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RESEARCH

Wetting Agent Influence on Putting Green Surface Firmness

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ABSTRACT

Soil wetting agents are commonly used in the golf course industry for managing soil moisture. Recently, there has been an interest in the influence wetting agents have on the firmness characteristics of putting surfaces. To date, there has been no established relationship between wetting agents and surface firmness of putting greens. Research was conducted in St. Paul, MN, to evaluate the surface firmness impacts from 13 commercially available wetting agents applied individually or in combination to a creeping bentgrass (*Agrostis stolonifera* L.) research green. Treatments were evaluated as season-long wetting agent programs with applications every 4 wk. Data collection included surface firmness (Clegg Impact Soil Tester), turfgrass quality (TQ), chlorophyll index (CI), volumetric water content (VWC), and spring water drop penetration tests (WDPT) to assess residual of fall-applied wetting agents. Firmness measurements were not affected by wetting agent applications in 2014. In 2015, Duplex (15% alcohol ethoxylates, 2% alkyl sulfonate, 7% ethylenediaminetetraacetic acid), Aquicare (100% blend of alkoxylated alcohols), and Primer Select (100% alkoxylated polyols) provided the firmest surfaces. Ratings for TQ and CI demonstrated only minor influence of wetting agent applications, as did VWC measurements. Spring WDPT tests indicated wetting agent residual from late-fall applications, and persistence was most evident at shallow depths. Revolution (100% modified alkylated polyol) demonstrated the greatest residual, whereas Duplex and Aquiflo (45% poloxanlene, 2-butoxyethanol, siloxane surfactants) had the least residual. These results indicate that firmness can be influenced by wetting agent applications, and that persistence in the soil through the winter months is possible.

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Abbreviations: CI, chlorophyll index; TQ, turfgrass quality; VWC, volumetric water content; WDPT, water drop penetration tests.

Soil wetting agents have been used in the turfgrass industry for nearly six decades (Moore, 1957). Golf course superintendents look to wetting agents for many purposes, such as improving moisture retention in hydrophobic soils and for promoting overall soil moisture uniformity (Zontek and Kostka, 2012). There is a breadth of knowledge and research around soil wetting agent impacts on moisture dynamics in soils and benefits to turfgrass health, although many regional and multiyear trials fail to replicate the same performance of wetting agent chemistries (Karnok, 2013).

Wetting agents are surfactants, or surface-active agents, that work by reducing the surface tension of water and restoring the polar bond between water molecules and soil particles (Karnok et al., 2004). A current classification system by Zontek and Kostka (2012) groups wetting agents into four categories: (i) anionics and blends with anionics, (ii) nonionics, (iii) cationics, and (iv) new chemistries. Nonionic products are by far the most widely used due to relatively low phytotoxicity and persistence in the soil (Carrow, 1989), and they can be further broken down into six categories based on specific active ingredients (Zontek and Kostka, 2012). Reported practitioner benefits of wetting agent use include relieving localized dry spot, improving drainage, managing water, improving pesticide movement, decreasing dew formation, removing frost, enhancing seed germination, reducing fairy ring, improving irrigation efficiency, reducing dust, and

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improving bunker firmness (Karnok et al., 2004). More recently, wetting agents are being promoted for their value in creating firmer playing surfaces, although several studies lack evidence for these claims (Moeller et al., 2007; Kaminski and Han, 2010; Nangle et al., 2015).

Maintaining firm playing surfaces has become popular among golf course superintendents, and various cultural practices are conducted on golf courses with the goal of creating firmer surfaces (Linde et al., 2011). Researchers have established relationships between surface firmness and management practices such as nitrogen fertility (Menchyk et al., 2014), potassium fertility (Shearman et al., 2005), irrigation (Shearman et al., 2005; Stowell et al., 2009; Linde et al., 2011), and cultivation (Rowland et al., 2009). Standard instruments for measuring surface firmness of putting greens include the Clegg Soil Impact Tester and USGA TruFirm Meter (Stowell et al., 2009). Research has demonstrated an inverse relationship between volumetric water content (VWC) and firmness (Stowell et al., 2009; Linde et al., 2011), and because of this, wetting agents have the potential to influence surface firmness by creating drier surfaces under moist soil conditions.

The objectives of this research were (i) to determine the surface firmness influence of wetting agents applied in season-long programs to putting greens, (ii) to evaluate turfgrass performance and soil moisture as influenced by wetting agents, and (iii) to investigate wetting agent persistence into the spring from late-fall-applied wetting agents.

MATERIALS AND METHODS

This study was conducted from 2014 to 2016 at the Turfgrass Research, Outreach, and Education Center in St. Paul, MN. Wetting agent treatments were performed on a sand-based putting green constructed in 2001 to USGA specifications with an 88:12 (sand:peat) mixture (USGA Green Section Staff, 2004). Separate locations were used for each year of the trial. The 2014 treatment area consisted of ‘Alpha’ creeping bentgrass (*Agrostis stolonifera* L.) (Jacklin Seed by Simplot) seeded 4 yr prior, and the 2015 treatments were applied to ‘Penn A4’ creeping bentgrass (Tee-2-Green) seeded 1 yr prior. Plots measured 1.5 × 1.5 m and treatments were applied in a randomized complete block with four replications.

Thirteen commercially available wetting agents or wetting agent combinations (Table 1) were applied at recommended label rates (or rates discussed with manufacturers) on 4-wk intervals (±2 d) beginning on 14 May 2014 and 21 May 2015, with final applications on 19 Oct. 2014 and 23 Oct. 2015. An untreated control was also included. Treatments were applied with a three-nozzle CO_2–operated research sprayer calibrated to deliver 0.08 L m^{-2}. Immediately following applications, the treatment area was irrigated to a depth of 0.64 to 0.89 cm. Additional irrigation was applied to the entire treatment area when individual plots reached a threshold level of 10% VWC; this only occurred once in 2014, and never in 2015.

Table 1. Wetting agent treatment list.

Product	Rate	Company
	mL 100 m^{-2}	
Aquiflo	118	Winfield
Aquicare	89	Winfield
Cascade Plus	118	Precision Laboratories
Duplex	30	Precision Laboratories
Cascade Plus + Duplex	118 + 30	Precision Laboratories
Fleet	236	Harrell’s
Revolution	177	Aquatrols
Primer Select	118	Aquatrols
Sixteen90 + Dispatch Sprayable	118 + 30	Aquatrols
Sixteen90	118	Aquatrols
Dispatch Sprayable	118	Aquatrols
Tournament Ready	Initial 236, 118	Kalo
Tricure AD	59	Mitchell Products
Untreated	–	–

Treatments were evaluated weekly or biweekly for quality, color, VWC, and firmness. Surface firmness was measured with a Clegg Impact Soil Tester (0.5-kg model, Lafayette Instruments) by dropping the weight four consecutive times in the same place and recording the average of three locations per plot. The Clegg is designed to measure the hardness or shock absorption properties of a surface by measuring the deceleration of a free-falling mass; values are reported in tens of gravities. Turfgrass visual quality was assessed on the basis of color, density, uniformity, texture, and biotic or abiotic stresses using a 1-to-9 scale where 9 is the best turf quality and 6 or above is considered acceptable (Morris and Shearman, 2010). Nonsubjective color ratings were taken by a measurement of canopy greenness with a chlorophyll index meter (CM 1000, Spectrum Technologies) by averaging nine measurements per plot taken at 12:00 PM (±2 h). Volumetric water content was assessed with a time-domain reflectometer (TDR 300, Spectrum Technologies) by taking the average of five measurements to a depth of 12.0 cm.

Cores for water drop penetration tests (WDPT) were pulled from plots on 26 Mar. 2015 and 22 Mar. 2016 after mid-October applications; these tests were conducted to measure surfactant residual in the soil after a late-fall application. For this, four 19.0-mm soil cores were taken from each plot to a depth of 7.0 cm. Soil cores were set to air dry at room temperature for 14 d. Drops (35 μL) of distilled water were placed at depths of 1.0, 2.5, 4.0, and 5.5 cm on each soil core, and a penetration time in seconds was recorded. Soil water repellency is an indication of surfactant residual, and penetration times were compared with classifications by Dekker et al. (2001).

The treatment area was fertilized weekly beginning in May each year at 0.49 g N m^{-2}. Plots were mowed five times per week at 3.2 mm. Data were analyzed using ANOVA with Agricultural Research Manager (ARM, Gylling Data Management) with Fisher’s protected LSD at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Firmness

In 2014, there were no statistical differences ($p = 0.05$) in surface firmness measurements with the Clegg across 16 sampling dates (data not shown). During this first year, VWC ranged from 8.9% at the lowest (24 July 2014) to

24.1% at the highest (20 June 2014), as averaged across all plots. Clegg readings were taken under conditions with adequate soil moisture, as well as during dry and wet conditions, although no firmness differences were present. In 2015, surface firmness was significantly different ($p = 0.05$) according to treatment for 6 of 13 rating dates (Table 2). The difference in statistical significance from 2014 to 2015 is likely attributed to better surface consistency and less thatch across the 2015 trial area, as well as greater VWC values during the second year. In 2015, VWC ranged from an average of 13.9% (6 Aug. 2016) to 29.4% (28 May 2016), and VWC levels never dropped below 12%. It is likely that greater VWC levels allowed for more potential water movement and therefore greater differences in firmness. Additionally, better surface consistency resulted in more uniform Clegg readings from individual plots. Lastly, thatch can have a high affinity for wetting agents, causing soils to dry more slowly (Karnok et al., 2004), potentially binding the wetting agent in 2014 before it was distributed throughout the profile.

Products that consistently provided firmer surfaces in 2015 as measured by the Clegg included Duplex, Aquicare, and Primer Select (Table 2). Aquicare and Primer Select are reverse block copolymer surfactants with the a.i. alkoxylated alcohols, and Duplex is a straight block copolymer containing alcohol ethoxylates, alkyl aryl sulfonate, and ethylenediaminetetraacetic acid. All three of these products are marketed as improving infiltration and establishing more uniform soil moisture. Products that consistently provided softer surfaces included Aquiflo, Cascade Plus, and the Sixteen90 + Dispatch Sprayable combination. Both Cascade Plus and Sixteen90 are straight block copolymers. Dispatch Sprayable combines straight block copolymer with alkyl polyglucoside. Aquiflo is a combination of poloxanlene, butoxyethanol, and siloxane. Aquiflo and Cascade Plus are specifically marketed as products that will increase firmness of turf surfaces, although firmness with these products was rarely different from the untreated control in this trial.

Interesting and conflicting results were observed between Years 1 and 2 in this study. For example, Cascade Plus provided one of the firmest putting surfaces throughout the 2014 season; in 2015, however, this same treatment resulted in consistently softer surfaces. The authors acknowledge these conflicting results and speculate that the difference is due, at least in part, to differences in the thatch or mat level and seasonal weather patterns. For example, from April to October 2014, the research center received 8.05 cm more precipitation compared with the same time period in 2015. Additionally, other treatments performed differently from year to year, although data from Year 1 lacked statistical significance.

Turfgrass Quality and Chlorophyll Index

Turfgrass quality and chlorophyll index measurements were not statistically different ($p = 0.05$) by treatment during the 2014 growing season (data not shown). As stated above, irrigation was applied to the treatment area only when VWC

Table 2. Effect of wetting agent treatment on Clegg impact values on individual rating dates in 2015. Larger numbers indicate firmer surfaces.

Treatment	Clegg impact values												
	Rating date (2015)												
	28 May	4 June	12 June	18 June	25 June	9 July	23 July	6 Aug.	20 Aug.	11 Sept.	18 Sept.	16 Oct.	16 Mar.
	tens of gravities												
Aquiflo	14.1	14.3	15.7	17.7	17.3	16.5	16.3	18.7	17.9	17.6	17.5	18.7	15.4
Aquicare	14.6	14.6	16.4	18.9	18.1	17.1	17.0	19.7	18.9	18.9	18.3	19.3	16.3
Cascade Plus	14.1	13.7	15.6	17.5	17.3	16.7	16.9	18.7	17.7	18.2	17.5	19.6	15.8
Duplex	15.1	14.7	16.2	18.8	18.5	17.6	17.5	20.0	19.1	18.8	18.6	20.4	16.9
Cascade Plus + Duplex	13.5	13.8	15.4	18.0	17.6	17.0	17.0	19.7	18.0	17.9	17.9	20.1	15.8
Fleet	14.0	14.2	15.9	18.6	17.8	17.0	16.7	19.5	18.0	18.4	17.8	19.3	15.4
Revolution	13.8	14.3	15.6	18.3	18.3	17.2	16.8	19.6	18.1	18.3	18.0	19.9	15.6
Tournament Ready	13.9	14.4	15.7	18.1	17.9	17.6	17.4	19.1	18.8	18.3	18.3	20.2	16.3
Dispatch Sprayable	14.2	14.0	15.7	17.8	17.2	16.4	16.3	18.6	18.0	17.8	18.0	19.5	15.8
Primer Select	14.5	14.6	16.8	18.7	18.6	17.6	17.4	19.8	18.5	18.9	18.6	19.5	16.5
Sixteen90 + Dispatch Sprayable	13.9	13.9	15.7	17.8	17.1	16.6	16.3	18.7	17.8	17.7	17.6	19.0	15.2
Sixteen90	14.6	14.3	16.3	18.2	17.5	16.9	17.0	19.5	18.5	18.5	18.4	20.3	16.1
Tricure	14.2	14.3	15.9	18.0	17.7	17.1	16.4	19.6	18.6	18.2	18.1	20.3	16.3
Untreated control	13.9	14.0	16.0	17.9	17.6	16.5	16.0	19.7	18.1	18.1	17.3	18.7	15.5
Significance level	**	NS†	*	*	NS	*	NS	NS	*	NS	NS	NS	**
LSD ($p = 0.05$)	0.6	0.7	0.7	0.9	1.2	0.8	1.3	1.1	0.9	1.0	0.9	1.3	0.8

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† NS indicates non-significance.

dropped below 10%, which occurred once in 2014. At this time, there were differences in turf quality on the basis of moisture status of individual plots; however, treatment effects were not consistent across replications. In 2015, both chlorophyll index (CI) and turfgrass quality (TQ) were significant once on separate occasions, 18 June and 9 July, respectively (Table 3). The combination treatment of Sixteen90 + Dispatch Sprayable recorded the highest CI reading (canopy greenness), but it was not statistically different than seven other treatments, including the untreated control. Primer Select had the lowest CI reading, and three other treatments were statistically the same. This difference in canopy greenness was not apparent in turfgrass quality visual ratings on this date. Turfgrass quality visual ratings were only different on one date during this trial, 9 July 2015. On this date, VWC averaged 18% and plots were not showing signs of wilt stress. Treatments with the highest turfgrass quality were Sixteen90 + Dispatch Sprayable and Cascade Plus, whereas the lowest quality treatments were Duplex and Primer Select, but they were not statistically different from six additional treatments and the untreated control. Although some TQ and CI differences were apparent in 2015, TQ and CI appear to be influenced very little by wetting agents in a research setting under adequate growing conditions. We did attempt to moisture stress the turf by withholding irrigation; however, precipitation was generally sufficient when combined with the supplemental irrigation applied after treatments.

Volumetric Water Content

Trends in VWC correlated with observations in surface firmness, and rootzones holding more moisture tended to have softer surfaces; however, VWC data were not significant on any rating date in 2014 or 2015 (data not shown). Additionally, spring VWC values from fall-applied wetting agent treatments were not statistically different. These data are surprising given the differences in surface firmness. A possible explanation for nonsignificance in VWC values is the lack of water repellency over the trial area. Also, the accuracy of the Spectrum TDR 300 is reported as ±3% VWC with electrical conductivity <2 mS cm^{-1} (specmeters.com), which could be too great of an error for detecting statistical differences in this research trial.

Table 3. Effect of wetting agent treatment on chlorophyll index (CI) and turfgrass quality (TQ) on two rating dates in 2015. Larger numbers more canopy greenness (CI) and better TQ.

	CI	TQ
	Date	
Treatment	18 June 2015	9 July 2015
Aquiflo	182ab	6.5bc
Aquicare	177bc	6.5bc
Cascade Plus	181ab	7.8a
Duplex	178bc	6c
Cascade Plus + Duplex	179b	6.8bc
Fleet	177bc	6.8bc
Revolution	179ab	7ab
Tournament Ready	181ab	7ab
Dispatch Sprayable	182ab	7ab
Primer Select	172c	6.3bc
Sixteen90 + Dispatch Sprayable	186a	7.8a
Sixteen90	179b	6.8bc
Tricure	180ab	6.5bc
Untreated control	182ab	6.8bc
Significance level	*	**
LSD (p = .05)	6.3	0.79

* Significant at the 0.05 probability level.

** Significance at the 0.01 probability level.

Wetting Agent Residual

Wetting agent residual from late-fall applied treatments was assessed through WDPT tests in the spring. In 2015, WDPT tests were not significant at the 4.0- and 5.5-cm depths, indicating a lack of surfactant presence, and water drop penetration times varied from 7 to 22 s (4.0 cm) and 6 to 13 s (5.5 cm) (data not shown). According to the classification by Dekker et al. (2001), penetration times >5 s indicate slight water repellency. At the 1.0- and 2.5-cm depths, significant differences in penetration times indicate the presence of surfactant closer to the surface near the thatch or mat layer (Table 4). Explanations for this include a greater attraction to thatch by wetting agents and greater organic matter levels causing water repellency. At 1.0 cm in 2015, Duplex and the untreated control recorded penetration times of 59.7 and 52.7 s, respectively. All other treatments tested statistically the same at 1.0 cm; Aquiflo penetrated in 14.0 s, and the remaining treatments were <9 s. Revolution had the fastest WDPT time of 1.8 s at 1.0 cm, demonstrating the persistence of this product. At 2.5 cm, Revolution again had the fastest penetration time of 1.9 s, whereas the Aquiflo-treated soil took 27 s to penetrate. This data validates the results at the 1.0-cm depth, although Duplex appeared to be more persistent at the 2.5-cm depth.

In 2015, overall WDPT values were reduced by 50% (faster penetration times), and this is likely due to the lack of thatch buildup on the newly established Penn A4 research green (Table 4). Penetration times at the 2.5-cm depth or greater were not statistically different according to treatment, and all WDPT times at the three deepest depths were <13 s. At the 1.0-cm depth, Duplex, Aquiflo, and the untreated control all took the longest for the water drop to penetrate (22.2, 21.9, and 31.3 s, respectively), indicating a lack of persistence. Revolution again had the fastest WDPT time of 2.2 s. These results clearly indicate differences in wetting agent residual into the spring from a late-fall application, and some chemistries appear to be more persistent than others. Wetting agent application rate may play a role here, as it appeared that the higher-rate products were more persistent, and the opposite was true for low-rate products. More research is needed to confirm this hypothesis.

Table 4. Spring water drop penetration test (WDPT) soil core penetration time in 2015 and 2016 after October-applied wetting agent applications.

	WDPT soil core penetration time			
	Date			
	26 Mar. 2015		22 Mar. 2016	
Treatment	1-cm soil depth	2.5-cm soil depth	1-cm soil depth	2.5-cm soil depth
	s			
Aquiflo	14.0b	26.5a	21.9ab	10.5a
Aquicare	2.6b	13.5bc	7.0de	7.3a
Cascade Plus	3.4b	11.6cd	12.8b–e	13.2a
Duplex	59.7a	14.8bc	22.2ab	10.1a
Cascade Plus + Duplex	4.5b	9.3cd	10.8cde	5.6a
Fleet	2.5b	6.6cd	3.8e	3.7a
Revolution	1.8b	1.9d	2.2e	6.2a
Tournament Ready	5.0b	13.1bc	16.2bcd	11.7a
Dispatch Sprayable	8.7b	24.1ab	20.1bc	10.3a
Primer Select	5.9b	6.4cd	6.9de	5.3a
Sixteen90 + Dispatch Sprayable	3.4b	8.1cd	12.9b–e	10.7a
Sixteen90	6.0b	16.1abc	12.3b–e	11.5a
Tricure	5.4b	16.7abc	12.7b–e	9.2a
Untreated control	52.7a	16.8abc	31.3a	14.1a
Significance level	***	**	***	NS†
LSD (p = 0.05)	13.6	11.1	11.2	8.1

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† NS indicates nonsignificance.

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