Black Layer Formation In Highly Maintained Turfgrass Soils

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Golf course superintendents nationwide have noticed the appearance of a black layer in some highly maintained turfgrass soils. This layer is frequently found in depressions and natural drain slopes but is not limited to these sites. Layer thickness varies from site to site, as does depth of occurrence. Affected turf may show symptoms of decline and require extensive cultural input like coring to prevent further deterioration. In severe cases, outright turf loss results.

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Research at Michigan State University has indicated that sulfur and sulfur derivatives such as sulfate (SO_4^{-2}) are the root cause of the black layer. Intimately involved in the process are obligately anaerobic soil bacteria belonging to two distinct genera: *Desulfovibrio* and *Desulfotomatuclum*.

Recent experimentation in our laboratory has successfully created the black layer when sulfur and crude cultures of "sulfate reducers" were added to either a sand-peat mix or sand alone under saturated conditions. In addition, "pockets" of the black sediment, as opposed to actual layer development, were formed in the sand under non-saturated but moist conditions at high rates of sulfur. Formation of the black layer was evident after only four days. As rates of sulfur were increased, the color intensity of the layer increased.

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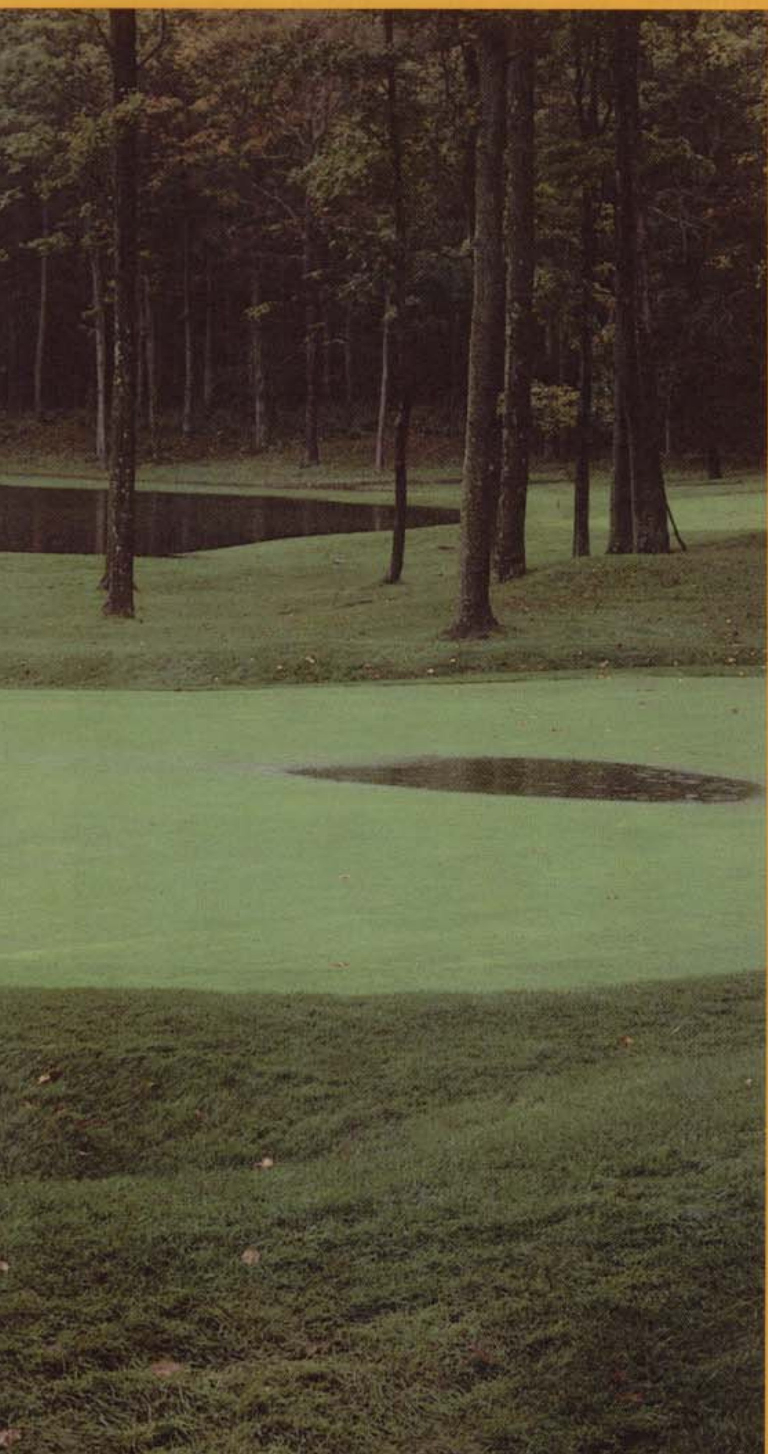

Heavy fall rains may produce ponding on greens (left) containing the black layer (typical example from northern Michigan shown below). This ponding was relieved by penetrating through the black layer with a soil probe.

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Where no sulfur was added, no black layer appeared, even though the soils remained completely saturated for 33 days.

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Experiments With Algae

Our research indicates that algae is not the basic cause of the black layer. In many soils where black layer is found, no algae problem is encountered. However, algae may contribute to the layer secondarily. Cell walls of algae contain a high proportion of "Sulfate esters" (non-carbon bonded sulfates), which may readily be converted to hydrogen sulfide. Thus, if the black layer produces a thin turf, algae may proliferate on the soil surface. Natural death of the algae and subsequent degradation of the cell walls allow these sulfate esters to enter the sulfate pool and possibly contribute to layer formation.

In our experimentation, even though light and water were not limiting for growth, algae were found only in the experimental units to which sulfur was added, regardless of soil type. In every case, the algae appeared after the formation of the black layer. Where no sulfur was added, no black layer was formed and no algae accumulated, even when the experimental soil remained saturated for 33 days. This finding suggests that sulfur may contribute to both the development of the black layer and surface algae, but more research is needed to substantiate this.

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Evidence obtained in our lab also suggests that although excess water may be important in initiating the black layer, in most cases it is not the cause of the layer. Experimental units that did not contain sulfur and were saturated for 33 days did not develop the black layer. Seventy-five percent of the experimental units that did contain sulfur (at the highest rate), and were not saturated but were kept moist, did develop the black layer. Thus, sulfur appears to be the key to black-layer formation.

Layer Formation

Essentially, the black-layer formation process involves microbial respiration. Aerobic respiration can occur by utilizing oxygen; anaerobic respiration utilizes other compounds when no oxygen is available. Both types of respiration produce end products that differ chemically. When specific groups of microorganisms (i.e., *Desulfovibrio*) use sulfate during respiration, much as animals use oxygen, the end product is hydrogen sulfide (H_2S). Large quantities of gaseous hydrogen sulfide are produced when these organisms have a sulfate enriched, non-oxygenated environment (i.e., anaerobic conditions). Hydrogen sulfide is extremely toxic, and it is also very reactive with soil metals such as iron or manganese. When hydrogen sulfide reacts with soil metals a metal sulfide is produced, and

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The Biology Of Black-Layer Formation

The layer is produced directly from a biological process using sulfate, sulfite and various other oxidized sulfur compounds as the terminal electron acceptors in microbial carbon metabolism. The initial process is termed dissimilatory sulfate reduction.

Essentially, dissimilatory sulfate reduction is microbial respiration using sulfate in place of molecular oxygen. Electrons from lactate, pyruvate or soil organic matter are transferred through reduced nicotinamide nucleotides, ferrodoxans and flavins to cytochrome and eventually sulfate. When transferred to sulfate, these electrons produce the most highly reduced form of sulfur, sulfide (S^{-2}).

The sulfide ion (S^{-2}) may exist mainly as H_2S, which is a weak acid ($pKa = 7.2$). H_2S is very toxic and very reactive and is one of the gaseous compounds associated with the foul odor of the layer. Production of even trace amounts of H_2S in soil has a negative effect on aerobic plant and micro-organism activity.

At moderate pH, heavy metal cations, mainly of the $+2$ valance state, become available to combine with the H_2S. Such ions could be Fe^{+2}, Mg^{+2} or Zn^{+2}. When the combination occurs, a black, acid soluble, metallic sulfide precipitate forms. This precipitate is responsible for the layer formation.

The ultimate end product in this process when iron is involved is pyrite (fool's gold). The rate of sulfate reduction is dependent on the availability of electron donors (i.e., organic matter, lactate, etc.) and sulfate concentration. Precipitate formation is dependent on aeration status and dissolved metal content.

The respiratory process is unique to several genera of strictly anaerobic soil bacteria. Thus lack of soil oxygen is a necessary prerequisite for the process. The most prevalent of these organisms in soil are of the genus *Desulfovibrio*. *Desulfovibrio* spp. are non-spore-forming, heterotrophic motile, spiral-shaped organisms belonging to the order Pseudomonales. Other genera capable of sulfate reduction include *Desulfomonas, Desulfobulbus, Desulfobacter, Desulfococcus* and *Desulfonemia*. Additional reduction pathways involving organisms such as *Pseudomonas* and *Bacillus* are known.

Sulfate-reducing organisms are found to inhabit soils with a wide range of pH, salinity and moisture potential. As a group they can tolerate heavy metals and dissolved sulfide concentrations of up to 2 percent (Paul).

— *W. L. B.*

References

Paul, E.A., 1980, *Soil Microbiology and Biochemistry*, University of Saskatchewan Printing Services, Saskatoon, Saskatchewan, Canada.

Smith, R.L., 1981, *Sulfate Reduction in a Hypereutrophic Lake Sediment*. Dissertation for Ph.D., Michigan State University, East Lansing, Mich.

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the black layer is formed.

The presence of an "infant" layer, formed by deposition of the metal sulfide into soil pore spaces, is in itself *initially* not detrimental to turf plant growth. It is simply an indication of lack of oxygen ("reducing" soil conditions). It appears that initial turf decline may be related to high concentrations of toxic compounds (i.e., H^2S) produced in the absence of oxygen. However, if substantial quantities of sulfur or its derivatives have been previously deposited in the soil, heavy rains could induce a prolonged anaerobic condition leading to black-layer formation. This can occur in as little as four days, as seen with our research. Because rain patterns are very difficult to control, this may be a key problem for the superintendent.

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Pockets of remaining sulfur remain visible in this example of an experimentally produced black layer from a Lake Michigan sand dune. This layer was completely oxidized by atmospheric oxygen in less than 24 hours.

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With an advanced layer, the metal sulfides clog soil pore spaces, effectively hindering subsurface drainage and oxygen diffusion, causing extended anaerobiosis (conditions devoid of oxygen). If sulfate reduction continues over an extended period, a layer with a glue like consistency eventually may be produced. This could promote a permanently anaerobic condition by sealing the soil profile. This sealing effect may cause supplemental irrigation or rain water to pond on top of the layer, further delaying oxygen re-entry into the soil until water loss occurs by evaporation or seepage.

The sulfide is also an oxygen scavenger, chemically binding oxygen very tightly and making it unavailable for aerobic respiration. In addition, the fine texture of the black layer makes it more conducive to retaining water. With the retention of water in the soil profile, layer development continues, with more toxic compounds and metal sulfides being produced. The process is a vicious cycle, because initially induced anaerobiosis plus the addition of sulfur leads to chronic layer formation, which leads to prolonged anaerobiosis and more layer formation. Oxygen becomes unavailable to the turfgrass roots for proper uptake of nutrients and water; consequently, normal growth and development stop. Beneficial aerobic

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organisms are poisoned and cease to exist. Sulfate "reduction" ultimately becomes the factor causing the anaerobiosis and subsequent turf decline; soil structure is permanently altered and turf loss accelerates.

Getting Oxygen Into Soil

To avoid the black layer, anything one can do to increase the amount of oxygen in the soil profile will be beneficial. Soil oxygen will oxidize the existing sulfide, causing the formation of sulfate. Sulfate may, in time, be leached from the profile. Deep core aerification with hollow tines, penetrating completely through the layer, may enhance oxygen flow into the soil profile. However, hollow tine coring also will bring a considerable portion of the glue like black layer to the greens surface, where plant matting may occur.

If your soil has the black layer and you decide to core, remove the plugs and leave the tine holes open, as this should increase the aeration status of the profile. Solid tine coring may help if the soil profile is dry enough to "shat-

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In contributing researchers' experiments, core samples (above) from experimentally produced black layers were all submerged in water for 33 days. The core designated "0" contained no added sulfur. Cores "1" and "5" received quantities of sulfur corresponding to 1 pound and 5 pounds of sulfur per 1,000 square feet. Where more sulfur was added, intensity of the layer increased. Note secondary growth of algae on cores "1" and "5"; algae growth is conspicuously absent on the core not receiving sulfur. Close-up photo (below) reflects the detailed appearance of the core receiving 1 pound of sulfur per 1,000 square feet.

Other experimentally produced black layers (below) support a conclusion that compounds such as sulfur, ferrous sulfate (FeSO^4) and ferrous ammonium sulfate (FeAm-Sul) will contribute to black layer formation.

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ter." However, coring with solid tines when the profile is wet may serve only to compact the glue like layer.

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Orient your management practices so that conditions favoring black-layer development are minimal. Keep a close eye on soil moisture and adjust irrigation scheduling accordingly. It may be wise to curtail lengthy irrigation cycles and rely more upon syringing. This should help the soil profile to dry, thereby alleviating any water-induced anaerobiosis. Unfortunately, little can be done to prevent the black layer from forming in soil saturated by heavy rains that occur in the spring and fall in many parts of the country. This is especially true for those superintendents who have a black layer resulting from rain water containing sulfate (acid rain).

Subsurface tiles should be cleaned so that drainage is unimpeded, and surface drainage patterns should be analyzed and possibly re-evaluated. Irrigation water has been shown to contain appreciable amounts of dissolved sulfur in certain areas. Therefore, it is advisable that the irrigation water be checked for sulfur content. If your irrigation water does contain an appreciable quantitity of sulfur each irrigation cycle could be adding to the formation potential of the black layer. A long-term solution might be substitution of sulfate-free water for sulfated irrigation sources.

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If you are currently on a sand-topdressing program, do what is possible to avoid layering. Layers created by infrequent topdressing practices that form perched water tables are favorable places for the black layer to form. Try to match the topdressing particle size to the original base mix as closely as possible. Topdressing applied lightly and frequently is most desirable.

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Most important, if a sand-topdressing program is instituted, you should follow rate and frequency guidelines carefully. Also, because calcium sulfate is a common co-precipitate with calcium carbonate in some calcareous topdressing soils, have the sulfate content checked. If the topdressing mix you use has an appreciable sulfate concentration, you may want to discontinue its use.

It may be wise to evaluate the topical application of iron sulfate and other sulfur compounds (i.e., ammonium sulfate) to areas where the black layer exists. Use of these products might, in essence, be "feeding" the layer by making sulfates freely available. Experimentation in our lab suggests that compounds such as ferrous sulfate and calcium sulfate (gypsum) may indeed contribute to black-layer formation.

Finally, try to reduce the amount of supplemental sulfur applied to your turf. The use of elemental sulfur for pH reduction where the black layer exists should be discontinued, as it appears to be the basic cause of the problem. Many superintendents have successfully grown bentgrass turf in high pH conditions for many years, but many are struggling where the use of sulfur has led to a black layer. □