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Evaluation of the surfactant Aqueduct® for recovery of turfgrass quality on a severely water-repellent golf green

Bruk av vætemidlet Aqueduct® for å gjenopprette graskvaliteten på en sterkt vannavstøtende golfgreen

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Nøkkelord

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Field of work:

Horticulture and Urban Greening

Summary:

This research has demonstrated the ability of the surfactant Aqueduct® to increase soil water content and restore turfgrass quality on severely to extremely water-repellent golf greens with severe drought symptoms.

Sammendrag:

Dette forskingsprosjektet har vist at vætemidlet Aqueduct® øker vanninnholdet i jorda og gjenoppretter graskvaliteten på sterkt vannavstøtende golfgreener med alvorlige tørkesymptomer.

Approved

Svein O. Grimstad	Trygve S. Aamlid
Leader, Horticulture and Urban Greening Division	Project leader

Contents

1. Abstract

Soil water repellency (SWR) caused by organic compounds coating soil particles is a common phenomenon on golf greens. Soils are considered severely water repellent if water droplets remain on the surface of undisturbed, air-dried soil samples for more than 600 seconds before penetrating, and extremely water repellent if the water droplet penetration time (WDPT) is more than 3600 seconds. The objective of this research was to evaluate the ability of the surfactant (wetting agent) Aqueduct® to overcome SWR and restore turfgrass quality on a severely to extremely water-repellent straight sand golf green with severe drought symptoms at Bioforsk Øst Landvik, SE Norway. Aqueduct® was applied at a rate of 25 L ha^{-1} at weekly intervals from 4 June through 25 June 2008, either alone or in combination with aeration with solid tines to 5 cm depth before each application. The experiment was irrigated uniformly corresponding to 1.6 times pan evaporation values from 4 June till 12 June, after which irrigation was not necessary due to 61 mm rainfall from 13 through 24 June. Turfgrass quality was evaluated and soil water content (SWC) measured at weekly intervals during the application period and at monthly intervals for the rest of the growing season.

Conspicuous and statistically significant improvements in turfgrass quality occurred 10-12 days after the first application of Aqueduct®. The difference from untreated control plots continued to increase for about two and a half months after the completion of surfactant treatments. The improvement was accompanied by a significant increase in the SWC of the 0-20 cm soil layer and a deeper root system as determined by the length of intact soil cores extracted from the greens. The difference between treated and untreated plots in WDPT was significant at 1 cm, but not at 2, 3, 5 or 10 cm soil depths which were always far more water repellent than the thatch layer. Repeated aeration had no significant effect on turfgrass quality, and there was also no significant interaction between surfactnat and aeration treatments.

In conclusion, Aqueduct® is an efficient surfactant in overcoming SWR and restoring turfgrass quality on severely hydrophobic golf greens.

Key words: aeration, golf green, localized dry spots, hydrofobicity, soil water repellency, surfactants, wetting agents, turfgrass quality, water droplet penetration time,

2. Introduction

Soil water repellency (SWR) is a common phenomenon on sand-based golf greens. As SWR is caused by hydrophobic organic compounds coating the soil particles (e.g. Doerr et al. 2000, Schlossberg et al. 2005), sands with a small particle surface area are more liable to this condition than more finely textured agricultural soils. Gibbs et al. (2000), Larsbo at al. (2008) and Aamlid et al. (2009) found that straight sand greens constructed with no organic amendment to the root zone were especially prone to SWR. As the occurrence and development of water repellency is closely related to soil moisture content (Doerr et al., 2000), this may also be attributed to the low water holding capacity of such root zones. Generally, soil water repellency is insignificant or absent during wet conditions but becomes severe during dry periods (Karnok & Tucker 1999). Soils become water repellent at a critical water content, the value of which depends on the soil properties and wetting and drying history (Dekker et al. 2001).

Surfactants (weeting agents) are commonly applied on golf courses with SWR to improve turf quality and water and nutrient use efficiency (Kostka 2000). Surfactants may have different modes of action, but a common feature is that the surfactant molecules attach to hydrophobic soil surfaces rendering them wettable (Cisar et al. 2000, Kostka 2000, Dekker et al. 2005). Some surfactants are primarily formulated for preventative use, while others can used curatively on turfgrass areas that have already developed SWR with visible drought symptoms.

Apart from surfactants, mechanical cultivation or aeration treatments are commonly suggested to correct SWR (e.g. Schlossberg et al. 2005). The rationale behind this is that coring or spiking provides channels for water movement into the dry soil. Wilkinson & Miller (1978) found that coring alone reduced the severity of SWR significantly, however, the combination of surfactant plus coring was even more beneficial. Gibbs et al. (2000) reported that the combination of surfactant and HydroJect aerator was very efficient in controlling dry patch disorders on golf greens in New Zealand.

The American company Aquatrols Inc. is a world leader in surfactant technology. Among the surfactants marketed by this company, the non-ionic block copolymer 'Aqueduct®' is supposed to have the best curative effect and provide the shortest recovery time on sand-based greens that have already developed SWR. According to the company's Norwegian representative, Aqueduct® will immediately relieve dry spots on greens even when used only a couple of days before tournaments (Svein Haug, personal communication, May 2008). Cisar et al. (1997) reported that plots treated with either Aqueduct® or the alternative Aquatrol product 'Primer' had significantly better turfgrass quality than untreated control plots both through a drought period which induced SWR and through a five month recovery period, but they were not able to discriminate statistically among the two products. In a large comparison of surfactants at nine sites in USA, Aqueduct® produced the strongest reduction in water droplet penetration time (WDPT) in about 40% of the trials and was considered among the best products in about 80 % of the trials where significant SWR occurred (Throssell 2005).

The objective of this project was to evaluate the ability of Aqueduct® to overcome SWR and restore acceptable turfgrass quality on a severely hydrophobic straight sand golf green.

3. Methods

3.1 Experimental site, soil analyses and turfgrass maintenance

The experiment was conducted during June through October 2008 on four straight sand plots, each plot 2 m x 3 m, of USGA-spec. green covered with creeping bentgrass 'Penn A-4' at Bioforsk Øst Landvik, Norway (58°19'N; 8°30'E, 5 m a s.l.). The four plots had been established in 2003 using straight sand root zone material with no organic or inorganic amendment. Because the sand was slightly coarser than recommended by USGA (1.2% fine gravel >2.0 mm, 12.2% very coarse sand 1.0–2.0 mm, 37.8% coarse sand 0.5–1.0 mm, 36.4% medium sand 0.25–0.5 mm, 6.9% fine sand 0.15–0.25 mm , 2.5% very fine sand 0.05-0.15 mm, 2.2% silt 0.002–0.05 mm and 0.8% clay <0.002 mm (European Turfgrass Laboratory, Stirling, Scotland, Jan 2004), these greens were very prone to SWR and turfgrass drought, as also indicated by earlier trials using the same root zone material (Larsbo et al. 2008, Aamlid et al. 2009).

Table 1. Root zone physical properties in undisturbed cylinder samples taken in April 2007 (n=8).

	2.2-5.9 cm depth	15-18.7 cm depth
Bulk density, Mg m-3	1.69	1.58
Total porosity, %	42.9	43.9
†Air filled porosity, %	31.0	33.2
†Volumetric water content, %	11.9	10.7
Saturated hydraulic conductivity, mm h^{-1}	126	169

† At -2 kPa.

Table 2. Results from soil chemical analysis, 0-20 cm, October 2008.

pH (H_2O)	Plant available nutrients, mg (100 g dry soil)$^{-1}$				
	P-AL	K-AL	Mg-AL	Ca-AL	Na-AL
6.2	1.3	2.4	1.9	9.0	1.7

Results from physical and chemical soil analyses are given in Tables 1 and 2, respectively. The turf had a 16 mm thatch layer. The green was mowed with a walk-behind green mower to 3.0 mm from 15 June till 20 September, the height gradually being raised to 4.5 mm at both ends of the season. Granular fertilizer was applied at biweekly intervals in the form of Arena products (Hydro Agri, Landskrona, Sweden) and Andersson 13-2-13 (N as ammoniumisulfate), the seasonal amount of N, P and K being 2.1, 0.3 and 2.3 kg (100 m^2)$^{-1}$, respectively.

3.2 Weather data and experimental plan

Weather data were collected at Landvik meteorological station, about 200 m from the experiment. With absolutely no natural rainfall from 2 May through 12 June 2008, the spring and early summer were exceptionally dry at the experimental site (Fig. 1). From 2 May until the start of this experiment, pan evaporation had accumulated to 77 mm. Despite the fact that the green had been irrigated three or four times per week with a total irrigation volume of about 90 mm, severe drought symptoms had developed (Photo 1).

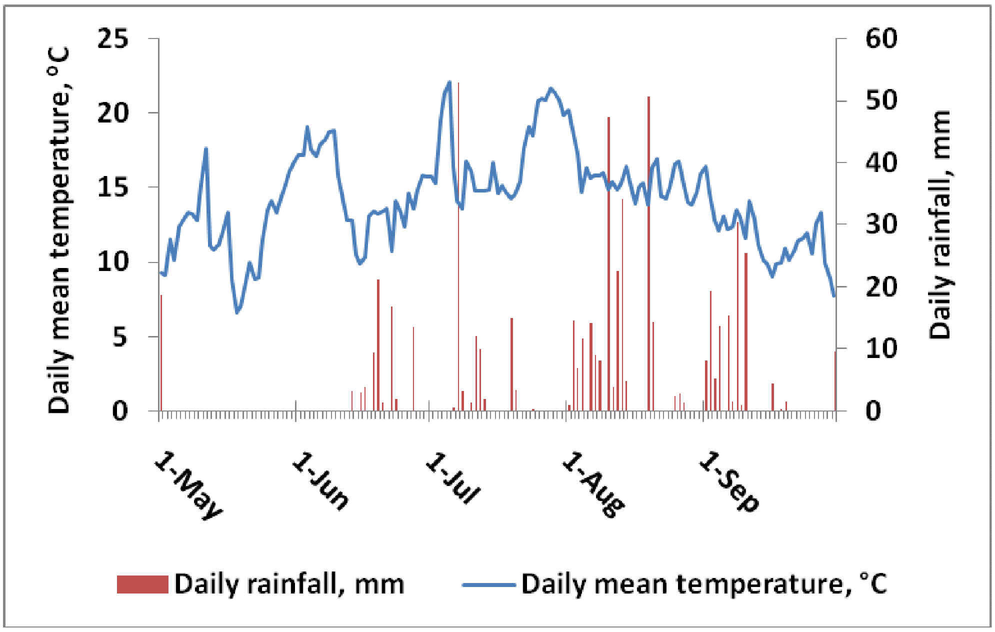

Fig. 1. Daily rainfall and mean air temperature at Landvik meteorological station, May – Sept. 2008.

Photo 1.

One of the four straight sand plots before the first treatments on 4 June. Each plot was split into four quarters and treatments assigned randomly. Photo: Tatsiana Espevig.

On 4 June, each of the four straight sand plots was considered one replicate (hereafter referred to as ‘block’) and split into four subplots, 1.0 m x 1.5 m (hereafter referred to as ‘plot’). The four combinations of the following treatments were assigned randomly to the plots:

Factor 1 – Surfactant

1. No surfactant
2. Aqueduct®, 25 L in 800 L water ha^{-1}, one application per week for four weeks.

Factor 2 – Aeration just before each application of Aqueduct®

a) No aeration
b) 5 cm deep holes punched with a fork at at distance 5 cm x 5 cm (corresponding to 400 holes pr m^2) (Photo 2)

The aeration and surfactant treatments were carried out on 4 June, 11 June, 18 June and 25 June. From 4 June until the first natural rainfall on 13 June, use of an experimental irrigation wagon (Photo 3) four to five times per week ensured that all plots received a total of 49 mm water, which was 65% more than pan evaporation during the same period. After this, irrigation was not necessary until 2 July (Fig. 1). The natural rainfall in June, July, August and September were 74, 101, 250 and 137 mm, respectively.

Photo 2 (upper left).
Due to lysimeters in the ground, aeration treatments had to be accomplished manually.
Photo: Trygve S. Aamlid

Photo 3 (upper right).
Drip irrigation wagon used for exact irrigation of each plot. Photo: Trygve S. Aamlid

Photo 4 (lower left).
Water puddling on the surface due to hydrophobicity. Photo: Trygve S. Aamlid

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3.3 Registrations and statistical analyses

From 4 June till 4 July, turfgrass visual quality was evaluated and photographs taken (Photo 5) at weekly intervals on all plots. Thereafter, quality was assessed at monthly intervals in mid-July, mid-August, mid-September and mid-October. Ratings were always taken on a scale from 1 to 9, with 1 equalling completely brown (dead) turf and 9 high-quality, freshly green turf. Approximately on the same dates, volumetric soil water content (SWC) was determined using the portable TDR-instument HydroSence CS 620 (Campbell Scientific, Australia, Photo 6). Four readings were at random locations within each plot, and the average value and coefficient of variation (CV value) calculated. Usually the instrument was equipped with 20 cm probes giving the average SWC in the 0-20 cm soil layer, but on 9 June we also measured the average SWC in the 0-7 cm soil layer and on 17 October in the 0-12 cm layer.

Photo 5.
During the four week application period, photos were taken regularly of each plot. Photo: Trygve S. Aamlid.

Photo 6.
TDR instrument with 20 cm probe used for measurement of volumetric soil water content. Photo: Trygve S. Aamlid.

On 1 July, turfgrass root depth was estimated using a root auger, 30 cm long and 5 cm in diameter. One core was extracted per plot, and the length of the intact core taken as an indication of root depth.

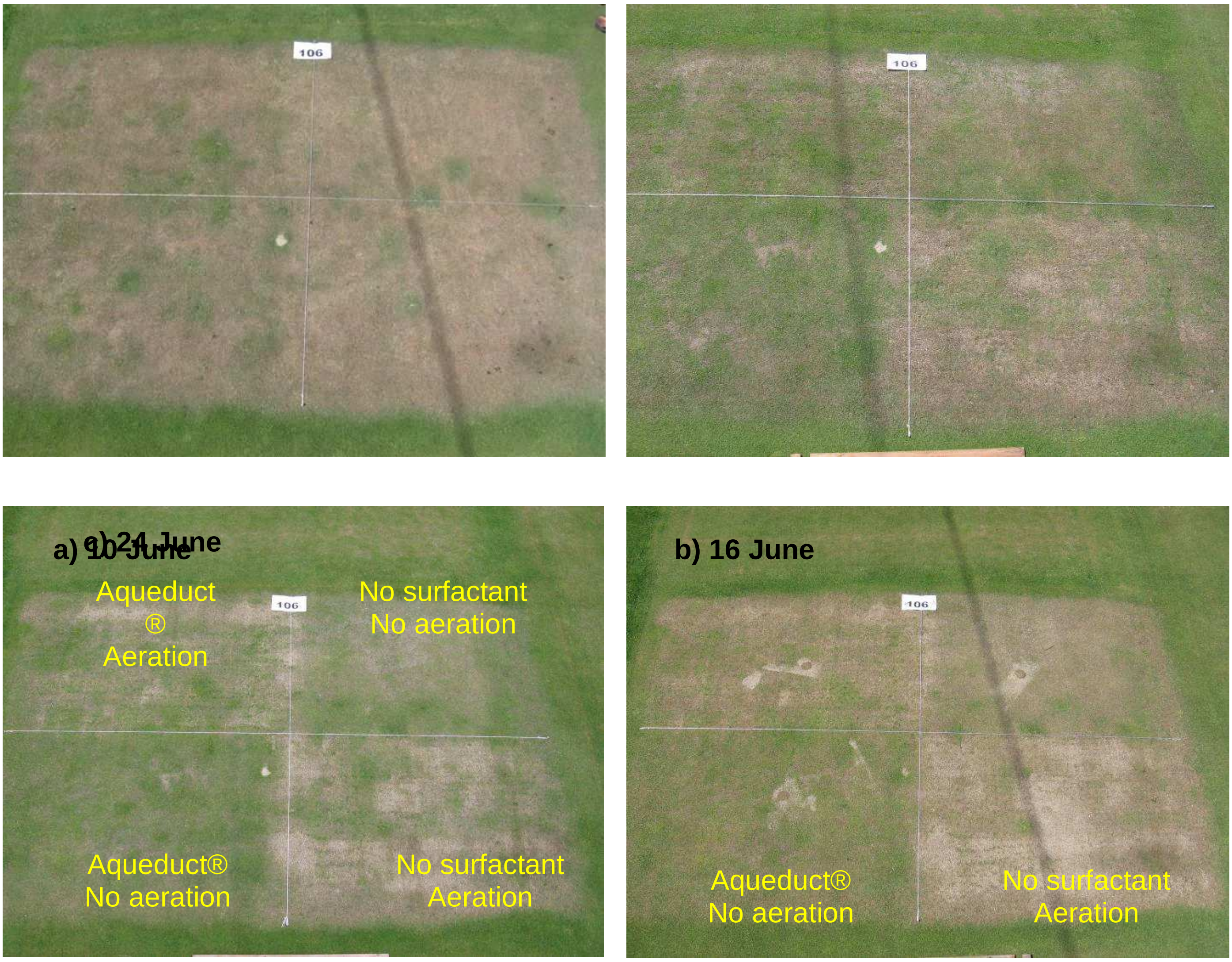
On 7 July, one undisturbed soil sample, L x W x D = 11 cm x 3 cm x 10 cm, was taken from each plot. The samples were brought the laboratory and actual SWR determined immediately using the water drop penetration time (WDPT) test. Three 60 µL drops of water were placed at 1, 2, 3, 5 and 10 cm depth on the surface of the samples and the time until infiltration measured. The samples were then allowed to dry at room temperature for 48 h before repeating the procedure to determine potential SWR (Dekker and Ritsema, 1994; Dekker et al., 2001). According to Dekker et al. (2001) a soil is considered wettable if WDPT<5s, slightly water repellent if 5 s<WTPT<60s, strongly water repellent if 60s<WTPT<600s, severely water repellent if 600s<WDPT<3600s, and extremely water repellent if WDPT>3600s. Any droplot remaining after 3600s (1 h) was recorded as 3600s.

All experimental data were analyzed using the analysis of variance (ANOVA) procedure of the SAS software version 9.1 (SAS Institute 2002). Probability levels have been indicated in the text and figures. Throughout this paper, the term ‘significant’ always refers to P<0.05, and ‘tendencies’ to 0.05<P<0.10.

4. Results

4.1. Turfgrass visual quality

After the first treatment with Aqueduct®, turfgrass visual merit scores were always significantly higher on treated than on untreated plots (Fig. 2a). Coinciding with the start of summer rains on 13 June, there was a marked improvement in visual quality at the observation on 16 June (Photo 7b, Fig. 2). Quality scores decreased, mostly on untreated plots, during a dry and warm spell in early July, but on plots treated with Aqueduct® they resumed to increase in late July, August and early September (Photo 8). On average for July – October, i.e the remainder of the growing season after the four applications of Aqueduct® had been completed, the ratings on treated and untreated plots were 4.2 on and 2.0, respectively. Repeated aeration treatments lowered turfgrass visual impression in late June and early July, but had no significant effect when averaged over the whole growing season (Fig. 2b). Significant interactions among the two main factors did not occur.



Photos 7a-d.
Visual impression of the four treatment combinations in one of the blocks on four consecutive days in June-July 2008. Aqueduct® and aeration treatments were first conducted on 4 June. All photos: Tatsiana Espevig.

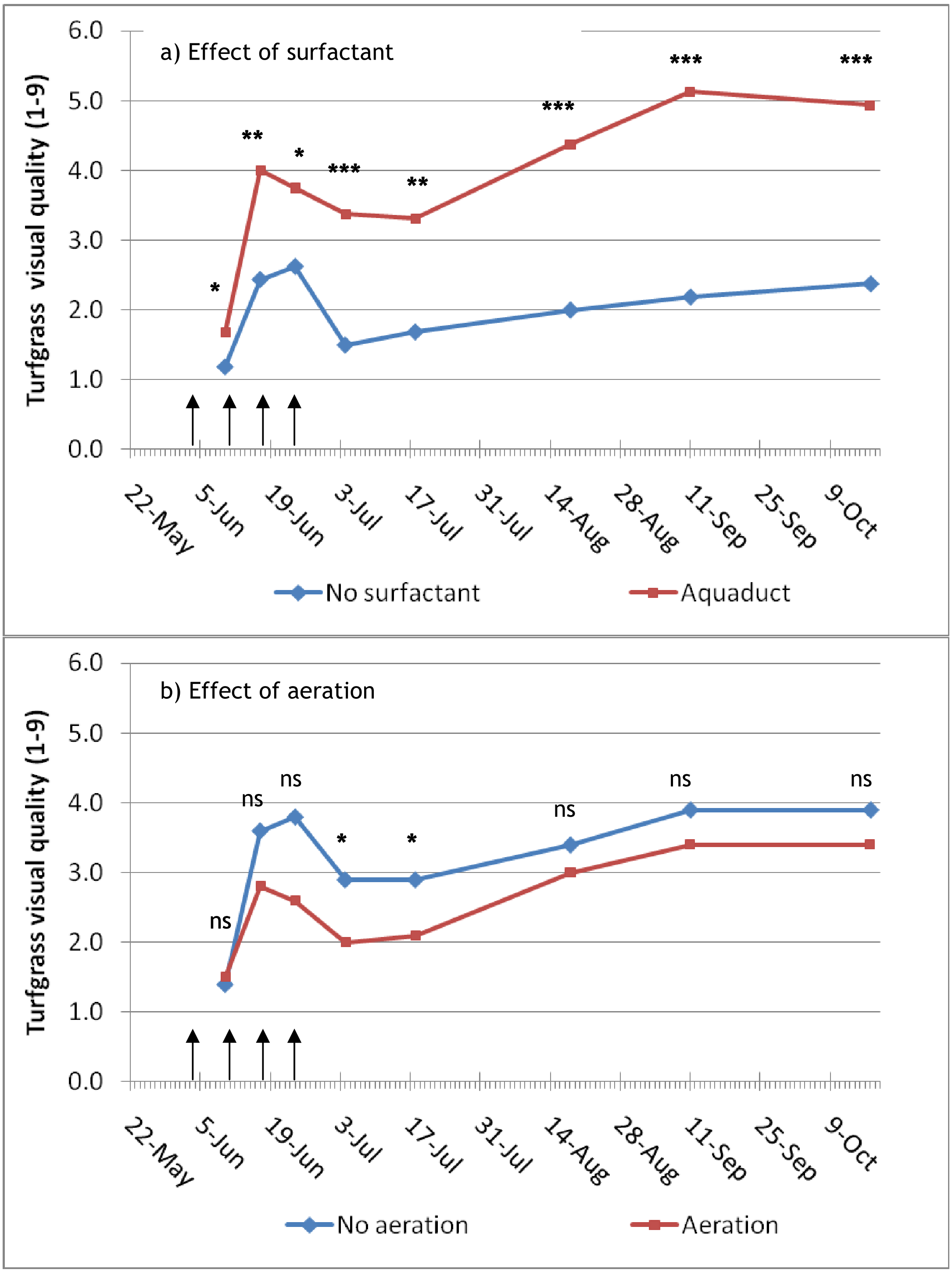


Figure 2. Main effects of (a) surfactant and (b) aeration treatments on turfgrass visual quality throughout the season 2008. Days of treatment are indicated with black arrows. Significant differences are symbolized as follows: * : *P*<0.05; ** : *P*<0.01; *** : *P*<0.001; ns: not significant.

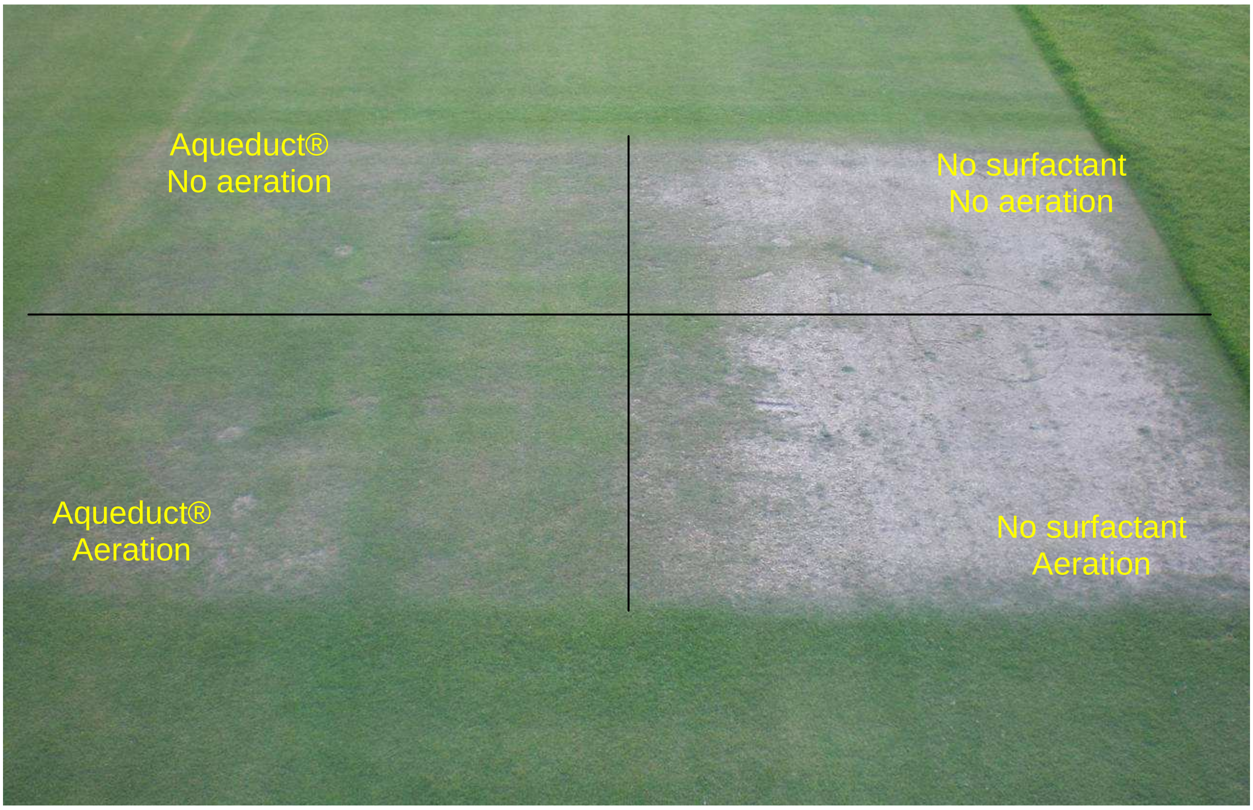


Photo 8.
Visual impression of the four treatments in one of the blocks on 18 August 2008. Photo: Trygve S. Aamlid

4.2. Soil volumetric water content (SWC)

At the first treatment with Aqueduct® on 4 June, SWC in the 0-7 cm layer was only 1.7 %. Five days later, it was down to 0.9 % on untreated plots and 1.4 % on plots treated with Aqueduct® (difference significant at $P<0.01$); aeration had no effect on SWC in the 0-7 cm layer on this date (data not shown).

On average for the 0-20 cm soil layer on aerated and unaerated plots, application of Aqueduct® caused a significantly higher SWC at all observations except 17 June (Fig. 1). When averaged over six observations from 4 July through 17 October, SWC was 8.2 % on plots treated with Aqueduct® versus 6.9 % on untreated plots (difference significant at $P<0.01$).

As a main effect, SWC tended to be higher on aerated than on non-aerated plots on many of the observation dates, but the difference was significant only on 17 July when the average values were 5.9 and 4.7 %, respectively. On average for six observations from 4 July through 17 October, SWC was 8.0 % on aerated plots vs. 7.2 % on unaerated plots (difference significant at $P<0.05$).

On 17 October, the relative increase in SWC caused by Aqueduct® was greater in the 0-12 cm layer (+23%) than in the 0-20 cm layer (+9%).

Interactions between Aqueduct® and aeration treatments on SWC were not significant on any date or for any soil depth. The main effects of Aqueduct® and aeration, and their interaction, were also not significant when analyzing the horizontal variation in SWC as expressed by CV-values.

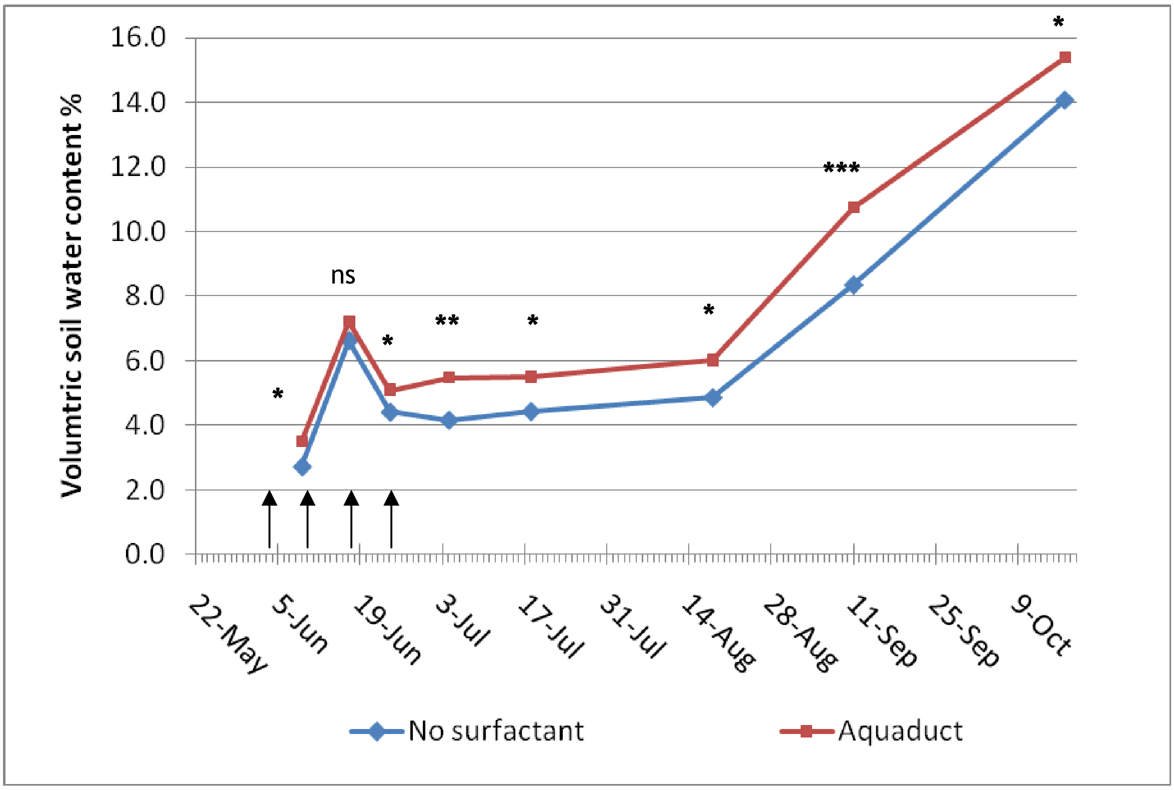


Figure 3. Main effect of four Aquaduct® applications (indicated by black arrows) on mean soil water content at 0-20 cm depth. Significance symbols as in Fig. 2.

4.3. Root depth

On 1 July there was an almost significant tendency (*P*=0.06) for roots to be developed at greater depths on plots sprayed with Aqueduct® (average length of intact cores 21 cm) than on untreated plots (average length 16 cm; data not shown in tables or figures). Aeration had no effect on root depth.

4.4. Actual and potential SWR as determined by water droplet penetration times (WDPT)

Regardless of surfactant and aeration treatments, the actual WDPT just after sampling on 7 July was less than 5 seconds at 1 cm depth (i.e. in the thatch layer), but exceeded 20 minutes at 2, 3, 5 and 10 cm depth (Fig. 4). The longest WDPT for the fresh samples, on average 53 minutes, was found at 5 cm depth. After two days drying, the WDPT at 1 cm depth was significantly (*P*<0.01) shorter on plots treated with Aqueduct® (15 seconds) than on untreated plots (260 seconds). Other effects of Aqueduct® (Fig. 4) or aeration (data not shown) treatments on actual or potential SWR were not significant.

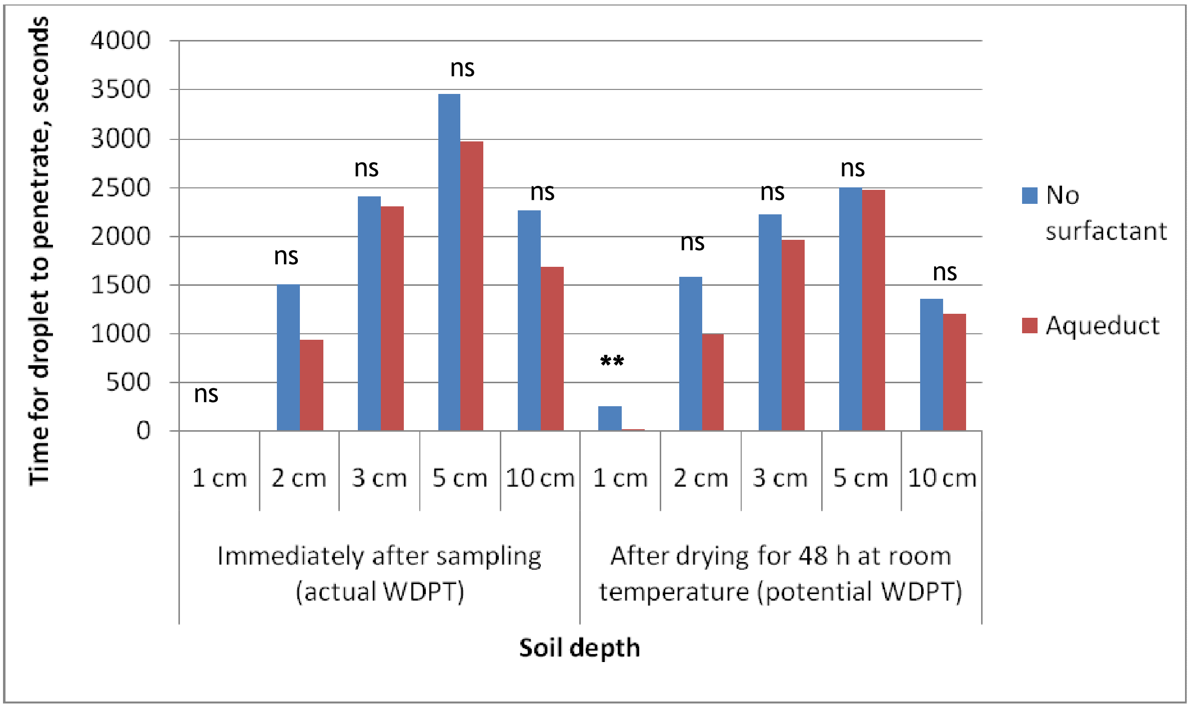


Figure 4. Actual and potential water droplet penetration times at various soil depths as affected by use of Aqueduct® . Samples were taken on 7 July 2008. Significance symbols as in Fig. 2.

5. Discussion

According to the classification by Dekker et al. (2001), the straight sand root zone used for this evaluation was severely, and in many cases extremely water repellent. Droplet penetration times beyond 600 seconds were never reported in the comprehensive evaluation of surfactants at nine sites in USA (Throssell 2005), but in our study, droplets were often sitting on the surface for more than 1 hour (3600 sec.). Also, while most workers have reported SWR on golf greens to be limited to the 5 cm top layer (e.g. Wilkinson & Miller, 1978, Schlossberg et al. 2005, Leinauer et al., 2007), we found severe SWR to at least 10 cm depth with a maximum around 5 cm (Fig. 4). Although two of the four blocks had been treated with Revolution in 2007 (Aamlid et al. 2009), the experimental area as a whole had a 3-4 year history of reduced turfgrass quality due to SWR. Factors contributing to this were the coarse sand used for construction, lack of organic amendment, and the fact that the original sprinkler system, despite a routine of irrigating 4-5 times per week during dry periods, did not provide sufficiently uniform irrigation until the new irrigation wagon was built in May 2008. At the initiation of this trial, each straight sand block therefore appeared as one distinct dry spot on the experimental green. Clearly, this put the surfactant on a hard test.

Following the first application of Aqueduct® on 4 June, visual turfgrass quality did not change much during the first six days. After another six days, on 16 June, the improvement in turfgrass quality was quite evident (Fig. 2a, Photo 7b). This is in agreement with Cisar (2001) who reported significant improvements in turfgrass quality 10-14 days after the first application of Aqueduct® on water repellent greens in Florida. In our study, turfgrass recovery after the second application on 11 June was probably enhanced by the drop in temperatures from 10 June onwards and by the start of a rainy period on 13 June. All in all, our results confirms earlier reports by Cisar et al. (1997), Cisar (2001), and Throssell (2005) that Aqueduct® is an efficient surfactant in overcoming SWR and restoring turfgrass quality on severely water repellent golf greens

The improvement in turfgrass quality after application of Aqueduct® was accompanied, and probably preceded, by an increase in SWC, usually in the range 1-2 per cent units. As the water holding capacity of the sandy root zone material was only 10-12 % (v/v), this increase was not only statistically, but also biologically significant. Moreover, as the SWC values presented in Fig. 3 are averaged over the 0-2 cm soil layer, there is no doubt that the relative increase in the SWC of the top 10 cm, where most roots are found, was higher than these average values. This was also confirmed by the comparison of the 20 and 12 cm probe depths on 17 October.

In a study of creeping bentgrass root development in the rhizotron at the University of Geogia, USA, Karnok & Tucker (2001) found that surfactant treatment stimulated root length in the top 8 cm of soil but had no significant effect at deeper horizons. The authors explained this as a result of SWR being limited the top 5 cm of the profile. As already mentioned, SWR was expressed at greater depths in our study, and the fact that intact cores could be withdrawn to greater depths from plots treated with Aqueduct® than on untreated plots probably reflects that root development was stimulated even at deeper horizons.

Even though treatments with Aqueduct® were discontinued after 25 June, the difference in turfgrass quality between treated and untreated plots continued to increase until mid September (Fig. 2a). This is not surprising as the difference in SWC (Fig. 3), and thus probably the absorption of water and nutrients by turfgrass roots, remained higher on treated than on untreated plots for the rest of the growing season. Much of the fertilizer applied to plots not treated with surfactant probably leached through the drainage system, as found by Aamlid et al. (2009) in earlier trials with Revolution.

By the end of the growing season, the untreated plots still appeared as dry spots on the experimental green, whereas treated plots had acquired almost the same quality as surrounding plots with organic amendment to the root zone. However, as the WDPT test indicated that SWR was far from cured, plots treated with Aqueduct® in June 2008 may again decline in turfgrass quality should a dry period occur in 2009. This would resemble our previous project with Revolution where five applications in 2007, the last one on 30 August, had no effect on turfgrass quality in May 2008 (Aamlid et al. 2009). Surfactants are subjected to biodegradation after application, and Miller (2001) found that treatment every four to six weeks was necessary for continuous prevention of dry spots, even with the use of so-called 'long-term' products.

Contrary to our hypothesis, aeration (spiking) treatments had no positive effect on turfgrass quality in this study. There was also no significant interaction between surfactant and aeration. The likely interpretation of this is that Aqueduct® was able to penetrate the surface and reach the most water-repellent layer under the thatch without any help from aeration channels. On the straight sand green used in this trial, the disruptive effect of repeated spiking treatments on surface quality appeared to be more influential than potential positive effects such as improved oxygen availability, increased infiltration or increased penetration of the surfactant. While this is good news for greenkeepers trying to combat SWR on straight sand greens, it is important not to extrapolate these results to older greens with more thatch and more organic matter in the root zone.

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