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THE EFFECTS OF ROOT ZONE DEPTH AND SOIL TYPE ON SURFACE MOISTURE UNIFORMITY ON A SLOPED USGA PUTTING GREEN

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THE EFFECTS OF ROOT ZONE DEPTH AND SOIL TYPE ON SURFACE MOISTURE UNIFORMITY ON A SLOPED USGA PUTTING GREEN

By

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ABSTRACT

THE EFFECTS OF ROOT ZONE DEPTH AND SOIL TYPE ON SURFACE MOISTURE UNIFORMITY ON A SLOPED USGA PUTTING GREEN

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The United States Golf Association (USGA) specification for putting green construction requires a uniform root zone mix depth of 30 cm over a pea gravel layer. Greens constructed to these specifications have experienced soil moisture problems especially in areas of undulation. Lateral flow of water has lead to excessive soil moisture in low areas, and insufficient soil moisture in elevated areas. A sloping putting green with two construction types, and three different soil types was constructed at the Hancock Turfgrass Research Center at Michigan State University. The two construction types were: the standard USGA, with a uniform root zone depth of 30 cm; and a modified USGA, with a variable root zone depth of 20 and 40 cm at the highest and lowest elevations, respectively. The three soil types were: sand, sand/peat and sand/soil root zone mixes. Time domain reflectometry was used to measure volumetric soil moisture content (VWC) at four locations within each profile.

The results show that the addition of peat and/or soil to the root zone mix increased the water holding capacity; however, increasing the water holding capacity of the root zone mix had a limited effect on improving the uniformity of VWC across all locations of a sloped putting green. The modification of the root zone depth, regardless of soil type, resulted in more uniform moisture contents within the 0-20 depth, across all locations of a sloped putting green.

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INTRODUCTION

The quality of a golf course is largely determined by the condition of the putting greens. A great deal of time and money is spent maintaining putting greens to the standards golfers have come to expect. To maintain high quality putting surfaces, a golf course superintendent must institute superior mowing, fertilization, cultivation, and irrigation programs.

Mowing, fertilization, and cultivation are flexible cultural practices that can be tailored to fit the unique and variable growing conditions of individual putting greens, however, irrigation is less flexible. Irrigation on an individual putting green is dependent on the initial installation of the in-ground irrigation system, and on the design of the putting green. While irrigation systems are designed to apply a uniform amount of water to the irrigated area, even the most effective design can be rendered ineffective if the irrigated area does not “dry out” uniformly.

For 40 years the United States Golf Association (USGA) has provided specifications for the construction of putting greens. The USGA specifies that a uniform 30 cm layer of a sand-based root zone mix be placed over a 10 cm layer of pea stone or gravel. The sand-based root zone mix provides adequate aeration and is resistant to compaction. Placing the sand mixture over gravel increases the water holding capacity of the sand while avoiding complete saturation of the root zone following irrigation or rainfall (Dougrameji, 1965). Putting greens constructed to USGA specifications function very well on a level putting surface (Taylor et al., 1993); however, when the green has undulating areas, moisture extremes in the rootzone may lead turfgrass decline (Prettyman and McCoy, 1999).

Two conditions associated with moisture extremes in the rootzone are localized dry spot (LDS) and black layer (Cullimore et al., 1990; Berndt and Vargas, 1992; Wilkinson and Miller, 1978). Both impair turfgrass growth and can be problematic on undulating USGA putting greens.

Localized dry spot (LDS) appears on putting greens as small irregular areas of stressed turfgrass (Karnok and Tucker, 2001). The sand particles in these areas have become hydrophobic, making it difficult to return to optimum moisture levels (Hudson, et al., 1994). The formation of LDS is not well understood; however, LDS occurs most frequently in dry sandy soils (Cisar et al., 2000). The best method to avoid the formation of LDS is to maintain adequate soil moisture (Wilkinson and Miller, 1978; Henry, 1970). Localized dry spots are normally a problem on high areas of an undulating USGA green.

Black layer is the term used to describe a black banding of the root zone in sand based putting greens. Putting greens provide can be an ideal growing environment for cyanobacteria and other organisms that are responsible for the formation of black layer: "The abundance of water, nutrients, light, and calcareous sands often used in the construction of high-sand greens provide ideal conditions for cyanobacterial proliferation" (Hodges, 1992). The formation of black layer reduces the internal drainage of putting greens due to the cyanobacteria produced organic matter that fills the pore spaces in the sand material (Bond, 1964 and Fogg, 1973). While several explanations have been suggested for the cause of turfgrass decline associated with black layer, one constant has been anaerobic conditions in the soil profile due to near saturated conditions (Elliot, 1998). Black layer formation can become a problem on low areas of undulating USGA putting greens.

Moisture extreme problems on USGA putting greens can be attributed to the uniform depth of the root zone layer. On a level putting surface, equal gravitational potential results in minimal lateral flow of water, and the putting green dries at a uniform rate. On an undulating putting green, unequal gravitational potential results in the lateral flow of water from the higher elevations to lower elevations, and the putting green does not dry at a uniform rate. A root zone layer of uniform depth on an undulating putting green does not compensate for the lateral movement of water, resulting in soil moisture contents in the low elevations to be greater than soil moisture contents in high elevations, making it difficult to maintain an optimum moisture level across the entire putting green with an in-ground irrigation system.

The objective of this research is to determine whether a modification of the depth of the root zone layer will increase the uniformity of soil moisture levels in USGA putting greens. Reducing the depth of the root zone layer at the peak of a slope from 30 cm to 20 cm will potentially increase the soil moisture at the surface, reducing the occurrence of LDS. Increasing the depth of the root zone layer from 30 cm to 40 cm at the base of the slope will potentially reduce the amount of water at the surface, reducing the occurrence of black layer formation.

LITERATURE REVIEW

According to the United States Golf Association (USGA) "the putting green is all the ground of the hole being played which is specially prepared for putting, or otherwise defined as such by the committee" (USGA, 2002). To play a model round of golf on a par 72, 18-hole course, 36 shots will be putts played on the putting green, "which represents approximately 1.6 % of the total area of the golf course" (Beard, 2002). Dave Pelz observed that a foursome left as many as 500 footprints on each putting green (Pelz, 2000). Bengeyfield (1963) calculated that if golfers wore shoes averaging 24 spikes per pair, two hundred golfers would leave 72,576,000 spike marks daily on the putting greens of an 18-hole golf course. The large amount of traffic that is concentrated on putting greens results in excessive turfgrass wear and soil compaction leading to a decline in turfgrass quality.

In the earliest days of golf course construction many putting greens were constructed by pushing and shaping the existing soil to achieve the desired contoured putting surface, hence the term of "push-up" green. Because of the variability in soils, golf course superintendents were often forced to employ different maintenance practices on each putting green to achieve uniform playing conditions. In the late 1940's and early 1950's, in an effort to improve the overall quality of golf courses, the USGA began examining the soils used in the construction of putting greens (Latham, 1990).

In one of the earliest USGA-funded studies (Humbert and Grau, 1949), golf course superintendents supplied one soil sample from their best putting green, and one from their worst, so that soil characteristics could be compared. The most notable difference between the two samples was in pore size distribution. The samples from the good greens had a better balance of small pores to retain moisture, and large pores to support drainage. Although the authors stressed that no definitive conclusions could be made without further research, they did recommend that "in the construction of new greens, or in the rebuilding of old ones, the total sand content be developed to 50 or 65 percent, and the clay content be held below 15 percent" (Humbert and Grau, 1949). The use of a high sand content soil, with low clay content, was suggested as a means to reduce the effects of compaction.

The effect of traffic on soil compaction can be severe. A study conducted at Pennsylvania State College (Alderfer, 1951) reported that foot traffic on test plots with an unspecified soil type reduced the water infiltration rate (from 1.7 to 1.2 cm per hour), increased water runoff (from 52 to 67%), and reduced "non-capillary" porosity in the upper 2.54 cm of the soil (from 19.2 to 8.6%). Comparing the effect of "trampling" on two different soil types, clay loam and sandy loam, showed no difference in the amount of permeability, runoff, and "non-capillary" porosity in the upper 2.54 cm of either soil. Alderfer, however, did not ascertain the ratio of sand, silt, and clay of each soil type.

By 1956, soil specifications for putting green construction were becoming more precise. Lunt (1956) noted that the lack of oxygen, associated with reduced porosity, might be a reason for turfgrass decline in areas of heavy traffic. In a laboratory study, Lunt examined the effect of compaction on porosity in soils with different sand contents, and concluded that soil required a minimum of 85% sand to reduce the effects of compaction encountered on a putting green. When columns of soil (85% sand) were compressed, a 10.2 cm layer of sand was sufficient to protect an underlying soil from the effects of compaction. Particle size distribution of the sand materials was analyzed and

Lunt determined that in a desirable sand mixture, 75% of the sand particles should be in the 0.4 to 0.2 mm range, with no more than 6-10% smaller than 0.10 mm.

A field study was conducted by Kunze et al. (1957), to determine the ratio of sand, soil, and peat best suited for putting greens. The best ratio should hold enough moisture for turfgrass growth, while providing adequate drainage to remove excess amounts of water. Test plots were constructed using various particle sizes, and mixtures of sand, soil, and peat. To evaluate the effectiveness of the mixtures, clipping weights and percolation rates were compared before and after compaction. It was recommended that the soil mixture best suited for the construction of a putting green would have a sand, soil, peat ratio of 8:1:1, or 8.5:0.5:1 (Kunze et al., 1957).

In 1957, Dr. Walter Gardner, produced a time-lapsed movie titled "Water Movement in Soils". The movie demonstrated that water movement through a layer of fine-textured soil was interrupted (perched) as it came in contact with an underlying layer of coarse-textured soil. As Dougrameji (1965) explained, at the interface of the two soils, high moisture tension in the unsaturated small pores prevents movement of water into the larger pores below. As the fine-textured soil nears saturation, the moisture tension decreases to the point that water enters the large pores of the underlying course-textured soil.

The above studies laid the groundwork for the first USGA specifications for putting green construction in 1960 (The USGA Green Section Staff, 1960). The USGA cited two main reasons for publishing their specifications. At the time the number of golf courses being built, or rebuilt, was at an all time high. To keep maintenance costs low, many courses were building putting greens that were flat and featureless. The USGA felt that a standardized construction method would allow designers more creativity, while assuring owners that the greens would be easy to maintain. The second reason cited was that, as the number of golfers increased, the importance of drainage and resistance to compaction increased.

The 1960 specification for putting green construction was divided into seven individual steps, with "each step in construction dependent upon all the others" (The USGA Green Section Staff, 1960):

Step #1: Subgrade

Step #2: Drainage

Step #3: Gravel and Sand Base

Step #4: "Ringing the Green" (Preparing the area surrounding the green.)

Step #5: Soil Mixture

Step #6: Soil Covering, Placement, Smoothing and Firming

Step #7: Sterilization of Soil and Establishment of Turf

To provide good drainage and resistance to compaction, the 1960 publication specifies that putting greens be constructed by layering soils of different textures. A subgrade was to be excavated into the existing soil, 35.6 cm below the surface of the proposed putting green, with the same contour as the finished grade. Placed over the subgrade were 10.2 cm of gravel, 3.8 to 5.1 cm of coarse sand, and 30.5 cm of topsoil. It was specified that the topsoil meet certain physical properties. When compacted the topsoil should have a minimum total pore space of 33%, with 12 to 18% non-capillary pores, and 15 to 21% capillary pores (The USGA Green Section Staff, 1960). According to Hummel (1993) the permeability of the root zone mix, "expressed in terms used today", should have a saturated conductivity rate of 15 to 46 cm hr^{-1}.

The first USGA specification was very innovative. The topsoil root zone mixture provided the necessary aeration and drainage that previous research had shown to be important in a putting green. Placement of the root zone mixture over a coarse sand and a layer of gravel increased the water available to the plants, yet provided rapid drainage after heavy rains.

The USGA published revisions to the putting green construction specifications in 1973, 1989, and 1993. Modifications were made to all seven steps of the specification; however, one portion remained unchanged. There have been no changes to the specification that the root zone mix be a uniform depth of 30.5 cm. Putting greens constructed to USGA specifications function very well where the putting surfaces are horizontal (Taylor et al., 1993); however, when the green has undulating areas, moisture extremes in the root zone may contribute to turfgrass decline (Prettyman and McCoy, 1999). Two conditions associated with moisture extremes in the root zone are localized dry spot (LDS) and black layer. Both impair turfgrass growth and can be problematic on undulating USGA putting greens.

On putting greens, LDS appears as irregular patches of dry soil with moisture stressed turfgrass that are surrounded by moist soil and healthy turfgrass. Because the dry soil is hydrophobic, the LDS areas are very difficult to return to optimum moisture. Both humic (Roberts and Carbon, 1972) and fulvic acids (Miller and Wilkinson, 1977) have been identified as organic substances that coat soil particles and cause soils to become hydrophobic. Bond and Harris (1964) suggested that the cause of hydrophobic soils might be of fungal origin. The mycelium of Marasmius oreades (Bolt ex. Fr), a fairy ring producing fungi, have been shown to create hydrophobic conditions on putting greens in the United Kingdom (York and Canaway, 2000), however the exact cause of the phenomenon could not be ascertained. The exact cause of hydrophobic soils on putting greens is not known.

Wilkinson and Miller (1978) used scanning electron micrograph photographs (SEM) to examine soil particles taken from a high sand content green (85-90% sand). The SEM photographs revealed that sand particles in LDS areas had fungal mycelium present, and were coated with an irregular shaped material. There were no fungal mycelium or coatings on sand particles in areas of healthy turf. Heating the coated sand particles to 500° C removed the coating, revealing that the coating was an organic material. Washing the sand particles with 5% HCl did not remove the coating, however washing with 5% NaOH did, revealing that the material was an acidic material. Wilkinson and Miller (1978) concluded that the organic coating was a result of fungal mycelial growth that was responsible for the hydrophobic condition of the soil, however, since the fungi were not present at the time of testing it was not possible to identify the causal organism.

To control and/or reduce the effects of LDS on putting greens, Karnok, et al (1993) attempted to solubilize the organic coating by raising the pH of the soil. While putting greens treated with 0.1 M NaOH, and flushed with water, did show some reduction in soil hydrophobicity, the authors felt that the phytotoxic nature of NaOH may limit its use. Slow release fertilizers have been used to stimulate the microbial breakdown of waxes that form on soil particles. Slow release fertilizers increased the populations of wax degrading microorganisms, however during the heat of the summer, the accumulations of wax exceeded the microbial breakdown, and LDS was formed (Franco, et al., 2000).

The use of wetting agents and surfactants has been shown to temporarily reduce the hydrophobicity of LDS. Cisar, et al (2000) demonstrated that five different brands of surfactants improved the quality of turfgrass when compared to untreated plots. Three products drastically reduced the percent dry spot compared to the control plots (from 92.5% to 2.5%, 6.3%, and 10.0 %). Karnok and Tucker (2001) demonstrated that wetting agents improved turfgrass color and quality 78% of the time, and increased root length 27%, in the 0-7.6 cm depth. Karcher (1999) concluded that the combination of a wetting agent, with fungicide and water injection cultivation showed the potential to lessen the symptoms of LDS.

The best method to avoid the formation of LDS is to maintain adequate soil moisture (Wilkinson and Miller, 1978; Henry, 1970). The severity of hydrophobicity increases if the soil is allowed to dry. Frequent irrigation is often required to maintain high soil moistures, however this can be a problem in areas where water sources are scarce. Over watering can also lead to problems with the formation of black layer.

Black layer is a disorder that is commonly found on high sand content putting greens. A continuous or irregular subsurface blackened layer in the root zone characterizes Black Layer. Excessive amounts of water from rain or irrigation provide an environment for the formation of black layer (Elliot, 1998). The black layer may be formed by an assortment of bacteria or cyanobacteria that produce biofilms in the sand that impede drainage of water. The biofilms generate anaerobic conditions and provide organic matter that supports the formation of sulfate-reducing bacteria and the subsequent development of black layer (Hodges and Campbell, 1998). The black layer is often associated with a noxious sulfur odor, and over time the turfgrass may show symptoms of chlorosis, wilting, thinning, and eventually death.

Black layer formation results from the interaction of cyanobaterium growing on the surface of the putting green and the sulfate reducing bacterium Desulfovibrio desulfuricans (Hodges, 1992 A). Hodges observed the growth responses of creeping bentgrass (Agrostris palustris) grown in soil columns exposed to black layer formed by this interaction. He concluded that the organisms responsible for the formation of black layer were not the direct cause of death of creeping bentgrass, the roots of creeping bentgrass seem to have the ability to aerate the soil in the area of the black layer reducing the severity of black layer, and that shoot growth of creeping bentgrass is more sensitive to black layer formations than root growth (Hodges, 1992 B). To avoid the adverse effects of black layer, it is important to avoid excessive amounts of water in the root zone. Anything that impedes water percolation to create a waterlogged zone can initiate the formation of black layer (Carrow, et al, 2001). Smith (2001) suggests that reduced irrigation and improved soil drainage will help prevent the formation of black layer.

MATERIALS AND METHODS

A sloped USGA putting green was constructed at Michigan State University's Hancock Turfgrass Research Center in 1998. The putting green was designed for monitoring the down slope movement of water in the root zone. Time domain reflectometry (TDR) instrumentation was installed to monitor soil volumetric water content (VWC), and rain gauge tipping buckets were installed to monitor drainage.

The putting green was constructed with a summit 36.3 cm in height, with two downhill slopes of different magnitude (Figure 1). The peak of the summit was constructed 7.8 m from the northern edge of the green, and 16.7 m from the southern edge. North of the summit, the putting green has a seven percent slope (north slope) to the flat north toe slope. South of the summit, the putting green has a gradual three percent slope (south slope) to the flat south toe slope.

The putting green was divided into 15 plots, 2.5 m wide and 24.5 m long. Twelve of the plots were test plots, and three were utility strips built to accommodate the installation of monitoring equipment (Figure 2). Three root zone mixes were used in the construction of the test plots: four plots were built with a sand root zone, four plots were built with an 85:15 sand/peat root zone material, and four plots were constructed with an 85:15 sand/soil root zone material. The sand/peat root zone and sand/soil root zone mixes conform to USGA specifications (Table 1 and 2). The sand root zone mix does not conform to the USGA specifications for hydraulic conductivity and percent capillarity (Table 1 and 2).

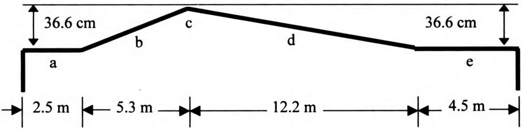

Figure 1. Cross sectional view, and dimensions of putting surface:
(a) north toe slope, (b) 7% north slope, (c) summit,
(d) 3% south slope, and (e) south toe slope.

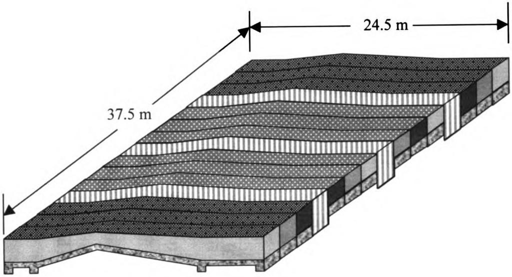

Figure 2. Three-dimensional diagram of the sloping green.

Standard plots
Modified plots
Maintenance strips
Sand plots
Sand/peat plots
Sand/soil plots

Table 1. Root zone mix physical properties.

		Root zone Mix		
Physical Properties	USGA Recommendation*	Sand	Sand/Peat	Sand/Soil
Organic Matter (%)	1-5	1.2	3.2	2.0
Hydraulic Conductivity (cm hr^{-1})	15-30	86.2	27.9	15.7
Bulk Density (g cm-3)	N/A	1.75	1.57	1.74
Particle Density (g cm-3)	N/A	2.64	2.35	2.66
Porosity:				
Total (%)	35-55	35.2	42.8	36.0
Capillary at 40 cm tension (%)	15-25	8.9	16.7	15.8
Air Filled at 40 cm tension (%)	15-30	27.3	26.1	20.2

*The USGA Green Section Staff, 1993.

Table 2. Root zone mix particle size distribution.

Particle Size (mm)	USGA Recommendation* (%)	Root zone Mix Sand (%)	Root zone Mix Sand/Peat (%)	Root zone Mix Sand/Soil (%)
2.0 - 3.4†	Maximum 10	0.1	0.1	0.8
1.0 - 2.0		7.6	7.3	12.0
0.5 - 1.0	Minimum 60	26.0	25.4	24.6
0.25 - 0.50		45.6	46.4	36.6
0.15 - 0.25	Maximum 20	19.1	18.3	16.6
0.05 - 0.15‡	Maximum 5	0.6	1.1	1.3
0.002 - 0.05‡	Maximum 5	1.2	1.2	7.9
< 0.002‡	Maximum 3			

*The USGA Green Section Staff, 1993.

† Maximum of 3%, preferably none.

‡ Maximum of 10% total between the three categories.

Six test plots were built to standard USGA specifications consisting of a uniform depth (30 cm) sand based root zone. The remaining six test plots were built with variable depth sand based root zone: 20 cm at the summit and 40 cm at the toe slopes (Figure 3).

A polyvinyl chloride liner was placed between adjacent plots to prevent the lateral movement of water between plots. Drainage tiles were installed at five locations within each test plot: at the extreme north and south end of each plot, the base of each slope, and 3.0 m from the summit on the south slope (Figure 3). Each tile was connected to a solid drainage tile that discharged either out the north or south end of the putting green. The amount of drainage from each location was quantified with a rain gauge tipping bucket (TE525, Campbell Scientific, Logan, UT.), connected to a series of multiplexers (MDX8, Campbell Scientific, Logan, UT.), that are controlled by a datalogger (CR10X, Campbell Scientific, Logan, UT.), programmed to record the amount of water draining from each individual drainage tile.

After the construction of the putting green was completed, 108 TDR probes (locally manufactured by B.R. Leinauer) were buried in the soil to measure volumetric soil moisture at four locations within each test plot: probe location 1 at the base of the north slope, probe location 2 at the summit, probe location 3 at the base of the south slope, and probe location 4 in the middle of the south toe slope (Figure 3). Each probe was electronically connected to a portable TDR 100 (Campbell Scientific, Logan, UT.) through a series of multiplexers (MDX50, Campbell Scientific, Logan, UT.) that are controlled by a data logger (CR10X, Campbell Scientific, Logan, UT), which is programmed for synchronized measurements at all 108 locations. The TDR probes were

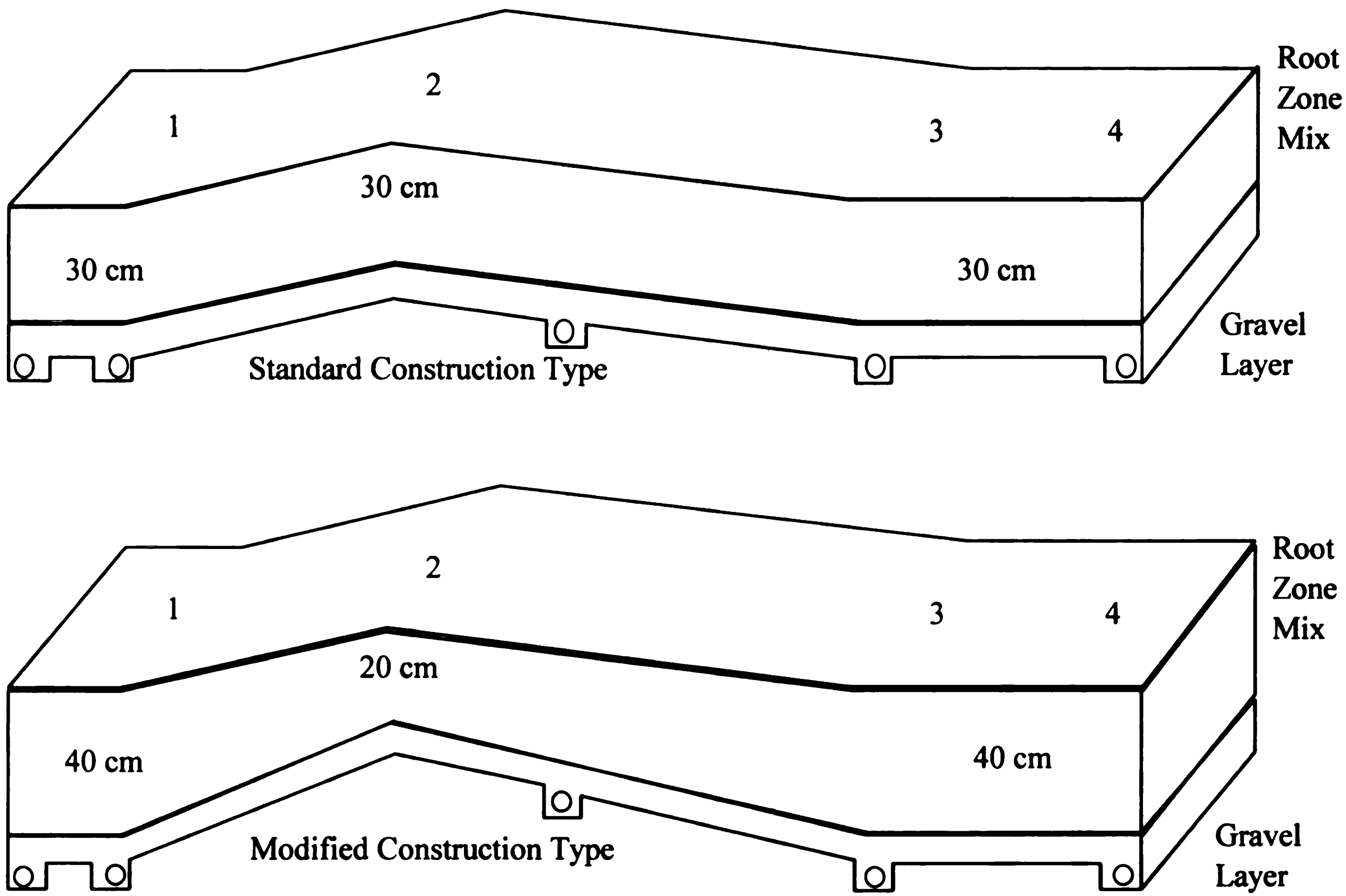

Figure 3. Cross sectional three-dimensional view of standard and modified construction types with TDR probe locations: (1) Location 1, (2) Location 2, (3) Location 3, and (4) Location 4.

positioned in the soil at a 45-degree angle to measure VWC at depths of 10-20, 20-30, and 30-40 cm. A hand-held TDR (Trime-FM, FM2, Mesa Systems Co., Framingham, MA) was used to record volumetric soil moisture contents at the four locations at the surface level (0-10 cm). The two TDR's were calibrated according to manufacturer's recommendations.

After installation of the TDR probes, in the summer of 1998, the putting green was seeded with creeping bentgrass (Agrostis palustris cv. L-93). After establishment the putting green was mowed five times a week at a height of 4.0 mm. The putting green was fertilized at an annual rate of 24.4 g $N \cdot m^{-2}$.

To evaluate water movement within the two construction types, and the three root zone materials, the putting green was subjected to "dry down" cycles, five cycles in the summer of 2000, and four cycles in the summer of 2001, and 2002. Dry down cycles were scheduled during dry periods without rainfall, and no irrigation was applied to the putting green. During each cycle, VWC was monitored daily with the 108 permanently installed probes connected to the TDR 100™, and with the hand held TRIME-FM™ TDR at the four locations in each plot. VWC readings were recorded at the 0-10 cm depth on 49 out of a possible 52 dates, and at the 10-20 cm depth on 44 out of 52 dates.

Each dry down cycle began with uniform, healthy turf across the entire putting surface. To establish near field capacity soil moisture content, irrigation (0.25 cm) was applied the night before each cycle, and the morning of "day 0" (1.25 cm). After the morning irrigation, TDR readings were taken at the four locations on each individual plot. The TDR readings were taken at 24-hour intervals for the length of the cycle. Each dry down cycle was ended when there were visible signs of severe turfgrass moisture stress.

Experimental design of the sloping green was a split plot design with two factors. The whole plot factor was construction type consisting of the standard and modified construction types. The split plot factor was soil type consisting of the sand, sand/peat, and sand/soil root zone mixes. For each dry down cycle statistical analysis was conducted independently on the daily VWC at the 0-10 cm and 10-20 cm depths, as these were the only depths present at each location within each test plot. Treatment differences were tested using Proc Mixed statistical analysis (SAS Institute Inc., 1999). When appropriate, means were separated using Fisher's LSD procedure.

RESULTS AND DISCUSSION

Five dry down cycles were completed in 2000, and four dry downs were completed in 2001 and 2002. During each dry down cycle, volumetric water content (VWC) was recorded at four locations at depths of 0-10, 10-20, 20-30, and 30-40 cm. Statistical analysis was conducted independently on the VWC at the 0-10 and 10-20 cm depths, as these were the only depths present at each location within each construction type.

At the 0-10 cm depth, the construction x location x soil interaction was significant on one out of a possible 49 dates, the location x soil interaction was significant on 26 out of 49 dates, the soil main effect was significant on all 49 dates, the construction x location interaction was significant on 35 out of 49 dates, and the location main effect was significant on 17 out of 49 dates. Analysis of variance for the VWC at the 0-10 cm depth is listed in Tables 3-5.

At the 10-20 cm depth, the construction x location x soil interaction was significant on two out of a possible 44 dates, the location x soil interaction was significant on 14 out of 44 dates, the soil main effect was significant on 37 out of 44 dates, the construction x location interaction was significant 28 out of 44 dates, and the location main effect was significant on 15 out of 44 dates. Analysis of variance for the VWC at the 10-20 cm depth is listed in Tables 6-8.

Table 3. Analysis of variance for 2000 volumetric water contents at the 0-10 cm depth, for dry down 1 (DD1) through dry down 5 (DD5).

		2000 Day 0					2000 Day 1				
		DD1	DD2	DD3	DD4	DD5	DD1	DD2	DD3	DD4	DD5
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	**	NS	NS	#	NS	NS	NS	NS	NS	NS
Location	3	NS	**	NS	#	NS	NS	**	NS	*	**
Const. x Loc.	3	**	*	**	#	**	*	**	**	*	*
Soil	2	*	*	*	#	*	*	*	*	*	*
Const. x Soil	2	NS	NS	NS	#	NS	NS	NS	NS	NS	NS
Loc. x Soil	6	NS	**	*	#	NS	NS	**	*	*	*
Const. x Loc. x Soil	6	NS	NS	NS	#	NS	NS	NS	NS	NS	NS

		2000 Day 2					2000 Day 3				
		DD1	DD2	DD3	DD4	DD5	DD1	DD2	DD3	DD4	DD5
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	**	NS	NS	NS	NS	NS	NS	NS	NS	NS
Location	3	**	**	NS	NS	*	NS	*	NS	NS	*
Const. x Loc.	3	*	**	*	**	*	*	*	*	*	*
Soil	2	*	*	*	*	*	*	*	*	*	*
Const. x Soil	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Loc. x Soil	6	*	NS	*	**	*	*	*	*	**	NS
Const. x Loc. x Soil	6	NS	NS	NS	NS	NS	*	NS	NS	NS	NS

*, **, and NS indicate significance at P=0.05, 0.10, and not significant at P=0.10, respectively.

No data.

Table 4. Analysis of variance for 2001 volumetric water contents at the 0-10 cm depth, for dry down 1 (DD1) through dry down 4 (DD4).

		2001 Day 0				2001 Day 1			
		DD1	DD2	DD3	DD4	DD1	DD2	DD3	DD4
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	NS	NS	NS	NS	**	NS	NS	**
Location	3	NS	*	NS	NS	*	**	**	NS
Const. x Loc.	3	*	NS	NS	NS	*	*	*	*
Soil	2	*	*	*	*	*	*	*	*
Const. x Soil	2	NS	NS	NS	NS	NS	NS	NS	NS
Loc. x Soil	6	NS	NS	**	**	*	*	NS	*
Const. x Loc. x Soil	6	NS	NS	NS	NS	NS	**	NS	NS

		2001 Day 2				2001 Day 3			
		DD1	DD2	DD3	DD4	DD1	DD2	DD3	DD4
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	#	NS	NS	NS	NS	**	NS	NS
Location	3	#	NS	*	**	*	**	*	NS
Const. x Loc.	3	#	*	*	*	*	*	*	*
Soil	2	#	*	*	*	*	*	*	*
Const. x Soil	2	#	NS	NS	NS	NS	NS	**	NS
Loc. x Soil	6	#	NS	*	*	*	*	*	*
Const. x Loc. x Soil	6	#	NS	NS	NS	NS	NS	NS	NS

*, **, and NS indicate significance at P=0.05, 0.10, and not significant at P=0.10, respectively.
No data

Table 5. Analysis of variance for 2002 volumetric water contents at the 0-10 cm depth for, dry down 1 (DD1) through dry down 4 (DD4).

		2002 Day 0				2002 Day 1			
		DD1	DD2	DD3	DD4	DD1	DD2	DD3	DD4
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	#	NS	NS	NS	NS	NS	NS	NS
Location	3	#	*	**	NS	NS	NS	*	NS
Const. x Loc.	3	#	*	**	*	NS	*	*	NS
Soil	2	#	*	*	*	*	*	*	*
Const. x Soil	2	#	NS	NS	NS	NS	NS	NS	NS
Loc. x Soil	6	#	*	NS	**	NS	*	*	NS
Const. x Loc. x Soil	6	#	NS	NS	NS	NS	NS	**	NS

		2002 Day 2				2002 Day 3			
		DD1	DD2	DD3	DD4	DD1	DD2	DD3	DD4
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	NS	NS	NS	NS	NS	NS	**	NS
Location	3	*	*	*	**	NS	*	*	*
Const. x Loc.	3	*	*	*	**	*	*	*	*
Soil	2	*	*	*	*	*	*	*	*
Const. x Soil	2	NS	NS	NS	NS	NS	NS	NS	NS
Loc. x Soil	6	NS	*	*	NS	NS	NS	*	*
Const. x Loc. x Soil	6	NS	NS	NS	NS	NS	NS	**	NS

*, **, and NS indicate significance at P=0.05, 0.10, and not significant at P=0.10, respectiviely.

No data

Table 6. Analysis of variance for 2000 volumetric water contents at the 10-20 cm depth, for dry down 1 (DD1) through dry down 5 (DD5).

		2000 Day 0					2000 Day 1				
		DD1	DD2	DD3	DD4	DD5	DD1	DD2	DD3	DD4	DD5
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Location	3	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Const. x Loc.	3	**	NS	*	*	*	**	NS	**	*	**
Soil	2	*	*	*	**	*	*	**	**	**	*
Const. x Soil	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Loc. x Soil	6	*	*	*	*	*	*	NS	NS	*	*
Const. x Loc. x Soil	6	**	NS	**	NS	**	NS	NS	NS	NS	NS

		2000 Day 2					2000 Day 3				
		DD1	DD2	DD3	DD4	DD5	DD1	DD2	DD3	DD4	DD5
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	NS	NS	NS	NS	NS	#	NS	NS	#	NS
Location	3	NS	**	NS	NS	NS	#	*	NS	#	NS
Const. x Loc.	3	NS	**	NS	NS	**	#	*	*	#	*
Soil	2	*	*	**	NS	*	#	*	*	#	*
Const. x Soil	2	NS	NS	NS	NS	NS	#	NS	NS	#	NS
Loc. x Soil	6	*	**	NS	*	*	#	*	*	#	*
Const. x Loc. x Soil	6	NS	NS	NS	NS	NS	#	NS	NS	#	*

*, **, and NS indicate significance at P=0.05, 0.10, and not significant at P=0.10, respectively.
No data

Table 7. Analysis of variance for 2001 volumetric water contents at the 10-20 cm depth, for dry down 1 (DD1) through dry down 4 (DD4).

		2001 Day 0				2001 Day 1			
		DD1	DD2	DD3	DD4	DD1	DD2	DD3	DD4
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	**	**	NS	#	**	**	#	#
Location	3	*	NS	NS	#	*	**	#	#
Const. x Loc.	3	*	*	NS	#	*	*	#	#
Soil	2	*	*	NS	#	*	*	#	#
Const. x Soil	2	NS	NS	NS	#	NS	NS	#	#
Loc. x Soil	6	NS	NS	NS	#	NS	NS	#	#
Const. x Loc. x Soil	6	NS	NS	NS	#	NS	NS	#	#

		2001 Day 2				2001 Day 3			
		DD1	DD2	DD3	DD4	DD1	DD2	DD3	DD4
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	**	**	**	#	**	**	**	#
Location	3	*	*	*	#	*	*	*	#
Const. x Loc.	3	*	*	*	#	*	*	*	#
Soil	2	*	*	*	#	*	*	*	#
Const. x Soil	2	NS	NS	NS	#	NS	NS	NS	#
Loc. x Soil	6	NS	NS	NS	#	NS	NS	NS	#
Const. x Loc. x Soil	6	NS	NS	NS	#	NS	NS	NS	#

*, **, and NS indicate significance at P=0.05, 0.10, and not significant at P=0.10, respectively.

No data

Table 8. Analysis of variance for 2002 volumetric water contents at the 10-20 cm depth, for dry down 1 (DD1) through dry down 4 (DD4).

		2002 Day 0				2002 Day 1			
		DD1	DD2	DD3	DD4	DD1	DD2	DD3	DD4
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	NS	#	**	NS	**	**	NS	**
Location	3	NS	#	NS	NS	**	*	NS	NS
Const. x Loc.	3	*	#	*	*	*	*	**	*
Soil	2	*	#	*	*	*	*	*	*
Const. x Soil	2	NS	#	NS	NS	NS	NS	NS	NS
Loc. x Soil	6	NS	#	NS	NS	NS	NS	NS	**
Const. x Loc. x Soil	6	NS	#	NS	NS	NS	NS	NS	NS

		2002 Day 2				2002 Day 3			
		DD1	DD2	DD3	DD4	DD1	DD2	DD3	DD4
Source	Num DF	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Construction	1	**	**	NS	NS	**	**	**	NS
Location	3	*	*	NS	NS	*	*	**	NS
Const. x Loc.	3	*	*	**	**	*	*	*	NS
Soil	2	*	*	*	*	*	*	*	*
Const. x Soil	2	NS	NS	NS	NS	NS	NS	NS	NS
Loc. x Soil	6	NS	NS	NS	NS	NS	NS	NS	NS
Const. x Loc. x Soil	6	NS	NS	NS	NS	NS	NS	NS	NS

*, **, and NS indicate significance at P=0.05, 0.10, and not significant at P=0.10, respectively.

No data

Construction x Location x Soil Interaction:

Although the complexity of the construction x location x soil interaction led to infrequent statistical significance, the interaction demonstrated consistent practical significance. (See Appendix Tables 1A-14A for VWC construction x location x soil data for day 0 and day 3.)

Construction x Location x Soil Interaction: 0-10 cm depth

The construction x location x soil interaction was significant on day 3 of the first dry down in 2000 (Table 3). Within the standard construction type, the VWC at the peak of the slope, location 2, was less than the highest value among the four locations (Table 9). Within the modified construction type, the VWC at location 2 was equal to the highest value among the four locations (Table 9). Location 2 had a low VWC on all three of the soil types within the standard construction type, and a high VWC on all three of the soil types within the modified construction type.

The construction x location x soil interaction was significant, $\alpha = 0.10$, on day 1 and day 3 of the third dry down in 2002 (Table 5). At the beginning of the dry down, day 0, the effect of the irrigation event (1.5 cm) prior to the start of the dry down cycle resulted in no significant differences in VWC among the locations, soil types, and construction types (Table 10). After one, and three days without irrigation, within the standard construction type, location 2 had the lowest VWC among the four locations; however, within the modified construction type, the VWC at location 2 was equal to the highest VWC among the four locations (Table 10). Location 2 had a low VWC on all three of the soil types within the standard construction type, and a high VWC on all three of the soil types within the modified construction type.

Table 9. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the first dry down in 2000.

	Location			
	1	2	3	4
Standard Sand	16.1 B[†]d[‡]	14.1 Bc	20.2 Acd	19.5 Ac
Standard Sand/Peat	28.0 ABa	25.8 Bab	29.9 Aa	27.4 ABa
Standard Sand/Soil	27.1 Aab	23.1 Cb	26.2 ABb	23.9 BCb
Modified Sand	14.6 Bd	16.4 ABc	17.6 Ad	15.5 ABd
Modified Sand/Peat	24.1 Bb	28.4 Aa	22.0 Bc	23.3 Bb
Modified Sand/Soil	19.9 Bc	25.6 Aab	20.6 Bcd	21.5 Bbc

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

Table 10. Volumetric water contents for the construction x location x soil interaction, at the 0-10 cm depth for the third dry down in 2002.

	Location			
Day 0	1	2	3	4
Standard Sand	23.5[†]	23.2	23.3	22.8
Standard Sand/Peat	30.2	31.5	32.4	32.0
Standard Sand/Soil	29.7	30.6	30.6	30.6
Modified Sand	23.6	23.5	24.0	21.7
Modified Sand/Peat	30.2	32.8	30.1	29.2
Modified Sand/Soil	29.4	31.7	29.6	29.1
Day 1	1	2	3	4
Standard Sand	24.2 A[‡]c[§]	16.3 Bb	23.8 Abc	24.8 Ac
Standard Sand/Peat	33.4 Aa	27.4 Bab	33.2 Aa	31.5 Aa
Standard Sand/Soil	35.3 Aa	26.4 Cb	31.5 Ba	29.7 Bab
Modified Sand	18.8 Bd	22.1 Ac	21.1 Ac	20.7 ABd
Modified Sand/Peat	28.5 Bb	31.1 Aa	25.2 Cb	26.6 BCbc
Modified Sand/Soil	28.8 Ab	30.0 Aab	25.8 Bb	25.4 Bb
Day 2	1	2	3	4
Standard Sand	23.5	13.1	24.7	25.5
Standard Sand/Peat	32.9	26.6	32.4	31.1
Standard Sand/Soil	34.1	24.0	30.7	29.8
Modified Sand	17.0	18.2	18.4	17.6
Modified Sand/Peat	28.6	27.8	25.8	26.0
Modified Sand/Soil	26.8	28.0	25.0	25.1
Day 3	1	2	3	4
Standard Sand	20.8 Ac	11.8 Bd	21.1 Ac	22.2 Ab
Standard Sand/Peat	29.9 Aa	23.8 Ba	30.9 Aa	29.0 Aa
Standard Sand/Soil	31.4 Aa	20.3 Cb	28.0 Bb	28.1 Ba
Modified Sand	14.3 Ad	14.7 Ac	15.1 Ad	14.2 Ac
Modified Sand/Peat	24.3 ABb	26.1 Aa	22.2 Bc	22.0 Bb
Modified Sand/Soil	21.6 ABc	23.7 Aa	20.5 Bc	21.6 ABb

[†]Not significant at P=0.10.

[‡]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.10)

[§]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.10)

When the construction x location x soil interaction was significant, the results show that the modification of the root zone depth resulted in a more uniform VWC among the four locations within all three of the soil types (Figures 4 and 5). This trend was evident on day 3 of all of the dry downs, even on dates when the construction x location x soil interaction was not significant (See Figures 6-9 for 2001 data, and Appendix Figures 1A-7A for 2000 and 2002 data).

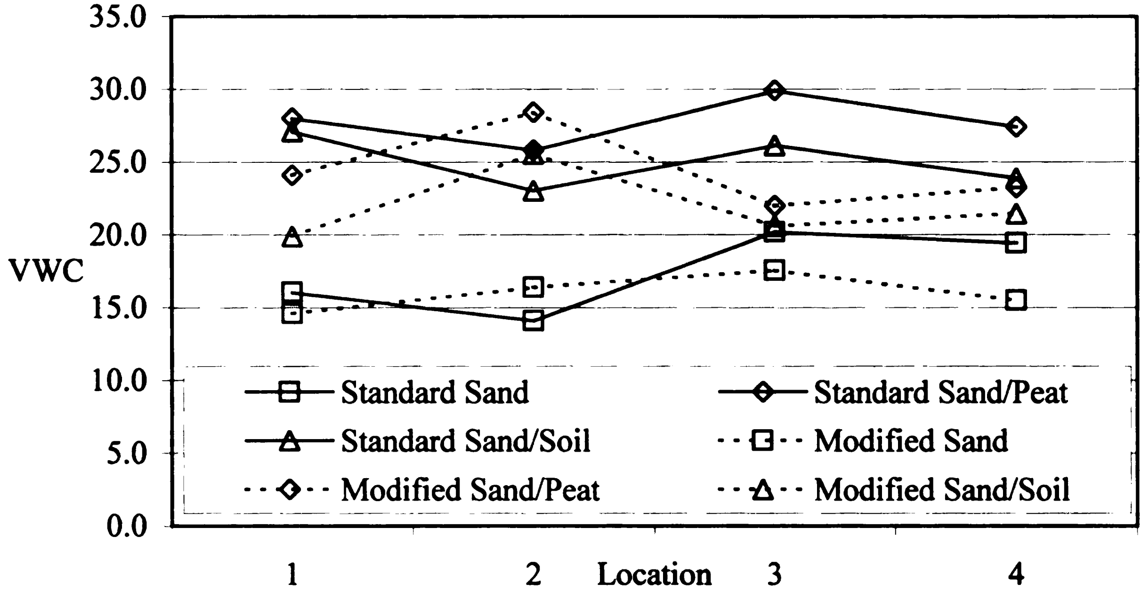

Figure 4. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the first dry down in 2000.

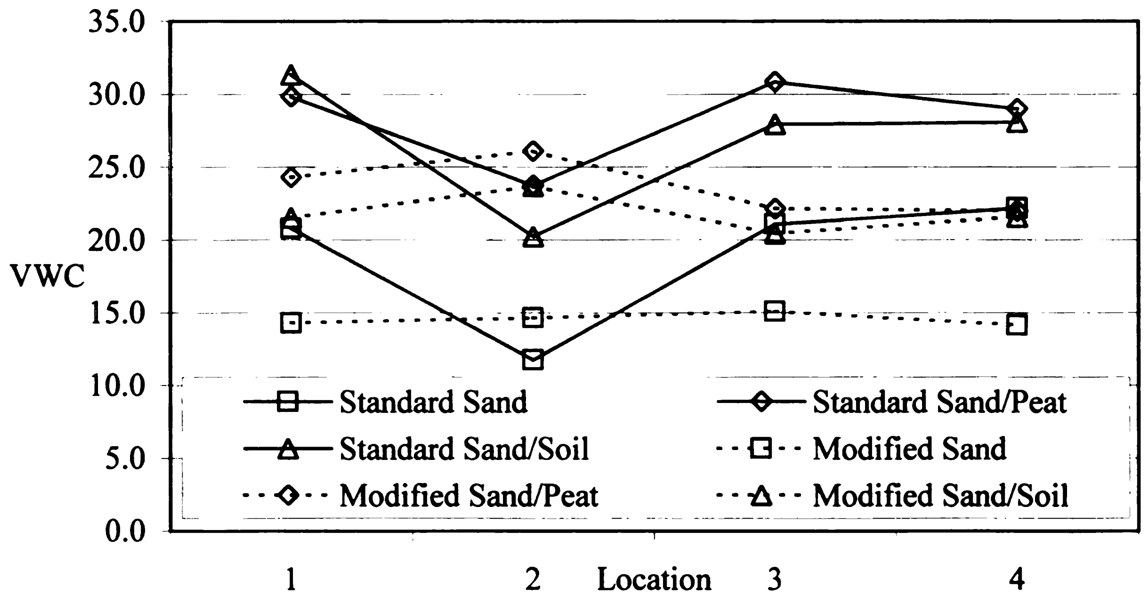

Figure 5. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the third dry down in 2002.

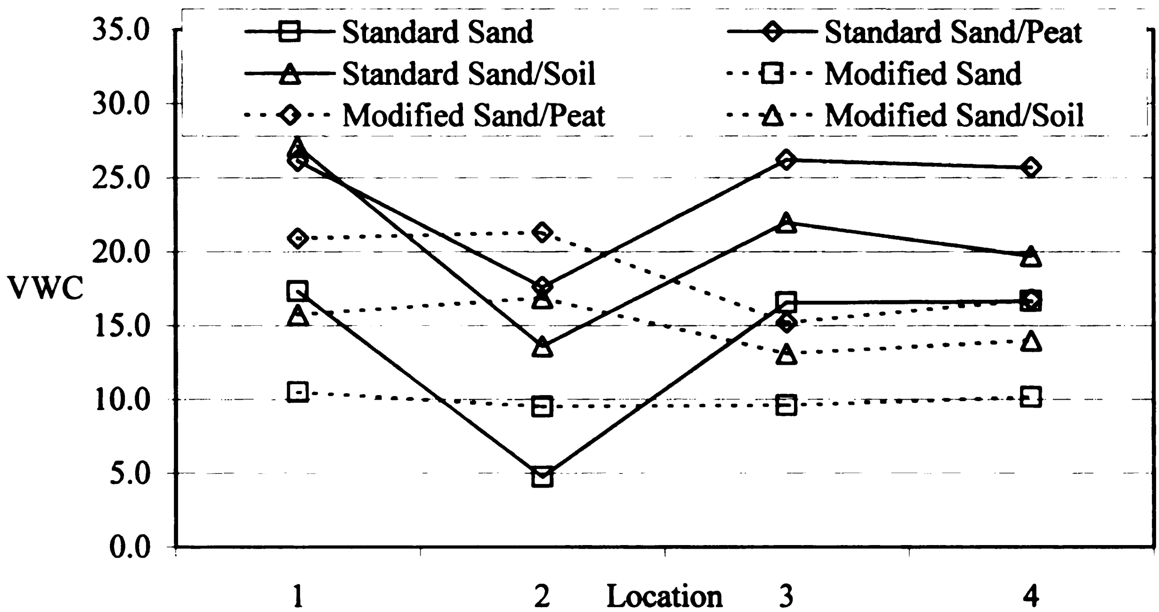

Figure 6. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the first dry down in 2001.

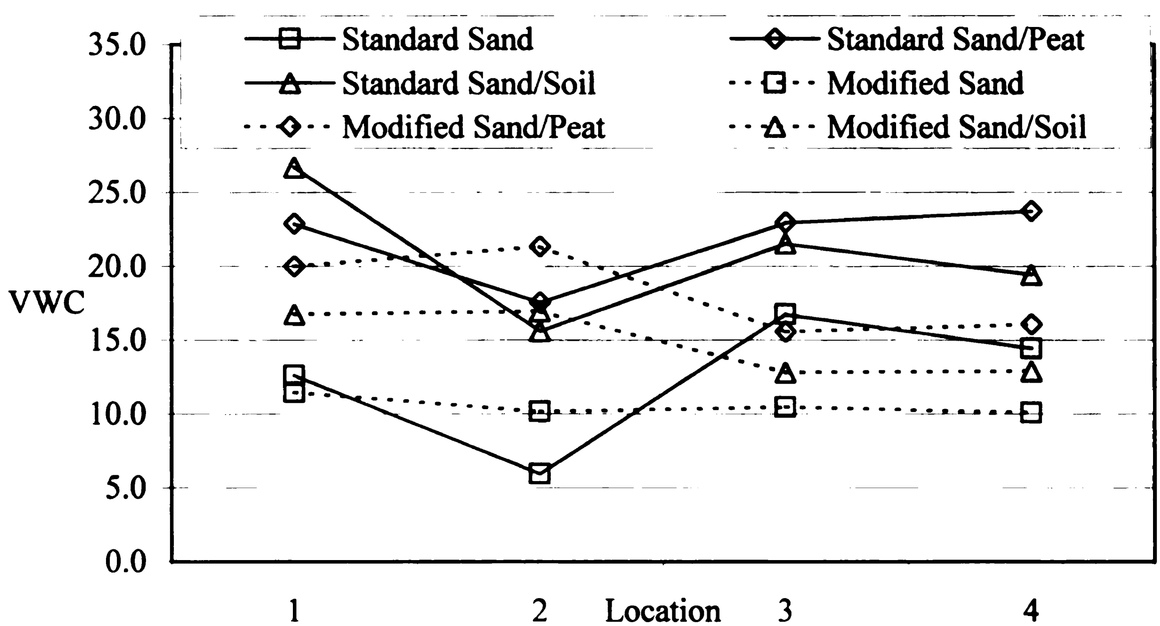

Figure 7. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the second dry down in 2001.

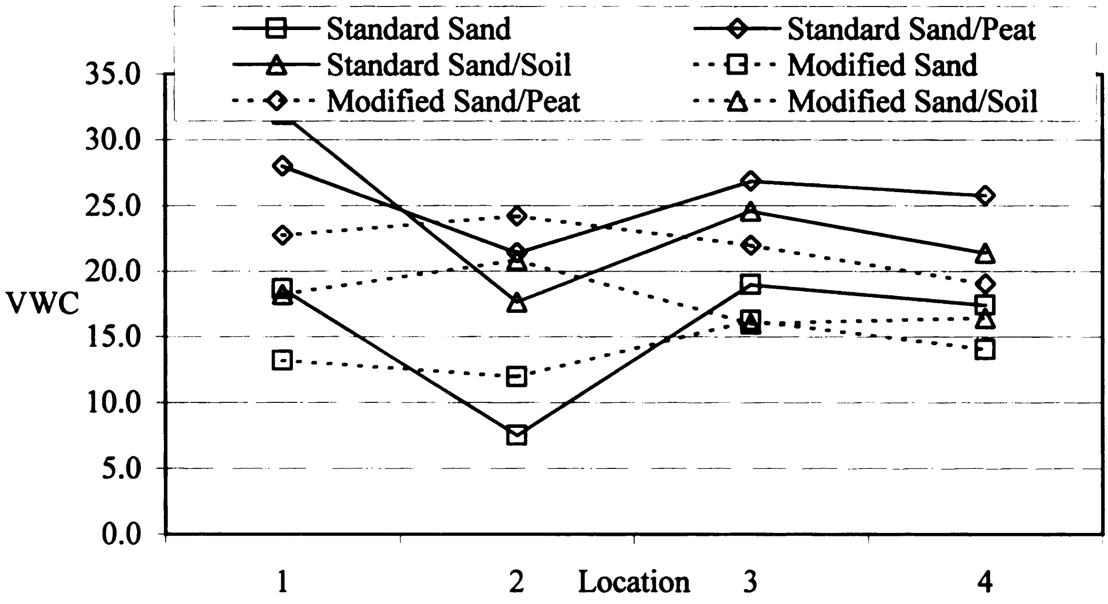

Figure 8. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the third dry down in 2001.

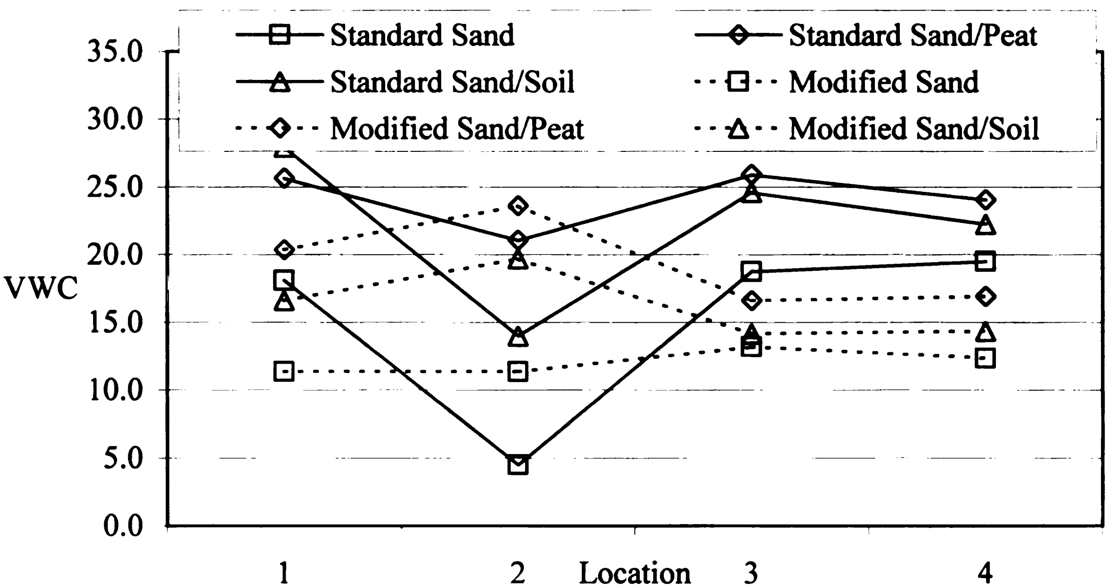

Figure 9. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the fourth dry down in 2001.

Construction x Location x Soil Interaction: 10-20 cm depth

The construction x location x soil interaction was significant at the beginning, day 0 ($\alpha = 0.10$), and the end, day 3 ($\alpha = 0.05$), of the fifth dry down in 2000 (Table 6). On day 0, within the uniform construction type: the sand root zone location 2 had the lowest VWC among the four locations, the sand/peat root zone location 2 had a VWC less than the highest value among the four locations, and the sand/soil root zone had no differences in VWC among the four locations. There was less variability within the modified construction type: the sand/peat and sand/soil root zones had no differences in VWC among the four locations, and the sand root zone location 2 had a VWC equal to the highest value among the four locations (Table 11).

After three days without irrigation, within the uniform construction type: the sand root zone location 2 continued to have the lowest VWC among the four locations, the sand/peat root zone location 2 continued to have a VWC less than the highest value among the four locations, however the sand/soil location 2 developed a VWC less than the highest value among the four locations. There continued to be less variability within the modified construction type: the sand/peat and sand/soil root zones had no differences among the four locations, and the sand root zone location 2 had a VWC equal to the highest VWC among the four locations (Table 11).

When the construction x location x soil interaction was significant, the results show that the modification of the root zone depth resulted in more uniform VWC among the four locations within all three of the soil types (Figure 10). This trend was evident on day 3 of all of the dry downs, even on dates when the construction x location x soil interaction was not significant (See Figures 11-13 for 2001 data, and Appendix Figures 8A-14A for 2000 and 2002 data).

Table 11. Volumetric water contents for the construction x location x soil interaction, at the 10-20 cm depth for the fifth dry down in 2000.

	Location			
Day 0	1	2	3	4
Uniform Sand	19.7 A[†]bc[‡]	13.5 Bb	21.6 Aa	21.0 Ab
Uniform Sand/Peat	25.2 Aa	19.6 Ba	22.4 ABa	25.7 Aa
Uniform Sand/Soil	23.0 Aab	18.4 Aa	22.5 Aa	19.2 Ab
Modified Sand	12.6 Bd	20.3 Aa	17.2 ABb	14.1 Bc
Modified Sand/Peat	20.8 Abc	20.9 Aa	17.8 Ab	17.8 Ab
Modified Sand/Soil	17.6 Ac	20.6 Aa	17.2 Ab	16.9 Abc
Day 1	1	2	3	4
Uniform Sand	19.6[§]	13.1	21.7	21.0
Uniform Sand/Peat	25.2	19.4	22.4	25.7
Uniform Sand/Soil	23.2	17.7	21.1	19.2
Modified Sand	12.5	16.7	17.2	14.2
Modified Sand/Peat	20.7	20.5	17.6	17.6
Modified Sand/Soil	17.1	20.1	17.1	16.7
Day 2	1	2	3	4
Uniform Sand	18.7	12.3	21.0	20.4
Uniform Sand/Peat	24.5	18.3	21.4	24.6
Uniform Sand/Soil	22.6	17.0	22.0	18.8
Modified Sand	11.9	15.3	16.6	13.9
Modified Sand/Peat	20.3	18.9	17.3	17.3
Modified Sand/Soil	16.7	18.4	16.4	16.5
Day 3	1	2	3	4
Uniform Sand	18.1 A[#]bc[††]	11.3 Bb	20.4 Aa	19.7 Ab
Uniform Sand/Peat	23.2 ABa	17.3 Ca	20.6 BCa	24.6 Aa
Uniform Sand/Soil	22.4 Aa	16.4 Ca	21.3 ABa	18.4 BCb
Modified Sand	11.1 Bd	14.9 ABab	15.7 Ab	13.7 ABc
Modified Sand/Peat	19.8 Aab	17.9 Aa	17.1 Aab	17.1 Ab
Modified Sand/Soil	16.2 Ac	16.9 Aa	16.0 Ab	16.4 Abc

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.10)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.10)

[§]Not significant at P=0.10.

[#]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[††]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

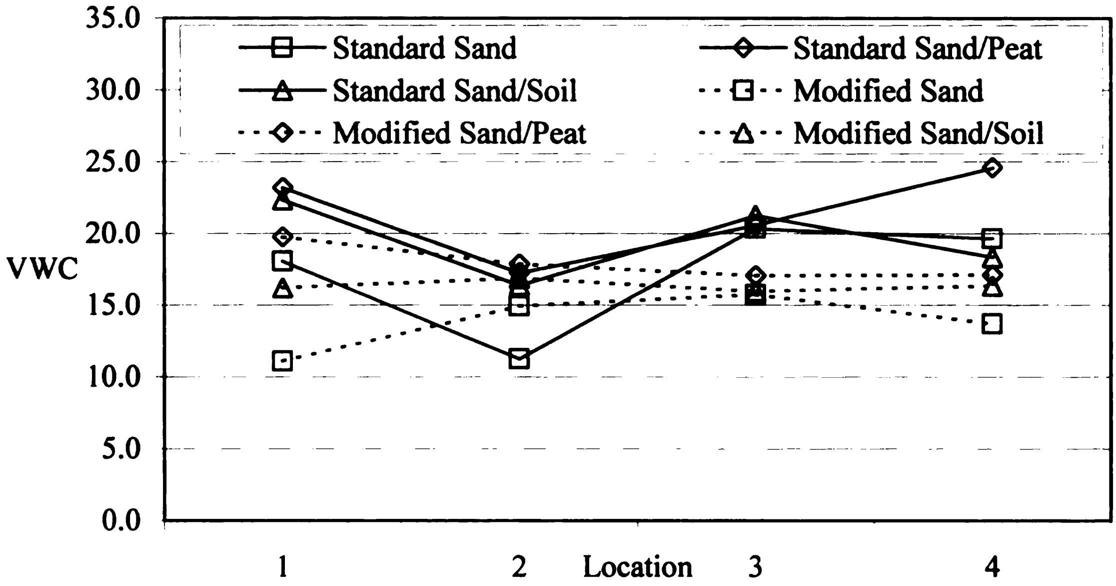

Figure 10. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the fifth dry down in 2000.

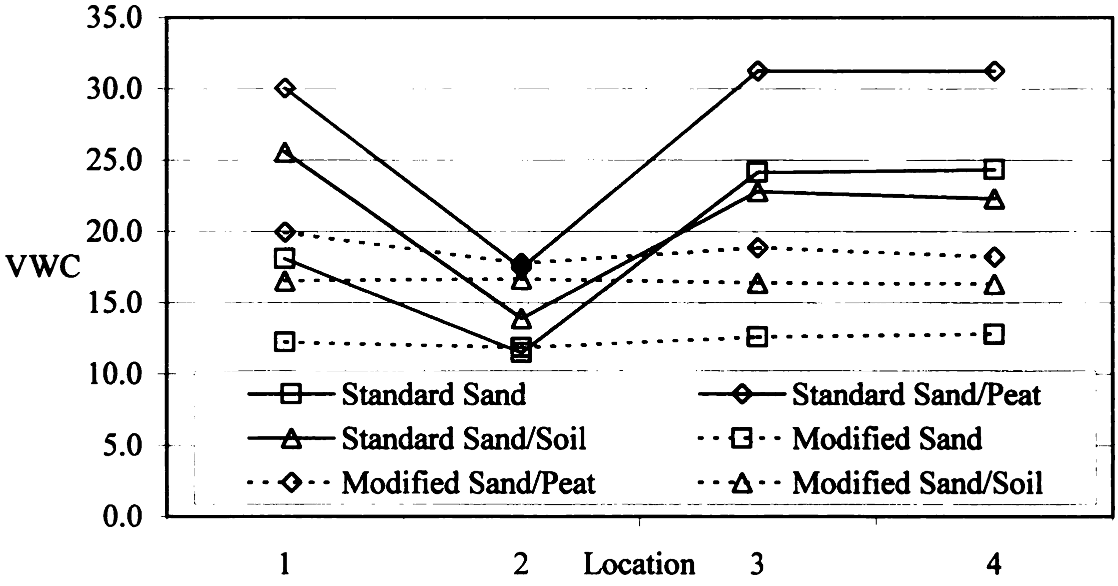

Figure 11. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the first dry down in 2001.

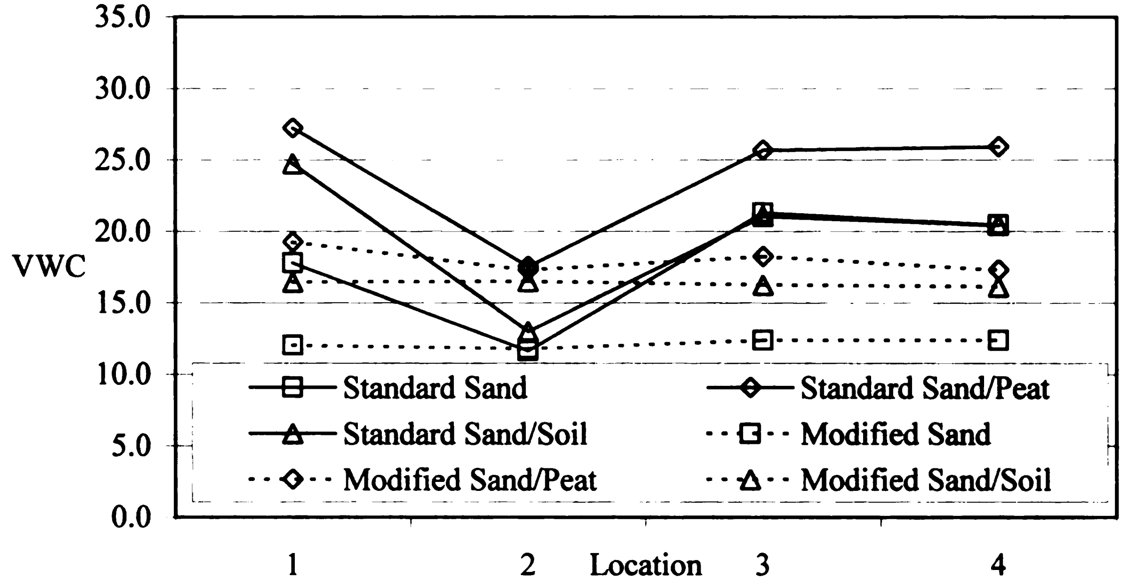

Figure 12. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the second dry down in 2001.

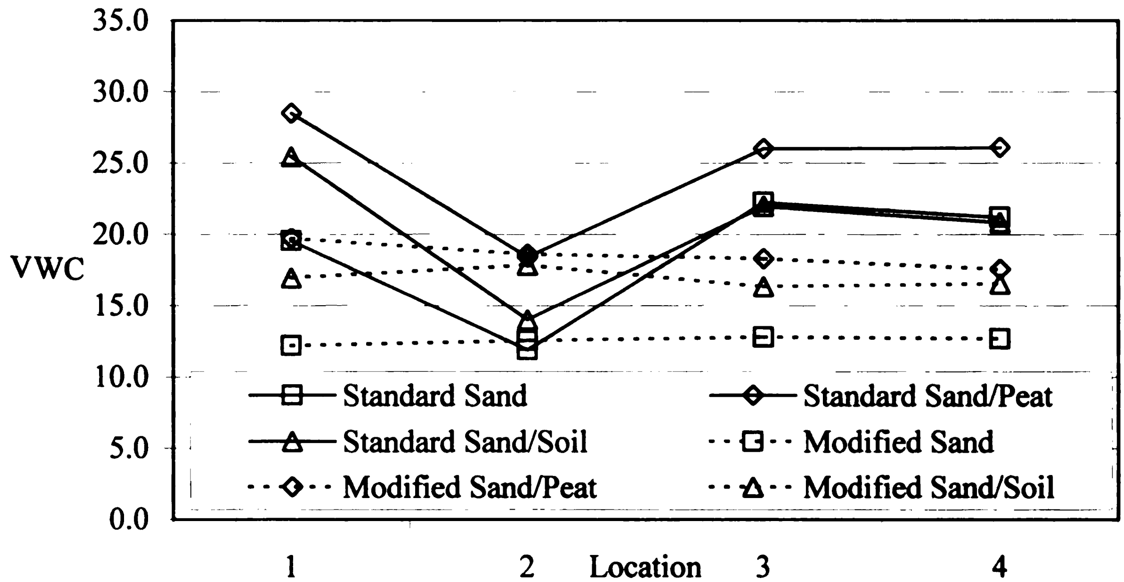

Figure 13. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the third dry down in 2001.

Location x Soil Interaction: 0-10cm depth

The irrigation event (1.5 cm) prior to the start of the dry down cycles resulted in no significant differences in the VWC among locations and soil types on nine of eleven possible dates, on day 0. The location x soil interaction was significant on day 0 of dry down 3 in 2000, and dry down 2 in 2002 (Tables 3-5). In 2000, the sand/peat and sand/soil root zones had no differences in VWC among the four locations. In 2002, within the sand/peat and sand/soil root zones, location 2 had a VWC that was equal to the highest value among the four locations. In 2000 and 2002, within the sand root zone, location 2 had the lowest VWC among the four locations (Table 12). (See Appendix Tables 15A-20A for VWC location x soil data for day 0 and day 3 of each year.)

After three days without irrigation, the location x soil interaction was significant on nine of 13 possible dates (Tables 3-5). There was more variability among the four locations within the sand root zone than the sand/peat and sand/soil root zones. Within the sand root zone, location 2 had the lowest VWC among the four locations on eight of the nine dates, and on the remaining date had a VWC less than the highest value among the four locations (Table 13). The sand/peat root zone had no differences in VWC among the four locations on three of the nine dates. Within the sand/peat root zone, location 2 had a VWC equal to the lowest value among the four locations on five of the remaining six dates, and had the lowest VWC among the four locations on one date (Table 13). The sand/soil root zone had no differences in VWC among the four locations on one of the nine dates. The sand/soil root zone location 2 had a VWC value equal to the lowest value

Table 12. Volumetric water contents for the location x soil interaction, 0-10 cm depth, day 0, for the third dry down in 2000, and the second dry down in 2002.

Dry down 3, 2000	Location			
	1	2	3	4
Sand	11.1 BC†b‡	7.1 Cc	16.6 Ab	15.2 ABb
Sand/Peat	23.2 Aa	23.8 Aa	23.9 Aa	19.9 Aa
Sand/Soil	21.4 Aa	17.8 Ab	20.2 Aab	18.4 Aab

Dry down 2, 2002				
	1	2	3	4
Sand	12.1 Ab	7.9 Bb	15.7 Ab	13.2 Ab
Sand/Peat	26.2 Aa	23.3 ABa	21.4 ABa	22.3 Ba
Sand/Soil	22.8 Aa	21.8 ABa	20.7 ABa	18.3 Ba

†Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

‡Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

Table 13. Volumetric water contents for the location x soil interaction, day 3, for the 0-10 cm depth.

Dry down 1, 2000	Location			
	1	2	3	4
Sand	15.3 B†c‡	15.3 Bc	18.9 Ac	17.5 Ac
Sand/Peat	26.1 Aa	27.1 Aa	26.0 Aa	25.3 Aa
Sand/Soil	23.5 Ab	24.3 Ab	23.4 Ab	22.7 Ab
Dry down 2, 2000				
	1	2	3	4
Sand	10.5 Ab	4.8 Bc	12.3 Ab	12.0 Ab
Sand/Peat	20.8 Aa	13.7 Ca	17.7 Ba	18.0 Ba
Sand/Soil	17.7 Aa	10.2 Cb	14.5 Bab	12.9 Bb
Dry down 3, 2000				
	1	2	3	4
Sand	12.1 Ab	7.9 Bb	15.7 Ab	13.2 Ab
Sand/Peat	26.2 Aa	23.3 ABa	21.4 ABa	22.3 Ba
Sand/Soil	22.8 Aa	21.8 ABa	20.7 ABa	18.3 Ba
Dry down 1, 2001				
	1	2	3	4
Sand	13.9 Ab	7.1 Bc	13.1 Ac	13.4 Ac
Sand/Peat	23.5 Aa	19.5 Ba	20.7 ABa	21.2 ABa
Sand/Soil	21.4 Aa	15.2 Bb	17.6 Bb	16.9 Bb
Dry down 2, 2001				
	1	2	3	4
Sand	12.0 Ab	8.1 Bc	13.6 Ab	12.3 Ac
Sand/Peat	21.5 Aa	19.5 Aa	19.3 Aa	19.9 Aa
Sand/Soil	21.7 Aa	16.3 Bb	17.2 Ba	16.2 Bb

Dry down 3, 2001	Location			
	1	2	3	4
Sand	15.9 Ab	9.7 Bc	17.6 Ab	15.8 Ac
Sand/Peat	25.4 Aa	22.8 ABa	24.5 ABa	22.4 Ba
Sand/Soil	25.1 Aa	19.3 Bb	20.3 Bb	18.9 Bb
Dry down 4, 2001				
	1	2	3	4
Sand	14.7 Ab	7.9 Bc	16.0 Ab	15.9 Ab
Sand/Peat	23.0 Aa	22.3 Aa	22.3 Aa	20.5 Aa
Sand/Soil	22.3 Aa	16.9 Bb	19.4 ABab	18.3 Bab
Dry down 3, 2002				
	1	2	3	4
Sand	17.6 Ab	13.2 Bc	18.1 Ac	18.2 Ab
Sand/Peat	27.1 Aa	24.9 Ba	26.5 ABa	25.5 ABa
Sand/Soil	26.5 Aa	22.0 Cb	24.2 Bb	24.9 ABa
Dry down 4, 2002				
	1	2	3	4
Sand	16.4 Ab	9.1 Bb	14.1 Ab	14.2 Ac
Sand/Peat	27.4 Aa	22.5 Ba	23.3 Ba	23.6 Ba
Sand/Soil	25.9 Aa	19.5 Ba	20.9 Ba	18.3 Bb

†Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05).

‡Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05).

among the four locations on six of the remaining eight dates, and had the lowest VWC among the four locations on two dates (Table 13).

The difference in water holding capacity among the three soil types was evident in a comparison of the VWC, on day 3, at the peak of the slope, location 2 (Table 13). At location 2, the sand root zone had the lowest VWC among the three soil types on all nine dates. On two of the nine dates, the sand/peat location 2 and sand/soil location 2 had equal VWC, however, on the remaining seven dates, the sand/peat location 2 had a VWC higher than the sand/soil location 2 (Table 13). The lateral movement of water down the slope resulted in inconsistent differences among the three soil types at the lower elevations, locations 1, 3, and 4. The addition of peat and soil into the root zone mix increased the water holding capacity of the sand/peat and sand/soil root zones.

The results from the location x soil interaction show that increasing the water holding capacity of the root zone mix, regardless of construction type, had a limited effect on improving the uniformity of VWC among the four locations at the 0-10 cm depth. The peak of the slope for the sand/peat plots had the highest VWC among the three soil types on seven of nine dates, however on four of the nine dates the peak of the slope had a VWC less than the highest VWC among the four locations, and the four locations had similar VWC on three of the nine dates (Table 13).

Location x Soil Interaction: 10-20 cm depth

At the 10-20 cm depth, significant differences in VWC among locations and soil did not occur as frequently as at the 0-10 cm depth. Drainage from the surface layer resulted in a more uniform VWC among the four locations and three soil types. The location x soil interaction was not significant on any date in 2001 or 2002. In 2000, the interaction was significant on day 0 of all five dry downs in 2000 (Table 14). The interaction was significant on day 3 of all three of the possible dry downs (Table 15) (See Appendix Tables 21A-26A for VWC location x soil data for day 0 and day 3 of each year.)

On day 0 of the fifth dry down, there were no significant differences in VWC among the four locations within the three soil types (Table 14). After three days without irrigation, during the fifth dry down there remained no differences in VWC among the four locations within the sand/soil root zone, however, within the sand/peat and sand root zones, location 2 had a VWC less than the highest value among the four locations (Table 15). On day 3 of the second dry down in 2000, within all three soil types, location 2 had a VWC less than the highest value among the four locations. On day 3 of the third dry down in 2000 there were no differences among the four locations within the sand/peat root zone, the sand/soil root zone location 2 had a VWC equal to the highest value among the four locations, and the sand root zone location 2 had a VWC less than the highest value among the four locations (Table 15).

The difference in water holding capacity among the three soil types was evident in a comparison of the VWC, on day 3, at the peak of the slope. On all three significant dates, the sand root zone location 2 had the lowest VWC among the three soil types, and the sand/peat location 2 and the sand/soil location 2 had equal VWC. The addition of peat and soil into the root zone mix increased the water holding capacity of the sand/peat and sand/soil root zones.

The results from the location x soil interaction show that increasing the water holding capacity of the root zone mix by adding peat or soil, regardless of construction type, had a limited effect on improving the uniformity of VWC among the four locations at the 10-20 cm depth. On day 3, within the sand/peat root zone there were no differences among the four locations on one of the three dates, however, on the two remaining dates location 2 had a VWC less than the highest value among the four locations. On day 3, within the sand root zone there were no differences among the four locations on one of the three dates, however, on the two remaining dates location 2 had a VWC less than the highest value among the four locations.

Table 14. Volumetric water contents for the location x soil interaction, day 0, for the five dry downs in 2000, at the 10-20 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	17.1 BC[†]b[‡]	14.9 Cb	21.2 Aa	17.9 Bb
Sand/Peat	22.9 Aa	20.8 ABa	20.4 Ba	21.0 ABa
Sand/Soil	19.7 Bb	23.1 Aa	18.9 Ba	18.0 Bb

Dry down 2	Location			
	1	2	3	4
Sand	15.7 Bb	14.1 Bb	20.9 Aa	17.5 ABa
Sand/Peat	22.0 Aa	18.2 Ba	19.4 ABa	19.8 ABa
Sand/Soil	20.0 Aa	17.8 Aa	19.5 Aa	18.0 Aa

Dry down 3	Location			
	1	2	3	4
Sand	15.8 BCb	13.6 Cb	19.5 Aa	17.8 ABb
Sand/Peat	22.0 Aa	16.7 Ba	19.5 Aa	20.2 Aa
Sand/Soil	20.4 Aa	16.9 Ba	20.1 Aa	18.4 ABab

Dry down 4	Location			
	1	2	3	4
Sand	18.4 Ac	20.2 Aa	20.9 Aa	18.8 Aa
Sand/Peat	26.8 Aa	23.2 ABa	21.4 Ba	22.2 Ba
Sand/Soil	22.1 Ab	21.9 Aa	19.1 Aa	20.0 Aa

Dry down 5	Location			
	1	2	3	4
Sand	16.2 Ac	16.9 Ab	19.4 Aa	17.6 Ab
Sand/Peat	23.0 Aa	20.3 Aa	20.1 Aa	21.7 Aa
Sand/Soil	20.3 Ab	19.5 Aab	19.9 Aa	18.1 Ab

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

Table 15. Volumetric water contents for the location x soil interaction, day 3, for the five dry downs in 2000, at the 10-20 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

Dry down 2	Location			
	1	2	3	4
Sand	16.0 B[†]b[‡]	13.2 Cb	19.6 Aa	18.1 ABb
Sand/Peat	22.3 Aa	16.4 Ca	19.4 Ba	20.5 ABa
Sand/Soil	21.0 Aa	16.6 Ca	20.6 ABa	18.3 BCb

Dry down 3	Location			
	1	2	3	4
Sand	16.2 Bb	15.7 Bb	20.0 Aa	17.6 ABa
Sand/Peat	22.1 Aa	20.4 Aa	19.8 Aa	20.2 Aa
Sand/Soil	20.7 ABa	20.0 ABa	22.0 Aa	18.1 Ba

Dry down 4	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

Dry down 5	Location			
	1	2	3	4
Sand	14.6 BCc	13.1 Cb	18.1 Aa	16.7 ABb
Sand/Peat	21.5 Aa	17.6 Ba	18.8 ABa	20.9 Aa
Sand/Soil	19.3 Ab	16.6 Aa	18.6 Aa	17.4 Ab

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

[*]No data.

Construction x Location Interaction: 0-10 cm depth:

The irrigation event (1.5 cm) prior to the start of each dry down cycle resulted in no significant differences in VWC among construction types and locations on seven of eleven possible dates, on day 0 (Tables 3-5). Within the standard construction type, location 2 had the lowest VWC among the four locations, on three of the four dates that the interaction was significant (Table 16). The VWC at location 2 was less than the highest value among the four locations on the remaining date. Within the modified construction type, there were no differences among the four locations on any of the four significant dates (Table 16).

After three days without irrigation, the interaction was significant on 13 of 13 possible dates (Tables 3-5). Within the standard construction type, location 2 had the lowest VWC among the four locations on 12 of the 13 dates (Table 17). The VWC at location 2 was less than the highest value among the four locations on the remaining date. Within the modified construction type, there were no differences in the VWC among the four locations on 11 of 13 dates (Table 17). The VWC at location 2 was equal to the highest value among the four locations on the remaining two dates.

The results from the construction x location interaction show that the modification of the root zone depth, when compared to the standard construction type, resulted in more uniform VWC among the four locations (Figures 14-16). The uniformity of VWC within the modified construction type can be attributed to the differences between the two construction types at each location.

After three days without irrigation, the modified construction type consistently had a lower VWC than the standard construction type at the north and south toe slopes (locations 1, 3, and 4) (Table 17). At location 2 there were no differences in VWC between the two construction types on 10 out of 13 dates, however, the modified construction type had higher VWC than the standard construction type on the remaining three dates (Table 17). The results from the construction x location interaction show that increasing the depth of the root zone at the base of the slope reduced the VWC within the 0-10 cm depth, and decreasing the depth of the root zone at the peak of the slope did not decrease the VWC within the 0-10 cm depth.

Table 16. Volumetric water contents for the construction x location interaction, on day 0, at the 0-10 cm depth.

2000		Location 1	Location 2	Location 3	Location 4
Dry down 1:	Standard	24.9[†]	19.0	23.7	22.0
	Modified	18.5	19.7	18.5	18.5
Dry down 2:	Standard	23.9 A[‡]a[§]	15.7 Ba	22.3 Aa	21.7 Aa
	Modified	16.8 Ab	18.6 Aa	16.6 Ab	16.1 Ab
Dry down 3:	Standard	21.2	13.9	22.1	20.6
	Modified	16.0	18.5	18.3	15.1
Dry down 4:	Standard	*	*	*	*
	Modified	*	*	*	*
Dry down 5:	Standard	24.2	17.5	23.4	22.5
	Modified	17.5	20.8	16.2	17.6

2001		Location 1	Location 2	Location 3	Location 4
Dry down 1:	Standard	26.7 Aa	24.2 Ba	26.7 ABa	24.4 ABa
	Modified	24.9 ABa	26.4 Aa	22.8 Bb	22.6 Ba
Dry down 2:	Standard	29.2	27.6	26.9	25.2
	Modified	28.0	28.2	25.7	25.0
Dry down 3:	Standard	27.7	24.1	26.3	25.1
	Modified	25.2	25.2	24.3	24.0
Dry down 4:	Standard	27.9	24.6	25.8	26.3
	Modified	25.2	26.9	24.1	24.8

2002		Location 1	Location 2	Location 3	Location 4
Dry down 1:	Standard	*	*	*	*
	Modified	*	*	*	*
Dry down 2:	Standard	28.4 Aa	19.2 Ba	28.3 Aa	26.1 Aa
	Modified	22.1 Ab	22.4 Aa	19.7 Ab	20.5 Ab
Dry down 3:	Standard	27.8	28.4	28.7	28.5
	Modified	27.7	29.3	27.9	26.6
Dry down 4:	Standard	28.6 Aa	21.4 Ba	29.4 Aa	26.7 Aa
	Modified	24.3 Aa	25.5 Aa	22.6 Ab	23.8 Aa

[†]Not significant at P=0.05.
[‡]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)
[§]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)
* No data

Table 17. Volumetric water contents for the construction x location interaction, on day 3, at the 0-10 cm depth.

2000		Location 1	Location 2	Location 3	Location 4
Dry down 1:	Standard	23.7 A[†]a[‡]	21.0 Ba	25.4 Aa	23.6 ABa
	Modified	19.5 Bb	23.5 Aa	20.1 Bb	20.1 Bb
Dry down 2:	Standard	20.8 Aa	8.3 Ca	18.5 ABa	17.5 Ba
	Modified	11.8 Ab	10.8 Aa	11.1 Ab	11.1 Ab
Dry down 3:	Standard	23.8 Aa	15.5 Ba	23.5 Aa	20.7 Aa
	Modified	17.0 Ab	19.8 Aa	15.0 Ab	15.1 Ab
Dry down 4:	Standard	21.5 Aa	13.8 Ba	23.2 Aa	21.3 Aa
	Modified	15.8 Ab	17.8 Aa	14.0 Ab	14.3 Ab
Dry down 5:	Standard	21.2 Aa	11.3 Ba	20.8 Aa	19.1 Aa
	Modified	14.1 Ab	14.5 Aa	14.8 Ab	13.6 Ab

2001		Location 1	Location 2	Location 3	Location 4
Dry down 1:	Standard	23.5 Aa	12.0 Bb	21.6 Aa	20.7 Aa
	Modified	15.7 Ab	15.9 Aa	12.6 Ab	13.6 Ab
Dry down 2:	Standard	20.7 Aa	13.0 Ba	20.4 Aa	19.2 Aa
	Modified	16.1 Ab	16.2 Aa	12.9 Ab	13.0 Ab
Dry down 3:	Standard	26.2 Aa	15.5 Ca	23.5 ABa	21.6 Ba
	Modified	18.1 Ab	19.0 Aa	18.1 Ab	16.5 Ab
Dry down 4:	Standard	23.9 Aa	13.2 Bb	23.1 Aa	21.9 Aa
	Modified	16.1 Ab	18.2 Aa	14.7 Ab	14.5 Ab

2002		Location 1	Location 2	Location 3	Location 4
Dry down 1:	Standard	24.4 Aa	14.8 Ba	21.4 Aa	21.0 Aa
	Modified	15.3 Ab	16.2 Aa	14.1 Ab	14.0 Ab
Dry down 2:	Standard	21.0 Aa	11.6 Ba	22.7 Aa	22.3 Aa
	Modified	15.7 Ab	14.5 Aa	14.2 Ab	13.4 Ab
Dry down 3[a]:	Standard	27.3 Aa	18.6 Bb	26.6 Aa	26.4 Aa
	Modified	20.1 Ab	21.5 Aa	19.2 Ab	19.3 Ab
Dry down 4:	Standard	26.2 Aa	16.0 Ca	22.6 ABa	21.4 Ba
	Modified	20.2 Ab	18.1 ABa	16.2 Bb	16.0 Bb

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

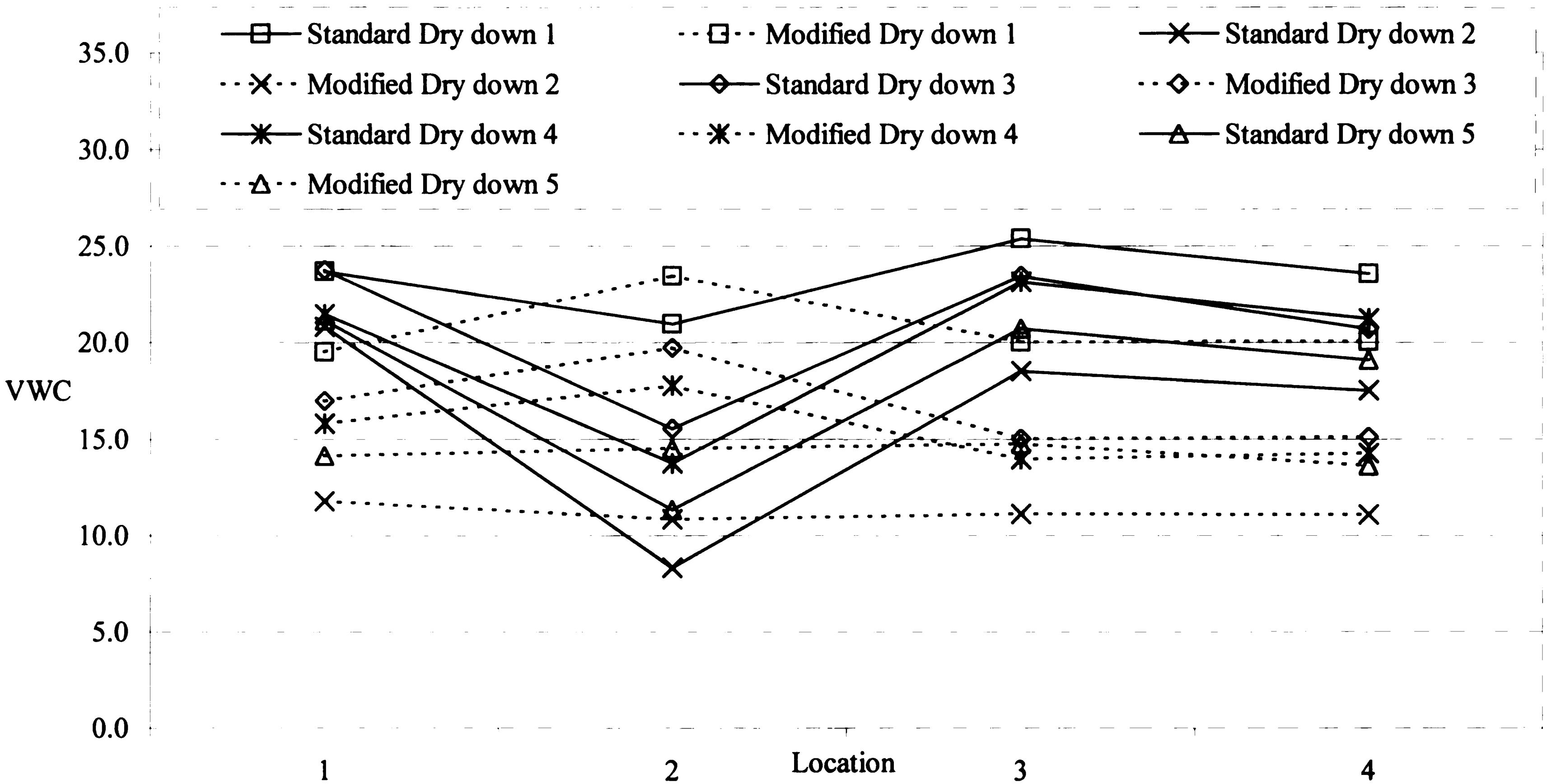

Figure 14. Volumetric water contents for the significant construction x location interactions for day 3, at the 0-10 cm depth, in 2000.

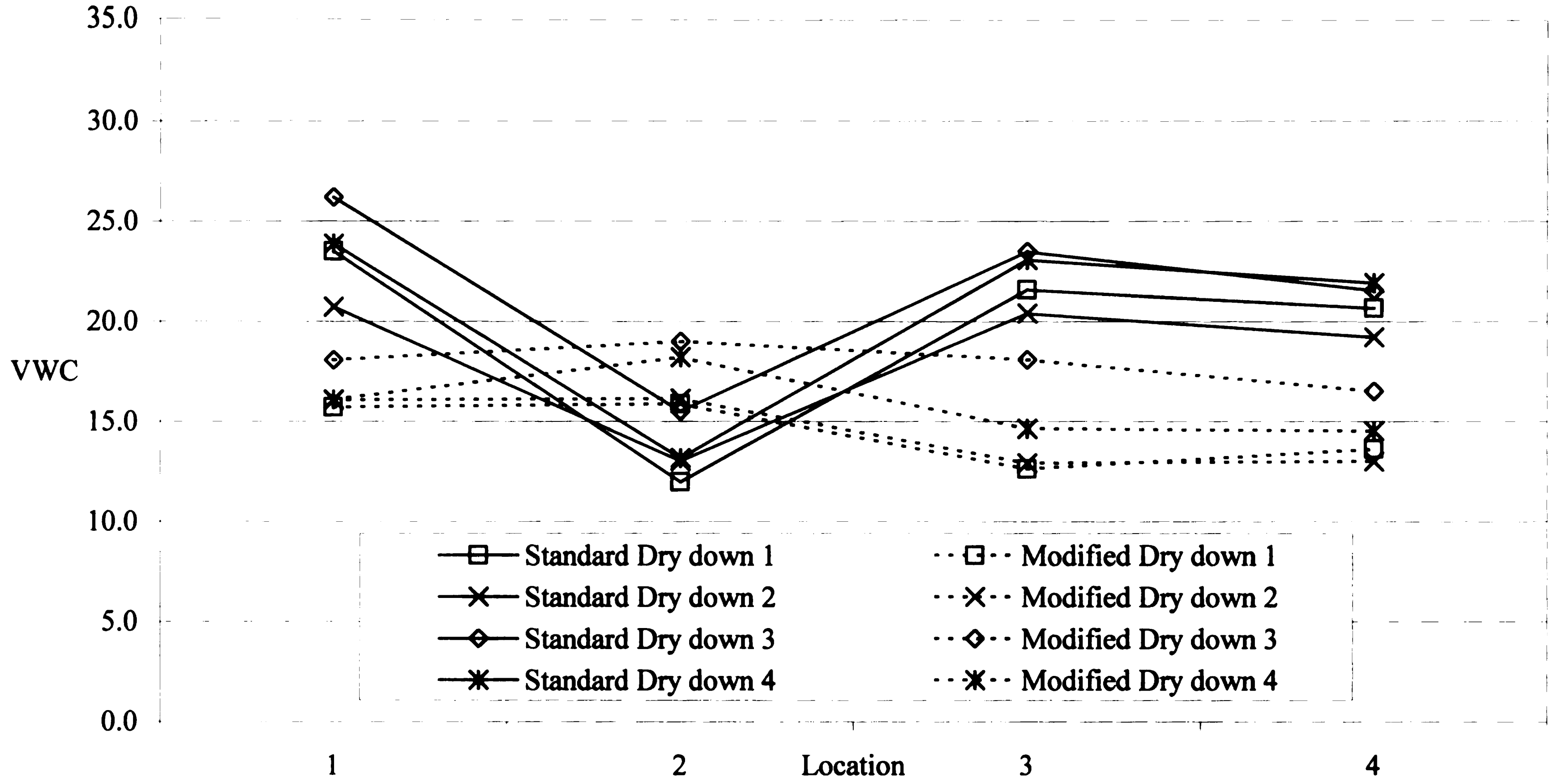

Figure 15. Volumetric water contents for the significant construction x location interactions for day 3, at the 0-10 cm depth, in 2001.

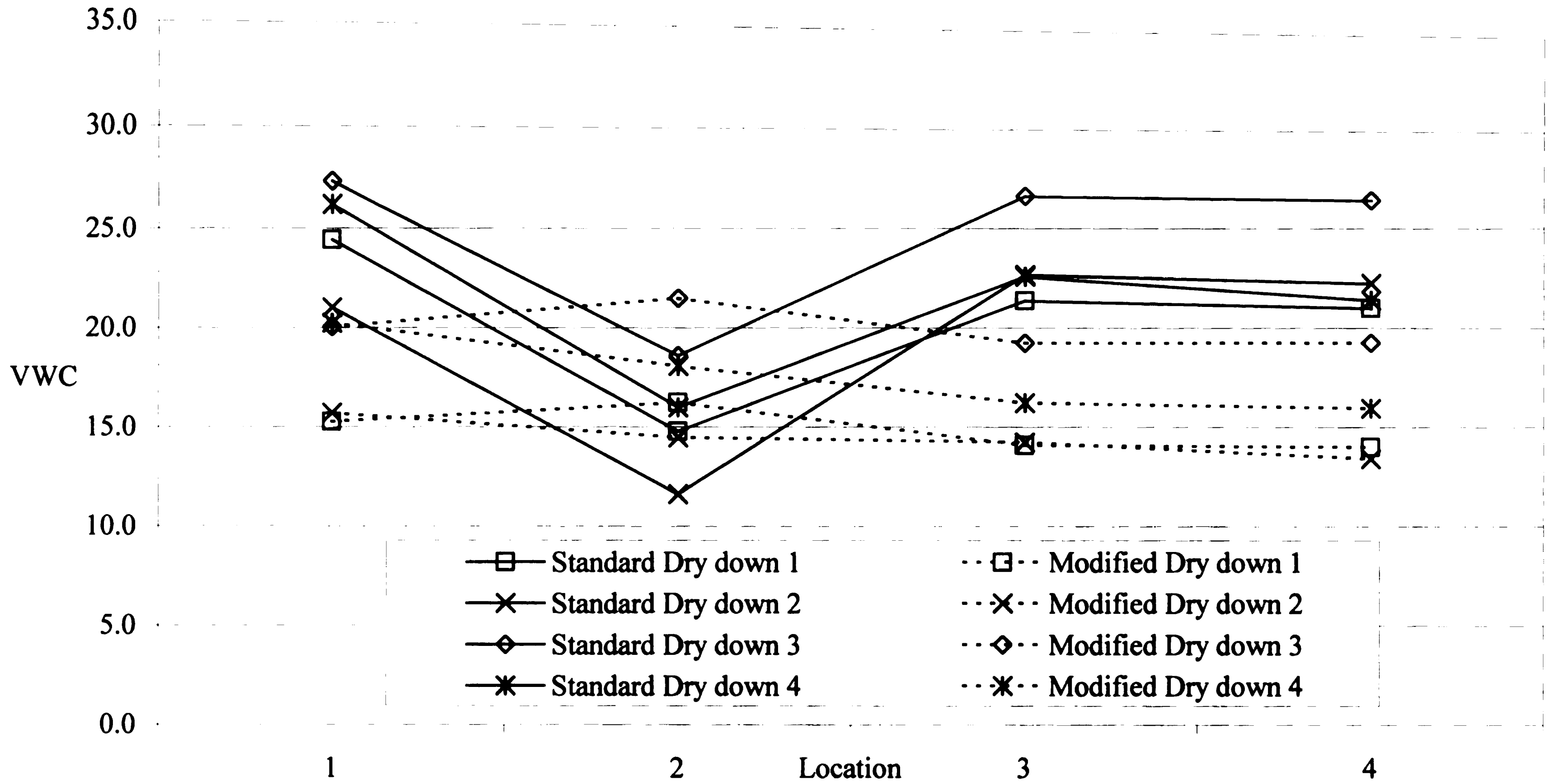

Figure 16. Volumetric water contents for the significant construction x location interactions for day 3, at the 0-10 cm depth, in 2002.

Construction x Location Interaction: 10-20 cm depth:

The construction x location interaction was significant on day 0, eight out of 11 dates (Tables 6-8). The peak of the standard construction type had the lowest VWC among the four locations on four of the eight significant dates (Table 18). The VWC at location 2 was less than the highest value among the four locations on the remaining four dates. Within the modified construction type there were no differences among the four locations on five of the eight dates (Table 18). The VWC at location 2 was equal to the highest VWC among the four locations on two dates, and had the highest VWC among the four locations on one date.

After three days without irrigation, the construction x location interaction was significant on 9 out of 10 dates (Tables 6-8). The peak of the standard construction type had the lowest VWC among the four locations on all nine significant dates (Table 19). Within the modified construction type there were no significant differences among the four locations on 8 of 9 dates, and a VWC equal to the highest value among the four locations on the remaining date (Table 19).

The results from the construction x location interaction show that the modification of the root zone depth, when compared to the standard construction type, resulted in more uniform VWC among the four locations (Figures 17-19). The uniformity of VWC within the modified construction type can be attributed to the differences between the two construction types at each location.

After three days without irrigation, the modified construction type consistently had a lower VWC than the standard construction type at the north and south toe slopes (locations 1, 3, and 4). At location 2 there were no differences in VWC between the two construction types on 8 out of 9 significant dates, however, the modified construction type had higher VWC than the standard construction type on the remaining date (Table 19). The results from the construction x location interaction show that increasing the depth of the root zone at the base of the slope reduced the VWC within the 10-20 cm depth, and decreasing the depth of the root zone at the peak of the slope did not decrease the VWC within the 10-20 cm depth (Table 19).

The construction x location interaction demonstrates that a modification of the depth of the sand based root zone, regardless of soil type, resulted in more uniform moisture contents within the 0-20 cm depth, across all locations of a sloped putting green.

Table 18. Volumetric water contents for the construction x location interaction, day 0, at the 10-20 cm depth.

2000		Location			
		1	2	3	4
Dry down 1:	Standard	24.9†	19.0	23.7	22.0
	Modified	18.5	19.7	18.5	18.5
Dry down 2:	Standard	22.2	15.2	20.5	20.8
	Modified	16.3	18.2	19.3	16.1
Dry down 3:	Standard	21.9 A‡a§	14.1 Ba	22.1 Aa	21.1 Aa
	Modified	16.9 Ab	17.4 Aa	17.3 Ab	16.5 Ab
Dry down 4:	Standard	25.2 Aa	19.4 Bb	22.0 ABa	22.6 ABa
	Modified	19.6 ABb	24.2 Aa	18.9 ABa	18.1 Bb
Dry down 5:	Standard	22.6 Aa	17.2 Ba	22.1 Aa	22.0 Aa
	Modified	17.0 Ab	20.6 Aa	17.4 Ab	16.3 Ab
2001		Location			
		1	2	3	4
Dry down 1:	Standard	27.2 Aa	17.3 Ba	29.3 Aa	28.3 Aa
	Modified	17.6 Ab	19.8 Aa	17.6 Ab	16.7 Ab
Dry down 2:	Standard	25.7 Aa	17.9 Ba	25.5 Aa	24.4 Aa
	Modified	17.4 ABb	19.9 Aa	17.2 ABb	16.2 Bb
Dry down 3:	Standard	25.8	17.4	24.4	23.3
	Modified	17.2	28.7	16.7	16.2
Dry down 4:	Standard	*	*	*	*
	Modified	*	*	*	*
2002		Location			
		1	2	3	4
Dry down 1:	Standard	23.2 Aa	18.0 Ba	21.2 ABa	21.4 ABa
	Modified	17.6 Ab	20.2 Aa	16.8 Ab	16.2 Ab
Dry down 2:	Standard	*	*	*	*
	Modified	*	*	*	*
Dry down 3:	Standard	25.8 Aa	20.3 Ba	24.1 ABa	22.6 ABa
	Modified	18.5 Bb	23.7 Aa	17.6 Bb	16.7 Bb
Dry down 4:	Standard	23.5 ABa	18.7 Ba	24.3 Aa	22.3 ABa
	Modified	18.3 Ab	21.7 Aa	18.9 Ab	17.6 Aa

†Not significant at P=0.05.

‡Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

§Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

* No data

Table 19. Volumetric water contents for the construction x location interaction, day 3, at the 10-20 cm depth.

2000		Location			
		1	2	3	4
Dry down 1:	Standard	*	*	*	*
	Modified	*	*	*	*
Dry down 2:	Standard	22.2 A[†]a[‡]	14.0 Ba	22.2 Aa	21.3 Aa
	Modified	17.4 Ab	16.8 Aa	17.5 Ab	16.6 Ab
Dry down 3:	Standard	22.5 Aa	16.8 Bb	23.2 Aa	21.3 Aa
	Modified	16.8 ABb	20.6 Aa	18.2 ABb	16.0 Bb
Dry down 4:	Standard	*	*	*	*
	Modified	*	*	*	*
Dry down 5:	Standard	21.2 Aa	15.0 Ba	20.7 Aa	20.9 Aa
	Modified	15.7 Ab	16.6 Aa	16.3 Ab	15.7 Ab
2001		**Location**			
		1	2	3	4
Dry down 1:	Standard	24.6 Aa	14.3 Ba	26.1 Aa	26.0 Aa
	Modified	16.3 Ab	15.4 Aa	16.0 Ab	15.8 Ab
Dry down 2:	Standard	23.3 Aa	14.1 Ba	22.7 Aa	22.3 Aa
	Modified	15.9 Ab	15.2 Aa	15.6 Ab	15.3 Ab
Dry down 3:	Standard	24.5 Aa	14.8 Ba	23.4 Aa	22.7 Aa
	Modified	16.3 Ab	16.3 Aa	15.8 Ab	15.6 Ab
Dry down 4:	Standard	*	*	*	*
	Modified	*	*	*	*
2002		**Location**			
		1	2	3	4
Dry down 1:	Standard	19.7 Aa	14.2 Ba	19.7 Aa	18.6 Aa
	Modified	15.7 Ab	15.1 Aa	15.2 Ab	14.7 Ab
Dry down 2:	Standard	18.7 Aa	13.2 Ba	19.2 Aa	18.5 Aa
	Modified	15.1 Ab	13.9 Aa	14.5 Ab	14.1 Ab
Dry down 3:	Standard	23.1 Aa	16.6 Ba	22.9 Aa	21.7 Aa
	Modified	17.2 Ab	18.3 Aa	16.6 Ab	15.7 Ab
Dry down 4:	Standard	21.5[§]	15.3	19.9	20.8
	Modified	16.8	16.9	16.1	16.4

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

[§]Not significant at P=0.05.

* No data

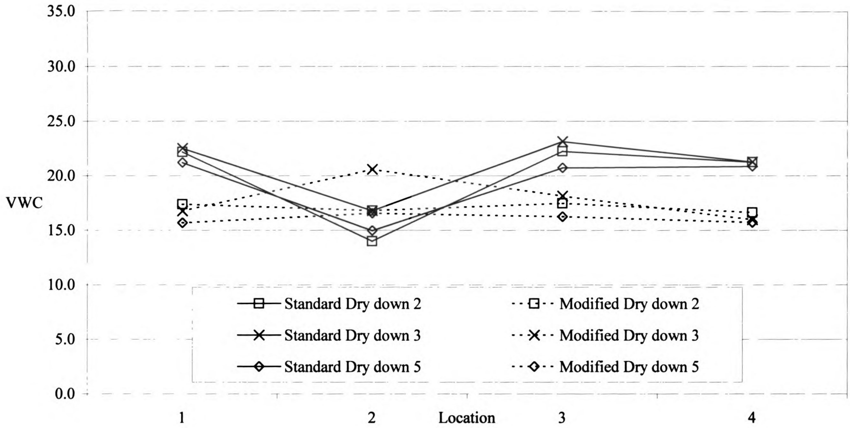

Figure 17. Volumetric water contents for the significant construction x location interactions for day 3, at the 10-20 cm depth, in 2000.

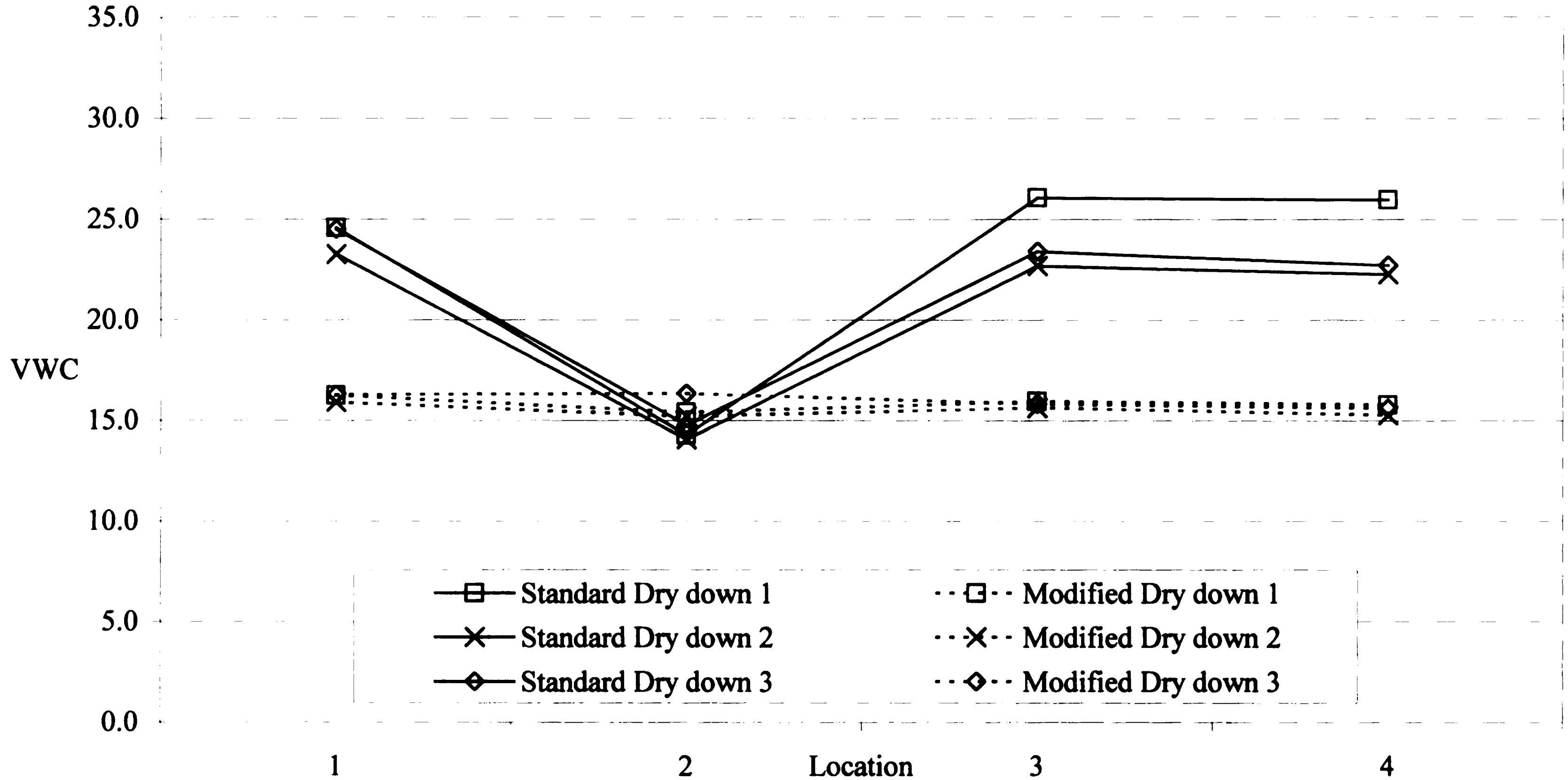

Figure 18. Volumetric water contents for the significant construction x location interactions for day 3, at the 10-20 cm depth, in 2001.

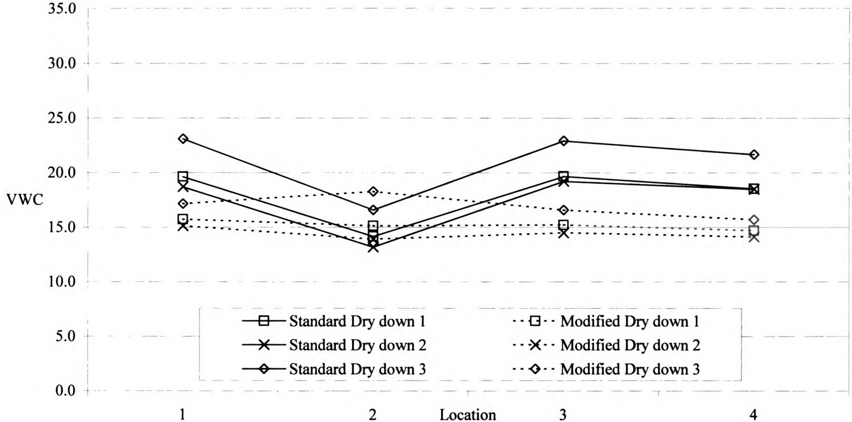

Figure 19. Volumetric water contents for the significant construction x location interactions for day 3, at the 10-20 cm depth, in 2002.

CONCLUSIONS

The United States Golf Association (USGA) specifications for putting green construction, first published in 1960, were designed to improve the quality of putting greens. Although the USGA published revisions in 1973, 1989 and 1993, the recommendation for a uniform 30 cm root zone layer has remained unchanged. The layering of a sand based root zone mix over a gravel layer maintains optimum moisture across the putting green on a level-putting surface, however, in areas of undulation the uniform root zone layer can result in moisture extremes at the different elevations.

The occurrence of moisture extremes across the surface of an undulating putting green will diminish the efficiency of an irrigation system, which is designed to apply a uniform amount of moisture. Irrigating to maintain optimum water contents at higher elevations will result in excessive water contents at lower elevations. Irrigating to maintain optimum water contents at lower elevations will result in water deficiencies at higher elevations.

The location x soil interaction confirmed that the addition of peat and/or soil to the root zone mix increased the water holding capacity. Increasing the water holding capacity, however, had a limited effect on improving the uniformity of VWC among the four locations at the 0-20 cm depth, regardless of construction type. These data suggest that for greens constructed with a more porous material, such as the sand root zone, it would be beneficial to modify the depth of the root zone to maintain uniform water contents across the surface of the putting green.

Although the construction x location x soil interaction was not consistently significant, the interaction demonstrates that a modification of the root zone depth increased the uniformity of VWC across the slope of the green. Within the standard construction type, the peak of all three of the soil types became drier than the lower elevations. Within the modified construction type, all three of the soil types had more uniform water content across all of the locations on the putting green.

The construction x location interaction shows that modifying the depth of the root zone mix, regardless of soil type, resulted in improved uniformity of moisture contents across the surface of an undulating putting green. The peak of the standard construction type consistently had the lowest VWC among the four locations, while there were no differences among the four locations of the modified construction type. The uniformity of VWC within the modified construction type was the direct result of the changes to the root zone depth. Reducing the depth of the root zone from 30 cm to 20 cm at the peak of the slope maintained or increased the VWC when compared to the standard construction type. Increasing the depth of the root zone depth from 30 cm to 40 cm at the lower elevations decreased the VWC in the top 20 cm when compared to the standard construction type.

Modification of the root zone depth will result in more uniform VWC across the surface of the putting green, increasing the effectiveness of irrigation systems and reducing problems associated with moisture extremes. A modification to the depth of root zone material, regardless of soil type, on an undulation USGA putting green will enhance the overall quality of the putting green.

APPENDIX

Table 1A. Volumetric water contents for the construction x location x soil interaction, day 0, at the 0-10 cm depth for the first four dry downs in 2000.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	18.5†	12.9	19.8	19.2
Uniform Sand/Peat	28.6	22.9	27.2	24.0
Uniform Sand/Soil	27.7	21.1	24.2	22.9
Modified Sand	13.7	13.9	15.5	14.6
Modified Sand/Peat	22.6	21.7	21.1	21.3
Modified Sand/Soil	19.4	23.6	19.1	19.7
	Location			
Dry down 2	1	2	3	4
Uniform Sand	17.5	8.7	17.7	18.6
Uniform Sand/Peat	27.3	21.9	25.4	23.9
Uniform Sand/Soil	26.9	16.5	23.9	22.6
Modified Sand	11.3	11.3	12.7	13.1
Modified Sand/Peat	21.7	24.3	20.5	19.4
Modified Sand/Soil	17.4	20.3	16.6	15.9
	Location			
Dry down 3	1	2	3	4
Uniform Sand	15.0	5.0	17.9	16.3
Uniform Sand/Peat	24.3	22.7	25.7	23.6
Uniform Sand/Soil	24.3	14.2	22.8	21.9
Modified Sand	7.2	9.1	15.4	14.2
Modified Sand/Peat	22.1	24.9	22.0	16.2
Modified Sand/Soil	18.6	21.5	17.7	14.8
	Location			
Dry down 5	1	2	3	4
Uniform Sand	17.6	8.5	19.3	18.3
Uniform Sand/Peat	27.9	23.7	27.5	26.5
Uniform Sand/Soil	27.1	20.5	23.6	22.8
Modified Sand	9.7	14.0	14.5	13.5
Modified Sand/Peat	22.9	25.5	15.8	20.7
Modified Sand/Soil	20.0	23.0	18.2	18.7

†Not significant at P=0.05.

Table 2A. Volumetric water contents for the construction x location x soil interaction, day 0, at the 0-10 cm depth for the four dry downs in 2001.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	20.8†	17.9	23.0	18.9
Uniform Sand/Peat	31.2	28.6	29.4	29.4
Uniform Sand/Soil	30.8	26.0	27.6	25.0
Modified Sand	19.3	19.9	17.5	18.6
Modified Sand/Peat	29.0	30.9	26.6	24.5
Modified Sand/Soil	26.5	28.5	24.3	24.8
	Location			
Dry down 2	1	2	3	4
Uniform Sand	23.9	23.4	22.7	20.5
Uniform Sand/Peat	32.0	30.7	30.1	28.4
Uniform Sand/Soil	31.9	28.9	28.0	26.8
Modified Sand	21.6	21.6	19.9	19.5
Modified Sand/Peat	32.1	33.1	29.9	28.6
Modified Sand/Soil	30.3	29.8	27.4	26.9
	Location			
Dry down 3	1	2	3	4
Uniform Sand	23.1	18.0	22.1	21.0
Uniform Sand/Peat	30.5	28.2	29.3	27.5
Uniform Sand/Soil	29.6	26.1	27.6	26.7
Modified Sand	19.7	19.5	20.8	20.0
Modified Sand/Peat	29.2	28.6	26.7	26.2
Modified Sand/Soil	26.8	27.7	25.4	25.9
	Location			
Dry down 4	1	2	3	4
Uniform Sand	21.0	18.5	22.3	22.6
Uniform Sand/Peat	31.7	28.1	29.1	28.8
Uniform Sand/Soil	31.0	27.2	25.9	27.6
Modified Sand	19.3	20.1	20.5	21.3
Modified Sand/Peat	29.2	31.3	26.1	26.2
Modified Sand/Soil	27.3	29.3	25.6	26.9

†Not significant at P=0.05.

Table 3A. Volumetric water contents for the construction x location x soil interaction, day 0, at the 0-10 cm depth for the four dry downs in 2002.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	*	*	*	*
Uniform Sand/Peat	*	*	*	*
Uniform Sand/Soil	*	*	*	*
Modified Sand	*	*	*	*
Modified Sand/Peat	*	*	*	*
Modified Sand/Soil	*	*	*	*
	Location			
Dry down 2	1	2	3	4
Uniform Sand	22.3†	13.5	23.8	22.8
Uniform Sand/Peat	32.0	27.0	31.0	29.2
Uniform Sand/Soil	30.8	17.2	30.1	26.4
Modified Sand	16.5	15.8	17.9	14.5
Modified Sand/Peat	25.3	27.7	20.0	24.3
Modified Sand/Soil	24.5	23.7	21.3	22.7
	Location			
Dry down 3	1	2	3	4
Uniform Sand	23.5	23.2	23.3	22.8
Uniform Sand/Peat	30.1	31.4	32.3	32.0
Uniform Sand/Soil	29.7	30.6	30.5	30.5
Modified Sand	23.6	23.5	24.0	21.7
Modified Sand/Peat	30.2	32.8	30.1	29.2
Modified Sand/Soil	29.4	31.6	29.5	29.1
	Location			
Dry down 4	1	2	3	4
Uniform Sand	23.0	13.1	22.0	17.8
Uniform Sand/Peat	32.8	25.1	25.3	23.1
Uniform Sand/Soil	31.2	20.6	30.2	20.5
Modified Sand	18.0	14.0	17.8	15.0
Modified Sand/Peat	21.4	26.8	22.8	22.5
Modified Sand/Soil	23.1	24.3	20.6	20.2

†Not significant at P=0.05.

*No Data

Table 4A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the first four dry downs in 2000.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	16.1 B[†]b[‡]	14.1 Bc	20.2 Acd	19.5 Ac
Uniform Sand/Peat	28.0 ABa	25.8 Bab	29.9 Aa	27.4 ABa
Uniform Sand/Soil	27.1 Aab	23.1 Cb	26.2 ABb	23.9 BCb
Modified Sand	14.6 Bd	16.4 ABc	17.6 Ad	15.5 ABd
Modified Sand/Peat	24.1 Bb	28.4 Aa	22.0 Bc	23.3 Bb
Modified Sand/Soil	19.9 Bc	25.6 Aab	20.6 Bcd	21.5 Bbc
	Location			
Dry down 2	1	2	3	4
Uniform Sand	14.5[§]	3.9	15.4	15.7
Uniform Sand/Peat	24.9	12.7	21.4	20.4
Uniform Sand/Soil	23.1	8.4	18.8	16.5
Modified Sand	6.4	5.8	9.2	8.3
Modified Sand/Peat	16.7	14.7	14.0	15.6
Modified Sand/Soil	12.3	12.1	10.2	9.4
	Location			
Dry down 3	1	2	3	4
Uniform Sand	15.7	4.5	19.1	16.7
Uniform Sand/Peat	28.7	22.0	27.0	24.4
Uniform Sand/Soil	27.0	20.2	24.4	21.1
Modified Sand	8.6	11.3	12.3	9.7
Modified Sand/Peat	23.7	24.6	15.8	20.2
Modified Sand/Soil	18.7	23.4	17.0	15.5
	Location			
Dry down 4	1	2	3	4
Uniform Sand	16.2	5.2	18.6	16.7
Uniform Sand/Peat	25.7	21.0	27.7	25.7
Uniform Sand/Soil	22.6	15.1	23.3	21.4
Modified Sand	10.1	9.7	9.2	11.1
Modified Sand/Peat	20.7	24.7	18.6	18.5
Modified Sand/Soil	16.6	19.1	14.1	13.2

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

[§] Not significant at P=0.05.

Table 5A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the fifth dry down in 2000.

	Location			
Dry down 5	1	2	3	4
Uniform Sand	14.7†	4.6	17.3	16.0
Uniform Sand/Peat	25.5	17.8	24.3	23.0
Uniform Sand/Soil	23.3	11.6	20.8	18.4
Modified Sand	8.6	7.9	12.3	10.1
Modified Sand/Peat	19.3	19.4	16.9	17.2
Modified Sand/Soil	14.6	16.2	15.1	13.6

†Not significant at P=0.05.

Table 6A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the four dry downs in 2001.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	17.3[†]	4.8	16.6	16.7
Uniform Sand/Peat	26.2	17.6	26.2	25.7
Uniform Sand/Soil	27.1	13.6	22.0	19.7
Modified Sand	10.5	9.5	9.6	10.2
Modified Sand/Peat	20.9	21.3	15.2	16.8
Modified Sand/Soil	15.8	16.9	13.1	14.0
	Location			
Dry down 2	1	2	3	4
Uniform Sand	12.6	6.0	16.8	14.5
Uniform Sand/Peat	22.9	17.6	23.0	23.8
Uniform Sand/Soil	26.7	15.6	21.6	19.5
Modified Sand	11.5	10.2	10.5	10.1
Modified Sand/Peat	20.0	21.4	15.6	16.1
Modified Sand/Soil	16.8	17.0	12.8	12.9
	Location			
Dry down 3	1	2	3	4
Uniform Sand	18.7	7.5	19.0	17.5
Uniform Sand/Peat	28.0	21.4	26.9	25.8
Uniform Sand/Soil	31.9	17.7	24.6	21.4
Modified Sand	13.2	12.0	16.3	14.1
Modified Sand/Peat	22.8	24.2	22.0	19.1
Modified Sand/Soil	18.3	20.9	16.0	16.5
	Location			
Dry down 4	1	2	3	4
Uniform Sand	18.1	4.5	18.8	19.5
Uniform Sand/Peat	25.7	21.1	25.9	24.1
Uniform Sand/Soil	27.9	14.0	24.6	22.3
Modified Sand	11.4	11.4	13.2	12.4
Modified Sand/Peat	20.4	23.6	16.6	16.9
Modified Sand/Soil	16.6	19.7	14.2	14.4

[†]Not significant at P=0.05.

Table 7A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the four dry downs in 2002.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	19.1[†]	8.7	16.3	16.1
Uniform Sand/Peat	27.5	20.1	25.1	25.4
Uniform Sand/Soil	26.7	15.6	22.7	21.6
Modified Sand	10.1	9.9	10.1	8.9
Modified Sand/Peat	19.0	21.0	17.5	18.2
Modified Sand/Soil	16.8	17.9	14.8	15.0
	Location			
Dry down 2	1	2	3	4
Uniform Sand	15.8	5.8	16.9	18.7
Uniform Sand/Peat	25.6	17.9	26.3	27.2
Uniform Sand/Soil	21.7	11.3	24.9	20.9
Modified Sand	10.0	8.5	11.1	9.7
Modified Sand/Peat	21.5	18.6	16.1	16.4
Modified Sand/Soil	15.7	16.4	15.6	14.3
	Location			
Dry down 3	1	2	3	4
Uniform Sand	20.8 A[‡]c[§]	11.8 Bd	21.1 Ac	22.2 Ab
Uniform Sand/Peat	29.9 Aa	23.8 Ba	30.8 Aa	29.0 Aa
Uniform Sand/Soil	31.4 Aa	20.3 Cb	28.0 Bb	28.1 Ba
Modified Sand	14.3 Ad	14.7 Ac	15.1 Ad	14.1 Ac
Modified Sand/Peat	24.3 ABb	26.1 Aa	22.2 Bc	22.0 Bb
Modified Sand/Soil	21.6 ABc	23.7 Aa	20.5 Bc	21.6 ABb
	Location			
Dry down 4	1	2	3	4
Uniform Sand	20.1	7.9	16.3	17.3
Uniform Sand/Peat	30.0	22.6	27.4	25.6
Uniform Sand/Soil	28.5	17.4	24.1	21.3
Modified Sand	12.6	10.3	11.9	11.1
Modified Sand/Peat	24.8	22.3	19.2	21.6
Modified Sand/Soil	23.3	21.6	17.6	15.2

[†]Not significant at P=0.10.

[‡]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.10)

[§]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.10)

Table 8A. Volumetric water contents for the construction x location x soil interaction, day 0, at the 10-20 cm depth for the first four dry downs in 2000.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	21.0 A[†]ab[‡]	13.9 Bc	22.9 Aa	21.6 Aab
Uniform Sand/Peat	24.9 Aa	20.3 Bb	22.8 ABa	24.0 Aa
Uniform Sand/Soil	21.8Bab	25.7 Aa	20.5 Bab	19.4 Bb
Modified Sand	13.1 Bc	15.8 Bc	19.5 Ab	14.2 Bc
Modified Sand/Peat	20.8 Aab	21.3 Ab	17.9 Bb	17.8 Bbc
Modified Sand/Soil	17.5 Bb	20.5 Ab	17.2 Bb	16.6 Bbc
	Location			
Dry down 2	1	2	3	4
Uniform Sand	19.2[§]	12.2	21.6	20.9
Uniform Sand/Peat	24.1	17.8	21.5	22.1
Uniform Sand/Soil	23.3	15.5	18.2	19.3
Modified Sand	12.1	15.9	20.1	14.1
Modified Sand/Peat	19.9	18.5	17.1	17.4
Modified Sand/Soil	16.6	20.1	20.7	16.6
	Location			
Dry down 3	1	2	3	4
Uniform Sand	19.1 Ab	10.3 Bb	21.8 Aa	21.0 Aab
Uniform Sand/Peat	23.5 Aa	16.7 Ba	21.8 Aa	22.3 Aa
Uniform Sand/Soil	23.1 Aa	15.4 Ca	22.8ABa	19.9 Babc
Modified Sand	12.5 Bc	17.0 Aa	17.2 Ab	14.6 ABd
Modified Sand/Peat	20.5 Aab	16.8 Ba	17.3 Bb	18.0 ABbc
Modified Sand/Soil	17.7 Ab	18.5 Aa	17.4 Ab	16.8 Acd
	Location			
Dry down 4	1	2	3	4
Uniform Sand	22.8	16.3	23.3	22.2
Uniform Sand/Peat	28.7	22.1	23.7	24.6
Uniform Sand/Soil	24.2	19.8	19.2	21.1
Modified Sand	13.9	24.2	18.5	15.5
Modified Sand/Peat	24.8	24.4	19.1	19.8
Modified Sand/Soil	20.0	24.0	19.1	18.9

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.10)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.10)

[§]Not significant at P=0.10.

Table 9A. Volumetric water contents for the construction x location x soil interaction, day 0, at the 10-20 cm depth for the fifth dry down in 2000.

	Location			
Dry down 5	1	2	3	4
Uniform Sand	19.7 A†bc‡	13.5 Bb	21.6 Aa	21.0 Ab
Uniform Sand/Peat	25.2 Aa	19.6 Ba	22.4 ABa	25.6 Aa
Uniform Sand/Soil	23.0 Aab	18.4 Aa	22.5 Aa	19.2 Ab
Modified Sand	12.6 Bd	20.3 Aa	17.2 ABb	14.1 Bc
Modified Sand/Peat	20.7 Abc	20.9 Aa	17.7 Ab	17.8 Ab
Modified Sand/Soil	17.6 Ac	20.6 Aa	17.2 ABb	16.9 Abc

†Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.10)

‡Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.10)

Table 10A. Volumetric water contents for the construction x location x soil interaction, day 0, at the 10-20 cm depth for the four dry downs in 2001.

	Location			
<u>Dry down 1</u>	1	2	3	4
Uniform Sand	21.6†	14.0	28.0	27.4
Uniform Sand/Peat	32.5	21.1	34.5	33.3
Uniform Sand/Soil	27.4	16.9	25.3	24.2
Modified Sand	13.6	16.8	14.6	14.0
Modified Sand/Peat	21.2	22.3	20.2	19.2
Modified Sand/Soil	18.1	20.5	18.0	17.1
	Location			
<u>Dry down 2</u>	1	2	3	4
Uniform Sand	20.9	15.6	24.5	22.8
Uniform Sand/Peat	29.6	21.4	29.0	28.5
Uniform Sand/Soil	26.5	16.6	23.0	21.9
Modified Sand	13.4	16.6	14.3	13.5
Modified Sand/Peat	20.6	22.7	19.8	18.2
Modified Sand/Soil	18.2	20.6	17.7	17.0
	Location			
<u>Dry down 3</u>	1	2	3	4
Uniform Sand	20.9	14.5	23.4	21.8
Uniform Sand/Peat	30.6	21.4	27.4	26.8
Uniform Sand/Soil	25.9	16.5	22.4	21.2
Modified Sand	13.3	43.4	13.6	13.5
Modified Sand/Peat	20.4	22.1	19.3	18.0
Modified Sand/Soil	18.1	20.6	17.4	17.2
	Location			
<u>Dry down 4</u>	1	2	3	4
Uniform Sand	*	*	*	*
Uniform Sand/Peat	*	*	*	*
Uniform Sand/Soil	*	*	*	*
Modified Sand	*	*	*	*
Modified Sand/Peat	*	*	*	*
Modified Sand/Soil	*	*	*	*

†Not significant at P=0.10.

*No data.

Table 11A. Volumetric water contents for the construction x location x soil interaction, day 0, at the 10-20 cm depth for the four dry downs in 2002.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	20.2†	14.8	21.7	20.3
Uniform Sand/Peat	25.1	21.3	24.9	23.3
Uniform Sand/Soil	24.3	18.0	17.0	20.6
Modified Sand	13.4	17.2	13.2	13.0
Modified Sand/Peat	21.1	22.1	19.8	18.1
Modified Sand/Soil	18.3	21.4	17.3	17.5
	Location			
Dry down 2	1	2	3	4
Uniform Sand	18.8	11.8	21.2	23.4
Uniform Sand/Peat	24.0	20.3	24.8	20.5
Uniform Sand/Soil	23.1	15.4	19.9	15.6
Modified Sand	12.4	14.3	13.3	12.9
Modified Sand/Peat	20.7	20.1	19.6	17.9
Modified Sand/Soil	17.2	18.1	16.9	15.9
	Location			
Dry down 3	1	2	3	4
Uniform Sand	20.9	17.2	22.7	20.7
Uniform Sand/Peat	31.3	24.8	26.6	25.1
Uniform Sand/Soil	25.3	18.9	23.1	22.0
Modified Sand	14.2	20.0	14.2	13.9
Modified Sand/Peat	22.2	26.6	20.8	19.1
Modified Sand/Soil	19.1	24.7	17.9	17.2
	Location			
Dry down 4	1	2	3	4
Uniform Sand	20.4	15.6	22.7	20.5
Uniform Sand/Peat	25.5	22.7	26.5	25.8
Uniform Sand/Soil	24.7	17.8	23.7	20.4
Modified Sand	14.0	18.5	17.1	13.8
Modified Sand/Peat	22.0	24.7	21.1	21.4
Modified Sand/Soil	18.8	21.9	18.4	17.6

†Not significant at P=0.10.

Table 12A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the first four dry downs in 2000.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	*	*	*	*
Uniform Sand/Peat	*	*	*	*
Uniform Sand/Soil	*	*	*	*
Modified Sand	*	*	*	*
Modified Sand/Peat	*	*	*	*
Modified Sand/Soil	*	*	*	*
	Location			
Dry down 2	1	2	3	4
Uniform Sand	19.1†	10.1	22.0	21.3
Uniform Sand/Peat	23.9	16.5	21.6	22.4
Uniform Sand/Soil	23.7	15.4	23.2	20.0
Modified Sand	13.0	16.4	17.1	14.9
Modified Sand/Peat	20.8	16.4	17.2	18.5
Modified Sand/Soil	18.4	17.7	18.1	16.6
	Location			
Dry down 3	1	2	3	4
Uniform Sand	19.9	12.6	22.4	21.3
Uniform Sand/Peat	23.9	19.5	22.1	22.6
Uniform Sand/Soil	23.8	18.3	25.1	19.9
Modified Sand	12.4	18.8	18.1	13.9
Modified Sand/Peat	20.4	21.2	17.5	17.7
Modified Sand/Soil	17.6	21.8	18.9	16.3
	Location			
Dry down 5	1	2	3	4
Uniform Sand	18.1 A‡bc§	11.3 Bb	20.4 Aa	19.7 Ab
Uniform Sand/Peat	23.2 ABa	17.3 Ca	20.6 BCa	24.6 Aa
Uniform Sand/Soil	22.4 Aa	16.4 Ca	21.3 ABa	18.4 BCb
Modified Sand	11.1 Bd	14.9 ABab	15.7 Ab	13.7 ABc
Modified Sand/Peat	19.8 Aab	17.9 Aa	17.1 Aab	17.1 Ab
Modified Sand/Soil	16.2 Ac	16.9 Aa	16.0 Ab	16.4 Abc

†Not significant at P=0.10.

‡Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

§Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

*No data.

Table 13A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the four dry downs in 2001.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	18.1[†]	11.5	24.2	24.3
Uniform Sand/Peat	30.0	17.4	31.3	31.2
Uniform Sand/Soil	25.6	13.9	22.8	22.3
Modified Sand	12.3	11.8	12.6	12.8
Modified Sand/Peat	20.0	17.8	18.9	18.2
Modified Sand/Soil	16.6	16.7	16.4	16.3
	Location			
Dry down 2	1	2	3	4
Uniform Sand	17.8	11.7	21.3	20.5
Uniform Sand/Peat	27.3	17.6	25.7	26.0
Uniform Sand/Soil	24.8	13.0	21.1	20.5
Modified Sand	12.1	11.8	12.4	12.4
Modified Sand/Peat	19.3	17.3	18.3	17.3
Modified Sand/Soil	16.5	16.5	16.3	16.2
	Location			
Dry down 3	1	2	3	4
Uniform Sand	19.6	11.9	22.3	21.2
Uniform Sand/Peat	28.5	18.4	26.0	26.1
Uniform Sand/Soil	25.5	14.0	22.0	20.8
Modified Sand	12.2	12.6	12.8	12.7
Modified Sand/Peat	19.7	18.6	18.3	17.6
Modified Sand/Soil	17.0	17.9	16.4	16.6
	Location			
Dry down 4	1	2	3	4
Uniform Sand	*	*	*	*
Uniform Sand/Peat	*	*	*	*
Uniform Sand/Soil	*	*	*	*
Modified Sand	*	*	*	*
Modified Sand/Peat	*	*	*	*
Modified Sand/Soil	*	*	*	*

[*] No Data

[†] Not significant at P=0.10.

Table 14A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the four dry downs in 2002.

	Location			
Dry down 1	1	2	3	4
Uniform Sand	16.1[†]	11.2	17.9	16.9
Uniform Sand/Peat	21.6	17.5	21.5	20.6
Uniform Sand/Soil	21.3	13.8	19.7	18.2
Modified Sand	11.7	12.5	12.1	12.5
Modified Sand/Peat	19.2	16.7	18.1	16.6
Modified Sand/Soil	16.4	16.3	15.5	15.1
	Location			
Dry down 2	1	2	3	4
Uniform Sand	14.9	9.8	17.4	16.5
Uniform Sand/Peat	21.0	16.6	20.9	20.6
Uniform Sand/Soil	20.3	13.3	19.3	18.5
Modified Sand	11.0	11.3	10.7	11.4
Modified Sand/Peat	18.9	15.3	17.8	16.3
Modified Sand/Soil	15.6	15.3	15.0	14.8
	Location			
Dry down 3	1	2	3	4
Uniform Sand	19.5	13.2	21.3	20.0
Uniform Sand/Peat	25.8	20.6	24.9	24.1
Uniform Sand/Soil	24.1	16.1	22.6	21.1
Modified Sand	13.2	14.5	12.8	13.0
Modified Sand/Peat	20.9	20.9	19.8	18.3
Modified Sand/Soil	17.4	19.5	17.2	15.9
	Location			
Dry down 4	1	2	3	4
Uniform Sand	17.8	12.1	19.9	18.6
Uniform Sand/Peat	23.8	19.3	23.9	24.5
Uniform Sand/Soil	23.1	14.7	15.9	19.4
Modified Sand	12.4	14.0	12.5	12.7
Modified Sand/Peat	20.8	19.0	19.5	20.2
Modified Sand/Soil	17.4	17.9	16.4	16.3

[†]Not significant at P=0.10.

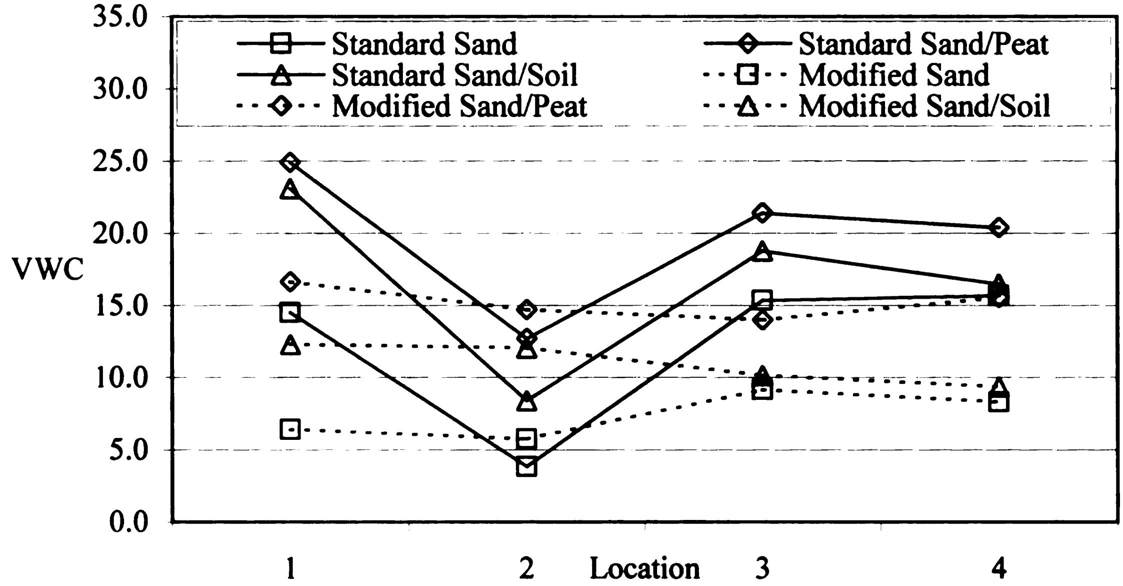

Figure 1A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the second dry down in 2000.

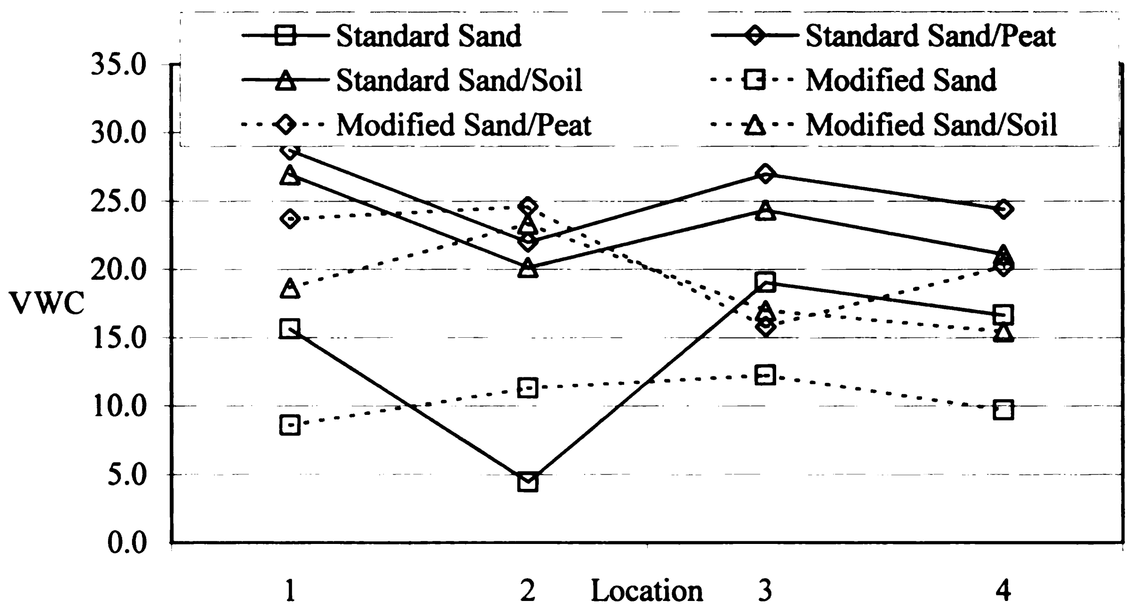

Figure 2A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the third dry down in 2000.

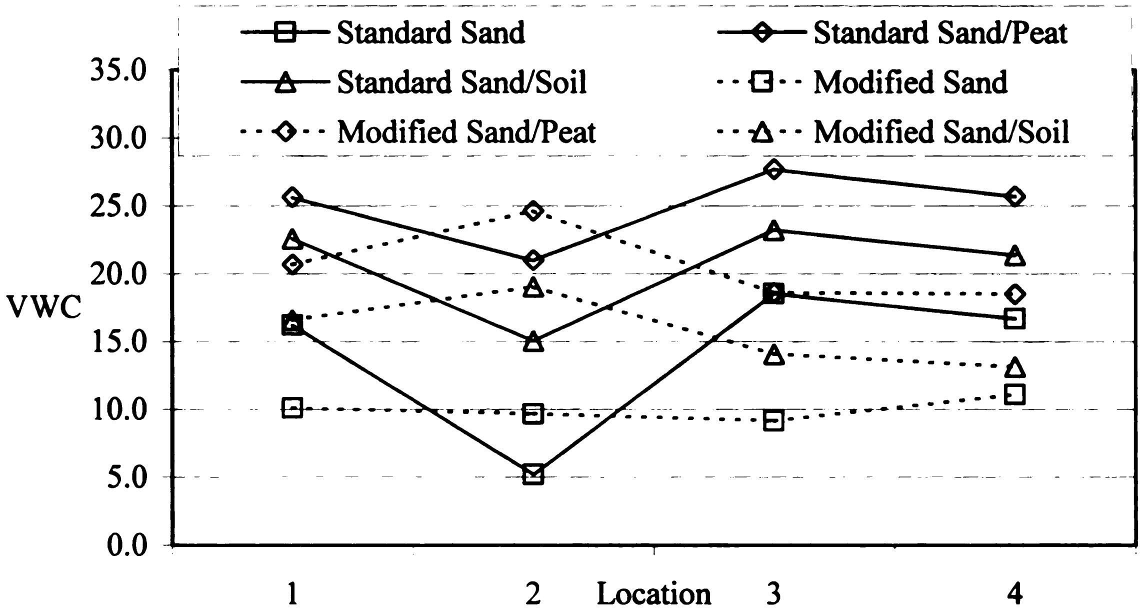

Figure 3A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the fourth dry down in 2000.

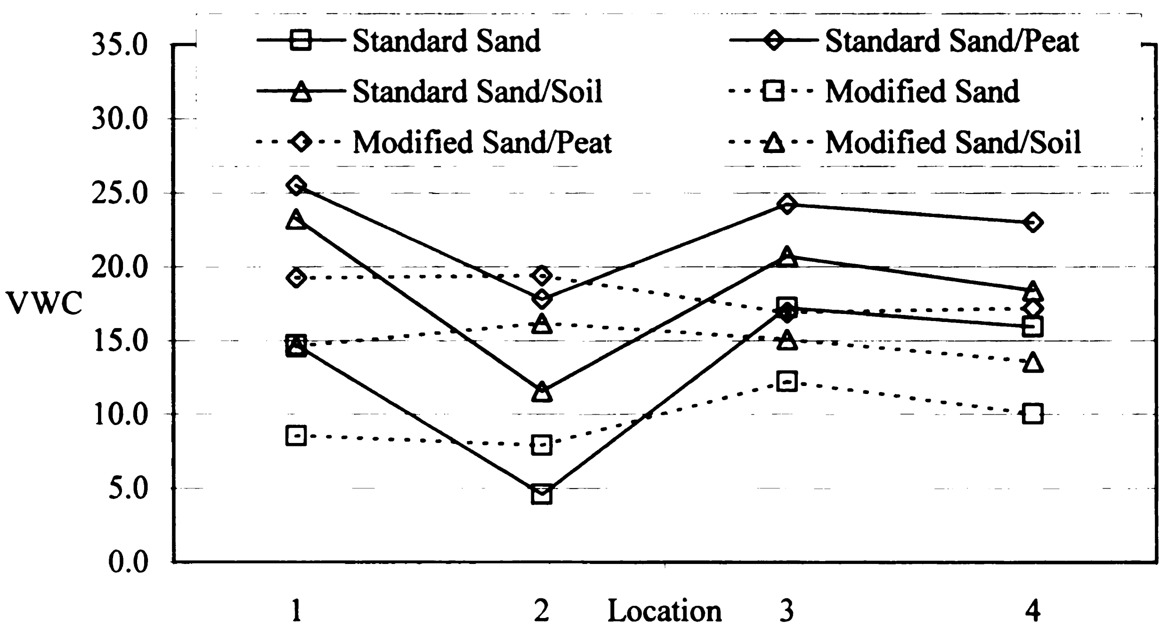

Figure 4A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the fifth dry down in 2000.

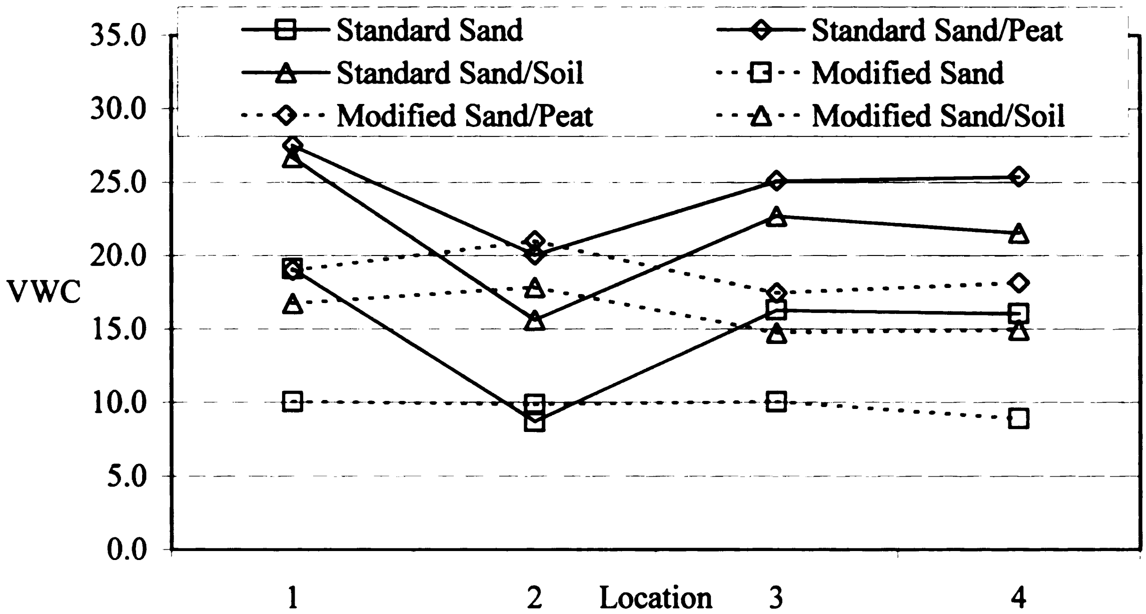

Figure 5A. Volumetric water contents for the construction x location x soil interaction, day 3, the 0-10 cm depth for the first dry down in 2002.

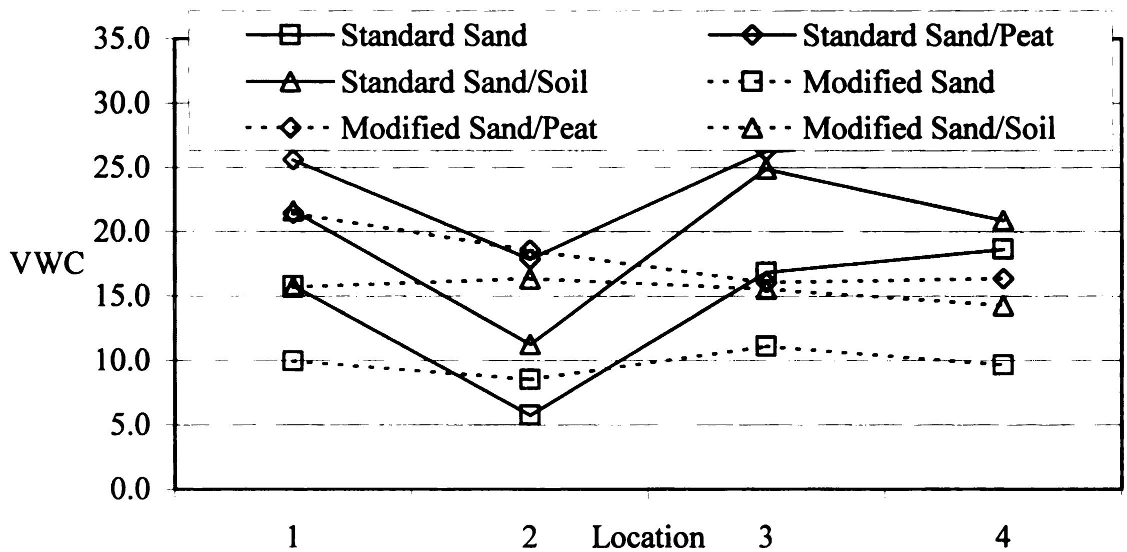

Figure 6A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the second dry down in 2002.

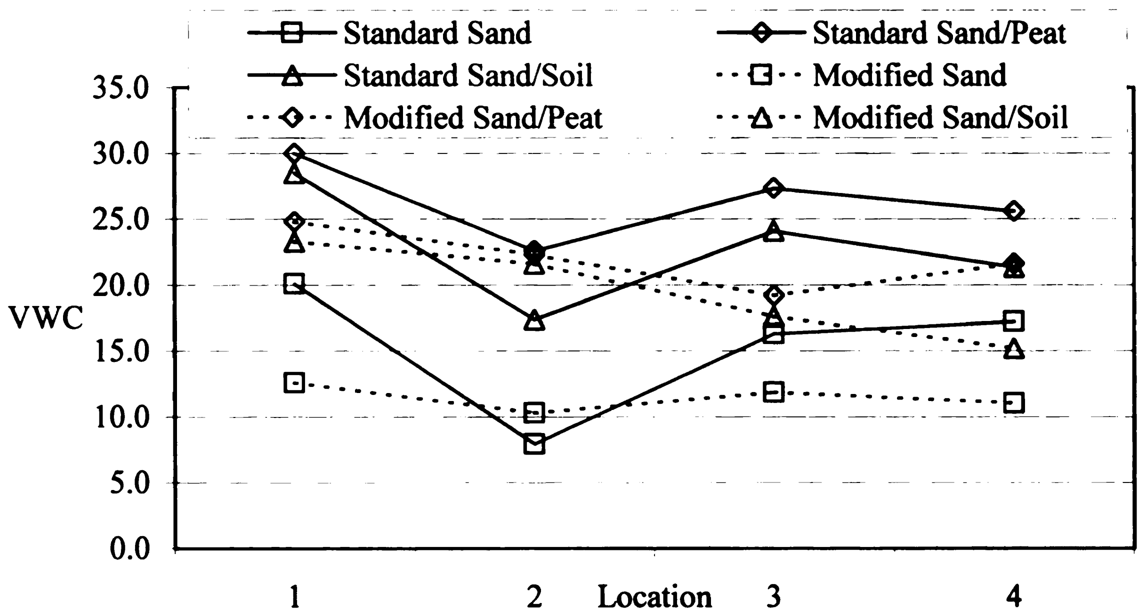

Figure 7A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 0-10 cm depth for the fourth dry down in 2002.

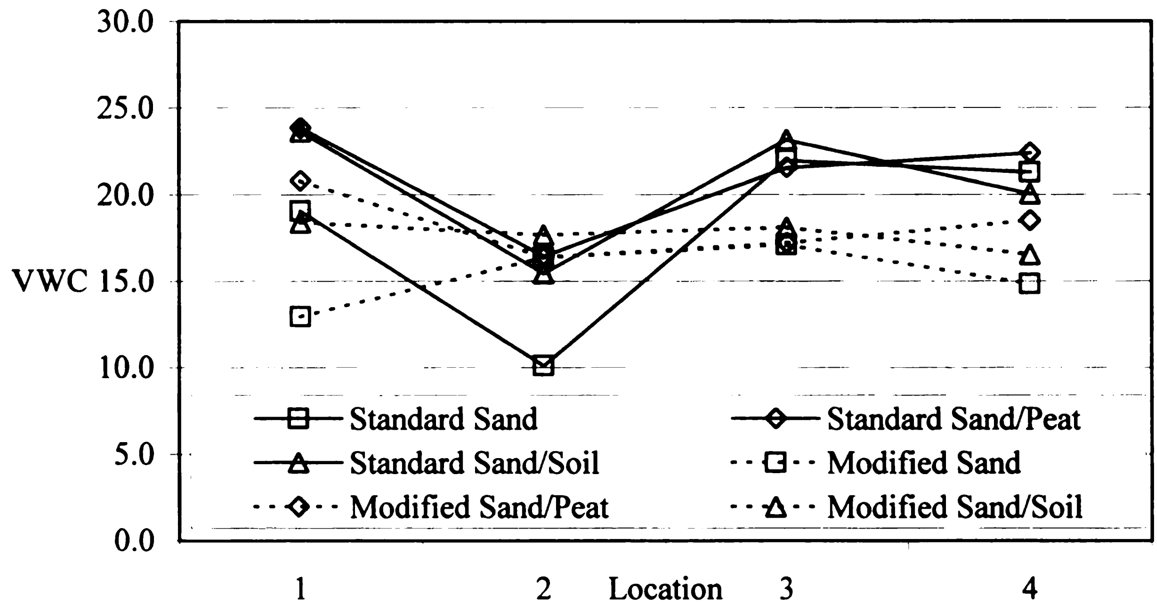

Figure 8A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the second dry down in 2000.

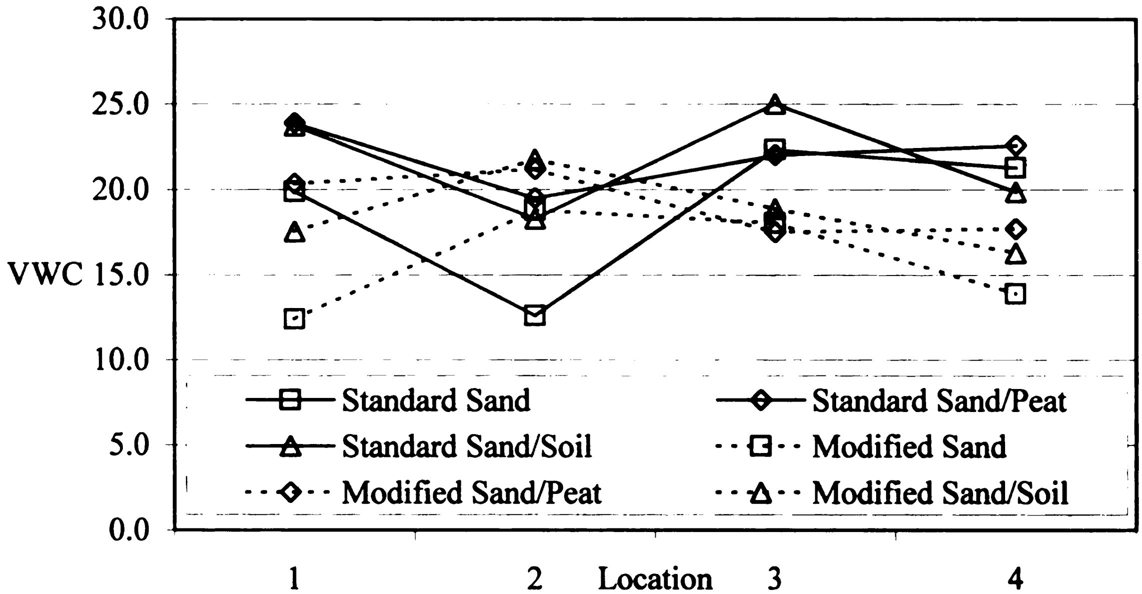

Figure 9A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the third dry down in 2000.

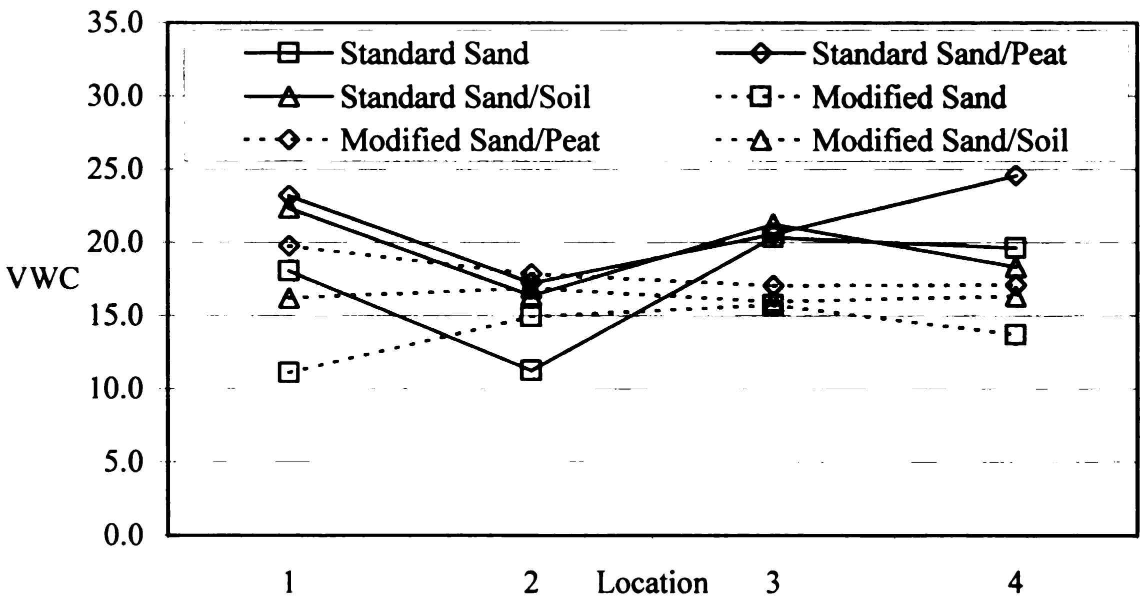

Figure 10A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the fifth dry down in 2000.

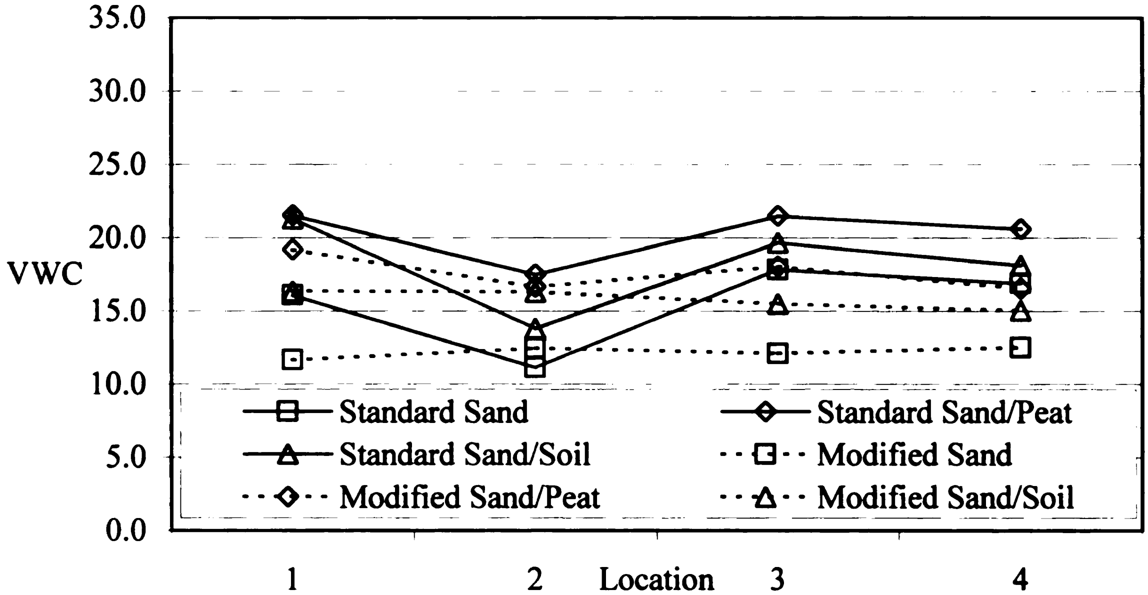

Figure 11A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the first dry down in 2002.

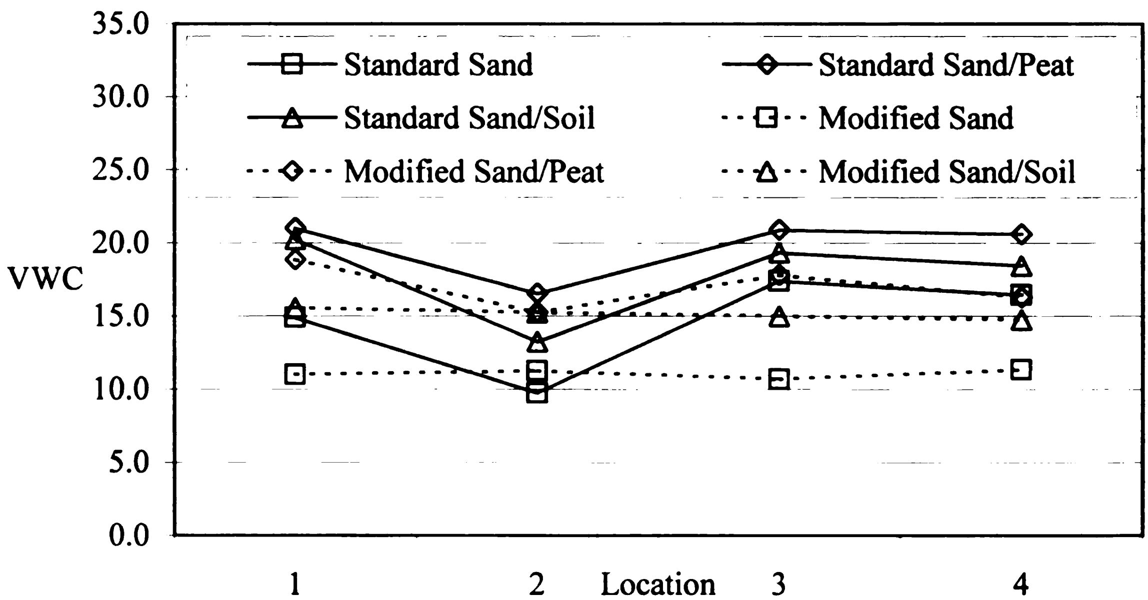

Figure 12A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the second dry down in 2002.

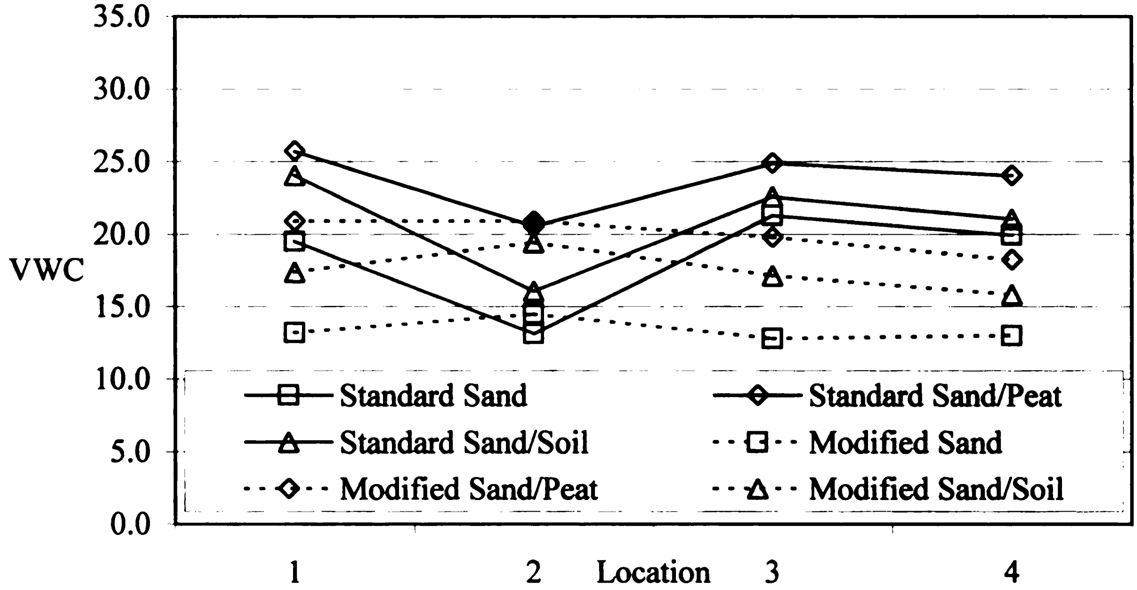

Figure 13A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the third dry down in 2002.

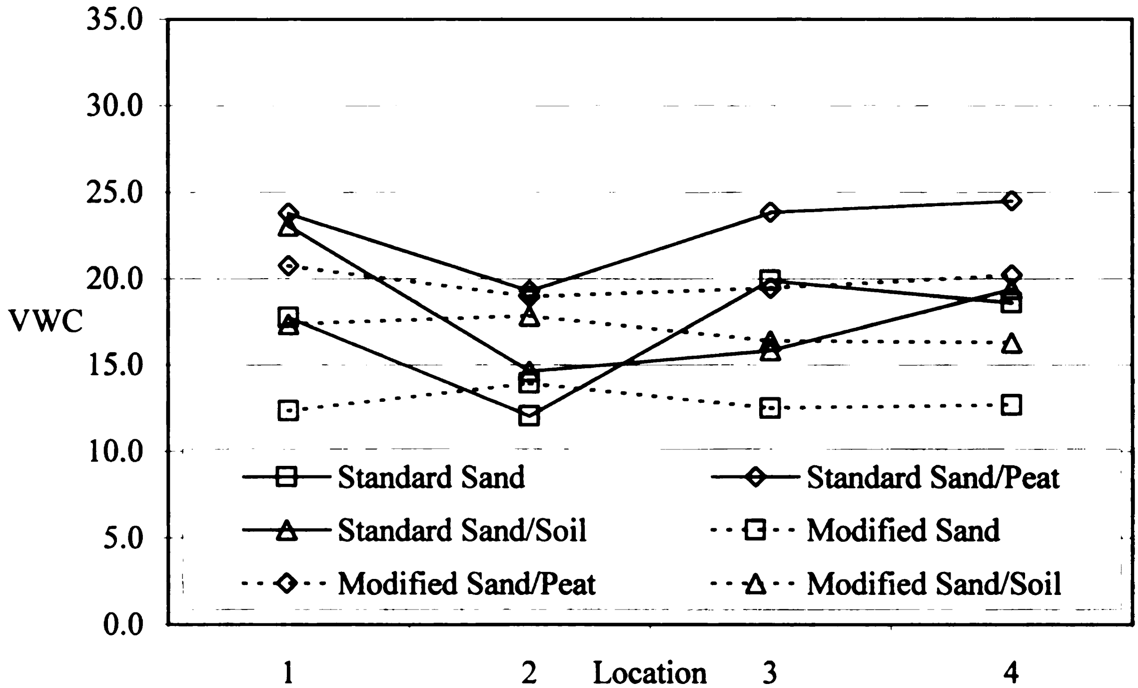

Figure 14A. Volumetric water contents for the construction x location x soil interaction, day 3, at the 10-20 cm depth for the fourth dry down in 2002.

Table 15A. Volumetric water contents for the location x soil interaction, day 0, for the five dry downs in 2000, at the 0-10 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	16.1[†]	13.4	17.6	16.9
Sand/Peat	25.6	22.3	24.1	22.7
Sand/Soil	23.5	22.4	21.6	21.3

Dry down 2	Location			
	1	2	3	4
Sand	14.4	10.0	15.2	15.9
Sand/Peat	24.5	23.1	23.0	21.6
Sand/Soil	22.1	18.4	20.2	19.2

Dry down 3	Location			
	1	2	3	4
Sand	11.1 BC[‡]b[§]	7.1 Cc	16.6 Ab	15.2 ABb
Sand/Peat	23.2 Aa	23.8 Aa	23.9 Aa	19.9 Aa
Sand/Soil	21.4 Aa	17.8 Ab	20.2 Aab	18.4 Aab

Dry down 4	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

Dry down 5	Location			
	1	2	3	4
Sand	13.7*	11.2	16.9	15.9
Sand/Peat	25.4	24.6	21.6	23.6
Sand/Soil	23.5	21.7	20.9	20.7

[†]Not significant at P=0.05.

[‡]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[§]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

Table 16A. Volumetric water contents for the location x soil interaction, day 0, for the four dry downs in 2001, at the 0-10 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	20.1†	18.9	20.3	18.7
Sand/Peat	30.1	29.7	28.0	26.9
Sand/Soil	28.6	27.2	25.9	24.9

Dry down 2	Location			
	1	2	3	4
Sand	22.7	22.5	21.3	20.0
Sand/Peat	32.0	31.9	30.0	28.5
Sand/Soil	31.1	29.3	27.7	26.8

Dry down 3	Location			
	1	2	3	4
Sand	21.4	18.7	21.4	20.5
Sand/Peat	29.8	28.4	28.0	26.8
Sand/Soil	28.2	26.9	26.5	26.3

Dry down 4	Location			
	1	2	3	4
Sand	20.1	19.3	21.4	21.9
Sand/Peat	30.4	29.7	27.6	27.5
Sand/Soil	29.1	28.2	25.7	27.3

†Not significant at P=0.05.

Table 17A. Volumetric water contents for the location x soil interaction, day 0, for the four dry downs in 2002, at the 0-10 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

Dry down 2	Location			
	1	2	3	4
Sand	19.4 A[†]b[‡]	14.7 Bc	20.9 Ab	18.6 Ab
Sand/Peat	28.6 Aa	27.3 Aa	25.5 Aa	26.8 Aa
Sand/Soil	27.6 Aa	20.4 Bb	25.7 Aa	24.6 Aa

Dry down 3	Location			
	1	2	3	4
Sand	23.5[§]	23.4	23.7	22.2
Sand/Peat	30.2	32.1	31.2	30.6
Sand/Soil	29.6	31.1	30.1	29.8

Dry down 4	Location			
	1	2	3	4
Sand	20.5	15.9	21.7	21.6
Sand/Peat	31.5	28.5	29.0	27.9
Sand/Soil	27.4	25.9	27.3	26.2

†Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

‡Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

§Not significant at P=0.10.

*No data.

Table 18A. Volumetric water contents for the location x soil interaction, day 3, for the five dry downs in 2000, at the 0-10 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	15.3 B[†]c[‡]	15.3 Bc	18.9 Ac	17.5 Ac
Sand/Peat	26.1 Aa	27.1 Aa	26.0 Aa	25.3 Aa
Sand/Soil	23.5 Ab	24.3 Ab	23.4 Ab	22.7 Ab

Dry down 2	Location			
	1	2	3	4
Sand	10.5 Ab	4.8 Bc	12.3 Ab	12.0 Ab
Sand/Peat	20.8 Aa	13.7 Ca	17.7 Ba	18.0 Ba
Sand/Soil	17.7 Aa	10.2 Cb	14.5 Bab	12.9 Bb

Dry down 3	Location			
	1	2	3	4
Sand	12.1 Ab	7.9 Bb	15.7 Ab	13.2 Ab
Sand/Peat	26.2 Aa	23.3 ABa	21.4 ABa	22.3 Ba
Sand/Soil	22.8 Aa	21.8 ABa	20.7 ABa	18.3 Ba

Dry down 4	Location			
	1	2	3	4
Sand	13.2[§]	7.4	13.9	13.9
Sand/Peat	23.2	22.8	23.2	22.1
Sand/Soil	19.6	17.1	18.7	17.3

Dry down 5	Location			
	1	2	3	4
Sand	11.6	6.3	14.8	13.0
Sand/Peat	22.4	18.6	20.6	20.1
Sand/Soil	18.9	13.9	17.9	16.0

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

[§]Not significant at P=0.05.

Table 19A. Volumetric water contents for the location x soil interaction, day 3, for the four dry downs in 2001, at the 0-10 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	13.9 A[†]b[‡]	7.1 Bc	13.1 Ac	13.4 Ac
Sand/Peat	23.5 Aa	19.5 Ba	20.7 ABa	21.2 ABa
Sand/Soil	21.4 Aa	15.2 Bb	17.6 Bb	16.9 Bb

Dry down 2	Location			
	1	2	3	4
Sand	12.0 Ab	8.1 Bc	13.6 Ab	12.3 Ac
Sand/Peat	21.5 Ab	19.5 Aa	19.3 Aa	19.9 Aa
Sand/Soil	21.7 Ab	16.3 Bb	17.2 Ba	16.2 Bb

Dry down 3	Location			
	1	2	3	4
Sand	15.9 Ab	9.7 Bc	17.6 Ab	15.8 Ac
Sand/Peat	25.4 Aa	22.8 ABa	24.5 ABa	22.4 Ba
Sand/Soil	25.1 Aa	19.3 Bb	20.3 Bb	18.9 Bb

Dry down 4	Location			
	1	2	3	4
Sand	14.7 Ab	7.9 Bc	16.0 Ab	15.9 Ab
Sand/Peat	23.0 Aa	22.3 Aa	22.3 Aa	20.5 Aa
Sand/Soil	22.3 Aa	16.9 Bb	19.4 ABab	18.3 Bab

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

Table 20A. Volumetric water contents for the location x soil interaction, day 3, for the four dry downs in 2002, at the 0-10 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	14.6[†]	9.3	13.2	12.5
Sand/Peat	23.3	20.5	21.3	21.8
Sand/Soil	21.7	16.7	18.7	18.3

Dry down 2	Location			
	1	2	3	4
Sand	12.9	7.1	14.0	14.2
Sand/Peat	23.5	18.2	21.2	21.8
Sand/Soil	18.7	13.8	20.2	17.8

Dry down 3	Location			
	1	2	3	4
Sand	17.6 A[‡]b[§]	13.2 Bc	18.1 Ac	18.2 Ab
Sand/Peat	27.1 Aa	24.9 Ba	26.5 ABa	25.5 ABa
Sand/Soil	26.5 Aa	22.0 Cb	24.2 Bb	24.9 ABa

Dry down 4	Location			
	1	2	3	4
Sand	16.4 Ab	9.1 Bb	14.1 Ab	14.2 Ac
Sand/Peat	27.4 Aa	22.5 Ba	23.3 Ba	23.6 Ba
Sand/Soil	25.9 Aa	19.5 Ba	20.9 Ba	18.3 Bb

[†]Not significant at P=0.05.

[‡]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[§]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

Table 21A. Volumetric water contents for the location x soil interaction, day 0, for the five dry downs in 2000, at the 10-20 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	17.1 BC[†]b[‡]	14.9 Cb	21.2 Aa	17.9 Bb
Sand/Peat	22.9 Aa	20.8 ABa	20.4 Ba	21.0 ABa
Sand/Soil	19.7 Bb	23.1 Aa	18.9 Ba	18.0 Bb

Dry down 2	Location			
	1	2	3	4
Sand	15.7 Bb	14.1 Bb	20.9 Aa	17.5 ABa
Sand/Peat	22.0 Aa	18.2 Ba	19.4 ABa	19.8 ABa
Sand/Soil	20.0 Aa	17.8 Aa	19.5 Aa	18.0 Aa

Dry down 3	Location			
	1	2	3	4
Sand	15.8 BCb	13.6 Cb	19.5 Aa	17.8 ABb
Sand/Peat	22.0 Aa	16.7 Ca	19.5 Aa	20.2 Aa
Sand/Soil	20.4 Aa	16.9 Ba	20.1 Aa	18.4 ABab

Dry down 4	Location			
	1	2	3	4
Sand	18.4 Ac	20.2 Aa	20.9 Aa	18.8 Aa
Sand/Peat	26.8 Aa	23.2 ABa	21.4 Ba	22.2 Ba
Sand/Soil	22.1 Ab	21.9 Aa	19.1 Aa	20.0 Aa

Dry down 5	Location			
	1	2	3	4
Sand	16.2 Ac	16.9 Ab	19.4 Aa	17.6 Ab
Sand/Peat	23.0 Aa	20.3 Aa	20.1 Aa	21.7 Aa
Sand/Soil	20.3 Ab	19.5 Aab	19.9 Aa	18.1 Ab

[†]Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

[‡]Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

Table 22A. Volumetric water contents for the location x soil interaction, day 0, for the four dry downs in 2001, at the 10-20 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	17.6[†]	15.4	21.3	20.7
Sand/Peat	26.9	21.7	27.4	26.2
Sand/Soil	22.8	18.7	21.6	20.6

Dry down 2	Location			
	1	2	3	4
Sand	17.1	16.1	19.4	18.1
Sand/Peat	25.1	22.0	24.4	23.3
Sand/Soil	22.4	18.6	20.3	19.5

Dry down 3	Location			
	1	2	3	4
Sand	17.1	29.0	18.5	17.7
Sand/Peat	25.5	21.7	23.3	22.4
Sand/Soil	22.0	18.5	19.9	19.2

Dry down 4	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

[†]Not significant at P=0.05.
*No data.

Table 23A. Volumetric water contents for the location x soil interaction, day 0, for the four dry downs in 2002, at the 10-20 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	16.8†	16.0	17.4	16.6
Sand/Peat	23.1	21.7	22.4	20.7
Sand/Soil	21.3	19.7	17.1	19.1

Dry down 2	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

Dry down 3	Location			
	1	2	3	4
Sand	17.5	18.6	18.5	17.3
Sand/Peat	26.8	25.7	23.7	22.1
Sand/Soil	22.2	21.8	20.5	19.6

Dry down 4	Location			
	1	2	3	4
Sand	17.2	17.0	19.9	17.2
Sand/Peat	23.7	23.7	23.8	23.6
Sand/Soil	21.7	19.8	21.0	19.0

†Not significant at P=0.05.
*No data.

Table 24A. Volumetric water contents for the location x soil interaction, day 3, for the five dry downs in 2000, at the 10-20 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

Dry down 2	Location			
	1	2	3	4
Sand	16.0 B†b‡	13.2 Cb	19.6 Aa	18.1 ABb
Sand/Peat	22.3 Aa	16.4 Ca	19.4 Ba	20.5 ABa
Sand/Soil	21.0 Aa	16.6 Ca	20.6 ABa	18.3 BCb

Dry down 3	Location			
	1	2	3	4
Sand	16.2 Bb	15.7 Bb	20.0 Aa	17.6 ABa
Sand/Peat	22.1 Aa	20.4 Aa	19.8 Aa	20.2 Aa
Sand/Soil	20.7 ABa	20.0 ABa	22.0 Aa	18.1 Ba

Dry down 4	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

Dry down 5	Location			
	1	2	3	4
Sand	14.6 BCc	13.1 Cb	18.1 Aa	16.7 ABb
Sand/Peat	21.5 Aa	17.6 Ba	18.8 ABa	20.9 Aa
Sand/Soil	19.3 Ab	16.6 Aa	18.6 Aa	17.4 Ab

†Means in a row followed by the same capital letter are not significantly different according to Fischers protected LSD (p=0.05)

‡Means in a column followed by the same lower case letter are not significantly different according to Fischers protected LSD (p=0.05)

*No data.

Table 25A. Volumetric water contents for the location x soil interaction, day 3, for the four dry downs in 2001, at the 10-20 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	15.2†	11.7	18.4	18.6
Sand/Peat	25.0	17.6	25.1	24.7
Sand/Soil	21.1	15.3	19.6	19.3

Dry down 2	Location			
	1	2	3	4
Sand	14.9	11.7	16.9	16.4
Sand/Peat	23.3	17.4	22.0	21.6
Sand/Soil	20.6	14.8	18.7	18.3

Dry down 3	Location			
	1	2	3	4
Sand	15.9	12.2	17.5	17.0
Sand/Peat	24.1	18.5	22.2	21.8
Sand/Soil	21.2	15.9	19.2	18.7

Dry down 4	Location			
	1	2	3	4
Sand	*	*	*	*
Sand/Peat	*	*	*	*
Sand/Soil	*	*	*	*

†Not significant at P=0.05.
*No data.

Table 26A. Volumetric water contents for the location x soil interaction, day 3, for the four dry downs in 2002, at the 10-20 cm depth.

Dry down 1	Location			
	1	2	3	4
Sand	13.8†	11.8	15.0	14.7
Sand/Peat	20.4	17.1	19.8	18.6
Sand/Soil	18.8	15.1	17.6	16.6

Dry down 2	Location			
	1	2	3	4
Sand	13.0	10.5	14.1	13.9
Sand/Peat	19.9	15.9	19.4	18.5
Sand/Soil	17.9	14.3	17.2	16.6

Dry down 3	Location			
	1	2	3	4
Sand	16.4	13.8	17.1	16.5
Sand/Peat	23.3	20.7	22.4	21.2
Sand/Soil	20.7	17.8	19.9	18.5

Dry down 4	Location			
	1	2	3	4
Sand	15.1	13.0	16.2	15.7
Sand/Peat	22.3	19.1	21.7	22.4
Sand/Soil	20.2	16.3	16.1	17.9

†Not significant at P=0.05.

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