CHAPTER I

Effect of Rootzone Material and Type of Construction on the Growth of Bentgrass (*Agrostis palustris*)

REVIEW OF LITERATURE

The inability of most native soils to withstand compaction due to traffic has stimulated much research on determining the approximate quantities of sand and peat to add to soil to achieve a suitable rootzone material. Ferguson[10] stated that a soil must provide support, nutrients, water, air, as well as resist compaction in all weather, hold a properly played shot and resist pitting. Engel[8] emphasizes that poor drainage results in compaction, lower oxygen level in soil air, reduced efficiency of soil organisms, inactivation of the root system, and a root system which is more susceptible to drought and disease.

Waddington[43] provides an in-depth review of the literature concerned with the properties of soil and related problems which must be considered in soil modification work.

Kunze et al.[20] concluded that 85 to 90 percent of a uniform coarse sand should be added to a Houston black clay to reduce the effects of compaction. Based on this Texas work, Ferguson et al.[12] proposed specific laboratory tests for determining the compactibility and permeability of a soil mix; the results of which can be used to specify the amounts of sand, soil and peat to use for the rootzone mix of a green built by the method recommended by the United States Golf Association.[41] In a later article, Ferguson[11] specified that the permeability of a soil mix when compacted near field capacity should not be less than 0.5 in/hr or more than 1.5 in./hr. for use in a USGA green.

Swartz and Kardos[39] concluded that about 70% of a medium sand should be added to a Chester silt loam soil found in Pennsylvania to achieve a suitable percolation rate under laboratory tests. In contrast they found that when Gilpin silt loam soil was used in the mix, it became completely impermeable after compaction even though the mix contained 70% total sand. This illustrates the inherent variability between soils with the same texture class due to type and quantity of clay and silt present.

Aldefer[1] found that there was no difference in compactibility between a clay loam and a sandy loam soil. In working with a Kentucky bluegrass sod, he found that foot tramping only once at near maximum water-holding capacity markedly decreased the infiltration rate. Garman[16] emphasized that silt, clay, and organic matter reduce water movement through soil and he reported that soil-sand mixtures containing 5% clay had 4.1 in/hr infiltration rate while those with 10% clay had only 0.4 in/hr. Lunt[29] found that soil mixes with 80% sand could be compacted so he concluded that at least 85% sand is necessary for sand to form a framework in soil mixtures.

The most extensive study to date on the use of amendments to alter the physical properties of soil is being conducted at Penn State. Initial work on the project by Shoop[34] included both laboratory percolation tests and field plot studies on the use of three sands, two slags, calcined clay, and perlite to modify a Hagerstown silt loam soil. Shoop concluded that differences in lab percolation tests were not significant unless the coarse textured materials were greater than 70% by weight. The field plot mixtures which contained 60% (volume basis) or more coarse textured material generally maintained percolation rates of more than 1.0 inch per hour. Analysis of the infiltration data over a five year period, 1963-1967, by Zimmerman[47] showed that compaction significantly decreased infiltration rates. Infiltration rates decreased with time and the compaction times years interaction was significant. Zimmerman concluded that at least 70% (volume basis) or more coarse textured material was needed to exceed 1.0 inch per hour infilteration.

The existing philosophy has been to modify soil by the addition of coarse textured materials to help form a skeletal framework which would improve permeability to air and water and increase resistance to compaction. A different approach was taken for this investigation. The objective was to determine what, if any, additives are needed with sand to provide a suitable rootzone material for turf. Therefore, by not using soil in the mix, the rootzone material could be compacted during construction so that further compaction by traffic would not become the limiting factor to water movement in and through the rootzone.

Bingaman and Kohnke[6] established criteria for sand selection for a structurally stable rootzone for athletic turf. They concluded that the porous properties of a compacted sand can be predicted with reasonable accuracy from data of the mechanical analysis since rather close correlations were found between the desorption curve and mechanical analysis sets of data. They specify that a sand should have a mid-particle diameter between 0.2 and 0.4 mm with most of the particles between 0.1 and 0.5 mm. Clay, silt and very fine sand should be essentially absent. Because of the low water-holding capacity of sand and its restricted height of capillary rise, it is recommended that an impermeable barrier be placed at 30 to 50 cm depth depending on the fineness of the sand used.

METHOD AND MATERIALS

Three groups of plots were built on the experimental putting green on the Purdue campus to study the properties of the various rootzone materials and methods of construction. In 1966 plastic lined sand and calcined aggregate plots were built on the north side of the green under the supervision of David Bingaman. The second group of plots was constructed in 1967 along the south edge of the green to study how variation in depth and type of material without plastic lining would affect water management. In the fall of 1969, a third group of plots was built on the west edge to further study the PURR-Wick concept with relation to the type of sand, depth to water table, and additives used in the surface two inches. Mechanical analysis results for the materials used in the rootzone plots is presented in Table I-1. See Appendix A for more information on the physical properties of the materials used as well as plot diagrams for the experimental putting green.

Penncross bentgrass was seeded on the north and south plots and both Penncross and Evansville were used for the west plots. Except during experiments all plots on the green were managed very nearly the same. The green was mowed four times a week with the mower set at about 5mm, fertilized as needed with a complete turf fertilizer, watered as needed, aerified once a year (except for north and south plots which were not aerified), topdressed with same rootzone material, and sprayed for disease and insects in preventative program. Play on the green would be considered

TABLE I-1. Mechanical Analysis by weight for materials used in Rootzone Plots

Material	Location*	Particle Size (mm)						
		4.0-2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.125	0.125-0.053	<0.053
1. Sands		Percent by weight						
Local No. 3 Mortar	N,S,W	1.7	18.4	34.8	34.6	8.8	1.1	0.6
Lake Michigan Dune	N	0	0	1.2	59.5	38.9	0.4	0
Poultry Farm Dune	W	0	0	0.9	29.2	51.9	17.3	0.6
2. Calcined Aggregate								
Calcined Clay	N,S	12.1	67.6	19.0	0.9	0.4	0.2	0.1
Dialoam	N,S,W	20.3	48.0	29.3	1.6	0.3	0.2	0.2
3. Mixes								
80-20 C.C. - P.	N	18.2	58.7	18.0	3.0	1.1	0.6	0.4
60-20-20 C.C.-D.S.-P.	N	10.9	18.7	15.4	22.8	31.2	0.6	0.4
40-40-20 C.C.-L.S.-P.	N	7.8	17.1	38.3	19.3	13.2	2.4	0.8
2-1-1 L.S.-Dialoam-P.	S	2.6	13.9	27.4	41.6	11.3	2.1	1.1
2-1-1 L.S.-C.C.-P.	S	2.3	17.9	25.4	39.7	11.4	2.3	1.0
3-1 L.S.-P.	S	1.8	17.0	36.0	34.0	8.8	1.7	0.8

* N - North Plots, S - South Plots, W - West Plots

average, consisting mainly of infrequent physical education classes during the day and students during the evening hours.

The two parameters considered most important were infiltration rate and moisture holding capacity for the various plots. Infiltration rate was measured in 1968-1969 using the double ring infiltrometer with rings of 20 and 40 cm diameter. All plots to be measured were watered heavily the night before to establish uniform conditions. Before each time period of measurement was started, at least 5 cm of water was added to the plot through the center ring while the waterlevel in the outside ring was held at about the same level as the inner ring. The level of water during the measurement period was maintained at about 3 cm by the addition of water at a controlled rate. The infiltration rate for each of two thirty-minute time periods was determined for each plot.

The ability of plots to retain water after drainage was determined by allowing the plots to dry-down between rains in August, 1968 and July, 1969. The plots were rated each afternoon for wilt susceptibility on a scale of 1 to 9 in which 1-2 was normal growth, 3-5 showed foot-printing, 6-8 was blue wilt and 9 was severe wilt. As each plot reached 9 it was individually watered to prevent complete death. In addition to visual ratings, the experiment conducted in July, 1969 included moisture content measurements with the Troxler Surface Neutron Gauge, Model 105-217, in conjunction with a Troxler Portable Scaler, Model 200B. Figure I-1 is the standard curve used to convert the count ratio to volume percent moisture for all plots.

The first dry-down experiment was initiated following a 5.7 cm rain on August 16, 1968 which saturated all plots. All excess water in the

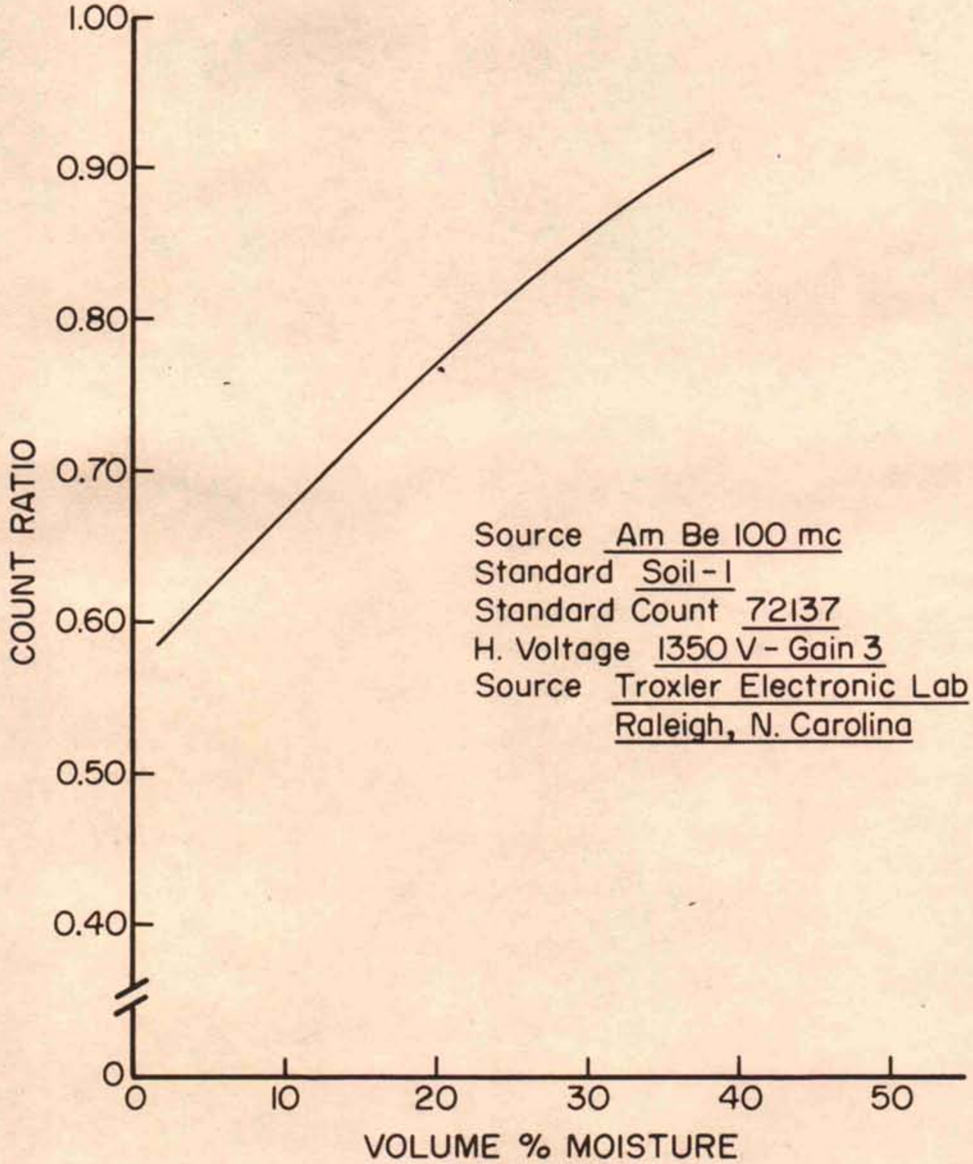


Figure I-1. Standard Curve Used for Surface Neutron Meter.

plots was drained away within 24 hours after the rain stopped. The experiment was terminated by a rain on August 31 after 15 days of hot, dry weather as shown in the weather data for the Purdue Agronomy Farm located 6 miles NW of campus presented in Table I-2. Evapo-transpiration was determined by taking 0.80 (pan evaporation) for each day of the July and August experiments. Eighty percent of the pan evaporation is considered a reasonable approximation of the evapo-transpiration for most crops during the summer months in the Lafayette area. Tovey et al. [40] reported a ratio of 0.79 for measured E-T and pan evaporation for lawngrass grown in a sandy loam soil in Nevada.

The second dry-down experiment was conducted between July 8th and 25th, 1969. The experiment was started following 5.3 cm of rain over a four day period which saturated the plots and was terminated by a heavy rain on July 25th. Precipitation was measured by a rain gauge on the experimental green. Two light rains of 0.66 cm on July 11th and 0.32 cm on July 19th had an effect on the number of days to severe wilt for the plots compared to the 1968 data but the experiment was not terminated since all the plots received the same amount of moisture.

The subsurface irrigation water level controls were adjusted so that at least 5 cm of water was maintained above the plastic in plots D, E, F-1, and F-2 for the 1969 experiment. No surface water was added to any plot until it showed severe wilt and then the plots were watered individually as needed to revive them.

Monthly root measurements were taken throughout the growing season using the standard cup cutter to obtain samples. The loose sand was carefully shaken from the roots and the length from the crown to the deepest

TABLE I-2. Weather Data for Dry-down Experiments

	Dry-down I - 1968					Dry-down II - 1969				
		Air Temp*					Air Temp*			
Day	Date	Max °F	Min °F	Precip* cm	E-T+ cm	Date	Max °F	Min °F	Precip** cm	E-T cm
0	Aug. 16	85	69	5.69	---	July 8	77	63	5.33#	----
1	17	89	65	0	0.41	9	73	61	0	0.10
2	18	84	63	0	0.36	10	83	67	0	0.18
3	19	88	68	0	0.36	11	87	69	0.66	0.36
4	20	90	73	0	0.53	12	88	65	0	0.46
5	21	91	72	0	0.46	13	88	65	0	0.58
6	22	93	74	0	0.41	14	86	63	0	0.51
7	23	90	72	0	0.41	15	85	62	0	0.46
8	24	91	74	0	0.46	16	86	66	0	0.53
9	25	89	60	0	0.66	17	93	69	0	0.51
10	26	76	51	0	0.41	18	90	73	0	0.43
11	27	70	42	0	0.33	19	91	67	0.32	0.56
12	28	71	44	0	0.53	20	89	71	0	0.36
13	29	74	48	0	0.33	21	83	63	0	0.28
14	30	75	48	0	0.30	22	85	67	0	0.33
15	31	78	55	0.13	0.25	23	85	62	0	0.41
16	Sept. 1			0.56		24	87	64	0	0.41
17				--	--	25	84	58	0	0.30
18						26			1.64	
	Ave.	83	61	Total	5.99	Ave.	86	65	Total	6.76

* Data for Agronomy Farm weather station (6 miles NW of Plots)
** Data for rain gauge on experimental green
\# Total precip. for four day period of July 4 to 8, 1969
\+ E-T values reported are 0.80 (pan evaporation)-

intact roots was measured. Root samples from similar plots were photographed monthly for comparison of possible changes throughout the growing season.

RESULTS AND DISCUSSION

General Observations

The general condition of the test plots through the summers of 1968 and 1969 with regard to maintenance and playability was encouraging. Little difference in appearance between plots was apparent when they were all managed for top performance. The green was usually watered when the soil in the center and the variable depth plots along the south edge showed signs of moisture stress. The plastic lined plots on the north edge required little water in addition to normal rainfall with the exception of the high percentage calcined clay plots.

Playability of a turf rootzone is a difficult parameter to quantify. Two basic things are required of a golf green rootzone material. First, it must absorb the energy of a properly played golf shot to the green to stop the ball within a reasonable distance after landing. And second, the surface of the rootzone must be smooth and consistant so that it putts true. Due to the location of the experimental green and the relatively small plot size, it was not feasible to hit shots to test the ability of the various materials to stop the ball. An attempt was made to compare plots by measuring the ball indentation into each plot after a known amount of downward force was applied to the ball with limited success. The smoothness of the plots was dependent on the number of topdressings the plot received and the manicuring of the bentgrass so no attempt was made to measure the difference in play between plots.

The fertilizer requirement was higher on the newer test plots on the north and south sides of the green compared to the older soil plots in the center. The test plots were fertilized about every three weeks with a complete turf fertilizer so that a total of about 8 pounds N/1000 sq.ft. (3.8 kgs/100m^2) was applied during the growing season. The soil in the center of the green was fertilized about once a month for approximately 6 lb N/1000sq ft. (2.9 kgs/100m^2). Two factors contributed to the higher nutrient requirement for the test plots. First, the coarse textured materials had a lower nutrient storage capacity than the fine textured soil. The second factor was the difference in the variety of bentgrass. The Penncross bentgrass on the test plots had a lighter green natural color than did the Old Orchard variety on the soil in the center. This inherent difference could be seen in the bentgrass variety plots on the green where both were fertilized at the same level. Thus, there was a tendency to fertilize the Penncross more heavily to achieve a darker green color for comparison with the Old Orchard.

The important thing to keep in mind is that the level of fertility could be adjusted to suit the need. This study showed that quality turf could be maintained in any of the rootzone materials with proper management. On the other hand, little can be done to alter or adjust the physical properties of a rootzone once it is constructed. Therefore, the physical properties of the materials were considered far more important than the chemical aspects.

The disease susceptibility of Penncross on the test plots was about the same as for the turf on the rest of the green. A preventative spray program was maintained throughout the summer months so that disease was not a serious problem. It was noted that disease resistance appeared higher during the first year of establishment for the Penncross compared to the second and third years. After the first year, dollar spot and brownpatch were found when conditions were favorable unless treated. Pythium was not found on the green during either summer.

Cup cutting in the porous materials was not found to be a problem if the sand was in a moist condition. The turf roots would hold the coarse textured materials together so that a plug of 10 to 15 cm could be removed in the first cut. It was necessary to remove any additional material desired by hand. A simple auger type cup cutter could be made to eliminate this inconvenience. If the rootzone material were too wet or too dry, it was difficult to remove the first cup due to lack of friction to hold the material in the standard cup cutter. The sod plug could be removed by hand once cut, however.

Winter frost heave was a serious problem for the plastic lined plots containing Dialoam as can be seen in the picture in Figure I-2 which was taken in March, 1968. The raised plots in the background are the Dialoam plots in C and D which would heave each winter as much as 10 to 15 cm above the surrounding plots. The pot-marked appearance of the Dialoam half of Plot B in the foreground of the picture shows what foot traffic can do to the unstable heaved condition as the plot thaws. With repeated rolling and firming, the plots containing Dialoam could be smooth for play by late spring.

Dialoam or diatomaceous earth is a calcined aggregate with about the same particle size range as calcined clay (Table I-1), but the individual particles have more internal porosity than calcined clay particles. The

Figure I-2. Effect of Frost Action on Plastic Lined Plots Containing Dialoam.

bulk density of Dialoam is very low, 0.46 gms/cc, compared with calcined clay, 0.66 gms/cc, and mortar sand, 1.75 gms/cc (see Appendix A). The frost heave of Dialoam is thought to be due to water movement from pores deep in the rootzone to the cooler interface at the surface, where it condenses to form long ice crystals. The water moves to the surface both in the vapor phase, in the large pores between the particles, and in the liquid phase, within the fine internal pores within the particles through capillary action. The ice crystals appeared to form just below the surface thatch layer and tended to slowly lift the turf off the plot so that by late winter, the turf would be supported on ice crystals about 10 to 15 cm long. This would cause breaking of the roots in many cases.

Frost heave of mixtures containing Dialoam was only found to be a problem for the plots which were lined with plastic. The variable depth of material plots containing Dialoam but not plastic lined showed normal frost action and could be easily smoothed for play in the spring. The effect of the plastic barrier was to increase water retention in the pores deep in the rootzone which could move to the surface to form the ice crystals. Therefore, due to the frost action characteristic of the material, it would be recommended that Dialoam be used only in very low percentages, if at all, in rootzone mixes placed above plastic.

Frost heave was not a problem for the other rootzone materials studied. In fact, where dune sand was used along in Plots A and F, frost heave was less than for soil in the center of the green. Note the firm appearance of the dune sand plots (A) at the bottom of the picture in Figure I-2. The high sand content plots above plastic were firm throughout the winter which would be very desirable for winter and early spring play. The sand rootzones are compacted when built so that play during this period of the year would not pose the problem of further compaction which is associated with many soil greens when played under wet conditions.

Infiltration Rate

Infiltration rate was measured in 1968 and 1969 on all south plots, selected plots on the north side of the green, and the soil in the center using the double ring infiltrometer. Data for the variable depth to subsoil plots presented in Table I-3 is the average of two replicates. Note that all the rates are above 4 in/hr and most are between 10 and 20 in/hr. The F value for the depth to subsoil variable was highly significant (0.01 level of probability) and the F values for depth to drain line and all interactions were nonsignificant (See Appendix B). The 10 cm deep plots

Table I-3. Infiltration Rate for Variable Depth of Materials Study.

Infiltration Rate - in/hr

Depth to Drain Line cm	1968 Depth to Subsoil 10	15	20	25	1969 Depth to Subsoil 10	15	20	25
25	6.8	13.6	16.2	17.2	4.1	13.5	10.7	17.0
33	8.3	11.7	15.0	13.4	4.9	11.6	17.2	16.0
40	7.3	13.8	12.6	17.6	4.5	9.0	18.0	21.6
48	9.5	11.8	14.2	12.6	4.4	14.4	12.2	14.8

had a significantly lower infiltration rate compared to the deeper plots but 4 in/hr would still be considered adequate.

The infiltration rates for representative plots on the north side of the green for 1968 and 1969 are presented in Table I-4. The rates were all above 3 in/hr and some were over 20 in/hr. The rate in 1969 for many plots was higher than 1968 which could have been caused by a difference in prior saturation of the plots. The plots on the north side were watered heavily the night before the 1969 measurements were made but infiltration was not measured until late the following afternoon after the south plots were measured. At least 5 cm of water was put through the center ring for all plots to reduce this effect as much as possible.

The infiltration rate for the finer fraction of the dune sand in plot A was less than for the medium fraction but a rate of about 6 in/hr would be adequate for most wet conditions. The high percentage calcined clay plots in C and D had rates above 11 in/hr which could be expected from the coarse particle size of the material. When sand was added to the

Table I-4. Infiltration Rate for Plastic Lined Plots and Soil.

Plot No.	Material	Infiltration Rate 1968 in/hr	Infiltration Rate 1969 in/hr
A-1-4	Dune sand - M/F	11.2	20.8
2-4	Dune sand - F	6.0	11.2
3-4	Dune sand - M	7.2	14.0
C-1-4	100 Calcined clay	17.6	60.0
2-4	80-20 CC - peat	15.2	44.0
3-4	80-20 Dune sand-peat	3.2	5.4
4-4	80-20 Local sand-peat	3.2	3.0
D-1-4	100 Calcined clay	16.0	15.2
2-4	100 Calcined clay F/C	11.0	17.0
3-4	80-20 Dune sand-peat	4.0	6.0
4-4	80-20 Local sand-peat	3.0	9.6
E-1-4	Calcined clay	3.2	26.0
2-4	Dialoam	3.0	6.0
3-4	Dune sand	4.0	8.6
4-4	Local sand	4.0	7.0
F-1-4	Dune sand - F/M	7.4	7.0
2-4	Dune sand - M	5.4	10.2
3-4	Dune sand - M/C	4.0	14.0
4-4	Dune sand - C	11.0	14.6
Soil - center of green		0.8	0.9

calcined clay plots in C and D, the rates were reduced to between 3 and 10 in/hr. Infiltration did not appear to be a limiting factor for the other plots on the north side of the green. The infiltration rates for the soil in the center of the green was less than 1 in/hr for both years.

One very important factor should be pointed out which the double ring infiltrometer method does not fully take into consideration. Before water can enter a rootzone, air must be displaced. The purpose of the outer ring is to reduce this effect by having water enter all around the test area in the center ring. However, air in the soil pores can move somewhat laterally deep in the rootzone and air can escape out the surface. The actual infiltration rate would no doubt be less than the measured value during a heavy storm when the entire surface is covered with water. When this is the situation, air must either move through the rootzone and out the drain line or bubble up through the water covering the surface before more water can enter the rootzone.

Infiltration is also dependent on the rate of movement through the thatch which can be hydrophobic. The inability to wet the thatch appeared to be a limiting factor for infiltration for some of the high sand content plots. The combination of a wetting agent, to reduce the hydrophobic nature of the thatch and aerification plus topdressing to permit more rapid water movement through the thatch would be a practical solution to this problem. The porous nature of the high sand content rootzones permits rapid water movement through the rootzone to the drain line so that the aerifier holes would not tend to fill up with water as could be the case for soil in which the percolation rate often limits infiltration.

One objective of the research was to build a rootzone in which compaction would not become limiting so that all the test plots were compacted as much as possible during construction. The infiltration rates both increased and decreased during the second year. As mentioned, some of the differences could be attributed to the difference in saturation of the plots prior to measurement. Two years' data would be considered inadequate to draw conclusions so that yearly measurements should be taken for at least five more years to provide evidence on the effect of time and traffic on the infiltration rate.

An infiltration rate of at least 1 in/hr is considered adequate by many people working with turf.[9] Ferguson[11] suggested an acceptible range for laboratory percolation rate of between 0.5 and 1.5 in/hr. Shoop[34] found that reduction in percolation rate due to compaction was severe with most mixtures. He concluded that there was not sufficient evidence to justify rejection of mixtures with percolation rates as high as 5.0 in/hr. Zimmerman[47] found that infiltration rates decreased significantly with time over a five year period after construction for the soil mix test plots. He concluded that 70 percent or more of coarse textured material was needed to exceed the 1 in/hr value for the Hagerstown soil.

High infiltration rates have been discouraged by many workers because they are synonomous with droughty conditions. Many feel that the inconvenience of the low water storage capacity of sandy materials under field conditions greatly outweighs the ability of the porous materials to rapidly remove water. Therefore, soil is added to sand to provide capillary pores in order to retain moisture for the turf needs at the expense of reducing the percolation rate. Even with the high infiltration rates of between 5 and 20 in/hr found for many the materials used in this study, the moisture reserve was good for most of the plots as will be discussed in the following section.

Dry-down Experiments

The key test for any rootzone under repeated use is its ability to remain moist and supply water uniformily under a wide variety of conditions. Generally the most extreme is extended dry, windy weather which favors wilting, foot-printing, and desiccation.

Therefore, perhaps the most important finding of this study was the relative difference in moisture retention of the plots during the dry-down experiments which were conducted in August, 1968 and July, 1969. It should be stressed that the purpose of the dry-down experiments was to determine the maximum length of time the various plots could go without adding water. Play during the experiments was not heavy so that wear from traffic did not appear to put a stress on the turf. The plots were rated each afternoon for wilt and none was watered until it showed severe wilt. It is recognized that it would not be practical to permit turf under heavy play to wilt as much as some of the plots wilted due to the long time required for the turf to recover.

Dry-down I - 1968

The average wilt ratings for selected treatments and cummulative evapo-transpiration curve for the 15 day experiment in August, 1968 are presented in Figure I-3. The length of the horizontal bar for each material indicates the number of days from saturation by the 5.7 cm rain on August 16th to either severe wilt or the rain on August 31st which terminated the experiment. Wilt ratings are the average of three similar

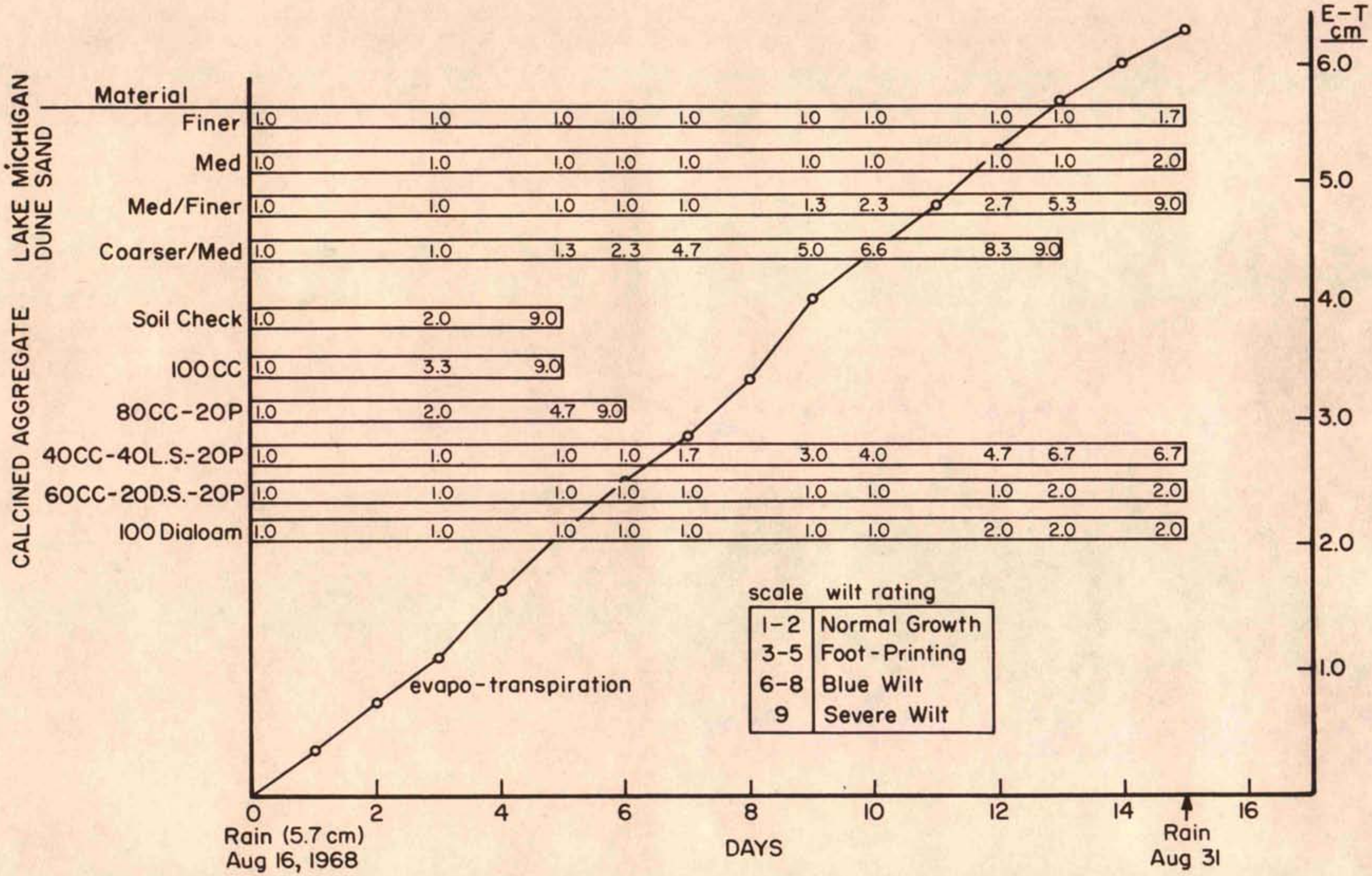


Figure I-3. Cumulative Evapo-Transpiration Curve and Wilt Ratings for Dry-down Experiment I (August 1968).

plots taken in the afternoon of the indicated days.

Weather data for the 1968 test period presented in Table I-2 show that the first nine days of the experiment were considerably warmer with temperatures in the high 80's and low 90's compared to the last six days in which the maximum daily temperatures were in the 70's. The hot weather during the first nine days resulted in high daily evapo-transpiration rates of between 0.36 and 0.66 cm/day. The total E-T for the 15 day period was 5.99 cm (2.36") indicating hot and dry weather. The combination of the heavy rain (5.69 cm) on August 16th which saturated the plots and the hot, dry two week period after the rain provided favorable conditions to determine which treatments would show moisture stress.

Comparison of the daily wilt ratings for the Lake Michigan dune sand treatments (Plot A) in Figure I-3 shows the difference in water storage for the different size fractions. The smaller pores in the finer sand retained sufficient water after drainage stopped to supply the turf needs for the entire 15 day period. In contrast, the larger pores in the coarser/medium treatment retained only enough water after the rain to supply the evapo-transpiration needs for the first week. The coarser/medium plots showed blue wilt during the second week and all three replicates had to be watered by the 13th day to prevent complete death. The medium dune sand plots made it the entire 15 days without showing stress but where 10 cm of medium sand was placed over 10 cm of finer sand, the plots showed wilt during the second week and severe wilt by the end of the test period. This observation was not substantiated by the 1969 experiment in which the moisture content was higher in the medium/finer plot and the wilt ratings were about the same for both treatments as shown in Figures I-4 and I-5.

The turf on the silt loam soil in the center of the green showed foot-printing on the third day after the rain. Nearly all of soil areas needed to be watered by the fifth day to prevent complete loss of turf.

The plastic lined calcined aggregate plots in C, D, and E showed very striking differences in the number of days to severe wilt. The 100% calcined clay plots showed wilt by the third day and severe wilt by the fifth day. This was about the same moisture supplying ability as the soil. Where 20% peat was added to the calcined clay mix in the surface 20 cm, the plots did not show severe wilt until the sixth day. Where either dune or local mortar sand was added to the calcined clay and peat the plots made it the entire two week period without severe wilt. It is interesting to note that the plots which contained 20% dune sand had lower wilt rating average than did the plots which contained 40% of the somewhat coarser, less well graded local mortar sand. All the plots which contained Dialoam showed good moisture storage ability and all showed near normal appearance throughout the test period.

During the first dry-down experiment, it soon became evident that the morning dew pattern was a very good indicator of moisture stress. The plots which did not have dew in the morning were the ones which showed wilt stress in the afternoon. Thus, soil water availability to the turf roots could be predicted by the dew pattern.

The dew pattern of the calcined aggregate plots in C, D, and E and the dune sand plots in F on the fifth day of the 1968 experiment is shown in Figure I-4. See Figure A-1 for a picture of the north plots before seeding for location of the calcined aggregate plots. The three plots without dew at the bottom of the picture (Figure I-4) are the 100% calcined

Figure I-4. Morning Dew Pattern of the Plastic Lined Plots on the Fifth Day of the 1968 Dry-down Experiment.

clay plots. These three plots showed severe moisture stress in the afternoon of the day the picture was taken and were watered. The three plots immediately above the dry plots with the light dew pattern are the 80% calcined clay- 20% peat plots. They required watering the day after the picture was taken. The two plots in the first two rows with the heavy dew pattern are the 100% Dialoam and the 80% Dialoam-20% peat plots which did not require watering for the entire test period.

The plots with the heavy dew pattern in the third and fourth rows from the bottom of the picture are the ones which contained dune sand and local mortar sand with calcined aggregate and peat. They were not watered for the 15 day period.

The dew pattern for similar plots in D was the same as for the C plots. The long horizontal strip without dew in the center of the picture is the calcined clay plot in E. The other treatments in E and all of the dune sand plots in F which show a heavy dew pattern in the picture were not watered before the rain on August 31st.

Note that the soil in the center of the green on the right hand side of the photograph had only a very light dew pattern. Most of the bentgrass on the soil showed severe wilt the day the picture was taken and all of it was watered to prevent death.

Slatyer(35) lists three sources of dew: 1. condensation from the atmosphere, 2. distillation or condensation of water vapor coming from the soil, and 3. guttation. Condensation of dew depends on radiational cooling of the leaf surface to the dew point. The lack of dew on certain plots could have been caused by a combination of higher surface temperature of the plot, less water vapor coming up from the drier rootzone, and lack of guttation water. It was noted that much of the dew on the plots which had a heavy dew pattern appeared to be guttation water.

Dry-down II - 1969

A second dry-down experiment was conducted in July, 1969 to substantiate the findings of the 1968 experiment. In addition to visual ratings, the decrease in moisture content with time was measured with the surface neutron meter. Two attempts to start the experiment in June were unsuccessful due to frequent rains during the month.

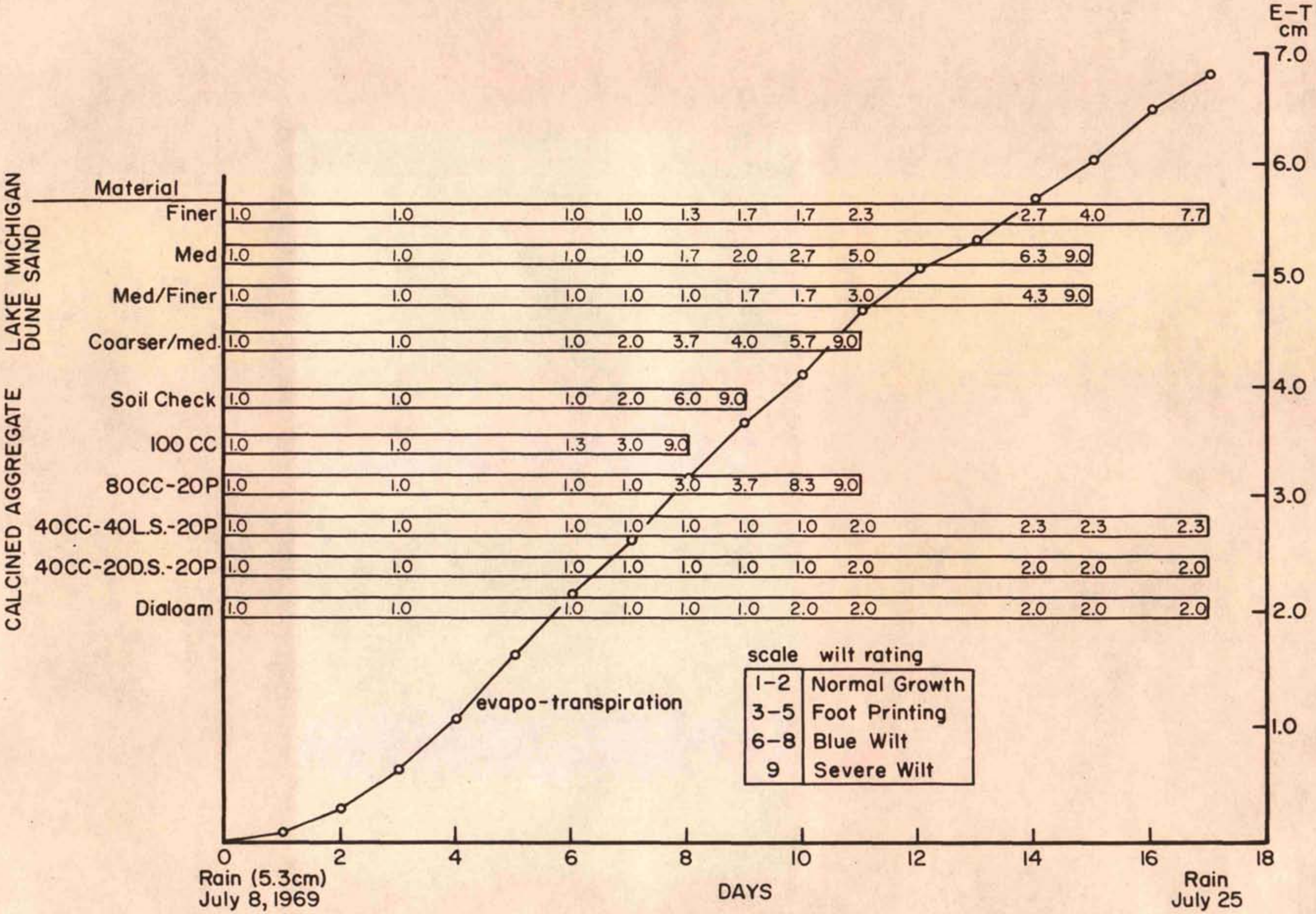
The weather data in Table I-2 show that for the 1969 experiment, the conditions were not as favorable as for the 1968 experiment. The rain which saturated the plots came over a four day period from July 4 to 8th and there was no quick change from wet to dry conditions. The evapo-transpiration rate for the first two days of the experiment were low (0.10 and 0.18) due to overcast conditions. A shower on July 11th of 0.66 cm and a shower on July 19th of 0.32 cm had a definite effect on the total number of days until wilt for the plots. However, it was decided that the experiments would not be terminated after the showers since all plots received the same amount of moisture.

The maximum air temperatures during the first week of the 1969 experiment were lower than the 1968 experiment. The temperatures were somewhat higher during the last half of the 1969 experiment. The evapo-transpiration rates were very low initially, then varied from 0.28 to 0.58 cm per day for a total of 6.76 cm for the 17 days. The cumulative evapo-transpiration curve in Figure I-5shows the gradual increase during the first few days then the more rapid increase for the remainder of the test period.

The differences between treatments for each of the two dry-down experiments were very apparent. Comparisons can be made within either experiment but discretion should be made when comparing differences between the two dry-down experiments due to the two light rains in the second experiment.

The length of the horizontal bar graph and the average wilt ratings for the various treatments presented in Figure I-5 show the relative differences between plots for the 1969 experiment. The first four lines

Figure I-5. Cumulative Evapo-Transpiration Curve and Wilt Ratings for Dry-down Experiment II (July, 1969).



Material
LAKE MICHIGAN DUNE SAND
Finer
Med
Med/Finer
Coarser/med.
CALCINED AGGREGATE
Soil Check
100 CC
80CC-20P
40CC-40L.S.-20P
40CC-20D.S.-20P
Dialoam
evapo-transpiration
scale wilt rating
1-2 Normal Growth
3-5 Foot Printing
6-8 Blue Wilt
9 Severe Wilt
E-T cm
Rain (5.3cm) July 8, 1969
DAYS
Rain July 25

Figure I-5.

for the dune sand plots in A show that the finer fraction moisture reserve was higher than for the medium or coarser fractions. The finer fraction showed foot printing by the 15th day and blue wilt by the 17th day. One of the replicates of the finer sand had to be watered on the 17th day. In comparison, the coarser sand showed foot printing on the 9th day and all three replicates needed water by the 11th day. The average wilt ratings for the medium dune sand were slightly higher than for the medium/finer treatment but both treatments required watering by the 15th day after the rain.

Figure I-6. Morning Dew Pattern of plastic Lined Dune Sand Plots (A) on Ninth Day of the 1969 Dry-down Experiment.

The difference in moisture status between the coarser/medium and the three other dune sand treatments in Plot A can be seen in the dew pattern picture taken the morning of the ninth day in Figure I-6. The three plots without dew are the 10 cm coarser over 10 cm medium dune sand replicates. The plots showed foot-printing in the afternoon of the day the picture was taken and were watered two days after the picture was taken.

The moisture status of the dune sand plots in A for the 17 day experiment in 1969 is presented in Figure I-7. The F test for the sands was highly significant (0.01 level) and the Least Significant Difference (LSD) between sands at any one time period was 4.46 (see Appendix A). The difference in moisture content between the finer and the medium sand treatments was significant for all days measured. The finer sand moisture content ranged from 23% down to 5% while the medium sand moisture content varied from 17% down to 3%. The differences in moisture content between the medium and the medium/finer treatments were not significant but the values were consistantly higher for the medium/finer plots. The moisture content for the coarser/medium treatment was significantly less than the other three treatments except for the first day and the volume percent ranged from about 14 to 2%, where it was watered to prevent death.

Turf on the soil check in the center of the green showed stress after 7 days and was watered on the 9th day as shown in Figure I-6. This is almost twice as many days as in the 1968 experiment in which the soil plot was watered on the 5th day illustrating the difference in weather conditions for the two years. The moisture content of the soil varied from about 22 to 10 percent as shown in Figure I-7. The turf showed severe wilt at 10.3% moisture compared to the dune sands which did not show wilt until the moisture content was as low as 2 to 4 percent.

The calcined aggregate plots in C, D, and E again showed differences

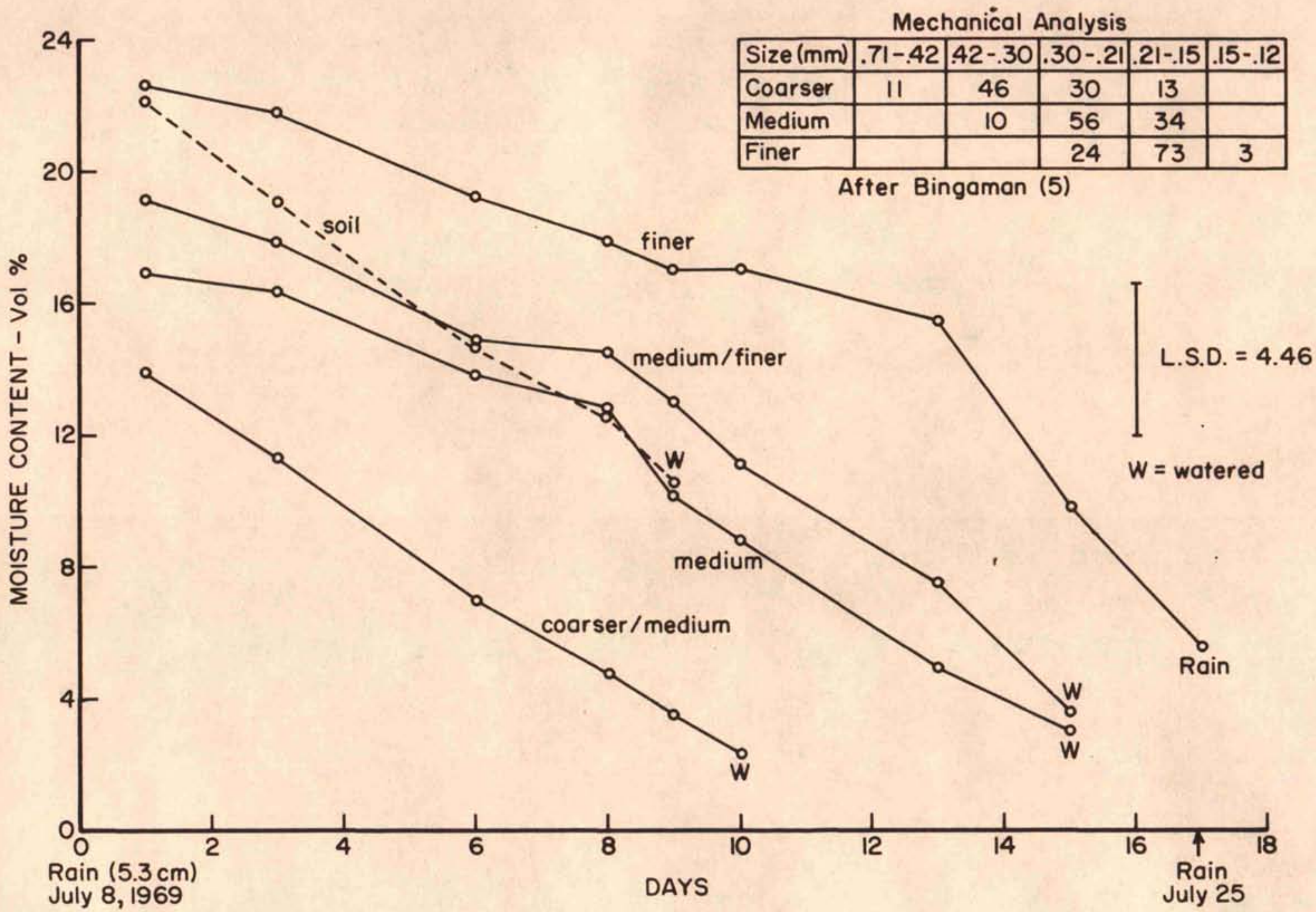


Figure I-7. Daily Moisture Content of Lake Michigan Dune Sand Treatments in Plot A (Dry-down II) in water storage ability as shown by the wilt ratings in Figure I-5. The 100% calcined clay plots did not show signs of wilt up until the 7th day and then by late afternoon of the 8th day, the plots showed severe wilt and were watered. The plots in which 20% peat was added to calcined clay showed wilt on the 8th day but the wilt was not severe until the 10th day for two of the replicates and the 11th day for the third. Where sand was added to the calcined clay and peat, all plots made it the 17 days of the experiment and most had normal growth wilt ratings (1-2) on the last day. As in the 1968 experiment, all plastic lined plots containing dialoam in the rootzone mix did not require watering during the test period.

The moisture content of the calcined aggregate plots during the 1969 experiment are presented in Figure I-8. The F value for the 4 treatments and the soil check was significant (0.05 level of confidence) and the L. S.D. between treatments at any single time period was 3.76 (see Appendix) Note the general decrease in moisture content with time for the 100% calcined clay and 80-20 mix until the plots were watered. While the difference in moisture content between them is not significant, the plots containing 20% peat consistantly had a higher moisture content than the 100% material. The plots which contained 20% dune sand had significantly higher moisture content than the plots which had 40 percent of the local mortar sand for all days measured. The dune sand was a finer material with a more uniform particle size than the mortar sand. Both curves tended to level out after the gradual decrease in moisture content during the first 10 days. After 17 days, the 60-20-20 (calcined clay-dune sand-peat) had 22.5% and the 40-40-20 (calcined clay-local sand-peat) mix had an average of 18.4% moisture content.

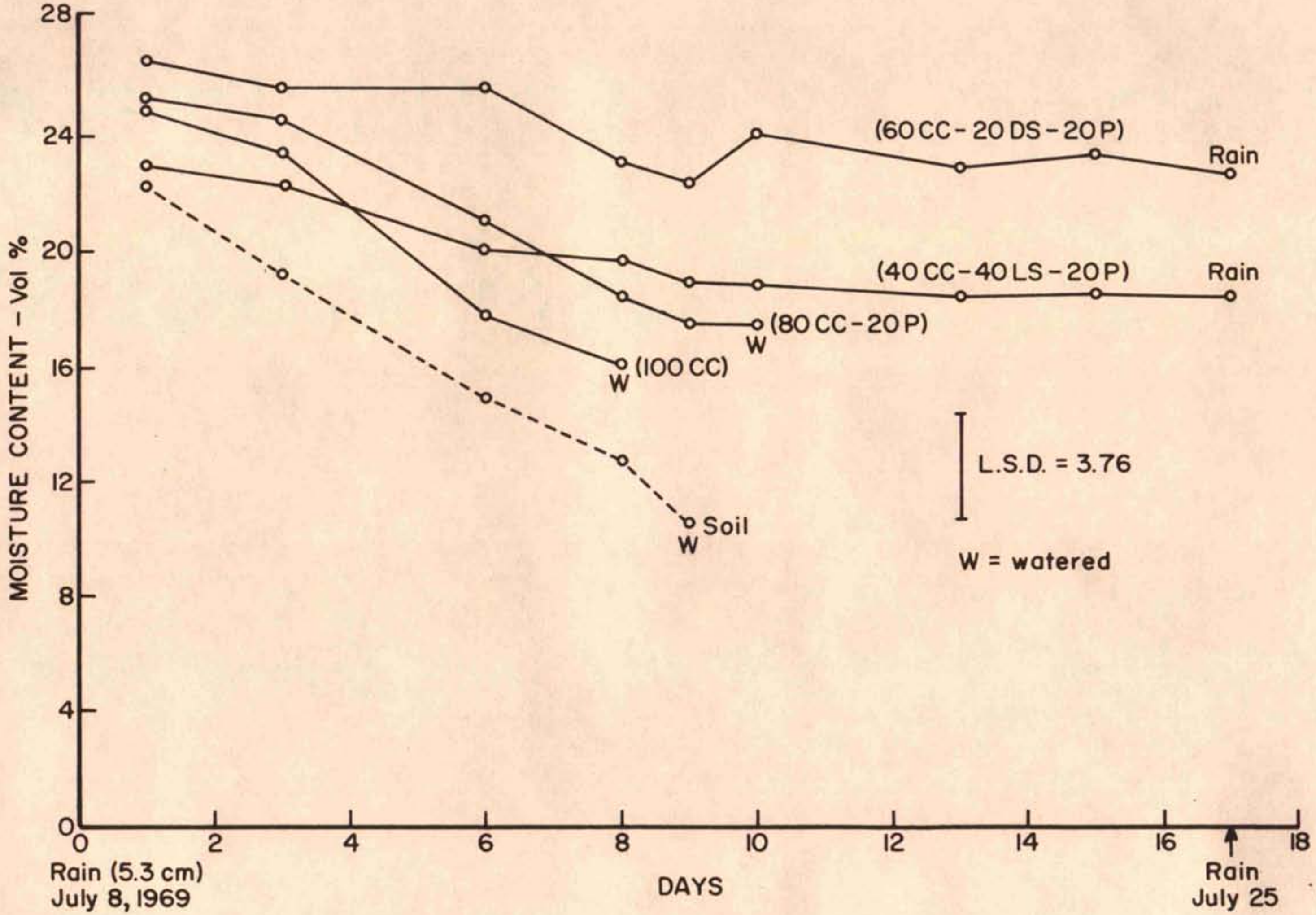


Figure I-8. Daily Moisture Content of Calcined Aggregate Treatments in Plot C and Soil Check (Dry-down II).

Subsurface Irrigated Plots

The plots in D, E, and F all had float control chambers so that a constant level of water could be maintained above the plastic liner in the plots (see Appendix). The only subsurface irrigated plots to show moisture stress during the 1969 dry-down experiment were the 100% calcined clay and the 80-20 (calcined clay-peat) plots in D and E. The other sand mix plots in D and E showed near normal appearance throughout the 17 day test period.

The float control for the F plots was adjusted so that at least 5 cm of water was maintained above the plastic in F-2. Therefore, the water table was about 30 cm below the surface for the 8 plots in F-1 and F-2. The average moisture content for the dune sand treatments in F-1 and F-2 is compared with the average moisture content for the non-irrigated treatments in plot A for the 1969 dry-down experiment in Figure I-9. Moisture content comparisons can be made even though the combination of the three dune sand fractions in the top 20 cm of the plots is not exactly the same for the A and F plots.

The dune sand treatments in plot F all had higher initial moisture contents than the dune sand in A. The moisture content for the subirrigated plots in F remained about the same throughout the 17 day experiment compared to the steady decrease in moisture content for the non-irrigated A plots. The moisture content for the finer/medium treatment was between 26 and 30% compared to the other three treatments in F which were between 22 and 24% for the 17 days. In contrast, the moisture content of the finer fraction in plot A varied from about 23 to 5% and the coarser/medium fraction varied from 14 to less than 4% during the experiment.

Figure I-9. Comparison of Daily Moisture Contents for Dune Sand Treatments in Unwatered Plots (A) and Subirrigated Plots (F).

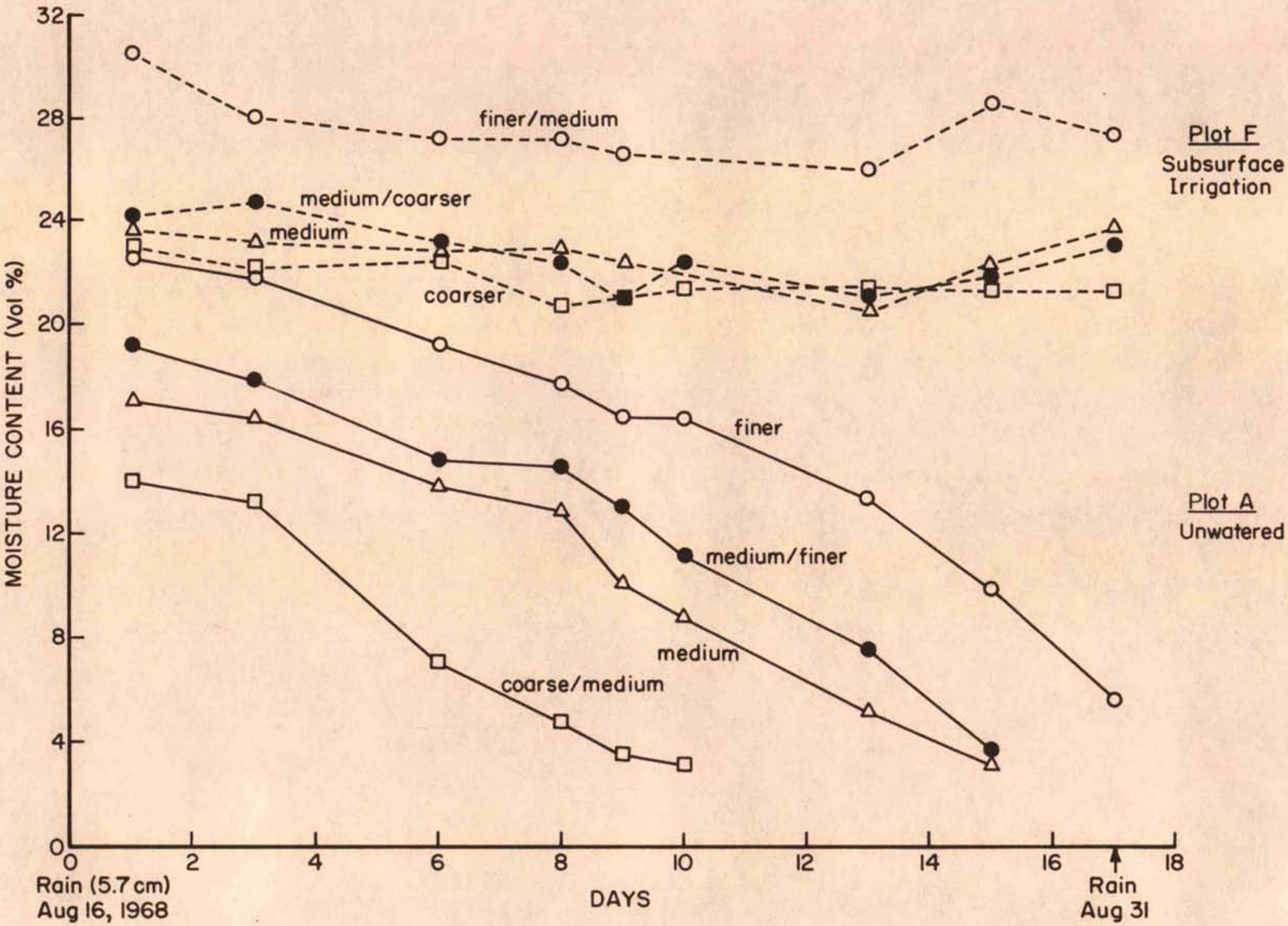

MOISTURE CONTENT (Vol %)
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
16
18
Rain (5.7 cm)
Aug 16, 1968
DAYS
Rain
Aug 31
finer/medium
medium/coarser
medium
coarser
Plot F
Subsurface
Irrigation
finer
medium/finer
medium
coarse/medium
Plot A
Unwatered

Figure I-9.

The wilt ratings for the subirrigated plots in F were all in the 1-2 range throughout the 17 days which indicated no apparent moisture stress. The wilt ratings for the dune sand plots in A presented in Figure I-5 illustrate that all of the treatments had moisture stress but there was a considerable difference in the number of days to severe wilt depending on the size fraction of the sand.

Comparison of dry-down moisture data for the A and F plots shows that subsurface irrigation can provide a means of supplying the evapo-transpiration needs of turf. The moisture content of the subirrigated dune sand plots in F remained fairly constant throughout the 17 day test period. Distribution of water stored above plastic by wick or capillary action to the turf roots provides a promising method of irrigating golf greens and tees. Continual supply of moisture to replenish that lost through evapo-transpiration is especially desirable during the hot afternoon hours when demand is greatest. Uniform playing conditions throughout the day is another important feature of the plastic lined, subsurface irrigated sand rootzones.

The most desirable depth for the watered table depends on the sand used in the rootzone. Bingaman and Kohnke (6) established guidelines for sand selection based on mechanical analysis data of the sand. They recommend that the sand be uniform and that most of the particles be in the fine and medium sand size range. The depth of the water table then is a function of the fineness of the sand where the general rule is the finer the sand, the deeper the water table.

During the 1968 growing season, the water table was maintained about 20 cm below the surface for the F plots so that the shallowest plot, F-4, would be subirrigated. By the end of the summer, the finer and medium dune sand treatments in F had become reduced by anaerobic microoganisms due to the poor aeration within the rootzones. The sand color changed from light brown to varying shades of gray and a stagnant odor was very evident when cups were cut in the finer sand plots. This problem was avoided during the 1969 season by lowering the water table to 30 cm. Thus, only the two deepest plots (F-1, 40 cm and F-2, 35 cm deep) were subirrigated during the summer of 1969.

Variable Depth Plots

The rate of dry-down for the variable depth plots without plastic lining on the south side of the green is shown in Figure I-10. The rootzone material was 2-1-1 mix (mortar sand-Dialoam-peat) for all plots and the depth to subsoil was 10, 15, 20, and 25 cm. The data in Figure 10 are the average of 4 replicates for each of the 4 depths to subsoil in Plot I. The F value for the treatments was significant (0.05 level of confidence) and the L.S.D. within any one time periods was 2.32 (see Appendix).

The average moisture content for the 10 cm deep plots ranged from 24.2 to 11.8% for the nine days and had a significantly higher moisture content than the other three depths except for the first day. The moisture contents of the 15, 20 and 25 cm deep plots did not differ significantly and ranged from about 22% after the rain to 9% at severe wilt.

The variable depth plots started to show wilt on the 7th day after the rain and by the end of the 9th day, most were showing severe wilt. The moisture stress appeared more severe on the 20 and 25 cm deep plots compared with the shallower plots. The difference in wilt between the

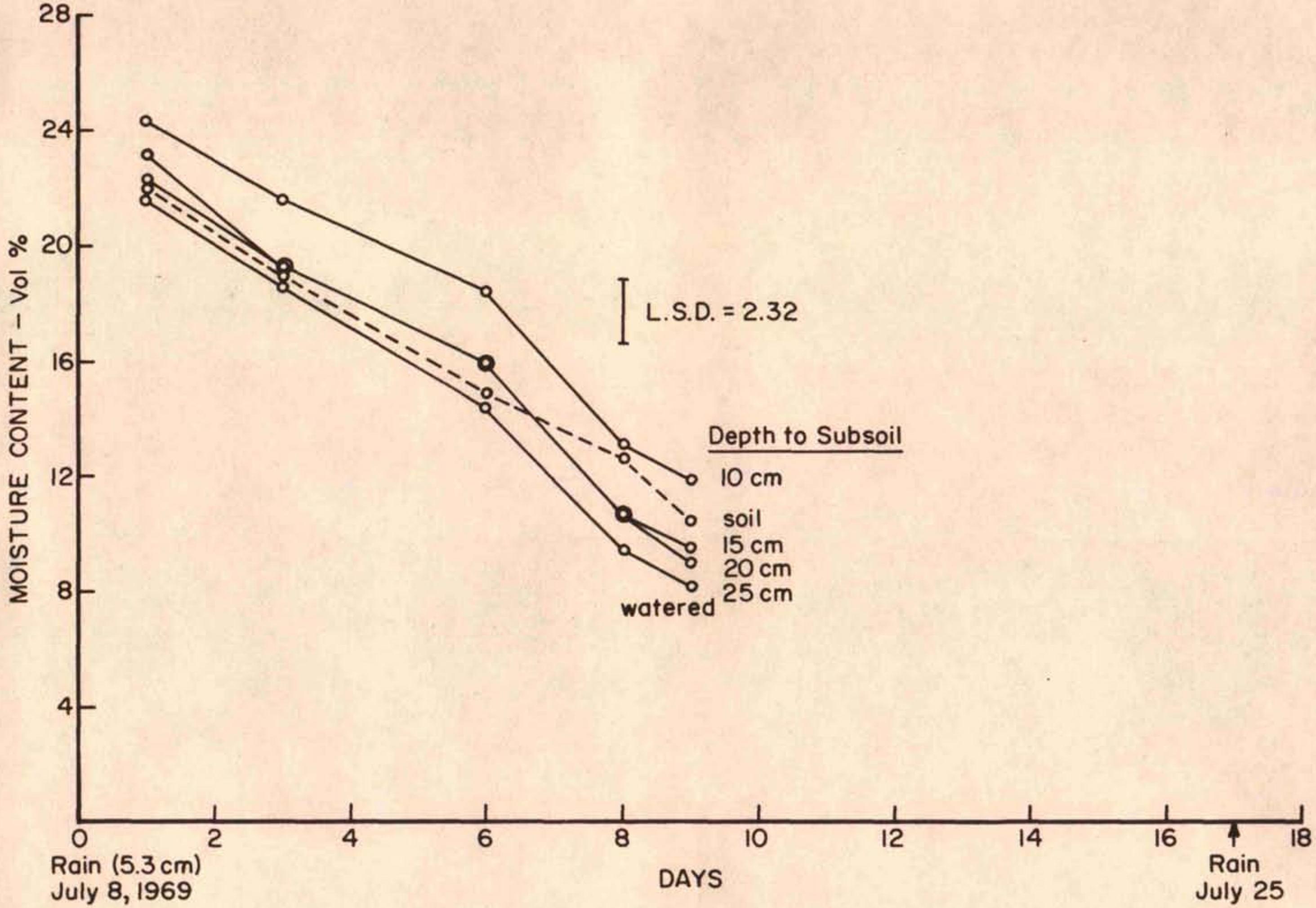


Figure I-10. Daily Moisture Content of Variable Depth Plots (Dry-down II) treatments was not considered sufficient to warrent individual watering of the plots on the 9th day so all plots were watered at the same time.

The soil in the center of the green showed about the same rate of moisture loss as shown in Figure I-10 and was watered on the same day as the south plots. The moisture retention of the shallower plots was as good as, but not much better than, the soil in the center of the green.

Richards et al.(33) found that the amount of water retained following drainage was a function of depth in a thoroughly wetted shallow soil. Work by Gardner and Fireman(15) showed that shallow lysimeters, when drained, retained more water per unit depth of soil than did those of greater depth.

Root Growth

The extent of the root system for the bentgrass throughout two growing seasons for all rootzone materials under study appeared adequate to supply the turf's moisture and nutrient requirements. New growth of roots was observed only during the winter and early spring months when the roots appeared thick and white. As the weather turned warmer in May and June the roots appeared to turn brown and become smaller in diameter. No new root development was observed during the hot summer months but there was no noticeable reduction in overall root depth. These observations agree with those reported by Stucky(38) and Beard and Daniel(4) on the seasonal growth of bentgrass.

Monthly root data for the 1969 growing season in Table I-5 show that roots were between 10 and 20 cm deep in all materials under test throughout the season. Data for the 1968 season was similar to that presented for 1969. Note that for the variable depth to subsoil plots (I & J) the

TABLE I-5. Monthly Root Depth Measurements for 1969 Growing Season

Plot	Treatment	Root Depth - cm Date - 1969 4/25	5/29	6/26	7/31	8/29	9/30	10/31
I & J*	Depth to Subsoil 10 cm	11.6	11.6	11.5	12.7	12.7	11.6	11.2
	15 cm	14.5	14.8	15.2	15.4	15.5	14.2	14.2
	20 cm	13.0	14.2	14.6	16.4	16.1	15.9	15.8
	25 cm	13.4	14.2	14.9	16.6	15.3	16.8	16.8
K*	2-1-1 sand-CC-Peat	12.2	13.6	13.7	13.5	12.6	13.4	12.5
	3-1 sand-peat	13.1	13.8	14.8	14.2	14.0	13.2	12.8
A-2-1	Dune sand C/M	11	15	14	15	17	15	
2-2	" " M/F	15	13	14	13	13	13	
2-3	" " M	10	14	14	14	13	16	
2-4	" " F	11	15	14	14	13	16	
C	100 Cal. clay	14	15	15	17	17	18	18
	100 Dialoam	12	14	14	11	15	18	18
	80-20 CC-peat	13	16	19	17	15	18	17
Soil check-center		8	11	10	13	13	8	10

* Data are average of 8 replicates

roots were into the soil for the 10 cm deep plots and down to the subsoil for the 15 cm deep plots. The F value for the four depth treatments was highly significant and the L.S.D. was 2.57 (see Appendix). Thus, the difference in root depth between the 15, 20, and 25 cm deep plots was not significant while the difference between the 10 cm deep plot and any of the other three is significant. This would be expected since relatively few roots were found in the subsoil in the shallowest plots.

The picture of one replicate of the variable depth plots taken on August 29, 1969 in Figure I-12 shows the large number of roots in the three deeper treatments compared to the 4" (10 cm) treatment. Note the large amount of peat clinging to the roots for all samples. Pictures were taken for all the monthly measurements for comparison of similar plots throughout the season.

The depth of roots in the two different materials in Plot K did not differ significantly. The depth to subsoil of the rootzone material was 15 cm for both materials. Root depth average was between 12 and 15 cm for both the 2-1-1 (mortar sand-calcined clay-peat) and 3-1 (mortar sand-peat) treatments throughout the growing season.

Root depth for the Lake Michigan dune sand plots varied from 10 to 16 cm for the 1969 season (Table I-5). The difference between the three size fractions was not considered significant. The roots in the dune sand did appear to maintain their white color longer into the summer than the other materials as can be seen in the comparison photograph in Figure I-11. Note the thicker, whiter appearance of the roots in the A-1-3 sample of dune sand compared to the C-1-1 calcined clay sample.

The calcined aggregate plots in C had good roots throughout 1969 as

Figure I-11. Root Growth in Four Materials on Experimental Green in June, 1969.

J-4-4 (2-1-1 mix of mortar sand-Dialoam-peat)
Soil (silt loam, center of green)
C-1-1 (100 calcined clay-Turface)
A-1-3 (Lake Michigan dune sand-finer fraction)

Figure I-12. Root Growth in Variable Depth of Materials Plots in August, 1969.

(2-1-1 mix of mortar sand-Dialoam-peat)

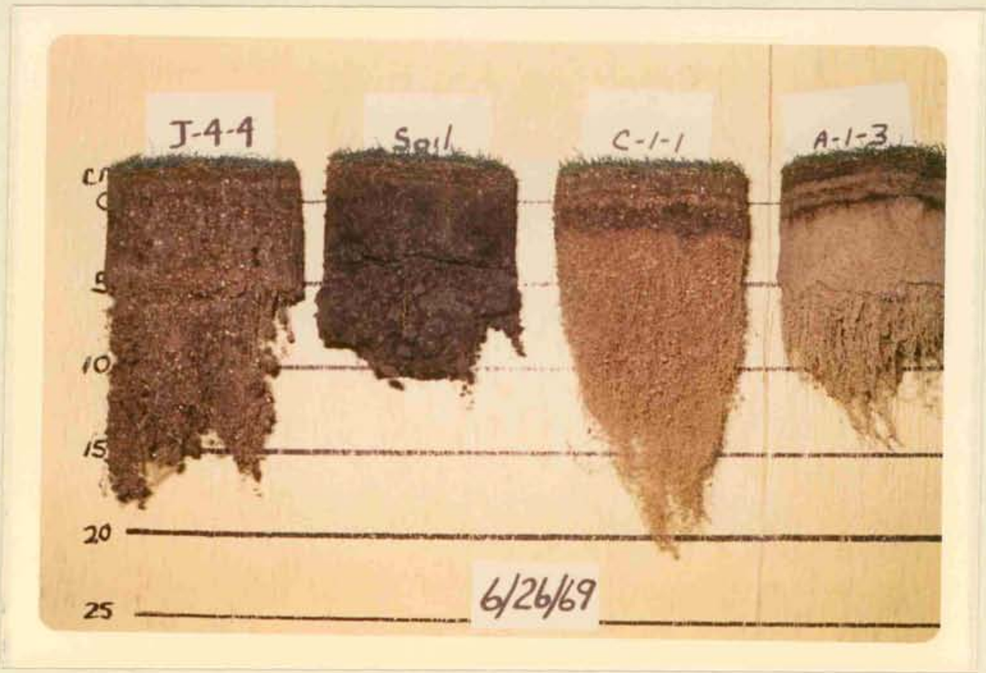


Figure I-11.

Figure I-12.

shown in Table I-5. The values ranged for 12 to 18 cm in depth for the three treatments reported. In the picture in Figure 11, note the large number of fine roots for the C-1-1 plot which is 100% Turface treatment. An interesting observation was made when the comparison photograph was taken at the end of May. Both thick, white roots and smaller diameter, brown roots were apparent in the Turface sample when it was first taken from the plot. It was placed on the support for the picture and within a few minutes the drying action of the breeze caused the white roots to shrivel and turn brown. By the time the sample was replaced in the plot, all the roots were spindly and brown in color.

It is felt that the same thing happened to the turf roots on the green. As the temperatures increased and the plots were permitted to dry out during the summer, the roots turned darker in color and tended to become smaller in diameter. The overall depth of the roots did not appear to be affected by the change in color and diameter of the roots. The study reported in Chapter II illustrates the importance of temperature as well as the effect of water table depth on root development.

Root depth in the silt loam soil in the center of the experimental green was between 8 and 13 cm for the 1969 season but the total number of roots for a given volume of material was considerably less than for the test materials. The comparison picture in Figure I-11 shows the plug of soil with relatively few roots at the bottom compared to the other three materials. Except for the first measurement in May, the roots in the soil throughout the summer months were very thin and spindly. Lunt[29] stated that it is a common observation to find but few active roots below a depth of 5 cm on a putting green. Roots were found down to 13 cm for the soil but the relative activity of the roots is questionable.

Several methods for comparison of root growth were attempted but none was found to be completely satisfactory. The values reported are a rough estimate of root depth in the plots but they give no information on the relative number of roots or the root activity. The method of counting the total number of roots at selected depths in the profile used by Beard[4] was not used because of the large numbers of roots found in the test materials. The methods which involve separation of the roots from the rootzone material were rejected because of the problem of separating the peat from the roots. It was not possible to remove the peat without loss of the roots imbedded within the peat material. Therefore, the oven dry weight of roots and the total length of root procedures used in the controlled climate study reported in Chapter II were not practical for use in the field experiments.

The important thing to recognize is that the big difference in root growth was between the bentgrass grown on soil and that grown in the test materials. The large number of roots in the 10 to 20 cm depth for most of the porous materials indicated that the turf could utilize this volume of material for moisture and nutrient needs. Considerably fewer roots were observed at these depths for the bentgrass in the soil.

SUMMARY

This study has demonstrated that coarse textured rootzone materials, when placed above plastic sheeting or in shallow layers above subsoil, can provide a desirable rootzone for putting green turf. The rootzone materials, such as sand and calcined aggregate, have the ability to permit rapid removal of excess water during wet weather; yet retain enough moisture to supply the evapo-transpiration needs of the turf. The amount of moisture retained was found to be dependent upon the type of construction and the texture of the rootzone material.

Data for the two dry-down experiments conducted in August, 1968 and July, 1969, which is summarized in Table I-6, show the relative ability of the various materials to retain moisture under the two types of construction. The variable depth of material plots, which had no plastic lining, needed to be watered in the same number of days after the rain as the soil check in the center of the green. In comparison, many of the test plots which had plastic lining retained enough moisture after the rains to supply the turf's needs throughout the 15 day test period in 1968 and the 17 day experiment in 1969. The effect of sand texture on moisture retention is shown in the difference in number of days to severe wilt for the four dune sand treatments where the finer fractions retained more moisture than did the coarser fractions.

The available moisture for the various treatments presented in Table I-6 was calculated from the difference between the moisture content

TABLE I-6. Summary of Data

Type of Construction	Rootzone Material	Moisture Content Initial	Moisture Content At severe wilt	Available Moisture	Days to severe wilt 1968	Days to severe wilt 1969	Root Depth Ave
Plastic Lined	Dune Sand (A)	vol %	vol. %	vol. %	days	days	cm
(PURR-Wick)	Finer	22.6	5.6	17.0	15+	17+	13.8
	Medium Finer	19.2	3.6	15.6	15	15	13.0
	Medium	17.0	3.0	14.0	15	15	13.5
	Coarser/medium	14.0	2.2	11.8	13	11	14.5
	Calcined Aggregate						
	100 (CC)	24.8	16.1	8.7	5	9	16.3
	80-20 (CC-Peat)	25.3	17.1	8.2	6	11	16.6
	60-20-20 (CC-DS-P)	26.5	22.5*	---	15+	17+	16.0
	40-40-20 (CC-LS-P)	22.9	18.4*	---	15+	17+	15.4
	Dialoam	29.0	25.4*	---	15+	17+	14.6
No Plastic	2-1-1 (L.S.-Dialoam-P)						
Variable	10 cm	24.2	11.8	12.4	6	9	11.8
Depth	15 cm	23.0	9.5	13.5	6	9	14.8
to Subsoil	20 cm	22.1	9.0	13.1	6	9	15.1
	25 cm	21.5	8.1	13.4	6	9	15.4
Check Plot	Silt loam Soil						
	Center of green	22.2	10.5	11.7	6	9	10.4

* - Moisture content when rain terminated experiment - no wilt.

+ - Plot not showing severe wilt on final day of experiment.

on the first day after the rain and the moisture content at severe wilt for the 1969 dry-down experiment. The dune sand treatments in Plot A varied from 17 percent for the finer fraction to 11.8 percent for the coarser/medium treatment. Available moisture for the high percentage calcined clay plots over plastic was considerably lower at 8.7 percent. The available moisture in the plastic lined plots which contained sand and peat could not be determined since the plots did not reach severe wilt during the 17 day test period.

The available moisture in the variable depth to subsoil plots was about 13 percent which compared with the 11.7 percent found for the silt loam soil check plot.

The summary of the root depth data presented in Table I-6 is the average for the 1969 months from May to October. The root system for all test materials was considered more than adequate to supply the moisture and nutrient requirements of the turf under normal growth conditions. Root depth was between 10 and 20 cm for the test materials and the total number of roots was considerably more than for the turf in the soil check plots.

The infiltration rates for all test plots were above 3 in/hr and most were between 10 and 20 in/hr compared to the soil check which was less than 1 in/hr. Water movement through the porous materials should not become a limiting factors since the materials were compacted during construction to essentially stabilize the pore size. This is possible since the size of the pores is a function of the particle size and not a function of the size or stability of aggregated material in the rootzone, as is often the case when soil is included in the mix. Therefore, further compaction by traffic during wet periods should not affect the management of the turf on the rootzones. If infiltration rate is reduced by a thatch or dust layer at the surface, it can be improved by aerification and top-dressing to assure continued ample infiltration.

Management of the test plots through the 1968-69 growing seasons was the same as for the soil in the center of the green except for the fertility program. The porous materials required more frequent application than did the soil but this was not considered a serious limitation since the level of fertility could be maintained as desired. Cup cutting in the porous materials was not a problem after the root system was well established.

The playing surface of the test plots was firm and the smoothness could be attained by the normal topdressing procedures. One important feature of the high sand content rootzones is their ability to remain firm through the late winter and early spring period when play is often desired.