Nonwettable Sands: A Problem of Putting Green Soils

By

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Chapter 1

INTRODUCTION

The popularity of golf has increased dramatically in the past decade. Along with this has come a concomitant increase in foot traffic which has been especially serious on putting greens. As the play increased, so did the problem of soil compaction on the greens. To help alleviate this problem, many golf course superintendents have turned to sand as a base for their greens, since it does not become compacted even under heavy traffic.

As sand based greens became more common, superintendents in areas with high summer temperatures noticed a problem developing on the greens. In the summer greens develop areas that do not absorb water when the dry greens are irrigated. These hydrophobic "dry spots" can become a serious management problem where they occur.

The symptoms of a dry spot are usually pronounced. An area, usually less than one foot in diameter, takes on a smoky, gray-green color due to wilting of the grass. This area retains these symptoms after irrigation. In contrast, the surrounding turf rooted in wettable soil returns to its healthy, bright green color after irrigation. If a core is taken from the affected area, one finds that the sand below the spot is dry; the irrigation water has not penetrated the sand. Water runs off the top of the sand layer and does not penetrate into the dry sand. If this area does not receive special watering, it will soon turn brown and will eventually die, leaving an unsightly spot on the green. Usually supplemental hand watering, along with the use of surfactants will temporarily solve the problem. However, if the green is allowed to dry out again, the problem will reoccur. The problem completely disappears in the rainy season, but returns with dry weather in the late spring and summer. The "dry spots" may increase in size and number over the years until large areas of a green are affected. Whether the dry spots reoccur in exactly the same location remains to be seen. Observation of the Experimental Green at the University of California, Davis, indicates that they do not.

No obvious morphological or micro-relief differences between wettable and nonwettable areas have been noticed. pH readings indicated that the nonwettable sands were .3 to 1.1 pH units lower than the surrounding wettable sand. This is the only obvious chemical difference that has been detected.

Often variations in the soil mix, differences in elevation on the green, or poor sprinkler coverage, cause an area of a green to dry out faster than the rest of the green. These "dry spots" however, may not be water repellent and water will infiltrate during irrigation. This investigation is concerned only with situations where the sand beneath a dry spot actually becomes water repellent.

The terms water repellent, hydrophobic, and nonwettable will be used synonymously in this report, to denote a sand which has developed an aversion to water. A water drop, when applied to this type of sand, remains beaded up on the surface for a long period of time before it finally penetrates into the sand.

The intent of this research project was to (1) find out exactly where in the soil profile this problem was located, (2) discover the cause of the problem and (3) recommend means of avoiding the problem through management techniques.

Chapter 2

LITERATURE REVIEW

Numerous explanations have been proposed to account for nonwettability of sands in various situations throughout the world.

V. C. Jamison (1945) worked on the problem of nonwettable sands at the Citrus Experiment Station, Lake Alfred, Florida.

He used different solvents to try and extract the substance responsible for the hydrophobic state. He found that all solvents used, except water, readily penetrated the sands but did not dissolve any substance that accounted for the water repellence. The sands remained nonwettable.

He stated that alternately mixing and wetting the surface layer of these soils was effective in improving the wettability. Tests adding clay soils to the sands proved to be of some benefit, but only at rates of 20 tons per acre six inches, which was too high to be of practical value. He stated that development of the nonwettable surface layer is associated with colloidal organic matter. It is this water impermeable "roof" that prevents the wetting of the subsoils. Water enters the soil only through deep cracks in the surface layer or in the soil beneath irrigation pipes. The remainder of the soil stays dry even after heavy rainfall. The author suggests that, "the cause is related to the orientation of the molecules in the surfaces of colloidal organic debris, such that water insoluble parts of large molecules are exhibited in the outer surface. Wetting with water may disrupt this arrangement and cause water soluble parts to be exposed in the outer surfaces, thus imparting wettability to the sand."

Soil, stirred and wetted at frequent intervals, retained wettability. Jamison concluded that the nonwettable condition was a surface phenomenon and was not due to an accumulation of oily or waxy water repellent materials, since merely wetting with water destroyed the hydrophobic condition and extraction with solvents had no definite effect.

A few years later, I. W. Wander (1949), also working at the Citrus Experiment Station, Lake Alfred, Florida, offered another possible explanation for water repellent sands in citrus groves of central Florida. He noted differences in the prevalence of nonwettability were seemingly related to different fertilizer treatments. Specific fertilizer formulations were applied for ten years, then the percent water repellence was determined for the soil by taking 80 samples from each plot and noting whether or not a water drop penetrated the sample in a ten second period. From this study it appeared that the use of magnesium in the fertilizer, along with a separate application of limestone to control the soil pH at 5.8 was associated with the water repellent condition. Citing work by Waksman (1936) as to the presence of fatty acids in soils, he concluded that the calcium and magnesium combined with fatty acids in the soil to form insoluble soaps. When dry, these soaps became extremely water repellent. Nonwettable soil samples were "heated with strong sodium hydroxide solution, neutralized with sulfuric acid and steam distilled in the presence of a slight excess of acid. A small amount of solid material was observed which gave a test for a carboxylic group". The author gave this as evidence of the presence of fatty acids in the nonwettable soil. Wander treated wettable soils with stearic acid in ether, then calcium or magnesium hydroxide which produced an extremely water repellent soil. He concluded that a coating of water repellent metallic soap on the sand particles caused the hydrophobic properties of many Florida soils.

Work done at Adelaide, South Australia by Bond and Harris (1964) was concerned with microbial effects on sandy soils. They studied various sands in South Australia and found that hydrophobic sands were always associated with well developed plant cover. However, the accumulation of large amounts of organic debris was not necessary for water repellence. Samples with as little as 0.1% total organic matter were very hydrophobic. Clay content was always less than 5%. They found the soils to contain fungal hyphae of variable morphology, thought to be mainly basidiomycetes. Laccaria laccata, Cortinarius spp., Naucoria arenacolens, Clathrus gracilis, Polystictus oblectas, Psilocybe subaeruginosa and Peziza vesiculosa were the species most commonly encountered. Crumbs of soil with associated mycelia floated on the surface when placed in water. Bond and Harris did not make any definite statement as to the degree of water repellence caused by the basidiomycetes. They noted that there were also many bacteria and other fungal species present in the soils.

Bond (1963) did field studies on nonwettable soils in South Australia, noting the infiltration patterns and contact angles of wetting. He believed that organic products of microbial activity coated the sand grains and thus caused nonwettability. He observed that water penetrated the soil in narrow channels leaving the intervening soil dry. This situation produced a mottled vegetation pattern in pastures, with grass growing on areas where penetration was good, the bare areas being dryer, more water resistant, and having a slower infiltration rate. He also found that the species of plant was very important in determining the degree of repellence. Soil under a Phalaris pasture was the most repellent, with mallee, heath and pine vegetation giving increasing infiltration rates. (Pine, 0.4 inches/min., Phalaris 0.04 inches/min.) He also found that repellence increased as the age of the pasture increased. A pasture eleven years old had an infiltration rate of only 0.02 inches per minute, a four year old pasture 0.08 inches per minute and a ploughed plot, left fallow for one year had a 0.24 inch per minute infiltration rate.

Krammes and Debano (1965) studied the nonwettable condition of sandy soils after wild-fires had swept over the chaparral land in the San Dimas Forest, near Glendora, California. They wanted to determine if the hydrophobic condition was the result of a somewhat permanent condition or a temporary state, due to low moisture levels. They applied water to thoroughly dry soils under vacuum pressure. They found that the water readily penetrated normally wettable soils. However, naturally hydrophobic soils did not take up water to any appreciable degree under vacuum. Thus, they concluded that the nonwettable character was of a permanent nature, even in soils with a 10-15 percent moisture content. They postulated that the hydrophobic substance was an organic coating on the soil particles, derived from the litter of the overlying plant cover.

Letey (1962) showed that medium grain beach sand can be made hydrophobic by treatment with an ammonium hydroxide extract of chaparral litter. This increased the time it took water to penetrate by a factor of two or three. Studies of soils after fires showed that all size fractions repelled water with the general trend being that water repellence decreased as particle size decreased, and clay loam soils did not become nonwettable after treatment with chaparral leachate. The hydrophobic condition of soils was eliminated by temperatures of 800°C and higher. However, the nonwettable properties were intensified by temperatures of 300° to 600°C for 10 to 15 minutes.

In a later paper, Debano et al (1967) ranked plant species by the degree of nonwettability produced when extracts (using 0.1 NaOH) of leaf material were applied to a wettable sand. Chamise, (Adenostoma fasciculatum) r ted highest, with Mountain mahogany, shrub oak and Ceanothus spp. giving decreasing nonwettability. As a result of tests simulating fire conditions they theorized that nonwettable substances in the overlying litter vaporized and then condensed at a lower level in the soil column. They concluded that vaporization and condensation were responsible for the production of a nonwettable layer below the soil surface.

They also mentioned the textural relationship, observing that nonwettability was difficult to induce in soils with a high clay content. They reasoned that this was due to the greater specific area in the clays. A given amount of hydrophobic substances would coat a smaller proportion of the soil particles in a clay soil than in the larger sand particles. With fewer soil particles coated, water repellency would be decreased.

A paper by van't Woudt (1959) discussed soil wettability and offered theories of the physical properties involved. He observed a volcanic ash soil from the central plateau on the North Island of New Zealand. He studied the behavior of water drops applied to the soil surface. Heating of the water reduced the time needed for penetration into the nonwettable soil. He also observed that the volcanic soil remained nonwettable after ether extraction for 20 hours. This indicated to him that soil particles were not coated by a loosely adhering film, but that the hydrophobic properties were imparted by hydrophobic bonds on complex radicles well adsorbed to the sand particles. He claimed that this ether extract made other (wettable) soils nonwettable.

Savage, Martin and Letey (1969) studied water repellency in sand in relation to effects of microbial products. They used a loam humic acid, a microbial polysaccharide, peat humic acid, and microbial humic acids recovered from solutions of Epicoccum nigrum, Stachybotrys atra and Streptomyces spp. They also studied the effect of metallic cations and of pH on the degree of water repellency. They mixed varying amounts of organic matter with the sand, added the solution containing the desired metallic cation, and mixed by shaking. Only S. atra humic acid caused water repellency in the sand. Results indicated that pH was important with greatest repellency occuring at pH 10 and decreasing with lower pH's. (Concentration of humic acid was 0.05%). Concentrations of Fe^{+3} and Al^{+3} as low as 0.001 N when added to the above treatment caused water repellency. These concentrations are unlikely to be found in nature, and the authors concluded that these substances probably contribute little to water repellency in sands.

None of the work reviewed to date has positively indicated the cause of nonwettability. However, a number of theories offer interesting explanations which may apply to the golf green situation.

Wander's work (1949) offers a reasonable explanation of the non-wettable condition when applied to a golf green situation. The possibility of high Ca^{++} and Mg^{++} concentrations (from water and/or fertilizer) along with fatty acids in the sand is credible.

Jamison (1945) offered some convincing evidence that nonwettability was not caused by waxy or fatty substances coating the sand particles. Wetting the nonwettable soils with fat solvents (Ethanol, methanol and ether) decreased the degree of water repellence, but none made the soil wettable. Thus removing the waxy substances from the soils did not correct the hydrophobic condition.

Work on plant extracts by Debano, Osborn, Krammes and Letey (1967) suggested that substances from plant litter were coating the soil particles. They did not offer any explanation as to the nature of the substances.

Bond and Harris (1964) gave no evidence that microbial products were responsible for the nonwettability of sands. They showed that fungal mycelium itself was hydrophobic in some cases when dried out. Thus if a very extensive mat of mycelium permeated the soil, a nonwettable condition could exist. They did not suggest that such a condition was a main factor in the nonwettable sands, and could not give any indication as to how extensive a role fungal mycelium plays in hydrophobic sands.

Chapter 3

INVESTIGATION TECHNIQUES

The determination or measurement of the degree of nonwettability of a sand is a relative process. Bond and Harris (1964) termed a sand nonwettable if a 4 mm drop of water remained on the surface for 5 seconds or longer without penetrating. Wander judged a soil nonwettable if a water drop failed to penetrate after 10 seconds. Jamison (1945) measured relative wettability by the rate of water entry (infiltration). Letey (1962) used a method for determining the relative degree of nonwettability by measuring the contact angle formed between the soil surface and the side of the water drop. Water on a hydrophobic surface balls up, giving a large liquid-solid contact angle. Water placed on a wettable surface spreads out giving a smaller angle. The effect of wetting agents or other agents to increase wettability can theoretically be evaluated by measuring the change in the solid-liquid contact angle. In practice this method gives a useful qualitative estimation that can be used to compare the wettability of soils having different textures. While wettability affects soil infiltration rates, comparing infiltration rates is valid only between soils of the same texture. Since this study was concerned with degree of nonwettability and not with comparing the effect of different treatments on the sand, the simple infiltration or absorption rate was used to determine the degree of nonwettability of sand samples.

The water drop absorption method was the technique used throughout this study to test the relative degree of nonwettability of sands.

A capillary pipet was used to place a drop of deionized water on the sand surface. The time elapsed until the drop had completely penetrated the sand was then recorded as the infiltration time. This test was used to determine the degree of nonwettability produced in the laboratory experiments, and in greenhouse studies. It was also used to determine the degree of nonwettability of field samples.

In January 1972, 24 pots of Seaside Bentgrass (Agrostis palustris) were sown on Robertson sand in six inch plastic pots, 12 were sown on Dillon Beach sand and 12 on Yolo Clay Loam. These pots were grown in the greenhouse with 65°F day temperature and 55°F night temperature. These pots were used for experiments throughout the Spring, Summer and Fall of 1972. The Robertson sand is a coarse sized sand with 80 percent of the particles greater than .5 mm in diameter. Dillon Beach sand is a medium fine sand with a uniform particle size, having 94 percent in the .10 mm to .50 mm range.

For laboratory work, a clean, 20 mesh silica sand was used. It was selected to reduce the introduction of unknown factors that would be present in a field sand. Robertson sand was used at times to compare results on a field sand with those obtained using silica sand. Unless otherwise stated, the sand used for laboratory experiments was silica sand.

Much early work on this project was carried out on the Experimental Golf Green at the Environmental Horticulture Department, University of California, Davis, California. This green was built in the Fall of 1971, with sections of either Robertson sand, Dillon Beach Sand or USGA greens mix, all planted with 'Penncross' Bentgrass.

Observations during the Summer of 1972 showed that of the three soil types, only the Robertson sand developed nonwettable areas. A partial explanation for this situation is the fact that both the Dillon Beach sand and the USGA mix held more moisture, so they did not dry out as severely or as frequently as the Robertson sand.

Many of the sand samples from nonwettable areas were obtained from the experimental green. Field samples were collected from the Los Arroyos Golf Course, Sonoma, California and the Wikiup Golf Course, Santa Rosa, California. Both courses had greens that contained large areas of nonwettable sand beneath brownish or yellowish turf. The sand base used on both of these courses had a very wide particle size distribution with 92 percent of the particles fairly evenly distributed in the range from .10 mm to 2.00 mm.

Cores were taken from "dry spots" and normal areas, with a 3/4 inch diameter coring tool. The cores were then carefully removed and placed in small plastic bags, which were rolled around the cores, keeping them intact. Upon returning to the laboratory, the cores were removed from the bags, sliced with a razor blade at measured intervals and dried at room temperature. The cores were allowed to dry until they reached equilibrium with the room air. This was necessary to assure that the water drop absorption tests were run on samples that contained approximately the same amount of moisture. Otherwise the moisture content would influence the infiltration time.

Chapter 4

DETERMINING THE LOCATION OF HYDROPHOBIC AREAS IN THE SOIL PROFILE

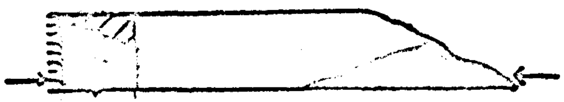
One primary area of investigation was that of locating the level in the soil profile at which the nonwettable condition occurred.

Cores, approximately 10 cm long were taken from "dry spots" on golf greens using a coring tool. These cores were then sliced transversely with a razor blade at roughly 1 cm intervals along the core. A water drop was then placed on the surface of each section and the infiltration time was recorded for each level in the core. This relationship between depth in the soil profile and water drop infiltration time was plotted on graph paper.

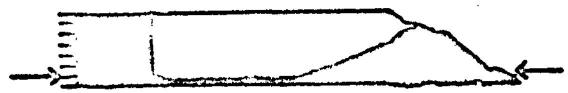
The graphs show that the area of greatest nonwettability is located directly beneath the thatch layer, at the surface of the sand. The thatch layer itself is not hydrophobic. This is shown in Figure 1, an illustration taken from time lapse photographs of water uptake by a dry nonwettable core (from the Experimental Green). The core was placed on its side in a shallow pan and distilled water was added to the level indicated by the arrows (approximately 1/4 to 1/2 cm deep). Time lapse photographs were taken to record the areas of water uptake in the core. Well over half of the thatch region was saturated 2 minutes after the water was added. Further proof is seen in Figure 1a, which gives the results from an infiltration test on a core sample from a "dry spot" taken two hours after a normal (30 minute) irrigation of the experimental green. This again shows that the thatch layer was not nonwettable,

Figure 1. Water uptake by a dry nonwettable core (from Experimental Green). The thatch region readily absorbed the water at the end of two minutes as shown. After 48 hours the region below the thatch remained dry.

WATER UPTAKE BY NONWETTABLE CORE

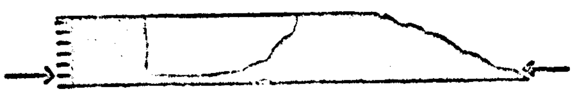


2 min.

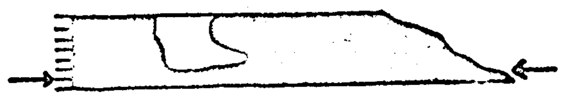


1/2 hr.

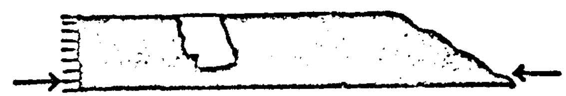
2 hrs.



4 hrs.

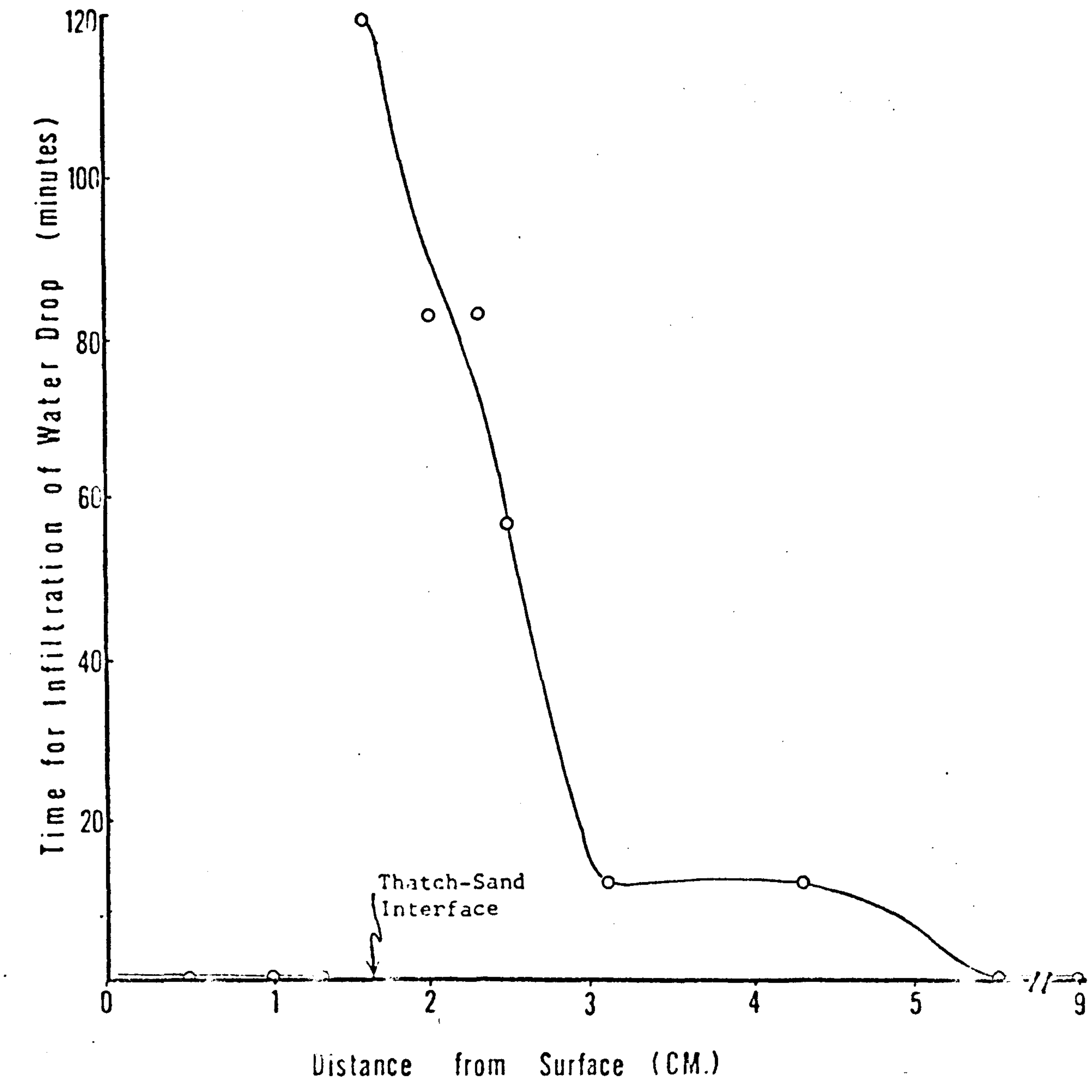


24 hrs.



48 hrs.

Figure 1a. Water drop absorption test on dry spot core from experimental green. Core taken 2 hours after a normal 30 minute irrigation. The core was tested immediately to show the sharp increase in infiltration time below the thatch-sand interface.


120
100
80
60
40
20
0
1
2
3
4
5
9
Time for Infiltration of Water Drop (minutes)
Thatch-Sand Interface
Distance from Surface (CM.)

since the moist thatch readily absorbed water while the sand directly below was still dry. As soon as the water reached the nonwettable sand surface in the field it moved horizontally until it reached an area of wettable sand and moved down into the sand.

Figure 2 compares the infiltration rates of two cores, one from a nonwettable area and the other from an adjacent wettable part of a green at the Los Arroyos Golf Course. Both cores were dried in the laboratory at room temperature before the infiltration test was conducted. Infiltration time for the nonwettable core had a maximum of over 60 minutes, while the time for infiltration of the wettable (normal) portion of the green had a maximum value of only 6 minutes. This gives an indication of the magnitude of the problem. Samples from dry spots collected during the course of this study had infiltration times ranging from 20 to over 120 minutes.

An average infiltration value for twelve nonwettable cores taken from the Robertson sand sections of the Experimental Green is presented in Figure 3. This gives a general picture of the situation found on sand-based golf greens. The dried thatch area is more readily wettable than the sand surface immediately below the thatch. The degree of water repellency decreases with distance below the sand surface. Since this is an average, the curve is spread out over a wider distance, giving the impression that the condition is found in a rather wide region of the soil profile. In actuality, the situation is rather sharply defined in each individual core sample tested, as can be seen in Figure 4, a graph representing the values obtained from a single core of nonwettable Robertson sand.

The nonwettable condition found on sand-based golf greens is concentrated in the upper region of the sand, directly below the thatch layer. The thatch layer did not prevent wetting of the sand, since the thatch itself was always observed to be totally saturated after irrigation, and the sand in the uppermost region of the profile repelled water drops for periods ranging from 20 to 120 minutes. Clearly the sand particles themselves were affected by some condition which rendered the surface water repellent.

Figure 2. Infiltration times from a dry spot sample and a wet spot (normal) sample from the Los Arroyos Golf Course. The thatch area contained a high amount of sand and loamite (from top dressing) which may explain the high degree of nonwettability in the lower thatch area.

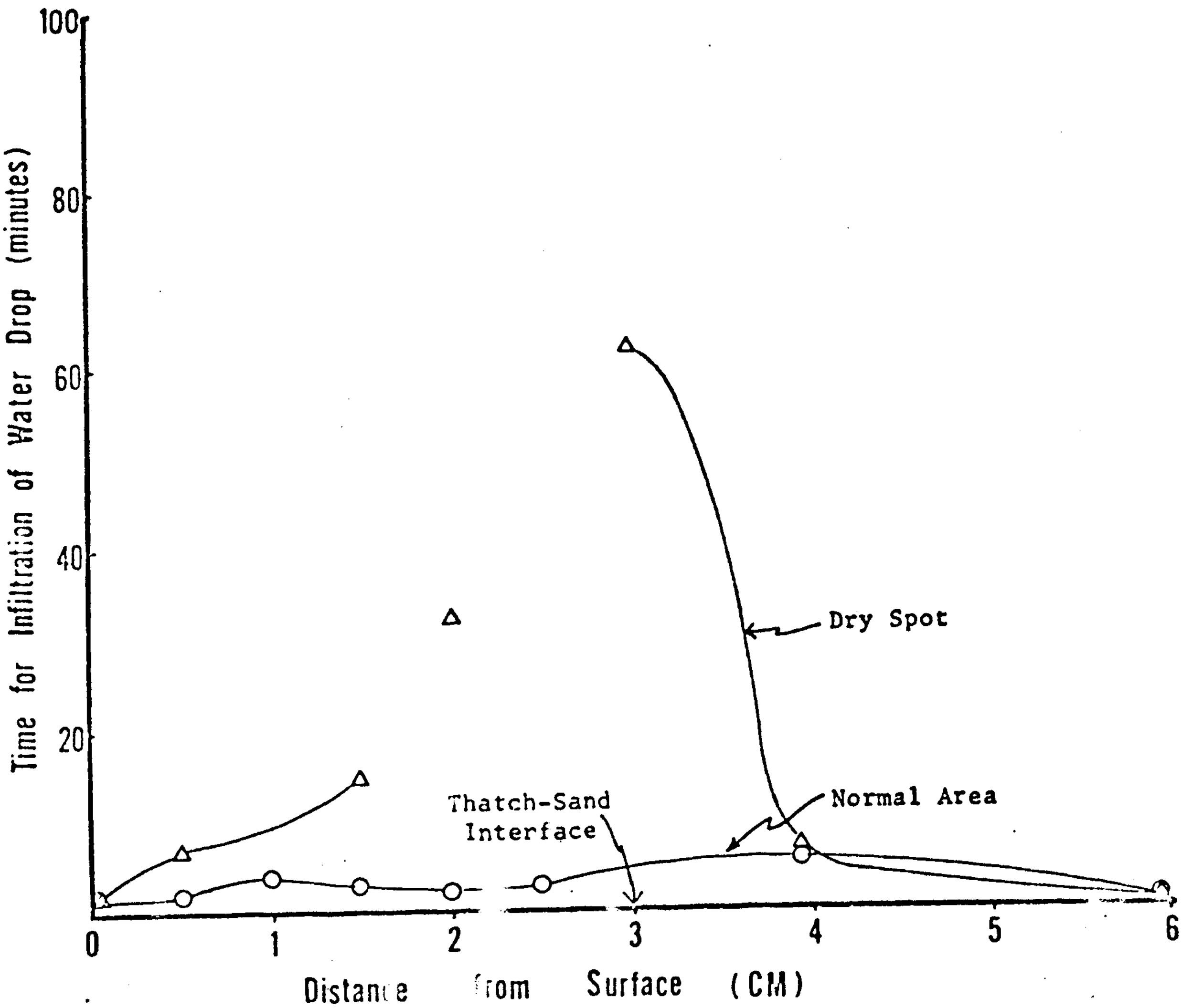
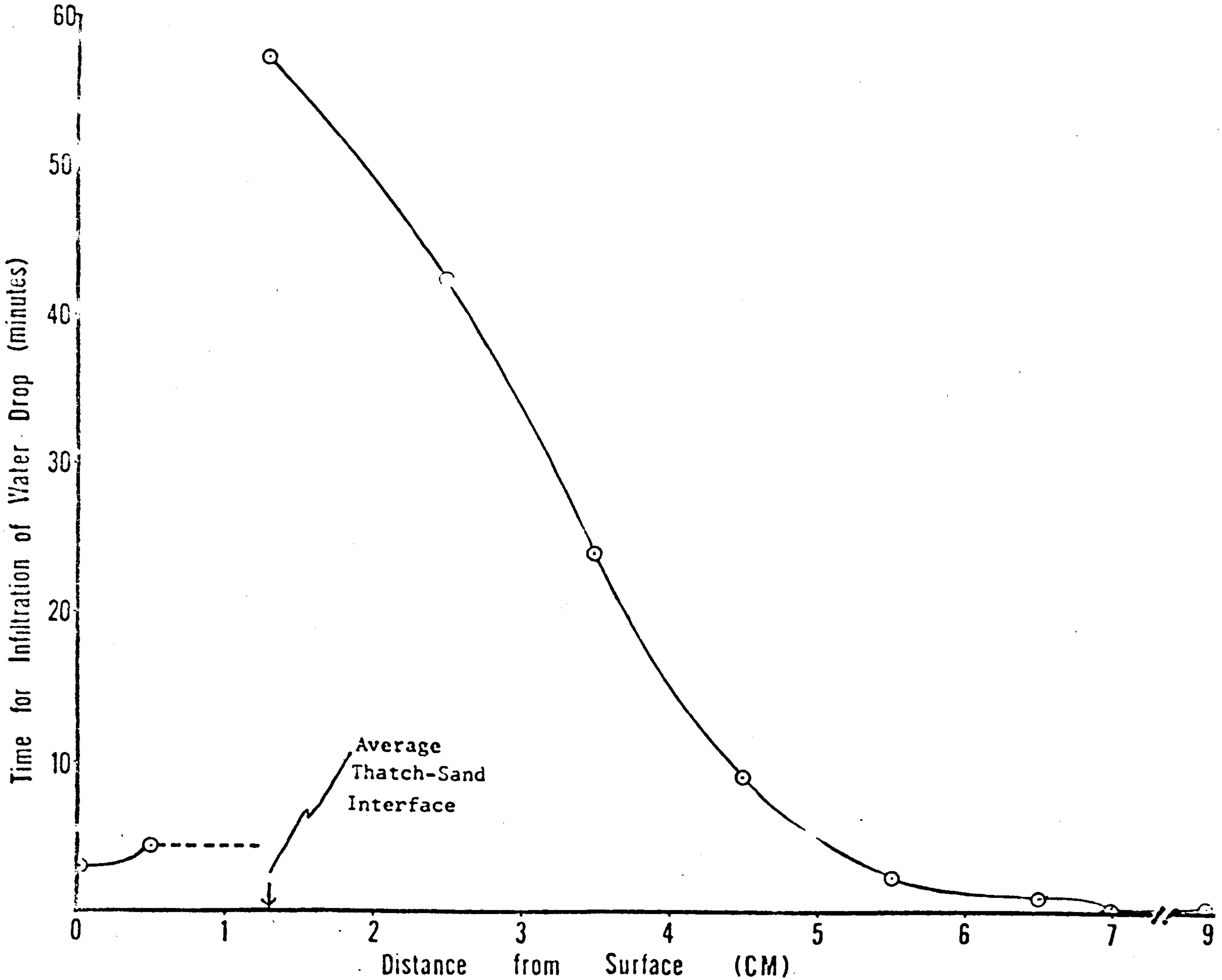
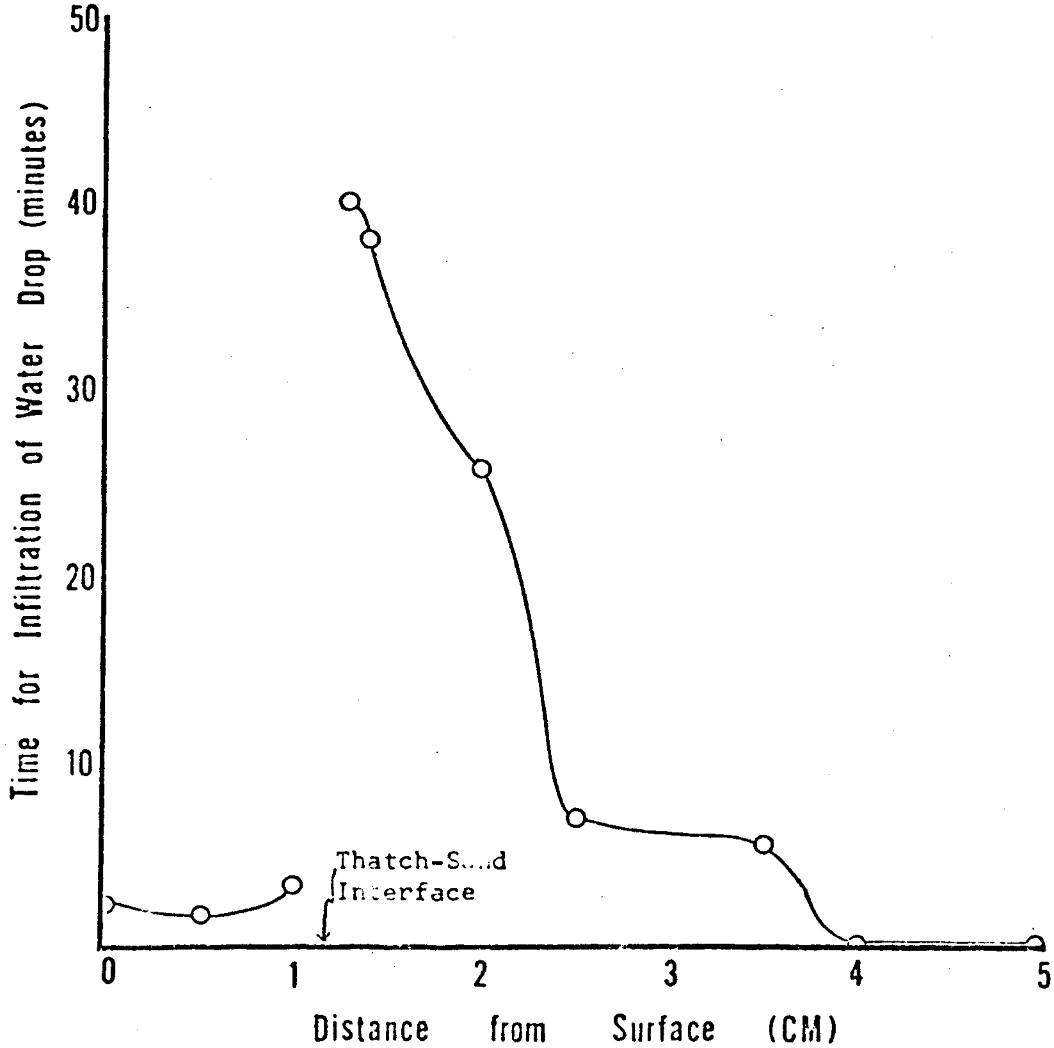

100
80
60
40
20
0
1
2
3
4
5
6
Time for Infiltration of Water Drop (minutes)
Distance from Surface (CM)
Dry Spot
Normal Area
Thatch-Sand
Interface

Figure 3. Average infiltration time of twelve nonwettable cores from the U.C. Experimental Green. The standard deviation for the 1-5 cm values was 30 minutes.



Time for Infiltration of Water Drop (minutes)
60
50
40
30
20
10
Average
Thatch-Sand
Interface
0
1
2
3
4
5
6
7
9
Distance from Surface (CM)

Figure 4. Example of infiltration time of a dry spot core from the experimental green, U.C. Davis, showing the dramatic increase in infiltration time at the thatch-sand interface, even when the core has been dried at room temperature.



Time for Infiltration of Water Drop (minutes)
50
40
30
20
10
Thatch-S..d
Interface
0
1
2
3
4
5
Distance from Surface (CM)

Chapter 5

ATTEMPTS TO INDUCE NONWETTABILITY BY DRYING

The role of drying in inducing a nonwettable condition was studied since drying of the golf green was necessary for development of nonwettability.

Four pots of Seaside Bentgrass were selected for dry-down studies in the greenhouse. Six similar pots were placed outside for dry-down studies under conditions to which greens are exposed. The pots were watered with tap water and were then allowed to dry until the grass reached the wilting point. Next, an infiltration test was run on the side surface of the sand ball, exposed by partially removing the intact sand-root ball from the plastic pot. (See Fig. 13, p. 63). After replacing the ball in the pot, the turf was watered. Once the water had penetrated, some of the turf was cut with a knife and spread apart to ascertain if the sand had actually adsorbed the water or if the water had run down the side of the sand-root ball. Similar studies were carried out on the pots dried outside the greenhouse. This experiment was conducted from June through September 1972. In all instances, the pots remained wettable throughout the study. No increase in infiltration time was evident. It was therefore concluded that cyclic drying itself did not produce a nonwettable condition and hypothesized that some condition present with the sand was rendered hydrophobic upon severe drying.

The temperature at which the sand was dried also was considered. Temperature readings at the sand layer (2 cm below the turf) on the green rarely reached 100°F even when air temperature in the shade was over 110°F. Studies of sands and thatch dried in laboratory ovens at 100°F showed no increase in infiltration times. Temperatures around 200°F did give slight increases in infiltration time in some samples of organic matter, such as thatch, and even in bacterial suspensions evaporated at that temperature. However this high a temperature was not encountered on the turf area, so it was not considered a critical factor in the nonwettable phenomenon on golf greens.

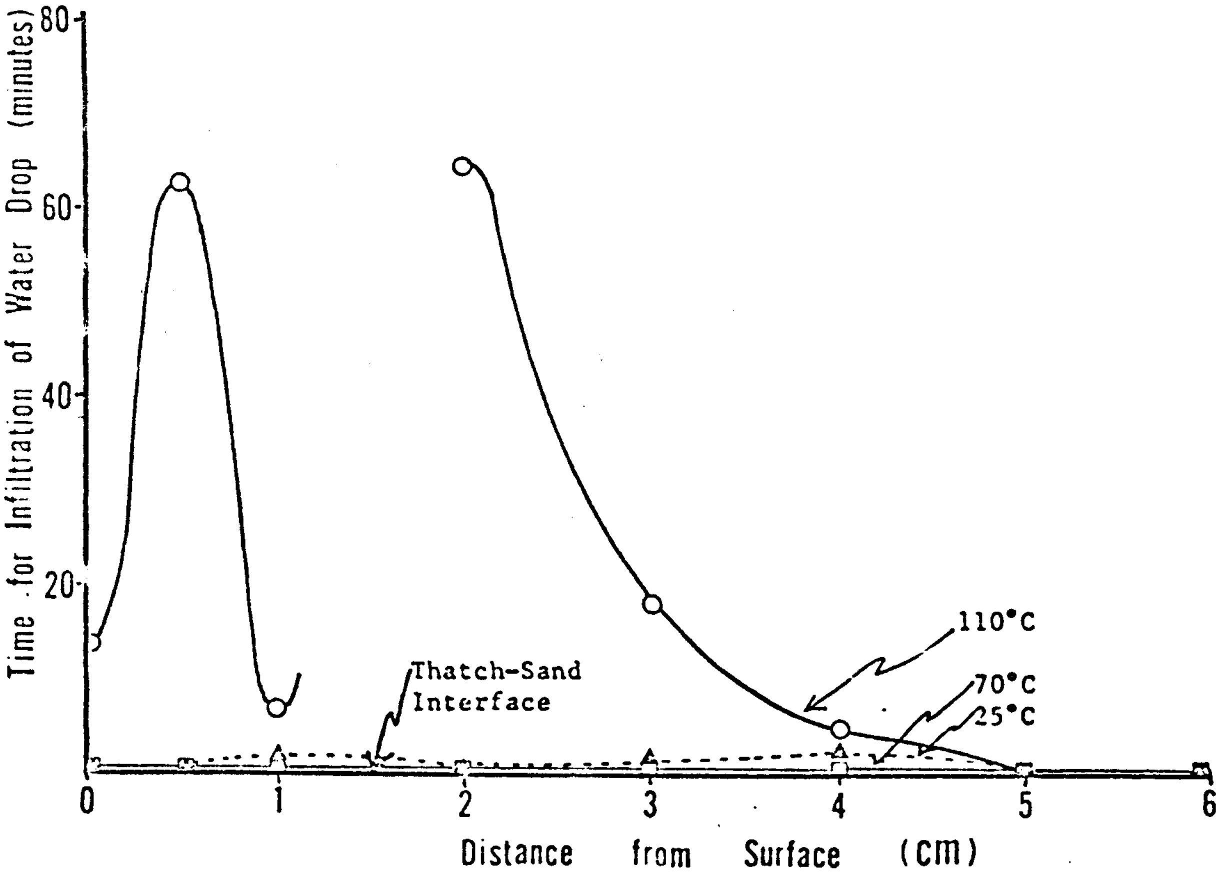
Effects of Drying Temperature on Wettable Cores. Various drying temperatures were used on moist wettable cores from the experimental green. Temperatures of 25, 70 and 110°C were used to dry intact cores. The dry cores were then sliced at various depths and a water drop absorption test was made on each section.

Figure 5 compares the absorption times of three wettable cores dried at 25°, 70° and 110°C respectively. The 25° and 70°C temperatures caused no noticeable increase in absorption time. The core dried at 110°C did become nonwettable in the upper 3 cm. This section included the thatch layer plus approximately 1.5 cm of sand. The large decrease in infiltration time at the 1 cm level cannot be explained.

An important fact to note is that the thatch, along with the sand was rendered nonwettable. Nonwettable cores from the field never exhibited nonwettability in the thatch region.

Controlled Drying of Wettable Cores. Although the 110°C drying of cores gave an indication of causing nonwettability, such severe temperature conditions are not found on a golf green. The primary means of water loss is through uptake by the grass roots. Since the majority of the roots are concentrated in the upper 1-2 cm of the sand, this region is subject to more frequent and rapid drying than the lower portions of the soil profile. Also, the air temperature at the surface of the green rarely

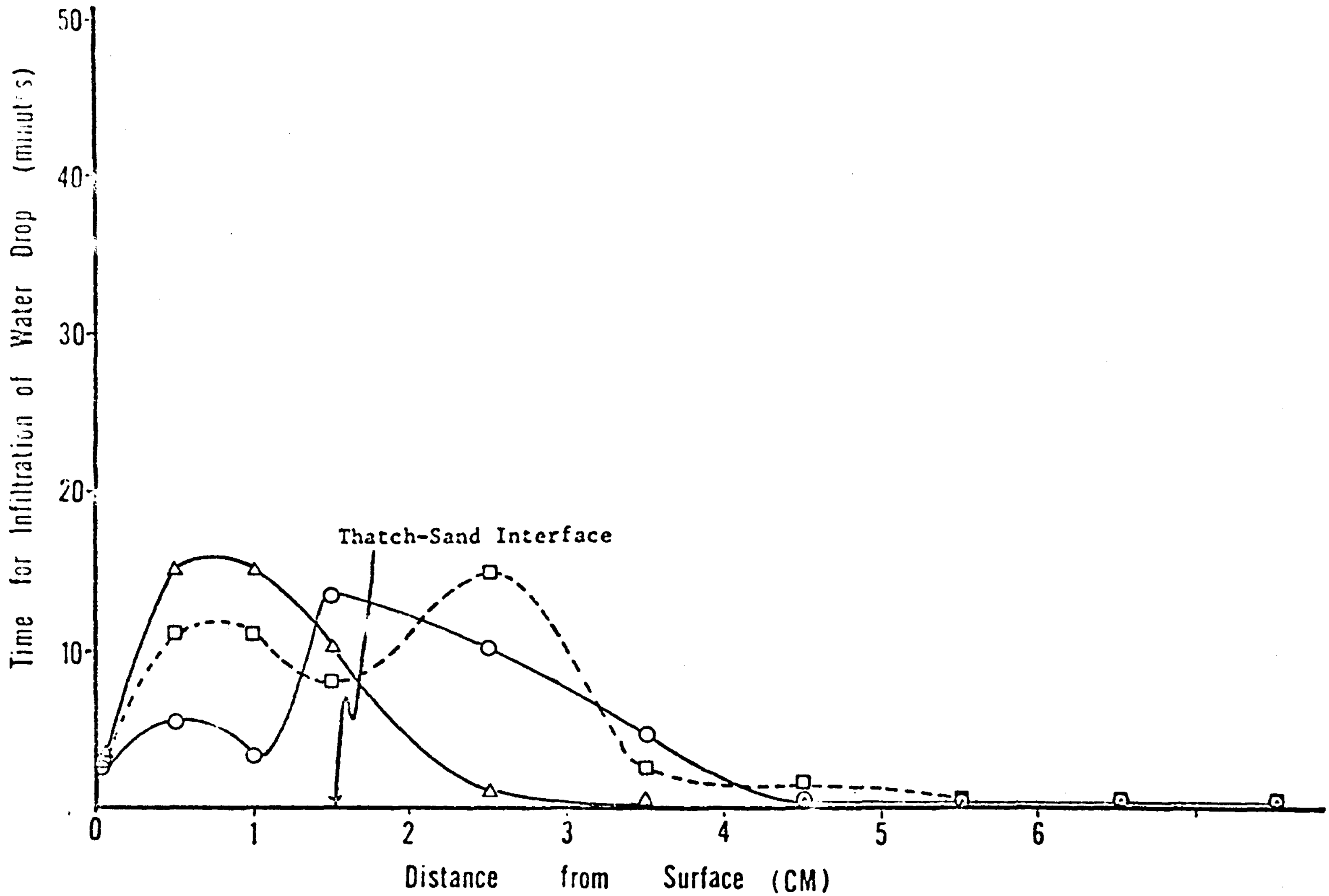
Figure 5. Absorption times of three wettable cores (from Experimental Green, U.C. Davis) oven dried at 25°C, 70°C and 110°C. Note the apparent nonwettable condition produced in the thatch as well as the sand of the core dried at 110°C. (The drop in absorption time at 1 cm on the core dried at 110°C cannot be explained).


Time for Infiltration of Water Drop (minutes)
80
60
40
20
0
1
2
3
4
5
6
Distance from Surface (cm)
110°C
70°C
25°C
Thatch-Sand
Interface

exceeds 120°F and the sand temperature does not rise above 100°F. Temperature readings were taken on the experimental golf green for six days in July 1972. The thatch temperature (1 cm below the surface of the green) ranged from 1°F above air temperature to 4°F below air temperature. The sand at 3 cm below the green's surface was generally 4-10°F below the air temperature reading. For example, at 3PM on July 11, 1972 the air temperature at the surface of the green (in full sun) was 102°F, the thatch (at 1 cm depth) was 101°F and the sand (at 3 cm depth) was 95°F.

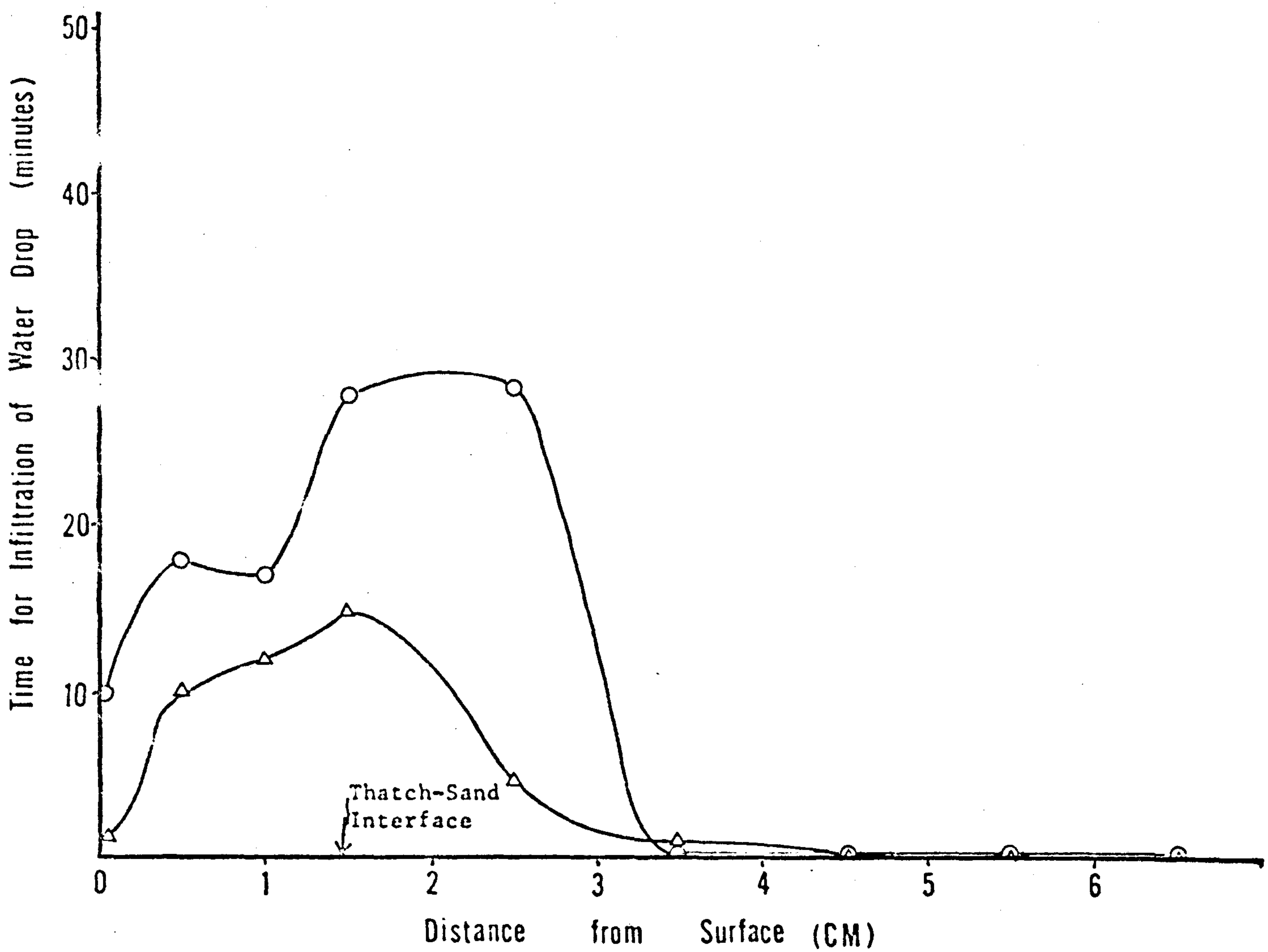
In order to test cores under more realistic conditions, wettable cores with live grass plants were placed in glass test tubes to prevent evaporation from the sides and bottom of the cores. Cores were subjected to drying in full sun or under an incandescent light bulb in the laboratory. The full-sun cores were submerged in a 20°C water bath, with only the top 1 cm of the core above the water. The cores in the laboratory were placed in a room temperature water bath (24°C) with the surface of the core above the water level. This allowed a slow drying of the sand, similar to the conditions found on a golf green. The cores were dried under these conditions for approximately one week. The air temperature beneath the light bulb was approximately 85-90°F. The bulb was turned off during the night. The outside temperature ranged from approximately 60°F at night to 110°F during the day. After 7-10 days the cores were removed from the test tubes. The grass plants were dead, most having died after 3-4 days. The lower portions of the cores were still moist but the top 3-5 cm (thatch and upper 1.5 to 3.5 cm of sand) were dry. The cores were removed intact from the test tubes, sliced at 1 cm intervals and tested, by the water drop absorption test. The cores represented in Figures 6 and 7 were tested immediately after removal

Figure 6. Absorption times of three wettable cores (from experimental green) after slow drying in a room temperature water bath under an incandescent light. Cores were tested immediately upon removal from water bath.



Time for Infiltration of Water Drop (minutes)
50
40
30
20
10
Thatch-Sand Interface
0
1
2
3
4
5
6
Distance from Surface (CM)

Figure 7. Absorption times of cores from slow drying experiment in direct sunlight. Two cores were dried outside in a 20°C water bath. Cores were tested immediately upon removal om water bath.


Time for Infiltration of Water Drop (minutes)
50
40
30
20
10
0
1
2
3
4
5
6
Thatch-Sand Interface
Distance from Surface (CM)

from the water baths. The cores in Figure 8 were dried at room temperature after removal from the water bath and test tube. A curve representing the absorption time of a wettable core (from the experimental golf green) dried at room temperature after removal from the green is shown as a comparison (Figure 9).

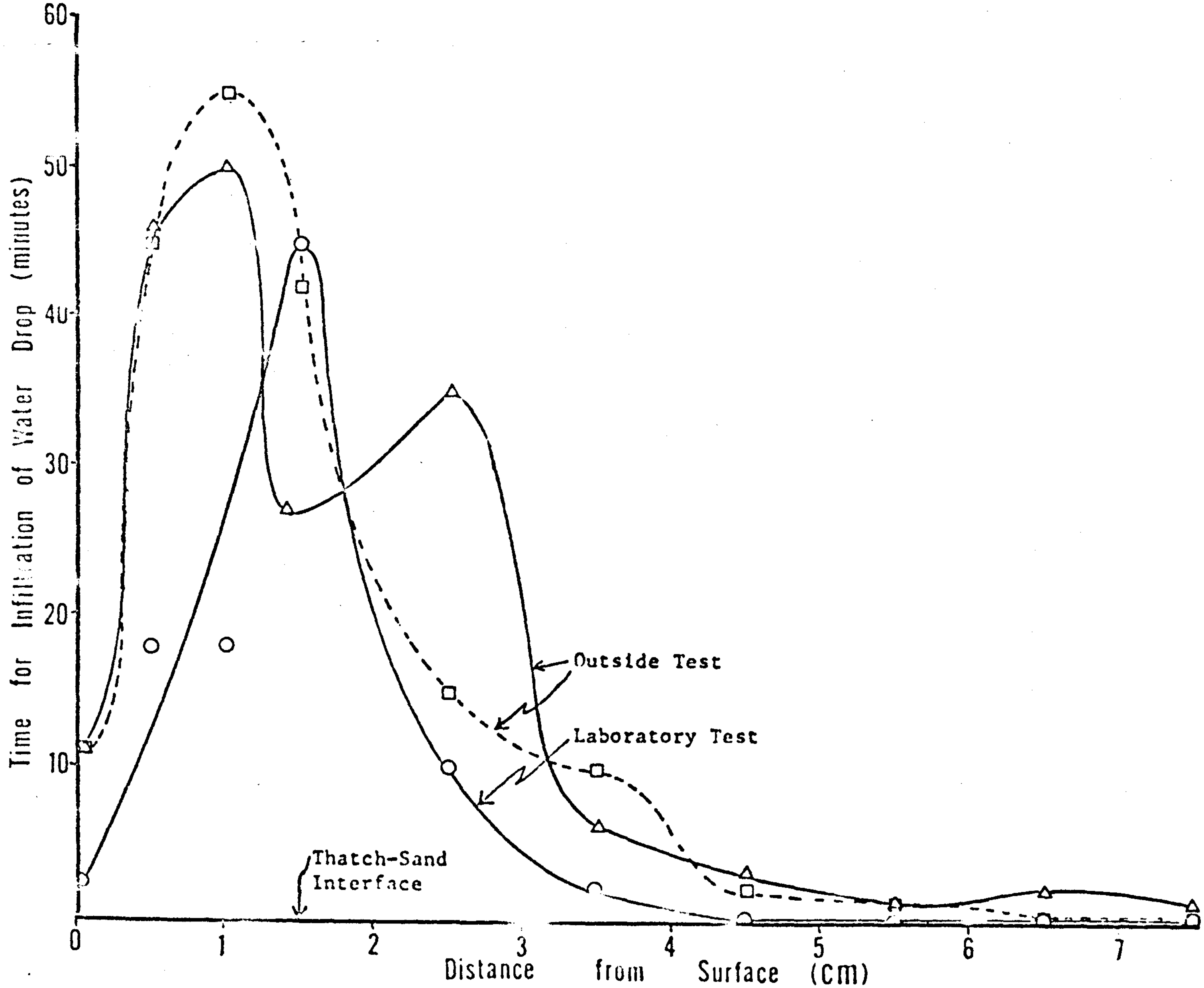
Both the cores in Figures 6 and 7 had areas of nonwettability that directly correlated with the dry regions of the cores. This appeared to indicate that drying at a slow rate induced nonwettability in wettable cores. The thatch became as nonwettable as the sand, which was not the case found in cores from golf green dry spots.

This experiment more closely resembled the drying conditions thought to exist on a golf green. The slow evaporative conditions produced a definite nonwettable condition in the thatch and upper region of the sand of a wettable core. Relatively rapid drying of wettable cores at 25°C did not cause a nonwettable condition to develop in wettable cores (Figures 8 and 9). This indicates that rate of drying may play a major role in the production of dry spots.

<u>Volatilization of a Nonwettable Substance from Thatch.</u> An experiment was devised to test the Debano hypothesis concerning the volatilization and condensation of a nonwettable substance in soils after forest fires have swept a chaparral area. Debano used temperatures ranging from 300°F to 800°F, while air temperatures at the surface of a turf area are around 100°F on a hot summer day.

The experiment was conducted using direct sunlight or a 75 watt incandescent light bulb four inches above the surface of the thatch (as in the controlled core-drying experiment). Core sections of thatch from the experimental green were wrapped in aluminum foil leaving the top and bottom open. This thatch cylinder was placed over a .5 g sample

Figure 8. Absorption times of three cores, two dried outside as those in Figure 7, and one dried in the laboratory, similar to those in Figure 6. These cores were removed from the test tubes after the slow drying treatment and were then allowed to continue drying at room temperature (for 48 hours) before testing.



60
50
40
30
20
10
0
Time for Infiltration of Water Drop (minutes)
1
2
3
4
5
6
7
Distance from Surface (cm)
Outside Test
Laboratory Test
Thatch-Sand Interface

Figure 9. Absorption time of a wettable core (from experimental green) after drying at room temperature. Note the difference between this core and those that underwent slow drying in the water baths while enclosed in test tubes. (Figures 6, 7, 8).

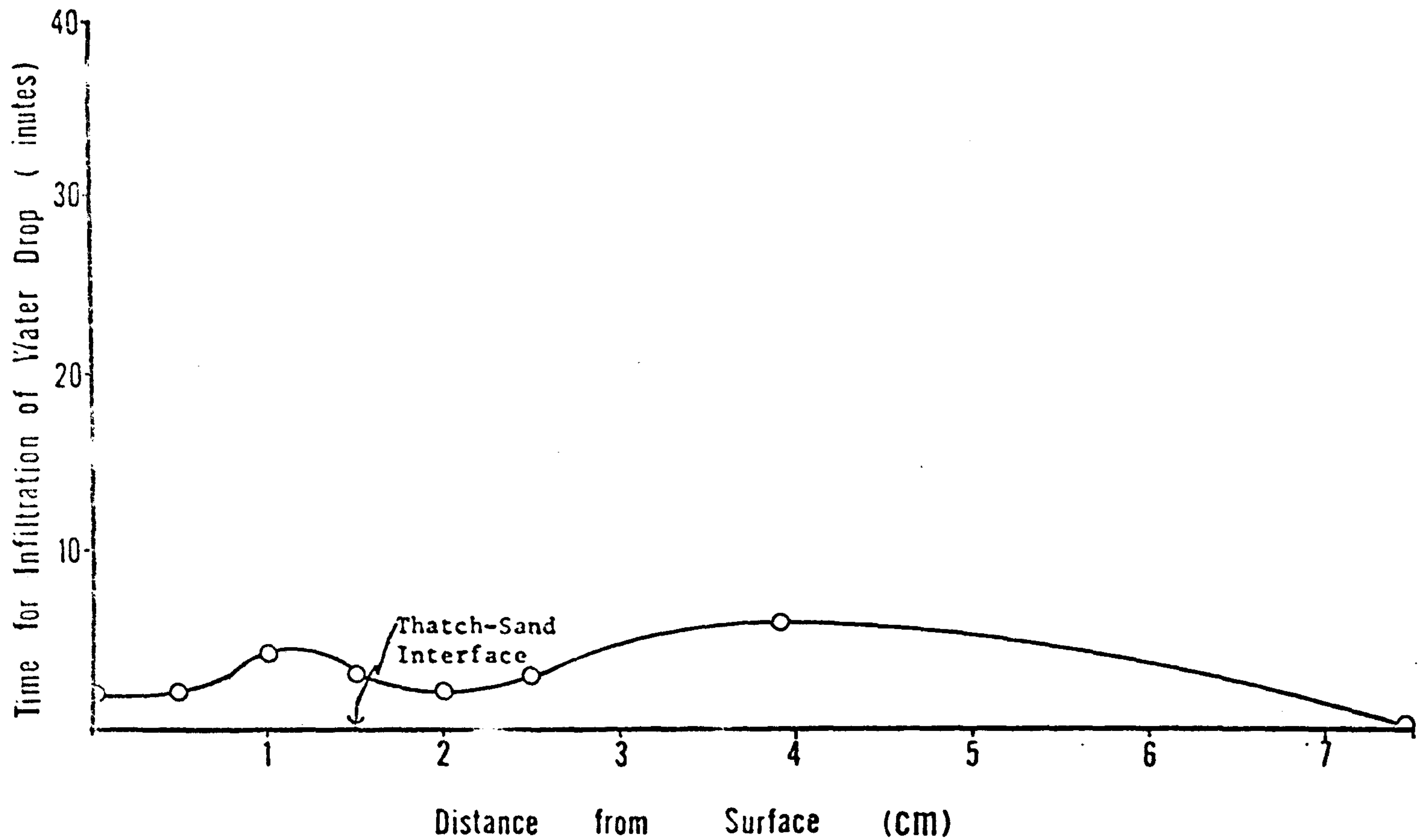
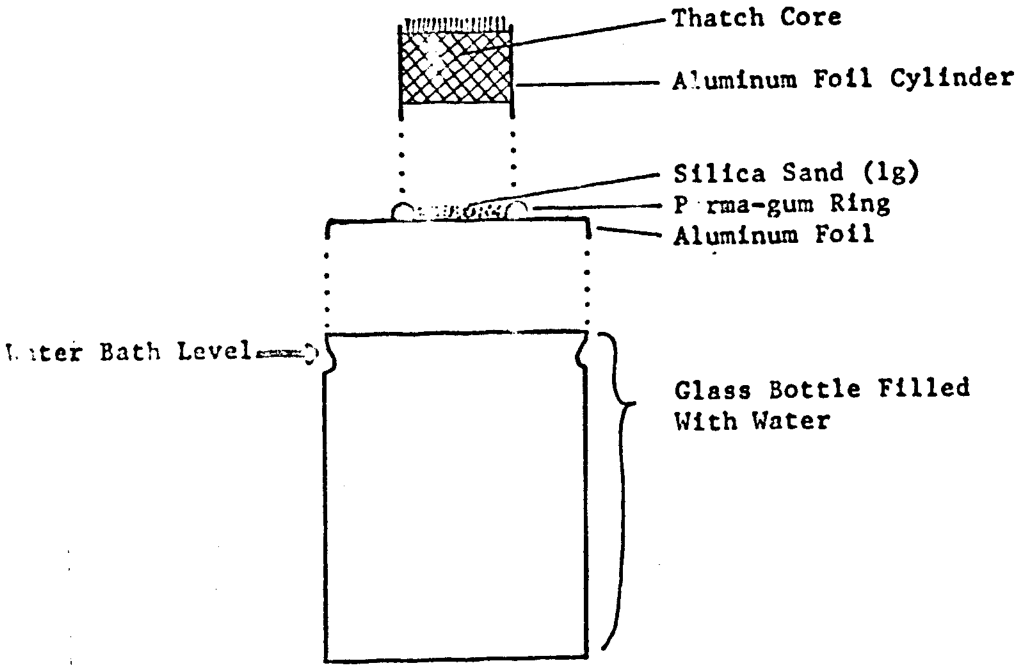

Time for Infiltration of Water Drop (inutes)
40
30
20
10
Thatch-Sand
Interface
1
2
3
4
5
6
7
Distance from Surface (cm)

Figure 10. Illustration of apparatus used to test for volatilization of a non-wettable substance from turf thatch.


Thatch Core
Aluminum Foil Cylinder
Silica Sand (1g)
P rma-gum Ring
Aluminum Foil
ater Bath Level
Glass Bottle Filled
With Water

of silica sand resting on a 1" square of aluminum foil. The foil cylinder around the thatch was held to the foil square with a ring of "Perma-gum" making a complete seal. The foil square containing the sand and thatch was placed over the mouth of a small bottle filled with water so the foil was in contact with the water. The bottle was placed in a water bath which kept the sand at a cooler temperature than the thatch above. (See Figure 10). Two such samples were placed in a 25°C water bath in the laboratory with a light bulb overhead. The air temperature at the thatch surface in the laboratory experiment was approximately 85-90°F. Two similar samples were placed outside in the 20°C water bath. The outside maximum temperatures often reached over 100°F.

The samples were kept in the water baths for 10 days. The light over the samples in the laboratory was turned off at night. The thatch was removed and the sand tested four times during the experiment. The results of the tests are compiled in Table 1.

Although Debano's experiment utilized high temperature volatilization of a nonwettable substance, the possibility of a nonwettable substance with a low volatilization temperature existing on a golf green was considered. The volatilization experiment offered no evidence of such a mechanism existing on a golf green. It was concluded that at temperatures incurred at the surface of a golf green, volatilization of a nonwettable substance and subsequent condensation at a lower level in the sand was not likely to be the case.

Evaporation of Sodium Meta-silicate Solution on Silica Sand. Since silica is known to be a strong binding agent in soils, an experiment was performed to determine if a silica solution could render sand nonwettable upon drying.

TABLE 1

Results of Water Drop Absorption Test on Sand Samples from the Volatilization Experiment on Thatch from the Experimental Golf Green

DATE	OUTSIDE WATER BATH	INSIDE WATER BATH
1 July 72	Start treatment	Start treatment
2 July 72	Wettable	Wettable
5 July 72	Wettable	Wettable
6 July 72	Wettable	Wettable
10 July 72	Wettable	Wettable

Sodium Meta-silicate (Na_2SiO_3) was dissolved in distilled water at a 100 ppm concentration. The pH was adjusted to 5.4 by adding .01N HCl. This solution was added until 1 gram samples of 20 mesh silica sand were saturated. Two sand samples were then allowed to evaporate to dryness at room temperature, the other two were placed in a 70°C oven until dry (18 hours). Sixteen applications of silica solution were made with the samples tested by the water drop absorption method between applications. (See Table 2).

Throughout the test all of the samples remained completely wettable. The sand samples were strongly held to the watch glasses by the silica solution, but nonwettability was in no way produced.

It was concluded that silica in the water and/or sand itself had no apparent affect on the infiltration time on the sand.

TABLE 2

Results of Evaporation of Sodium Meta-silicate
Solution on Silica Sands

Date	Number of Applications	Results of Water Drop Absorption Test	
		Samples dried at 70°C	Samples dried at 25°C
13 Sept 72	1	Wettable	Wettable
14 Sept 72	4	Wettable	Wettable
15 Sept 72	6	Wettable	Wettable
18 Sept 72	7	Wettable	Wettable
20 Sept 72	8	Wettable	Wettable
21 Sept 72	9	Wettable	Wettable
22 Sept 72	11	Wettable	Wettable
24 Sept 72	12	Wettable	Wettable
25 Sept 72	13	Wettable	Wettable
26 Sept 72	14	Wettable	Wettable
3 Oct 72	15	Wettable	Wettable
16 Oct 72	15	Wettable	Wettable

Chapter 6

SOLVENT EXTRACTS

The hypothesis is widely held that the hydrophobic condition results from changes involving the surface of the sand grains. Studies were carried out to determine if a substance was coating the surface of the sand grains, rendering them nonwettable. The studies were concerned with a) trying to remove the nonwettable condition from the sand, b) transferring the condition to wettable sand, and c) testing various thatch and grass clippings as possible sources of hydrophobic substances.

Water Extracts. In an attempt to produce nonwettability in the laboratory, water extracts of bentgrass clippings were applied to 20 mesh silica sand and then were allowed to evaporate at room temperature.

Clippings from greenhouse grown pots of Seaside bentgrass were dried in the greenhouse for 1, 3, 7, and 14 days. It was thought that the amount of drying might be related to the release of the nonwettable material from the clippings. The clippings were extracted by shaking 2 g of the clippings with 25 ml of distilled water for one hour. The extracts were then added to 10 g samples of silica sand and were allowed to evaporate at room temperature. When dry they were tested by the water drop absorption method. In all cases the sand was unaffected by the extract application, since all the samples had infiltration times of zero to five seconds.

The next step was to use multiple applications of the extract on the sand samples. It was hoped that this method would more closely parallel the conditions thought to exist on a golf green. The grass extract was obtained by shaking 20 g of clippings (dried 5 days in the greenhouse) in 200 ml of tap water. A soil extract obtained by shaking 5 g of field soil (Yolo clay loam) in 50 ml of tap water was used as a source of soil microorganisms for some of the treatments. A total of five treatments were used for this experiment. Each treatment was applied to eight 5 g Robertson sand samples, covered and then incubated at 70°F for five days, then dried at room temperature. The treatments were as follows:

control - 6 ml tap water plus the 70°F incubation period

treatment A - 5 ml of the clippings extract plus 1 ml of the soil extract and incubation at 70°F

treatment B - 5 ml clippings extract and 70°F incubation

treatment C - 5 ml clippings extract with immediate drying at 60°C (no incubation)

A total of six applications were made, with the results tabulated in Table 3. No change had been brought about by the treatments on the sand grains, with all treatments essentially ineffective in producing an increase in the infiltration time on the samples.

From these studies it appeared unlikely that the hydrophobic condition was derived from the thatch layer in the form of a water soluble substance that was leached down onto the sand grains.

Nonpolar Solvent Extracts. A strong nonpolar solvent, Benzene, was used to try and extract the hydrophobic substance from clippings and thatch. Benzene extracts were obtained by shaking dry grass clippings, fresh grass clippings and thatch from the Experimental green (5 g plant matter with 25 ml Benzene for 1 hour). Each extract was then applied to 1 g samples of silica sand and allowed to evaporate at room temperature. This was repeated until all 25 ml had been added to

TABLE 3

Infiltration Times[1] (in seconds) after Multiple Applications of Water Extracts of Grass Clippings to Robertson Sand Samples

	Number of Applications					
Treatment	1	2	3	4	5	6
Control - Tap H_2O plus incubation[2]	0	0	0	0	0	0
Grass Extract, Soil suspension, Incubation	0	4	3.5	2	2	1.4
Grass Extract, Incubation	0	7	4	2.3	2.6	2.5
Grass Extract, Drying at 60°C	0	0	0	0	0	0

[1]Average times from eight replications

the sand. Thoroughly dried sand samples were then tested by the water drop absorption method. The extract from the dried clippings and from the thatch both produced a hydrophobic response on the sand. The response from the extract of fresh clippings was small. The control (adding pure benzene) showed no water repellence. The infiltration times are recorded in Table 4.

Benzene was used to extract samples of nonwettable soils. It was theorized that benzene would dissolve the water repellent substance which could then be evaporated onto a wettable sand, thus transferring the hydrophobic state to that sand.

Samples of nonwettable sand were shaken with benzene for approximately 1 hour (10 g sand per 25 ml benzene). The sand-benzene mixture was then filtered through Watman #1 filter paper to separate the sand from the solvent. The benzene extract was collected in a flask and the sand was allowed to dry at room temperature, then was tested for degree of nonwettability by the water drop absorption method. In all cases the sand samples were still nonwettable. The absorption times were only slightly reduced, remaining in the highly water repellent range. The extraction process was repeated on each sand sample until wettability was attained. Generally, it required over 4 extracts before the sand became relatively wettable.

Since the hydrophobic condition was not readily removed by the nonpolar solvent, it was concluded that the nonwettable substance associated with the sand grains was probably of a polar nature.

<u>Polar Solvent Extracts.</u> Water was used as the polar solvent to extract nonwettable sand samples. The procedure for the extraction was the same as with the benzene. Ten grams of soil and 25 ml of distilled water were shaken for approximately 1 hour, then the extract was

Table 4

Infiltration Times on Silica Sand Samples after Evaporation of Benzene Extracts of Plant Matter

Treatment	Infiltration Time (minutes)
Control	0
Dry Grass Clippings	126
Fresh Grass Clippings	26
Thatch from Green	68

filtered through filter paper and collected in a flask. The extracted soil was allowed to dry at room temperature, then was tested by the water drop absorption method. The soil samples all proved to be completely wettable.

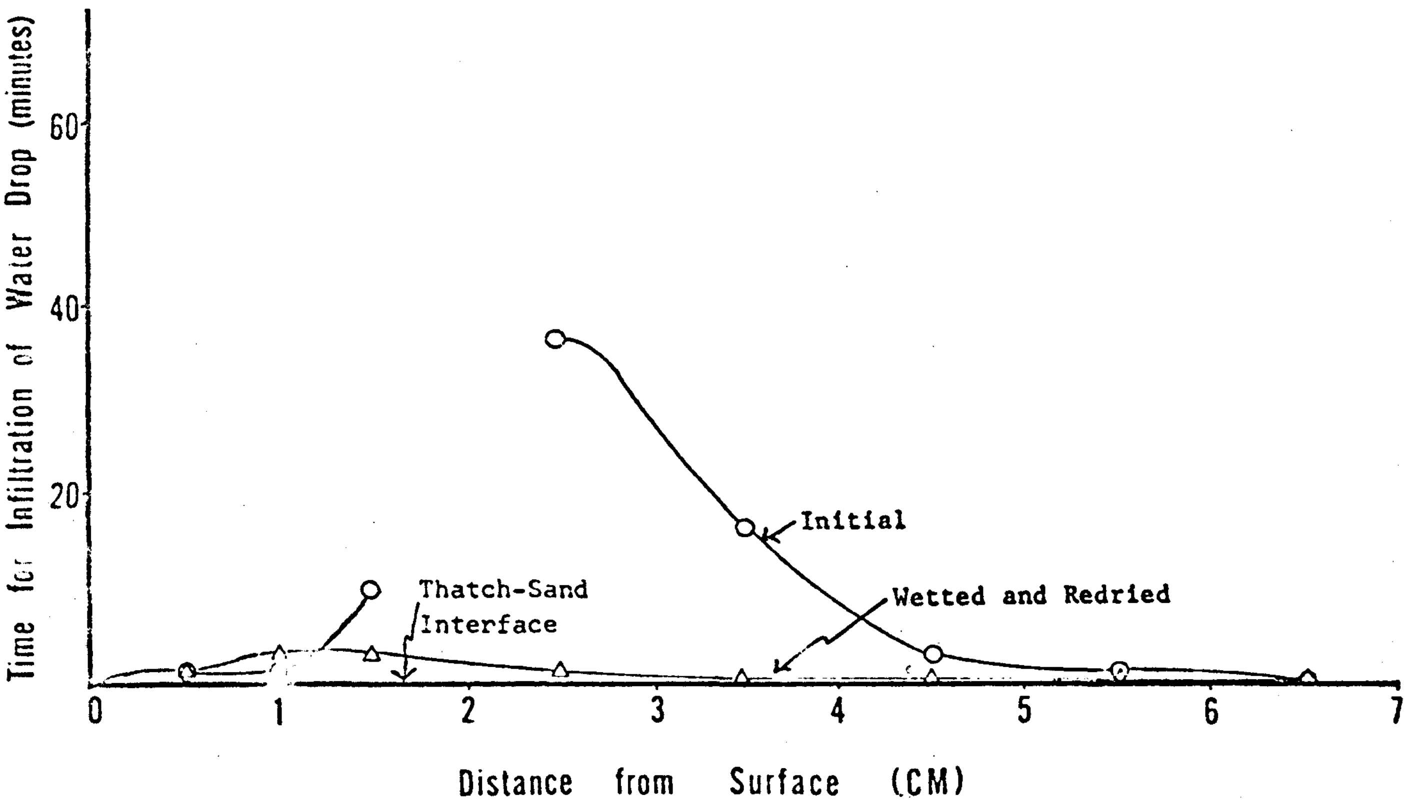
To determine if the shaking and physical moving of the soil was an important factor in the removal of the nonwettable condition, intact, nonwettable cores were wetted by sprinkling with water for up to six hours. When thoroughly saturated the cores were dried at room temperature, then tested by the water drop absorption method. All cores were found to be wettable, with the drops penetrating in a matter of seconds. Figure 11 compares the initial infiltration times with those after the core was thoroughly wetted and then tested.

Thus the water itself and not the disruption of the sand structure was in some way responsible for removing or changing the nonwettable condition in the sand.

The water extract was applied to three 1 g samples of Robertson sand in approximately 1/2 ml aliquots with drying at room temperature between applications. After seven applications, the sand was dried at room temperature and then tested for evidence of transfer of the nonwettable condition. The water drop absorption test showed that no water repellent substance had been deposited on the sand grains, all three samples were wettable.

A nonwettable sample, shaken with water, was set out in the laboratory and the water extract was allowed to evaporate from the sand. When the 25 ml had evaporated, the soil (sand) was dried at 100°F and tested. The soil sample was entirely wettable. This demonstrated that the water extract did not reinstate the nonwettable condition on the sand by simple evaporation. This test, along with previous tests, indicated a more complex condition than had been anticipated.

Figure 11. Comparison of infiltration times before and after thorough wetting of a nonwettable core from the U.C. Experimental Green.



Time for Infiltration of Water Drop (minutes)
60
40
20
Initial
Thatch-Sand
Interface
Wetted and Redried
0
1
2
3
4
5
6
7
Distance from Surface (CM)

The work by Wander (1949) employed solvents to extract the nonwettable substance from soils. He found that ether had no effect on nonwettable soils, but that methanol readily extracted the nonwettable substance (possibly a calcium-magnesium soap) and the extract produced nonwettability when evaporated on an easily wettable soil. The ether extract had no effect when evaporated on a wettable soil. Wander's theory was well substantiated by his solvent extract findings.

Wander's method was duplicated on Los Arroyos and Wikiup nonwettable sands to determine if these soils responded similarly to the nonwettable soils Wander used Ten-gram samples of nonwettable soil were extracted with water, benzene, ether and methanol. The samples were extracted with 25 ml of solvent for 30 minutes, with periodic shaking. The soil was then filtered through filter paper and rinsed with 5-10 ml of clean solvent. The extract was collected and the sand was allowed to dry at room temperature. After each extraction the dried sand samples were tested by the water drop absorption test. The results from the Los Arroyos samples are contained in Table 5 and those from the Wikiup samples in Table 6. At the conclusion of the extract experiment, approximately 250 ml of each solvent extract had been collected. These extracts were then evaporated on 1 g samples of silica sand. A total of approximately 15 ml was evaporated on each sample, 1/2 ml at a time. The extracts did not transfer any nonwettable substance to the sand samples. The results are tabulated in Table 7.

The water removed the nonwettable condition after one extract in both the Wikiup and Los Arroyos samples. The benzene had little effect after four extracts. The ether had no effect on the Wikiup sand after five extracts, but did remove the nonwettable condition in the Los Arroyos sample after the fifth extract. The methanol removed the nonwettability

TABLE 5

Absorption Time After Solvent Extractions - Nonwettable Los Arroyos Sand Samples[1]

Number of Extractions	Time in Minutes			
	Water Extractions	Benzene Extractions	Ether Extractions	Methanol Extractions
Initial Absorption Test	140, 165, 170	-	-	-
1	3, 3, 4	99, 80, 100	165, 165, 160	0, 0, 60
2		80, 120, 150	60, 80, 90	0, 0, 0
3		120, 130, 135	100, 100, 100	0, 0, 0
4		80, 120, 120	90, 70, 99	-
5		-	0, 0, 0	-

[1]Samples were sieved to remove particles larger than 1 mm in diameter.

TABLE 6

Absorption Time After Solvent Extraction - Nonwettable Wikiup Sand Samples[1]

Number of Extractions	Time in Minutes			
	Water	Benzene	Ether	Methanol
Initial Absorption Test	40, 70, 100			
1	2, 2, 3	30, 50, 90, 100	70, 90, 110	5, 20, 90, 115
2	-	90, 90, 90	150, 160, 150	90, 70, 70
3	-	180, 180, 180	90, 90, 90	60, 60, 90
4	-	85, 120, 130	80, 130, 150	90, 120, 135
5	-	90, 100, 120	130, 180, 140	35, 55, 70

[1]Samples sieved to remove particles greater than 1 mm in diameter.

TABLE 7

Solvent Extract Evaporation on 1 g Samples of Silica Sand

	Absorption Time in Minutes			
	Test 1	Test 2	Test 3	Test 4
	5 Applications	10 Applications	15 Applications	20 Applications
A. Wikiup				
Ether	2	2	2	1.5
MeOH	0	0	0	0
Benzene	1	0	0	0
B. Los Arroyos				
Ether	0	0	0	0
MeOH	0	0	0	0
Benzene	0	0	0	0

after two extracts on the Los Arroyos sand. The Wikiup samples remained nonwettable after five methanol extracts.

Following Wander's example, the ether extracted Wikiup sample was extracted with methanol. The methanol did not remove the nonwettable condition after 3 extracts as shown in Table 8. Although the results of the methanol extractions of nonwettable golf green sands were not as definitive as those reported by Wander using nonwettable Florida sands, the methanol did remove the nonwettable condition in the Los Arroyos sample.

This result dictates a need for more investigation of the Wander theory in relation to the problem on golf greens.

TABLE 8

Absorption Test on Ether and Methanol Extracted
Nonwettable Sand from Wikiup Golf Course

After 5 Ether Extractions Number of MeOH Extractions	Absorption Time in Minutes
1	70, 80, 95
2	85, 105, 120
3	90, 110, 115

Chapter 7

INVESTIGATION OF FUNGAL AND MICROBIAL POPULATIONS AS POSSIBLE SOURCES OF THE NONWETTABLE CONDITION

In the paper by Bond and Harris (1964) it was suggested that fungi and/or bacteria were responsible for the hydrophobic condition found on sandy soils in South Australia. This possibility was investigated using samples from the Experimental green and greenhouse pots.

Direct observations of sand were made from layers at approximately 1 cm intervals to find out if a relationship existed between the number of fungal mycelia in a layer and its degree of nonwettability.

Grains of sand were placed on a dry slide with a cover slip and observed under 100 and 160 power. A number of grains had strands partially attached to them. It could not be determined if the strands were, in fact, mycelia or some other organic matter such as roots.

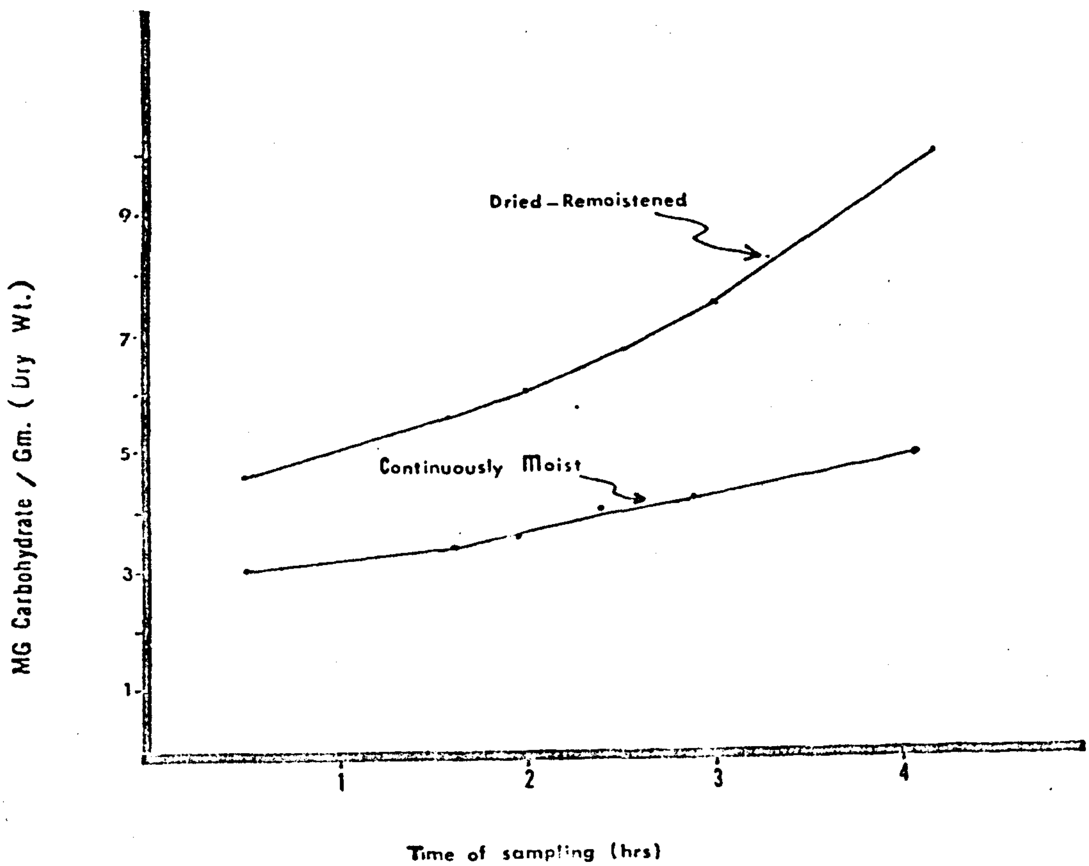
The large size of the sand grains made it difficult to focus on the strands, which were too small to pull off the sand grains for a thorough microscopic examination. For this reason, no definite statement can be made concerning the role of fungal mycelia in nonwettable soils. Observation showed no apparent difference between the number of strands in the hydrophobic and normal sand samples. No concentration of strands appeared to be present in any of the core samples observed.

A recent report by Dr. R. M. Endo and P. F. Colbaugh (1971) lead to the formulation of a hypothesis concerning the cause of "dry spots" on golf greens.

In their study of drought stress as a factor which triggers diseases of turfgrass, Endo and Colbaugh discussed an interesting aspect of dehydration of the thatch layer. It was found that rewetting of dried thatch brought about release of large quantities of sugars and proteins. Both the amount and rate of release were greater from dried thatch that was rewetted than from moist thatch (Figure 12). As a result, the microbial population in the underlying soil was greatly stimulated by the increased food supply.

This suggests the hypothesis that bacteria actively lead to the hydrophobic condition. During the change from winter to summer, drying of the thatch layer increases in degree and frequency, which suggests that the carbohydrates released upon rewetting also increase. Thus the bacteria population increases until severe drought takes place. When this occurs the substances produced by the microorganisms are dehydrated and the bacterial population and activity is lowered. The dehydration of these microbial products, perhaps gums or gels, (McLaren 1967, Wolfrom 1961) might render them resistant to wetting so that when the thatch and soil are irrigated these substances are not dissolved or leached, but remain closely attached to the surface of the sand grains. As the season progresses and these drying cycles increase to perhaps a daily frequency, the hydrophobic substances build up on the surface of the sand grains in the region below the thatch layer. When a high proportion of the sand grains are covered with this substance and a severe drought takes place, the area is rendered hydrophobic. Apparently the environmental parameters and/or biological factors necessary to produce this condition are rather specific and are not found over an entire green, since usually only certain areas of a green or perhaps just a few small spots are affected at one time.

Figure 12. Taken from "Drought Stress as a Factor Triggering Fungal Diseases of Turfgrass", by R. M. Endo and P. F. Colbaugh, 1972, USGA Green Section Record, July 1972, Vol. 10, No. 4, page 11.



Release of soluble carbohydrates by bluegrass thatch residue.

To test this hypothesis a longer term experiment was started using nine month old Seaside bentgrass grown in six inch pots in the greenhouse. Two pots were used as checks, two were given sucrose solution and two pots containing only Robertson sand were given sucrose solution. If the hypothesis were correct, some significant change in the infiltration rate of the sucrose treated turf pots would be expected.

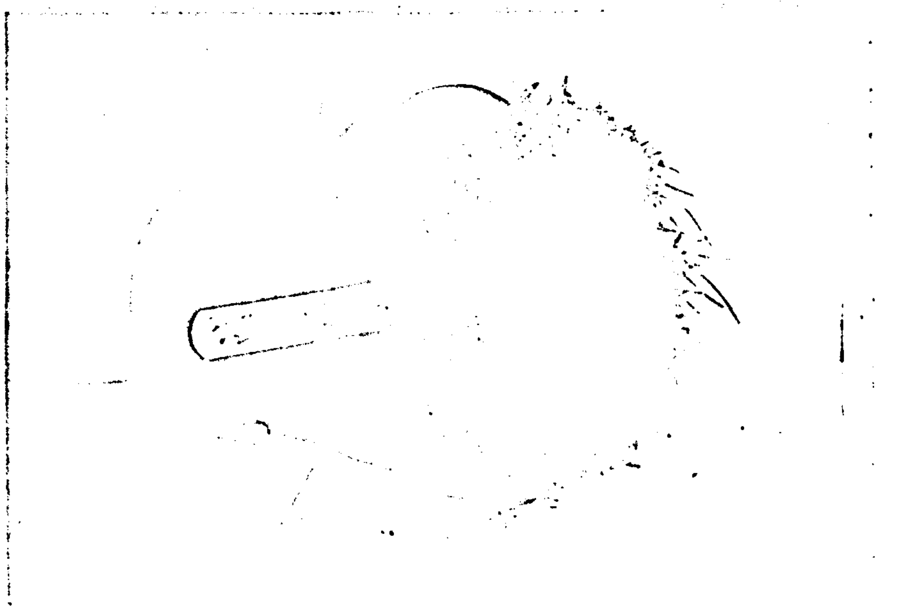
Before starting the treatments, the pots were watered thoroughly, drained, and weighed. They were then placed in an 80°F growth chamber and reweighed at two hour intervals in order to determine the rate of water loss from each pot. This was done for 12 hours and then a mean rate of water loss/pot/24 hours was calculated.

Using the maximum value for dried thatch, (10 mg sucrose/gram dry weight of thatch) the amount of sucrose per pot was calculated as 52 mg per pot. (See Figure 12). This much sucrose was dissolved in the amount of distilled water to allow the turf pot to dry to the wilting point in 24 hours. The same method was used for the Robertson sand pots. The control turf pots received distilled water in the appropriate amount to allow drying in 24 hours.

In general, two sucrose applications were followed by two applications of nutrient solution of the same volume and then a thorough leaching with nutrient solution was made as the turf began to deteriorate.

After the daily weights were taken on the pots, they were tested by the water drop absorption method to see if any decrease in infiltration had taken place. The Robertson sand pot was tested by placing a water drop on the surface. The turf pots were tested by partially removing the turf from the pot, placing it on its side, making a radial cut through the sand and turf at the surface and then placing a drop on the horizontal plane of the cut. (See Figure 13).

Figure 13. Method used to test infiltration time on turf pots, both in the dry-down studies and the bacterial stimulation experiment. The water drop was placed on the sand surface where the wooden label is resting.



After eight weeks no change had occurred in the infiltration rates of any of the pots. All of the pots remained wettable.

This hypothesis was also explored by use of cultures of bacteria from nonwettable and wettable soil samples.

A 1/100 soil extract was taken from nonwettable and wettable soil. These were streaked on PDA in petri dishes. Then 1/1000 and 1/10,000 dilutions were made and struck. (Salle 1967). These were incubated at 72°F for five days to one week.

Hydrophobic bacteria often form colonies that appear dry on the surface (not glistening) and have a wrinkled rather than a smooth surface. The plates were then examined for colonies that appeared dry and wrinkled, or that looked out of the ordinary. Two of these different colonies were scraped off the surface of the agar and each suspended in 5 ml of deionized water. These suspensions were then added to dry Robertson sand in 1/2 ml increments waiting for the sand to dry between applications (24 hours). Half of the samples were dried at room temperature and the other half were dried at 100°F. Four applications of the concentrated bacterial suspensions were made. At the end of the treatments, no appreciable change in the infiltration rates had occurred.

Other experiments in which solutions of sucrose and Hoagland solution were used to culture bacteria also proved to be fruitless. The bacteria were concentrated by centrifugation, then suspended in 5 ml tap water and applied to 1 g Robertson sand samples and dried at 70°C. These samples remained completely wettable.

Another test was designed to observe the effect of different drying temperatures on the bacterial suspensions added to Robertson sand samples. The bacterial suspensions added consisted of the following: .3 ml concentrated bacterial suspension in tap water plus .1 ml of a mixture of

.1% sucrose solution and 20 ml of 1/2X Hoagland solution. This was added to all samples twice in 24 hours. Then the temperature treatments were begun. Two samples were dried at each of the following temperatures, with one receiving a bacteria-sucrose-Hoagland aliquot every 24 hours and the other no additional applications after the initial two.

Room Temperature

80°F
110°F
160°F
212°F

After application of the suspension the samples were left at room temperature for approximately 6 hours to incubate, then were placed at the various temperatures for drying overnight.

After five days the daily application samples at all temperatures except 212°F showed a very slight (less than 1 second) increase in infiltration time when compared to the controls. After 16 applications none of the samples showed more than a 1 second infiltration time.

In an effort to produce a bacterial population similar to a natural population on the surface of a golf green, grass clippings were allowed to decompose under anaerobic conditions. One batch was placed at 100°F and the other left at room temperature. After one week the dark brown exudate was poured off the decomposing clippings. This exudate was applied to eight 1 gram samples of Robertson sand. Five applications were made, one per day. The exudate was evaporated at room temperature for half the samples and at 100°F on the others.

Again no increased in the water drop absorption time on the samples occurred.

Chapter 8

CONCLUSIONS

Previous explanations for dry spots on golf greens often implicated thatch build-up as a major contributor to the problem. It was believed that a thick thatch layer impeded the downward movement of water, thus allowing spots to dry out even with normal irrigation. This research brought out the fact that the thatch layer was not a direct contributor to the nonwettable situation. Greens with relatively thin thatch layers (1 to 1-1/2 cm) contained serious dry spot problems. Also, infiltration studies and direct observation (Figure 1a) showed that the thatch layer was not hydrophobic, even when very dry. It was determined that the sand itself had taken on a water repellent nature, which prevented the penetration of irrigation water into these areas.

Two of the conditions necessary to produce nonwettable areas are a coarse grade sand base and climatic conditions which bring about frequent drying of the surface of the green. These two conditions often occur together. The coarser sands hold less water to begin with so they naturally dry out faster than a fine sand or a greens mix. Thus, factors which contribute to the drying out of a green will also increase the possibility of problems with "dry spots". Another reason that the coarser sands are involved with this problem is the fact that they have a smaller surface area than a fine sand or a soil mix. A hydrophobic substance can more readily coat the surfaces of the coarse sand, since there is less area to cover. A finer textured soil possibly has too large a surface area to be totally covered by the amount of material produced or released by the source of this hydrophobic substance.

Two rather simple solutions are evident. If a sand based green is to be built, it should consist of a fine to medium sand base, not a coarse grade sand. The second remedy is to prevent the green from drying out. In certain situations this may be easier said than done. Perhaps watering once in the morning and then again in the early afternoon would be necessary to prevent drying of the green during periods of high evapotransporation.

As far as the cause of the nonwettable condition is concerned, the numerous theories proposed give some indication of the complexity of the problem.

Seemingly, the most logical and widely held theory concerning the cause of nonwettable sand is that an organic substance coats the sand grains and when this material is dried out it becomes nonwettable.

Wander (1949), Bond and Harris (1964), Savage et al (1969), and Debano et al (1967) all gave some amount of credit to this general theory.

Wander offered experimental evidence that fatty acids combined with Ca++ and Mg++ to form a nonwettable substance. This theory could be applied to golf green conditions. Further investigation of this possibility is warranted since methanol did, in one case, remove the nonwettable substance from a nonwettable golf green sand.

Although Debano et al (1967) found that extracts of the plant cover produced nonwettability when placed on wettable sands, this did not seem to be the case in the golf green situation. Water extracts of plant matter di not produce nonwettability in any degree. The fact that benzene extracts of plant matter (grass clippings) did produce nonwettability when evaporated on wettable sand was not taken as evidence of the source of nonwettability for two reasons; a) the benzene did not readily remove the nonwettable substance from actual nonwettable sand samples, and b) the benzene extract was not selective. No less than 20 substances in the extract were separated using florescent thin-layer chromatography plates. It appeared that the benzene extracted waxes and oils in large quantities. These probably resulted in production of a water repellent condition when the extract was applied to sands. It was concluded that the benzene was not a solvent for the actual nonwettable substance.

The temperature effect on nonwettability appears to be of a secondary nature. Drying of wettable cores in laboratory ovens at 25°C, 70°C, and 110°C indicated that temperature itself was not a causal factor in the nonwettable condition. The 110°C temperature did produce a nonwettable condition in the thatch as well as the sand. Since this temperature would never be found on a golf green it was not considered as a possible factor in the production of nonwettable sand. The 25°C and 70°C drying temperatures caused no decrease in the wettability of the cores, they remained completely wettable. However, controlled drying of wettable cores in the water baths at similar temperatures (approximately 25°C) did produce a definite nonwettable response in the thatch and upper portion of the sand. It is important to note that the thatch, as well as the sand, was rendered nonwettable. This is contrary to the situation found on cores taken from "dry spots" in which the thatch proved to be relatively wettable.

The controlled dry-down experiment seems to indicate that the rate of dry down, not the temperature, is an important factor in the nonwettable condition. Cores which had evaporation restricted to only the turf covered surface showed a definite nonwettable response. Cores which were dried with all surfaces exposed to the air showed no degree of nonwettability except at very high temperatures (110°C).

The fact that enclosed cores at 25°C became nonwettable and fully exposed cores dried at 25°C did not become nonwettable, indicates that temperature is not a direct factor in the nonwettable situation.

This leads to the conclusion that the rate of dry-down is a determining factor in the nonwettable phenomenon. Controlled drying with the sand kept at a relatively cool temperature in comparison to the overlying thatch and turf was the only condition which produced non-wettability in originally wettable sand. Whether the temperature difference between the turf and the sand is of significance cannot be commented on at this time. The rate of dry-down and perhaps a temperature difference appear to be of primary importance in producing nonwettability on golf greens.

Work to date investigating bacterial populations as the causal agents has not yielded any conclusive results.

It has been established that of the bacterial colonies isolated from nonwettable sands, none of those tested were hydrophobic under the growing condition in the petri dishes. Suspensions of the colonies in water followed by evaporation of the suspension resulted in no change in the wettability of the bacteria. Drying of the bacteria seemingly did not induce nonwettability, however, only three species have been tested thus far. Continued investigation of the numerous bacterial colonies will result in a more conclusive statement concerning the direct affect f bacterial populations on nonwettability.

The investigation of living bacterial populations in a turf situation seemed to be the most realistic method of determining whether or not a bacterial product was being produced which, when dried, caused nonwettability. Although the first experiment met with little success, numerous modifications of the experimental conditions could possibly result in producing the environment for production of the nonwettable substance. For instance, the experiment was run at 80°F under continuous light; perhaps temperature fluctuations of 60°F night to 95°F day are necessary to induce the production of the nonwettable substance. Also, the balance between the amount of sucrose added and the nitrogen available to the turf environment is likely to be of importance. An extensive study of this relationship was beyond the scope of this study, but future work in this area could be fruitful. The frequency and severity of drying is also an important aspect which could be more closely studied. In the sucrose-bacterial stimulation experiment run on turf pots in the growth chamber, the above parameters were not closely regulated. The sugar concentration applied and the frequent drying of the pots led to the rapid deterioration of the turfgrass. Clearly less severe conditions are necessary if the turfgrass-bacteria system is going to produce a nonwettable substance. Just what these environmental parameters are can only be found by extensive studies of actual nonwettable areas on golf greens, or by trial and error methods under closely controlled environmental and experimental conditions.

A number of factors including rate of dry-down, soil type and particle size, release of carbohydrates from thatch, and size and type of bacterial populations present in the turfgrass-soil environment may contribute to the delicately balanced environment which can develop a nonwettable character under the proper conditions.

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