LAYERS IN GOLF GREEN CONSTRUCTION
1998 ANNUAL REPORT

For

United States Golf Association
Green Section Research

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EXECUTIVE SUMMARY

LAYERS IN GOLF GREEN CONSTRUCTION

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Goals

- *To examine particle migration from the rootzone layer into underlying gravels of increasing size in situations where no intermediate layer is present.*
- *To assess the effects of different intermediate and drainage layers on moisture retention in the rootzone layer.*
- *To review the particle size criteria for the selection of intermediate layer and drainage layer materials.*

Particle Migration

Particle migration is being examined for two contrasting rootzone materials placed directly over ten drainage layer gravels of varying sizes. The two rootzones are an 85/15 mix of medium sand and sphagnum peat and a 70/30 mix of medium-coarse sand and peat. Five of the gravels are rounded and the other five are angular and the D_{15} size values ranged from 2.2 mm to 5.6 mm. Gravel sizes were selected so that in theory no migration should occur from the rootzone into the gravel for the finer gravels but the risk of particle migration into the coarser gravels is high. Each profile is receiving 3000 mm of simulated rainfall before particle migration is examined.

A technique has been developed to examine whether migration has occurred at the interface of the rootzone layer and the gravel (see Figs 1 and 2). The profile is stabilised using plaster of Paris, this is then impregnated with an araldite resin containing fluorescent dye. When the resin has hardened the profile can be sectioned and photographed under ultra-violet light so that we can examine any blockage of the pore space within the gravel as a result of particle migration from the rootzone.

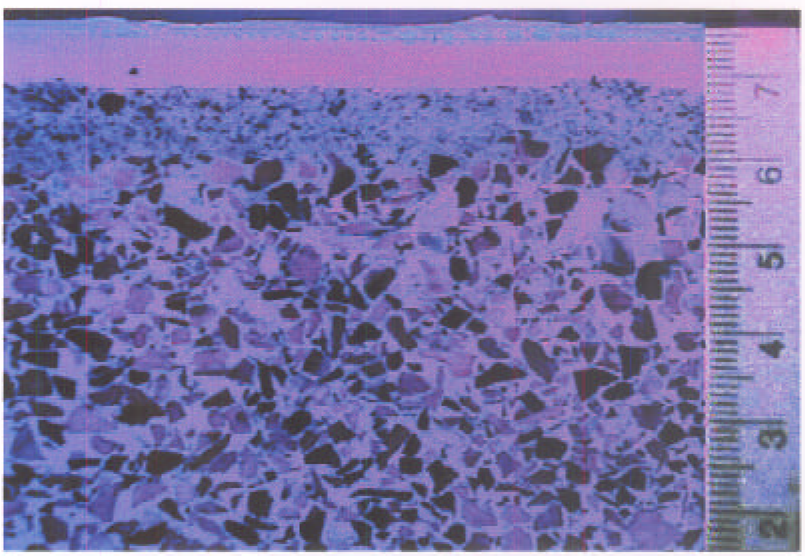
Moisture Profiles

The vertical distribution of moisture within the profiles discussed above is being measured after 48 hours of gravitational drainage to examine whether variations in the type of gravel influence moisture retention in the profile.

In a separate study the influence of particle size of the intermediate layers on moisture retention within an 80/20 sand/peat rootzone has been examined. The underlying gravel was predominantly a 6-9 mm material while the intermediate layer was based on a 1-4 mm grit but with increasing proportions of medium (0.25-0.5 mm) and coarse sand (0.5-1.0 mm). Moisture profiles were assessed after saturation followed by 48 hours gravitational drainage. Increasing proportions of coarse and medium-coarse sand had significant effects on the moisture content of the intermediate layer. For example volumetric moisture content increased from 7.5% when the 1-4 mm grit included no sand to 18.4% when 50% coarse sand was added to the grit. However no strong relationships were found between the composition of the intermediate layer and moisture retention with the rootzone. These data suggest that it should be possible to increase the proportion of material between 0.25 mm and 1 mm in the intermediate layer without a significant reduction of water retention in the rootzone. However the work on moisture profiles directly over a gravel base must be completed before firm recommendations are made.

FIGURE 1. Profile of rootzone over fine gravel under normal light conditions (the rootzone/gravel interface can be seen running horizontally between 5 and 7 cm on the adjacent scale). No particle migration is evident.

FIGURE 2. Profile under UV light.



LAYERS IN GOLF GREEN CONSTRUCTION

By Dr. S.W. Baker & D.J. Binns
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Introduction

This report gives an update on progress of the project on the effects of material selection for the intermediate and drainage layers on moisture distribution in the rootzone layer and on potential particle migration into the drainage layer.

PART 1. PARTICLE MIGRATION AND WATER RETENTION IN SITUATIONS WHERE THE ROOTZONE DIRECTLY OVERLIES THE GRAVEL LAYER.

Objectives

In the 1993 revision of the USGA *Recommendations for a Method of Putting Green Construction*, an alternative to the three-layered construction profile (i.e. rootzone, intermediate layer, drainage layer) was permitted in which the rootzone could be laid directly on a fine gravel base. However, strict criteria were recommended to prevent the downwards migration of particles.

The objective of this project is to assess whether the bridging criteria that have been proposed can be relaxed to allow slightly coarser gravels to be used in the base layer. In addition, the experimental design allows us to assess the effects of different underlying gravel bases on the moisture distribution of the rootzones.

Current status of project

The first run, in which a total of 3000 mm of water was applied to the rootzones was completed on 20 February 1998. Equilibrium moisture contents of the rootzone were then determined 48 hours after the final application of water. This was done by carefully excavating the profile at 50 mm intervals. The gravel layer was successfully impregnated with plaster of Paris to stabilise the profile, this was then removed from its cylinder and allowed to dry before impregnation with resin so that particle migration can be assessed.

Profiles were re-constructed for the second run and water application commenced on 27 April 1998. The application of 3000 mm of water is due to finish on 20 November 1998, and this will be followed by the determination of moisture profiles and resin impregnation.

Development of technique for monitoring particle migration

After careful excavation of the surrounding rootzone and gravel layers the profiles are impregnated *in situ* with a slurry of plaster of Paris made up from a dry weight of 1 kg poured over the entire sample.

After setting, the whole block is removed from its surrounds and allowed to thoroughly air dry over a period of at least a month. After this time, the block is placed in a tight-fitting plastic bag and impregnated with a fluorescent resin of the following mixture:

- 3 parts liquid epoxy resin (Araldite MY753)
- 1 part hardener (Araldite XD716)

0.1 g of UV reflective dye (Tinopal SWN conc.) is added to each 100 ml of total solution. To reduce the viscosity of the impregnating solution, it is further diluted with a 20% (v/v) addition of acetone. Impregnation is carried out under atmospheric conditions and the block is continually topped up with resin to maintain saturation at the base of the block.

Once fully saturated, the resin is allowed to harden over a period of approximately two weeks. Removing the plastic bag as soon as conditions allow accelerate this process. After complete hardening the block is sectioned at right angles to the gravel/rootzone interface using a powered diamond-toothed saw. The exposed surface is then photographed under an UV light to highlight the physical structure of the block. Using image analysis software the percentage of pore space can be identified and the migration of particles can be studied.

FIGURE 1. Profile under normal conditions (the rootzone/gravel interface can be seen running horizontally between 5 and 7 cm on the adjacent scale).

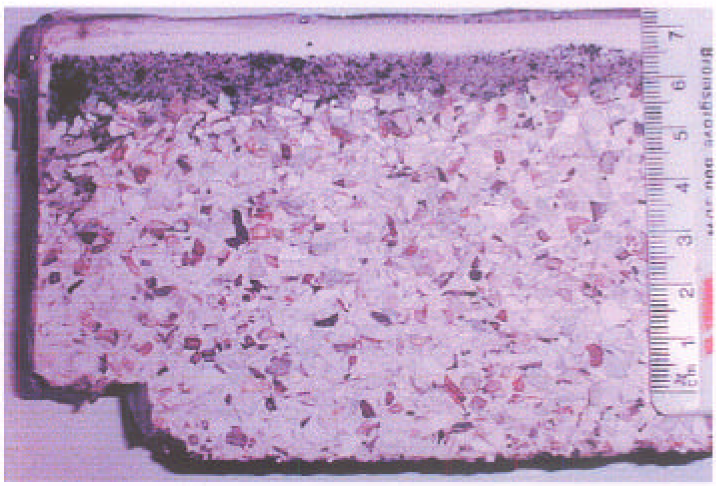
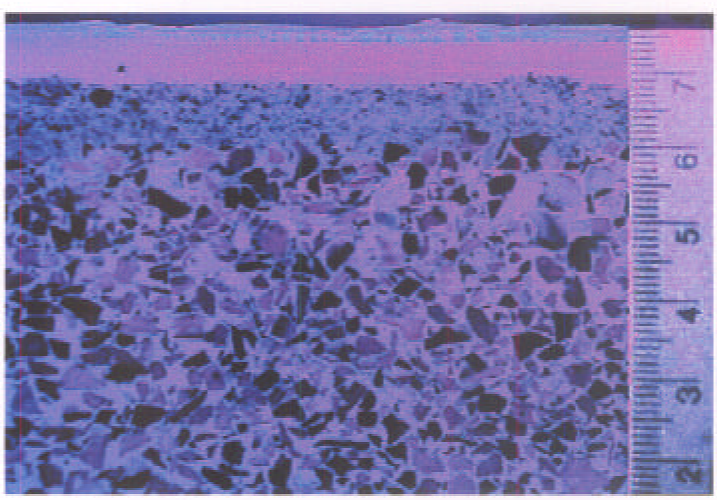


FIGURE 2. Profile under UV light.



PART 2. WATER RETENTION IN THE ROOTZONE LAYER OVER INTERMEDIATE LAYERS OF VARYING SIZE COMPOSITION

Objectives

In the *Recommendations for a Method of Putting Green Construction* (USGA Green Section Staff 1993) it is suggested that where three layers are used in the construction profile the gravel should have at least 80% of its particles between 2 mm and 12 mm diameter and at least 65% between 6 mm and 9 mm. The recommendations for the intermediate layer are for 90% between 1 mm and 4 mm diameter. In Britain, although 1-4 mm is the preferred range for an intermediate layer overlying a 5-10 mm gravel, up to 70% material below 1 mm can be used as long as it is greater than 0.25 mm (Baker 1990). This means that a greater range of construction materials is available.

The main consequence of using finer grade intermediate layers is that the principal interface restricting downward percolation of water is likely to be that between the intermediate layer and the gravel base, rather than between the rootzone layer and the intermediate layer. As such, moisture content in the upper section of the rootzone may be slightly reduced when finer grade intermediate layers are used (Hunt & Baker 1996). The objective of this part of the study was to examine the effects of increasing proportions of finer material between 0.25 mm and 1.0 mm in the intermediate layer on moisture retention in the rootzone layer.

Experimental design

Both the gravel and rootzone material conformed to USGA specifications. For the gravel 84% of the particles fell between 6.3 mm and 9.5 mm and 85% of the rootzone contained particles between 0.25-1.0 mm. The full particle size analysis of the gravel and rootzone can be found in Tables 1 and 2 respectively. Table 3 lists the physical properties of the rootzone material.

TABLE 1. Particle size analysis of 6-9 mm gravel.

Particle Size (mm)	Sieve Analysis (%)
> 12.5	0
12.5 - 9.5	6
9.5 - 6.3	84
6.3 - 4.0	10
4.0 - 3.35	0
3.35 - 2.0	0
2.0 - 1.0	0
< 1.0	Trace

TABLE 2. Particle size analysis of rootzone material.

Category	Particle Size (mm)	Sieve Analysis (%)
Stones & Coarse Gravel	> 3.4	1
Fine Gravel	3.4 - 2.0	1
Very Coarse Sand	2.0 - 1.0	3
Coarse Sand	1.0 - 0.5	26
Medium Sand	0.5 - 0.25	59
Fine Sand	0.25 - 0.15	5
Very Fine Sand	0.15 - 0.05	1
Silt	0.05 - 0.002	2
Clay	< 0.002	2
Organic Matter Content	-	1.0

TABLE 3. Physical properties of the rootzone material after compaction.

Hydraulic conductivity (mm h^{-1})	283
Bulk density (g cm^{-3})	1.65
Total porosity (%)	37.3
Air-filled porosity at -4 kPa (%)	20.8
Capillary porosity at -4 kPa (%)	16.5

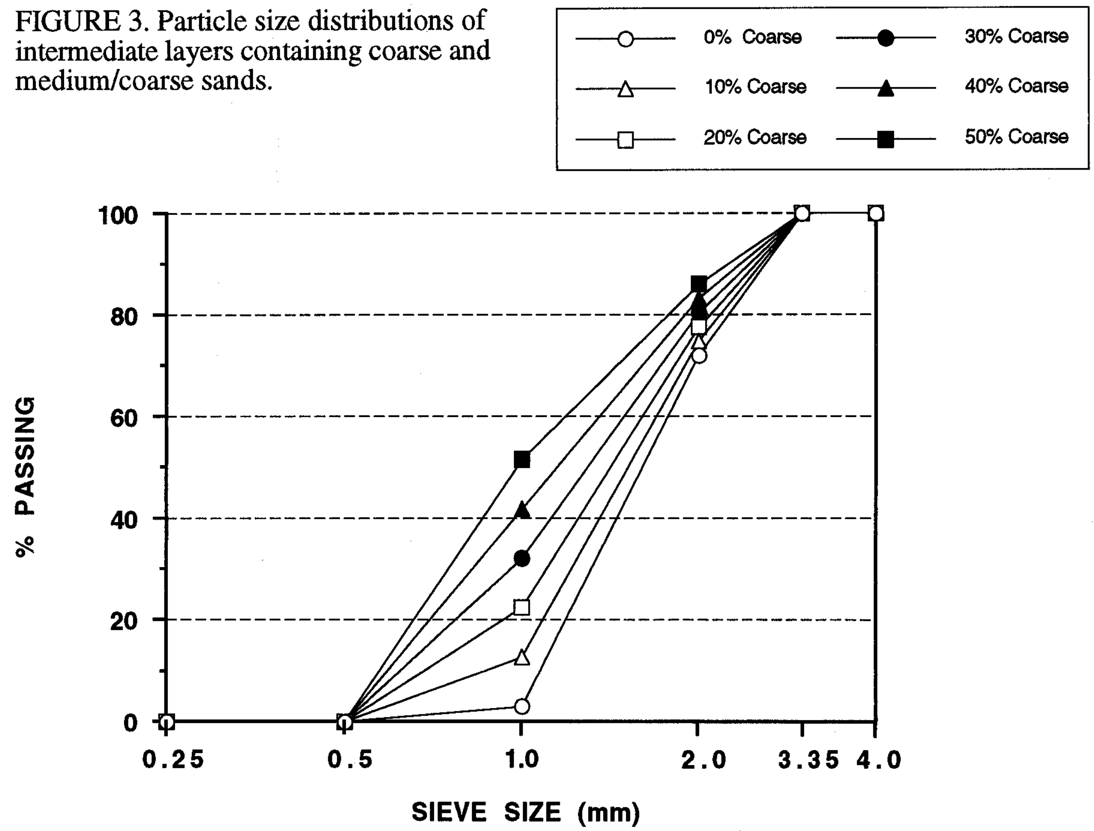
The intermediate layer contained a clean 1-4 mm grit with 43% falling between 2.0-3.35 mm, 55% between 1.0-2.0 mm and 2% less than 1.0 mm. Increasing contents of medium and coarse sand where added to this as follows :

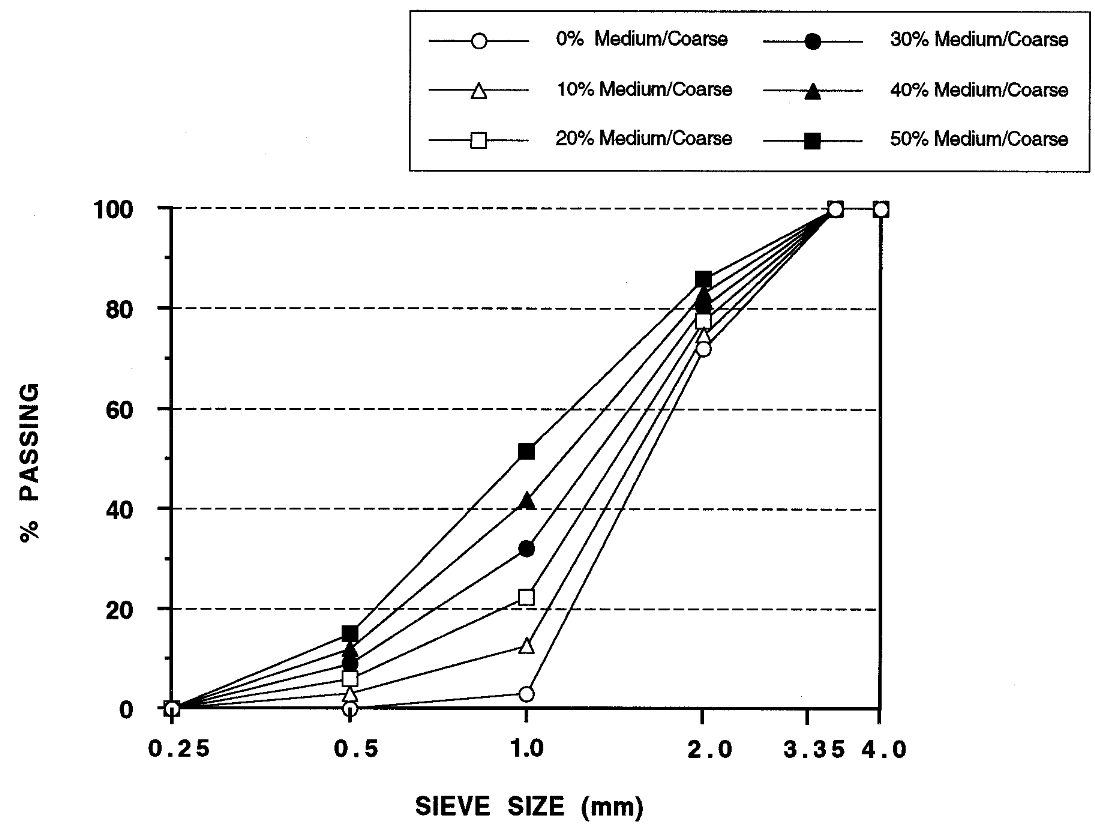
- 1-4 mm grit + 0, 10, 20, 30, 40, 50% coarse sand (0.5-1.0 mm diameter).
- 1-4 mm grit + 0, 10, 20, 30, 40, 50% medium/coarse sand (30% 0.25-0.5 mm diameter, 70% 0.5-1.0 mm diameter).

The sands included in the intermediate layer were artificially manufactured using sieved components from several different sands. This gives a variation in shape and avoids any concentration of particles of any specific size. The sand combinations also satisfied the bridging criteria used when placing a rootzone layer directly over a gravel. The particle size distributions of the resulting mixtures with coarse and medium-coarse sands are plotted in Figure 3.

The experiment was replicated in a three-fold factorial design.

FIGURE 3. Particle size distributions of intermediate layers containing coarse and medium/coarse sands.





Profile Construction
Profiles were built inside stout PVC tubes of 425 mm length and 150 mm diameter (Fig. 4). A strong filter membrane of porous fabric was attached to the base of the tube allowing free drainage of water from the profile.

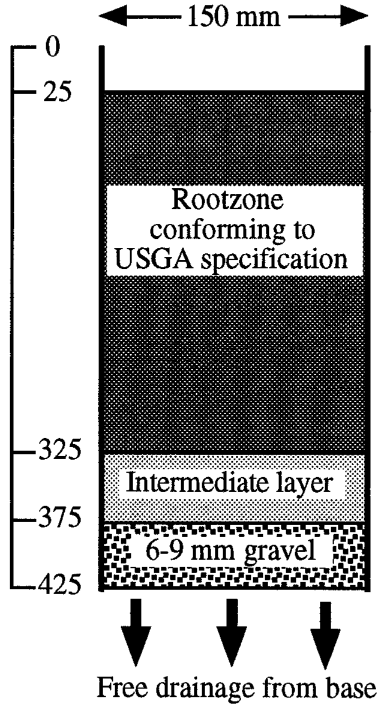


FIGURE 4. Cross-section of cylinder arrangement to examine moisture retention in the profile with intermediate layers of varying composition.

(depths shown are in mm)

The profiles were constructed by first adding 50 mm of gravel to the bottom of the cylinder, this was tapped down and levelled with a static weight of 8.48 kg. Then, 50 mm of intermediate material was added, tapped down and levelled with the static weight. Finally, the rootzone material was added in 100 mm layers and the static weight was again used to consolidate each layer. Once complete, a packing energy of 10 kJ m^{-2} (10 blows of a 5.75 kg hammer dropped from a height of 0.31 m) was applied to the whole profile to simulate compaction after construction.

Measurement of rootzone drainage
To initiate surface ponding water was sprinkled onto the surface of each rootzone through a fine mesh to minimise disturbance. A constant head of water was maintained over the profile for a period of 20 minutes before measurements started. Infiltration rates were measured over a further 20 minutes based on the volume of water required to maintain a constant head. Infiltration values were standardised to a common temperature using the ratio of water viscosity at 10°C to that at the measurement temperature.

To examine the rate of water loss from each profile, changes of weight over time were recorded. Timing started when the ponded water disappeared from the rootzone surface and no further water applications were made. Each profile was then allowed to drain under gravity for 4 weeks and weighed 1, 2, 4, 8, 24, 48, 120 hours, 1, 2 and 4 weeks after the start of timing. Whilst drainage took place, lids were placed loosely over the cylinders to minimise evaporation and an extra cylinder with a sealed base was used to estimate evaporation losses.

Moisture profiles
After 4 weeks each profile was re-saturated with the addition of 5.3 litres of water, this being the equivalent volume of rootzone per cylinder. After gravitational drainage for 48 hours, the material from each 50 mm layer was carefully excavated and weighed. The gravimetric moisture content of each layer was then measured by taking a sub-sample of approximately 200 g and oven drying it at 105°C. The bulk density of each 50 mm layer was also determined by calculating the dry weight of rootzone material and its volume for each section. For the 250-300 mm it was difficult to measure bulk density accurately because of the presence of the rootzone / intermediate layer interface. Consequently bulk density was assumed to correspond to that of the 200-250 mm layer.

Statistical Analysis
The data were examined using a two-way analysis of variance to determine the effects of the composition of the intermediate layer on infiltration and water retention properties of the profiles. Least significant difference (LSD) values at P=0.05 were calculated to examine differences between treatment means.

Results
Infiltration rates averaged 392 mm h^{-1}. The differences in intermediate layers had no significant effect on water infiltration rates.

The majority of gravitational drainage took place in the first hour after the cessation of ponding. Averaged over all profiles and assuming that the change of cylinder weight over time was solely attributable to drainage from the rootzone, 55% of all drainage over a four week period took place in this first hour and 74% in the first 24 hours. Evaporation losses over a four week period were estimated to be less than 1.2 mm, based on cylinder measurements with a sealed base.

Moisture profiles were significantly influenced by the size of sand fraction in the intermediate layer whilst drying out over the whole four week period. Profiles containing a coarse sand intermediate layer released more water than those with a medium-coarse layer (Fig. 5). The percentage of sand fraction to grit, ranging from 0 to 50 percent, had no significant effect throughout the data collection period.

After re-saturation and gravitational drainage for 48 hours, increasing amounts of coarse and medium/coarse sand had significant effects on the moisture content of the intermediate layer (Fig. 6), for example volumetric moisture content increased from 7.5% when the 1-4 mm grit included no sand to 18.4% when 50% coarse sand was added to the grit. However no strong significant relationships were found between the composition of the intermediate layer and moisture retention in the rootzone. As would be expected, moisture content of the rootzone increased with depth (Figs. 7 & 8). The greatest amounts of moisture were found at a depth of 250-300 mm. Mean pore saturation was calculated as 36% in the top 200 mm of rootzone as opposed to 78% in the bottom 200-300 mm layer.

FIGURE 5. Cumulative moisture loss of profiles over time.

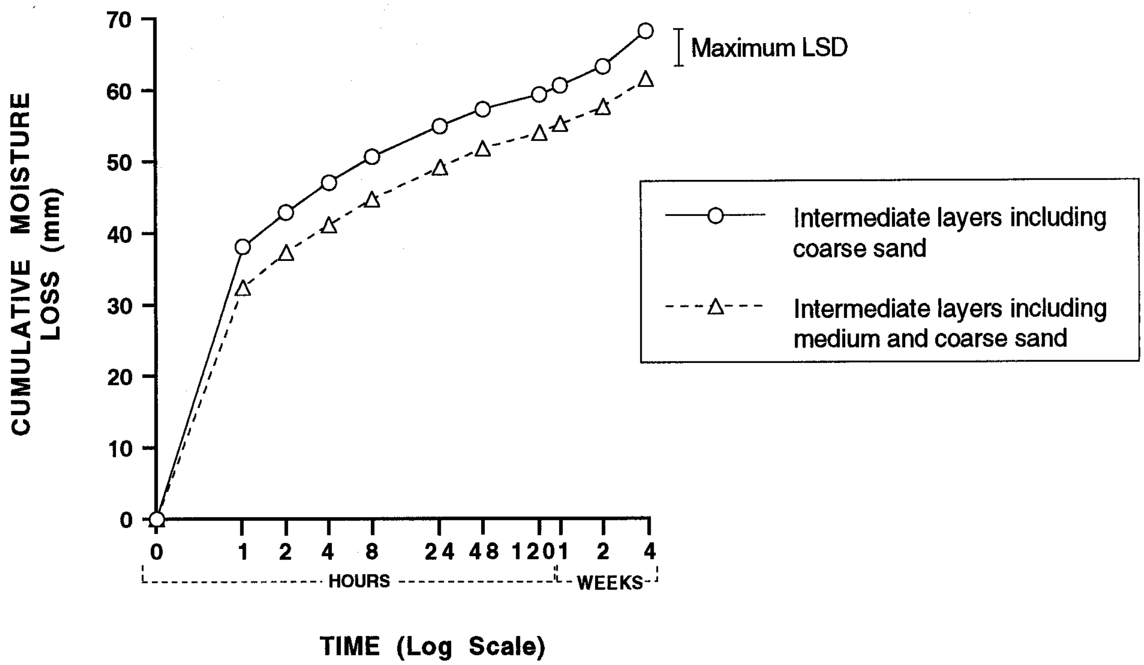


FIGURE 6. Comparison of volumetric moisture contents measured in the intermediate layer in relation to increasing proportions of coarse and medium/coarse sand.

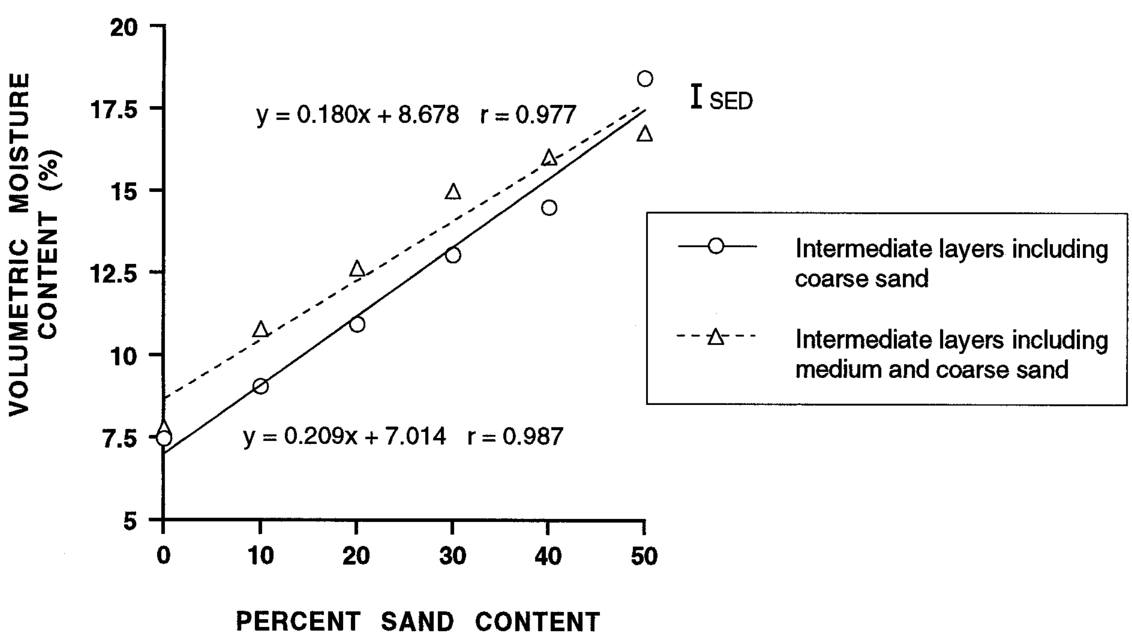


FIGURE 7. Moisture profiles comparing differences in volumetric moisture content for intermediate layers containing either coarse or medium/coarse sand.
(LSD 5% values are shown by the error bar for any depths where a significant difference in treatment means was recorded. For all other depths no significant differences were found).

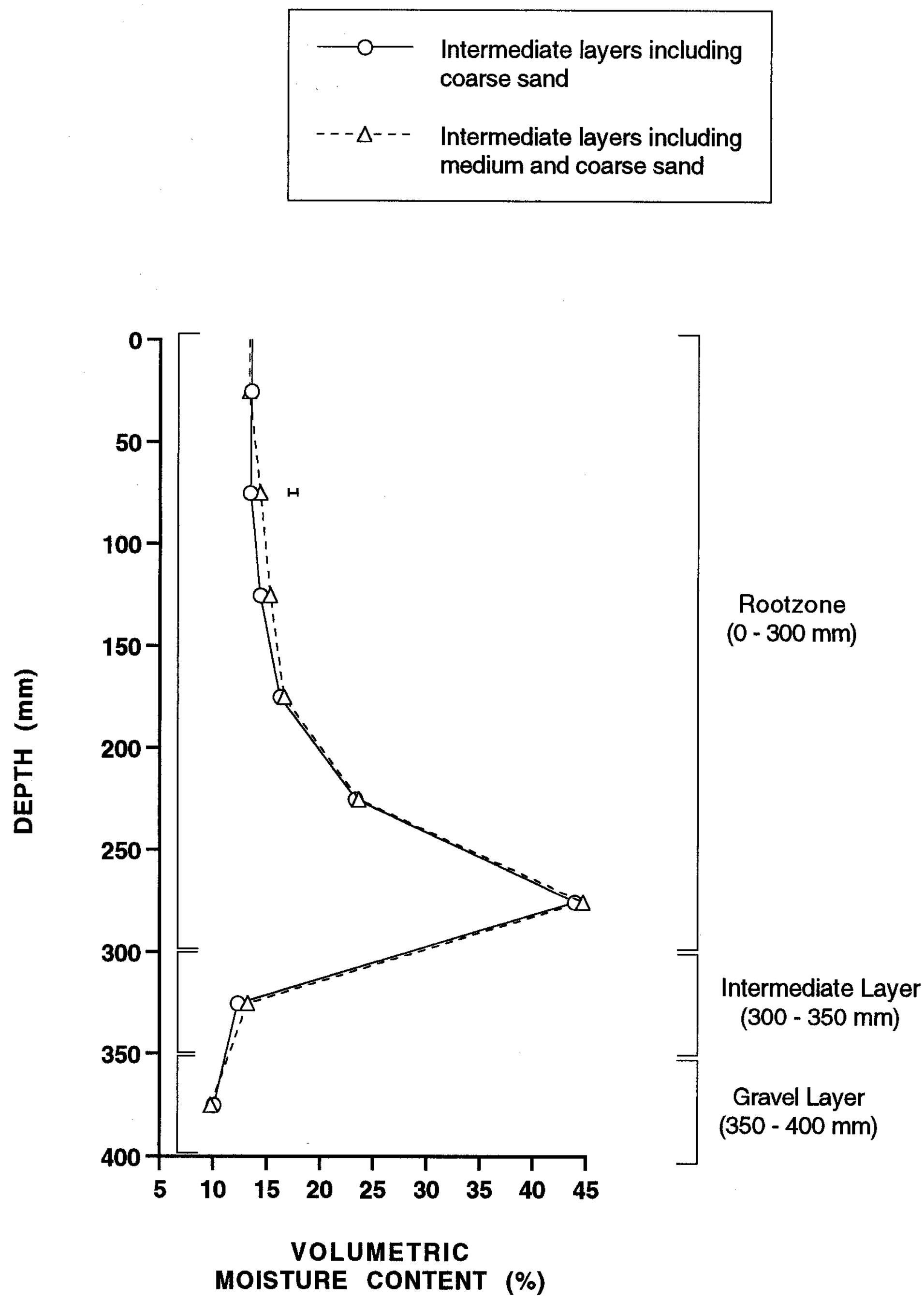
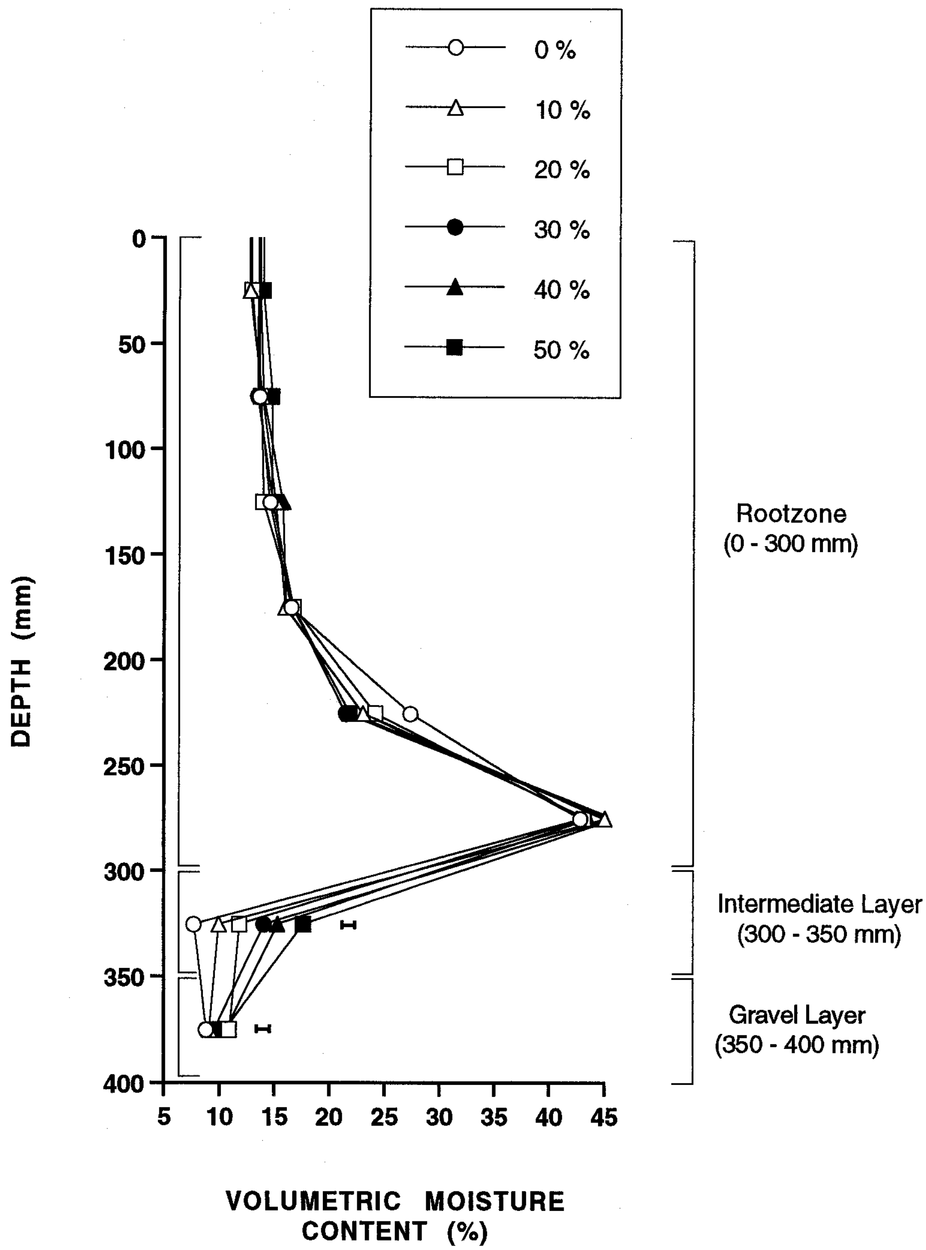


FIGURE 8. Moisture profiles comparing differences in volumetric moisture content with increasing proportions of sand in the intermediate layer.
(LSD 5% values are shown by the error bar for any depths where a significant difference in treatment means was recorded. For all other depths no significant differences were found).



Discussion

Although increasing proportions of both coarse and medium/coarse sand within the 1-4 mm grit layer increased equilibrium moisture contents within the intermediate layer, this had relatively little effect on moisture content in the rootzone. Similar results were found by Hunt & Baker (1996) when moisture retention profiles were compared for constructions having intermediate layers of predominantly 0.25-2.0 mm sand and clean 1-5 mm grit. However in Hunt & Baker's study moisture content of the upper 100 mm of the profile was higher when the rootzone was placed directly over a 5-10 mm gravel.

The data would suggest that it should be possible to increase the proportion of material between 0.25 mm and 1 mm in the intermediate layer without disrupting the suspended water table that helps retain moisture in the rootzone. However Part 1 of the study also includes information on equilibrium moisture profiles and it would be premature to propose modifications to the grading of the intermediate layer until that information becomes available. Any changes to intermediate layer specifications would also have to take into account the risk of particle migration which is also being examined in Part 1 of the work.

References

Baker, S.W. (1990). *Sands for Sports Turf Construction and Maintenance.* The Sports Turf Research Institute, Bingley, 71 pp.

Hunt, J.A. & Baker, S.W. (1996). The influence of rootzone depth and base construction on moisture retention profiles of sports turf rootzones. *J. Sports Turf Res. Inst.* **72**, 46-41.

USGA Green Section Staff (1993). USGA recommendations for a method of putting green construction. *USGA Green Section Record*, March/April 1993, 1-3.

PROJECT BUDGET

Man-hours to end of September 1998	1005.6
Approximate Split:	
Dr S W Baker (Head of Soils and Sports Surface Science)	20%
Mr D J Binns	60%
Technician	20%
Costs to Date:	$
Resin, hardener, fluorescent dye (majority of sectioning costs still to come)	2578
Cylinders, stands, sands and gravel, consumables	2513
Travel Costs	71