Lowering Soil pH to Optimize Nutrient Management and Crop Production[1]

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In the southeastern United States, most mineral soils are naturally acidic due to high weathering resulting from relatively high rainfall and temperatures. A sustained management of soils for both pH and nutrients is required to maintain the soil fertility levels and ensure economic agricultural production. In the absence of regular pH management and balanced nutrient additions based on appropriate soil test recommendations, most mineral soils will gradually return to their natural low fertility levels and acidic regimes. In order to keep the soil in the 6.0-6.5 pH range, which is best for most crops, farmers have been asked to apply lime to the soils routinely. While calibrated lime requirement tests are part of standard soil tests in this region, there is a tendency to over-lime the soils. Agricultural lime and amendments with liming effects are relatively inexpensive and abundantly available, and that sometimes leads to over-liming. The effectiveness of liming materials is determined by the chemistry of the compounds as well as the fineness of the ground material (Table 1). Liming materials not calibrated for agricultural use, such as basic slag, slaked builder's lime, and unlabeled lime by-products, can change the soil pH too much or too little. Furthermore, because applying lime in amounts lower than 0.5 ton/acre is not economical, lime is usually bulk-applied, and farmers and dealers generally round off the amounts to the nearest ton. Finally, because the liming material takes a few weeks to a few months to react with the soil and raise the pH, the decision to err on the side of excess only becomes easier. Hence applying lime without a soil test will potentially only increase chances of over-liming.

Agricultural Soils of Florida and Their Management

Several agricultural commodities are intensively managed for soil pH, nutrients, and water on most of the soils found in Florida. Predominant soils in Florida include Entisols (deep sands), Spodosols (poorly drained flatwoods), Alfisols and Ultisols (soils with deeper clay layer), and Histosols (muck or organic soils). Additionally, in Miami-Dade and Monroe counties and several other localized parts of the state, the soils are calcareous with high soil pH between 7.4 and 8.4, with predominance of free calcium carbonate on the surface (marl and krome soils). So, the soil and crop management options available will be specific to the soils, crops produced, the ecosystem, the local BMPs implemented, and economics. Therefore, before attempting to remedy a soil with high pH, it becomes rather important to understand what factors, other than liming, can result in an increased soil pH.

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Reasons for Soil pH Increases in Florida

Soil Genetic Factors

CALCAREOUS SOILS OF SOUTH FLORIDA

Miami-Dade and Monroe counties in particular, along with several other smaller localized areas around the state fall into the calcareous soil category, where the free calcium carbonate on the soil surface can be as high as 90%. These soils consist largely of the natural limestone bedrock that underlies most of Florida, but in these areas it is exposed and at the surface of the soils. Nutrient availability, particularly micronutrients, in such soils, will be severely limited in these soils.

EVERGLADES AGRICULTURAL AREA SOILS

The soil pH in the Everglades Agricultural Area (EAA) (muck soils) has been increasing for many years and is now around 7.0 or higher. The soils are drained each year to cultivate crops, which causes oxidation of the soil carbon and consequently the subsidence of soils. Each year, tillage mixes up more of the $CaCO_3$ from the bedrock into the plow layer, increasing the pH.

Similar conditions can exist at other localized places around the state, and a similar situation can arise because the entire Florida platform has emerged from limestone geology. Soil depth tapers in Florida from the north to the south and from the high central ridge towards the east and west coasts.

High pH can also occur in drier areas, where evaporative demand pulls dissolved salts along with water from deeper parts of the soil profile and leaves the salts on the surface. Such conditions are not common, however, because rainfall is usually adequate and distributed relatively evenly through the year, so that salts on the soil surface leach back into lower levels.

IRRIGATION WATER QUALITY

In several parts of the state, particularly coastal areas due to salt water intrusion, irrigation with high-pH water can cause a gradual increase in soil pH. The irrigation water drawn from the limestone aquifer has a liming effect on the soil. This is a very common reason for high soil pH in Florida and therefore it is strongly recommended that an irrigation water-quality test be done when in doubt. Such a test can diagnose the reason for the cause of high pH and may help avoid unnecessary liming expense. In some cases, the irrigation wells may be too deep, tapping into the seawater. In unavoidable situations, irrigation frequency should be altered or reduced to minimize salt accumulations. However, any solutions should have a long-term strategy to be sustainable.

SOIL AMENDMENTS

In 2012 in Florida, farmers purchased an estimated total of 213,307 dry tons of class AA biosolids products, both imported and domestically produced, and land-applied approximately 108,272 dry tons of class B biosolids (FDEP 2012). Numerous other amendments to include composts, non-composts, organic and inorganic materials, and industrial sludges do also get land-applied as a cheaper method of disposal. Such materials, while containing certain nutrient value, may have varying degrees of liming values, resulting in unintended and arbitrary alteration of soil pH in agricultural soils.

INTENSIVE LIME AND NUTRIENT APPLICATIONS

Most crops, particularly vegetables, are grown very intensively in Florida. Sandy soils with low CEC naturally require such intensive nutrient and water management practices, keeping economic viability and competitive markets in mind. Additionally, subscription to the notions by the growers and consultants that a certain level of nutrients should always be maintained and that all the nutrients that are removed with crop harvests must be replaced can lead to potential over-application of lime and fertilizer. Some farmers use lime as a means to achieve higher soil calcium concentrations thinking that high soil-Ca can alleviate certain fruit postharvest disorders and improve fruit firmness and quality. As a result, the cumulative effects of over-applications, especially lime, can lead to gradual pH increase above the targeted range over a short period of time.

COMBINATIONS OF FACTORS

In many farming situations, uncontrolled increases in soil pH are the result of combinations of the factors described above. In Florida, for instance, the routine additions of lime plus lime in the irrigation water (lime leaches from the limestone aquifer) can result in rapid increases in soil pH, leading to micronutrient deficiencies.

Available Options for Reducing Soil pH

1. The best option for managing soils and nutrients is to develop a long-term management strategy. Identifying a right source of nitrogen fertilizer is the key. If the nitrogen fertilizer source has ammonia included, then that fertilizer will result in a residual acidity (Tables 2 and 3). One has to keep in mind that it is not the sulfate or

nitrate or phosphate ion in these nitrogen fertilizers that is causing the pH decrease. It is instead the number of hydronium (H+) ions that result during the soil reaction process, which can be either chemical or biological. For example, for ammonium sulfate, the reaction is chemical and is not dependent on the soil bacteria. On the other hand, soil bacteria are required for oxidation of elemental sulfur.

Long-term use of ammoniacal fertilizers will result in lowering the pH gradually and keeping it in the desired range. Ammonium sulfate or iron sulfate can be better options for the home gardener because the likelihood of over-application is limited.

2. When high soil pH is due to salt accumulation on the soil surface in the drier regions, usually calcium sulfate (gypsum) is recommended. Calcium ions (Ca^{+2}) in gypsum will replace sodium ions (Na^{+}) from the soil exchange sites and lower the pH. The Na^{+} in the soil will then have to be flushed out with fresh water from rainfall or good-quality (low-soluble-salt-content) irrigation water as an effective long-term solution.

3. In certain cases, elemental sulfur (S) may be applied to the soil. It has to be recognized, however, that S is an essential plant nutrient. Plants take up only the oxidized form—sulfate (SO_4^{-2})—and not its elemental form (S). So, the source(s) for supplying this essential element as fertilizer should always include sulfate. Sulfur-containing fertilizer products such as potassium-magnesium sulfate (or "sul-po-mag" is the most popular), ammonium sulfate, calcium sulfate (or gypsum), potassium sulfate, or magnesium sulfate (Epsom salts) are usually recommended, as appropriate, either as direct or an indirect sources of sulfur for plant nutrition.

Elemental sulfur (S) applied to the soil will not be taken up by the plants as is. First, elemental sulfur has to be mixed well with soil for optimum soil contact. Over time, the soil bacteria will convert the elemental form into the sulfate form. This reaction will take time depending on the soil moisture, temperature, and aeration. So, the response in soil pH decrease will not be immediate because it will take some time to react with the help of soil bacteria. When elemental sulfur is applied, the first effect will be on soil pH and then on the plant nutrition. Use elemental sulfur for acidification cautiously because any over-application or improper application can result in severe damage to the crops, decreasing the yields or quality of the products. Elemental S is becoming more expensive; therefore its use to change soil pH over a wide range could be prohibitively expensive, another reason to develop a long-term strategy to manage soil pH.

4. High-pH irrigation water usually is the result of salts, such as chloride, sodium, etc., dissolved in the water in quantities above normal levels. While application of calcium sulfate (gypsum) is an option, the effect is usually temporary unless better-quality irrigation water is available. Irrigation with good-quality water or regular rainfall events can flush the salts out of the rootzone. If these alternatives are not available and the irrigation water source continues to be of low quality with high dissolved salts, then the options might be limited. High-pH irrigation water from high lime content is equally difficult to manage. One should avoid over-irrigation. In certain situations, for high-pH-sensitive crops like blueberry, neutralizing the lime with acids injected into the irrigation water may offer some help. Lime deposits that may clog drip irrigation lines may be reduced by injecting acids into the irrigation system.

5. In some cases, for instance, when the cause of high soil pH is natural, there may be no alternatives for amelioration and no cost-effective mechanism of lowering the pH. Options may be limited in that case to just choosing plants/crops that can tolerate higher or alkaline pH ranges.

References

Florida Department of Environmental Protection. 2010. "Summary of Class AA Biosolids- Calendar Year 2009."

FDEP. 2013. "Biosolids in Florida 2012 Summary." Domestic Wastewater Section, Florida Department of Environmental Protection, Tallahassee, FL http://www.dep.state.fl.us/water/wastewater/dom/docs/BiosolidsFlorida-2012-Summary.pdf

Table 1. Effectiveness of common liming materials expressed as a % of calcitic lime; the greater the value the greater the liming effect, when compared with calcitic lime.

Materials (100% purity and fine mesh, as appropriate)	$CaCO_3$ equivalent (CCE, %)
Standard Calcitic lime - $CaCO_3$	100
Dolomitic lime- $CaMg(CO_3)$	109
Slaked or builder's lime- $Ca(OH)_2$	136
Quicklime- CaO	179
Basic slag- $CaSiO_3$	86
Lime-stabilized biosolids	50–75
Wood ash	75

Table 2. Common fertilizers and the associated residual acidity, and the relative amount of calcitic lime needed to neutralize the residual acidity.

N Source	%N	Chemical Formula	Acid Residue	$CaCO_3$ Equiv
Ammonium nitrate	34	NH_4NO_3	$2H^+$, $2NO_3^-$	1.8
Urea	46	$(NH_2)_2CO$	$2H^+$, $2NO_3^-$	1.8
Anhydrous ammonia	82	NH_3	H^+, NO_3	1.8
Diammonium phosphate (DAP)	18	$(NH_4)_2HPO_4$	$3H^+$, $2NO_3^-$, $H2PO_4^-$	3.6
Monoammonium phosphate (MAP)	11	$NH_4H_2PO_4$	$2H^+$, NO_3^-, $H_2PO_4^-$	5.4
Ammonium sulfate	21	$(NH_4)SO_4$	$4H^+$, $2NO_3^-$, SO_4^{2-}	5.4

Table 3. Acidic nutrient sources and calcitic lime (pure) required to neutralize the residual acidity.

Fertilizer Source	Pounds of Pure $CaCO_3$ Required to Neutralize 100 lb of Fertilizer
Ammonium nitrate (34-0-0)	60
Ammonium sulfate (21-0-0)	110
Urea (46-0-0)	81
Sulfur-coated urea (38-0-0)	118
Diammonium phosphate (18-46-0)	70
Elemental sulfur	312