Black Layer: A Symptom – Not the Cause of Anaerobic Soils

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Bottom line: When soils become anaerobic (oxygen-free), turf roots "suffocate", leading to wilting, yellowing, and death of the foliage above. Soil chemistry and structure also becomes damaged from a build-up of toxic materials, the generation of polysaccharide slimes, and sometimes by the development of a black, awful smelling slime known as "black layer". Because black layer is easy to identify by color and by smell, it receives a great deal of attention. Unfortunately, by the time black layer is detected, low oxygen conditions have existed for some time, and significant damage to the turf and to the soil may have already occurred. To avoid anaerobic soils, the critical components are good infiltration and drainage, careful irrigation management and frequent "venting" through aerification. Selecting an appropriately sized top-dressing sand, avoiding the use of organic or ammonia based fertilizers during the summer and controlling algae are good secondary measures to keep turf healthy.

Anaerobic soils: there is no consensus

"Anaerobiosis is the condition but sulfur is not the cause" Dr. Houston Couch, Virginia Polytechnic Institute. (1987)

"Thus, people who say sulfur does not directly contribute to the anaerobic condition of the soil simply don't understand soil chemistry." Dr. Joe Vargas, Michigan State University. (1994)

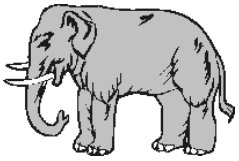
The symptoms are familiar and undeniable. Thinning, wilting or yellowing turf, especially in low areas. Waterlogged, slimy soil underneath that roots are unable to penetrate. And sometimes (though not always) a black layer of soil near the soil surface that reeks of something that is politely referred to in the literature as the smell of rotten eggs. The look and smell of this condition makes it relatively easy to identify as black layer caused by anaerobic (oxygen free) soil.

But while the symptoms may be obvious, there is a great deal of disagreement about the reasons **why** these symptoms develop, and therefore about the best way to avoid them. The quotations above, from two highly respected and knowledgeable plant pathologists, reflect the divergence of opinions on this topic. And that's only the tip of the iceberg.

In this issue of *PACE Insights*, we will try to bring some clarity to this murky picture by synthesizing the available information and by presenting some management strategies for avoiding turf damage due to anaerobic soils.

Looking at the whole elephant

The famous folk story about the three blind men and the elephant can, strangely enough, provide some insights as we review the technical literature on anaerobic soils and black layer.



In this story, three blind men are asked to describe an elephant. The man near the tail declares that he's touching a snake, the man near the leg insists that it's a tree, while the third man, feeling the trunk, believes that it is a hose. Given each of their perspectives, each man is providing an accurate description. But if each of them could see the whole elephant, they would know instantly that they were mistaken.

Historically, the question of anaerobic soils and black layer has been approached similarly – missing the whole story by focusing on one component and one concept at a time. This is why, over the last 25 years, we have seen so many seemingly contradictory explanations for anaerobic soils and black layer. Some researchers believe that over-application of sulfur is responsible (Vargas, 1994; Berndt, 1996) while others feel that low soil phosphorous levels are involved (Lubin, 1987). Others have identified microbes as the culprits – algae or bacteria that form slimy layers known as **biofilms** that can interfere with water movement (Hodges and Campbell, 1997). Shifts in microbial populations due to excessive use of fungicides has been proposed, as has poor water movement due to the use of inappropriate topdressing sands (Beard, 1987). Poor drainage is also frequently cited (Couch, 1987). And this is only a sampling of the many theories that have been put forth.

Like the blind men and the elephant, most of these explanations are technically accurate in the narrow sense, but each fails to take the larger picture – the whole elephant, so to speak – into account.

Anaerobic soils: a grab-bag of causes

Why has it been so difficult for turf experts to reach a unified, big picture understanding of anaerobic soils and black layer? It's probably because, depending on the golf course, low oxygen soils can result from a variety of different causes. For example, while poor drainage, algal growth and the use of organic fertilizers may be the most important factors at one golf course, another course may suffer the same symptoms due to a dense organic layer, along with the use of inappropriately sized topdressing mixtures. In other words, there is no one, predictable reason that soils become oxygen deprived. Instead, a whole grab bag of conditions can produce the same negative effect on turf by blocking water and air movement in soil.

All plugged up, and nowhere to go

Turf roots and the millions of naturally occurring bacteria, algae and fungi that live in the soil are hungry consumers of oxygen, gobbling up about a gallon of oxygen per day for every four square feet of turf (Drew and Lynch, 1980). And since oxygen makes up only 21% -- about 1/5 -- of the gasses in air, this means that almost 5 gallons of air per day is required to keep four square feet of turf supplied with enough oxygen to stay alive! And keep in mind that as roots and microbes ravenously ingest oxygen so that they can grow and remain healthy, they are also producing waste products – most notably carbon dioxide – which can build up to toxic levels if it is not released or "vented" from the soil into the atmosphere (see below).

Under good drainage and aerification conditions, gasses of all types move easily through pores (spaces) between sand particles. In this way, oxygen is delivered where it is most needed – to the plant roots, and injurious carbon dioxide is vented out of the soil to the atmosphere. However, if these pores become plugged – with water, silt, organic matter or bacterial slime -- the movement of all gasses is restricted. Under these conditions, oxygen is not delivered fast enough to growing roots to keep them alive, and carbon dioxide can quickly build up to toxic levels. For this reason, soils do not need to be completely anaerobic before significant turf damage occurs. Even small changes in oxygen and carbon dioxide movement can result in severe damage to turf.

There are a multitude of factors that can lead to plugged up soils and reduced gas movement, but they can be divided into two main categories: 1) Poor sub-surface drainage; 2) sealing of the surface layer.

Poor drainage

When drainage is poor, either because the drainage system doesn't exist, or because the drains are plugged or were poorly constructed in the first place, there is no outlet for the build-up of water that gradually accumulates in the soil. Eventually, water levels move up to the root zone, filling pores with water, rather than with air. And since the movement of gasses in water is so slow as to be almost non-existent (1/10,000th the normal rate in air filled pores [Drew and Lynch, 1980]), soils can rapidly become oxygen poor. This is why the turf in perennially wet areas does so poorly. The yellow, slow growing, poorly rooted turf suffers from lack of oxygen. If poor construction is the culprit, then there are few options available. The only way to avoid problems in the future is to reconstruct with proper drainage.

Surface sealing

While poor drainage problems start at the bottom of the soil profile and work their way up, problems can also be created from the top down if the soil surface and/or the root zone become sealed up so that water and air cannot penetrate. We have listed below some of the most important processes that contribute to sealing, as well as management strategies to prevent them.

Organic matter build-up: Organic matter (any carbon containing material derived from a living organism) can be a blessing or a curse, depending on the amount present. When intentionally added to root zone mixes, usually in the form of peat, organic matter can improve the movement and retention of nutrients and water. But build-up of organic matter in the form of excessive thatch or decaying plant material can create a dense slimy layer that acts like a coat of waterproofing – water and air can barely penetrate it to reach the roots.

Regular verticutting and topdressing can help prevent thatch build-up, as can the aerification program described in the February, 1999 *PACE Insights*. This program relies on core aerification followed by deep tine aerification (at least once per year in the spring) PLUS monthly venting with ¼ inch solid tines.

Organic matter and microbes: High organic matter also provides the ideal nutritional diet for soil microorganisms – bacteria, fungi and algae – and can therefore cause microbe numbers to skyrocket. While most soil microbes are either beneficial or at worst benign, too much of anything can cause trouble. And in the case of high microbial populations, their increased numbers and growth rate puts them in direct competition with turf plants for the one element that neither can survive without -- oxygen. If microbe numbers are high enough, they can actually suck most of the air right out of the rootzone, leaving turf roots gasping for air, and resulting in anaerobic soils. This is why we urge you to avoid the addition of any organic materials to greens – whether in the form of fertilizers, soil amendments or topdressing materials. This is especially important in the summer, when warm temperatures promote even more rapid microbial growth and increased demand for oxygen. If you do elect to use these organic materials, it's a good idea to wait until the cooler months, when microbes replicate much more slowly.

Bacterial and algal slime: Dental plaque, the thin, slimy layer that can form on teeth and can promote tooth decay, is a ***biofilm*** that helps to protect and even nourish the bacteria that produce it in the human mouth. Similar slimy biofilms are produced in the soil by many of the bacteria that live in the top few inches of the soil profile. In addition to promoting bacterial growth (by protecting the enclosed bacteria from toxic materials and by trapping nutrients for them), these biofilms can be thick enough to promote "decay" of the soil by blocking air and water movement.

Algae (*Oscillatoria, Nostoc,* and *Anacystis* are common blue green algae found on golf courses) also produce slimy, impermeable polysaccharide layers as they grow. When algal populations become very high, they can cause sealing at the soil surface, or even a few

inches underneath. In addition to their contribution to anaerobic soils, algae such as *Oscillatoria* can also produce direct damage to turf, probably through the production of toxins that damage plant tissue.

In most cases, extremely high bacterial or algal growth is a sign of some other stress or imbalance in the turf system, such as excessive organic matter (see above). High heat not only leads to an increased replication rate of many microbes, but by killing some turf, also provides extra nutrition to bacteria and algae in the form of dead plant tissue.

Avoiding addition of organic matter (especially during the summer) and sticking with a regular aerification program will help prevent many of these problems. If algae continue to cause problems (this is most likely during the summer months), three weekly applications of a chlorothalonil-based product have been an effective treatment in many locations.

Frequent and shallow irrigation: The practice of frequent, shallow irrigations can also lead to surface sealing. This is because although water and air are transported to the top few inches of the soil, which keeps some roots alive, there is never enough irrigation applied to carry water and air throughout the soil profile. As a result, the lower end of the profile becomes anaerobic, and cannot support root growth.

If the irrigation system and drainage can support deep irrigation, it is the most desirable method to use. However, keeping surrounds from getting swampy in the process is an issue. Some success in overcoming this problem has been achieved at several golf courses following installation of half-heads on greens. Under this system, greens can be irrigated or leached when necessary, without resulting in muddy surrounds. The benefits of this approach – avoidance of anaerobic soils, black layer, salt accumulation and a whole host of other problems – is well worth the investment.

Topdressing issues: Fine particles of sand or organic matter can fill pores or create layers so that air and water movement is impeded. This problem can be exacerbated if aerification procedures are not regularly practiced (see photo below). USGA recommendations for topdressing sand particle sizes and composition will avoid this problem (Moore, 1998).

Compaction: Soil compaction is a major cause of decreased water infiltration, decreased ability of roots to penetrate the soil, and limited gas exchange between the soil surface and the atmosphere. Aeration, particularly deep tine aeration, is the most effective method that we are aware of for relieving compaction – short of re-building greens. In many ways, aeration allows us to re-build greens on a continuous and relatively non-disruptive basis.

A sand topdressing program on the green to the left failed to alleviate black layer because the sand remained at the top of the soil profile. To relieve black layer, it would be necessary to conduct annual deep tine aeration, followed by sand application to fill the holes, as in the green on the right.

The top few inches of the soil profile below illustrate the effects of several years of sand topdressing with no aerification. The result is a layer of coarser sand particles on top of a soil layer – a situation that can result in reduced water and air movement and anaerobic soil.

Black layer: only one part of the story

Black layer is an unsightly, obnoxious and very dramatic warning that soils are oxygen poor, and that turf management practices need to be changed. As such, it is important to understand this phenomenon. But before we review the physical and biological basis for black layer, there are a few important points we want you to keep in mind:

- Turf damage due to oxygen poor soils can develop without black layer. Do not wait for black layer to develop before you institute the preventive measures outlined above.
- If black layer does develop, it usually means that some serious problems have been developing for a long time – problems that will be difficult and time consuming to correct.
- In other words, once you detect black layer, it's too late. Rapid recovery of highly anaerobic soils is difficult, if not impossible.

The components necessary for the formation of black layer are:

- Low oxygen soils
- Soils that contains sulfate and iron
- High numbers of anaerobic ***sulfate reducing bacteria*** such as *Desulfovibrio*

The smelly part of black layer comes about due to the production of ***hydrogen sulfide*** gas by anaerobic, sulfate-reducing bacteria. When soils become deprived of oxygen, the oxygen-loving bacteria that are normally present will die off and will become replaced by specialized bacteria that can survive without oxygen. If sulfur is readily available (and it usually is in most soils), these sulfate reducing bacteria will use sulfur, rather than oxygen, to survive, using the chemical reaction illustrated below:

$$2(CH_2O) + SO_4^{2-} = H_2S + 2HCO_3^-$$

ORGANIC MATTER — SULFATE — HYDROGEN SULFIDE

The hydrogen sulfide gas that is produced is what gives black layer its characteristic, disgusting odor. It is also toxic to plants, and is responsible for some of the damage seen under low oxygen conditions.

The "black" part of black layer is caused by a second chemical reaction, where the toxic hydrogen sulfide gas generated above combines with iron in the soil to make a black, insoluble material known as ***iron sulfide***. While iron sulfide is not toxic to plants, high levels may contribute to pore clogging and therefore to increased anaerobiosis.

The role of fertility in anaerobic soils

If you review the literature, you will see sulfur, nitrogen and organic based fertilizers most frequently discussed for their role in the development of anaerobic soils.

Sulfur: Several researchers feel strongly that addition of sulfur or sulfur derivatives (sulfate, sulfuric acid injection, potassium sulfate, etc) to soil or water is a direct cause of many cases of black layer (Berndt, 1996; Vargas, 1994). They reason that because sulfur is required for black layer to form, adding it to the soil will promote the problem. While we agree that addition of sulfur to soils that are already anaerobic may lead to further turf decline, it seems unlikely that sulfur alone can cause the problem. There are two reasons for this. First, the growth of sulfate reducing bacteria and the black layer that results cannot happen if oxygen is present at normal levels in the soil. Thus, before black layer can form the soil must become depleted of oxygen through one of the many processes described above. Secondly, most soils contain natural levels of sulfur and sulfates – usually more than enough to generate black layer if all other conditions (anaerobic soil) are right. Addition of sulfur in the form of fertilizer may add fuel to the fire, but black layer can form just fine without it.

Superintendents frequently avoid the use of sulfur containing products such as gypsum because of their concern about black layer, and on this basis have also tried to keep soil sulfate concentrations at 50 ppm or less. However, results from a six year study conducted by PACE Consulting on California and Illinois golf courses indicates that levels of 100 ppm of sulfate or more occur widely on greens that superintendents have classified as "good performers" (January, 2000 *PACE Insights*).

Nitrogen: There are two key reasons to select nitrate fertilizers instead of ammonium generating fertilizers, especially if low oxygen soils are a concern:

- When soil oxygen levels are on the low side, the nitrification process that normally functions to convert ammonium to nitrate can slow down or even stop. As a result, ammonium can build up to toxic levels in the soil and can cause serious damage to turf roots.
- Ammonium nitrogen utilization by roots requires about double the oxygen, as well as increased use of carbohydrates, when compared to roots supplied with nitrate nitrogen.

Organic fertilizers: We have reviewed above the way that organic fertilizers can increase the incidence of anaerobic soils. These should be avoided, particularly in the summer, when microbial activity is at its peak.

Is there a cure for anaerobic soils?

We'll end with this important reminder. A rigorous ***preventive*** aerification and topdressing program, such as that described above, can be your best friend in the struggle to avoid anaerobic soils. But for success, this program, as well as the other suggestions above must be instituted BEFORE anaerobic soils occur, and must be carried out on a regular basis. If you are in the unenviable position of detecting anaerobic soils or black layer, the situation can be slowly reversed by applying the recommendations above, but with one important exception. ***Do not do anything that will stress the turf any further.*** For example, procedures such as deep tine aerification should be delayed until turf is healthy and actively growing.

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