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Localized Dry Spots as Caused by Hydrophobic Sands on Bentgrass Greens

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ABSTRACT

Construction of creeping bentgrass *(Agrostis palustris* Huds.) golf greens with topsoil mixtures that contain 90% or more sand has led to the appearance of irregularly shaped areas of wilted or dead turfgrass known as localized dry spots (LDS). Objectives were to determine by means of a survey the association between management practices and the severity of LDS, and to compare the chemical and physical properties of LDS and adjacent healthy areas (HA) of greens. Turf managers from ten golf courses and the University of Georgia Turfgrass Plots completed a 34-question survey pertaining to management practices used on their respective greens. Four of the golf courses and the University Turf Plots were selected as sampling sites for soil from both LDS and HA. Soil was analyzed for moisture content, and particle size, as well as hydrophobicity via the water droplet penetration time, and contact angle methods. Soil organic matter, soluble salts, pH, P, K, Ca, Mg, Zn, Mn, B, and NO,, were also determined. In addition, soil from each area was viewed with a scanning electron microscope. Dry spots occurred at all locations surveyed and no correlation was observed between management practices and the severity of LDS. No differences in soil chemical properties were found between LDS and HA, but water droplet penetration time and contact angle were greater in LDS compared to HA. This hydrophobic condition was confined to the top 50 mm of soil in the dry spot samples and coincided with the presence of an organic coating on sand grains that was observed by scanning electron microscopy.

CERTAIN surface soils exhibit a hydrophobicity that retards or prevents infiltration of rain or irrigation water. Hydrophobic conditions occur in uncultivated sandy soils and have been reported in grasslands in Australia (Bond, 1968), citrus groves in Florida (Jamison, 1942), and in burned forest lands in southern California (DeBano et al., 1970).

In the early 1960s the United States Golf Association (USGA) began advocating the construction of golf greens with topsoil mixtures that contained greater than 90% sand (USGA Green Section Staff, 1960). Shortly thereafter, irregular patches of water-stressed turfgrass known as localized dry spots (LDS), began to appear in newly constructed creeping bentgrass golf greens (Wilkinson and Miller, 1978). There are several possible causes of LDS including excessive thatch, compacted soil, poor irrigation coverage, steep sloping grade, or hydrophobic soil.

Very little research has been reported on the cause of LDS in bentgrass greens in the USA. To our knowledge, the only study is that of Wilkinson and Miller (1978), performed on Ohio State University experimental golf greens. They found that sand grains from the LDS had an organic coating that was absent on sand grains taken from adjacent healthy areas (HA).

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Miller and Wilkinson (1979) reported that this organic coating had an infrared spectrum similar to that of soil fulvic acid. They attributed the LDS condition to the formation of Ca and Mg fulvate which became hydrophobic after prolonged drying. Organic coatings have also been found in hydrophobic sands of grasslands in Australia (Bond and Harris, 1964). Basidiomycetous fungi were associated with the dry spot areas and the authors hypothesized that the organic coating was a metabolic product of the fungi. Wilkinson and Miller (1978) isolated several fungal species in the genera of *Helminthosporium*, *Alternaria*, and *Curvularia* which were present in both LDS and HA.

Several management practices have been developed for control of LDS. Allowing the soil to dry out for any period of time seems to hasten the development of dry spots, so more frequent irrigation of affected areas is a common practice (Paul and Henry, 1973). Coring (Rieke and Beard, 1975) and wetting agents (Miyamoto, 1985) are also used to improve infiltration. The addition of a small amount of clay and silt in combination with coring has also been recommended (Bond, 1978).

The purpose of this study was to survey a number of golf courses in northeast Georgia to determine the correlation between management practices and the severity of dry spots, and to examine samples from LDS and HA of operating golf courses to determine differences in soil chemical and physical properties, and to determine if an organic coating was associated with LDS as reported by Wilkinson and Miller (1978).

MATERIALS AND METHODS

Ten golf courses, each having a history of LDS on creeping bentgrass greens, were surveyed in the spring of 1984 (Table 1). Each superintendent was asked to complete a questionnaire pertaining to the use of various cultural practices, fertilizers, and pesticides on the greens. The University of Georgia Experimental Golf Green was also included in the survey. Information from the completed questionnaires was used to determine if there were any common management practices among golf courses having a history of LDS.

When LDS appeared on greens in the summer of 1984, soil samples were taken from LDS and immediately adjacent HA using a JMC "O" Contamination Tube soil sampler (Clements Assoc. Inc., Newton, IA) at Fairfield Plantation, Hidden Hills Country Club, Peachtree Golf Course, Summit Chase Country Club, and the Univ. of Georgia Turf Plots. A 23-mm diam. soil core was removed, intact, in an acetate tube which was sealed with plastic caps. Soil sampling depth varied from 0.10 to 0.20 m depending on location.

Three to five greens were sampled at each location. A total of 12 cores were taken from six to eight LDS and HA on each green at each location for chemical and physical measurements. On six of the cores, water droplet penetration time was measured according to the procedure described by Wilkinson and Miller (1978). A microliter syringe was used to place a 0.01 mL droplet of distilled water at 12.5-mm intervals along each soil core, which was in a horizontal position. The top 50 mm of soil from these six cores was then air dried and mixed together to form a bulk sample of LDS

Table 1. Frequency of occurrence of localized dry spots (LDS) and cultural practices on 11 Georgia golf greens.

Name and location†	Number of greens with LDS	Time after green construction when LDS first appeared	Year of green construction	Number of corings per year	Cores removed	Number of topdressings per year	Topdressing material
Athens Country Club (Athens, GA)	3	Unknown	1926	2	Yes	2	Sand
Brookfield West Country Club (Roswell, GA)	7	7–8 months	1972	2	Yes	2	Sand
Dunwoody Country Club (Dunwoody, GA)	18	Unknown	1967	3	Yes	6	Sand
Fairfield Plantation (Villa Rica, GA)	8	Unknown	1972	3	Yes	3	Sand
Hidden Hills Country Club (Stone Mt., GA)	5	6–8 months	1971	3	Yes	3	Sand
Peachtree Golf Club (Atlanta, GA)	18	Unknown	1972	2	No	5	Sand-peat
Pinetree Country Club (Kennesaw, GA)	5	20 y	1959	3	No	3	Sand
The Standard Club (Atlanta, GA)	17	28 y‡	1949	3	Yes	10	Sand
Summit Chase Country Club (Snellville, GA)	10	Unknown	1973	2	No	2	Sand
Univ. of Georgia Golf Club (Athens, GA)	3	Unknown	1967	3	Yes	8	Sand
Univ. of Georgia Turf Plots (Athens, GA)	1	5 yr	1977	2	Yes	2	Sand

† All locations had 18 greens except the Univ. of Georgia Turf Plots which had a single green.
‡ After conversion from bermudagrass greens to creeping bentgrass greens.

or HA for each location. The bulk samples were sent to the University of Georgia Soil Testing and Plant Analysis Laboratory to determine pH (water), organic matter, P, K, Ca, Mg, Zn, Mn, Bo, NO_3, and soluble salts.

The top 50 mm of soil from each of the six remaining cores was transferred to moisture cans and the oven-dry water content was determined by weight. Subsequently, the oven-dried soil cores were mixed together to form a bulk sample of LDS or HA from each location. Contact angle measurements, particle-size analysis, and scanning electron microscope (SEM) observations were made using these bulk samples.

Contact angle was measured using a modified version of the Emerson and Bond (1963) method. Soil from the bulk sample was screened through a 2-mm-mesh sieve. The dry soil was placed into a 6-mm-diam. glass tube and packed to a bulk density of 1.5 Mg m^{-3}. The inside surface of the glass tube had previously been coated with paraffin to prevent water from moving along the surface of the glass tube. To keep the soil in place, a piece of cheesecloth was fastened to the end of the tube. The tube was lowered into a 1000-mL beaker of distilled water to a depth of 100 mm. Height (mm) of rise of the water within the tube was measured and recorded at 1-min intervals for 10 min. Then the soil was removed from the tube and placed in a beaker. At this point the Emerson and Bond (1963) method was modified. In their procedure the soil was heated to 500 °C to remove any organic coating on the soil particles. In the procedure used in this study, H_2O_2 was used to remove any organic coating. This was accomplished by treating the soil with 40 mL of boiling 30% H_2O_2 for 2 h.

After the H_2O_2 treatment, the soil was air dried and height of rise was measured again in the same manner. The maximum heights of rise before and after H_2O_2 treatment (h and h_0, respectively) were obtained from a plot of rate of rise vs. reciprocal of height of rise in the manner described by Emerson and Bond (1963). Contact angle was calculated as the inverse cosine of the ratio of h and h_a. This method assumes that the contact angle after H_2O_2 treatment is zero.

Particle-size analysis was performed using the pipette method (Soil Survey Staff, 1984). For the SEM observations, several sand particles from the bulk samples were affixed with double stick tape to electron microscope specimen stubs. Additional soil cores were taken from LDS and HA of the University of Georgia Experimental Golf Green. Sand particles from depths of 25 and 75 mm were removed from these soil cores and affixed with double stick tape to electron microscope specimen stubs. The specimen stubs were placed in a desiccator and air dried for 24 h. After drying, the stubs were placed into a sputter coater and the sand particles were coated with a Au-Pd alloy. After coating, both the LDS and HA sand particles were scanned with a Phillips 505 (Phillips Electronic Instruments, Inc., Mahwah, NJ) scanning electron microscope.

A completely randomized experimental design with location and treatments as the sources of variation was used to test for statistical significance. For water droplet penetration time and water content, individual measurement on each core provided subsampling within each location. For the other measurements which were made on the bulk samples, there was no subsampling within location, other than the distinction between HA and LDS.

RESULTS AND DISCUSSION

Survey

The survey showed that LDS occurred at all of the golf courses contacted, and that the frequency of occurrence varied from three to all 18 greens, excluding the University of Georgia turf plots (Table 1). Cultural practices also varied, as did the year of green construction, but none of the factors seemed to be related to the frequency of occurrence of LDS. Topdressing the greens constructed prior to the 1960s with sand may explain why these presumably heavier textured greens have started to show LDS. In two cases, dry spots appeared within a year after green construction in 1971 and 1972. In another case, a green constructed in 1949 did not show dry spots until conversion to bentgrass. Remedial management practices that had been adopted to control LDS centered around the use of wetting agents and/or increased irrigation duration times (Table 2). Aqua-Gro was the principal wetting agent in use and most golf courses used half the recommended rate of 50.8 L ha^{-1}.

Table 2. Remedial management practices adopted to control localized dry spots on Georgia golf greens.

Location	Wetting agent	Application rate	Application frequency	Increase in irrigation duration	No. of extra irrigations
		L ha^{-1}	yr^{-1}	min	
Athens Country Club	–	–	–	5	0
Brookfield West Country Club	–	–	–	5–10	0
Dunwoody Country Club	–	–	–	0	0
Fairfield Plantation	–	–	–	5–10	0
Hidden Hills Country Club	Aqua-Gro	25	2	0	1
Peachtree Golf Club	–	–	–	0	0
Pinetree Country Club	Aqua-Gro	25	As needed	0	0
The Standard Club	Aqua-Gro	25	As needed	2	0
Summit Chase Country Club	Aqua-Gro	13–19	As needed	5–20	0
Univ. of Georgia Golf Club	Hydro-Wet	25	2	0	0
Univ. of Georgia Turf Plots	Aqua-Gro	25	As needed	0	0

Table 3. Particle size distribution of the upper 50 mm of soil from localized dry spots and healthy greens combined from each location.

Location	Particle size distributiont								
	VCS‡	CS§	MS¶	FS#	VFS‡‡	Sand	Silt	Clay	Organic matter
	%								
Fairfield Plantation	10.4a	31.7a	17.5a	18.9a	6.3a	84.6b	4.2a	11.2a	3.8a
Hidden Hills Country Club	5.5a	42.4a	25.9a	17.8a	3.8ab	95.4a	0.6b	4.0b	0.9c
Peachtree Golf Club	13.4a	39.4a	22.6a	14.5a	3.9ab	93.9a	1.6b	4.5b	1.9b
Summit Chase Country Club	12.9a	37.9a	21.2a	17.3a	4.7ab	93.0a	1.9ab	5.1b	2.6b
Univ. of Georgia Turf Plots	14.6a	36.6a	23.6a	17.2a	3.3b	95.1a	0.3b	4.6b	2.1b

† Numbers within a column joined by the same letter are not significantly different at 0.05 level of probability according to Duncan's Multiple Range Test.
‡ VCS = very coarse sand (1–2 mm).
§ CS = coarse sand (0.5–1 mm).
¶ MS = medium sand (0.25–0.5 mm).
# FS = fine sand (0.1–0.25 mm).
†† VFS = very fine sand (0.05–0.1 mm).

Particle-Size Analysis

No significant differences between LDS soil and HA soil were observed in particle-size analysis (data not shown). The appearance of LDS in localized areas within a green did not appear to be related to differences in texture or organic matter, nor had the difference in infiltrability affected these properties. Both LDS and HA soil contained greater than 90% sand.

Due to the lack of statistical significance between HA and LDS positions, values for particle-size distribution were pooled at each location so that differences between locations could be tested for significance (Table 3). The Fairfield Plantation had a lower sand content and higher silt and clay content compared to the other locations. A subsequent sampling and analysis of the soil at Fairfield Plantation revealed that the top 25 mm of soil was similar in texture to that of the other locations (91.0, 1.1, and 7.9% sand, silt, and clay, respectively) but below this depth silt and clay contents were higher (8.2 and 11.4%), respectively. The golf greens at Fairfield Plantation were constructed in 1972 from native soil. For the next 18 yr, however, the greens were topdressed with sand, producing the difference in texture with depth. Golf greens at the four other locations that were sampled were built to USGA specifications using a soil mixture that contained over 90% sand. Soil organic matter was also higher at Fairfield Plantation and this may have been due to the higher clay content of the soil (Table 3).

Chemical Properties

No differences between LDS soil and HA soil were detected for the inorganic chemical properties measured (data not shown). Wilkinson and Miller (1978) speculated that the hydrophobic condition might be due to Ca and Mg soaps of fatty acids, but in this study there was no evidence of higher concentrations of Mehlich I extractable Ca or Mg in the dry spot areas. Differences in chemical properties did exist between locations when the LDS and HA data were pooled by location (Table 4). These differences were due in part to the different fertilization practices used. For ex-

Table 4. Chemical properties of the upper 50 mm of soil from localized dry spots and healthy areas combined from each location.

Location	Chemical properties†									
	pH	P	K	Ca	Mg	Zn	Mn	B	NO_3	Soluble salts
	kg/ha									
Fairfield Plantation	6.5a	67.8ab	235.0a	1971.8a	161.8a	17.4a	239.1a	0.7a	79.0a	31.1a
Hidden Hills Country Club	6.1b	34.2b	91.8b	1028.7b	58.2c	10.6ab	161.8ab	1.0a	25.8a	17.9a
Peachtree Golf Club	6.2b	33.6b	56.0b	1034.3b	126.6ab	8.4ab	233.0a	0.6a	21.8a	17.4a
Summit Chase Country Club	5.9c	48.7b	63.3b	766.1b	141.1ab	6.7b	62.2b	0.8a	23.5a	17.9a
Univ. of Georgia Turf Plots	5.7d	125.4a	84.0b	1293.0b	102.5bc	10.6ab	92.4b	0.8a	70.6a	19.0a

† Numbers within a column joined by the same letter are not significantly different at the 0.05 level of probability according to Duncan's Multiple Range Test.

Table 5. Water droplet penetration time in seconds of localized dry spots (LDS) and healthy areas (HA) in Georgia golf greens by depth and location.

	Depth, mm													
	12.5		25.0		37.5		50.0		62.5		75.0		87.5	
Location	LDS	HA	LDS	HA	LDS	HA	LDS	HA	LDS	HA	LDS	HA	LDS	HA
	s													
Fairfield Plantation	>25†	4a	>25	2ab	19b	2a	7c	2a	2d	<1	<1d	<1	<1c	<1
Hidden Hills Country Club	>25	<1b	>25	<1b	>25a	<1b	>25a	<1b	23a	<1	12b	<1	5ab	<1
Peachtree Golf Club	>25	3a	>25	3a	>25a	2a	>25a	1b	21ab	1	17a	<1	6a	<1
Summit Chase Country Club	>25	3a	>25	1b	>25a	1b	23b	<1b	16c	<1	6c	<1	4bc	<1
Univ. of Georgia Golf Club	>25	4a	>25	3a	>25a	<1b	>25a	<1b	19b	<1	14ab	<1	2c	<1

† Droplets that did not penetrate in 25 s, persisted for a minimum of 10 min.

Table 6. Water content of the upper 50 mm of soil from localized dry spots (LDS) and healthy areas (HA) at each location.

	Water Content	
Location	**LDS**	**HA**
	kg kg '	
Fairfield Plantation	**280**	**2300***
Hidden Hills Country Club	**120**	**1190***
Peachtree Golf Club	**320**	**2240***
Summit Chase Country Club	**110**	**2010***
Univ. of Georgia Turf Plots	**700**	**2580***
Mean	**310**	**2060***

* Means within a row are significantly different at a level of $P < 0.05$.

Table 7. Contact angle of the upper 50 mm of soil from localized dry spots (LDS) and healthy areas (HA) from each golf green.

	Contact Angle (degrees)	
Location	**LDS**	**HA**
Fairfield Plantation	**76.8**	**70.1**
Hidden Hills Country Club	**83.2**	**76.0**
Peachtree Golf Club	**92.5**	**86.9**
Summit Chase Country Club	**95.2**	**66.7**
Univ. of Georgia Turf Plots	**82.1**	**73.7**
Mean	**86.0**	**74.7***

* Means within a row are significantly different at a level of $P < 0.059$.

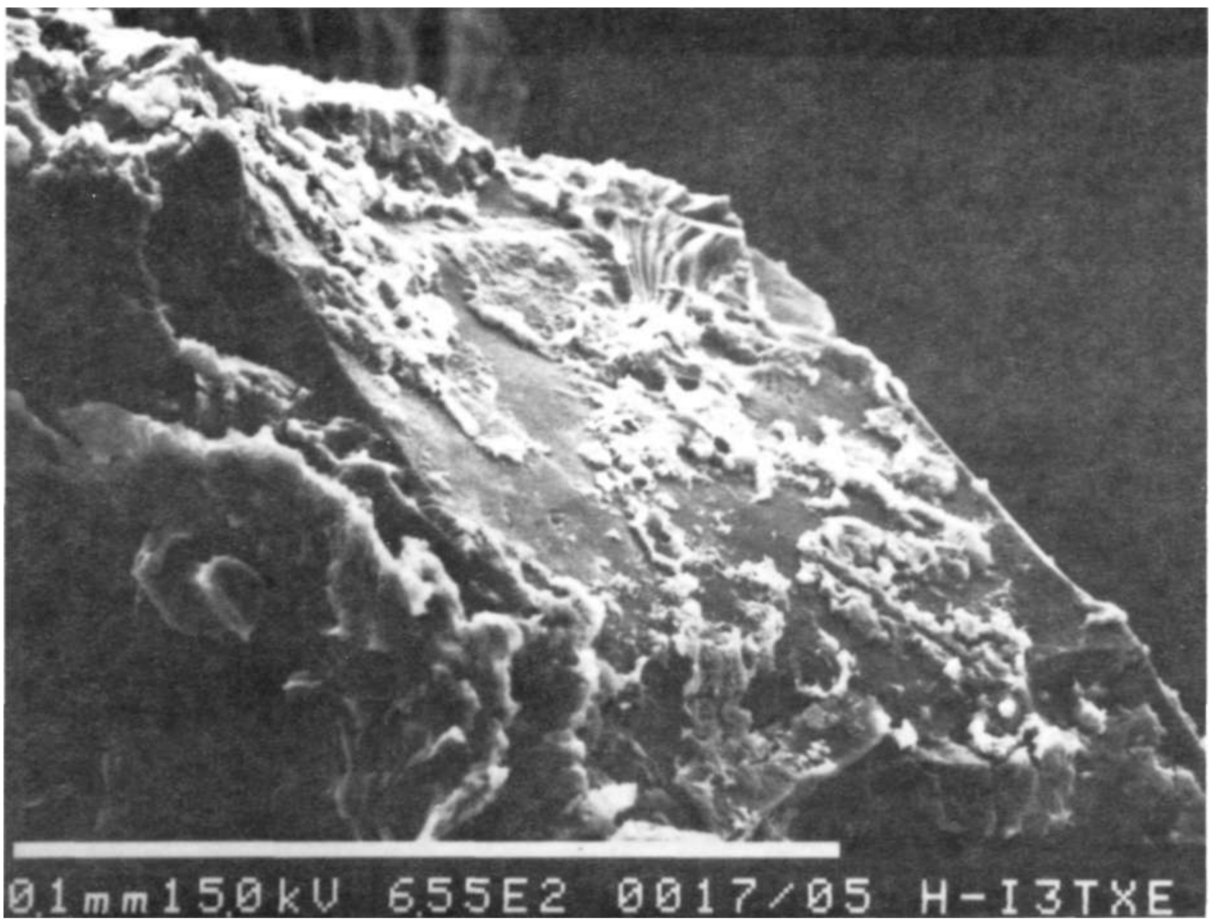

Fig. 1. Scanning electron microscope photograph of a sand particle (X 655) **from** a **localized dry spot at a depth of 0 to** 25 **mm. White bar = 0.1 mm.**

ample, Peachtree Golf Club and Hidden Hills Country Club showed the lowest phosphorus (P) levels (33.6 kg ha^{1} and 34.2 kg ha^{1}, respectively) of all locations. Phosphorus was not applied at either of these locations. On the other hand, the University of Georgia Experimental Golf Green received 19.5 kg ha^{-1} of P per year and it had the highest amount of P measured, 125.4 kg ha^{1}. Higher levels of Ca and K were observed at Fairfield Plantation and these may be due to the higher CEC associated with increased content of clay and organic matter.

Differences in inorganic chemical properties at the five locations imply that LDS are not caused by any specific inorganic chemical property studied. In other words, LDS were present at each location despite differences in chemical properties.

Water Droplet Penetration Time

At each location, water droplet penetration times were much higher in the LDS cores than in the HA cores at 12.5 and 25.0 mm below the surface (Table 5) indicating that a hydrophobic condition in the LDS cores retarded wetting. If a value of greater than 25 s is used to identify hydrophobic soil (droplets that did not penetrate in 25 s, persisted for at least 10 min), then hydrophobic soil in the LDS areas extended to a depth of 25 mm at Fairfield Plantation and to a depth of about 50 mm at the other locations. In Wilkinson and Miller's (1978) study, the hydrophobic condition was limited to the top 20 mm of soil.

Soil Water Content

Water content of the LDS was lower than HA at all locations (Table 6). All of the locations had been irrigated within the 24 h prior to sampling. The extremely low water content in the LDS soil explains why turfgrass growing in these areas exhibit drought stress symptoms.

Contact Angle

Contact angle tended to be higher in the dry spot areas than in the healthy areas, indicating a more hydrophobic condition (Table 7). As discussed earlier, the water droplet penetration time test indicated that the hydrophobic condition of the LDS soil at Fairfield Plantation was restricted to the upper 25 mm of soil due to the higher clay content below this depth. Since contact angle was determined on the upper 50 mm of soil, the second 25 mm of nonhydrophobic LDS soil was included in the test. This had a diluting effect on the contact angle determined for the LDS soil. A subsequent contact angle test on the upper 25 mm of LDS soil from Fairfield Plantation yielded a contact angle of 88.2°. Using this value, the means for all locations were significantly different between healthy areas and dry spot areas at $P < 0.05$.

These results agree with other research which has shown that hydrophobic soil has a higher contact angle than wettable soil in the same area (Bond, 1964; DeBano, 1968). Although contact angle of the HA soil appeared to be high, other research has shown that

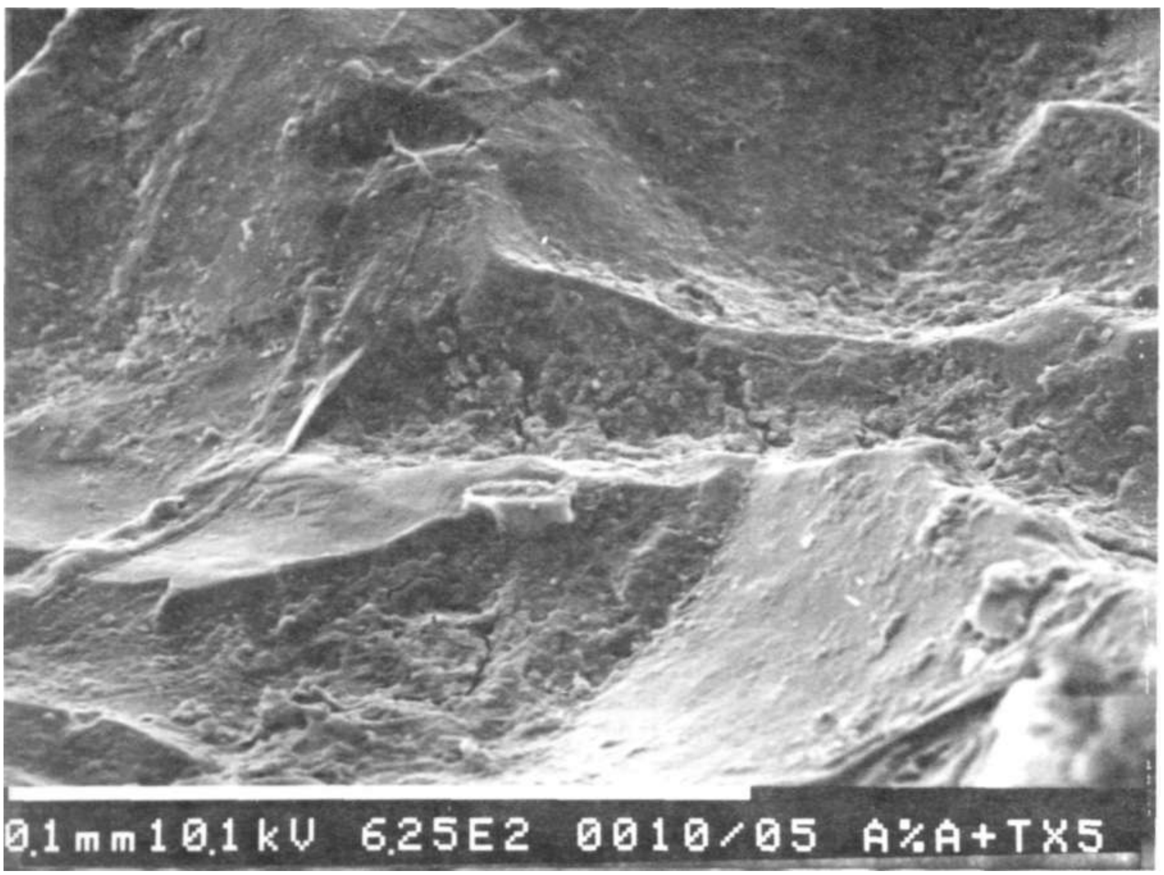

Fig. 2. Scanning electron microscope photograph of a sand particle (X 625) from a healthy area of a golf green at a depth of 0 to 25 mm. White bar = 0.1 mm.

Fig. 3. Scanning electron microscope photograph of a sand particle (X 655) from a localized dry spot at a depth of 0 to 25 **mm, treated with 300 g L^{-1} (30% H_2O_2). White bar = 0.1** mm.

wettable soil may have a contact angle greater than 50° (Letey et al., 1962). It has also been shown that contact angle of a soil decreases as moisture content increases (DeBano, 1968). In order to perform the contact angle measurement, the soils had to be dried completely. Since the soil in the healthy areas of golf greens is probably at a much higher water content when irrigated (Table 6), the contact angle in these areas may be lower than the values shown in Table 7, and the difference in contact angle between healthy areas and dry spots may be greater.

Scanning Electron Microscopy

Scanning electron microscopy of bulk samples from each location revealed that sand particles from the LDS had a coating that was absent in the HA. The LDS sand particles from the 25-mm-depth cores taken from the University of Georgia Turf plots also showed a coating (Fig. 1) that did not appear on sand particles from the same depth in HA (Fig. 2). Treating the LDS cores with 300 g L^{-1} (30% H_2O_2) removed the coating (Fig. 3), indicating that the coating was organic. Miller and Wilkinson (1979) also found a coating on sand grains from LDS of greens in Ohio. They concluded that the coating was similar to fulvic acid. Compounds such as fulvic acids have the ability to become hydrophobic upon drying, perhaps because of an internal pairing of proton acceptor and donor groups (Tan, 1982). Sand particles from a depth of 75 mm on the same cores discussed above showed no evidence of any coating. Absence of a coating at this depth explains the decrease in water droplet penetration times of dry spot cores below 50 mm (Table 5).

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