SULFATE REDUCTION IN HIGHLY MAINTAINED TURFGRASS SOILS

W. Lee Berndt and J. M. Vargas, Jr.
Botany and Plant Pathology
Michigan State University

A black layer has recently been observed in some highly maintained turfgrass soils, especially golf putting greens. 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. Associated with the layer is loss of turf, a noxious odor and unknown fungal biotypes. Adjacent turf often has diminished usability and appearance requiring increased cultural input to prevent further deterioration.

We at Michigan State University believe the layer to be the direct result of a natural process termed dissimilatory respiratory sulfate reduction. Dissimilatory sulfate reduction can occur over a wide range of pH, pressure, temperature and salinity (1). The reduction process is mediated by a select group of anaerobic, heterotrophic bacteria known commonly as the sulfate reducers. The primary sulfate reducers in soils are of the genus Desulfovibrio, although other groups such as Pseudomonas, Bacillus and Saccharomyces can aerobically reduce sulfur compounds.

Soil anaerobiosis, the lack of molecular oxygen (O_2), is usually a prerequisite for sulfate reduction to take place. Saturated soil can increase the severity of soil anaerobiosis. Essentially, when O_2 is absent from the soil profile, other compounds become available to accept electrons released from the anaerobic decay of organic matter or cellular respiration. Sulfate ion (SO_4^{-2}, derived from sulfur (S), is such a compound. Sulfur is a naturally occurring element in most soil systems derived from plant amino acids (i.e., cystine) and is commonly found in rainwater as $SO_2$from automobile exhaust. When electrons flow via electron transport to SO_4-2, in anaerobic soil conditions, hydrogen sulfide (H_2S) is formed (i.e., the SO_4^{-2} or elemental sulfur is "reduced" with electrons from a suitable "donor"). Without an adequate sulfate pool or electron donor pool (i.e., organic matter, lactate, pyruvate or molecular hydrogen), or in the presence of inhibitors (i.e., NO_3^-), the reduction process will not happen.

Production of even small amounts of H_2S in soil has a marked effect on plant and micro-organism activity (1, 2, 3, 5, 6, 7, 8, 9). H_2S is a potent feedback inhibitor of respiratory electron transport and is, therefore, extremely toxic to aerobic life forms. Heavy metals, principally of the +2 oxidation state, are very reactive with H_2S. When metals such as iron II (Fe^{+2}) react with H_2S, a metallic sulfide precipitate is formed. This precipitate is the basis of the layer.
For example:

$$SO_4^{-2} + 8e^- \xrightarrow[\text{anaerobiosis}]{\text{Desufovibrio}} H_2S$$

$$H_2S + Fe^{+2} \longrightarrow FeS \downarrow$$

The presence of an "infant" metal sulfide layer, formed by deposition of the metallic precipitate into soil pore space is in itself initially not detrimental to turf plant growth. It is simply an indication of anaerobiosis and sulfide production in the soil profile. It seems logical then that initial turf decline is probably due to high concentrations of toxic metabolites (i.e., H_2S, C_2H_4, etc.) associated with the anaerobic conditions. When the anaerobiosis lingers (as with prolonged rain), layer development advances since conditions are now favorable for sulfate reduction (i.e., an anaerobic soil atmosphere producing H_2S). Once the layer becomes "advanced," soil drainage is physically impaired and the anaerobic conditions remain due to the presence of the layer, which now has a "glue-like" consistency. The sulfide precipitate clogs soil pore space and impedes water drainage from and oxygen diffusion into the affected profile. The layer effectively creates an impenetrable barrier causing supplemental irrigation water or rain water to stagnate and pond until loss by evaporation or very slow seepage. With the stagnation of the supplemental water in the profile, retention of the layer is encouraged and subsequent air or water drainage is further impeded. This process is a vicious cycle since anaerobiosis plus sulfate leads to black layer formation, which leads to prolonged anaerobiosis and more layer formation. Eventually plant growth ceases due to increases in concentrations of toxic metabolites associated with the anaerobic conditions and by the physical presence of the developed layer.

Many efforts have been spent trying to combat the advanced layer. Methods utilized range from aerification to complete renovation, each with varying degrees of success. But since so many differing factors seem to be involved, no single strategy is completely effective. In our opinion, if an infant layer is developing, it may be wise to curtail lengthy irrigation cycles and implement judicious syringing, curb the use of sulfur containing compounds such as elemental sulfur and ferrous sulfate, lower supplemental fertility rates and begin a vigorous aerification program. If possible, it may prove helpful to analyze surface and sub-surface drainage patterns. Prolonged rains obviously cannot be alleviated, therefore, adequate drainage is critical. A check on the sulfur (i.e., SO_4^{-2}) content of the irrigation water should be done. Also, the use of nitrate (i.e., NO_3) based fertilizers may be helpful since nitrate is an effective inhibitor of sulfate reduction (1). If the layer has become advanced and has a "glue-like" consistency, renovation coupled with postrenovation preventative practices may be the only viable alternative. Aerification with solid tines will be helpful only if the soil is dry enough to "shatter", which in a turf situation is unfeasible. Hollow tine aerification may help but remember that a portion of the layer will be brought up (i.e., cores) and may "mat" the plants to the soil surface. If the aerification does not fully penetrate the layer profile, a severe "plow pan" due the compactive forces of the aerifier may make matters worse by compacting the very fine precipitate particles of the layer. In the case of a deep layer, deep aerification (penetrating through the layer into the subsoil) should be more helpful.

There are also several methods currently in use which we feel may not be beneficial. These include applying hydrated lime (which does control algae). Raising the soil pH only serves to make conditions more conducive to layer formation. If the pH is raised enough to stop the metal ions from reacting with the sulfide (i.e., higher than pH 8), a severe turf chlorosis may develop. Applications of algicides also do not work since the formation of algae is secondary and due to sunlight penetrating the thin turf. There is, however, a problem with surface algae forming a "black crust", but this is not the "layer" in question. Flushing the soil profile with "oxygen rich" water will not work but will only make matters worse by contributing to anaerobiosis.

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Table 1. Some preliminary descriptive data for a black layer observed in 1986. The column labeled AFFECTED refers to soil which visually possessed a black layer. The column labeled UNAFFECTED refers to adjacent soil which was visibly free from the layer.

	AFFECTED	UNAFFECTED
OXYGEN DIFFUSION ($g\ cm^{-2}\ min^{-1}$)	2.53×10^{-8}	2.55×10^{-7}
HYDRAULIC CONDUCTIVITY ($cm\ H_2O\ da^{-1}$)	112.9	330.5
SOIL REACTION (in water)	7.30	7.62
TOTAL SULFUR (#/acre)	207.5	98.0
IRON (ppm)	83	38
SULFIDE TEST** (qualitative)	++	--

** Note that ++ denotes a positive result (i.e., sulfide is present) while -- denotes a negative result.