Understanding Soil Water

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At least in the southern half of the state, the 2000 season started out abnormally wet, but got progressively drier as the season wore on. In July, we experienced a period of nearly 2 weeks without meaningful rainfall. This weather pattern led to some interesting concerns and comments. Early in the year, the big issue was bunker drainage. Later in the year, concerns arose regarding moisture stress, localized dry spot, and the need for hand watering. From these concerns, I've deduced that it's time to review some of the basics of water retention by soil, soil water movement, and the plant availability of soil water. The intent is to give you a solid basis from which you can deal more effectively with some of your water problems.

The Basic Forces

Two forces act upon water and govern its retention and movement in soil matric and gravitational.

Matric force gets its name from the fact that it is due to the attraction of water molecules to the solid particles that make up the "matrix" of soil. This is the force that holds water in soil and controls water movement after soils have drained. The amount or strength of the matric force acting on soil water is determined by how much solid surface area there is in soil and the sizes of the spaces between adjacent soil particles. The finer the texture of soil, the greater the amount of matrix surface area and the greater the number of small voids or pores. Therefore, the finer the texture of the soil, the greater the matric force exerted on water and the greater the amount of water held in the soil.

Gravitational force acts against matric force, pulling water downward in soil and causing drainage to occur. Contrary to popular belief, gravitational force is not the same in all soils. Gravitational force is the product of what is known as the acceleration of gravity and the mass (weight) of the object upon which it is acting. Acceleration of gravity varies with distance from the earth's center of gravity, but for practical purposes can be thought of as being constant. In contrast, the mass of water in soil is not constant. The greater the depth of soil, the more water it can hold and the greater the force of gravity acting upon that water.

Putting this all together, we can come up with some general statements regarding the amount of water retained by soil. The finer the texture of soil, the greater the amount of matric force and the greater the amount of water the soil will hold against the force of gravity. But for a soil of given texture, the greater the depth of the soil the greater the mass of water, the greater the gravitational force, and the less the amount of water retained.

Water Movement Into and Through Soil

When rain or irrigation water falls upon a dry soil surface, the water is initially drawn into the soil very quickly by matric force. But the pores at the soil surface soon fill with water. As soil pores fill with water, the water films on soil particles become thicker and thicker and eventually join together.

The further the bound water is from the soil particle surfaces, the less and less matric force is acting upon the water. Eventually, gravitational force exceeds matric force and water begins to move downward through the soil as a wetting front. In the wetting front, all the soil pores are filled with water (i.e., are"saturated"). Therefore, this type of water movement in soil is called saturated flow.

The rate of saturated flow of water through soil is commonly referred to as the soil's percolation rate.

It exists only as long as the soil pores are saturated with water.

The saturated flow rate of soil is governed by large pores because this is where there is the least amount of matric force acting upon the water. The larger the pore, the more rapidly water moves through it. In fact, when the radius of a pore doubles, its saturated flow rate increases 16 times. This is why coarse textured soils, which have a few very large pores, drain quickly while fine textured soils do not. Perhaps the largest pores naturally existing in soils are earthworm channels. These channels are very effective in increasing soil drainage rates. There is, however, something very important to understand about large pores and their influence on soil drainage. They must be open to the soil surface. Should they become sealed by fine material, soil percolation rates can decrease dramatically. A similar effect results from surface soil compaction, but for a somewhat different reason. When soils are subjected to traffic, it is the largest pores that are least stable and most susceptible to collapse. In essence, the openings of large pores at the soil surface are converted to small pores and there is a marked reduction in water infiltration and percolation rates.

When rainfall or irrigation ceases and the wetting front continues to move downward, water held in large pores above the wetting front drains while the smaller pores those in which the matric force is greater than that of gravity retain water. Eventually there is not enough water to maintain saturation at the wetting front and the downward movement of water slows to the point where any further movement is difficult to detect. It is at this point that all of the water in the soil is being held at a matric force equal to or greater then the gravitational force. We then say that the wetted soil is at its field capacity (FC), which is the maximum amount of water the soil can hold against the force of gravity.

Once soils reach the state of being at their FC, any further movement of water is caused by unbalanced matric forces in the soil. This type of water movement we refer to as unsaturated flow.

From a practical sense, this is the most important type of water flow in soil. Saturated flow exists only when there are saturated soil zones and these exist but for relatively short periods of time. More important, unsaturated flow is responsible for water movement to plant roots from all directions in soil. This multi-directional flow of water is a unique feature of unsaturated flow and exists as such because, unlike with gravitational force, matric force operates in all directions.

Unsaturated flow of water results when soil becomes drier in one zone than another. This can result from water evaporating from the soil surface or from plant roots taking up water. What this difference in soil moisture content does is create soil zones where the water is held with different amounts of matric force. The drier the soil, the greater the amount of matric force acting on the water that remains. The response in soil is for water to move from zones of lower matric force to zones of higher matric force. More simply stated, matric forces cause water to move from wetter to drier zones of soil.

Water movement in soil by way of saturated flow is much, much faster than unsaturated flow. The quantity of water that moves via unsaturated flow depends on the magnitude of the difference in matric forces that develop and the number of soil pores that contain water. If we put these two facts together, we come up with the conclusion that unsaturated flow of water in soil is greater in fine than coarse textured soils. This creates an interesting situation in sand-based putting greens. They have high saturated flow rates, but do not transmit water as well to plant roots as do finer textured, native soils.

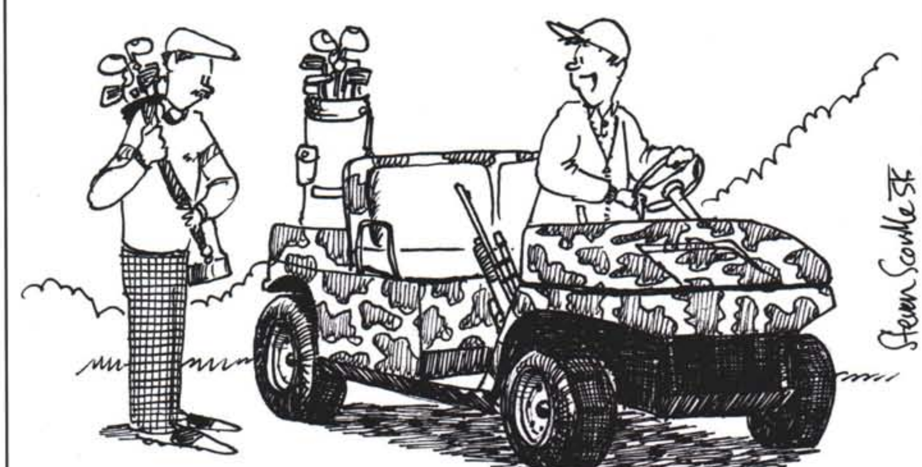
Table 1. Plant available water in different soils and putting greens.

Soil	Field capacity	Permanent wilt	Available water Percent (vol)	Available water Inches/12 inches
	----- % water by volume ----			
Sandy loam	22.0	8.9	13.1	1.6
Silt loam	32.3	14.4	17.9	2.1
Clay loam	32.7	21.2	11.5	1.4
Clay	40.2	29.2	11.0	1.3
80/20 mix	11.0	3.1	7.9	0.9
Pure sand	5.4	2.0	3.4	0.4

Plant Available Water

Soil can hold no more water than that allowed by its FC. Any water in excess of this amount drains through the soil to the groundwater. This is why I can't help but smile when someone says, "I don't understand it. Rainfall last month was 2 inches above average yet my turfgrass is wilting." That 2 inches of above-average rain has long drained away and no longer contributes to your supply of plant available water.

Not all of the water held in a soil when at its FC is available to plants. As water is withdrawn from soil, moisture films on particle surfaces become thinner and thinner and are held with greater and greater matric force. There is a point where the water remaining is held with such a high matric force that plants can no longer overcome this force. At this point, the plant is on the verge of death and we say that the soil water is at the permanent wilting point (PWP). This leads us to the definition of plant available water (AW). Plant available water is that held between FC and permanent wilt. In other words, AW= FC PWP. The



"I'M HOPING TO GET A DEER AND SOME BIRDIES."

quantities of water we're talking about are indicated in Table 1.

From the data presented in Table 1, we see that available water can range as low as 3.4 % by volume in a pure sand putting green to as high as 17.9 % in a silt loam soil. You'll also note in Table 1 that available water is expressed as inches/12 inches of soil as well as % by volume. This type of conversion is necessary anytime the concept of available water is employed to develop an irrigation program. The conversion is very simple as long as you have a reasonable estimate of available water expressed as % by volume. All that you have to do is divide the %AW by 100 and multiply by the depth of soil of interest to you. If your soil depth is in inches, then your answer is inches of AW in how many inches of soil you specified. An interesting exercise is to calculate the inches of AW for different soil depths. This quickly impresses upon you the importance of the depth of rooting of turfgrass with regard to water supply. As an example of this, I sometimes hear golf course superintendents complaining that during the heat of summer the rooting depth on their putting greens is only 2 inches. Applying the data in Table 1 for a putting green with an 80/20 root zone mix, we find that after irrigating to bring the mix to its FC, the amount of AW to a 2-inch depth is around 0.16 inch. What does this say if your daily evapotranspiration (ET) rate is 0.25 inch? The situation is actually much worse than indicated here.

In Wisconsin, on a clear day with temperatures in the 90s and a mild breeze blowing , turfgrass ET rates can approach 0.3 inch. Under these conditions and particularly with sand putting greens, afternoon wilt can occur even when the root zone soil still contains 75% of its AW. The reason this happens is simply the fact that, even with this amount of AW, the turfgrass is losing water faster than it can take it up. I'm telling you this to make a very important point. When we apply the concept of AW as a tool in helping us decide how frequently and what rate irrigation is advisable, we cannot operate on the basis that our water supply is 100% of the AW. Rather, we have to select some percentage of AW we're going to allow to be depleted before the need for irrigation arises. A reasonable figure is 50% of AW. This won't cover those days with exceptionally high ET rates, but is practical in the long run.

Application of the 50% AW criteria is a simple matter if we have knowledge of daily ET rates, know the depth of rooting of our turfgrass, and have a reasonable estimate of the inches of water we have to work with. Until now, the major stumbling block to doing this has been that of obtaining reliable estimates of daily ET rates. That obstacle no longer exits thanks to the efforts of Dr. William Bland and his group in the Department of Soil Science at UW-Madison. They've developed an elaborate computer model that calculates daily ET rates, which can be accessed via the following web site: www.soils.wisc.edu/wimnext/water/html. All you have to do is go to the web site and click on Wisconsin and Minnesota. The ET rates given are estimates of actual plant ET rates and not estimates of the type of ET rates obtainable from weather stations. Weather stations record the rate of water evaporation from open pans, which is often used as "potential" plant ET. Depending on the circumstances, weather station potential ET values can seriously over- or underestimate actual plant ET.

Now I'll attempt to analyze a couple of irrigation regimes to gain some idea of how well they meet turfgrass water requirements. To do this, I'll be applying the criteria of not exhausting more than 50% of AW, using data from Table 1 and applying the Bland ET rates in July of this year in the

Madison area. What I want to do first is address the statement I often hear "I like to keep my greens on the dry side." To do so, I have to assume that what this statement translates into is daily irrigation of an 80/20 putting green at something less than actual ET. I'm going with a figure of 75% of actual ET and will assume a rooting depth of 4 inches. From the data in Table 1, this means that our AW is 0.316 inch when the green is at FC. According to my calculations, by the start of the second day, the soil is at 80% of AW and irrigation has brought the top 3.2 inches back to FC. The next day begins with 62% of AW and 2.5 inches of the green at FC. The third day is trouble. The soil is now down to 38% of AW and the previous night's irrigation re-wet only the top 1.5 inches of the green.

My conclusion is that using this type of an irrigation program during the heat of summer under the conditions I assumed will satisfy the turfgrass water requirements for about 2 days, after which the full 4 inches of the soil must be brought back to its FC, either with 0.55 inch of rain or irrigationwater.

An irrigation regime sometimes used on fairways is irrigation at 70% of ET every 2 to 3 days. I'll use the Noer Facility bentgrass fairways established on silt loam soil with rooting to 8 inches to analyze this irrigation regime. I'll not go through the calculations here, but with irrigation every 3 days at 70% of actual ET rates in mid-July, I estimate that after 5 rainless days 60% of the AW was used up and the potential for moisture stress was unacceptably high. My conclusion here is that this type of an irrigation regime is based on the assumption that there will be a meaningful rainstorm every 4 to 5 days. How much rain am I talking about? In this scenario, it would have taken 0.85 inch of rain to restore the 8 inches of soil to its FC.

Localized Moisture Stress on Putting Greens

The USGA recommendations for putting green construction emphasize the importance of uniformity in the depth of the root zone mix. Whatever contours one wants in the green should be built into the underlying soil. My experience is that all too often this recommendation is ignored. Greens, more often than not, are contoured by varying the depth of the root zone mix. What are the consequences?

A golf course I visited a few years back had just reconstructed all of its greens "according to USGA recommendations." The reason I was called upon was that the superintendent was successful in getting bentgrass to establish on some areas of the greens but not on others. A few minutes with a pipe probe revealed that the depth of root zone mix on individual greens varied from approximately 8 to 22 inches. More recently, I looked at some new greens where in April the bentgrass was badly desiccated on the ridged areas and a nice, bright green in the low areas. That time, the depth of the root zone mix varied from about 23 inches on the ridges to 13 inches in the low areas. I took soil samples from both areas. On the ridges, the moisture content in the top 4 inches was 5.2% while the low areas averaged 12.3% water. Both of these situations reflect the effect of soil depth on moisture retention in sand-based putting greens. The greater the depth of the root zone mix, the greater the gravitational force exerted on the water and the lower the amount of water retained. In both instances, the superintendents were advised to either put up with extensive hand watering or have the greens reconstructed.

I've also been called upon to address complaints about the need to hand water the perimeters of greens during hot weather when there is heavy reliance on irrigation. Occasionally, part of the problem can be attributed to poor irrigation coverage. But more often, what I find is that during construction a plastic sheet barrier was not installed between the root zone mix and the surrounding soil. This results in abutment of two soils with contrasting matric forces. The native soil, with its much higher matric force, pulls water out of the perimeter of the green. The result is not only a need for hand watering, but turf that is more susceptible to development of triplex ring.

Bunker Drainage

If you had problems with slow draining and very wet bunkers this past spring, hopefully you attended the Wisconsin Golf Turf Symposium on November 14 and 15 and learned some techniques for resolving these problems. Just in case you didn't attend, let me explain to you why bunkers are often slow to drain and then remain wet for a seemingly long period of time. Knowing the causes of these problems is the first step in correcting them.

A question I frequently hear is, "Why don't my bunkers drain as well as my putting greens? They're both constructed with drain pipe underlying sand." While these two situations may seem to be very similar, there is a fundamental difference. That difference arises from the fact that soil water will not flow from a zone of high matric force to one of low matric force. To get water flow, into the zone of low matric force, the zone of high matric force must first become saturated with water. This reduces the matric force on some of the water to near zero, which allows it to flow into the larger pores. In putting greens and bunkers, you're trying to get water to flow into a drain pipe, a "pore" whose diameter is commonly 4 inches. This will only happen when the material surrounding the pipe is saturated with water. In putting greens, saturation is in the bed of pea gravel and you still have 12 inches of root zone mix above that. In a bunker with 6 inches of sand over the drain pipe, you have at best 4 inches of sand over the zone of saturation. The difference in the amount of gravitational force acting on water near the surfaces of the putting green and the bunker is obviously very different and it is simply not possible for drainage to reduce the moisture content of the sand surface in the bunker to the same level as in the putting green.

Three factors account for the relatively slow drainage of bunkers. One is capacity. Putting greens can take in much more water than bunkers before excessive surface wetness becomes apparent. The second is the difference in the amount of gravitational force acting on the water. The third factor is the medium through which water must flow in the saturated zone in order to reach the drain pipe.

At least in USGA greens, flow is through the pea gravel bed while in bunkers it is through sand.

Water simply flows much faster through the very large pores in the pea gravel.

So what are some options for getting faster and more complete drainage in bunkers? One is to increase gravitational force by increasing the depth of sand. The other is to reduce the distance the water must travel to get to the drain pipe by using closer spacings than in putting greens.