Soil Acidity Evaluation and Management

By Luís Prochnow

Today's agriculture needs to follow the principles of sustainability that include building up and maintaining long-term soil productivity. On soils where acidity limits crop yields, soil and subsoil acidity amelioration constitutes an important part of best management practices (BMPs) to achieve sustainability. A major aspect of soil acidity management is the application of lime, but other practices may also be needed to correctly address the problem. Proper soil acidity management, among other benefits, increases the efficiency of applied fertilizers, improves the effectiveness of some herbicides, protects the environment, and enhances the profit potential for the farmer.

Principles of Soil Acidity

In aqueous systems, an acid is a substance that donates hydrogen ions or protons (H^+) to some other substance. Conversely, a base is any substance that accepts H^+. The H^+ ions, or active acidity, increase with the strength of the acid. The undissociated H^+ contribute to a soil's potential acidity.

Buffer systems can maintain the pH of a solution within a narrow range when small amounts of an acid or a base are added. Buffering defines the resistance to a change in pH. Generally, buffer solution systems are composed of a weak acid (HA) and one of its salts (BA) or a weak base and one of its salts.

Soils differ in terms of active and potential acidity. Also, soils behave like buffered weak acids, with the H^+ in the cation exchange complex (CEC) of humus and clay minerals providing the buffer for soil solution pH.

Figure 1 shows a good example of how soils can differ in terms of lime requirement to reach the same soil pH. For example, while soil B required about 2 t/ha of calcium carbonate ($CaCO_3$) to reach pH 5.5, soil E needed more than 15 t/ha to reach the same soil pH. Obviously, this is related to a much higher buffering capacity of soil E as compared to soil B.

It is important to understand that it is not correct to only rely on soil active acidity as a means to measure the rate of lime to apply. When the soil active acidity is neutralized, there is plenty of acidity to replace it (soil potential acidity or soil buffering capacity). Therefore, it is necessary to correctly evaluate the potential acidity of a soil to accurately measure the rate of lime to apply.

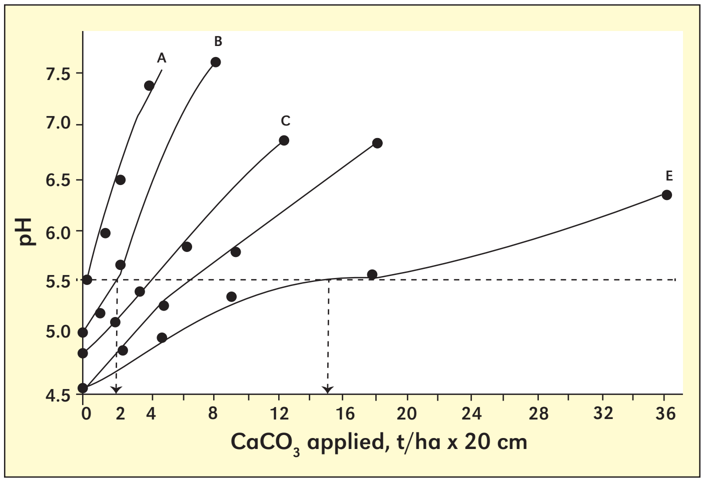

Figure 1. Neutralization curves with $CaCO_3$ for soils with different pH buffering capacities. Raij, 2011.

Why Soils Become Acid

Soils have a natural tendency to become more acid with time. Many factors, both natural (parent material, native vegetation, precipitation, soil depth) and managed (crops grown, N fertilization, organic matter decomposition, tillage, erosion) contribute to increasing soil acidity. If not appropriately controlled, acidity can seriously reduce crop yield, causing significant economic loss to the producer and can have a negative impact on the environment. Problems related to soil acidity are widespread, occurring in many areas throughout the world. It is estimated that about 30% of soils in the world are acidic and represent some of the most important food-producing regions.

Importance of Soil Acidity Amelioration

Proper use of liming materials is one of the most important management inputs in successful crop production and soil acidity amelioration. Consider some of the benefits of a sound liming program:

- Improved soil physical, chemical and biological properties.
- Improved symbiotic N fixation by legumes.
- Positively influence the availability of plant nutrients.
- Reduced toxicities to crops.
- Improved effectiveness of certain herbicides.
- Supply Ca, Mg and possibly other nutrients depending on their chemical composition.

The chemical availability of several nutrients such as P and S is improved by liming acid soils. Insoluble soil complexes of P and S are changed to more plant-available forms with the application of liming materials. Changes in soil pH affect the availability of the various plant nutrients differently. The availability of most nutrients is greatest in the soil pH range of 5.8 to 7.0.

Many research studies have shown the importance of applying appropriate amounts of lime on acidic soils for higher crop yields. **Table 1** summarizes results from some of these studies conducted around the world.

Choosing and Applying the Right Lime Source

Several factors should be carefully considered to have a successful program to apply lime to acid soils. Important factors include choosing an available and appropriate lime source, determining its rate and applying it under field conditions.

Source Factors

Chemical Form

The two major lime sources are calcitic lime and dolomitic

Abbreviations and Notes: N = nitrogen; P = phosphorus; S = sulfur; Ca = calcium; Mg = magnesium; Al = aluminum.

Table 1. Yield increases with lime application on acidic soils for different crops in different parts of the world.

Country	Crop	Yield increase with lime application, %	Citation	Observation
Argentina	Alfalfa	61	Gambaudo et al., 2001	
Brazil	Soybean	42	Oliveira and Pavan, 1996	No till; lime applied at the soil surface
Chile	Forage grasses	70	Alfaro et al., 1998	Average of three grass species
China	Cabbage	42	Lei et al., 2003	
China	Corn	59	Lei et al., 2003	
Ecuador	Pineapple	20	Mite and Medina, 2008	Optimum rate of 1.5 t/ha $CaCO_3$; higher rates induced root disease
Kenya	Corn	500%	Nekesa et al., 2005	Extremely acidic soil
Kenya	Beans	300%	Nekesa et al., 2005	Extremely acidic soil
Russia	Nine consecutive crops in rotation	As high as 32 (avg.=14)	Lukmanov et al., 2011	Lime applied once during crop rotation cycle
USA	Wheat	35	Beegle, 1996	
USA	Corn	500	Alley, 1996	
USA	Alfalfa	635	Alley, 1996	

lime. Calcitic lime is produced by mining and grinding $CaCO_3$ rock. When pure, it contains 40% Ca or 100% $CaCO_3$. It serves as the standard of comparison for neutralizing values of other liming materials. Dolomitic lime is produced from rock containing $CaMg(CO_3)_2$. When Mg is deficient in a soil, dolomitic lime should be the source of choice.

Particle Size Effectiveness (PSE)

The fineness of grind determines how rapidly the lime will react with soil and neutralize acidity, ranging generally from 60 to 100%. Such percentage represents how much of the lime will react in terms of neutralizing soil acidity in three months at ideal soil moisture content. Increased fineness of grind produces many more particles of lime to react with soil particles. Materials with lower PSE tend to have a higher residual effect, while those with higher PSE tend to react faster in the soil. Liming materials with lower PSE should be preferred in situations where a farmer wishes a longer residual effect (e.g., when introducing no-till or perennial crops in a farm). Liming materials with higher PSE should be preferred in situations where a farmer needs faster product reaction or when lime has to be applied on the soil surface (e.g., in established no-till systems or perennial crops).

Effective Calcium Carbonate Equivalent (ECCE)

The ECCE is a very important variable to be considered in calculations of rate to be applied. The ECCE or Relative Neutralizing Value combines two indexes (CCE and PSE) into one single value for the purpose of adjusting lime requirements under field conditions. ECCE is calculated as follow:

ECCE = (CCE x PSE)/100, where:

CCE = Calcium Carbonate Equivalent
PSE = Particle Size Effectiveness

with CCE and PSE obtained by laboratory analysis.

In practical terms the ECCE reflects how much of the lime, on a percent basis, will react in three months time as compared to finely-ground $CaCO_3$.

The lower the ECCE, the higher the rate of lime application should be to obtain the same effect in terms of soil acidity control. Formulas for calculating lime requirement are region-specific, but should always consider the ECCE. As an example, let's suppose that a laboratory's lime requirement for a material with 100% ECCE was 5.0 t/ha, but a farmer chooses a liming material with 80% ECCE. Thus, the farmer will need to apply (100 x 5.0/80) = 6.25 t/ha of the chosen liming material. In

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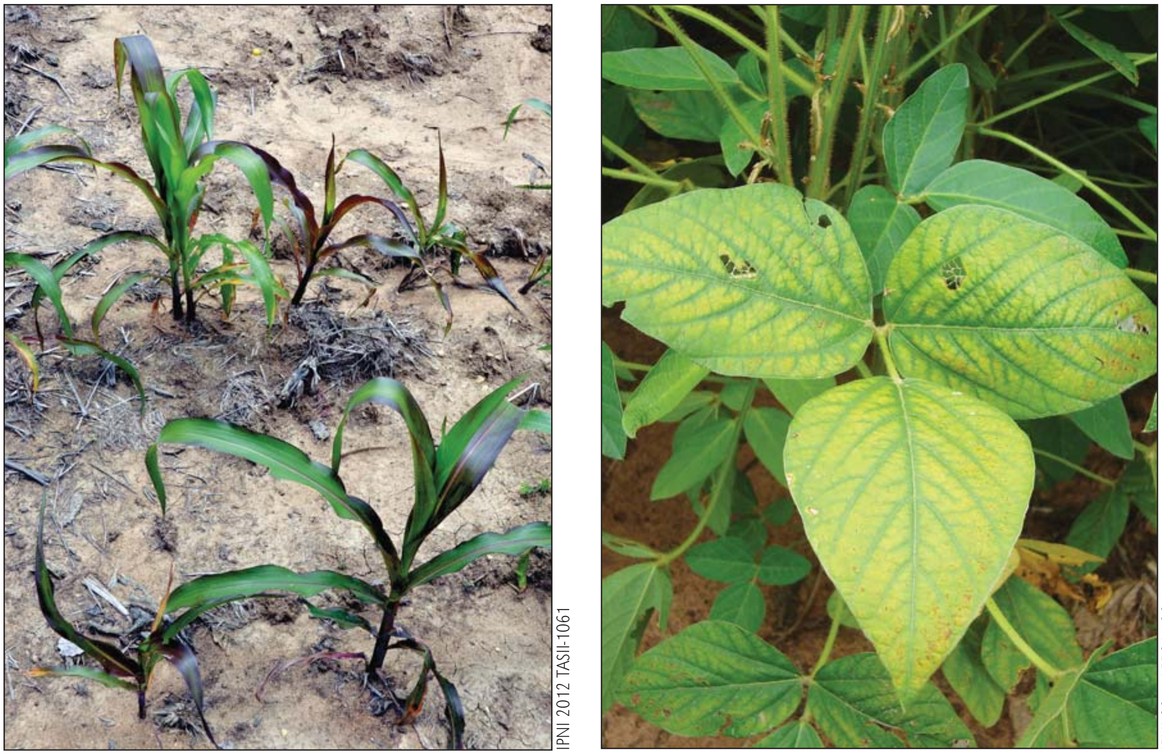
Lime application varies according to the farm scale, but its contribution to sustained productivity is critical regardless of the method of delivery.



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Deficiency symptoms for phosphorus in corn (*left*) and magnesium in soybean (*right*), which are two common issues on acidic soils.

case the farmer chooses a liming material with 110% ECCE, the lime application rate would be (100 x 5.0/110) = 4.54 t/ha.

Physical Form

Lime is available in several physical forms, the most common being crushed or ground rock. This is the form that is regularly used by growers under field conditions. Pelletized lime is produced by binding or compressing fine lime particles into larger granules or pellets. These larger particles are easier to spread and create less dust when handling. This makes pelletized lime quite popular under some situations (e.g., on home lawns and gardens). But pelletized lime is usually more expensive than conventional sources because of the added cost of pelletizing. Suspension lime is produced by suspending finely ground lime, up to 200-mesh, in water and applying with suspension fertilizer application equipment. Usually, it is applied at a rate of 225 to 450 kg (500 to 1,000 lbs) of a 50/50 water and finely ground lime mixture. The cost of suspension lime is also usually higher because of the additional cost of grinding the lime to the fine, 100- to 200-mesh size.

Rate Factors

Soil pH

As discussed earlier, soil pH identifies the degree or intensity of active acidity or alkalinity of the soil. It indicates the level of acidity a plant root will experience while growing in a specific soil. Used alone, however, it is not a good indicator of lime requirement.

Buffer Capacity

Lime requirement is related to soil pH and the buffer capacity or CEC of the soil. Buffer capacity reflects how strongly the soil resists a change in pH. Total amount of clay, type of clay, and the organic matter influences the buffer capacity. Sandy soils have low CECs and are weakly buffered, so they require less lime to raise the pH.

Crop to Be Grown

Some crops are more tolerant of soil acidity than others. Blueberries, potatoes and watermelons tend to be more acid- tolerant than crops like corn, soybeans, wheat, alfalfa, and clovers. As target pH for the crop to be grown increases, lime requirement increases.

Geographic Region

The types of clay present in soils can vary among geographic regions. Generally, humid regions have more highly weathered soils containing clays with low CEC. Soils in the less humid regions that have been exposed to less intense weathering processes, as well as those in the glaciated regions, tend to have clays with higher CECs. Areas of higher annual rainfall consequently may have a need for more frequent liming than semi-arid regions.

Applying Lime Under Field Conditions

Time and Frequency

Lime reacts with the soil only when water is available. Liming materials are however low in water solubility. Therefore, growers should apply lime to a soil as early as possible, before sowing a crop, as time and soil moisture can facilitate lime reaction and soil pH adjustment to the target crop. Two to three months before sowing a crop is usually the minimum length of time for good lime reaction. In case such a long time is not available, growers should plan on applying liming materials with a more rapid reaction in soil (e.g., CaO and $Ca(OH)_2$ or similar products can react with soil in two weeks time, if soil moisture is adequate). For forage and perennial crops, it is recommended to apply lime two months before the traditional period for extended rains starts. Liming acid soils is usually required every three to five years, depending on several factors like management, rainfall, soil characteristics, etc. Soils in areas of moderate to heavy rainfall patterns tend to become acid (or more acid) with time.

Placement and Soil Depth

Uniform application and thorough incorporation of lime in the soil are essential to a good liming program. Growers should choose the machinery and labor carefully for such an important operation. Experiments have shown that localizing lime is generally less effective than incorporating it in the whole field. In several specific situations, like in well-established no-till fields, perennial crops, pastures, hay meadows, lawn, and turf, incorporation of lime into the soil is not possible. In such cases local experiments should define the methodology for soil sampling and best possible placement.

In farms with heterogeneous soil pH areas, precision agriculture concepts and tools can help devise a sound lime application plan. This plan will include appropriate collection of soil samples, creation of maps, and variable-rate application of lime.

Lime recommendations are customarily made on the assumption that the liming material will be incorporated to the tillage depth represented by the sample submitted to the laboratory, which is most often 20 cm or 8 in. For cultivated crops and new pastures with depths of incorporation other than the regular 20 cm (deep tillage, no-till, etc.), the recommended rate of lime will need to be adjusted by multiplying the recommended rate with a factor calculated by dividing the real depth of incorporation by 20 cm.

Amount to Apply in Each Application

The maximum lime rate that is considered practical in a single application is about 10 t/ha (4.5 T/A). Recommendations in excess of this should probably be split into two separate applications. Splitting high recommendations into two applications, with separate incorporations, will help ensure that the lime is more uniformly distributed into the plant root zone by appropriate tillage.

Splitting the rate may also be necessary in cases where dolomitic lime is important (e.g., where Mg is also needed for crop development), but calcitic lime is available at a much lower cost in the region. In such a case, by splitting, it will be possible to apply dolomitic lime in at least one of the applications, adding Mg for crop development.

Other Practices Used for Soil Acidity Amelioration

Liming a soil is no doubt the best alternative to ameliorate surface soil acidity, which provides conditions for adequate crop development. No other practice is as efficient and economical as liming a soil. However, some other alternatives might be of use under specific situations for managing detrimental effects of soil acidity on crop growth.

Phosphogypsum or Gypsum Use

Chemically, gypsum ($CaSO_4{\bullet}2H_2O$) is a neutral salt with no direct effect on soil pH. However, many researchers have shown that phosphogypsum (PG), formed as a by-product of processing phosphate ore and sulfuric acid into phosphoric acid, can ameliorate subsoil acidity with positive influences on plant root development. This is especially important in rainfed cropping systems, where root absorption of water and nutrients may be limited, thereby affecting plant growth, if roots do not develop well and reach deeper soil layers.

The criteria to determine when to apply gypsum to ameliorate subsoil acidity should be based mainly on the amounts of soil exchangeable Ca and Al^{3+}, or sometimes soil clay content (determined from soil samples collected at 40 to 60 cm (15 to 24 in.) depth or beyond). Calcium lower than 5 $mmol_c/dm^3$ and/or Al^{3+} higher than 5 $mmol_c/dm^3$ indicates a good chance for a response to gypsum.

Soil clay content is used in some cases to recommend the rate of gypsum to apply. In Brazilian oxisols, where use of PG has become a routine practice, the amount to be applied is calculated by the following expression: PG = clay x 50

where, PG = amount of PG in t/ha and clay = clay content in % at 40 to 60 cm (16 to 24 in.) soil depth.

This formula has been extensively tested in Brazil with success. Other regions where PG is available will need to calibrate site-specific recommendations.

Cultivar Selection

The availability of toxic Al to plants is enhanced by low pH, and Al toxicity is a major factor limiting crop production on acid soils. Liming such a soil is a natural and logical practice to overcome soil acidity problems. However, in situations or regions where lime availability is low and/or the cost of lime is high, it might be useful to use a cultivar tolerant to soil acidity and especially tolerant to Al toxicity.

There is considerable variability in Al tolerance among plant species. This has been useful to breeders in developing Al-tolerant cultivars of various crops, as well as to researchers in studying the physiology and biochemistry of Al tolerance. Wheat has proven to be particularly useful in this respect, with up to 10-fold differences in Al tolerance among its different genotypes.

Thus, it is important to investigate in one's region if some local cultivars are available that are less susceptible to soil acidity and Al toxicity. In fact, using appropriate cultivars often leads to a higher degree of success in any liming program.

Information for this article was extracted from the new IPNI Publication entitled Soil Acidity Evaluation and Management. For more details on this publication please see http://info.ipni.net/SAEM or contact our circulation department at circulation@ipni.net.

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