Influence of various wetting agents on soil moisture, rooting, and drought stress on a research putting green, 2010

J.E. Kaminski and K. Han

Department of Crop and Soil Science
The Pennsylvania State University, University Park

INTRODUCTION

Wetting agents are often utilized by golf course superintendents to minimize the potential for drought related injury, conserve water, and/or to manage pests that reside in the soil and thatch (e.g., fairy ring, take-all patch, others). Despite a variety of information available on the various wetting agents commercially available in the golf turf market, many questions still remain regarding which is the best in each situation. In 2009, an area at the Valentine research facility exhibited extreme damage from drought related injury. This site was chosen to evaluate the impact of various wetting agents on minimizing drought stress on a golf course putting green. The overall objectives of this study were to: 1) determine the impact of various wetting agents on volumetric soil water content at two depths; 2) elucidate the impact of various wetting agents on putting green playability as measured by surface firmness; and 3) identify any other positive or negative impacts of the various wetting agents on turfgrass health.

MATERIALS & METHODS

This study was initiated at the Valentine Turfgrass Research Center located in University Park, PA. Soil was a sandy loam with a pH 7.1 and an OM of 2.7%. Turfgrass used for the wetting agent evaluation was a mixed stand of predominantly creeping bentgrass (*Agrostis stolonifera*) with a small amount of annual bluegrass (*Poa annua*). The area was maintained as a bentgrass green and mowed six times per week to a height of 0.125 in. All treatments were applied with a CO_2 pressurized (40 psi) sprayer equipped with an air-induction flat fan nozzle (AI9508E), and calibrated to deliver 2.0 gal water per 1000 ft^2. Treatments were initially applied on 2 Jun and reapplied on either 7 (Dispatch) or 28-day intervals. All treatments and application dates are listed in the data tables.

Plots measured 3 ft x 6 ft and were arranged in a randomized complete block with four replications. Turfgrass quality was visually rated on a 1 to 9 scale where 1 = entire plot brown or dead and 9 = optimum greenness and density. Dollar spot severity was assessed by counting the number of infection centers within each plot or by estimating the disease severity on a 0 to 100% scale where 0 = no disease present and 100 = entire plot area affected by dollar spot. Color measurements (NDVI) were taken using a FieldScout TCM 500 Turf Color Meter. Canopy temperatures were measured using a handheld infrared thermometer. Turfgrass drought injury was rated on a scale of 0 to 5 where 0 = no injury visible, ≤ 2.0 = minimum acceptable injury for a golf course green, and 5.0 = entire plot area brown or dead. Soil moisture measurements were taking using a FieldScout TDR 300 Soil Moisture Meter at a depth of 1.5” and 4.7”. Root depth was measured on 3 August by removing a soil profile (0.5” x 3” x 7”) and measuring the average depth of the entire root system as well as the depth of the longest root within each profile. Dew was rated on a scale 0 to 5 scale where 0 = no dew present and 5 = entire plot area covered with dew. Surface firmness was measured periodically using a USGA TruFirm device. Following the final application of wetting agents, irrigation was removed from the site and the area was allowed to naturally dry down beginning on 3 August. During this dry-down period, various data were recorded as described previously. All data were subjected to analysis of variance and means were separated at $P \leq 0.05$ according to Fisher’s Protected Least Significant Difference Test.

RESULTS

Soil Volumetric Water Content. Soil volumetric water content data were collected throughout the study using a Field Scout TDR 300 Soil Moisture Meter (Spectrum Technology). Data were measured by averaging the soil moisture content of three subsamples per plot taken at two different depths (1.5” and

4.7”). All subsamples were averaged for each plot prior to data analyses and soil volumetric water content was presented at each of the two depths (Table 1 and 2). At the 4.7” depth, no differences in volumetric soil moisture content were observed during the study until several days into the planned dry down of the site. Prior to ratings on 12 August the area received 0.81” of precipitation. Despite this additional moisture, differences in percent moisture were observed with the lowest soil moisture observed within the untreated control plots (8.88%) and those plots treated with Dispatch (7.40%) (Table 1). No differences among plots were observed on 16 Aug. On 18 and 20 Aug, however, differences among treatments were again observed with plots receiving Dispatch and no wetting agents again showing the lowest percent soil moisture. No differences in volumetric soil moisture at the 4.7” depth were observed among all other treatments on any rating date in the study.

Percent soil moisture at the 1.5” depth was consistently higher within all plots when compared to the 4.7” depth, regardless of treatment (Table 2). Few differences existed among treatments during the study until the area was subjected to a dry down. On 9 August (6 days after irrigation was withheld), plots treated with ACA 1872 had the greatest soil moisture when compared to the untreated control plots and those treated with ACA 1820, ACA 3029 and AQAAC. Although volumetric soil water content continued to decrease to 13.2 to 15.9% on 11 Aug, no differences among treatments were observed. Following the 0.81” of precipitation on 12 August, however, plots treated with Dispatch and the untreated control plots had significantly lower soil moisture content when compared to all other treatments. This reduction in volumetric soil moisture content continued to be observed until 20 Aug. During this period, variation in soil moisture was observed with plots treated with ACA 1872 generally exhibited the greatest volumetric soil water content at the 1.5” depth.

Surface Firmness. Similar to the results of the volumetric soil water content, no differences in putting green surface firmness were observed prior to the withholding of irrigation which began on 3 Aug. Prior to this date, surface firmness as measured by the USGA Tru-Firm device was considered excessively soft. Although firmness started to increase (lower numbers) approximately 6 days into the dry down cycle, no differences among treatments were observed until 18 Aug. At this time (16 days after initiation of the dry down), plots treated with no wetting agent and dispatch were significantly more firm when compared to all other treatments. On the final rating date (20 Aug), the untreated control plots were rated as the most firm, but no differences were observed among these plots and those treated with Dispatch. Plots treated with ACA 3029 were rated as having moderate firmness when compared to all other treatments, while those receiving OARS were among the softest. Although differences were observed among the various treatments, no plots were considered to have acceptable firmness for a golf course putting green.

Dew Formation. The presence or absence of dew was rated on 4 Jun (2 days after initial treatments were applied). On this date, significant differences in the visual presence of dew were clearly visible (Table 3). The lowest amount of dew was observed within plots treated with OARS, but no differences were observed among plots treated with this wetting agent and those treated with ACA 1820, ACA 3028, ACA 3029, or AQAAC. A slight increase in the presence of dew was recorded in plots treated with ACA 1820 when compared to plots receiving OARS. Dew within the untreated control plots and those treated with the wetting agent Dispatch was nearly covering the entire plot.

Miscellaneous Ratings. A variety of visual and quantitative measurements were made throughout the experiment. Based on the data collected, no differences were observed among treatments when rated for: 1) turfgrass quality; 2) canopy temperature; 3) dollar spot infection centers or percent plot area affected by dollar spot; 4) average or longest root depth; or 5) color as assessed using the TCM 500 Color Meter.

DISCUSSION

This study was designed to determine the influence of various wetting agents on soil moisture, turfgrass quality and surface playability (firmness). When adequate water was provided over the course of the study, no differences among wetting agents were observed in a variety of collected data. Prior to a planned dry down period, no differences among average or longest root length were observed among any treatments and/or the untreated control plots. When plots were not under drought stress, few differences in soil moisture existed among plots. Differences among treatments, however, were observed once plots

were subjected to drought stress. Approximately 6 to 9 days after water was withheld from the study area, plots receiving no wetting agents or Dispatch generally had the lowest volumetric soil water content. When soil moisture levels were at their lowest (18 Aug), plots receiving wetting agents had 21% to 96% higher moisture levels at the 1.5” depth and 13% to 86% higher moisture at the 4.7” depth.

Future studies should investigate the impact of the wetting agents on turf that is maintained at varying levels of soil moisture, rather than soil moisture that would be considered adequate or excessive. In this study, differences among treatments were only observed when irrigation was withheld at the end of the study. When not subjected to drought stress or decreased irrigation, very few differences were observed among treatments. When irrigation was withheld at the end of the study, all treatments (except Dispatch) resulted in a significant increase in volumetric soil moisture content when compared to the untreated control plots, regardless of depth. Although the aforementioned wetting agents resulted in a significant increase in soil moisture during the dry down period, they were also among the softest as measured with the USGA Tru-Firm device. It should be pointed out that although differences in soil moisture and firmness existed among treatments, all plots had moderate to severe drought injury on 13 Aug and no differences were observed among treatments.

ACKNOWLEDGEMENTS

We thank the staff and students at the Valentine Turfgrass Research Facility for their assistance in the maintenance and upkeep of the plots in this study. We also thank Aquatrols an Aqua-Aid for providing financial assistance for this study.

Table 1. Volumetric soil moisture content was measured at a depth of 4.7” using a TDR300 Soil Moisture Meter.

	Treatment and rate per 1000 sq ft	Application Code[y]	Volumetric Soil Moisture Content (%)				
			2 Jun	12 Jun	29 Jun	9 Jul	19 July
1	Dispatch 12 fl oz/A	ABCDEFGHI	18.48 a[x]	20.83 a	22.13 a	21.85 a	14.93 a
2	ACA 1820 6 fl oz	AEI	17.85 a	18.35 a	18.60 a	21.10 a	14.65 a
3	ACA 1872 6 fl oz	AEI	19.03 a	20.90 a	19.70 a	22.43 a	16.00 a
4	ACA 3028 6 fl oz	AEI	19.88 a	20.50 a	20.70 a	23.10 a	16.40 a
5	ACA 3029 6 fl oz	AEI	18.50 a	18.88 a	19.13 a	21.05 a	15.28 a
6	OARS 6 fl oz	AEI	19.58 a	20.35 a	19.23 a	22.55 a	16.48 a
7	AQAAC 4 fl oz	AEI	19.70 a	20.53 a	19.43 a	21.63 a	15.18 a
8	Untreated		19.15 a	21.23 a	19.65 a	23.83 a	15.40 a

[z] Percent volumetric soil moisture content was measured at a 4.7” depth using a TDR300 Soil Moisture Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher’s protected least significant difference t-test.

Table 1 (con’t). Volumetric soil moisture content was measured at a depth of 4.7” using a TDR300 Soil Moisture Meter.

	Treatment and rate per 1000 sq ft	Application Code[y]	Volumetric Soil Moisture Content (%)				
			27 July	3 Aug	4 Aug	5 Aug	6 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	19.60 a[x]	24.33 a	19.43 a	18.78 a	19.20 a
2	ACA 1820 6 fl oz	AEI	18.18 a	24.83 a	19.15 a	19.18 a	18.20 a
3	ACA 1872 6 fl oz	AEI	19.75 a	25.68 a	21.08 a	20.53 a	19.35 a
4	ACA 3028 6 fl oz	AEI	18.73 a	24.30 a	19.70 a	20.00 a	18.50 a
5	ACA 3029 6 fl oz	AEI	19.18 a	23.88 a	20.08 a	18.75 a	17.98 a
6	OARS 6 fl oz	AEI	19.75 a	23.80 a	20.38 a	19.15 a	19.73 a
7	AQAAC 4 fl oz	AEI	17.98 a	23.55 a	21.13 a	18.73 a	18.25 a
8	Untreated		19.05 a	24.23 a	20.25 a	19.53 a	18.23 a

[z] Percent volumetric soil moisture content was measured at a 4.7” depth using a TDR300 Soil Moisture Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher’s protected least significant difference t-test.

Table 1 (con't). Volumetric soil moisture content was measured at a depth of 4.7" using a TDR300 Soil Moisture Meter.

	Treatment and rate per 1000 sq ft	Application Code[y]	Volumetric Soil Moisture Content (%)				
			7 Aug	8 Aug	9 Aug	10 Aug	11 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	13.90 a[x]	12.78 a	11.50 a	7.40 a	5.10 a
2	ACA 1820 6 fl oz	AEI	12.18 a	11.65 a	10.95 a	7.10 a	4.78 a
3	ACA 1872 6 fl oz	AEI	14.03 a	12.83 a	12.73 a	8.70 a	6.15 a
4	ACA 3028 6 fl oz	AEI	13.88 a	12.33 a	11.90 a	7.70 a	5.50 a
5	ACA 3029 6 fl oz	AEI	13.08 a	12.43 a	10.70 a	8.20 a	4.98 a
6	OARS 6 fl oz	AEI	12.18 a	12.80 a	11.73 a	7.78 a	6.18 a
7	AQAAC 4 fl oz	AEI	12.30 a	12.45 a	10.78 a	6.90 a	4.88 a
8	Untreated		12.55 a	11.88 a	11.18 a	7.28 a	5.35 a

[z] Percent volumetric soil moisture content was measured at a 4.7" depth using a TDR300 Soil Moisture Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 1 (con't). Volumetric soil moisture content was measured at a depth of 4.7" using a TDR300 Soil Moisture Meter.

	Treatment and rate per 1000 sq ft	Application Code[y]	Volumetric Soil Moisture Content (%)				
			12 Aug	16 Aug	18 Aug	20 Aug	7 Sep
1	Dispatch 12 fl oz/A	ABCDEFGHI	7.40 b[x]	9.68 a	4.48 bc	10.85 b	9.05 a
2	ACA 1820 6 fl oz	AEI	12.40 a	12.25 a	6.38 ab	15.20 a	8.83 a
3	ACA 1872 6 fl oz	AEI	14.48 a	13.68 a	7.25 a	15.88 a	9.75 a
4	ACA 3028 6 fl oz	AEI	15.10 a	12.63 a	7.35 a	14.98 a	9.60 a
5	ACA 3029 6 fl oz	AEI	13.25 a	12.18 a	7.15 a	15.45 a	9.73 a
6	OARS 6 fl oz	AEI	14.10 a	12.20 a	7.23 a	14.98 a	10.08 a
7	AQAAC 4 fl oz	AEI	13.83 a	11.95 a	6.13 ab	15.15 a	8.93 a
8	Untreated		8.88 b	9.20 a	3.95 c	8.98 b	9.78 a

[z] Percent volumetric soil moisture content was measured at a 4.7" depth using a TDR300 Soil Moisture Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 2. Volumetric soil moisture content was measured at a depth of 1.5” using a TDR300 Soil Moisture Meter.

	Treatment and rate per 1000 sq ft	Application Code[y]	TDR/1.5				
			2 Jun	12 Jun	29 Jun	9 Jul	19 July
1	Dispatch 12 fl oz/A	ABCDEFGHI	26.23 ab[x]	31.93 a	29.85 a	33.75 a	24.40 a
2	ACA 1820 6 fl oz	AEI	25.63 b	30.93 a	29.78 a	32.43 a	24.38 a
3	ACA 1872 6 fl oz	AEI	28.35 ab	33.20 a	31.73 a	34.20 a	25.80 a
4	ACA 3028 6 fl oz	AEI	28.88 a	33.78 a	32.13 a	35.73 a	26.85 a
5	ACA 3029 6 fl oz	AEI	25.98 ab	31.60 a	30.50 a	33.00 a	24.63 a
6	OARS 6 fl oz	AEI	27.75 ab	32.28 a	30.40 a	33.58 a	25.05 a
7	AQAAC 4 fl oz	AEI	27.25 ab	31.85 a	31.08 a	34.15 a	24.08 a
8	Untreated		28.20 ab	33.03 a	31.13 a	35.65 a	24.83 a

[z] Percent volumetric soil moisture content was measured at a 1.5” depth using a TDR300 Soil Moisture Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher’s protected least significant difference t-test.

Table 2 (con’t). Volumetric soil moisture content was measured at a depth of 1.5” using a TDR300 Soil Moisture Meter.

	Treatment and rate per 1000 sq ft	Application Code[y]	TDR/1.5				
			27 July	3 Aug	4 Aug	5 Aug	6 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	28.30 a[x]	36.58 a	34.80 a	32.18 a	31.40 a
2	ACA 1820 6 fl oz	AEI	27.25 a	36.45 a	34.10 a	32.40 a	32.65 a
3	ACA 1872 6 fl oz	AEI	28.98 a	38.45 a	35.15 a	33.58 a	33.48 a
4	ACA 3028 6 fl oz	AEI	29.35 a	38.78 a	34.55 a	34.28 a	34.33 a
5	ACA 3029 6 fl oz	AEI	27.65 a	35.95 a	31.83 a	32.15 a	32.10 a
6	OARS 6 fl oz	AEI	28.53 a	36.75 a	33.90 a	33.18 a	32.08 a
7	AQAAC 4 fl oz	AEI	27.53 a	36.98 a	32.63 a	32.05 a	32.55 a
8	Untreated		28.13 a	36.33 a	33.98 a	32.68 a	32.38 a

[z] Percent volumetric soil moisture content was measured at a 1.5” depth using a TDR300 Soil Moisture Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher’s protected least significant difference t-test.

Table 2 (con't). Volumetric soil moisture content was measured at a depth of 1.5" using a TDR300 Soil Moisture Meter.

Treatment and rate per 1000 sq ft		Application Code[y]	TDR/1.5				
			7 Aug	8 Aug	9 Aug	10 Aug	11 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	27.08 a[x]	26.70 a	21.23 ab	16.35 a	13.20 a
2	ACA 1820 6 fl oz	AEI	26.55 a	26.03 a	20.23 b	15.23 a	14.63 a
3	ACA 1872 6 fl oz	AEI	28.73 a	28.15 a	24.13 a	18.50 a	15.90 a
4	ACA 3028 6 fl oz	AEI	28.10 a	27.78 a	22.38 ab	18.08 a	13.73 a
5	ACA 3029 6 fl oz	AEI	26.35 a	25.33 a	20.10 b	15.65 a	13.73 a
6	OARS 6 fl oz	AEI	26.25 a	26.83 a	21.55 ab	16.03 a	14.25 a
7	AQAAC 4 fl oz	AEI	26.10 a	25.18 a	20.03 b	16.20 a	13.55 a
8	Untreated		27.30 a	26.40 a	20.78 b	15.90 a	14.35 a

[z] Percent volumetric soil moisture content was measured at a 1.5" depth using a TDR300 Soil Moisture Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 2 (con't). Volumetric soil moisture content was measured at a depth of 1.5" using a TDR300 Soil Moisture Meter.

Treatment and rate per 1000 sq ft		Application Code[y]	TDR/1.5				
			12 Aug	16 Aug	18 Aug	20 Aug	7 Sep
1	Dispatch 12 fl oz/A	ABCDEFGHI	20.38 b[x]	20.00 b	11.58 cd	17.33 b	17.75 a
2	ACA 1820 6 fl oz	AEI	25.88 a	23.00 ab	14.43 bc	24.28 a	20.38 a
3	ACA 1872 6 fl oz	AEI	26.55 a	26.10 a	18.83 a	26.53 a	20.98 a
4	ACA 3028 6 fl oz	AEI	28.95 a	23.80 ab	16.18 ab	24.93 a	17.75 a
5	ACA 3029 6 fl oz	AEI	25.53 a	23.45 ab	15.95 ab	24.50 a	18.53 a
6	OARS 6 fl oz	AEI	26.43 a	24.50 a	15.40 ab	24.65 a	18.78 a
7	AQAAC 4 fl oz	AEI	25.55 a	23.45 ab	14.70 bc	24.80 a	18.20 a
8	Untreated		20.40 b	20.48 b	9.60 d	15.03 b	18.70 a

[z] Percent volumetric soil moisture content was measured at a 1.5" depth using a TDR300 Soil Moisture Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 3. Surface firmness of a golf course putting green following the application of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	Firmness[z] 11 Jun	29 Jun	9 Jul	19 Jul
1	Dispatch 12 fl oz/A	ABCDEFGHI	0.530 a	0.551 a	0.551 a	0.513 a
2	ACA 1820 6 fl oz	AEI	0.544 a	0.555 a	0.558 a	0.511 a
3	ACA 1872 6 fl oz	AEI	0.536 a	0.565 a	0.559 a	0.528 a
4	ACA 3028 6 fl oz	AEI	0.559 a	0.578 a	0.574 a	0.532 a
5	ACA 3029 6 fl oz	AEI	0.527 a	0.560 a	0.549 a	0.506 a
6	OARS 6 fl oz	AEI	0.540 a	0.553 a	0.549 a	0.515 a
7	AQAAC 4 fl oz	AEI	0.551 a	0.571 a	0.564 a	0.521 a
8	Untreated		0.550 a	0.570 a	0.568 a	0.521 a

[z] Surface firmness was measure using a USGA Tru-Firm firmness meter.
[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.
[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 3 (con't). Surface firmness of a golf course putting green following the application of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	Firmness[z] 3 Aug	4 Aug	5 Aug	6 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	0.553 a[x]	0.533 a	0.534 a	0.532 a
2	ACA 1820 6 fl oz	AEI	0.549 a	0.535 a	0.530 a	0.531 a
3	ACA 1872 6 fl oz	AEI	0.560 a	0.547 a	0.551 a	0.535 a
4	ACA 3028 6 fl oz	AEI	0.566 a	0.551 a	0.545 a	0.560 a
5	ACA 3029 6 fl oz	AEI	0.554 a	0.536 a	0.536 a	0.548 a
6	OARS 6 fl oz	AEI	0.545 a	0.538 a	0.529 a	0.545 a
7	AQAAC 4 fl oz	AEI	0.558 a	0.546 a	0.553 a	0.552 a
8	Untreated		0.563 a	0.546 a	0.546 a	0.547 a

[z] Surface firmness was measure using a USGA Tru-Firm firmness meter.
[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.
[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 3 (con't). Surface firmness of a golf course putting green following the application of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	Firmness[z] 7 Aug	8 Aug	9 Aug	10 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	0.533 a[x]	0.518 a	0.483 a	0.443 a
2	ACA 1820 6 fl oz	AEI	0.541 a	0.529 a	0.474 a	0.435 a
3	ACA 1872 6 fl oz	AEI	0.557 a	0.548 a	0.494 a	0.456 a
4	ACA 3028 6 fl oz	AEI	0.554 a	0.538 a	0.484 a	0.446 a
5	ACA 3029 6 fl oz	AEI	0.530 a	0.538 a	0.477 a	0.437 a
6	OARS 6 fl oz	AEI	0.520 a	0.530 a	0.487 a	0.441 a
7	AQAAC 4 fl oz	AEI	0.540 a	0.542 a	0.484 a	0.435 a
8	Untreated		0.536 a	0.538 a	0.484 a	0.444 a

[z] Surface firmness was measure using a USGA Tru-Firm firmness meter.
[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.
[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 3 (con't). Surface firmness of a golf course putting green following the application of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	Firmness[z]				
			11 Aug	12 Aug	16 Aug	18 Aug	20 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	0.412 a[x]	0.441 a	0.443 a	0.419 b	0.460 cd
2	ACA 1820 6 fl oz	AEI	0.391 a	0.451 a	0.476 a	0.452 a	0.483 ab
3	ACA 1872 6 fl oz	AEI	0.421 a	0.456 a	0.476 a	0.469 a	0.498 ab
4	ACA 3028 6 fl oz	AEI	0.410 a	0.446 a	0.478 a	0.454 a	0.501 ab
5	ACA 3029 6 fl oz	AEI	0.399 a	0.460 a	0.461 a	0.452 a	0.480 bc
6	OARS 6 fl oz	AEI	0.410 a	0.458 a	0.475 a	0.462 a	0.503 a
7	AQAAC 4 fl oz	AEI	0.398 a	0.447 a	0.477 a	0.451 a	0.497 ab
8	Untreated		0.417 a	0.416 a	0.462 a	0.413 b	0.454 d

[z] Surface firmness was measure using a USGA Tru-Firm firmness meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 4. Dew and drought injury following the application of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[x]	Dew[z]	Drought injury[y]
			4 Jun	13 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	3. 8 a[w]	3.0 a
2	ACA 1820 6 fl oz	AEI	1.0 bc	3.8 a
3	ACA 1872 6 fl oz	AEI	1.5 b	2.3 a
4	ACA 3028 6 fl oz	AEI	1.0 bc	3.0 a
5	ACA 3029 6 fl oz	AEI	0.5 bc	3.5 a
6	OARS 6 fl oz	AEI	0.3 c	2.5 a
7	AQAAC 4 fl oz	AEI	0.5 bc	3.5 a
8	Untreated		4.0 a	3.3 a

[z] Dew was rated visually on a 0 to 5 scale where 0 = no dew present and 5 = entire plot area covered with dew.

[y] Turfgrass drought injury was rated on a scale of 0 to 5 where 0 = no injury visible, < 3.0 = minimum acceptable injury for a golf course fairway, <2.0 = minimum acceptable injury for a golf course green, and 5.0 = entire plot area brown or dead.

[x] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[w] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 5. Turfgrass quality following the application of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	Quality						
			4 Jun	11 Jun	18 Jun	2 Jul	14 Jul	28 Jul	13 Aug
1	Dispatch 12 fl oz/A	ABCDEFGHI	6.5 a[x]	7.0 a	7.5 a	7.5 a	7.5 a	6.5 a	5.3 a
2	ACA 1820 6 fl oz	AEI	6.5 a	7.5 a	7.5 a	8.0 a	8.3 a	7.3 a	4.8 a
3	ACA 1872 6 fl oz	AEI	7.5 a	7.8 a	7.8 a	7.8 a	7.8 a	7.3 a	6.0 a
4	ACA 3028 6 fl oz	AEI	7.5 a	7.5 a	8.0 a	7.3 a	7.5 a	6.8 a	4.8 a
5	ACA 3029 6 fl oz	AEI	6.8 a	7.0 a	7.5 a	7.3 a	8.5 a	7.8 a	4.3 a
6	OARS 6 fl oz	AEI	7.0 a	7.3 a	7.8 a	7.5 a	7.5 a	7.5 a	6.0 a
7	AQAAC 4 fl oz	AEI	6.5 a	7.3 a	8.0 a	7.8 a	8.3 a	7.3 a	4.5 a
8	Untreated		7.0 a	6.8 a	7.5 a	7.5 a	7.3 a	6.5 a	4.5 a

[z] Turfgrass quality was rated on a 1 to 9 scale where 1 = entire plot area brown or dead; 7 = minimum acceptable quality for a golf course putting green; and 9 = optimum greenness and density.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 6. Canopy temperature of turfgrass following the application of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	Canopy temp			
			29 Jun	9 Jul	19 Jul	28 Jul
1	Dispatch 12 fl oz/A	ABCDEFGHI	81.3 a[x]	85.2 a	77.1 a	87.2 a
2	ACA 1820 6 fl oz	AEI	81.00 a	84.4 a	76.3 a	87.0 a
3	ACA 1872 6 fl oz	AEI	79.5 a	84.6 a	76.1 a	87.0 a
4	ACA 3028 6 fl oz	AEI	81.3 a	83.8 a	76.1 a	86.6 a
5	ACA 3029 6 fl oz	AEI	83.4 a	84.9 a	76.1 a	86.8 a
6	OARS 6 fl oz	AEI	81.2 a	84.4 a	76.8 a	87.7 a
7	AQAAC 4 fl oz	AEI	81.3 a	84.6 a	76.7 a	87.7 a
8	Untreated		79.5 a	84.8 a	76.8 a	87.2 a

[z] Canopy temperatures were measured using a handheld infrared thermometer.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 7. Dollar spot incidence and severity under Influence of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	Dollar Spot[z]			
			11 Jun	12 Jun	19 Jul	28 Jul
			No. infection centers			%
1	Dispatch 12 fl oz/A	ABCDEFGHI	13.0 a[x]	13.0 a	16.8 a	0.53 a
2	ACA 1820 6 fl oz	AEI	14.5 a	14.5 a	14.8 a	0.15 a
3	ACA 1872 6 fl oz	AEI	8.3 a	8.3 a	16.5 a	0.18 a
4	ACA 3028 6 fl oz	AEI	17.3 a	17.3 a	19.0 a	0.88 a
5	ACA 3029 6 fl oz	AEI	16.0 a	16.0 a	16.8 a	0.43 a
6	OARS 6 fl oz	AEI	10.3 a	10.3 a	11.5 a	0.20 a
7	AQAAC 4 fl oz	AEI	16.3 a	16.3 a	17.8 a	0.53 a
8	Untreated		8.8 a	8.8 a	12.0 a	0.40 a

[z] Dollar spot was rated by counting the number of infection centers per plot or visually rating the disease on a 0 to 100% scale where 0 = no dollar spot infection centers present and 100 = entire plot area affected by dollar spot.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 8. Average and longest root depth was measured on 3 August, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	Root Depth[z]	
			Longest depth (cm)	Average depth (cm)
1	Dispatch 12 fl oz/A	ABCDEFGHI	10.8 a[x]	8.5 a
2	ACA 1820 6 fl oz	AEI	10.4 a	8.2 a
3	ACA 1872 6 fl oz	AEI	10.2 a	8.0 a
4	ACA 3028 6 fl oz	AEI	11.1 a	8.6 a
5	ACA 3029 6 fl oz	AEI	10.9 a	8.4 a
6	OARS 6 fl oz	AEI	10.4 a	8.3 a
7	AQAAC 4 fl oz	AEI	11.2 a	8.0 a
8	Untreated		9.9 a	7.6 a

[z] Average and longest root depth was measured by removing three soil profiler (0.5"x3"x7") samples from each plot and subsample data were combined prior to statistical analyses.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.

Table 9. Turfgrass color (NDVI) ratings as measure with an TCM 500 Turf Color Meter following the application of various wetting agents, 2010.

	Treatment and rate per 1000 sq ft	Application Code[y]	NDVI[z]				
			12 Jun	29 Jun	9 Jul	19 Jul	27 Jul
1	Dispatch 12 fl oz/A	ABCDEFGHI	0.746 a[x]	0.774 a	0.775 a	0.798 a	0.761 a
2	ACA 1820 6 fl oz	AEI	0.753 a	0.782 a	0.780 a	0.796 a	0.777 a
3	ACA 1872 6 fl oz	AEI	0.762 a	0.781 a	0.783 a	0.802 a	0.777 a
4	ACA 3028 6 fl oz	AEI	0.763 a	0.782 a	0.780 a	0.801 a	0.784 a
5	ACA 3029 6 fl oz	AEI	0.762 a	0.783 a	0.779 a	0.801 a	0.777 a
6	OARS 6 fl oz	AEI	0.750 a	0.780 a	0.775 a	0.798 a	0.779 a
7	AQAAC 4 fl oz	AEI	0.754 a	0.789 a	0.784 a	0.802 a	0.755 a
8	Untreated		0.758 a	0.784 a	0.771 a	0.802 a	0.778 a

[z] Turfgrass color was rated using a NDVI TCM 500 Turf Color Meter.

[y] Treatments were applied as follows: A = 2 Jun, B = 10 Jun, C=17 Jun, D= 24 Jun, E= 1 Jul, F= 8 Jul, G= 15 Jul, H= 23 Jul, I=30 Jul.

[x] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ level according to the Fisher's protected least significant difference t-test.