SOIL QUALITY-AGRONOMY

Technical Note No. 8

Liming to Improve Soil Quality in Acid Soils

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Natural Resources Conservation Service

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This is the eighth note in a series of Soil Quality-Agronomy technical notes on the effects of land management on soil quality. This information is general and covers broad application.

Soil pH is an excellent chemical indicator of soil quality. Farmers can improve the soil quality of acid soils by liming to adjust pH to the levels needed by the crop to be grown. Benefits of liming include increased nutrient availability, improved soil structure, and increased rates of infiltration.

This technical note addresses the following topics: (1) soil pH, (2) liming benefits, (3) liming materials, and (4) practical applications.

Soil pH

Understanding soil pH is essential for the proper management and optimum soil and crop productivity. In aqueous (liquid) solutions, an acid is a substance that donates hydrogen ions (H^+) to some other substance (Tisdale et al., 1993).

Soil pH is a measure of the number of hydrogen ions in the soil solution. However, the actual concentration of hydrogen ions in the soil solution is actually quite small. For example, a soil with a pH of 4.0 has a hydrogen ion concentration in the soil water of just 0.0001 moles per liter. (One mole is equal to the number of hydrogen atoms in 1 gram of hydrogen). Since it is difficult to work with numbers like this, pH is expressed as the negative logarithm of the hydrogen ion concentration, which results in the familiar scale of pH ranging from 0-14. Therefore, pH = 4.0 = -log (0.0001).

Because the pH scale employs the use of logarithms, each whole number change (for example from 5.0 to 4.0) represents a 10-fold increase in the concentration of H^+ ions. Note that as the amount of hydrogen ions increases, pH decreases. A pH of 7 will have a hydrogen ion concentration 100 times less than a soil with pH of 5. Table 1 shows descriptive terms for various pH ranges.

Table 1. Descriptive ranges for pH in soils (Soil Survey Division Staff, 1993)

Ultra acid	< 3.5	Neutral	6.6-7.3
Extremely Acid	3.5-4.4	Slightly alkaline	7.4-7.8
Very strongly acid	4.5-5.0	Moderately alkaline	7.9-8.4
Strongly acid	5.1-5.5	Strongly alkaline	8.5-9.0
Moderately acid	5.6-6.0	Very strongly alkaline	> 9.0
Slightly acid	6.1-6.5		

Soil pH is also:

- an indicator for potential plant growth and
- an indicator of required lime, but does not tell how much lime is needed.

Generally, as you travel from northwest to southeast in the United States, soil acidity increases. As rainfall increases, bases (positively charged ions) like calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+) are leached out of the soil and are replaced by hydrogen (H^+). Short-term pH changes are due to natural processes and management such as:

- rainfall;
- plants removing bases (like Ca^{2+});
- acid forming fertilizers such as ammonia nitrate (NH_4NO_3);
- organic acids from plants during decomposition;
- CO_2 from root respiration and microbial respiration.

Active acidity (or soil-water pH) is due to the presence of H^+ ions in the soil solution. *Active acidity* will indicate a need for lime. *Potential acidity* (or buffer pH) is the amount of Al^{3+} and H^+ ions that are adsorbed on soil particles (negatively charged cation exchange sites) and can be desorbed from these exchange sites to the soil solution (buffering the soil) when liming materials are added. It is the *potential acidity* that determines the amounts of agricultural limestone to neutralize soil acidity. As *potential acidity* increases, a larger amount of lime is required to raise pH by a given amount. As cation exchange capacity increases (higher clay and organic matter), the amount of liming material needed to change soil pH also increases. Soils with a low cation exchange capacity may only require 1 ton of agricultural limestone to change a pH from 4.5 to 6.5; whereas, a soil with a higher CEC may require 2 tons of agricultural lime to make the same change.

Liming Benefits

Liming will provide the following benefits:

- reduces the possibility of Mn^{2+} and Al^{3+} toxicity;
- improves microbial activity;
- improves physical condition (better structure);
- improves symbiotic nitrogen fixation by legumes;
- improves palatability of forages;
- provides an inexpensive source for Ca^{2+} and Mg^{2+} when these nutrients are deficient at lower pH;
- improves nutrient availability (availability of P and Mo increases as pH increases at 6.0 – 7.0, however, other micronutrients availability increases as pH decreases).

Crops vary widely in their tolerance to acid soils. Table 2 shows the optimum soil pH levels for various crops.

Table 2. *Crops require different pH levels (adapted from Tisdale et al., 1993).

Soil pH	Crop	Soil pH	Crop
>6.5	Alfalfa Sweet clover Sugar beets	5.0-5.5	Blueberries Cranberries Potatoes Tobacco**
5.5-6.5	Red clover Corn Wheat Cotton Soybeans Peanuts Forages	<5.0	Azalea Hydrangea Rhododendron

* Organic soils are more productive at lower pH values than mineral soils.
** Tobacco is commonly grown on pH levels at 6.0.

Liming Materials

Liming materials are usually Ca and or Mg carbonates, oxides, and hydroxides. Liming materials are effective when they:

- remove H^+ and Al^+ off of exchange sites *(potential acidity)*;
- neutralize H^+ in solution *(active acidity)*;
- are economical.

In order for liming material to be economical, it generally has to be a salt. A strong base and strong acid such as NaCl (sodium chloride) or $CaSO_4$ (gypsum) are not effective in raising pH levels because a hydroxyl (OH^-) is not released to neutralize H^+ by forming water (H_2O). A salt of a strong base and a weak acid is required to raise pH as shown by the equation below.

$$CaCO_3 + H_2O \leftrightarrow Ca^{2+} + HCO_3^- + OH^-$$

The Ca^{2+} displaces H^+ and Al^{3+} on exchange sites where OH^- neutralizes the H^+ in solution. The effectiveness of liming material is based on two factors:

- Calcium Carbonate Equivalent (CCE) and
- fineness of material

These two factors when combined are called the Effective Calcium Carbonate (ECC).

Determining CCE

The CCE is a way to relate all liming materials to $CaCO_3$ as a standard. The molecular weight of $CaCO_3$ is 100 (Ca = 40, C =12, and O =16 x 3). The CCE of $CaCO_3$ has been theoretically established at 100. When using other materials other than $CaCO_3$, the molecular weight of $CaCO_3$ is divided by the other material's molecular weight.

For example, the calculation for the use of wood ash as a liming material is as follows:

Wood ashes (K_2CO_3) molecular weight = 138
$CaCO_3$ = 100
100/138 = 0.72 (CCE) or 72% effective compared to $CaCO_3$

So if a recommendation from a soil called for 1,000 lbs. of agricultural lime ($CaCO_3$), then you would divide the CCE of 0.72 (K_2CO_3) into the rate needed to determine the amount of K_2CO_3 needed.

1,000 lbs. $CaCO_3$ / 0.72 = 1,389 lbs. of K_2CO_3

In this case 1,389 lbs. of K_2CO_3 are needed to achieve the same effect as 1,000 lbs. of calcium carbonate. Table 3 shows the neutralizing value of other materials as compared to $CaCO_3$.

Table 3. Neutralizing Value (CCE) of Liming Materials (edited from Tisdale et al., 1993)

Material	Molecular Weight	Neutralizing Value %
Calcite	100	100
Burned lime or Calcium oxide (CaO)	56	179
Dolomite (Ca CO_3 + Mg CO_3)	184	109 *
Slag ($CaSiCO_3$)	116	86
Hydrated lime or Slaked lime [$Ca(OH)_2$]	74	135
Marl	**	70-90

* 184/2 then 100/92
** Depends on clay content.

The accurate calculation of CCE also must take into account the purity of the material being applied. If a material is 10% water or inert material, take the purity and multiply by the CCE to determine the final CCE of the material [e.g. 1.0 X 0.90 (purity) = 90 %]. Many state laws require liming materials to have a purity of 90 % or greater.

Determining ECC

The effectiveness of agricultural limestone depends on the degree of fineness because reaction rate depends on the size of the material (surface area) in contact with the soil. Agricultural limestone contains both coarse and fine materials. Many states require 75 to 100 % of the limestone to pass an 8 to 10-mesh screen and that 25% pass a 60-mesh screen. In many southern states, state lime laws require that no more than 10 % remain on a 10-mesh screen (the material is too coarse to react or 0% reactive), no more than 40% can remain on a 60-mesh screen (this size material that passes through the 10-mesh is 50 % reactive), and at least 50% must pass through a 60-mesh screen (this size material is 100% reactive) (J.T. Touchton, 1997 personal communication).

An example of how a fineness factor is calculated.

- 10% remained on the 10-mesh screen (0% reactive) = 0
- 40% of material passed the 10-mesh screen and remained on the 60-mesh screen [50 % is reactive (0.40 x 0.50 = 0.20)]
- 50% passed through the 60-mesh screen [100 % reactive (0.50 x 1.0 = 0.50)]
- add the 0.20 to 0.50
- fineness factor = 0.70

To calculate the effective calcium carbonate factor (ECC), multiply the fineness factor by the CCE: 0.70 (fineness) x 0.90 (CCE) = 0.63 (ECC).

In states where state laws require 0.70 fineness and CCE of 0.90, the ECC is 0.63. So, in those states, agricultural lime refers to 63% effective. It is important that you know your individual state lime law when dealing with liming materials and amounts to be applied.

An example of this is shown below:

- One ton of lime is recommended from state soil testing laboratory (assuming 63% effective);
- the effectiveness of your liming material is 100%;
- 2,000 lbs. x 0.63 = 1,260 lbs.;
- the producer would apply 1,260 lbs. of liming material per acre.

Practical Applications

(1) You are a District Conservationist providing technical assistance on an abandoned coal mine reclamation site. The contractor states that he can spread liquid lime (suspension) more evenly than agricultural limestone. The limestone requirement (soil test recommendation) is 4,000 lbs. (63% effective) per acre. How much suspension lime will be needed? The suspension lime consists of the following proportions:

48% finely ground lime (passes through 200-mesh, 100% effective);
2 % clay that will keep it in suspension;
50% water.

Calculations:

- 4,000 lbs. x 0.63 (effectiveness) = 2520 lbs. of 100 % effective lime needed;
- 2520 lbs/0.48 (% solids) = 5,250 lbs. of suspension lime.

  (Equivalent to 4,000 lbs. of agricultural limestone).

(2) You are a Soil Conservationist providing conservation planning assistance with a farmer. The farmer has been doing a good job with no-till for three years and would like to continue. A soil test report recommends an application of 1 ton of agricultural limestone per acre. The farmer states that tillage is needed to mix the lime. What is your response?

Answer: Both research and farmer experiences show that surface applications are sufficient. More infiltration because of animal and root channels allows a deeper movement of limestone than plowing. The surface layer (2-3 inches) of soil should be sampled separately, as this zone will become more acidic with surface applied nitrogen applications. More frequent and lighter applications of lime will maintain recommended pH levels in long-term no-till systems. By avoiding tillage, soil quality improvements achieved through past increases in organic matter are not disrupted.

For localized information follow your state's extension recommendations and local soil test recommendations.

References

Soil Survey Division Staff. 1993. Soil Survey Manual. USDA Handbook 18, U.S. Government Printing Office, Washington, DC.

Tisdale, S.L., W.L. Nelson, J.D. Beaton, and J.L. Havlin. 1993. Soil acidity and basicity. p.364-404. *In* Soil fertility and fertilizers. 5th ed. Macmillan Publ., New York.