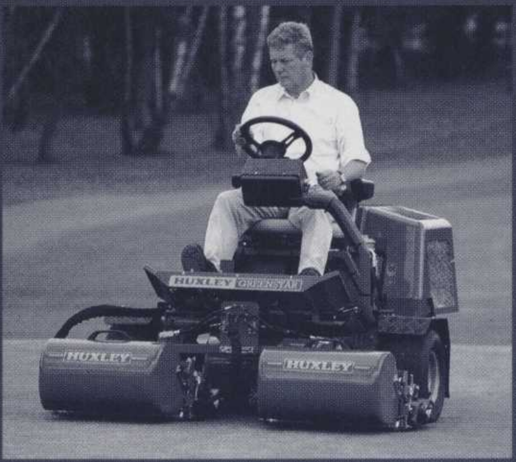

Dr Stephen Baker, Head of Soils and Sports Surface Science at the STRI, examines suspended water table greens construction

Kept in

The suspended or perched water table method of golf green construction is now widely used, for example forming the basis of the USGA (United States Golf Association) construction method. However few people understand exactly how the suspended water table (SWT) works and this is important as the physics of water movement and water retention determine the advantages and disadvantages of SWT greens. Abuse of some of these soil physical principles, particularly in terms of material selection and quality control, can turn a potentially very successful method of golf green construction into a wet, water retentive putting surface or conversely one susceptible to drought stress that is very hard to manage.

How does water move in golf green profiles?

The movement of water in any soil is influenced by a number of forces acting in different directions. It is a bit like tug of war on the individual water droplets; if the force in one direction is greater than the force in the opposing direction then water will move in the direction of the greatest force. The first major force is gravity and just like the effect on Isaac Newton's apple this force will pull water downwards. If there was no opposing force, all water would drain out of a rootzone very quickly, taking soluble nutrients with it, and our putting surfaces would quickly revert to a mass of dry sand or soil.

Fortunately there are opposing forces and indeed forces that can be manipulated by our selection of rootzone materials and the depth of the rootzone layer. The forces acting against gravity are firstly the surface tension of the water and secondly water adhesion to soil particles. Surface tension occurs at the interface of air and water because of the forces attracting the water molecules together and, combined with adhesion, these capillary forces are sufficient to hold water in the soil. Think back to school days and you may recall physics lessons in which fine capillary tubes were put in a beaker of water - water would rise in the tubes and the finer the hole in the tube the higher would be the column of water. If you think of the pores (ie the spaces between sand and soil particles) in a golf rootzone as a series of capillary tubes this is an important first step in understanding the suspended water table.

Although most water movement is downwards under the influence of gravity, there are times when the capillary forces are greater than the force of gravity an upwards movement will take place. A good example occurs if you put columns of dry sand in a container of water. Water will move upwards by capillary rise in exactly the same manner to the capillary tube the finer the sand the higher will be the level reached by the water. In a fine sand water may rise 300 mm (1 foot) or more but on a coarse sand the amount of rise may only be 100 mm (4 inches or less). Have a look also at stockpiles of sand drying out after heavy rain - particularly if the particles are uniform in size there is often a distinct line separating the drier sand at the top and the moister, therefore, darker, sand below. Yet again the same principle - the height of the line is determined by the grain size distribution of the sand.

Rates of water flow in porous materials

The other main factor that is important is understanding water movement in golf green profiles is to consider how quickly water will flow in pores of different sizes. If the pores are saturated (ie completely full of water) the situation is straight forward - the larger the pore or tube the faster the flow rate. Indeed the flow rate increases dramatically with pore size thus a fine sand may have saturated hydraulic conductivity of 500 mm/hr, while the comparable figures for a coarse sand and a gravel are in the order of 5000 mm/hr and 100,000 mm/hr. On the other hand as a soil dries out water is first lost from the largest pores thus water movement has to take place through finer and finer pores and thus flow rates decrease dramatically.

In the case of a gravel drainage layer, flow rates vary considerably depending on the moisture content of the gravel. When there is heavy rainfall and the gravel is close to saturation, water entering the gravel drainage layer moves quickly through the gravel to the underlying drains. However once water is lost from the large pores water movement can only take place along very thin films of water held tightly against the sides of the gravel particles and the rate of flow is virtually zero, certainly less then 1 mm per day.

The main process in the formation of a suspended water table results from the balance that occurs after initial drainage between capillary forces that

suspense

hold water in the pores against the downward pull of gravity. Water is eventually held more tightly in the pores in the rootzone than the gravitational pull at the interface of the rootzone and the underlying coarse material so vertical drainage ceases. The fact that unsaturated flow rates in the gravel are so slow is a complementary process reinforcing the effects of moisture retention in the rootzone.

Moisture profiles in golf greens

After heavy rainfall, drainage takes place with water being lost from the largest pores until gravity and capillary forces are balanced. This equilibrium situation is often termed field capacity, and is generally reached in 24-48 hours. Evaporation from the surface and water use by the grass (ie transpiration) allows the soil to dry out further, with around 20 mm of water per week being consumed in summer conditions in the United Kingdom. In winter however evapotranspiration rates are low (often less then 3 mm per week) and thus moisture content in a golf green profile will be close to field capacity for long periods - wetting up during rainfall then draining back to equilibrium. The moisture profile at this equilibrium position is therefore very important as it influences the quality of the grass, especially its root development and also the playing quality of the surface.

Some of the factors involved can be demonstrated using results from a recent study at the STRI in which we examined moisture profiles of a number of rootzone constructions. Profiles were built inside plastic tubes which had an internal diameter of 150 mm. Two rootzones were examined, firstly a fine rootzone (77% medium-fine sand, 9% fines less than 0.125 mm diameter) and secondly a coarse rootzone (84% medium-coarse sand, 4% less than 0.125 mm). In addition there were variations in rootzone depth, blinding layer characteristics and in the gravel drainage layer.

We measured soil moisture content at intervals of 50 mm and the first thing to note is that equilibrium moisture content after 48 drainage varied considerably depending on the texture of the rootzone material and the height above the interface with the gravel.

On both rootzones moisture content approached saturation at the base of the rootzone and moisture content decreased with height above the interface of the rootzone and the underlying gravel, rapidly for the coarser rootzone but only slowly for the fine rootzone. This is a good demonstration of the suspended water table phenomenon and how equilibrium moisture content is influenced by particle size distribution.

Some practical points also need to be considered. For the finer rootzone the volume of water held at a depth of 100 mm from the surface of a 300 mm deep profile was approximately 30%. As the total pore space was only 39% this only give 9% air-filled pore space which is only marginal for healthy grass growth, especially as in wet weather the volume of air-filled pore space will decline further. Air exchange in the soil would be restricted and the root development could suffer. In contrast the contents of water and air at the same depth for the coarser rootzone were about 13% water and 25% air. Under these circumstances there should certainly be no problems in terms of air supply to the root system.

With respect to drought susceptibility, knowledge of the variation of equilibrium moisture content with depth helps prediction of how much water is available to the grass plant. Assuming that root depth is 100 mm and if the average volumetric moisture content of the top 100 mm of the coarse rootzone is 12%, then 12 mm of water is held within the depth of rooting. In contrast if the corresponding moisture content for the fine rootzone is 25% then 25 mm of water are held within the depth of rooting. In contrast if the corresponding moisture content for the fine rootzone is 25% then 25 mm of water are held within the depth of rooting. About 6 mm of this water is held so tightly in the finest soil pores that the suction exerted by the grass roots cannot extract is, so it is unavailable to the plant. Therefore the available moisture content is approximately 6 mm for the coarse rootzone and 19 mm of the finer rootzone. In hot summer weather between 2 mm and 3 mm of water are lost daily by evapotranspiration thus there is only two or three days' supply of water available in the coarse rootzone but around one week's supply for the finer rootzone. These figures somewhat simplify the situation on a real green as in practice soil moisture would move upwards from the lower part of the profile as capillary suction would increase as water was removed by the plant. Furthermore, evapotranspiration rates would slow down as the grass became more drought stressed and in addition the root system in the coarser material may be more extensive to compensate for the lack of water near the surface. Nevertheless differences in the moisture profiles would have a profound effect on irrigation management.

Effect of underlying layers on the rootzone

The work also showed some other interesting effects. Firstly the depth of the rootzone had a major effect on the moisture content of the surface 100 mm of the profile. The shallow 150 mm rootzone had a much higher moisture content than the 250 mm and 350 mm deep rootzones and particularly when the finer rootzone was used the pore space would have been very close to saturation. In practical terms a 150 mm deep rootzone would be unlikely to be used on a golf green because of the depth required by the cup. However tees constructed with only 150 mm of rootzone over gravel could be very water retentive and many bowling greens that are constructed with such shallow rootzone depths must be close to saturation throughout the winter with consequent risks of anaerobic conditions and black layer developments.

An excessively deep rootzone could also create problems especially if the rootzone were coarse and had a low water retention capacity. I have certainly heard of problems occurring on some courses in the USA and Australia where coarse rootzones have been used because of high intensity rainfall but rooting is often restricted because of summer heat stress. Under these circumstances a 300 mm rootzone can potentially be too deep because the main part of the suspended water table lies well below rooting depth.

From a soil physics of view there is a strong case to adjust depth if either very coarse or very fine materials have to be used because more suitable materials are not available. For example I once had to increase the profile depth of a soccer pitch construction in Saudi Arabia from 250 mm to 350 mm because only very fine sands could be found around the site.

Although our study showed that the use of different gravels in the underlying drainage layer had no effect on moisture retention, we did find that material selection for the blinding or intermediate layer had an influence on moisture content in the rootzone. When the intermediate layer was omitted moisture contents in the rootzone were higher, mainly because there was a very pronounced difference in grain size at the interface of the rootzone and underlying gravel, meaning that there was no extra capillary pull from the underlying layer. In contrast for the finest blinding layer material there would have been some continuity in pore size and moisture content at the surface of the rootzone was slightly lower. We are currently investigating these effects in more detail in a study being carried out for the USGA.

Assessing water retention characteristics of rootzones

An indication of the potential soil water status of the rootzone material can be obtained from samples compacted in controlled laboratory conditions. USGA guidelines for rootzone materials are:

Total porosity	35-55%
Air-filled porosity	15-30%
Capillary porosity	15-25%

These requirements are designed to cover a range of climate zones and for United Kingdom conditions total porosity values would normally fall between 35-50% and very high air-filled porosity values are not normally needed, especially as this will be generally at the expense of capillary porosity, thus making rootzone materials potentially more droughty. When these limits were originally specified they were based on laboratory tests using a tension of 400 mm of water but in 1994 the test tension was revised to 300 mm to be compatible with the rootzone depth. On soil physics grounds this change in tension was entirely logical but as the requirements for air-filled porosity and capillary porosity were not also modified we have notice that this did seem to cause some apparently perfectly suitable mixes for UK conditions to fail because of slightly low figures for air-filled porosity (eg 13 or 14%) and slightly high figures for capillary porosity (eg 25-28%). The change in test protocol favoured coarse rootzone materials which although suitable in other parts of the world would be harder to manage in this country on fescue/bent (and annual meadow-grass) greens.

Unless the requirements are adjusted it is proposed that for United Kingdom conditions tests should be carried out at 400 mm tension and unless specifically requested the STRI will carry out all future tests at this tension.