1955 to 1964

The initial discussion of wetting agent use surrounded the idea that “plain water” could be improved upon, and “making water wetter” would produce a better turf. In fact, in one of the first articles written on the use of wetting agents, Bob Moore mentions “we have been governed by the physical limitations of plain water” (Moore, 1957). Just as today, the primary wetting agents being used to improve soil conditions sixty years ago were non-ionic wetting agents, or those wetting agents lacking an ionic charge. These products were thought to be less injurious to plant tissue, consistent, and more effective.

Around this time the talk of soil moisture tension surfaced. Soil moisture tension is the tendency of water to cling to soil particles. Water with a lower tension has a greater ability to move and replace moisture withdrawn by turfgrass roots. Figure 1 is a graph from Moore, 1957 showing a close relationship between soil moisture tension and root elongation. While this graph looks too perfect and we all know that 100 percent soil moisture is never good for root growth, it puts perspective on an idea that we don’t consider much these days, that is, allowing water to move more freely in our root zones, not just curing hydrophobicity. Reported benefits of lowering soil moisture tension included 1) increase in the availability of water and nutrient solutions, 2) freer movement of water and nutrient solutions, and 3) greater root growth (Moore, 1959). At this point in time, there was little turfgrass research to support these claims.

One of the first wetting agent studies in a turfgrass setting was published by the Soil Science Society of America. Researchers evaluated infiltration rate differences of three commercially available wetting agents when applied to quartz sand (Pelishek et al., 1962). The focus of this study was on the contact angle present between sand columns and the water solution applied to the columns. Pelishek et al. concluded that wetting agents can increase infiltration rates on hydrophobic soils, and there is a beneficial residual effect of wetting agents.

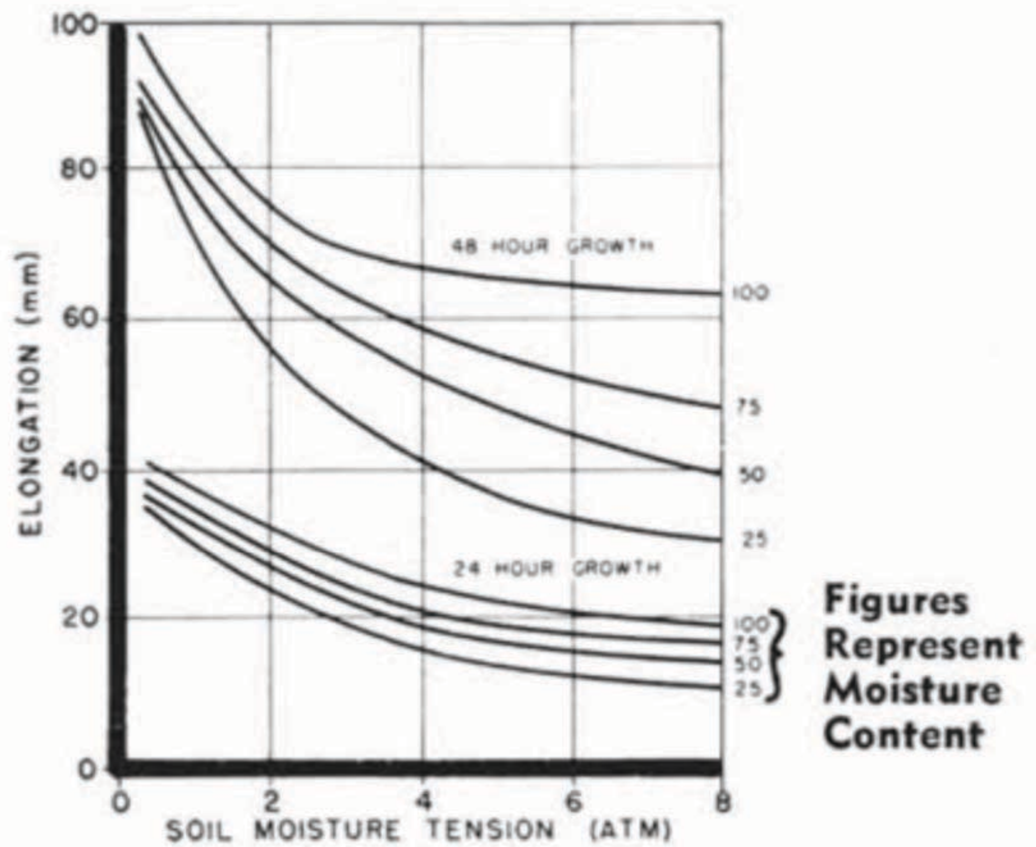


Figure No. 5. Elongation of roots as effected by soil-moisture tensions. Deeper roots are developed under low soil moisture tensions.

(Figure 1. Reference: Moore 1957)

1965-1974

Around the mid-1960s wetting agents were starting to become common tools used by golf course superintendents. Not surprisingly, this is when researchers began to evaluate their effectiveness and place in turfgrass management programs. Roberts (1966) studied the effects of four wetting agents applied monthly to creeping bentgrass, colonial bentgrass, and Kentucky bluegrass, grown both in the field and in a greenhouse at Iowa State University. The "old chemistry" wetting agents used in this study had no effect on turfgrass quality or moisture relations

under field conditions. In the greenhouse, turf grown hydroponically in a wetting agent and nutrient solution showed chlorosis and reduced growth. In this case, increasing surfactant level in the solution caused an increase in toxic levels of copper and zinc concentrations in the turf tissue causing phytotoxicity. It appeared that the soil in the field study was able to bind the wetting agent, in which case no injury was apparent. During this period, the non-ionic surfactants were only considered of value in hydrophobic or difficult to wet soils.

In a three part study conducted by researchers at the University of California-Riverside, soil wetting agents were evaluated with various levels of compaction, irrigation, and soil amendments on common bermudagrass grown in a greenhouse. While this study was fairly complex, strong correlations were made with the addition of wetting agent on improving infiltration of sandy loam soils (40% greater infiltration rates), but not sandy loams modified with 33% either peat, lignified redwood, or calcined clay. Overall infiltration rates on these modified soils were significantly greater than on sandy loam alone, which explains the lack of response from wetting agent additions. Other responses evaluated in this study included compactability, evapotranspiration, top growth, salinity, tissue mineral content, oxygen diffusion rate, and top growth; wetting agent treatments showed little effect on these responses (Morgan et al., 1966; Letey et al., 1966; Valoras et al., 1966).

These same researchers studied the effects of AquaGro and Soil Penetrant 3685 (both polyoxyethylene based) on seed germination, shoot growth, and root growth of creeping bentgrass, Kentucky bluegrass, bermudagrass, annual ryegrass, tall fescue, and barley. This was one of the first studies that demonstrated differences in phytoxocicity among similar wetting agent chemistries. Both root and shoot growth reductions were associated with higher wetting agent application rates, and Soil Penetrant 3685 treated plants were suppressed more than those treated with AquaGro; this was attributed to the higher soil retention of AquaGro and therefore less product present in soil solution (Endo et al., 1969), similar to the idea from Roberts (1966).

1975-84

In an eight year study, Murray and Juska (1977) studied the effects of several management practices, including wetting agent applications, on thatch accumulation, turfgrass quality, and leaf spot development in Kentucky bluegrass turf established in Maryland. These researchers hypothesized that the wetting agent treatment (AquaGro) would increase thatch moisture levels and therefore increase the rate of thatch decomposition. Over the duration of the study, wetting agent applications had little effect on thatch accumulation or turfgrass quality compared to the untreated control, however leaf spot damage was reduced in plots that were treated with a wetting agent. Leaf spot severity is increased in high moisture environments; therefore the wetting agent's ability to increase soil and canopy dry time, as well as reduce the formation of dew, is most likely the reason for the reduced leaf spot severity. However, Vargas and Detweiler (1980) failed to show this same relationship with leaf spot and AquaGro on 'Pennlawn' creeping red fescue. Also, Otto and Vargas (1984) saw no effect of wetting agent applications on leaf spot or dollar spot severity on Kentucky bluegrass.

After experiencing severely hydrophobic conditions on a newly seeded 'Penncross' creeping bentgrass sand-based experimental putting green, researchers at Ohio State University studied the influence of three commercially available wetting agents (Hydro-Wet, AquaGro, and Grozyme) with or without core aeration on improving soil moisture retention. The hydrophobicity was attributed to an organic coating on the soil particles. Treatments consisting of aeration plus Hydro-Wet or AquaGro performed the best at reducing the severity of the localized dry spot, and these two wetting agents applied without aeration also helped to alleviate the symptoms. Grozyme treatments showed no effect on reducing turf injury caused by hydrophobic soils (Wilkinson and Miller, 1978).

Numerous studies on the use of wetting agents were being conducted during this time period by institutions such as Michigan State University and University of California-Riverside. While these studies were published in field day or conference reports and not peer-reviewed journals, much of our knowledge on

the use of wetting agents was developed from these types of investigations. For example, Rieke (1974) demonstrated up to a 73% soil moisture increase one month after wetting agent applications on a hydrophobic fairway. This moisture increase resulted in a significant improvement in turfgrass quality for approximately two months after treatment in Michigan. The residual effects of AquaGro and Hydro-Wet were evaluated one year later. All of the wetting agent treated plots continued to hold more water than the untreated check, with the best treatment (Hydro-Wet applied at 32oz/1000ft2) holding 74% more water over one year after a single application in July. Turfgrass quality ratings closely reflected the increase in soil moisture content. Interestingly, soil cultivation treatments that were conducted on the same date one year prior showed no improvement in soil moisture or turfgrass quality.

This point validates the thought by many researchers at this time that coring and wetting agents should be used in combination for correcting hydrophobic soils. Soil moisture increases from the wetting agent applications were no longer evident after two years. In 1974, seven wetting agent treatments were added to a new study on the same site. AquaGro and Hydro-Wet treated plots exhibited the highest turfgrass quality ratings of all products tested (Rieke and Bay, 1975). While no phytotoxicity was witnessed during these studies, a follow up study was initiated to determine the phytotoxicity potential of the two best performing products, AquaGro and Hydro-Wet. Both products demonstrated some phytotoxic effects, although these effects were reduced as irrigation increased following application (Rieke and Bay, 1976).

Kaufmann and Jackson (1978) were some of the first researchers to study turfgrass water use rates as affected by wetting agents. This study was conducted on Kentucky bluegrass in-vitro by submerging the plants in solutions of either Hydro-Wet or AquaGro at 0, 200, 1000, or 5000 ppm dilution rates. At four and eight hours following submersion, water use rates were reduced in the wetting agent treated samples by 12-16% depending on treatment. Higher dilution rates did not increase this effect. These researchers conclude that water use rates can be reduced by as much as 10% with the use of wetting agents, but it is unclear whether or not this is desirable for the turfgrass being grown. Further investigation lead Kauffman (1980) to discover that transpiration is reduced in Kentucky bluegrass plants when the soil is treated with wetting agents or certain fungicides, and this closely resembles the relationship these compounds have on the stomatal conductance tested in this study. Figure 2 is a table from Kauffman's paper showing stomatal conductance, transpiration, and photosynthesis based on chemical treatment. Clearly, while low stomatal conductance reduces transpiration, it also has an effect on CO2 exchange, and therefore reduces photosynthesis. No turfgrass injury was observed in this study, but reducing photosynthesis should not be perceived as a positive attribute.

Table 1. The effect of four turfgrass chemicals on transpiration, photosynthesis and stomatal conductance of Merion Kentucky bluegrass

	(percent of untreated check)		
Chemical	conductance	transpiration	photosynthesis
Aquagro	62	68	87
Hydrowet	28	36	46
Tersan 1991	21	34	31
Chipco 26019	49	58	76
Check	100	100	100

(Figure 2. Reference: Kauffman 1980)

1985 to 1994

Wetting agent use was becoming so common by the mid-1980s that researcher's efforts were focused on finding secondary applications for these tools. Researchers at Cornell University studied annual bluegrass seed head suppression on a golf course fairway with several products, including the plant growth regulators mefluidide and amidochlor, and the wetting agents AquaGro, Hydro-Wet, Basic H, Amway Spray Adjuvant. All products were applied alone and not watered in. Surprisingly, over a three year period, spring AquaGro treatments reduced seed head production and yield from 26 to 77%; this treatment provided comparable suppression to the mefluidide treatment. Other wetting agents had no influence on seed head formation. Visual quality was slightly reduced with the highest AquaGro treatment from one to two weeks following application, however these effects were not present at three weeks after treatment. Clipping yields were not reduced with AquaGro.

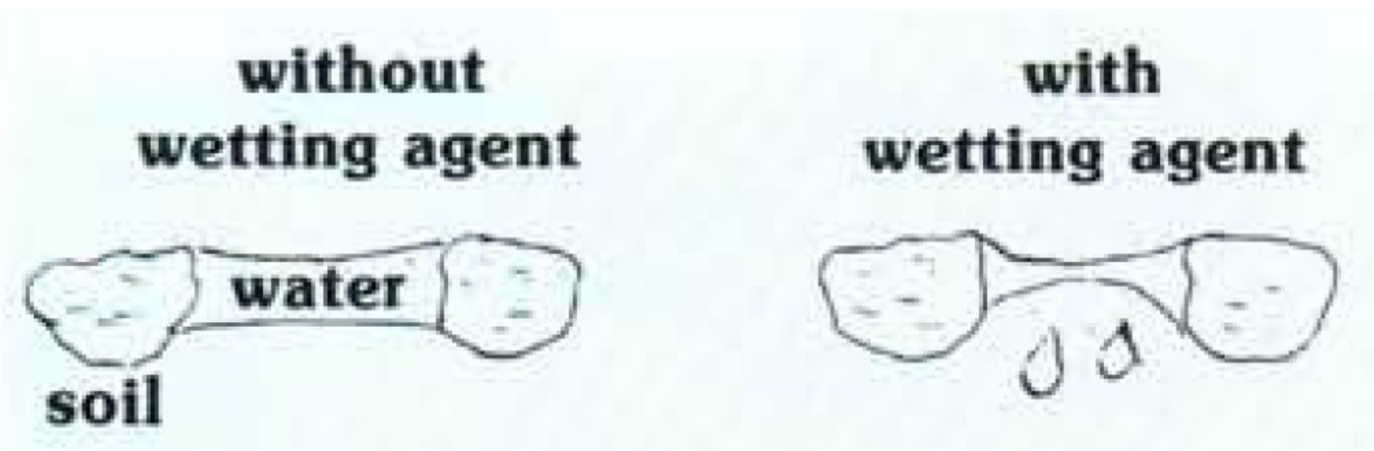
The authors concluded that AquaGro apparently has some growth regulating properties because of the level of seed head suppression in the study, although there was no research to support this at the time (Petrovic et al., 1985). Certainly, timing of application and lack of post-application irrigation play some role here. A similar study was conducted by Cooper et al. (1987) evaluating the effects of mefluidide and AquaGro on root growth, seed head production, and quality of annual bluegrass maintained at fairway height in Ohio. During the peak seed head production time, April to May, mefluidide and AquaGro suppressed seed head density by 76 and 20%, respectively. However, only mefluidide consistently suppressed seed head production throughout the study; it also effectively prevented summer root die back as compared to the control and AquaGro treatment.

The stimpmeter had become an important tool around this time period. With that, researchers began to evaluate practices that would have an effect on green speed. Langlois (1985) studied the influence of Surf Side wetting agent on the green speed of ‘Penneagle’ creeping bentgrass in Pennsylvania. Measurements taken for five consecutive days following the wetting agent application showed no significant change in the green speed as measured with a stimpmeter.

Few additional peer-reviewed wetting agent studies were published from 1985-1994, which is surprising. By now, many superintendents and researchers knew the benefits and potential drawbacks that wetting agents had to offer them. Some of the most interesting and informational trade articles being written at this time were from Golf Course Management Magazine (GCM). In a 1985 GCM article by Bruce Williams (former superintendent at Bob O'Link Golf Club), his success with using wetting agents on fairways to improve moisture distribution and retention was described, citing a 30 percent reduction in total water use since beginning the program six years prior.

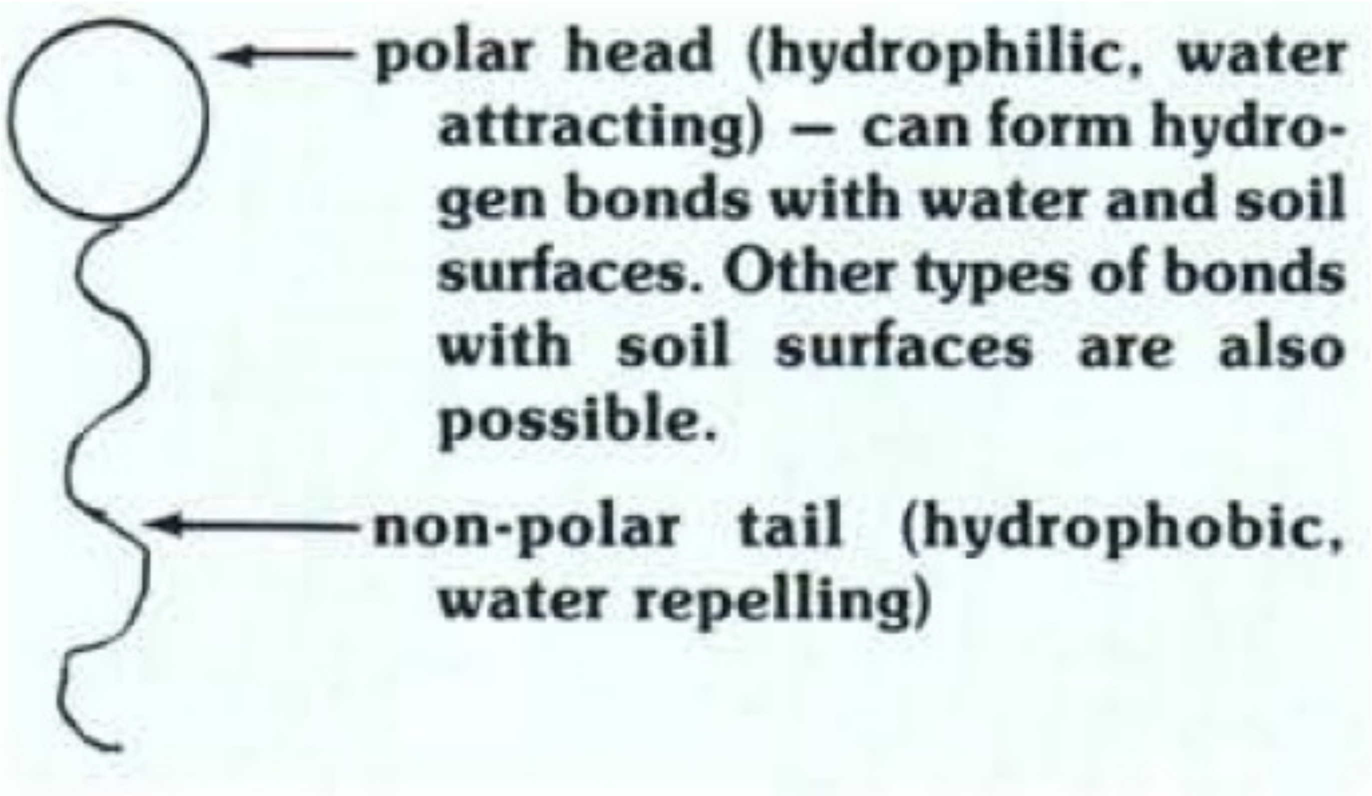
Another main benefit Bruce saw from wetting agent use was an elimination of wet areas that were favoring annual bluegrass (Williams, 1985). At a time when wetting agent benefits were primarily defined on hydrophobic soils, Dr. Bob Carrow (1989) discussed how wetting agents could be used to improve hydrophilic (wettable) soils in a GCM article titled "Understanding wetting agents: A look at how they influence soils can help superintendents better predict the results of treatment." Most turfgrass soils are in fact hydrophilic. In these situations, greater drainage could occur with the addition of a wetting agent due to decreased surface tension of the soil water. For this to happen, two factors need to be in place. First, the wetting agent must be present in sufficient quantities in the soil. Second, the soil must be able to drain, meaning no layers or extensive compaction present.

Figure 3 is a diagram of wetting agent interaction on hydrophilic soils from Dr.



(Figure 3. Reference: Carrow 1989)

Carrow's article. In addition to describing the wetting agents in hydrophilic situations, Dr. Carrow also discussed the mode of action of most wetting agents and how they behaved when in contact with hydrophobic soils. Non-ionic wetting agents have a polar (hydrophilic) head and a non-polar (hydrophobic) tail (Figure 4). As you would imagine, the tail attaches itself to the soil and the head attaches to



water, holding water in place for plant uptake.

(Figure 4. Reference: Carrow 1989)

Quinn (1993) described in a GCM article the "Special applications for wetting agents"; ranging from seed head reduction to overall water savings, however, much of this was still up for debate. At this time there were several proven products that were able to back up their claim of improving soil wettability or making "wetter water." Those products included: AquaGro (Aquatrols), Aqua-Aid (Aqua-Aid), Hydraflo (Grace-Sierra), Hydro-Wet (Kalo), Surf Side (Montco Products), Naiad (Naiad Co), Paragon (Precision Labs), and NOBURN (ROOTS).

Quinn also mentioned superintendent's successes injecting wetting agent through Toro's water aerator, the HydroJect. This process had been approved by the Toro Co. one year prior (Phillips, 1992). It was also in 1993 that the International Turfgrass Society Research Journal published a method for an individual to determine initial and residual effects of the wetting agents that they were using. The simple procedure involved filling a clear drinking straw with hydrophobic soil and measuring infiltration rates with different wetting agent concentrations (Mane, 1993). Even today, this simple procedure could be useful for a superintendent trying to justify the cost of wetting agents to his greens committee or membership.

1995 to 2004

By 1995, wetting agents were no longer considered out of the norm of basic agronomics, but research results were inconsistent and it was hard to identify the benefits that products could consistently produce on individual properties. In a study looking at three different wetting agents and their influence on alleviating soil water repellency of a 'Tifdwarf' bermudagrass stand, Cisar et al (1997) found that applications of Primer or Aqueduct provided significantly better turfgrass quality and reduced localized dry spot as compared to AquaGro and an untreated control. Combination treatments of Primer/Aqueduct or Primer/AquaGro did not provide higher turf quality ratings or fewer localized dry spots than the treatments applied alone. Also studying Primer, a researcher in Massachusetts evaluated the amelioration of water repellency on 100 percent sand-based creeping bentgrass tees using two rates of Primer (125ml and 185ml per 100m2) compared to an untreated control. After two applications, turfgrass quality improved, and localized dry spots and afternoon wilting were nearly eliminated. Kostka (2000) cited four benefits of the Primer application: 1) reduced soil water repellency, 2) enhanced turfgrass performance, 3) improved uniformity of turf, 4) increased available soil moisture. At Michigan State, researchers studied the effects of Primer and Midorich wetting agents on water retention and distribution in sand and loamy sand with no turf cover. While not significant, Midorich increased the water retention in the upper two inches of the sand system, whereas Primer significantly increased retention at six and ten inches. This data suggests that these two wetting agents react differently