AGRICULTURAL LIME AND LIMING, PART 2: LABORATORY TESTING TO DETERMINE LIME REQUIREMENTS

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AGRICULTURAL LIME AND LIMING, PART 2: LABORATORY TESTING TO DETERMINE LIME REQUIREMENTS

By
Wayne H. Thompson, Regional Agronomist and Dryland Cropping Systems Specialist, Extension Agriculture and Natural Resources Program Unit and Crop and Soil Sciences, Washington State University, **Carol McFarland**, Crop and Soil Sciences, Washington State University, **Tabatha Brown**, Crop and Soil Sciences, Washington State University, **David R. Huggins**, USDA-ARS

Abstract

Decreasing soil pH, also called soil acidification, is a growing concern in eastern Washington and northern Idaho. Researchers and farmers have measured soil pH values below 5.0 throughout the Palouse region, in particular. Decreasing soil pH has serious implications for the cropping systems of the Palouse.

This publication is part of a series on soil acidification and discusses the variations among soil types and why laboratory testing is used to characterize soil pH. The series begins with An Introduction, covering the fundamentals of soil pH and acidification, and continues with other fact sheets on more specific topics such as the influence of pH on pathogens and microbes, recommended varieties of specific crops, herbicide activity, crop nutrition, and liming.

Agricultural Lime and Liming is a three-part publication that introduces the basic principles of how and why calcareous amendments are land applied to elevate the pH of acid soils. Part 2 delves more deeply into variations among soil types and characterizations of soil pH by defining “lime requirement,” discussing common test methods, and providing a worksheet for reference.

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Agricultural Lime and Liming, Part 2: Laboratory Testing to Determine Lime Requirements

Agricultural Lime and Liming is a three-part publication that introduces the basic principles of how and why calcareous amendments are land-applied to elevate the pH of acid soils. It is also part of the companion series *Soil Acidification in the Inland Pacific Northwest.*

Part 1 – Introduction to Agricultural Lime and Liming. This section contributes to the discussion on the increasing incidence and severity of acid soils in the Inland Pacific Northwest (IPNW) and emphasizes: i) soil sampling and monitoring concepts to consider when managing acid soil conditions; ii) the role of soil testing; and iii) characterization of liming materials used to elevate pH of acidified soil.

Part 2 – Laboratory Testing to Determine Lime Requirements. This section delves more deeply into variations among soil types and why laboratory testing is used to characterize soil pH. We define the term "lime requirement" and how it relates to soil buffering capacity. We also provide information on lime requirement test methods commonly performed by soil testing laboratories. A companion Lime Requirement Worksheet based on common buffer tests and base saturation is provided for reference.

Part 3 – Aglime Product Selection and Comparison Calculator User Guide. This is a user's guide for the interactive online Agricultural Liming Material Selection and Comparison Calculator. The publication describes the attributes used to perform calculations to characterize liming material, while the interactive utility provides a platform to compare up to three liming materials for their relative effectiveness, costs, and economic efficiency.

Amending Acid Soils

Agricultural liming material applications increase the base saturation of a soil by displacing acid-forming (H^+ and Al^{3+}) cations with calcium and magnesium. The associated carbonates (CO_3^{2-}) and hydroxides (OH^-) of the liming materials bind with acid-forming cations to form insoluble compounds. The net result is an increase in soil pH, a significant decrease in phytotoxic concentrations of aluminum and manganese ions, and the release of carbon dioxide to the atmosphere (Anderson et al. 2013; Collins 2012; Havlin et al. 2013; Horneck et al. 2007).

Laboratory Testing

Soil testing for lime requirements is performed to determine the amount of pure calcium carbonate ($CaCO_3$) needed to displace hydrogen and other acid-forming cations and elevate soil pH by neutralizing an acid soil condition to a level where base saturation and exchangeable acidity are optimized for crop growth.

Laboratory testing quantifies a soil's buffering capacity along with active and exchangeable acidity, which are the acid-forming cations that occupy cation exchange sites on soil aggregates and organic matter and in the soil solution (Havlin et al. 2013).

Buffering Capacity

The amount of liming material needed to elevate pH is related to a soil's buffering capacity, which is its ability to resist change in pH. Buffering capacity of soil is proportional to the amount of clay and organic matter in a soil. As the clay and organic matter content of a soil increases, so does the buffering capacity. Higher buffering capacity increases a soil's resistance or resilience to acidification. Additionally, the amount of agricultural liming material required to elevate soil pH increases as the buffering capacity increases. A soil with high clay and organic matter content can require two to three times the amount of lime to elevate soil pH as a sandy soil with low organic matter content (Havlin et al. 2013).

Cation Exchange Capacity

Cation exchange capacity (CEC) is a measure of the nutrient-holding capacity of a soil. CEC is performed on a prepared soil solution and reported as milli-equivalents per 100 grams (meq/100 g) of oven-dried soil. The test result indicates the number of negatively charged sites closely associated with soil particles and organic matter, plus negatively charged sites in soil solution. The number of exchange sites in a soil is directly proportional to the surface area of the particles that make up the soil. CEC increases with increasing clay and organic matter content and decreases with increasing sand content.

Sand has a low surface area and sandy soil has a low to very low CEC (less than 5 meq/100g), while clay has a very high surface area and clay soil has a high to very high CEC (typically greater than 50 meq/100g). The CEC of agricultural loess soils in eastern Washington vary by soil type and depth. A typical range of CEC for loess soil is about 15 meq/100 g to over 25 meq/100 g. The CEC of soil is also pH dependent: in low pH soils the presence of acidic ions decreases the CEC. (In the companion Lime Requirement Worksheet, refer to the tab labeled CONVERSIONS to access an interactive unit of measure conversion utility).

Exchangeable Acidity and Base Saturation

Percent base saturation is the ratio of base-forming cations versus acid-forming cations that occupy cation exchange sites (Equation 1), and it reflects the exchangeable acidity of a soil or relative number of acid-forming cations that occupy cation exchange sites (Equation 2). As the concentration of base-forming cations increases, the exchangeable acidity decreases. Cations found at moderate to elevated concentrations are included in these equations (Havlin et al. 2013). Calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+1}), sodium (Na^{+1}), aluminum (Al^{+3}), manganese (Mn^{+2}), and iron (Fe^{+3}) are often found at high concentrations in IPNW soils and may appropriately be included as parameters in the equations.

$$Base\ Saturation\ = \frac{[Ca^{+2}]+[Mg^{+2}]+[K^{+1}]+[Na^{+1}]}{CEC} \qquad \text{Equation 1}$$

$$Exchangeable\ Acidity\ = \frac{[H^{+1}]+[Al^{+3}]+[Mn^{+2}]+[Fe^{+3}]}{CEC} \qquad \text{Equation 2}$$

The relative abundance of base-forming cations and acid-forming cations in a soil is related to its mineralogy. The mineral fraction of a soil serves as the residual source of cations and, in conjunction with organic matter, controls or buffers the liquid fraction of a soil. For example, pure distilled water is unbuffered. It contains no mineral ions. When distilled water is exposed to carbon dioxide, carbonic acid forms and the pH of the water drops from a neutral condition of about 7.0 to an acid condition with a pH as low as 5.3.

Water-filled soil pores and voids contain dissolved minerals. A concentration gradient of mineral ions forms around soil particles, with the highest concentrations adjacent to soil particles (e.g., soil clays, aggregates, and organic matter) where most cation exchange sites are located. If the mineral fraction of a soil is dominated by acid-forming cations, the soil solution will have an acid condition and low to very low base saturation. Conversely, if the mineral fraction is dominated by base-forming cations, the soil solution will have a neutral or basic condition and moderate to high base saturation.

No lime requirement test protocol is presently accepted as routine nor calibrated for the soils of eastern Washington and northern Idaho.

Lime Requirements

Lime requirement recommendations are based on soil tests. Soil testing laboratories use two or more of the following parameters when determining lime requirements: existing and target soil pH, soil organic matter content, bulk density, CEC, base saturation, exchangeable aluminum, exchangeable acidity, and buffer testing. Soil pH as measured in the field is used as an indicator to assess whether lime applications are needed.

A soil pH measurement alone is not a definitive parameter for determining a lime requirement because it does not provide information on the soil's unique buffering capacity or a quantitative measure of acid-forming cations and the number of base-forming cations needed to displace the acidity. Results from these tests are typically reported as estimates of the quantity of pure calcium carbonate recommended to be incorporated with soil, to a specified depth, to obtain a given target pH.

Buffer Testing

Buffer testing is the most common way of determining lime requirements in North America. Soil test labs appreciate the rapidity, ease of use, and accuracy of these region-specific tests. Buffer tests measure the exchangeable acidity of a soil sample.

Various buffer test methods have been developed to address region-specific lime requirements, each addressing defined soil conditions commonly occurring within a particular region. Common buffer testing methods include Woodruff (1948), Shoemaker-McLean-Pratt, or SMP (1961), and Adams-Evans (1962). In recent years, as concern for soil test lab disposal of hazardous waste has increased, greener chemistry options, including Sikora (2006) and modified Mehlich (Hoskins and Erich 2008), have been developed.

Woodruff (developed in 1948)

The Woodruff test was originally developed in Missouri in 1948, while various modifications to the original test have followed. It is not used as frequently as the other common buffers. The Woodruff buffer performs well on mollisol soils (Havlin et al. 2013). Effective use of the Woodruff buffer to predict lime requirements on northern Idaho soils was demonstrated by Mohebbi and Mahler (1988), using the standard buffer as well as a modification depressing the starting buffer pH to 6.

Shoemaker-McLean-Pratt (developed in 1961)

The SMP buffer test is the most commonly used buffer test in North America (Sparks and Bartels 1996) and is used to approximate lime requirements for acidity conditions ranging from pH 5.0 to pH 7.5. The test was developed in Ohio and has been shown to perform well on soils with high exchangeable aluminum, alfisols, and mollisols (Havlin et al. 2013). The SMP buffer test should be used on soils with a pH below 5.8 and organic matter less than 10%. The test is not recommended for soils with a lime requirement below 4.5 Mg ha^{-1}. For example, SMP buffer pH data are calibrated for the western Oregon Willamette Valley (Anderson et al. 2013). (In the companion Lime Requirement Worksheet, refer to the tab labeled SMP.)

Sikora (developed in 2006)

The Sikora buffer was developed to replace the hazardous materials in the SMP buffer. The Sikora method uses imidiazole and 2-(N-Morpholino) ethanesulfonic acid monohydrate (MES) in place of p-nitrophenol and chromate. The method has been shown to successfully replicate lime requirement recommendations given by the SMP buffer in several states.

Adams-Evans (developed in 1962)

The Adams-Evans buffer was developed in the southeastern US and has been shown to perform well on highly weathered, low CEC, ultisols with a low percentage of 2:1 soil clays (Havlin et al. 2013; Sparks and Bartels 1996). (In the companion Lime Requirement Worksheet, refer to the tab labeled Adams-Evans.)

Mehlich (developed in 1976)

Mehlich (1976) developed a buffer pH method that is widely accepted and calibrated for use in multiple regions of the US. This buffer test was developed to offset acidity to attain optimum crop yield rather than a specific target pH. This is done primarily by mitigating the negative influences of soil exchangeable aluminum on the crop. The lime requirement provided by the original test was found to generally recommend enough lime to elevate soil pH slightly above 5.5 (Sparks and Bartels 1996). Though the test was developed for use on ultisols, recent tests show that it also provides accurate lime recommendations for mollisol and alfisol soils (Havlin et al. 2013). (In the companion Lime Requirement Worksheet, refer to the tab labeled Mehlich.)

Modified Mehlich (developed in 2008)

Hoskins and Erich (2008) developed the modified Mehlich buffer that replaced the hazardous chemical barium in the buffer with calcium. The substitute produces comparable lime recommendations, though many analytical labs do not use this buffer because of its shorter shelf life.

Base Saturation

A lime requirement calculation based on soil test values for CEC and base saturation (Reganold and Harsh 1985) can be appropriate for rough approximations and long-range planning purposes and are used on highly weathered, low CEC, soils such as those found in South America. It assumes that soil pH increases with increasing base saturation. This method uses routine soil test values to calculate the amount of pure $CaCO_3$ (100% calcium carbonate equivalent) needed to decrease the ratio of acid-forming cations relative to the number of base-forming cations sharing a soil's cation exchange sites.

Percent base saturation represents the ratio of base-forming cations that occupy exchange sites (Equation 1), and points to a soil's percent acid saturation, or relative number of acid-forming cations, that occupy cation exchange sites (Equation 2). As base saturation increases, so does the soil pH. (In the companion Lime Requirement Worksheet, refer to the tab labeled Base Saturation.)

Calibration Methods

Using the most appropriate test and having recommendations calibrated for a region's unique soil characteristics greatly improves the accuracy of the recommendations provided. Calibration of lime requirement testing is accomplished with long-term field trials, laboratory-based titrations, and soil incubation studies (Aitken et al. 1995). Each approach provides reliable information to assess the characteristic response of a specific soil type to increasing application rates of lime.

Formal replicated field studies are generally cost prohibitive given the thousands of unique soil conditions that occur within a region. Laboratory-based soil incubation studies are designed to mimic field conditions and offer an efficient alternative by facilitating comprehensive evaluations of numerous soils in days, weeks, or months rather than years or decades.

Lime calibration research is an on-going process, incorporating long-term validation field trials with lab-based soil incubation studies, to keep pace with the intensification of farming technologies that accelerate soil acidification.

Considerations

No lime requirement test protocol is presently accepted as routine nor calibrated for the soils of eastern Washington. On-going collaborative research and extension efforts at WSU are addressing the need for a lime requirement method calibrated for use on eastern Washington soils.

Soil management practices that are known to cause soil acidification should be examined, and appropriate steps should be adopted to manage the soil acidification process:

1. Calculate the amount of liming material needed to counter the acidifying effects of ammoniacal-nitrogen and sulfur applications. (Refer to *Agricultural Lime and Liming – Part 1. Introduction to Agricultural Lime and Liming.*)
2. Consider using soil test data that include accurate measurements of soil CEC and base saturation to adjust liming material application rates. (In the companion Lime Requirement Worksheet, refer to the tab labeled Base Saturation.)
3. Balance the acidifying effects of soil management by scheduling applications of characterized agricultural liming material. (Refer to *Agricultural Lime and Liming, Part 3: Aglime Product Selection and Comparison Calculator User Guide*.)
4. Use the companion Lime Requirement Worksheet to assess lime requirement recommendations provided by laboratories that use buffer tests calibrated for soils outside of the IPNW. Interactive calculators for the SMP, Adams-Evans, and Mehlich buffer test methods are provided. A unit conversion calculator is also provided in the worksheet for convenience to facilitate soil test report unit of measure conversions.
5. Monitor for changes in soil pH over time following liming material applications to verify lime requirement test accuracy and to determine the appropriate frequency of liming material applications.

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