# High pH Treatments and the Alleviation of Soil Hydrophobicity on Golf Greens

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## ABSTRACT

Hydrophobic soil associated with localized dry spots (LDS) on creeping bentgrass *(Agrostis palustris* Huds.) putting greens has been shown to be caused by a humic and/or fulvic acid coating of the sand particles. Under laboratory conditions, humic acid begins to solubilize at pH 7.0 and is completely soluble at pH 9.5 or greater. The purpose of this study was to determine the potential of high pH treatments for alleviating soil hydrophobicity of a creeping bentgrass golf green. Three separate studies were conducted on the University of Georgia Experimental (iolf Green, Athens, (',A, during the spring and summer of 1990 and spring of 1991. The creeping bentgrass green, constructed with an 85% sand and 15% peat root zone mixture, had a well documented history of LDS caused by hydrophobic soil. Soil hydrophobicity was determined by the molarity of an aqueous ethanol droplet IMED) technique. Results showed that an application of 0.1 $M$ NaOH sufficient to saturate the upper 50 mm of soil, followed by a water flush of one pore volume, significantly reduced soil hydrophobicity if repeated three or more times. In one study, soil hydrophobicity was completely eliminated after nine consecutive daily treatments of 0.1 $M$ NaOH, each of which was followed by a water flush. A concurrent decrease in soil humic matter content suggested that its dissolution and removal was responsible for the increased wettability of the soil profde. Bentgrass treated with NaOH showed varying degrees of phototoxicity. The severity of injury depended on the number of consecutive applications and air temperature. Little or no discoloration was noted when air temperatures was <=24°C; however, severe wilt and desiccation occurred when treatments were applied when air temperature was >=35 °C. High pH treatments may be an effective means to reduce soil hydrophobicity on sand-based golf putting greens.

T HE U.S. GOLF ASSOCIATION (USGA) Green Section publishes specifications for the construction of golf putting greens (USGA, 1960, 1989). The recommended root zone mixture consists of >=90% sand, <5% silt, and 3% clay. A predominately sandy rooting medium increases the playability of the green by maximizing drainage and reducing the potential for compaction. The use of a sandy root zone mixture in putting green construction, particularly when creeping bentgrass is established, has resulted in the frequent occurrence of localized dry spot (LDS) caused by hydrophobic soil (Wilkinson and Miller, 1978; Tucker et al., 1990).

Hydrophobic soil associated with LDS is unusually dry in the upper rhizosphere, where turfgrass root density is greatest (Wilkinson and Miller, 1978). Consequently, particularly during periods of high temperature stress, the soil often lacks sufficient moisture for creeping bentgrass to survive without extraordinary maintenance. The condition usually occurs in irregular patterns at any elevation or slope throughout the putting green. Various methods such as the use of wetting agents and core cultivation used by golf course superintendents to alleviate LDS caused by hydrophobic soil usually have only a temporary effect. Localized dry spots usually persist regardless of rainfall or supplemental watering (Rieke and Beard, 1975).

Previous research has determined that soil hydrophobicity is most likely to occur in sandy soils (Jamison, 1942; Wander, 1949; Bond and Harris, 1964; Roberts and Carbon, 1971). It has been suggested that the hydrophobicity is due to an organic coating that envelops soil particles of both naturally deposited soils (van't Woudt, 1959; Roberts and Carbon, 1971; McGhie and Posner, 1980) and the artificial soils of golf putting greens (Wilkinson and Miller, 1978; Tucker et al., 1990). Ma'shum and Farmer (1985) suggested that soil hydrophobicity is derived from organically coated sand particles and from interspersed, partially decomposed plant residues.

Both humic (Roberts and Carbon, 1972) and fulvic acids (Miller and Wilkinson, 1977) have been implicated as the organic coating substance responsible for soil hydrophobicity. Humic acids are soluble in aqueous NaOH and are precipitated by acidification of the alkaline extract (Haworth, 1971), while fulvic acids are soluble in either alkali or acidic solutions (Stevenson, 1960). Both organic acids contain carboxyl (-COOH), and phenolic hydroxyl (-OH) functional groups that make these substances primarily hydrophilic (Chen and Schnitzer, 1978). Tschapek (1984) ascribed the interfacial activity of humic acid to an amphiphilic molecular structure that contains hydrophilic and hydrophobic contributing groups. He proposed that the outward orientation of nonpolar groups of dry humic acid is responsible for soil hydrophobicity. It has also been suggested that dehydrated humic matter (i.e., humic and fulvic acids) shares a proton between adjacent -COO and -OH groups attached to a benzene ring creating a nonpolar, hydrophobic surface (Tan, 1982).

Inorganic reagents that induce high and low pH have been used to extract organic coatings from hydrophobic sands in the laboratory. Roberts and Carbon (1972) reported that 0.5 M NaOH was most effective and that it completely removed the water-repellent organic coating from a Gavin sand after 1 d. A hydrophobic, heavy-textured Cuballing mallet soil was made hydrophilic after it was stirred with a 0.1 $M$ NaOH solution for 1 or 2 h (McGhie and Posner, 1980), and similar results were obtained with 0.1 $M$ HC1 at pH 1. Miller and Wilkinson (1977) determined that the coating was removed by washing with 1.25 $M$ NaOH. In the laboratory, McGhie and Posner (1980) showed that the water drop penetration time of a comminuted mallet litter was greatly affected by its pH. Specifically, as the pH increased from 3 to 10, the water drop penetration time of the litter decreased from > 1800 to 780 s and continued to decrease as the pH became even more alkaline. The ability of pH to ionize the organic

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coating and thereby reduce or eliminate soil hydrophobicity is well documented in the laboratory. There is no direct evidence, however, that a reagent may effectively reduce soil hydrophobicity in the field. Therefore, the objective of this study was to investigate the effectiveness of short- and long-term soil pH treatments for reducing soil hydrophobicity of a creeping bentgrass putting green.

## MATERIALS AND METHODS

### Study 1

The purpose of this study was to determine the effects of applying NaOH for up to three consecutive days on soil pH and soil hydrophobicity. On 9 Ap. 1990, a high pH/NaOH field study was initiated on a 'Penncross' creeping bentgrass experimental putting green at the University of Georgia Turfgrass Demonstration Plots, Athens. This green was constructed in 1977 with an 85% sand, 15% peat root zone mixture and had a well documented history of LDS caused by hydrophobic soil (Tucker et al., 1990). Five treatments were used: (i) 2.25 L of 0.1 $M$ NaOH, ponded to a depth of 12 mm, was applied on 1 d, (ii) 2 d consecutively, or (iii) 3 d consecutively; (iv) 2.25 L of water only, also ponded to a depth of 12 mm, was applied; and (v) a check was maintained without applied NaOH or water. Plexiglas frames, 0.43 by 0.43 m, were driven =25 mm into the soil surface surrounding each plot. All treatments were poured within the frames so that each application was ponded until it completely infiltrated. The plots were rinsed lightly with =0.55 L (3 mm) of water immediately after treatment infiltration. Except for the check, all plots were flushed 24 h later with 83.2 L (450 mm) of ponded water, to wash the treatment through the soil profile. Water used for the rinse and flush ranged from pH 8.0 to 8.5. No pesticides or fertilizers were applied to the green for at least 30 d prior to or during the study. In addition to rainfall (16 mm), the bentgrass was irrigated with 8 mm of water and maintained at a 6.4-mm cutting height. Less than 2 mm of thatch was present.

Soil hydrophobicity was determined by the MED technique (Watson and Letey, 1970; King, 1981). Soil samples (13 mm diam. by 50 mm deep), to determine hydrophobicity, humic matter content, and pH, were taken immediately before application of treatments and after the 24-h flush had been completed. Each soil sample was stirred, leveled, and air-dried for 14 d. The MED procedure consisted of placing a series of 40 yaL aqueous ethanol droplets at 0.4 $M$ intervals on the soil surface and recording the molarity of the droplet that completely infiltrated within 5 s. The greater the molarity of the aqueous ethanol droplet that completely infiltrated within 5 s, the greater the hydrophobicity.

For humic matter content determinations, 50 g of soil from each of two replicates per treatment was used. Each 50-g sample was placed in a 300-mL centrifuge bottle and a 250-mL aliquot of 0.1 $M$ NaOH was added to each bottle. The samples were placed on a mechanical shaker for 3.5 h, after which each was placed in a centrifuge at 40 000 rpm for 10 min. The supernatant was removed and recentrifuged at 10 000 rpm for 15 min to remove solid contaminants. The supernatant of each tube was collected and passed through two resin-filled columns: (1) Amberlite XAD-8 (Polysciences, Warrington, PA), to concentrate the humic matter fraction, and (ii) a H-saturated cation exchange column (Amberlite IR-120) for final purification. The effluent was collected and oven-dried at 60 °C for 24 h and then weighed to determine humic matter content. Total humic matter was recorded as milligrams per 100 g of soil.

All treatments were replicated three times in a completely randomized block design. Analysis of variance of the data was conducted utilizing the PROC ANOVA procedure of SAS, and means were separated by LSD (SAS, 1987). Significant differences were those that occurred at the $a = 0.05$ level.

### Study 2

The efficacy of NaOH applied on 9 consecutive days versus that applied infrequently on four occasions over 167 d to lessen or eliminate soil hydrophobicity was determined in a second field study. The study was initiated on 6 Sept. 1990 on the same experimental putting green as described in Study 1.

Plots (0.6 by 0.6 m) were established in known hydrophobic areas of the green. Treatments were (i) check, (ii) short-term 0.1 $M$ NaOH (applied 9 d consecutively), (iii) water only (applied 2 d consecutively), and (iv) long-term 0.1 $M$ NaOH (applied on Days 1, 27, 67, and 134). All treatments were replicated four times. Soil sampling, preparation, and testing were conducted as discussed for Study 1. Soil from short-term, water-only, and check plots was sampled on Days 8 and 10. Soil from long-term and check plots was sampled on Day 20 and then every 20 d thereafter.

Sodium hydroxide (3.05 L) in the short- and long-term treatments was applied so that approximately one pore volume of the upper 50 mm of soil was saturated with the treatment solution (9.15 L, or 25 mm). The short-term NaOH and water-only treatments were followed 24 h later by a 12.2 L (33 mm) water flush. The long-term NaOH treatment was not flushed with water following application. All plots were rinsed lightly with 1.1 L (3 mm) of water immediately after treatment infiltration. Phytotoxicity was monitored visually.

The green was maintained at a 6.4 mm cutting height and irrigated with 271 mm of water, in addition to 622 mm of rainfall. Nitrogen application was as follows: 12.2 kg of N ha$^{-1}$ as Milorganite (6-2-0 N-P-K) on 14 November, 24.4 kg of N ha-' as 20-10-20 on 15 November, and 73.2 kg of N ha-' as 14-7-14 on 18 December. Metalaxyl [A$^r$-(2,6-dimethylphenyl)-/V-(methoxyacetyl)-alanine methyl ester] and chlorothalonil (tetrachloroisophthalonitrile) fungicides were also applied at 0.78 and 3.13 L a.i. ha$^{-1}$, respectively, on Day 104 and again on Day 120.

Soil samples were taken on Day 10 and Day 160 from the short-term NaOH, water-only, and check plots for humic matter content determinations. Soil Na content from the short-term NaOH plots was determined on Day 10, 40, and 160. The humic matter content of the long-term treated plots was determined for Day 160. Humic matter extraction and statistical analysis procedures were the same as described for Study 1.

### Study 3

A third study was conducted in April 1991 on the same experimental putting green. The purpose was to determine the effects of rainfall on the treated areas as well as the check. Plots were established by pushing a beveled section of PVC pipe (20.3 cm i.d.) 25 mm into the soil. Approximately 150 mm extended above the soil surface. The technique was used for clearly marking the plots, as well as helping to contain treatment materials at each application. The pipes remained in place for the duration of the study. Treatments were (i) check, covered, and (ii) check, uncovered; 0.1 $M$ NaOH applied (iii) 3 d, (iv) 6 d, or (v) 9 d consecutively; and water only, applied (vi) 3 d, (vii) 6 d, or (viii) 9 d consecutively. Both the NaOH and the water plots received 0.8 L (25 mm) of water per application, so that approximately one pore volume of the upper 50 mm of soil was wetted. Twenty-four hours after application, each plot, except the check, was flushed with 1.2 L (38 mm) of water (=1.5 pore volumes). To determine the effect of rainfall on soil hydrophobicity, all plots, except the uncovered check, were covered when rain was expected. All plots received 57 mm of irrigation to prevent turfgrass wilt, and no fertilizer was applied during the study. Metalaxyl and propiconazole (l-([2-(2,4-dichlorophenyl)-4-propyl-l,3-dioxolan-2-yl]-methyl]-l$H$-l,2, 4-triazole) fungicides were applied to the green 12 d prior to application of treatments at rates of 0.78 and 1.04 L a.i. ha$^{-1}$, respectively. Mowing height was maintained at 6.4 mm.

Soil samples were taken from all plots before treatment ap-

plication and following water flushings. All soil samples were taken with a 7 mm diam. soil probe to a depth of 50 mm. The samples were oven-dried at 30 to 35 °C for 14 d. The MED method at 0.4 $M$ intervals was used to measure each sample for soil hydrophobicity.

Humic matter content was determined for the before and after 9-d NaOH, 9-d water, and the check treatments using procedures previously described. Because of severe LDS injury prior to treatment application, phototoxicity was not monitored.

Treatments were replicated three times within a completely randomized design. Statistical analysis of the data was conducted using the procedures previously stated in Study 1.

## RESULTS AND DISCUSSION

### Study 1

Prior to treatment application, there were no significant differences in soil hydrophobicity among plots (Table 1). After treatment, the MED values of the NaOH and water-only plots were significantly lower (i.e., more hydrophilic) than the check. The efficacy of the water-only treatment may be explained by a physical removal of the weakly bonded humic matter from the sand (Tucker, 1987). Reduction in hydrophobicity may also have resulted from the temporary rehydration of humic matter due to the release of the proton causing internal pairing between the -COO and -OH functional groups on the benzene ring (Tan, 1982).

The 3-d NaOH treatment increased soil pH to 8.3 and resulted in significantly less humic matter content after application (219 mg 100 g$^{-1}$ soil) compared with before (500 mg) treatment application (data not shown). This suggests a dissolution and removal of humic matter from the upper 50 mm of soil. The water-only treated soil had similar amounts of humic matter before (392 mg 100 g~' of soil) and after (434 mg) application (data not shown). Therefore, a comparable initial reduction in MED was obtained by the water-only treatment without a concurrent decrease of humic matter content. This suggests that temporary rehydration of the soil humic matter reduced MED values after treatment.

### Study 2

On Day 10, the short-term NaOH treated soil had a significantly lower MED value than the check or water-only treatment (Table 2). By Day 160, the water-only MED was the same as the check. On Day 160, the short-term NaOH treated had a significantly lower MED value

than the check and other treatments. The long-term NaOH MED value was also significantly lower than the check and water-only treatments.

Soil Na concentration of the short-term NaOH treatment increased from 32 mg kg$^{-1}$ before treatment applications to 745 mg kg$^{-1}$ on Day 10 (data not shown). With 108 mm of rainfall and 44 mm of supplemental irrigation, the Na concentration gradually decreased to 238 mg kg$^{-1}$ by Day 40. Then, with 454 mm of rainfall and 207 mm of supplemental irrigation, the soil Na concentration decreased further, to 65 mg kg$^{-1}$ by Day 160. Soil pH for the short-term NaOH treatment gradually decreased from a high of 10.0 on Day 10 to 7.8, 7.4, and 6.9 on Day 80, 120, and 160, respectively. The decrease in pH may have accounted for the slight increase in MED by allowing the precipitation of humic matter on soil particles. The soil pH for the long-term NaOH treatments fluctuated between 7.4 and 8.6.

On Day 10, soil humic matter content for the short-term NaOH treatment was significantly lower compared with the check and water-only treatments (Table 2). This agrees with Study 1, where a reduction was noted in both soil humic matter content and MED for the NaOH-treated soil. On Day 160, soil from the short- and long-term NaOH treatments contained significantly less humic matter than the check and water-only treatments.

Bentgrass treated with NaOH showed severe wilt and discoloration within 1 h of the first application. After 2 h, severe tissue desiccation was observed. These observations are in contrast to those noted in Study 1, in which no phytotoxicity occurred. The difference in phytotoxicity was probably due to high temperature stress. Study 1 was done during mild, nonstress conditions where air temperatures did not exceed 24 °C, whereas in Study 2, treatment applications were made when air temperatures were =35 °C. Daytime air temperatures remained between 30 and 35 °C for several days following application. The desiccation and loss of turf stand was severe enough that the NaOH-treated plots had not fully recovered to an acceptable level 1 yr after application.

### Study 3

There were no significant differences in soil hydrophobicity among the plots before treatment application (Table 3); however, after completion of all treatment applications on Day 9, the 6- and 9-d NaOH-treated soil had significantly lower MED values compared with all

Table 1. The pH and molarity of aqueous ethanol droplet (MED) of a hydrophobic soil before and after NaOH and water flush applications in Study 1.

| Treatment | pH | | MED† | |
|---|---|---|---|---|
| | Before | After | Before | After |
| check | 5.9 | 6.1 | 3.1a‡ | 2.9a |
| water only (1 d) | 6.0 | 6.5 | 2.9a | 1.2b |
| 1-d NaOH | 5.9 | 7.0 | 3.1a | 1.1b |
| 2-d NaOH | 5.8 | 7.6 | 2.9a | 0.9b |
| 3-d NaOH | 5.9 | 8.3 | 2.7a | 1.1b |
| F-test (Prob.) | | | 0.7130 | 0.0001 |
| CV, % | | | 13 | 19 |

† MED values: 0 = completely hydrophilic, 3 = severely hydrophobic
‡ Within columns, means followed by the same letter are not significantly different according to LSD means separation test at $\alpha$ = 0.05.

Table 2. Humic matter content (HM) and molarity of aqueous ethanol droplet (MED) of a hydrophobic soil following NaOH, and water applications in Study 2.

| Treatment | Day 10 | | Day 160 | |
|---|---|---|---|---|
| | MED† | HM | MED | HM |
| | | mg 100 g$^{-1}$ | | mg 100 g$^{-1}$ |
| check | 2.10a‡ | 798a | 2.65a | 1856a |
| water only | 1.70b | 794a | 2.60a | 2213a |
| short-term NaOH | 0.05c | 368b | 0.75c | 882b |
| long-term NaOH | —§ | — | 1.15b | 1002b |
| F-test (Prob.) | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| CV, % | 19 | 12 | 10 | 20 |

† MED values: 0 = completely hydrophilic, 3 = severely hydrophobic.
‡ Within columns, means followed by the same letter are not significantly different according to LSD means separation test at $\alpha$ = 0.05.
§ No samples were taken on Day 10.

Table 3. The molarity of aqueous ethanol droplet (MED) of hydrophobic soil **treated with** NaOH and water in Study 3.

| Treatment[†] | MED[‡] | |
| --- | --- | --- |
| | Before treatment | After treatment (Day 9) |
| check (covered) | 2.7a§ | 3.2a |
| check (uncovered) | 2.7a | 2.7ab |
| 3-d water | 2.9a | 2.4b |
| 6-d water | 2.8a | 2.3b |
| 9-d water | 2.5a | 2.3b |
| 3-d NaOH | 2.8a | 2.3b |
| 6-d NaOH | 2.8a | 0.5c |
| 9-d NaOH | 2.8a | 0.0c |
| *F*-test (Prob.) | 0.8761 | 0.0001 |
| CV, % | 12 | 20 |

† Treatment days are consecutive.
‡ MED values: 0 = completely hydrophilic, 3 = severely hydrophobic.
§ Within columns, means followed by the same letter are not significantly different according to LSD means separation test at $\alpha = 0.05$.

Table **4.** Soil **humic matter content before and after treatment with NaOH and water treatment application in Study** 3.

| Treatment[†] | Humic matter content of soil | |
| --- | --- | --- |
| | Before treatment | After treatment (Day 9) |
| | —————— mg 100 g$^{-1}$ —————— | |
| check | 1601a‡ | 2764a |
| 9-d water | 1862a | 1516b |
| 9-d NaOH | 1868a | 837c |
| *F*-test (Prob.) | 0.2272 | 0.0002 |
| CV, % | 52 | 14 |

† Treatment days are consecutive.
‡ Within columns, means followed by the same letter are not significantly different according to LSD means separation test at $\alpha = 0.05$.

other treatments. These results are similar to those obtained from Studies 1 and 2. The pH of the 9-d NaOH treatment was 10.1 and the MED was 0.0. The better efficacy of the 6- and 9-d treatments was probably due to the increased duration of the high soil pH, followed by the additional water flushes.

The uncovered check received 12.7 mm of rainfall during the study. This amount of rainfall had no significant effect on MED when compared with the covered check (2.7 vs. 3.2 *M*). In addition, there were no differences between the uncovered check and all other treatments except the 6- and 9-d NaOH treatments. The water and 3-d NaOH treatments showed a significant decrease in MED compared with the covered check. As discussed above, if enough water is applied, there appears to be a temporary rehydration of precipitated soil humic matter. Additionally, the soil of the covered check remained drier compared with the other treatments. The dry environment most likely intensified the development of hydrophobicity. The increased hydrophobicity of the covered check agrees with the results of Wilkinson and Miller (1978), who found the condition to worsen as the soil became drier. After all treatment applications, soil humic matter content was significantly different between the check, 9-d NaOH, and 9-d water treatment (Table 4). The reduced soil humic matter due to the water and NaOH treatments may be attributed to its partial washing away (Tucker, 1987), or to its ionization, respectively.

## SUMMARY AND CONCLUSIONS

These studies show that three or more applications of enough 0.1 *M* NaOH to saturate the upper 50 mm of soil, followed by flushing with at least one pore volume of water will alleviate soil hydrophobicity of a creeping bentgrass putting green. The potential phytotoxicity of NaOH to creeping bentgrass may limit its use by golf course superintendents for the control of LDS caused by hydrophobic soil; however, the potential for utilizing a short-term, high pH treatment for the control of hydrophobic soil on sand-based golf greens holds some promise. Research involving the use of other bases as well as other application techniques continues.

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