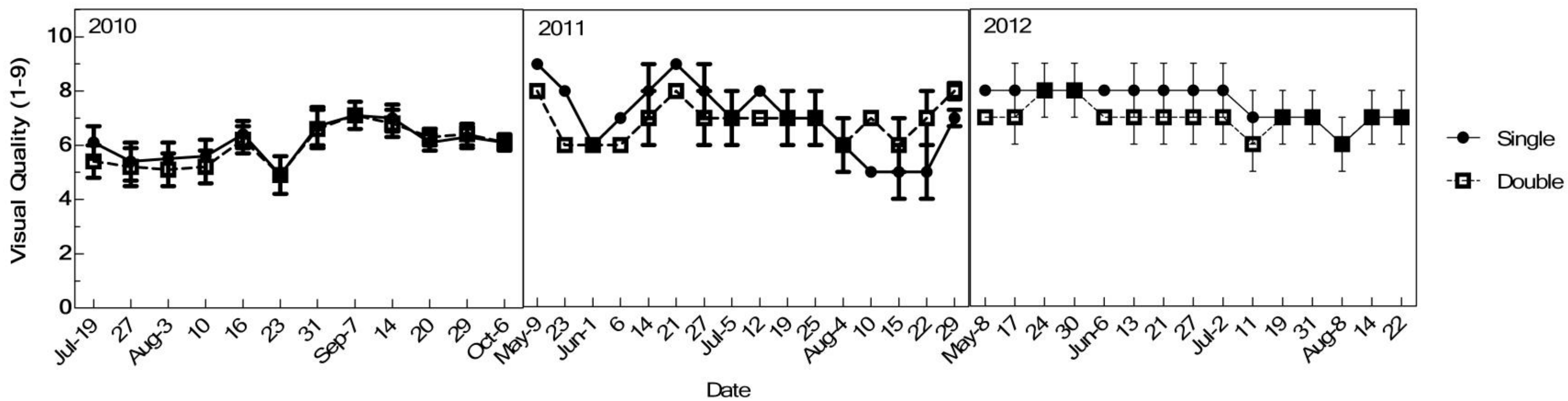

Figure 5. Mowing effects on visual quality 2010-12. Values are averaged over irrigation and wetting agent for each mowing treatment. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at α=0.05. N=3.

Reduction in irrigation amounts combined with physiological stresses of daily double mowing is believed to cause increased occurrence of localized dry spots (LDS). Analysis of variance means for each date of localized dry spot (LDS) as affected by irrigation, mowing, and wetting agent are shown in Tables 13 through 14.2. Interactions, if observed, are shown in Table 15.

From 2010-12, LDS was observed on one, three, and 10 days in each year, respectively. In 2010 and 2012, LDS was significantly higher in 30% ET treatments when compared to 60 and 90% ET ($P=0.0111$). Average LDS observations for daily occurrences due to irrigation in 2010-12 are presented in Figure 6 A, and shows irrigation regime significantly effected LDS counts in 2010 and 2012. 2011 was a wet year in terms of rainfall (See Appendix A), and mean separation did not occur on any date. For the one date in 2010, LDS showed statistically different ($P \leq 0.05$) average occurrences of 12, 9, and 7 in 30, 60, and 90% ET plots, respectively. Averaged across all dates in 2012, LDS showed statistically different ($P \leq 0.05$) average occurrences of 12, 3, and 2 in 30, 60, and 90% ET plots, respectively. In 2010 and 2012, watering to 60 or 90% ET were statistically similar, and significantly decreased LDS occurrence compared to the 30% regime.

Average LDS count for daily occurrences due to wetting agent in 2010-12 are presented in Figure 6(B), and show application of a wetting agent to significantly reduce LDS occurrence in 2012 ($P \leq 0.05$). 2012 was the hottest and driest of the three years (See Appendix A), and shows that wetting agent application may go unnoticed on flat topography in fine textured soils even when maintained at 0.3175 cm in terms occurrence until conditions favoring LDS are present. In 2010 or 2011, mild seasons with more precipitation did not allow for mean separation.

With proper irrigation and application of a wetting agent in 2010-11, daily double mowing maintained playability without detrimental effects to the turfgrass physiology. In 2012, LDS occurrence averages significantly ($P \leq 0.05$) increased from 4.8 to 6.1 counts per plot for single versus double mowing, respectively (Tables 24.1 and 24.2).

Table 13. 2010-2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on localized dry spot (LDS) observed at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average LDS (count per plot) 2010 & 2011				
Irrigation (IRR)	27 July 10	22 June 11	5 July 11	19 Aug 11	25 Aug 11
30% ET	11.92	0.17	3.58	1.83	1.33
60% ET	9.25	0.25	1.92	1.33	1.25
90% ET	7.08	0.33	2.67	1.25	1.33
Significance	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS
Mowing (MOW)					
1X daily	9.22	0.28	3.05	1.39	1.28
2X daily	9.61	0.22	2.39	1.56	1.33
Significance	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS
Wet-Agent (WA)					
Untreated	9.22	0.39	2.61	1.78b	1.50
1X monthly	9.61	0.11	2.83	1.17a	1.11
Significance	NS	NS	NS	*	NS
LSD (0.05)	NS	NS	NS	0.58	NS

		Mean Square and Pr>F									
Source	df										
Replication	2	206.08	0.0002	0.58	0.1770	1.36	0.3898	0.03	0.9598	1.69	0.1066
IRR	2	70.33	0.1780	0.08	0.8858	8.36	0.2582	1.19	0.7961	0.03	0.9452
Error for IRR	4	25.67	0.1782	0.67	0.1123	4.32	0.0396	4.94	0.0011	0.49	0.5837
MOW	1	1.36	0.7626	0.03	0.7665	4.00	0.1047	0.25	0.5507	0.03	0.8405
WA	1	1.36	0.7626	0.69	0.1490	0.44	0.5761	3.36	0.0387	1.36	0.1702
IRRxMOW	2	24.78	0.2086	0.19	0.5407	1.58	0.3372	2.08	0.0706	0.86	0.2991
IRRxWA	2	6.78	0.6335	0.19	0.5407	2.69	0.1689	0.53	0.4729	1.36	0.1588
MOWxWA	1	8.03	0.4660	0.03	0.7665	5.44	0.0616	0.03	0.8416	0.03	0.8405
IRRxMOWxWA	2	3.44	0.7906	0.86	0.0861	1.69	0.3139	0.86	0.3038	0.19	0.7505
Error	18	14.47		0.31		1.37		0.68		0.67	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 14.1. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on localized dry spot (LDS) observed at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average LDS (count per plot) 2012				
Irrigation (IRR)	13 June	21 June	27 June	2 July	11 July
30% ET	2.17	3.50	6.25b	7.83b	17.33b
60% ET	0.75	1.25	0.92a	1.75a	2.25a
90% ET	0.33	0.75	0.67a	0.42a	1.08a
Significance	NS	NS	*	*	*
LSD (0.05)	NS	NS	4.47	4.34	12.50
Mowing (MOW)					
1X daily	0.61	1.44	2.39	2.67	5.72
2X daily	1.56	2.22	2.83	4.00	8.06
Significance	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS
Wet-Agent (WA)					
Untreated	2.00b	3.61b	5.00b	6.22b	10.56b
1X monthly	0.17a	0.06a	0.22a	0.44a	3.22a
Significance	**	***	***	***	***
LSD (0.05)	1.17	1.53	1.52	1.40	2.45

		Mean Square and Pr>F									
Source	df										
Replication	2	4.00	0.2651	6.75	0.2692	9.03	0.1767	6.33	0.2326	45.03	0.0461
IRR	2	11.08	0.2289	25.75	0.2251	119.36	0.0428	187.58	0.0183	985.86	0.0391
Error for IRR	4	5.08	0.1694	11.63	0.0850	15.57	0.0341	14.67	0.0236	121.57	0.0002
MOW	1	8.03	0.1074	5.44	0.2999	1.78	0.5472	16.00	0.0608	49.00	0.0611
WA	1	30.25	0.0041	113.78	0.0001	205.44	<.0001	300.44	<.0001	484.00	<.0001
IRRxMOW	2	1.19	0.6588	3.36	0.5080	0.19	0.9597	6.58	0.2206	31.58	0.1041
IRRxWA	2	12.25	0.0282	22.53	0.0226	92.03	<.0001	122.69	<.0001	148.08	0.0005
MOWxWA	1	6.25	0.1522	7.11	0.2382	7.11	0.2356	21.78	0.0314	1.00	0.7786
IRRxMOWxWA	2	3.25	0.3352	4.69	0.3936	0.86	0.8348	10.36	0.1026	1.58	0.8798
Error	18	2.80		4.78		4.72		4.00		12.28	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 14.2. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on localized dry spot (LDS) observed at the Hancock Turfgrass Research Center in East Lansing, MI.

	Average LDS (count per plot) 2012				
Irrigation (IRR)	19 July	31 July	8 Aug	14 Aug	22 Aug
30% ET	18.67b	23.33b	30.42b	9.58b	4.33
60% ET	4.17a	2.50a	6.25a	2.00a	2.42
90% ET	2.75a	3.08a	2.67a	0.67a	0.42
Significance	*	*	*	*	NS
LSD (0.05)	13.05	14.53	15.59	7.15	NS
Mowing (MOW)					
1X daily	7.44	9.56	12.56	3.44	2.11
2X daily	9.61	9.72	13.67	4.72	2.67
Significance	NS	NS	NS	NS	NS
LSD (0.05)	NS	NS	NS	NS	NS
Wet-Agent (WA)					
Untreated	14.44b	17.06b	21.61b	7.17b	4.50b
1X monthly	2.61a	2.22a	4.61a	1.00a	0.28a
Significance	***	***	***	***	***
LSD (0.05)	3.12	3.54	4.66	2.80	1.39

		Mean Square and Pr>F									
Source	df										
Replication	2	16.03	0.4623	16.44	0.5363	65.53	0.2547	19.08	0.3255	5.44	0.2777
IRR	2	931.19	0.0490	1688.86	0.0265	2733.86	0.0148	277.58	0.0496	46.03	0.1944
Error for IRR	4	132.44	0.0018	164.24	0.0021	189.07	0.0134	39.79	0.0797	18.15	0.0099
MOW	1	42.25	0.1623	0.25	0.9222	11.11	0.6228	14.69	0.3500	2.78	0.4129
WA	1	1260.25	<.0001	1980.25	<.0001	2601.00	<.0001	342.25	0.0002	160.44	<.0001
IRRxMOW	2	33.08	0.2175	18.08	0.5052	28.03	0.5431	8.03	0.6130	2.86	0.4986
IRRxWA	2	237.25	0.0005	771.08	<.0001	683.58	0.0001	173.08	0.0008	29.36	0.0044
MOWxWA	1	12.25	0.4429	1.36	0.8199	0.11	0.9606	4.69	0.5943	0.00	1.0000
IRRxMOWxWA	2	10.58	0.5965	22.86	0.4253	12.19	0.7628	0.53	0.9675	0.08	0.9792
Error	18	19.90		25.49		44.37		15.96		3.95	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 15. 2012 localized dry spot (LDS) counts as affected by irrigation and wetting agent† (WA) at the Hancock Turfgrass Research Center in East Lansing, MI.

	2012							
	13 June		21 June		27 June		2 July	
Irrigation	WA	No WA	WA	No WA	WA	No WA	WA	No WA
30% ET	0.2a	4.2b	0.2a	6.8b	0.7a	11.8b	1.3ab	14.3c
60% ET	0.0a	1.5a	0.0a	2.5a	0.0a	1.8a	0.0a	3.5b
90% ET	0.3a	0.3a	0.0a	1.5a	0.0a	1.3a	0.0a	0.8a
LSD $_{(0.05)}$‡	2.03		2.65		2.64		2.43	
LSD $_{(0.05)}$§	2.87		3.75		3.73		3.43	
	11 July		19 July		31 July		8 August	
Irrigation	WA	No WA	WA	No WA	WA	No WA	WA	No WA
30% ET	9.7c	25.0d	7.7c	29.7d	6.7b	40.0c	13.5c	47.3d
60% ET	0.0a	4.5b	0.2ab	8.2c	0.0a	5.0ab	0.0a	12.5bc
90% ET	0.0a	2.2ba	0.0a	5.5bc	0.0a	6.2b	0.3a	5.0ab
LSD $_{(0.05)}$‡	4.25		5.41		6.12		8.08	
LSD $_{(0.05)}$§	6.01		7.65		8.66		11.43	
	14 August		22 August					
Irrigation	WA	No WA	WA	No WA				
30% ET	2.2a	17.0b	0.8a	7.8c				
60% ET	0.5a	3.5a	0.0a	4.8b				
90% ET	0.3a	1.0a	0.0a	0.8a				
LSD $_{(0.05)}$‡	4.85		2.41					
LSD $_{(0.05)}$§	6.85		3.41					

† Wetting agent was applied monthly from May till September with Revolution® from Aquatrols, Inc. (Paulsboro, N.J) at 1.87-ml/m^2.
‡ Between wetting agent means at same irrigation level on the single date listed above.
§ Among irrigation level at the same or different wetting agent on the single date listed above.

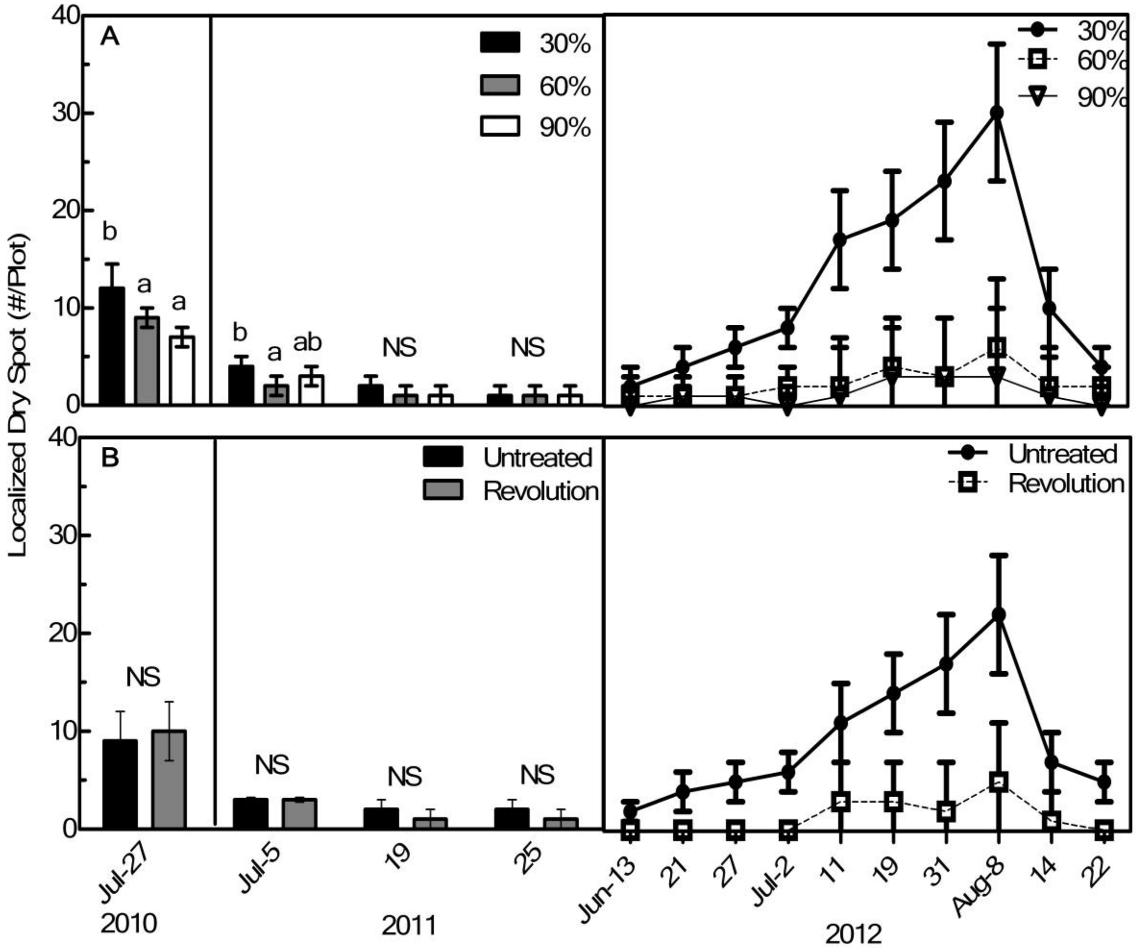

Figure 6. Irrigation (A) and Revolution® (B) effects on Localized Dry Spot (LDS) occurrence in 2010-12. (A) graph values are averaged over mowing and wetting agent for each irrigation treatment. (B) graph values are averaged over irrigation and mowing for each wetting agent treatment. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at α=0.05. N=12. (NS = not significant).

ET irrigation treatment level and wetting agent treatment are presented in Figure 7, resulting in statistically significant reduction of LDS in 2012 ($P<0.0001$). Data shows with addition of a wetting agent, LDS was significantly reduced for all levels of irrigation in 2012, especially 60 and 90% ET replenishment ($P\leq0.05$). Cumulative effects of wetting agent applications over three years are shown with the results observed in 2012 averages.

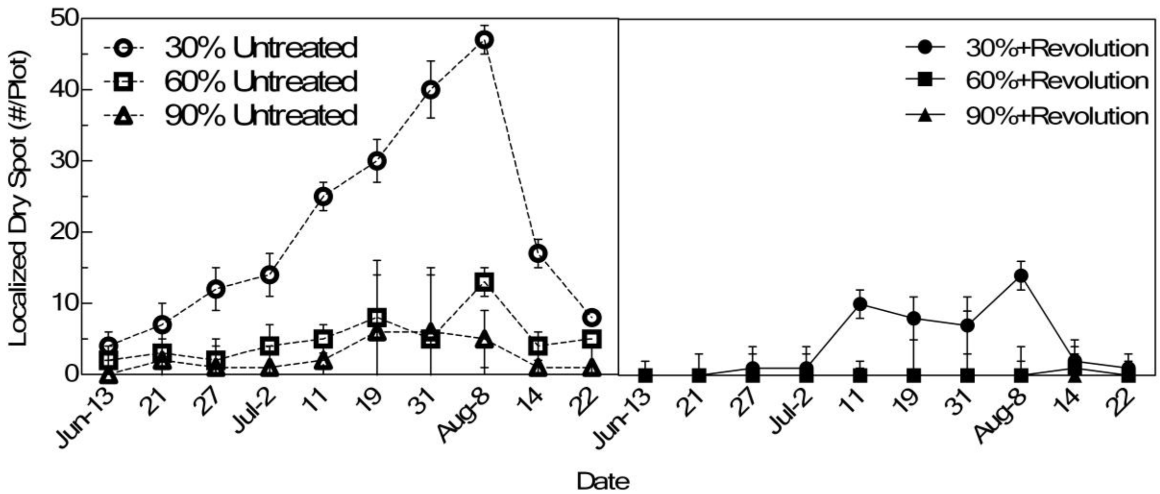

Figure 7. Irrigation and Revolution® interaction and effects on localized dry spot (LDS) in 2012. Values are averaged over treatments. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at $\alpha=0.05$. N=3.

Percent organic matter (%OM) from soil samples averaged approximately 3% +/- 0.5 for the duration of the study. Crenshaw is highly susceptible to *Sclerotinia homeocarpa* (dollar spot), and counts were taken in the fall of each year after cessation of preventative fungicide maintenance. This was performed to assure the putting green would be present for analysis of all other factors, and did not show significant differences. Tissue tests were taken in the fall of 2011 for nutrient analysis. %OM, dollar spot counts, and tissue test analysis were performed at $P \leq 0.05$ and no significant differences were observed (Data not shown).

CONCLUSIONS

Daily irrigation replenishment to 90% ET on native soil flat putting green in Michigan led to no observed benefits to the turfgrass plant. It seems apparent that 90% ET may lead to overwatering the putting surface and a waste of water. This is based upon data during the driest season in history showing no measureable benefit to irrigating to 90% versus 60% ET daily even at a height of cut (HOC) of 0.3175-cm.

30% ET irrigation replenishment was enough during early spring or late fall. In 2 of 3 successive years, irrigation to 30% ET provided acceptable turfgrass quality on a native soil non-pocketed flat putting green maintained at an HOC of 0.3175-cm. However, with proper application of a wetting agent, plots irrigated to 30% ET provided aesthetic quality and performance equal to those irrigated with twice the amount of water. Overall, the data indicates ET irrigation replenishment can be a useful tool depending upon putting green slope, topography, etc., but 100% ET is most likely not necessary for most locations.

Double mowing on a daily basis for three consecutive years yielded few of the numerous negative consequences on turfgrass often prescribed to the practice while yielding positive response to ball roll. This is based upon visual color, quality, disease, and %VWC via TDR measurements. However, 2X mowing required use of a wetting agent to sustain acceptable turfgrass quality levels at the 30% ET water replenishment in one of three years, and that was during the driest season of the three.

The wetting agent Revolution® improved turfgrass quality during the driest season of the three on plots irrigated with as little as 30% ET water replenishment. Additionally, Revolution® had no observed negative impact on ball roll distance or playability. Combining these two findings indicate that use of this product, and possibly other wetting agents, may lead to improved putting conditions with minimal irrigation.

30% ET irrigation replenishment consistently showed less %VWC measured with a TDR than 60 and 90% ET. 60 and 90% ET were often, if not always statistically the same. 90% ET replenishment did not provide significantly better visual quality or performance to 60% ET, which indicates water was most likely wasted and undue burden was placed upon the irrigation system. Making widely generalized irrigation recommendations based upon ET measurements is a poor idea. Additionally, TDR technology has improved immediate methods to measure %VWC, but the user is advised that a great deal of variation exists, and individual comfort in the instrumentation of the device will vary on a site by site basis mainly due to soil texture differences.

This research warrants further investigations in creeping bentgrass or other species on putting greens managed under United States Golf Association sand specifications.

CHAPTER TWO:

EFFECTS OF WATERING REGIME, MOWING, AND A WETTING AGENT ON A 'CRENSHAW' *AGROSTIS STOLONIFERA VAR. PALUSTRIS* (CREEPING BENTGRASS) PUTTING GREEN TOTAL MICROBIAL POPULATION & HYDROPHOBICITY

ABSTRACT

Microbial abundance is an indicator of good soil health as microorganisms are critical, and may affect soil particles covered in hydrophobic substances. Microbial populations are influenced by thatch, roots, and water levels in the soil. This study investigated treatment effects of daily evapotranspiration (ET) irrigation regimes, daily mowing frequencies, and monthly application of a wetting agent under golf course putting green management conditions. Treatments were compared in a split-plot experimental design on the same plots over three years. Total microbial biomass (TMB) data were determined by chloroform fumigation incubation method (Jenkinson and Powlson, 1976). Soil hydrophobicity data were determined by water drop penetration test (WDPT). Data on TMB and WDPT were measured with cores taken at the end of each year.

No significant differences in TMB were observed in soils treated with 30, 60 , or 90% ET daily irrigation from 2010 to 2012, with levels ranging from 29.9 to 60.1 µg g dry soil $^{-1}$ (Table 26). Daily double mowing and wetting agent application did not significantly affect TMB. However, during the driest season of 2012, TMB was significantly increased with the use of wetting agent at 30% ET replenishment (Table 27). Data obtained from water drop penetration (WDP) tests resulted in significantly lower hydrophobicity in soil at the 0-1 cm depth below plant and/or thatch with wetting agent applications in all years (8-18 seconds). No differences

were observed at sampling depths below 1 cm, and in response to irrigation or mowing treatments. Soil hydrophobicity reductions were more responsive to wetting agent applications than irrigation or mowing treatment effects.

INTRODUCTION

In production agriculture, healthy soils are defined as those with high levels of biological activity where total microbial biomass (TMB) can directly affect nutrient availability from soil organic matter (SOM), thus TMB is an effective indication of fertility and productivity in the cropping system (Bending et al., 2004; Friedel et al., 2001; Nair and Ngouajio, 2012; Smith and Paul, 1990). In soil, TMB is representative of the active pool of SOM present. Microbes in the soil are often carbon (C) limited (Smith and Paul, 1990) and lower microbial biomass is generally attributed to low organic C presence (Flie”bach and Mäder, 2000). The ideal microbe soil environment mirrors plant needs including nutrients, moisture, organic matter, and pores filled with air (Zuberer, 2012).

Microbes in USGA or native soil turfgrass putting green systems are abundant, are affected by the environmental conditions, and possibly cultural and mechanical practices created by managers (Zuberer, 2012). However, microbial putting green research is limited, and no research has evaluated the cumulative effects over multiple years of irrigation, mowing, and surfactant applications on a native soil putting green in relation to total microbial biomass (TMB). This research investigated total microbial biomass (TMB) levels in response to irrigation level, mowing frequency, wetting agent, turfgrass quality, and disease activity.

In regard to irrigation on turfgrass it appears inevitable that limitations and restrictions on irrigation use will increase for years to come (Water Reports, 2006). Obviously, native soil putting greens are more prone to anaerobic soil conditions compared to predominantly sand root zones. Ideally, irrigation regimes should be based on scientific principles and research;

however, in most instances, intuition and experience are used to replenish water through irrigation.

Managing water application rates by evapotranspiration (ET) through the onsite Enviro-weather station (East Lansing / MSUHTRC) of the Michigan Agricultural Weather Network (MAWN) provided a repeatable quantitative measurement of potential evapotranspiration (PET), or daily water loss. Use of this technology may reduce risk of over-watering. Replenishing irrigation water to 30, 60, and 90% of daily ET was studied for potential water conservation, and effects on total soil microbial populations. ET based watering may allow managers to establish acceptable baselines, which will reduce the potential for improper watering. It is hypothesized ET based irrigation regimes effect on total microbial biomass (TMB) may promote or compromise a healthy soil environment.

Double mowing compared to single mowing has be reported to have a negative physiological effect on turfgrass plants (Beard, 1973), however, it is not known if this negative impact is due to mechanical stress and if the degradation has an impact on TMB. Clippings returned to the soil may provide a nutrient source for microbes through decomposition. While clipping removal is normal on putting greens, an inevitable amount of clippings are not thrown in the mower bucket. Daily double mowing may enhance clipping collection by picking up missed clippings from the first pass. If this were true, it is possible that this reduction could be reflected in disease incidence and/or TMB.

Past wetting agent research has focused upon localized dry spot (LDS), enhanced infiltration, and its contribution to a more homogeneous wetting of the root zone (Oostindie, et. al., 2010). Wetting agents also allow soil water and solutes to move less rapidly to the subsoil and remain more accessible to the turf (Oostindie, et. al., 2010). However, wetting agents have never been evaluated for their impact on soil microbial populations. A soil with greater TMB indicates more potential from microbial biochemical activities. It seems possible that wetting agent application could provide greater TMB under dry soil conditions and possible decreased TMB under wet soil conditions.

Hydrophobic conditions due to soil texture, watering regimes, thatch, and organic matter development reduce aesthetics and playing conditions on golf course putting greens (DeBels and Soldat, 2010., McMillan et. al., 2012). While the origin of soil water repellency is not well understood, it is generally accepted to be caused by organic compounds from roots or microbes coating soil particles, whereas critical soil water content is dependent on soil properties plus wetting and drying history of the area (Doerr et al., 2000, Larsbo et al., 2008). Previous water drop penetration tests (WDPT) studies have shown water repellent soil is prevalently found in the thatch and mat area (0 to 1 cm depth) of a turfgrass profile (McMillan et. al., 2012). Localized dry spots (LDS) are one consequence of soil hydrophobic conditions on turfgrass putting greens, but wetting agents have been shown to reduce repellency and improve turfgrass quality (Cisar et al., 2000; Kostka, 2000; Larsbo et al., 2008). Research of the effects wetting agents have on hydrophobic conditions in predominantly sand USGA specification root zones are extensive (Cisar et al., 2000, DeBels and Soldat, 2010., Doerr et al., 2000, Kostka, 2000, Larsbo et al., 2008, McMillan et. al., 2012), but native soil putting green research is limited. An objective of this study was to evaluate LDS causing hydrophobic conditions in response to three watering regimes, daily single and double mowing, and a wetting agent on a native soil putting green.

The ability to provide water to a creeping bentgrass putting surface most efficiently could be characterized by microbial abundance, visual quality, ball roll distance, and time domain reflectometry (TDR) measurements. Presumption of soil health will be made based on TMB and/or WDP tests, along with statistical significance regarding irrigation, mowing, and wetting agent treatments.

Long-term research on the cumulative effects of daily ET irrigation, double mowing, and use of a wetting agent are lacking. These management practices in varying combinations were evaluated for efficacy by considering soil microbial populations, soil hydrophobicity, and turfgrass quality.

Expected results from this study include watering levels will have a significant impact on microbial populations. The aim of this research is to quantify the impact that different watering regimes, mowing frequencies, and a wetting agent has on soil health and putting green quality.

MATERIALS & METHODS

Data for TMB and WDPT provide cumulative treatment effects on long-term soil health and water repellency, respectively. Time of collections was annual, and is admittedly only a snapshot into the total picture of seasonal fluctuations.

Research was conducted at the Hancock Turfgrass Research Center (HTRC) at Michigan State University in East Lansing, Michigan, on a 1296-m^2 (36 x 36 m) owosso-marlette sandy loam native soil experimental putting green, seeded with creeping bentgrass (*Agrostis stolonifera var. palustris*) 'Crenshaw' in 2003. The area comprises nine 148-m^2 (12 x 12 m) plots. In each plot Hunter PGP™ (Hunter Industries Inc., San Marcos, CA USA) irrigation heads were installed on each corner. The nine plots were arranged in a randomized complete block design with three replications of main plot evapotranspiration (ET) replenishment levels (30,60, and 90% daily ET). Daily ET data were determined by the onsite Enviro-weather station (East Lansing / MSUHTRC) of the Michigan Agricultural Weather Network (MAWN). Each irrigation plot contained four 2.1 m by 9.8 m (20.6-m^2) sub-plots. Sub-plot treatments consisted of daily single mowing double mowing treatments with and without a wetting agent treatment.

From May to October daily irrigation replenishment at 30%, 60%, and 90% evapotranspiration (ET) were applied. Irrigation replenishment was determined with the Penman-Monteith equation to estimate potential ET (Penman, 1948; Monteith, 1965). Applicable rainfall was subtracted from ET to determine the overall daily replenishment for each ET treatment per current recommendations (MDA GAAMP's, 2010). Project technology provided by Spartan Distributors (Sparta, MI) included a TORO Site Pro 'Central' computer control center running software v. 2.2 (1996-2006 TORO Irrigation Division, Bloomington, MN

USA) and TORO NSN Connect© (The Toro Company, Bloomington, MN USA) computer software controls daily irrigation levels from an onsite computer and remotely via an iPhone 4© (Apple, Inc., Cupertino, CA USA) application. Irrigation audits were conducted throughout each of the growing seasons to ensure distribution of uniformity of 0.7 or greater and obtain data for scheduling accurate run-times (Leinauer and Smeal, 2012). Audits were conducted by placing six AcuRite™ Magnifying Rain Gauge 00850 (Chaney Instrument Company, Lake Geneva, WI USA) within each plot for three separate full-turns of the irrigation heads. Water amounts were averaged and run-times adjusted if needed until the system was corrected.

The area was mowed six times per week with a Toro 1000 (The Toro Company, Bloomington, MN USA) greens mower at a bench setting height of 0.125 in (0.3175 cm). Mowing treatment sub-plots within each plot were double-mowed daily. The second cut immediately followed the initial cut in a different pattern direction. The entire area was lightly topdressed with sand weekly throughout the growing season and the entire area was rolled three days per week with a DMI Speed Roller (DMI/IPAC Group, Amherst, NY). With the exception of preventative *Sclerotinia homeocarpa* (Dollar spot) treatments, pesticides were applied on a curative basis to allow disease, insect, and weed observations. To prevent total loss of the highly susceptible 'Crenshaw' creeping bentgrass putting green, the fungicides chlorothalonil (Bravo Weather Stik, Syngenta) and propiconazole (Banner MAXX, Syngenta) were applied to preventatively control Dollar spot throughout 2011 and 2012. Treatments that warranted a monthly application of a wetting agent (Revolution®, Aquatrols, Paulsboro, NJ USA) were applied at the labeled rate of 168 mL/ 90 m^2 (6 oz/ 1000 ft^2) from May-October.

Total microbial biomass (TMB) was determined by chloroform fumigation incubation method (Jenkinson and Powlson, 1976; Parkinson and Paul, 1982). In October of each year (1 Oct. 2010, 18 Oct. 2011, and 10 Oct. 2012) samples were obtained with a 2.54-cm diameter soil probe to a depth of 10.16 cm to evaluate treatment effects on TMB populations in soil. Approximately 1000 g of soil (twenty cores) were taken from each plot. Cores were placed in 1020.6 g Whirl-Pak (Aristotle Corporation, Stamford, CT) bags, and were immediately transferred to a refrigerator maintained at the temperature of 4 °C. Samples were removed from refrigerator and maintained at room temperature for 24 h. Individual samples were sieved through a 2 mm screen with visible organic residue and stones removed (Jenkinson and Powlson, 1976). Six 50 g soil samples from each treatment replication were weighed into beakers. Three of these samples were fumigated with alcohol-free $CHCl_3$ and incubated for 24 h, while the remaining three served as non-fumigated controls. After incubation, each fumigated sample was inoculated with approximately 1 g of its corresponding non-fumigated soil, thoroughly mixed and brought to 55% water holding capacity. Fumigated and non-fumigated samples were then incubated at 22 °C for 5 d in a 1 L airtight mason jar with rubber septum on the lid. After incubation, a CO_2 sample was drawn through the septum using 1 mL syringe and injected into an infrared gas analyzer (Qubit S151 CO2 analyzer, Qubit Systems Inc., Kingston, Ontario, Canada). Total microbial biomass (µg g^{-1} soil) in soil was calculated using the equation: $1.73F_C-0.56NF_C$, where F_C and NF_C are mineralized carbon from fumigated and non-fumigated soil samples, respectively (Horwath et al., 1996).

Soil hydrophobicity determined by water repellency was measured with the water drop penetration (WDP) test (Dekker and Jungerius, 1990; Larsbo et al., 2008). On 1 Oct. 2010, 18 Oct. 2011, and 10 Oct. 2012, three soil samples per plot were obtained with a 1.27 cm inside diameter soil probe to a depth of 10.16 cm. After 96 h of air-drying in the laboratory at approximately 20°C and 60% relative humidity, a 0.05 ml drop of water was placed by eye dropper (Walter Stern, Inc., Port Washington, NY) on each soil core surface at depths of 0-1, 1-2, and 2-3 cm just below visible plant and thatch layer. Times until the water drops infiltrated the soil were measured in seconds (s). Each WDPT was treated as an individual measurement, resulting in three sub-samples per treatment for statistical analysis. The WDPT test performed on air-dry samples is an acceptable standard of potential soil water repellency versus actual repellency due to removal of soil moisture variability present at time of sampling (Dekker and Ritsema, 1994; Larsbo, 2008). Dekker and Jungeris (1990) proposed a soil water repellency classification of: a soil is considered wettable if drop infiltration is immediate, non-repellent if WDPT < 5 s, slightly water repellent if 5 s < WDPT < 60 s, and strongly water repellent if 60 s < WDPT < 600 s (Larsbo, 2008).

Statistical analysis was performed in SAS v. 9.3 (SAS institute, Inc., Cary, NC) using Proc Gli-Mix Procedure. The model statement for each response variable analyzed all main factors evaluated and all possible interactions with the main treatment factors. All data analysis utilized mean separation conducted at alpha = 0.05. Microbial biomass and water drop penetration (WDP) test times include all data and over year analysis because sampling number and time were consistent for all three years. All parameters included the random term replication*irrigation level*mowing frequency*wetting agent. All parameters in this study were analyzed in this manner. Regression analyses were performed between TMB and WDPT to compare response variables of ball roll distance, percent volumetric water content (%VWC), and visual quality. Variables were additionally analyzed/imported into ARM v. 8.3.4© (Gylling Data Management 1982-2011, Brookings, SD) and/or GraphPad Prism (GraphPad Software, Inc., La Jolla, CA) for visual figure development.

RESULTS & DISCUSSION

Total irrigation amounts applied each day were calculated based on weather data (Appendix A) from approximately May to October each season. In 2010, total daily irrigation applied for 30, 60, and 90% ET were 11.25, 22.63, and 33.91 cm, respectively. In 2011, total daily irrigation applied for 30, 60, and 90% ET were 15.44, 30.63, and 46.05 cm, respectively. In 2012, total daily irrigation applied for 30, 60, and 90% ET were 17.27, 34.29, and 51.56 cm, respectively.

Analysis of variance means for total microbial biomass (TMB) as affected by irrigation are shown in Table 16. Irrigation, mowing, and wetting agent treatments had no significant effects on TMB on 2010-2012. However, an interaction was observed in 2012 between irrigation and wetting agent (Table 17). Table 17 indicates a significant increase in TMB at 30% ET replenishment with use of a wetting agent. Conversely, table 17 indicates a significant reduction in TMB at 90% ET replenishment. Soil microbes require a sufficient amount of water for growth and reproduction. Insufficient amounts of water may slow life processes, but too much water leads to anaerobic soil conditions which has a negative impact on most soil microbes and plant health. End of season TMB measurements (Figure 8) are average of mowing and wetting agent over each irrigation treatment. Year significantly affected average TMB ($P<0.0001$). The year difference is most likely attributed to management over time. 2010 was the wettest and coolest of the three years; 2012 was the hottest and driest season (Appendix A). Average TMB did not significantly differ in 2010, and measured 33.33, 32.08, and 29.89 µg g dry soil $^{-1}$ for 30, 60, and 90% ET, respectively ($P<0.05$). This result may be attributed to greater seasonal rainfall, and initiation of treatments on an established putting green not yet overcoming previous management practices. In 2011, average TMB did not significantly differ, and measured 60.08, 55.53, and 52.66 µg g dry soil $^{-1}$ for 30, 60 and 90% ET, respectively (P<0.05). In 2012, average TMB did not significantly differ, and measured 40.07, 45.58, and 42.13 µg g dry soil $^{-1}$ for 30, 60 and 90% ET, respectively (P<0.05).

Fluctuation of TMB over a season or from season to season may occur due to many factors, in particular due to porosity and moisture content. These fluctuations are reflected in the data as presented in Figure 8. No significant differences in TMB were observed due solely to irrigation replenishment regime in any one year from 2010 to 2012.

Mowing frequencies and wetting agent treatments were evaluated for effects on total microbial biomass (TMB). Analysis of variance for total microbial biomass (TMB) as affected by mowing and wetting agent are shown in Table 16. Interactions, if observed, are shown in Table 17.

In 2010, double mowing and wetting agent treatments did not result in statistically different TMB. TMB measured 31.19 and 32.34 µg g dry soil $^{-1}$ in daily single mowed compared to double mowed plots, respectively (P=0.1399). TMB measured 31.69 and 31.84 µg g dry soil $^{-1}$ in untreated compared to wetting agent treatments, respectively (P=0.8491). Both 2011 and 2012 supported no biological significance when neither treatment separated TMB levels statistically (See Table 16). The data shows that the hypothesis of a second mowing pass providing more carbon for microbial degradation as disproved. An interaction in 2012 (Table 17), showed application of wetting agent significantly increased TMB at 30% ET replenishment.

Chemical use on turfgrass remains under scrutiny for the possible negative effects they may have on the environment. TMB data from all three years indicate that the wetting agent had no negative impact on soil microbial activity, and in fact enhances TMB under low irrigation regimes. Additionally, the fact that the wetting agent at 30% ET replenishment also maintained adequate playing conditions indicates the surfactant could save water. Further investigation is warranted on other soil types and/or with even lower ET irrigation levels.

Table 16. 2010-2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on total microbial biomass (TMB) in micrograms per gram of soil obtained by chloroform fumigation incubation method at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average TMB (μg/g^{-1})				
Irrigation (IRR)		2010		2011		2012
30% ET		33.33		60.08		40.07
60% ET		32.08		55.53		45.58
90% ET		29.89		52.66		42.13
Significance		NS		NS		NS
LSD (0.05)		NS		NS		NS
Mowing (MOW)						
1X daily		31.19		55.02		42.54
2X daily		32.34		57.16		42.64
Significance		NS		NS		NS
LSD (0.05)		NS		NS		NS
Wet-Agent (WA)						
Untreated		31.69		55.79		41.86
1X monthly		31.84		56.39		43.33
Significance		NS		NS		NS
LSD (0.05)		NS		NS		NS
		Mean Square and Pr>F				
Source	df					
Replication	2	20.70	0.0339	1316.47	<.0001	462.29	<.0001
IRR	2	36.39	0.4224	168.25	0.2328	92.92	0.2076
Error for IRR	4	33.79	0.0017	78.45	0.0041	38.89	0.0167
MOW	1	12.02	0.1399	40.96	0.1044	0.08	0.9284
WA	1	0.19	0.8491	3.24	0.6363	19.51	0.1725
IRRxMOW	2	0.85	0.8460	1.17	0.9205	6.66	0.5150
IRRxWA	2	0.13	0.9739	13.15	0.4094	238.70	<.0001
MOWxWA	1	8.41	0.2127	25.00	0.1982	0.78	0.7795
IRRxMOWxWA	2	4.79	0.4050	11.27	0.4626	5.54	0.5737
Error	18	5.04		14.00		9.66	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 17. 2012 average total microbial biomass† (TMB) as affected by irrigation and wetting agent‡ (WA) at the Hancock Turfgrass Research Center in East Lansing, MI.

	2012	
Irrigation	WA	No WA
30% ET	45.95a	34.18c
60% ET	43.88ab	47.27a
90% ET	40.15b	44.12a
$LSD_{(0.05)}$ §	3.77	
$LSD_{(0.05)}$ #	5.33	

† Micrograms per gram of soil obtained by chloroform fumigation incubation method.

‡ Wetting agent was applied monthly from May till September with Revolution® from Aquatrols, Inc. (Paulsboro, N.J) at 1.87-ml/m^2.

§ Between wetting agent means at same irrigation level on the single date listed above.

Among irrigation level at the same or different wetting agent on the single date listed above.

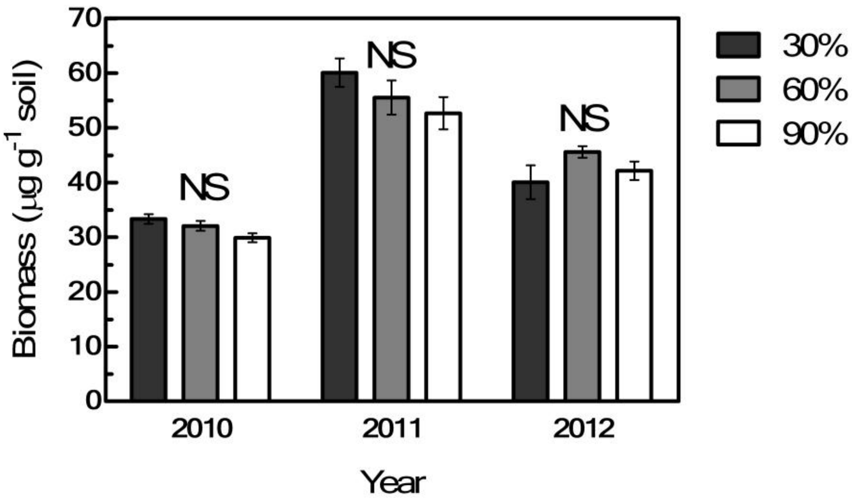

Figure 8. Irrigation effects on total microbial biomass (TMB) in 2010-2012. Values are averaged over treatments. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at α=0.05. N=9

Frequent wet to dry cycles along with several other factors contribute to soil hydrophobicity in golf course putting greens (McMillan et al., 2012). Analysis of variance means for water drop penetration (WDP) tests as affected by irrigation and mowing are in Table 18 through 20. Interactions, if observed, are in Table 21.

For all years of the study no significant differences in WDP tests were observed across averages for different treatments of irrigation or mowing at P<0.05. As stated in chapter one, irrigation reduction showed significant increase on LDS from counts and visual quality. Mowing followed the same trend as irrigation, and WDP test results contradict hydrophobicity observations that double mowing increases LDS.

WETTING AGENT AND HYDROPHOBICITY

Analyses of variance for water drop penetration (WDP) tests as affected by wetting agent are in Table 18 through 20. Interactions, if observed, are shown in Table 21.

Applications of wetting agent (Revolution®**)** significantly reduced soil water repellency at the 0 to 1 cm depth (Figure 9 and Tables 18, 19, and 20). No significant differences were observed below 1 cm in all years. Measurements in Figure 9 are averaged across irrigation and mowing treatments. In 2010, WDP test averages were 56 and 18 s for untreated versus wetting agent plots, respectively (P=0.0043 and LSD 25). In 2011, WDP test averages were 25 and 9 s for untreated versus wetting agent plots, respectively (P=0.0115 and LSD 13). The overall reduction to both untreated and wetting agent treatments support the combined management regime contributed positively to combating soil water repellency. In 2012, the driest year, WDP test averages were 28 and 8 s for untreated versus wetting agent plots, respectively (P=0.0276 and LSD 17). In each year a reduction in hydrophobicity from the previous was observed regardless of wetting agent treatment However, wetting agent plots were significantly less hydrophobic than untreated in every year. This WDP test data strongly supports data on wetting agent effects to playability, and suggests reduced hydrophobicity benefits are attained with long-term and repeated application.

Table 18. 2010 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on soil hydrophobicity measured by water drop penetration (WDP) tests at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average WDP (seconds) 2010					
Irrigation (IRR)		0-1 cm		1-2 cm		2-3 cm	
30% ET		47.50		8.00		3.75	
60% ET		49.58		3.83		0.67	
90% ET		18.08		5.25		0.75	
Significance		NS		NS		NS	
LSD (0.05)		NS		NS		NS	
Mowing (MOW)							
1X daily		30.28		4.17		0.61	
2X daily		46.50		7.22		2.83	
Significance		NS		NS		NS	
LSD (0.05)		NS		NS		NS	
Wet-Agent (WA)							
Untreated		61.78b		8.83		2.83	
1X monthly		15.00a		2.25		0.61	
Significance		**		NS		NS	
LSD (0.05)		26.78		NS		NS	
		Mean Square and Pr>F					
Source	df						
Replication	2	121.53	0.9206	21.19	0.8029	35.36	0.4370
IRR	2	3723.86	0.2640	53.86	0.7260	37.03	0.4147
Error for IRR	4	1967.44	0.2916	155.07	0.2110	33.49	0.5285
MOW	1	2368.44	0.2193	84.03	0.3603	44.44	0.3103
WA	1	19693.44	0.0018	354.69	0.0697	44.44	0.3103
IRRxMOW	2	1111.19	0.4821	16.36	0.8437	43.69	0.3633
IRRxWA	2	1601.36	0.3557	53.86	0.5783	29.86	0.4946
MOWxWA	1	5675.11	0.0644	140.03	0.2413	40.11	0.3344
IRRxMOWxWA	2	1253.36	0.4409	34.69	0.7000	51.19	0.3087
Error	18	1462.06		95.37		40.78	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 19. 2011 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on soil hydrophobicity measured by water drop penetration (WDP) tests at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average WDP (seconds) 2011					
Irrigation (IRR)		0-1 cm		1-2 cm		2-3 cm	
30% ET		18.79		5.19		1.83	
60% ET		15.04		3.96		1.40	
90% ET		17.61		7.68		2.59	
Significance		NS		NS		NS	
LSD (0.05)		NS		NS		NS	
Mowing (MOW)							
1X daily		17.73		5.11		1.71	
2X daily		15.57		6.11		2.17	
Significance		NS		NS		NS	
LSD (0.05)		NS		NS		NS	
Wet-Agent (WA)							
Untreated		25.46b		7.04		2.12	
1X monthly		8.83a		4.18		1.76	
Significance		**		NS		NS	
LSD (0.05)		11.40		NS		NS	
		Mean Square and Pr>F					
Source	df						
Replication	2	368.85	0.2739	79.89	0.1236	12.17	0.0360
IRR	2	44.14	0.9312	43.06	0.5695	4.36	0.4924
Error for IRR	4	608.56	0.0987	66.21	0.1457	5.13	0.1950
MOW	1	12.08	0.8333	9.11	0.6108	1.96	0.4321
WA	1	2489.84	0.0067	73.65	0.1581	1.17	0.5420
IRRxMOW	2	134.69	0.6098	33.25	0.3947	5.18	0.2090
IRRxWA	2	253.90	0.4022	1.62	0.9536	0.44	0.8659
MOWxWA	1	181.67	0.4184	2.91	0.7732	2.30	0.3954
IRRxMOWxWA	2	92.24	0.7106	22.07	0.5338	0.83	0.7641
Error	18	264.87		33.95		3.02	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 20. 2012 main effects and mean squares for treatment effects of irrigation, mowing, and wetting agent on soil hydrophobicity measured by water drop penetration (WDP) tests at the Hancock Turfgrass Research Center in East Lansing, MI.

		Average WDP (seconds) 2012					
Irrigation (IRR)		0-1 cm		1-2 cm		2-3 cm	
30% ET		30.22		7.33		2.97	
60% ET		13.03		4.83		1.95	
90% ET		11.08		3.06		1.53	
Significance		NS		NS		NS	
LSD (0.05)		NS		NS		NS	
Mowing (MOW)							
1X daily		20.55		5.33		1.69	
2X daily		15.67		4.81		2.61	
Significance		NS		NS		NS	
LSD (0.05)		NS		NS		NS	
Wet-Agent (WA)							
Untreated		27.83b		6.31b		2.67	
1X monthly		8.39a		3.83a		1.63	
Significance		**		*		NS	
LSD (0.05)		14.14		2.27		NS	
		Mean Square and Pr>F					
Source	df						
Replication	2	552.44	0.2832	47.99	0.0246	5.77	0.2486
IRR	2	1331.51	0.4853	55.37	0.1595	6.64	0.5762
Error for IRR	4	1528.69	0.0218	18.41	0.1812	10.45	0.0619
MOW	1	214.96	0.4772	2.43	0.6359	7.69	0.1738
WA	1	3402.58	0.0098	55.43	0.0336	9.69	0.1293
IRRxMOW	2	43.16	0.9002	1.54	0.8642	2.10	0.5870
IRRxWA	2	1653.99	0.0352	44.18	0.0314	0.21	0.9479
MOWxWA	1	15.09	0.8496	0.61	0.8126	0.99	0.6170
IRRxMOWxWA	2	143.57	0.7080	13.43	0.3014	0.84	0.8052
Error	18	407.92		10.47		3.83	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† NS, non-significant at the 0.05 level.

‡ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 21. 2012 hydrophobicity determined by water drop penetration† (WDP) tests as affected by irrigation and wetting agent‡ (WA) at the Hancock Turfgrass Research Center in East Lansing, MI.

	2012			
	0-1 cm		1-2 cm	
Irrigation	WA	No WA	WA	No WA
30% ET	6.94a	53.50b	3.89a	10.78b
60% ET	10.11a	15.94a	4.89a	4.78a
90% ET	8.11a	14.05a	2.72a	3.39a
LSD $_{(0.05)}$ §	24.50		3.92	
LSD $_{(0.05)}$ #	34.65		5.55	

† Time in seconds for absorption.

‡ Wetting agent was applied monthly from May till September with Revolution® from Aquatrols, Inc. (Paulsboro, N.J) at 1.87-ml/m^2.

§ Between wetting agent means at same irrigation level on the single date listed above.

Among irrigation level at the same or different wetting agent on the single date listed above.

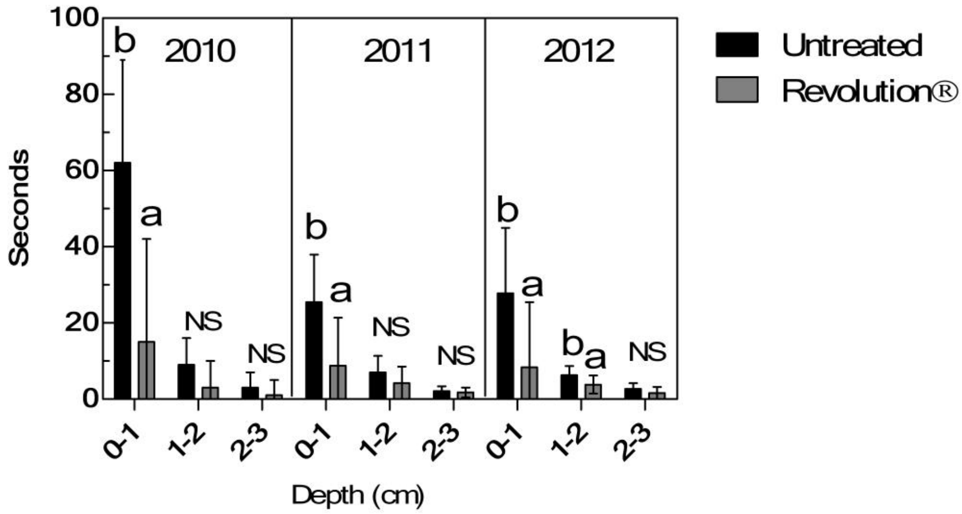

Figure 9. Revolution® effects on water drop penetration (WDP) tests in 2010-2012. Values are averaged over treatments. Error bars represent least significant difference (LSD) using Fisher's Protected Method. Overlapping error bars represent statistically similar treatments at α=0.05. N=9

Regression analyses were performed between TMB and WDPT to compare response variables of ball roll distance, percent volumetric water content (%VWC), and visual quality. Investigation of correlations was proposed to develop a prediction model development based on response variables, however, no significant correlations between variables were observed across years.

CONCLUSIONS

Daily irrigation replenishment to 90% ET on the research plots led to no observed benefits to the total microbial biomass (TMB) populations. Daily irrigation replenishment to 60% ET provided acceptable TMB on plots for the three-year study duration. TMB levels in plots receiving 60% ET were equal to or greater than the 90% ET, even in the driest of years (2012), indicating a potential thirty percent savings in water applied while maintaining aesthetics and soil health. 30% ET may be enough for TMB levels in temperate climates during early spring or late fall. However, consideration is warranted for dry years such as 2012.

TMB data from all three years indicate that the wetting agent had no negative impact on soil microbial activity, and in fact enhances TMB under low irrigation regimes. Additionally, the fact that the wetting agent at 30% ET replenishment also maintained adequate playing conditions indicates the surfactant could save water. Also, wetting agent appeared to improve plant uptake of volumetric water content (%VWC) present in plots, as represented in WDP tests. Combining these two findings indicate that use of wetting agents may lead to improved TMB levels with better water uptake potential in plots receiving 30% ET replenishment.

Double mowing on a daily basis for three consecutive years yielded few negative impacts to plots above ground (as represented in chapter one), and laboratory TMB plus WDP test measurements indicate no negatives in the root zone. Combining these two findings suggest double mowing daily over the long-term is possible.

Again, this research warrants further investigations in creeping bentgrass or other species on putting greens managed under United States Golf Association sand specifications. At the conclusion of the study and as expected, daily ET replenishment regime did not show an effect on TMB at $P<0.05$, but more sampling throughout the year is warranted in the future.

APPENDICES

APPENDIX A

Table 22. Seasonal weather data (May-October) summary for 'Crenshaw' native soil putting green at the Hancock Turfgrass Research Center in East Lansing, MI, in 2010-2012.

2010	°F Max	°F Min	Rainfall (In)	PET	2011	°F Max	°F Min	Rainfall (In)	PET	2012	°F Max	°F Min	Rainfall (In)	PET
5/1	72.4	61.9	0.05	0.109	**5/1**	71.6	51.1		0.167	**5/1**	59.2	46.8	0.01	0.062
5/2	71.5	54.7	0.4	0.074	**5/2**	55.9	46		0.13	**5/2**	81.3	50.3		0.147
5/3	72.6	52.9		0.16	**5/3**	49	38.3		0.068	**5/3**	84.7	57.8	0.85	0.177
5/4	72.9	44.3		0.189	**5/4**	60.4	36.9		0.147	**5/4**	78.4	55.4	0.35	0.098
5/5	66.5	55	0.01	0.153	**5/5**	64.3	34.1		0.178	**5/5**	66.6	49.1		0.074
5/6	64.3	47.4		0.156	**5/6**	63.3	48.7	0.03	0.154	**5/6**	67.3	50.1	0.28	0.115
5/7	58.6	46.3	1.1	0.037	**5/7**	68.7	39.1		0.161	**5/7**	69.1	50.4	0.12	0.068
5/8	49	38.1	0.02	0.075	**5/8**	68.4	43.6		0.179	**5/8**	67.7	48.1		0.156
5/9	55.6	32.1		0.145	**5/9**	69.2	39.4		0.195	**5/9**	62.5	45.9	0.02	0.114
5/10	57.6	29.2		0.158	**5/10**	72.3	52.1	0.04	0.175	**5/10**	65.9	39.9		0.181
5/11	46.6	41.2	0.7	0.036	**5/11**	78	54.2		0.194	**5/11**	73.3	38.3		0.198
5/12	51.1	41.3		0.043	**5/12**	86	54.7	0.25	0.163	**5/12**	62.4	55.2	0.32	0.055
5/13	65.5	44.3	0.7	0.036	**5/13**	85.6	58.2	2.26	0.156	**5/13**	72.9	49.6	0.14	0.144
5/14	63.9	48.1		0.165	**5/14**	63	48.5	0.2	0.035	**5/14**	75.1	41.3		0.196
5/15	64.9	45.4		0.136	**5/15**	49.8	39.7	0.39	0.047	**5/15**	79.6	44.4	0.03	0.217
5/16	65.5	40.6		0.152	**5/16**	55.2	39.1		0.14	**5/16**	64.9	48.6	0.05	0.184
5/17	66.8	46		0.144	**5/17**	56.3	44.2	0.07	0.09	**5/17**	69.7	35.3		0.176
5/18	65.4	47.9	0.05	0.089	**5/18**	62	48	0.43	0.042	**5/18**	77.1	43.8		0.206
5/19	76.7	42.2		0.187	**5/19**	72.8	54.8	0.1	0.099	**5/19**	84.3	49.3		0.228
5/20	81.2	48		0.191	**5/20**	75.3	56.3		0.132	**5/20**	87.4	58		0.253
5/21	69.3	58	0.97	0.06	**5/21**	76.7	53.3	0.03	0.159	**5/21**	74.2	56.6		0.083
5/22	75.6	57.7	0.02	0.105	**5/22**	83.2	58.3	0.07	0.207	**5/22**	71	49.6		0.16

Table 22 (cont'd)

5/23	83	52.7		0.205	**5/23**	77.5	61.8	0.04	0.185	**5/23**	77.7	41.1		0.207
5/24	85	61.9		0.209	**5/24**	74.6	57.7		0.175	**5/24**	84.9	56.3		0.229
5/25	82.7	60.1		0.195	**5/25**	60.6	50.5	0.77	0.035	**5/25**	80.1	63.7		0.24
5/26	90.4	60		0.218	**5/26**	56.6	44.2	0.35	0.034	**5/26**	74.7	59.4	0.08	0.129
5/27	85.6	66.8		0.25	**5/27**	54.4	45.4		0.051	**5/27**	81.1	59.4		0.184
5/28	85.5	60.4		0.237	**5/28**	66	52.3	0.01	0.076	**5/28**	90.2	61.4	0.01	0.243
5/29	84.8	58.2		0.224	**5/29**	74.5	55.9	0.69	0.09	**5/29**	81.9	63.8		0.269
5/30	86.9	56.6		0.224	**5/30**	88	58.5		0.216	**5/30**	68.5	49.9		0.152
5/31	81.7	65.1	0.07	0.099	**5/31**	88.2	67.8	0.03	0.226	**5/31**	56.8	44.1	0.18	0.067
6/1	80.6	63.5		0.205	**6/1**	74.8	61.4		0.27	**6/1**	53	46.1	0.58	0.03
6/2	72.9	61.2	0.61	0.073	**6/2**	71	50.5		0.201	**6/2**	70.2	46.1		0.168
6/3	75.2	60.5		0.105	**6/3**	75.6	51.6		0.193	**6/3**	75.7	56.8		0.226
6/4	78.7	53.5	0.1	0.12	**6/4**	89.4	60.7		0.215	**6/4**	71.2	52.2		0.168
6/5	78.4	60.2	0.55	0.138	**6/5**	85.4	56.8		0.221	**6/5**	68.5	49.1		0.145
6/6	67.7	55.4	0.98	0.116	**6/6**	84.7	55.6		0.214	**6/6**	77.5	43.8	0.01	0.209
6/7	70.5	48.6		0.191	**6/7**	92.9	73.8		0.242	**6/7**	78.7	51.1		0.214
6/8	69	47.7	0.12	0.106	**6/8**	91.4	74.9		0.271	**6/8**	80.5	49.3		0.221
6/9	77.2	56.2	0.01	0.182	**6/9**	82.4	57.4	0.01	0.129	**6/9**	84.5	62.7		0.25
6/10	75.9	56.8		0.191	**6/10**	60	52.9	0.44	0.049	**6/10**	88.2	58.7		0.235
6/11	78.9	59.9	0.1	0.126	**6/11**	75.2	58.1		0.108	**6/11**	80.3	64.8	0.02	0.147
6/12	84.9	69.4		0.141	**6/12**	66.2	50.3		0.112	**6/12**	74.5	57.7	0.02	0.231
6/13	74.4	62.1		0.094	**6/13**	78.4	52.2		0.216	**6/13**	72.7	47.5		0.19
6/14	75.3	65	0.04	0.083	**6/14**	76.5	50.1		0.219	**6/14**	79	47.8		0.222
6/15	74.8	61.4		0.114	**6/15**	67.3	47.5	0.05	0.096	**6/15**	85.7	53.3		0.245
6/16	73.5	64.7	0.04	0.133	**6/16**	73	57.7	0.51	0.14	**6/16**	86.9	62.6		0.21
6/17	77.9	60		0.192	**6/17**	77.8	53.2		0.122	**6/17**	80	59.6		0.152
6/18	87.8	58.1	0.24	0.203	**6/18**	82.6	56		0.213	**6/18**	79.6	57.6	0.37	0.143
6/19	80.7	64.9		0.198	**6/19**	80.2	56.6		0.198	**6/19**	91.5	73.4		0.259
6/20	80	61.3		0.174	**6/20**	76	59.8		0.107	**6/20**	90	71.3		0.259
6/21	81.5	57.5		0.168	**6/21**	86.8	66.8	0.24	0.158	**6/21**	84.8	62.9	0.05	0.176

Table 22 (cont'd)

6/22	82.6	63.9	0.74	0.193	**6/22**	79.9	63.9	0.26	0.142	**6/22**	80.5	58.2		0.194
6/23	86	65.6	0.26	0.154	**6/23**	70.1	62.1	0.02	0.082	**6/23**	82.7	52.8		0.196
6/24	79.5	68		0.205	**6/24**	64.5	58.3	0.05	0.074	**6/24**	84.2	64.7		0.193
6/25	79.5	52.8		0.212	**6/25**	77.7	57.4		0.209	**6/25**	73.8	54.7		0.208
6/26	83	64.9		0.181	**6/26**	81	52.2		0.207	**6/26**	80.7	46.6		0.212
6/27	82.1	64.4	0.13	0.106	**6/27**	78.3	58.1		0.116	**6/27**	86.7	52.7		0.236
6/28	80.1	64.8		0.215	**6/28**	70.9	61.3		0.171	**6/28**	94.5	66.2		0.248
6/29	70.3	54.5		0.195	**6/29**	78.7	53.3		0.217	**6/29**	87	64.5		0.201
6/30	72	45.2		0.202	**6/30**	83	51.4		0.177	**6/30**	87.5	65		0.232
7/1	76	49.1		0.2	**7/1**	85.6	58.4		0.188	**7/1**	90.8	61		0.206
7/2	79.6	49.7		0.213	**7/2**	91.6	68.9		0.229	**7/2**	94.7	61		0.201
7/3	83.7	52.1		0.235	**7/3**	86.7	66.1		0.224	**7/3**	92.4	70.1		0.21
7/4	90	59.8		0.227	**7/4**	85.4	62.7		0.236	**7/4**	96.9	72.4		0.231
7/5	89.2	73.1		0.238	**7/5**	87.6	57.7		0.238	**7/5**	95.7	68.4	0.03	0.18
7/6	90	68.5		0.226	**7/6**	86.1	67.5		0.225	**7/6**	100.9	68.9		0.231
7/7	91.3	69.9		0.204	**7/7**	79.6	56.5		0.166	**7/7**	92.3	73.2		0.232
7/8	84.7	70.8	0.16	0.1	**7/8**	86.1	56.8		0.215	**7/8**	83.2	63.9		0.216
7/9	85.4	68.8		0.184	**7/9**	89.4	60.2		0.207	**7/9**	86.2	57.5		0.177
7/10	84.8	59.6		0.185	**7/10**	89	66.2		0.213	**7/10**	82.6	61.1		0.211
7/11	85.1	61.3	0.01	0.164	**7/11**	80.1	66.8	0.34	0.092	**7/11**	85.2	54.7		0.206
7/12	81.5	65.4	0.06	0.153	**7/12**	86.1	66.2		0.234	**7/12**	88	53.9		0.22
7/13	80.7	66		0.117	**7/13**	78.1	59.4		0.21	**7/13**	90.4	59.4		0.209
7/14	85	59.7		0.196	**7/14**	80	51.5		0.187	**7/14**	90.3	63.8	0.2	0.217
7/15	89.3	70.3	0.7	0.154	**7/15**	84.5	61.8		0.182	**7/15**	88.4	68		0.221
7/16	85.8	61.4		0.238	**7/16**	90.9	57.4		0.215	**7/16**	92.6	65.9		0.227
7/17	86.2	67.5		0.241	**7/17**	91.2	64.8		0.226	**7/17**	95.9	75.2		0.294
7/18	84.7	63.2		0.107	**7/18**	90.4	74.6	0.2	0.159	**7/18**	84.7	68	0.4	0.144
7/19	80.7	68.6	0.04	0.156	**7/19**	93	72.6		0.203	**7/19**	74.8	65.9	0.26	0.081
7/20	82.2	63.9	0.03	0.118	**7/20**	92.9	70.3		0.199	**7/20**	80.5	60	0.01	0.193
7/21	85.1	65.9		0.227	**7/21**	93.9	72		0.263	**7/21**	85.1	53.9		0.204

Table 22 (cont'd)

7/22	79.5	58.6	0.52	0.096	**7/22**	82	65.7	0.03	0.093	**7/22**	89.2	65.1		0.189
7/23	87.3	73	0.12	0.154	**7/23**	86.8	67.7	0.02	0.136	**7/23**	93.4	71.7	0.04	0.252
7/24	81	70.9	0.1	0.088	**7/24**	86.3	67.2		0.145	**7/24**	83.2	65.6		0.22
7/25	81.5	63.3		0.194	**7/25**	86.9	71.4		0.217	**7/25**	88.4	55.8	0.02	0.206
7/26	84.7	57.5		0.16	**7/26**	82.5	65		0.234	**7/26**	84.5	69.3	0.19	0.107
7/27	84	58.3		0.194	**7/27**	77.4	56.5	1.28	0.092	**7/27**	79.3	65.7		0.119
7/28	84.7	70.3		0.141	**7/28**	86.1	69.2	1.62	0.135	**7/28**	80.9	59.9		0.2
7/29	82.3	59.8		0.188	**7/29**	87.2	70.4	1.61	0.192	**7/29**	85.5	53.8		0.186
7/30	82.3	55.4		0.163	**7/30**	88.2	62.4		0.22	**7/30**	87.6	59.6		0.206
7/31	76	64.3		0.082	**7/31**	88	64.2		0.232	**7/31**	85.4	62.7	0.31	0.187
8/1	82.4	59.9		0.144	**8/1**	88.8	71.6		0.208	**8/1**	83.8	60.6		0.204
8/2	83	61.5		0.153	**8/2**	85.7	68.3	0.06	0.105	**8/2**	89	61.7		0.156
8/3	85.5	71.6		0.178	**8/3**	84	70.2	0.77	0.132	**8/3**	94.2	66		0.206
8/4	85.4	67.2		0.144	**8/4**	80.8	64.9		0.091	**8/4**	89.4	68.1	0.11	0.194
8/5	83.9	67.3		0.222	**8/5**	84.5	61.9		0.168	**8/5**	81.8	66.1		0.23
8/6	78.7	60		0.191	**8/6**	80.8	69.9	0.09	0.071	**8/6**	83.1	50.7		0.205
8/7	80.5	52.2		0.166	**8/7**	81	66.3		0.133	**8/7**	86.5	54.5		0.203
8/8	84.8	66.6		0.162	**8/8**	81.2	-40	0.02	0.121	**8/8**	83.7	65.1		0.185
8/9	81.8	71.1	0.26	0.087	**8/9**	79.6	63.2	0.28	0.166	**8/9**	71.4	58.6	0.43	0.033
8/10	87.9	64.4		0.153	**8/10**	73.9	60.4		0.176	**8/10**	62.5	57.7	0.7	0.035
8/11	79.8	64.2	0.26	0.083	**8/11**	77.8	53.3		0.188	**8/11**	72.2	57.2	0.38	0.071
8/12	87.8	70.5		0.103	**8/12**	78.7	55.2		0.158	**8/12**	76.5	55.9		0.157
8/13	86.8	67.2		0.177	**8/13**	79.5	60.6	0.31	0.077	**8/13**	70.9	60	0.03	0.052
8/14	81.7	70.5		0.101	**8/14**	72.9	58.4	0.17	0.06	**8/14**	78	60.6	0.05	0.147
8/15	86.3	67.1		0.186	**8/15**	79.2	56.5		0.178	**8/15**	82.6	56.9		0.147
8/16	76.5	60.7		0.204	**8/16**	83.3	53.5		0.181	**8/16**	75.9	60.9	0.06	0.098
8/17	78.7	55.4		0.16	**8/17**	80.6	55.4		0.165	**8/17**	73.4	57.1		0.151
8/18	78.9	59.2	0.01	0.167	**8/18**	82.8	62.7	0.01	0.182	**8/18**	75.1	44.9		0.158
8/19	83.9	58.6		0.184	**8/19**	83.4	53.3		0.18	**8/19**	77.6	51		0.162
8/20	86.7	63.5		0.171	**8/20**	80.7	59.8	0.49	0.075	**8/20**	75.6	49.2		0.152

Table 22 (cont'd)

8/21	79.2	69.2	0.04	0.086	**8/21**	76.7	56.5	0.02	0.169	**8/21**	78.1	49.2		0.169
8/22	84	65.1		0.164	**8/22**	76.2	49.3		0.168	**8/22**	80.3	49.1		0.171
8/23	73.5	63.6		0.082	**8/23**	80.3	53.2	0.45	0.162	**8/23**	86.9	50.4		0.172
8/24	77.2	58		0.093	**8/24**	87.8	65.5	0.41	0.182	**8/24**	88.2	58.6		0.175
8/25	76.9	58.8		0.179	**8/25**	76.9	58.9		0.136	**8/25**	89.7	58.6		0.192
8/26	75.1	50.4		0.171	**8/26**	79.5	51.5		0.164	**8/26**	88.7	63.8	0.12	0.175
8/27	78.3	45.9		0.167	**8/27**	81.9	55.9		0.17	**8/27**	84.4	67.9	0.2	0.14
8/28	83.2	55.4		0.189	**8/28**	75.1	54.8		0.165	**8/28**	78.9	58.6		0.155
8/29	91.1	58.8		0.181	**8/29**	76.4	47.9		0.155	**8/29**	81.2	50.7		0.152
8/30	89.3	65.9		0.169	**8/30**	77.2	53.7		0.132	**8/30**	84.2	51.6		0.174
8/31	88.2	70.6		0.193	**8/31**	79.9	61.2		0.108	**8/31**	90.9	68.1		0.213
9/1	83.9	69.6	0.22	0.112	**9/1**	89.1	64.1		0.169	**9/1**	80.8	61.2		0.123
9/2	74	66.1	0.22	0.044	**9/2**	90.5	71.1	0.01	0.185	**9/2**	83.2	64.2		0.126
9/3	73.3	55.4	0.41	0.131	**9/3**	88.7	68.5		0.161	**9/3**	89.9	60.2	0.05	0.149
9/4	60.9	49.9		0.117	**9/4**	73.4	58.9	0.11	0.114	**9/4**	83.9	66.1	0.64	0.086
9/5	70.4	42.6		0.141	**9/5**	59.5	48.1		0.077	**9/5**	79	63.9		0.102
9/6	71.6	56.2	0.13	0.072	**9/6**	66.6	46.2		0.11	**9/6**	83.7	63.7		0.135
9/7	79.1	61.1		0.245	**9/7**	67.2	48.9	0.06	0.076	**9/7**	76.4	57.8	0.28	0.07
9/8	63.5	54.2		0.118	**9/8**	64.4	55.6		0.042	**9/8**	68	52.9	0.06	0.117
9/9	66.8	50.3		0.118	**9/9**	76.7	59.1	0.33	0.075	**9/9**	71.2	47.9		0.126
9/10	67.6	42.2		0.122	**9/10**	78.8	60.1	0.04	0.111	**9/10**	74	41.8		0.133
9/11	60.9	51	0.45	0.03	**9/11**	77.6	57.5		0.114	**9/11**	79.1	51		0.158
9/12	74	54.7		0.142	**9/12**	81.8	58.9		0.149	**9/12**	82.4	55.4		0.158
9/13	76.6	52.1		0.18	**9/13**	76.4	54.2		0.133	**9/13**	78.4	55.7	0.2	0.096
9/14	70.6	48		0.147	**9/14**	65.4	43.8	0.16	0.064	**9/14**	70.4	51.5	0.36	0.125
9/15	71.8	41.8		0.131	**9/15**	59.8	38.9		0.105	**9/15**	73.6	41.6		0.125
9/16	66.8	54.2	1.34	0.043	**9/16**	58.9	36.3		0.073	**9/16**	76.3	47.9		0.126
9/17	66.3	51.5		0.09	**9/17**	64.8	45.9		0.098	**9/17**	75.7	50.7	0.01	0.113
9/18	66.6	53.7	0.38	0.044	**9/18**	69.3	43.8		0.122	**9/18**	64.4	43.5	0.19	0.091
9/19	71.1	51.1		0.081	**9/19**	66.7	55.9	0.73	0.036	**9/19**	65	38.8	0.01	0.129

Table 22 (cont'd)

9/20	65.6	55.4		0.091	**9/20**	71	46.5	0.01	0.107	**9/20**	68.3	47.7	0.06	0.132
9/21	85.8	58.4	0.15	0.164	**9/21**	74.7	51.9		0.11	**9/21**	67.1	43.4	0.16	0.093
9/22	76.6	60.1		0.071	**9/22**	67.4	49.8		0.087	**9/22**	58.7	44.2	0.06	0.065
9/23	86.5	60.2		0.128	**9/23**	63.9	50.9		0.056	**9/23**	55.8	40.6	0.06	0.076
9/24	80.6	57	0.01	0.159	**9/24**	64.8	43.9		0.086	**9/24**	61.9	37.5	0.01	0.123
9/25	58.7	49		0.092	**9/25**	70.1	49.5	0.02	0.05	**9/25**	67.7	49.5	0.02	0.103
9/26	56.8	42.5		0.071	**9/26**	69.3	49.1	0.61	0.06	**9/26**	71.3	49.6	0.01	0.089
9/27	60.8	43.1	0.03	0.054	**9/27**	65.7	43.8	0.09	0.064	**9/27**	65	47.2		0.09
9/28	62.4	49.3	0.14	0.042	**9/28**	61.7	52		0.043	**9/28**	69.2	45.7		0.101
9/29	71.7	39.4		0.112	**9/29**	62.4	49.3	0.35	0.039	**9/29**	71.7	40.3		0.108
9/30	72.1	48.1	0.01	0.136	**9/30**	52.3	39.9	0.13	0.045	**9/30**	64.4	44.8		0.088
10/1	67.3	45.4		0.104	**10/1**	53.8	38.1		0.076	**10/1**	66.6	35.6		0.076
10/2	53.6	43.6	0.28	0.032	**10/2**	62	35.3		0.109	**10/2**	69.9	51.4		0.081
10/3	55.2	37.6		0.071	**10/3**	68.5	43.1		0.115	**10/3**	65.1	55.6		0.038
10/4	59.3	35.1		0.089	**10/4**	73.8	37.2		0.106	**10/4**	75.2	53.9	0.09	0.112
10/5	66.9	32		0.107	**10/5**	77.1	41.2		0.102	**10/5**	59.6	44.9	0.01	0.05
10/6	70.4	39.9		0.127	**10/6**	82	43.5		0.101	**10/6**	46.5	38.9		0.04
10/7	69.9	44.3		0.125	**10/7**	79	45.2	0.13	0.123	**10/7**	46.8	35.3		0.034
10/8	76.3	41.7		0.133	**10/8**	80.7	49.8	0.01	0.116	**10/8**	53.6	30.3		0.08
10/9	77	45.7		0.104	**10/9**	82	49.7		0.104	**10/9**	61.4	36.5		0.102
10/10	79.4	49.5		0.115	**10/10**	77.1	48.6		0.1	**10/10**	54.6	34.5	0.17	0.045
10/11	79.1	46.5		0.106	**10/11**	78.1	45	0.1	0.12	**10/11**	61.1	29.9	0.03	0.105
10/12	68.8	43.7		0.08	**10/12**	68.6	49.1		0.077	**10/12**	52	30.1	0.04	0.067
10/13	59.8	46.3	0.49	0.025	**10/13**	64.5	52.1	0.32	0.052	**10/13**	62.2	31.6	0.84	0.016
10/14	61.8	42		0.094	**10/14**	58.1	47.8	0.03	0.053	**10/14**	69.1	50.9	0.37	0.06
10/15	61.4	43	0.03	0.087	**10/15**	55.4	44.3	0.05	0.096	**10/15**	50.9	44.5	0.01	0.036
10/16	63.2	34.1		0.089	**10/16**	59.1	45.6	0.01	0.084	**10/16**	60.6	31.4		0.072
10/17	60.1	41.2		0.101	**10/17**	56.6	43.1		0.108	**10/17**	73	52.8	0.27	0.123
10/18	56.8	43.7		0.062	**10/18**	53.3	36.9	0.06	0.039	**10/18**	58.7	43.4	0.37	0.069
10/19	57	31.8		0.076	**10/19**	47.5	43	0.85	0.015	**10/19**	52.1	41.2	0.12	0.032

Table 22 (cont'd)

10/20	63.8	39.4	0.27	0.099	**10/20**	45.9	41.7	0.96	0.021	**10/20**	55.8	42.9	0.06	0.047
10/21	50.7	34.8	0.01	0.056	**10/21**	46.5	35.3			**10/21**	61.7	32.9		0.07
10/22	56.9	29.1		0.074	**10/22**	58.7	29.8		0.064	**10/22**	70	40	0.58	0.046
10/23	62.4	46.8		0.054	**10/23**	64.1	36.8		0.076	**10/23**	65	59.2	0.22	0.022
10/24	71.3	51	0.01	0.101	**10/24**	59.5	38.5	0.28	0.091	**10/24**	77.8	57.7		0.071
10/25	71.8	56.9	0.17	0.062	**10/25**	66.6	37	0.01	0.049	**10/25**	75.9	57.6		0.123
10/26	66.6	54.4	0.15	0.088	**10/26**	58	42.9		0.018	**10/26**	70.3	41.8	0.06	0.049
10/27	65	51.4		0.185	**10/27**	48.7	37.4		0.037	**10/27**	52.4	33.5		0.055
10/28	51.4	41.1		0.057	**10/28**	49.8	26.7		0.042	**10/28**	45.9	32.9		0.042
10/29	50.8	38.5		0.079	**10/29**	51.4	32.6	0.14	0.032	**10/29**	43.5	34.4		0.072
10/30	59.2	38.7		0.095	**10/30**	50.4	25.6		0.053	**10/30**	38.9	32.2	0.35	0.025
10/31	49.8	31.6		0.054	**10/31**	49.5	34.4		0.035	**10/31**	41.2	34.5	0.02	0.017

APPENDIX B

Figure 10. Sixty-five foot above plot overhead image portraying turfgrass quality between treatments at the lowest irrigation regime in NE block of daily 30% evapotranspiration (ET) replenishment. 29 June 2012 (first week of summer dry-down).

Figure 11. Sixty-five foot above plot overhead image portraying turfgrass quality between treatments at the lowest irrigation regime in NE block of daily 30% evapotranspiration (ET) replenishment. 11 July 2012 (second week of summer dry-down).

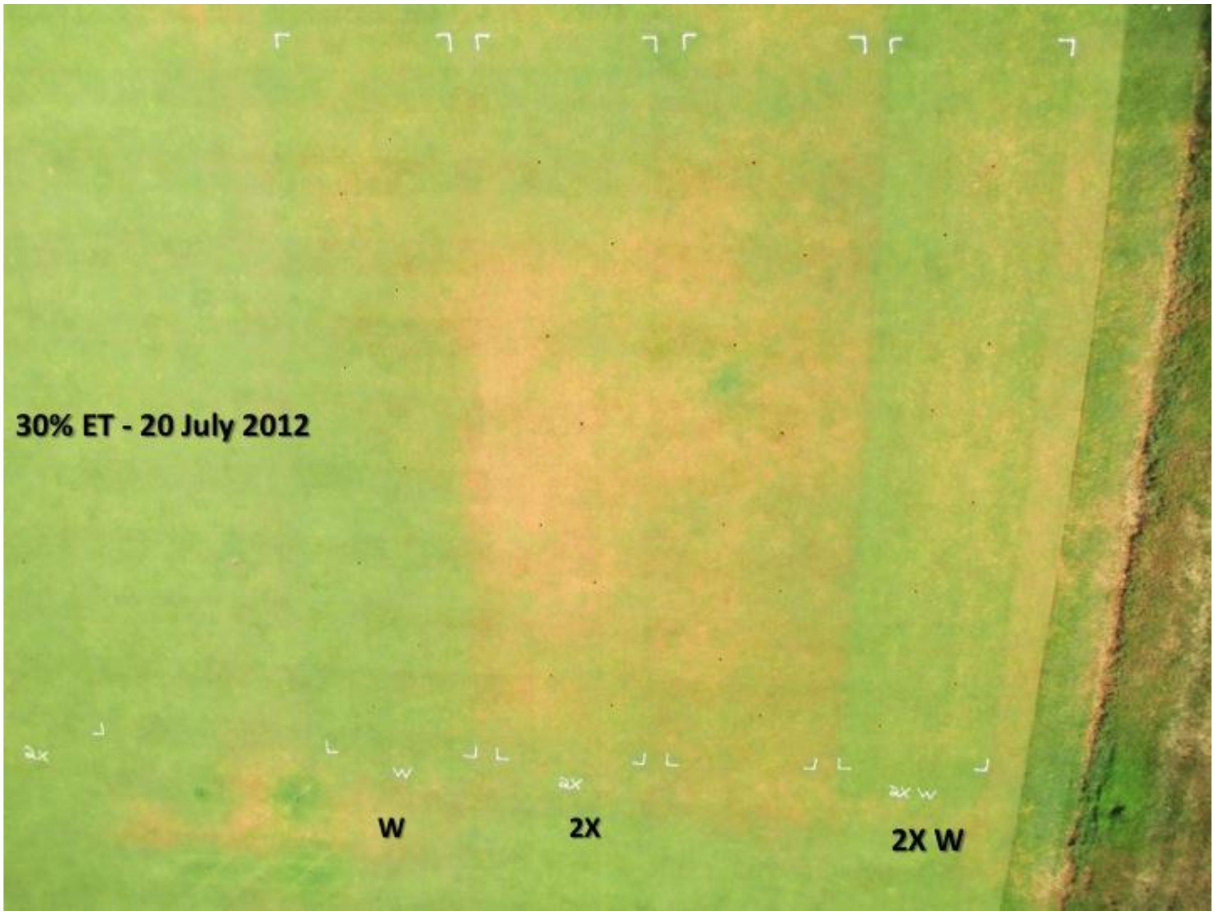

Figure 12. Sixty-five foot above plot overhead image portraying turfgrass quality between treatments at the lowest irrigation regime in NE block of daily 30% evapotranspiration (ET) replenishment. 20 July 2012 (third week of summer dry-down).

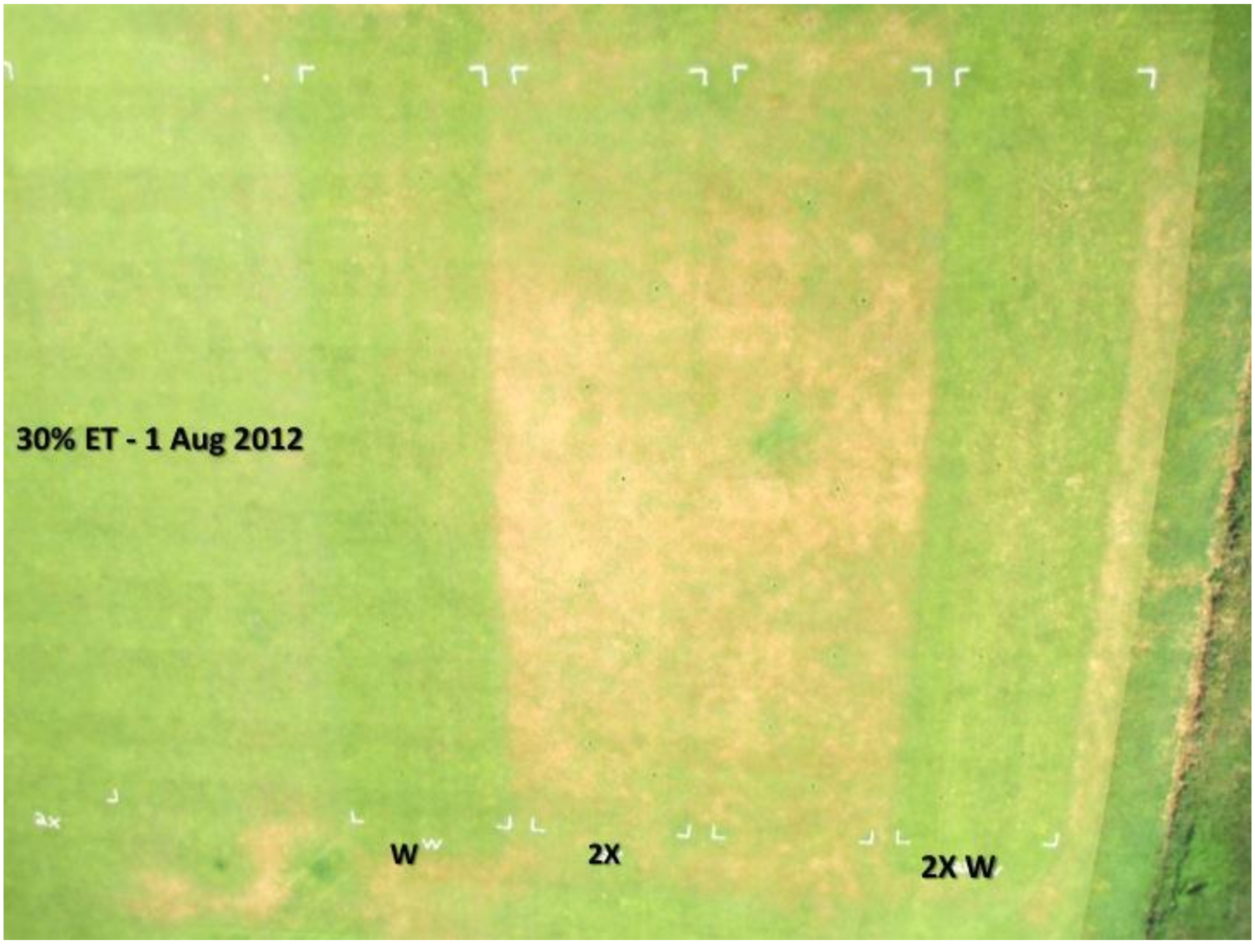

Figure 13. Sixty-five foot above plot overhead image portraying turfgrass quality between treatments at the lowest irrigation regime in NE block of daily 30% evapotranspiration (ET) replenishment. 1 August 2012 (fourth week of summer dry-down).

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