Water: a tug of war between soils and plants

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Bottom line: There is little argument that without water, plants will die. But despite the inarguable nature of this principle, insuring that sufficient water is regularly delivered to turf plants is difficult to achieve because so many factors are involved. Some, such as drought, poor irrigation system design, or the drying effects of tree roots are relatively obvious problems. But there are also other factors, which although less obvious, can just as seriously deprive turf plants of water. Because they affect water availability indirectly, factors such as high soil salts, high soil clay content and compaction can be easily overlooked. But beware -- turf survival can be imperiled if these forces are ignored for too long. By understanding the role of the invisible enemies that can rob plants of the water they need to survive, you can fight back with appropriate measures, such as salinity monitoring, leaching, improved irrigation management, aerification and topdressing.

Conundrum # 1: Your fairway is showing signs of drought stress, with footprinting and wilted, off-color turf that feels limp to the touch. You suspect that the soil underneath the turf will be dry, but when you examine it, the soil is moist.

Conundrum #2: Your bermudagrass fairways are being irrigated with reclaimed water that has a high salt content, and recent soil tests show that this has led to a build-up of soil salts to 10 dS/m – a level above the tolerance tolerance of bermudagrass. As a result, you expect the turf to be struggling to survive, but instead the turf looks absolutely fine, with no signs that it is being stressed by salinity.

What's going on?

In both of the puzzling cases above, our observations challenge some of the most basic assumptions about water availability and plant health. Yet drought-stressed turf growing on moist soils is a relatively frequently encountered problem, as is healthy turf growing in poisonously saline soils. To explain these, and other somewhat mysterious phenomena, it is helpful to understand the concept of **water potential,** which is typically represented with the Greek symbol **Ψ** (spelled, "psi" and pronounced "sigh").

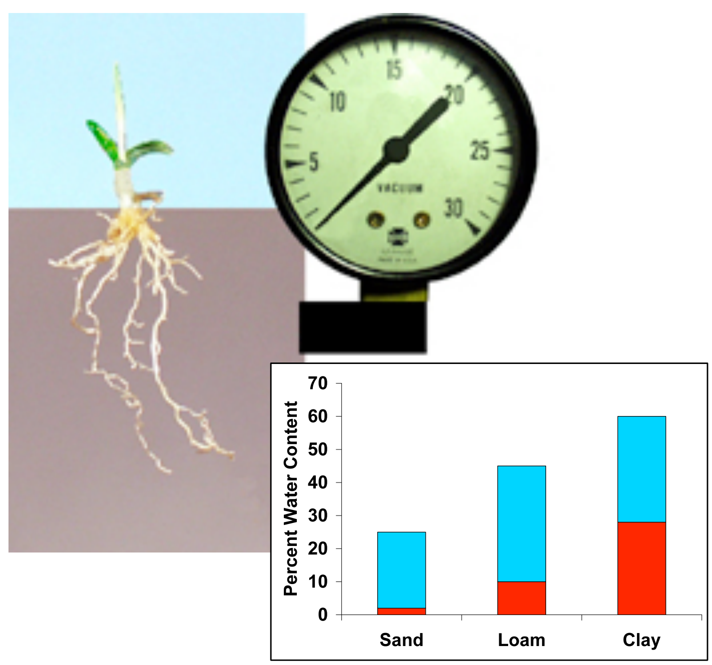
Water potential: The psi factor

When water moves, it's movement generally occurs in predictable patterns – for example, from wetter areas to drier areas rather than from dry to wet areas. Or from the roots of a plant up to the leaves, rather than from the leaves down. Why does water always tend to follow these same routes? What forces govern the movement of water?

It turns out that water, like other substances, needs energy to fuel its movement. To obtain this energy, water must move in such a way that it loses some of the energy it has (it's water potential) as it moves; this energy can be used to support water movement. Water will therefore always move from an area of high to low potential.

The highest of all water potentials belongs to pure water, and it has a water potential value of zero.

Figure 1. Zero, the best case scenario. When soil water potential measures 0 bars (as seen on the vacuum gauge below), the plant (with a lower potential) can easily suck water from the soil and deliver enough water to stay healthy. Although a water potential of zero is almost impossible to achieve in soil, conditions that lead to water potentials close to zero include: saturation of the soil with rain water (the closest thing to pure water that we see on a golf course); sandy soils, low soil salts and non-compacted soils. The graph below illustrates the water content of sand, loam and clay soils when the soil is saturated and water potential is 0 bars. Note that clay soils contain far more water than sand soils. However, almost half of the water in clay soils is held so tightly to the soil particles that it is unavailable to the plant roots (unavailable water is represented by red bars). In contrast, almost all of the water held in sand soils is available to the plant (blue bars).



The minute that anything is added to pure water, its energy level begins to decline, and its water potential becomes less than zero (a negative number). The use of negative numbers makes discussions of water potential even a bit more confusing; just remember that the bigger the negative number, the lower the water potential. This is illustrated in Table 1, where, for example, poor quality (salty) irrigation water has a water potential of –1.2 bars, while pure water has a water potential of 0 bars. Moist soil, which has more pure water in it than dry soil, has a higher water potential (– 0.5 bars) than dry soil (– 15 bars). It is for this reason that water will move from the moist soil (higher potential) to dry soil (lower potential). In the process of moving from a higher to a lower potential, energy will be released to help the water to continue to move.

Table 1. Some notable bars. Water potential is measured in units of pressure known as bars (1 bar = 14.5 lbs/in^2). Listed below are water potentials for a variety of environments.

Lower water potential = greater sucking ability

	Water Potential (Bars)
Air (50% relative humidity)	– 935.0
Air (90% relative humidity)	– 142.0
Permanent wilting point (dry soil)	– 15.0
Leaf surface	– 5.0
Low quality irrig. water (3 dS/m)	– 1.2
Soil at field capacity (moist soil)	– 0.5
Pure water	0

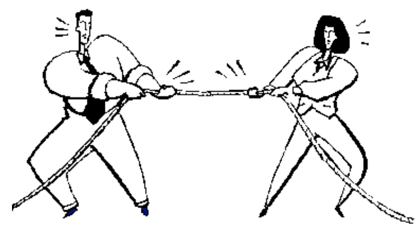
Similarly, water will always move from an area of low salt concentration (high water potential) to an area of higher salt concentration (low water potential).

This all sounds quite theoretical (and it is!) but the concept of water potential can help explain some very practical observations that are made on the golf course as we will explain below.

That sucking sound

Another way to think of water potential is as a measurement of the ability to suck water away from something else. A water potential of zero indicates no ability to suck water away, while increasingly lower potentials have greater and greater sucking capabilities. Environments with low water potentials (big negative numbers) will suck water towards them, and away from areas with higher water potentials. One of the most dramatically low water potentials exists in the atmosphere, at –935 bars for air with 50% relative humidity. The low water potential in the air is strong enough to literally suck water up through the plant – against the force of gravity.

Tug of war



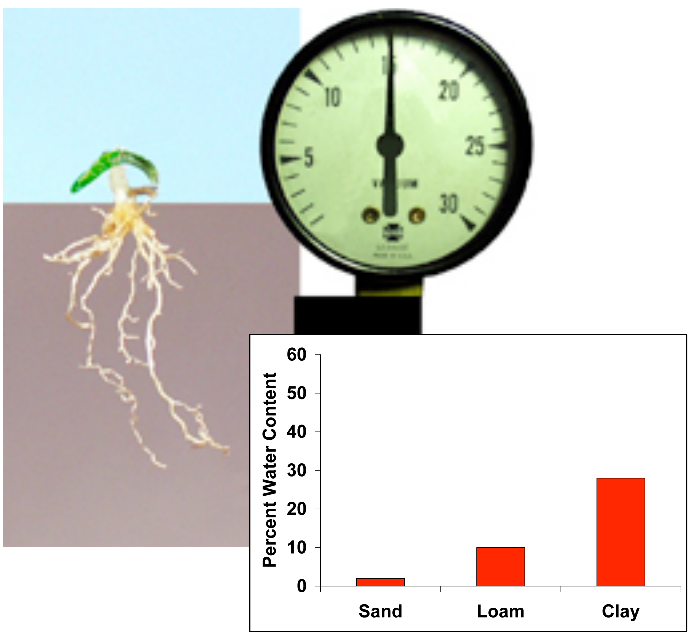
In the tug of war waged between plants and soil for the precious commodity of water, can we predict who will win and who will lose this life or death battle? Can the odds be manipulated in favor of the plant? The answer is yes, and a further look at the factors that influence water potential can help show why.

Soil texture: When their water contents are equal, fine textured soils such as clay soils have much lower water potentials than soils with coarser particles, such as sands. The clay particles hold onto water very tightly, and they suck harder on the water than the roots are able to suck back, and we end up with **conundrum #1**, described at the beginning of this ***PACE Insights***. Under these conditions, the soil wins the tug of war – the soil appears to be moist, but the turf plants wilt and die because they simply can't access the water. While some amount of fine textured soil particles can help increase the water holding capacities of soils, too much clay has a negative effect on water availability, drainage and compaction. It is for these reasons that USGA guidelines for greens rootzone mixtures specify less than 3% clay on sand greens, and less than 20% clay on soil greens. While there are no guidelines for tee, fairway and rough soils, clay content levels above 30% are generally cause for concern, and even lower clay percentages can cause water availability problems under some conditions.

Soil salinity: If a golf course was perpetually irrigated with pure water (regular, light rainfall is the closest real-life scenario), then roots would have little difficulty in sucking water out of the this moist, high water potential soil. Sadly, there are many areas where rainfall is neither regular nor frequent enough to achieve this water availability nirvana. When irrigation is relied upon heavily, soil salinities can begin to climb, and the tug of war gets rougher. Soil salinities above 3dS/m can cause enough suction to seriously compete with roots for water. High soil salts can also cause direct toxicity to turf, especially varieties such as bluegrass and bentgrass that are particularly sensitive to salts.

Compaction: Compaction gives an unfair advantage to soil in the battle for water by squashing the soil and turning the pores and spaces formerly available for water movement and root growth into miniscule passageways that restrict water movement.

Figure 2. Minus 15 bars, the worst case scenario. Plants will wilt and almost certainly die when soil water potentials reach –15 bars because the plant does not have enough suction to remove water from the soil. The high negative number indicates that the soil is holding on to water extremely tightly due to one or more of these factors: soils that are dry, have high clay content, high soil salinity or are compacted. In the graph below, notice that all of the water is unavailable (red bars) to the plant, even though water is present in the soil at levels of almost 30% in clay soils.



Water content: When soils are saturated with water, it is easy for roots to win the tug of war – the sucking forces of clay soils, soil salinity and compaction which normally can rob the plant roots of water can be at least partially drowned by the sheer volume of available water. This is how even a saline soil can support healthy turf growth, as described in **conundrum #2** – the soil is heavily irrigated, and thus kept in a constant state of water saturation. Unfortunately, unless irrigation precipitation rates are perfectly tuned and soil drainage is excellent, this practice would lead to unacceptably soggy soils and a loss of soil structure on most golf courses.

Winning the tug of war

By manipulating the four factors listed above – soil salinity, compaction, soil water content and soil texture – water availability to turf can be signficiantly improved. In most cases, the greatest impact will be made by focusing on improvements in soil salinity and compaction – these are the areas where cultural practices have the most influence. Modification of irrigation practices and of soil textures is more difficult to achieve and slower to show results, but should also not be ignored.

Lowering soil salinity

Soil salinity can be kept acceptably low through a program that relies on: 1) regular monitoring of soil salts, and 2) leaching or the use of leaching fractions.

1. Monitoring: This is a particularly important procedure in areas with low rainfall, where soil salts build up due to the use of irrigation water, as well as on golf courses using low quality, high salt content reclaimed or well water. The electrical conductivity or EC of a soil solution is directly related to the concentration of salts dissolved in the solution. For this reason, a measurement of soil EC is a direct way of assessing the level of soil salts, and can help you to avoid the problems associated with salt build-up, and can provide the justification for proper timing of leaching events.

To monitor soil ECs superintendents have typically relied on yearly soil tests – but this is not nearly enough. Ideally, soil salts should be monitored much more frequently – weekly is best – because the values can dramatically change with rainfall (or lack thereof), irrigation management, cultural practices, and changes in water quality. To make more frequent monitoring less time-consuming and less costly, we have developed a testing procedure and conversion values (see Reference 8:3). This procedure makes it possible to adapt the use of a relatively inexpensive EC meter for measuring soil salinity when the following guidelines are used.

Frequency of monitoring: In areas with low rainfall, or that use poor quality irrigation water, soil salts should be monitored monthly, at a minimum. Ideally, weekly measurements should be made.

Number of locations tested: Initially, you may want to test many areas on the golf course to get an idea of the range of values that are possible at your site, and of the relationship between turf performance and EC. Eventually, you may be able narrow down the number of locations that you regularly check to “hot spots” that perpetually have high salts – low spots and areas with poor drainage are typical high salt areas. These hot spots can give you early warnings that salts are beginning to build and that a leaching event should be scheduled soon.

Record keeping: Keep a notebook that records the date, the location (green, tee, fairway or rough number), the EC meter reading, and it’s conversion.

The enclosed data sheet may be convenient for this purpose.

Calibrate: The digital read-out on your EC meter can drift after repeated use. To keep the meter reading properly, calibrate about once a week according to the instructions in Reference 8:3.

2) Managing soil salts: There are two methods that can prevent soil salts from exceeding the limits of the turfgrass. The most popular method is termed **leaching** or **flushing** and refers to short periods of heavy irrigation that move soil salts from the surface of the soil profile to below the root zone. The second method applies extra water during every irrigation – a **leaching fraction** – to insure that salts do not accumulate to excessive levels. Both methods will be described below.

Soil EC reduction by leaching: The volume of water needed to leach soils from a high EC level to a lower level will depend upon many factors, including soil type and total amount of salts that needs to be leached. The rule of thumb is: six inches of water must flow through the soil profile to drop the soil EC by 50%. (these six inches cannot include runoff that occurs when the precipitation rate is higher than the soil infiltration rate can accommodate). Six inches of water is equivalent to 20,000 gallons per 5,000 sq ft. Less water will be needed if leaching is conducted more frequently, or if a smaller drop in EC is desired. Use an EC meter to monitor the leaching event so that water is not wasted and leaching stops when salts have been effectively moved to a lower level in the soil.

Soil EC management using a leaching fraction: The leaching fraction (also known as the leaching requirement) is the minimum volume of water needed to control salts within the salinity tolerance of the turf type that you are growing. It depends upon the EC of the irrigation water and the EC tolerated by the turf type that you are growing (see Table 2, Reference 8:3). The equation for calculating the leaching fraction is:

$$\text{Leaching Requirement} = \frac{EC_{water}}{5^*EC_{tolerated} - EC_{water}}$$

For example, when using a domestic water with an EC of 1.0 dS/m to irrigate poa greens that can tolerate soil salts of 3.0 dS/m, the leaching fraction is 1/14 = 7%. A leaching fraction would therefore be applied by increasing the water volume by 7% over the volume you would normally supply to meet ET requirements. To successfully keep soil salinity levels low, the leaching fraction must be added to each and every irrigation event. Continuing with the example above, if an irrigation or run time of 20 minutes is needed to replenish the soil with water lost due to evapotranspiration, then to prevent salt accumulation to damaging levels, an additional 1.4 minutes (20 X 0.07) would need to be added to your run times.

Leaching vs. leaching fractions: Both methods are equally effective, but we find that leaching is more frequently used than leaching fractions. This is primarily because the use of leaching fractions keeps turf wetter for longer than the more widely spaced leaching events.

Decreasing compaction

One of the many benefits of regular aeration is the decreased compaction and improved water movement that result. Tees and fairways should be aerated at least once a year. Greens should receive monthly venting with ¼" solid tines to decrease surface compaction and improve air exchange. In addition, greens should be treated to a spring aerification each year that utilizes:

- Core aerification with 5/8" hollow tines (remove the cores) followed by application of dry USGA spec sand to a depth of ¼"
- Deep tine aeration through the sand to an 8" depth, using ½" – ¾" diameter solid tines. Sweep or blow to fill the holes.

Improving soil texture

Cultural procedures, as described below, can help to slowly improve water availability in problem (i.e. heavy clay) soils. These include:

For tees, fairways, roughs and approaches with heavy clay soils and/or variable soil textures: Frequent and light sand topdressing can slowly develop a 4-6 inch sandy layer above the undesirable clay soils. This will eventually improve water availability to the plant.

For greens: a sandy root zone condition can be maintained through monthly venting and annual spring aerification, top dressing as described above, as well as frequent light sand topdressing,

Increasing soil water content

This is a complex topic that integrates factors such as irrigation uniformity (see June, 2000 ***PACE Insights***), properly matching the rates of irrigation precipitation and soil infiltration, and the role of ET in irrigation scheduling. For this reason, we will take on the topic in depth in an upcoming issue of ***PACE Insights***. For now, keep in mind that irrigation system maintenance is more important than most of us can imagine in the consistent production of high quality turf. Check to be sure that sprinkler precipitation rates match soil infiltration rates. This is almost always a problem and soak-cycle methods of irrigation are typically needed to supply sufficient water to problem areas.