A Primer on Soil Redox Potential

Superintendents need to know how to avoid redox potential

By William L. Berndt

Redox potential is a measure of soil aeration. It's a vital factor in culturing quality turf and is influenced every day through cultural practices. Golf course superintendents should be aware of what redox potential is and how it's manipulated.

The basics of redox potential

Chemical reactions in soil involve the gain and loss of electrons. Gain of electrons is reduction and loss is oxidation. An acronym for reduction and oxidation is redox. Redox potential is a measurement describing the tendency or potential to transfer electrons in chemical reactions.

Soil layering resulting from topdressing. Note how thatch is sandwiched between successive topdressings.

To illustrate the concept of electrons transfer, consider that when soil organic matter (SOM) decays electrons and hydrogen ions are lost from it, meaning it's breaking down into simpler substances.

If oxygen (O_2) is present in the soil, its chemistry is such that it attracts and binds the electrons and hydrogen ions and creates water (H_2O) in the process.

In this reaction, SOM loses electrons and O_2 accepts electrons. This is called a redox reaction, and is commonly known as respiration.

The tendency to transfer electrons between SOM and O_2 can be measured by determining the voltage (V) associated with it. This voltage, or redox potential (Eh), is plus 0.82 V. This is the highest voltage encountered in natural systems like soils. Thus, when O_2 is present in sufficient quantities and electrons from SOM or other sources flow to it, there is said to be a high redox potential.

When O_2 becomes depleted, the electrons released by SOM or other substances are transferred to other electron acceptors, creating substances other than water. If O_2 is absent and sulfate is present, then electrons flow to sulfate, creating highly toxic hydrogen sulfide (H_2S). This reaction is called sulfate reduction. The voltage associated with sulfate reduction is minus 0.21 V, a much lower redox potential. Hydrogen sulfide produced by this reaction kills turf, and is the basis for the formation of the dreaded black layer.

Maintaining high levels of soil O_2 prevents the release of H_2S and subsequent black layer formation by maintaining the flow of electrons to O_2, hence a high redox potential.

Preventing formation of black layer requires keeping redox potential higher than minus 0.21 V. An easy way to do this is to fertilize with nitrate. Because of its chemistry, nitrate has a greater affinity for electrons than SO42–. It is more electronegative than sulfate, but less electronegative than O_2. This means that if both are present and O_2 remains absent, the electrons preferentially flow to nitrate, which generates an Eh of plus 0.43 V.

The reduction of nitrate is also known as denitrification. If O_2 is present, neither denitrification or sulfate reduction can occur, because the redox potential is too high.

Soils with low redox potential are anaerobic, which means they lack available O_2. Anaerobic soils can develop in a variety of ways. Water-logging because of rainfall or over-irrigating creates anaerobic soils. So does the presence of layers within the soil profile. Microbial respiration may also consume available O_2. Sometimes cultural practices inadvertently generate anaerobic soils. For example, applying natural organic forms of nitrogen (N) fertilizer (sewage sludge) or soil amendments like elemental sulfur can induce low redox potential by scavenging soil O_2.

Consider the application of elemental sulfur to help lower soil pH. This is a common turf cultural practice. The only way elemental sulfur lowers soil pH is by reacting with O_2 to produce sulfuric acid. The sulfuric acid then dissociates releasing acidity, which lowers pH.

As elemental sulfur must react with O_2

Continued on page 62

Continued from page 60

to generate acidity, it can generate anaerobic soil and lower soil redox potential. Research was conducted to help illustrate this point.

When elemental sulfur was added to a water-logged turfgrass soil at a rate of 1.5 pounds or 3 pounds per 1,000 square feet, it depressed both pH and redox potential significantly. Research was also conducted to illustrate how keeping redox potential elevated can prevent formation of sulfide. Data says applying elemental sulfur significantly reduced redox potential and resulted in formation of high levels of sulfide. Applying nitrate with the sulfur kept redox potential poised at a point high enough to prevent the release of sulfide. This occurred because the presence of nitrate maintains an Eh of plus 0.43 V, higher than required for sulfate reduction to occur. But when the nitrate is depleted, redox potential falls.

Organic matter can also lower redox potential as it stimulates microbial respiration by acting as a food source for microbes in the soil. The respiratory activities of the microbes consume O_2 faster than it can be replenished. As another example concerning organic matter, natural and organic sources of N (sewage sludge) must nitrify to release the nutrient N. This involves reacting with O_2. This process, which scavenges O_2, is known as nitrification.

Keeping high redox potential

There are several ways to keep soils from becoming anaerobic. This requires an integrated approach involving frequent aerification and other cultural practices. Make sure to vary the nature of the aerification tines and depths of penetration. Failure to do so can generate what is called a "plow pan," which restricts diffusion of oxygen into the soil, generating low redox potential. The integrated approach also requires that topdressing events utilize appropriately sized materials, and that frequency is suitable to prevent development of layers within the soil profile.

Small-diameter sands may work into putting greens very well but can also create physical problems, such as perched water tables if the particle size does not match base materials. Perched water tables can be great generators of low redox. Do what is possible to encourage drainage, including mitigating both surface and subsurface drainage problems.

Inadequate drainage is a main cause of low redox, as water impedes diffusion of O_2 into the soil by a factor of 10,000 times compared to a relatively dry soil. Surface soils need a minimum of 1 to 2 percent slope to drain effectively, and all putting greens should drain in at least three directions. Subsurface drainage needs a minimum of 0.5 to 1 percent to drain, and be sure to daylight drainage out of high traffic/play areas so as to avoid ponding.

If low redox conditions do begin to develop as indicated by the appearance of black layer, fertilize with nitrate-based sources of N. The nitrate molecule is such that adding it to soil effectively adds oxygen, which poises redox at a point high enough to temporarily prevent most low-redox related problems. In addition, don't apply natural organic sources of N or elemental sulfur. Both of these materials scavenge O_2 creating a low redox potential, hence unfavorable growth conditions. Fertilizing with nitrate and withholding applications of elemental sulfur are best management practices for preventing low redox and associated black layer.

Understanding the chemistry and math behind redox potential is not important for turf managers. But what is important is having a thorough understanding of the implications of having a low redox potential and how to avoid it.

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