in the soil, specifically Midorich remains in the upper profile and Primer moves more rapidly to greater depths. Trends were similar in the loamy sand root zone (Leinauer et al., 2001).

Karnok and Tucker (2001) evaluated the color, quality, and root growth effects of the wetting agent Tilwa applied to ‘Penncross’ creeping bentgrass grown on hydrophobic soil. Only a single application of wetting agent was made. Ratings were taken up to 18 weeks after treatment and the single wetting agent application improved turfgrass color and quality 78 percent of the time. Overall root length at the 0 to 8 cm was increased by 27 percent with the wetting agent application; this and the increase in turf quality can be attributed to the six percent increase in volumetric water content (VWC) of the hydrophobic soil over the duration of the study. Consider that field capacity of a sand-based system is 10-15 percent; an increase in six percent VWC can have profound effects on the turf plant.

At this time we still questioned the effectiveness of wetting agents in reducing seed head production of annual bluegrass. Researchers from the Chicago District Golf Association studied the effectiveness of AquaGro, as well as a newer wetting agent, Cascade, at inhibiting seed head production compared to several standard plant growth regulators. After three years, mefluidide and ethephon provided the most consistent suppression of annual bluegrass seed heads on putting green and fairway turf; suppression reached 95 percent, but phytotoxicity was concerning. While inconsistent, the wetting agent treatments provided up to 50 percent suppression of seed heads (Kane and Miller, 2003).

In addition to alleviating localized dry spot, wetting agents have been evaluated for their effectiveness at controlling fairy ring, a basidiomycete fungi implicated at causing soil hydrophobicity. Gelernter and Stowell (1997, 1998) evaluated the wetting agents Primer (alone) or Respond (alone or combined with azoxystrobin or flutolanil). Both Respond and Primer were effective at reducing localized dry spot (type C fairy ring), but not at reducing type B fairy ring which is a more progressed form of the fungus. The fungicides azoxystrobin and flutolanil were most effective at suppressing the symptoms of type B fairy ring when

Respond or Primer were added. Based on these studies, Gelernter and Stowell (1999) developed new management approaches for both fairy ring and localized dry spot. These approaches included five basic steps: 1) maintain thatch thickness below ½ inch, 2) use wetting agents to alleviate localized dry spot, 3) use fungicides flutolanil or azoxystrobin to control associated fungi, 4) implement a spring cultivation program, 5) hand water hydrophobic soils thoroughly. In a similar study aiming to control localized dry spot symptoms with flutolanil and wetting agents, Karnok and Tucker (2001) demonstrated that flutolanil alone, while effective in preventing localized dry spot, will not control the symptoms once they have developed. Wetting agents are required to cure the hydrophobicity of the soil.

2005 to present

The most comprehensive research on wetting agent use was completed in 2005 by the Golf Course Superintendent's Association of America and the United States Golf Association. A total of nine sites across the United States were chosen to conduct this research on ten commercially available and popular wetting agents. Research objectives included an evaluation of five characteristics: 1) turfgrass phytotoxicity, 2) turfgrass color and quality responses, 3) impact on soil hydrophobicity, 4) dew formation, and 5) pest damage. All wetting agent treatments were applied per label instructions according to the highest rate recommended to cure hydrophobic soils. This study was conducted for four months in 2003 and 2004 corresponding to the peak stress period at each location. Figure 5 shows a table with all wetting agents and application rates and timings. Results varied based on region, turfgrass species, and degree of soil hydrophobicity. In Michigan, turfgrass quality ratings were consistent among treatments from 2003 to 2004, and all wetting agents tested (except for Naiad) significantly improved turfgrass quality over the control. This is not consistent with the turfgrass color ratings seen in Missouri, where Cascade Plus produced the lowest color ratings in 2003; there was no statistical color difference between these treatments in 2004. The water droplet penetration test (WDPT) was used at each location to determine wetting agent effects on soil hydrophobicity. This test involves removing ¾ inch cores from each plot, placing a droplet of distilled water at various depths on each core, and determining the time that it takes for each droplet to penetrate the core. Surprisingly, in Missouri the wetting agents that were most effective in curing hydrophobicity also reduced turfgrass color; this contradicts Michigan data. It appears that the Missouri sand rootzone was drastically less hydrophobic (WDPT = 18 seconds) than the sands in Michigan (WDPT = 322 to 340 seconds). This implies that the Missouri plots had less to benefit from the wetting agent applications. In Michigan, WDPT closely reflected turfgrass quality; Naiad and control plots had the longest time for water penetration and also the lowest turfgrass quality ratings. Observations from these two states indicate that the wetting agents Aquaduct, Brilliance, Cascade Plus, Hydro-Wet, LescoFlo, Primer Select, and TriCure all have the ability to reduce soil hydrophobicity, but produce inconsistent results in turfgrass color and quality (Throssell, 2005). For a detailed explanation regarding questions about this research, visit Karnok (2005). It's important to note that newer wetting agent chemistries have been released since this study, such as Aquatrols Revolution (Pioppi, 2005).

WETTING AGENTS AND RATES

Product/rate (ounces)*	Timing	Spray volume (gallons/1,000 sq. ft.)[†]	Watering in
Aqueduct			
8	first application	1	irrigate before next mowing
8	1 week after first application	1	irrigate before next mowing
8	once every four weeks after second application	1	irrigate before next mowing
Brilliance			
8	first application	2	immediately after application
8	10 days after first application	2	immediately after application
8	12 weeks after second application	2	immediately after application
Cascade Plus			
8	first application	2	immediately after application
8	10 days after first application	2	immediately after application
Hydro-Wet			
8	first application	10	immediately after application
8	two weeks after first application	10	immediately after application
2	every two weeks after second application	5	immediately after application
LescoFlo			
8	first application	10	immediately water in
8	two weeks after first application	10	immediately water in
Naiad			
8	first application	10	immediately after application
8	two weeks after first application	10	immediately after application
6	once every four weeks after second application	10	immediately after application
Primer Select			
6	first application	2	irrigate before next mowing
6	every four weeks following first application	2	irrigate before next mowing
Respond 2			
10	first application	8	immediately after application
10	8 weeks after first application	8	immediately after application
Surfside 37			
32	first application	10	immediately after application
4	every two weeks after first application	10	immediately after application
TriCure			
6	first application	2	immediately water in
6	every four weeks following first application	2	immediately water in

*2, 4, 6, 8, 10 and 32 ounces = 59.1 milliliters, 0.12 liter, 0.17 liter, 0.24 liter, 0.30 liter and 0.94 liter, respectively.
[†]1, 2, 5, 8, and 10 gallons/1,000 square feet = 40.7, 81.5, 203.7, 326 and 407.5 liters/1,000 square meters, respectively.

Table 1. Wetting agents, rates of application in fluid ounces, timing of application, spray volume and post-application watering instructions used in the GCSAA/USGA wetting agent evaluation. The first application of all wetting agents was made on the same date and before the appearance of any symptoms of localized dry spots.

(Figure 5. Left. Reference: Throssell, 2005)

More regional specific studies have been conducted in recent years by the University of Minnesota-Twin Cities and the University of Wisconsin-Madison. These studies have been published in Hole Notes and The Grass Roots. One study included in the June 2011 issue of Hole Notes, "2010 Wetting Agent Study Update", evaluated the effects of six wetting agents that were currently being used by twelve golf courses in Minnesota.

Through GPS mapping of TDR data, these researchers were able to track changes in soil moisture levels and uniformity following a wetting agent application. In this study, block polymer and modified block polymer wetting agents (TriCure, Revolution) increased soil moisture and uniformity distribution by an average of 4.7 and 4.8 percent, respectively. Gluco ether block polymer wetting agents (Tournament Ready, Dispatch) reduced soil moisture by 2.7 percent, while decreasing uniformity by 3.9 percent. This study is a good demonstration of the differences between the water-holding and soil-penetrating chemistries of wetting agents (Johnsen and Horgan, 2011).

A follow up study was conducted in 2011 on the same golf courses with a modified treatment list. Wetting agent chemistry differences continued to be apparent based on soil moisture and uniformity. TriCure, Revolution, Immerse GT, Magnus, and Performa Gold treatments increased soil moisture by an average of 4.4 percent. Dispatch decreased soil moisture by 4.7 percent. TriCure, Magnus, and Revolution increased uniformity by 6.5 percent, while Dispatch and Tournament Ready reduced uniformity by 4.5 percent (Johnsen et al., 2012). These results are fairly consistent with the data collected in 2010. For a detailed explanation of the various wetting agent chemistries, read the article published by Zontek and Kostka (2012). Karnok published a recent article in GCM (2013) and laments the difficulties of understanding the chemistry of wetting agents and states: "who cares about the chemistry".

Dr. Doug Soldat addressed the question of how wetting agents perform in wet (or hydrophilic) soils in a two-year study conducted in Madison, Wisconsin. Six wetting agents were evaluated for their ability to reduce VWC in high moisture conditions on a one-year-old 'Penn A4' creeping bentgrass USGA spec putting green. During the 2009 study year, all wetting agent treatments had consistently lower VWC levels than the untreated control, with Revolution reducing VWC the most (> 4 %). Treatments of Tournament Ready, Sixteen90, and two experimental products from Aquatrols all demonstrated similar VWC values, which were consistently 2 percent drier than the control. Revolution was tested alone in 2010 and resulted in a less dramatic reduction in VWC compared to the control on the same putting green. Moving the treatments to an eight-year-old putting green with approximately 4 percent organic matter resulted in little VWC statistical difference between Revolution and the control (Soldat, 2010).

This data further validates that the benefits of wetting agents differ by soils; that these wetting agents have the ability to improve the wetting of hydrophobic soils and will reduce soil moisture in wet conditions. Soldat et al. (2010) also evaluated wetting agent effects on localized dry spot development, turfgrass quality, moisture uniformity, and moisture content on a 'Penncross' creeping bentgrass green. Two control plots (replacement of 100 or 30 percent evapotranspiration, ET) were compared with the wetting agents Aquaduct, Primer 604, and Revolution water at a replacement 30 percent of ET. Control plots irrigated with 100 percent replacement of ET demonstrated the highest turfgrass quality and least amount of localized dry spot, whereas the 30 percent ET control plots were below acceptable levels for most of the study. All wetting agent treatments provided acceptable turfgrass quality for most of the study with only 30 percent ET replacement. Soil moisture uniformity was the highest in all wetting agent treatments. Soil moisture content in wetting agent plots reflected changes in weather patterns; wetting agents improved the moisture content under dry conditions and reduced the moisture content under wet conditions. Remember this was reinforced by Carrow (1989).

Conclusion

The breadth of information presented throughout this review demonstrates where our knowledge has originated related to wetting agents. Much like winter injury studies in turfgrass, wetting agent research can vary greatly by location, soil type, irrigation practices, species, product, season, etc. There are no clear cut recommendations on how to effectively utilize wetting agents at your property. Please use the research cited in this article in conjunction with your local knowledge and experience. We've all read the purported benefits of the so-called wetting agent that will cure every problem under the sun. But we've also acknowledged the fact that a single wetting agent can both increase VWC and decrease VWC of a rootzone, improving uniformity. These products are tools that, when used wisely, can make a nice complement to your turfgrass management arsenal.

Opportunities for future research on wetting agents might involve their impact on surface firmness or winter survivability. We anticipate this information to be available in the years to come. For more background on wetting agent basics, we suggest reading the highlighted articles in the references section.

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