



Acid Sulfate Soils in Virginia: A Primer

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What are acid sulfate soils?

Acid sulfate soils are earthen materials that have been degraded by oxidation of sulfides (like pyrite – FeS_2) to produce unusually low soil pH (< 3.8) conditions and a wide array of associated plant growth and material damage problems. Essentially, they contain sulfidic minerals that react with water and oxygen to form sulfuric acid. This active set of processes is called *sulfuricization*. The vast majority of acid sulfate soils are the result of land disturbing activities that bring previously unoxidized (reduced) materials up to the surface and allow them react.

What is soil pH and what is normal for Virginia soils?

Soil pH is a measure of the relative acidity vs. alkalinity of a soil. In reality, we measure the pH of water in equilibrium with the soil solids and a pH of 7.0 reflects neutrality where the level of acidic vs. basic soil components is approximately equal. Soil pH values less than 7.0 indicate net acidic soil conditions. Since pH is a logarithmic function of the concentration of acidity (H^+) in soil solution, each 1.0 unit of change in pH actually reflects a 10-fold change in acidity. For example, pH 5.0 is actually 100 X more acidic than pH 7.0 while pH 4.0 is 1000 X more acid!

The normal range of pH for soils in Virginia is between 3.8 and 7.5. In the absence of liming, the vast majority of our soils are naturally acidic with a pH between 4.5 and 5.5. In almost all instances, any soil with a pH of less than 3.8 in Virginia is indicative of active or historic acid sulfate soil conditions and is quite toxic to plant growth. In worse case instances, we have measured soil pH values of 1.8 at locations such as the Stafford Airport. This pH is associated with the direct and intense oxidation of reduced Fe and associated acidic hydrolysis reactions in the absence of neutralizers like carbonates.

Where do sulfidic materials come from what do they look like?

Sulfides precipitate naturally in tidal marshes and are also enriched in certain metamorphic and igneous rocks. Thus, they occur naturally in many of the sediments underlying our Coastal Plain and in certain rocks of the Piedmont. In fact, most of the soils in the Fredericksburg/Stafford area formed out of parent materials that originally contained sulfides, but they oxidized and weathered out of the surface soil

horizons (layers) tens of thousands of years ago. These subsoil horizons are usually bright yellow to red in color and are usually quite acidic (pH 4.0 to 5.5). However, many deeper cuts (> 10 to 20 feet) can reveal unoxidized sulfidic materials that are typically gray, steel blue or sometimes black in color, but still have a high pH (> 6.0) *in situ*.

How do I recognize acid sulfate materials?

Since fresh, unreacted sulfidic materials have a near neutral pH, the only way to identify them before disturbance is appropriate testing and lab analyses as described later. Once they react to become *active acid sulfate* soils, distinctive indicators include (A) dead vegetation, (B) red iron staining on concrete and block walls, (C) concrete etching and dissolution, (D) rapid corrosion of iron and galvanized metal, and occasionally, (E) strong sulfurous odor from rubbed hand samples.

What is the potential risk and damage from acid sulfate soil processes?

Acid sulfate soil conditions and associated *sulfuricization* reactions generate a number of extreme soil and water quality challenges. First of all, plants are killed by direct effects of low pH, high heavy metal solubility and soluble sulfate salt stress. The extremely acid (pH 1.8 to 3.8) soil solutions and percolates directly degrade concrete, iron, and galvanized metal via a number of mechanisms. Finally, acid runoff and seepage from these materials can seriously degrade local receiving streams. Thus, it is critically important that these materials be isolated or treated to remediate their acid producing potential and limit damage.

How do I confirm whether or not I have acid sulfate materials in my yard?

In addition to the visual symptoms described above, active acid sulfate materials will usually exhibit a combination of low pH (< 3.8) and high levels of potential acidity (total lime demand) relative to native soils. Fresh, unoxidized sulfidic materials may have a normal pH, but will have high levels of potential acidity (see below). To be certain, however, you need to have your soil tested!

Where should I take my soil samples from?

First, delineate areas of your yard or property where you see obvious contrasts in plant growth or other differences such as being part of a steep cut bank vs. a large convex fill. Also, areas that are clearly well-drained or droughty should be sampled separately from areas that are wet or poorly drained. Next, you need to take at least 8-10 small samples (e.g. ½ cup or so) from random spots within each area to a depth of 6 inches and place them into a plastic bucket or a large plastic bag. Don't sample sod or other intact vegetative material. You should also discard large rocks and gravels. Once you've completed your sampling for a given area, mix the soil sample thoroughly to form a good "composite sample" and then carefully take a uniform subsample out to repackage and ship as directed for soil testing. More detailed information on appropriate soil sampling techniques by homeowners can be found at <http://pubs.ext.vt.edu/452/452-129/452-129.html>.

It is important for us to emphasize that it is *absolutely inappropriate* to simply collect one point sample from a given lot to characterize potentially acid forming materials! This is due to the fact that these soils tend to be highly variable due to construction, grading, mixing and time of exposure to weathering. As outlined above, it is also very valuable to sample contrasting areas of “good” vs. “bad” apparent soil and turf conditions to make an appropriate prescription.

How can I get my soil tested?

Our laboratory at Virginia Tech can run a limited number of potential acidity analyses as described below upon request from Cooperative Extension personnel or local government officials. Fortunately, the University of Kentucky Extension Soil Testing Lab offers a routine test for potential acidity. Go to <http://soils.rs.uky.edu/tests/optional.php> for information. Their current (2010) price is \$25. We also suggest that you request their “routine soil test” for pH and available nutrients at the same time which is currently (2012) available for no added cost. Of course, you can also have the routine test run at Virginia Tech!

What is potential acidity and how is it expressed?

Potential acidity is estimated by several lab techniques that have been used and refined by the mining industry since the 1970’s to prevent the formation of *acid mine drainage* from coal and metal mines. The most widely used technique is called *acid-base-accounting* (ABA) and assumes that all sulfides in the material will fully react to form sulfuric acid and then balances that against the material’s inherent lime or neutralizing capacity. The results are expressed in tons of lime demand per 1000 tons of material, which handily also happens to be the average weight of one acre of soil six inches deep. Reduced sulfur is very reactive and every 1.0% sulfidic-S, if fully reacted, generates enough acidity to require approximately 32 tons of agricultural limestone (finely ground CaCO₃) per 1000 tons to fully neutralize! Thus, even 0.3% sulfidic-S in these materials can generate a lime demand of 10 tons per acre (6” deep) which is much higher than we ever apply to “normal soils”. Occasionally, our Coastal Plain sediments do contain sufficient lime (as fine shell fragments etc.) to completely or partially offset their acid forming potential, but this is a rare occurrence.

At Virginia Tech, we use similar technique to ABA for potential acidity called the hydrogen peroxide oxidation technique (we abbreviate this as PPA for “peroxide potential acidity”). In this method, we use strong H₂O₂ to force the complete reaction of the sulfides and their internal neutralization by carbonates. In our experience, it correlates very well with ABA and with % total S for a wide range of Virginia materials.

Our long-term research results indicate that acid sulfate materials in the Fredericksburg/Stafford region average between 10 and 20 tons of lime demand per acre (or per 1000 tons) in their fresh/unoxidized state. On occasion, we have tested small pockets of materials that exceeded 40 tons per 1000 net acid

demand! Once these materials have fully reacted and oxidized, however, they typically require only 4 to 6 tons of lime per acre to bring their low (< 4.0) pH up to 7.0.

What can I do to remediate acid sulfate soil conditions?

First of all, the only way to prevent these reactions from occurring in disturbed cut/fill materials is to keep them out of contact with the oxidizing atmosphere and water. However, once they are placed and graded on a home site, the only practical way to remediate them is to bulk-blend sufficient agricultural limestone (or other approved liming materials) with them to offset the full amount of acidity that will be produced over extended periods of time (e.g. their potential acidity). We also recommend applying 25% more lime to ensure long term alkaline buffering in the system. For example, let's assume the soil in your back yard has a net potential acidity of -10 tons per acre lime demand. With the 25% buffer factor added to it, you need to add the equivalent of 12.5 tons of lime per acre six inches deep. Usually, your yard will be much less than an acre in size, so we need to convert this to a more practical liming rate per 1000 square feet. As a matter of convenience, one 50 lb bag of certified (see next section) agricultural lime per 1000 square feet is approximately equivalent to one ton per acre. So, the basic liming requirement for your back yard would be $12.5 \times 50 \text{ lbs} = 625 \text{ lbs}$ of agricultural lime per 1000 square feet. These materials would need to be well-mixed (with a roto-tiller or air knife) to a depth of 6 inches to ensure full reaction and remediation of the surface rooting zone. Once this material is allowed to react following several rainfall or irrigation events, you should be able to use normal plant/lawn establishment procedures, but we recommend adding compost to the surface soil mix whenever possible. It is important to note that the deeper soil layers will not be affected by this treatment, so planting holes for deep-rooted vegetation (e.g. trees) require deeper treatment.

We also recommend a similar remedial treatment for all soils in direct contact with uncoated concrete or foundations, block walls, or metal conduits and pipes. The exception would be where those materials (concrete, metal etc.) are under the water table or buried deeply enough in the soil such that they are beyond the depth of oxygen diffusion.

What is lime and what kind should I use?

Simply put, liming materials neutralize soil acidity by sucking up protons (H^+) and then turning them into water plus CO_2 . This is a very nifty and important reaction! The "lime" that we refer to above is *agricultural lime* (CaCO_3 or Ca/MgCaCO_3) and not hydrated lime (Ca(OH)_2) or burnt lime (CaO). These two latter materials are commercially available and occasionally used by the geotechnical engineering community for soil cementation or waste treatment. They do have advantages of being more concentrated and quicker to react. However, they are more expensive, can burn your eyes, and can rapidly drive soil pH to very high values that are also toxic to plants. Therefore, we only recommend the use of Virginia certified agricultural lime for this purpose.

It is also important to point out that agricultural lime (CaCO_3) can vary in their purity which is expressed as their "calcium carbonate equivalence" or CCE. For example, pure CaCO_3 would be 100% CCE while

a lower grade lime with some impurities might be 90% or lower. Dolomitic limes contain significant magnesium (Mg) content in addition to calcium (Ca) and may actually have CCE's slightly above 100%. All commercial liming products sold in Virginia contain a certification label that specifies their CCE along with other important properties. Just as long as the label indicates that the CCE is at least 90%, the calculations for application discussed in the previous section hold true. However, if the CCE is less than 90%, additional lime should be added per 1000 Ft² of soil area to compensate.

What is the historical and scientific basis for all this?

Sulfidic materials and the very same sulfuricization reactions that we describe above have been the bane of the global mining industry for years, particularly on coal and metal mines. In fact, they were responsible for the thousands of acres of acidic Appalachian coal mined lands and associated acid mine drainage that led to the passage of the federal Surface Mining Control and Reclamation Act in 1977. In the following decades, the U.S. government and mining industry spent tens of millions of dollars on scientific research on the prediction and remediation of these problems. Since 1977, all coal mining materials are tested before mining for their acid forming potential and any materials with a net lime demand of more than -5 tons per thousand tons material are classified as *toxic materials* and must be isolated and/or treated via specific permit conditions. Viable treatment options include (A) disposal below the water table, (B) isolation in lined cells to exclude water and air, or (C) addition of bulk lime to offset acid forming potential. No other treatments have ever been proven economically viable and permanent for preventing or remediating these problems.

Ideally, how can we avoid these problems in the first place?

Based on our work with VDOT and others (see website below for details), we have developed a statewide map layer that identifies all geologic strata that have documented sulfide risk. Pre-disturbance geologic drill cores by developer's consultants in these units should be evaluated for color, and any gray, blue-gray or black strata should be tested for total S. If total S is > 0.25%, those same strata should be tested for acid-base-accounting (ABA) or peroxide potential acidity (PPA). Any materials with a net lime demand of more than -5 tons of lime per 1000 tons should be isolated away from the surface and either heavily compacted in place to limit permeability or bulk limed before placement to offset acidity production over time.

Where can I get more information on this?

We have a considerable amount of current information and reports on this subject posted to our research website at Virginia Tech (<http://www.landrehab.org>). Additionally, we believe that the most sophisticated program in the world for recognition and remediation of acid sulfate materials is carried out in Queensland, Australia, where they routinely manage them in both urban and rural landscapes. Their website (<http://www.nrw.qld.gov.au/land/ass/index.html>) is quite comprehensive and informative with numerous links to their reports, methods and regulations.