NebGuide

University of Nebraska–Lincoln Extension, Institute of Agriculture and Natural Resources

Know how. Know now.

G1503
(Revised March 2009)

Management Strategies to Reduce the Rate of Soil Acidification

Charles S. Wortmann, Nutrient Management Specialist
Martha Mamo, Soil Scientist
Charles A. Shapiro, Soil Scientist—Crop Nutrition

Soil acidification is a gradual process that results from long-term intensive crop production. The rate of this process depends on soil type and management practices. Management practices that reduce the rate of soil acidification are discussed.

Soil acidity problems are increasing in areas of Nebraska because of continuous cropping and use of acidifying fertilizers. Soil acidity problems develop slowly, with acidification occurring much faster on sandy soils than on fine textured soils. Soil acidity may be reduced with lime application (see *Lime Use for Soil Acidity Management, G1504)*, but distance from the lime source can make this a costly option. Adopting practices to reduce the rate of soil acidification may be economical for many producers.

Plant growth and soil microbial activity are affected by soil acidity, resulting in reduced crop yields. Indirect effects on nutrient availability and on the presence of toxic ions such as exchangeable aluminum and manganese are generally more important to crop performance than the direct effect of acidity on the plants. Some nutrients become less available as soils become acid, while other nutrients become more available.

Soil Acidity

Causes of Soil Acidity

Initially, factors such as soil parent material, rainfall, and type of vegetation were the major determinants of soil acidity in Nebraska. Under cultivation, however, repeated use of ammonium-based acid-forming fertilizers, leaching of nitrate-N, and plant removal of cations eventually cause topsoil (e.g. 0- to 8-inch depth) to acidify. Thus, soils under long-term crop production become increasingly acid unless amended with acid-neutralizing agents such as lime. Soil acidity levels can be adequately monitored if representative soil samples are analyzed every four years.

Types of Soil Acidity

Soil acidity is estimated by pH measurement. Soil pH is an index of active acidity. Active acidity is the concentration of hydrogen ions in the soil solution *(Figure 1)* and is measured in a soil and water mixture. Soil pH is a general indicator of nutrient availability, the presence of free lime (calcium carbonate), and excessive availability of some ions including sodium, hydrogen, aluminum, and manganese.

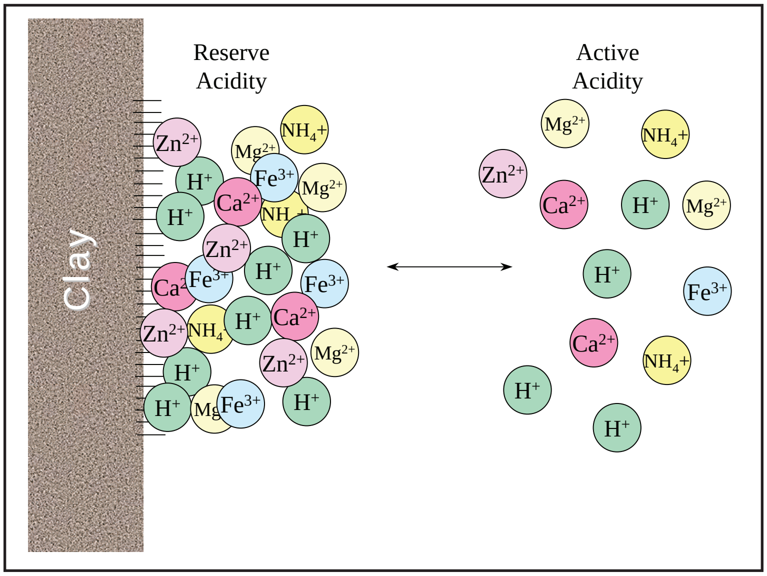

Figure 1. Active and reserve acidity: two sources of acidity in equilibrium. (Source: *Nutrient Management for Agronomic Crops in Nebraska*, EC155)

Reserve acidity is the concentration of hydrogen ions attached to clay and organic matter and is measured as buffer pH in a buffer solution.

Active and reserve acidity are related, but the relationship is not constant across soils. It is influenced by type and amount of clay and the amount of organic matter and free lime in the soil. The ratio of reserve to active acidity relates to the buffer capacity of the soil, or the capacity of the soil to resist change in pH. As the clay and organic matter content of soil increase, the cation

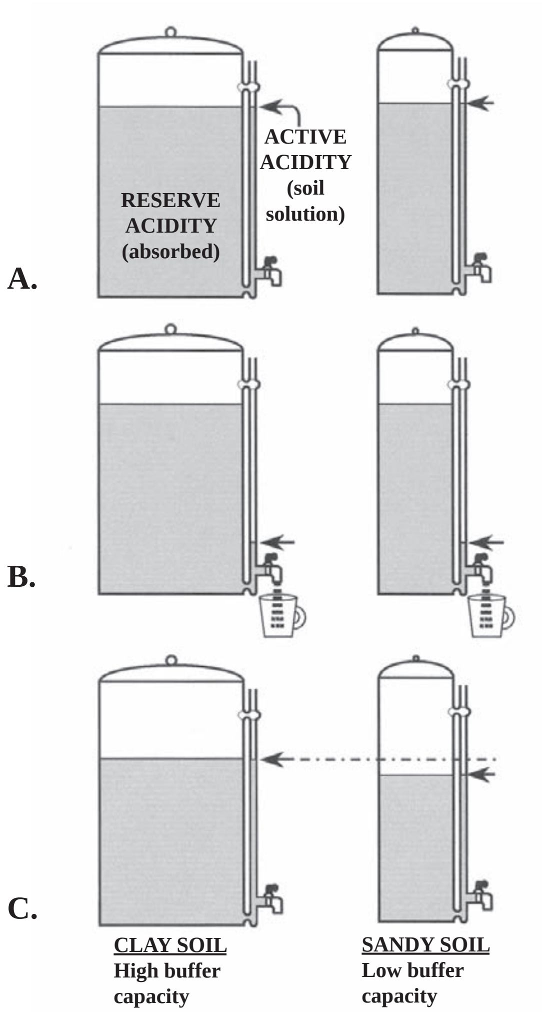

Figure 2. An analogy of coffee removal from urns to lime effects on active and reserve acidity.

exchange capacity and the ratio of reserve to active acidity increase. Thus, the buffer capacity, or reserve acidity, of a sandy soil is much less than that of a soil containing more clay, such as a silt loam. When the soil pH is 6.3 or lower, the buffer pH is measured to determine the amount of lime required to neutralize a major portion of the reserve acidity.

To better understand the concepts of active acidity, reserve acidity, and buffering capacity, consider an analogy of two full coffee urns *(Figure 2A)*, one with a 50-cup capacity and the other with a 10-cup capacity. Both have the same size indicator tube and spigot. Coffee in the indicator tube represents the active acidity (measured by soil pH) and that in the urn represents the reserve acidity (measured by buffer pH). Let the large urn represent a clay soil high in organic matter while the small urn represents a sandy soil. Both urns have equal amounts of coffee in the indicator tube (i.e., the same active acidity or pH). Consider the effect of opening the spigot and removing one cup of coffee from each urn *(Figure 2B)*; the level in the indicator tube drops below the level in the urn but will return to near the original level after the spigot is closed. The momentary drop in coffee in the indicator tube represents the initial reduction in active acidity when a small amount of lime is added, but reserve acidity partially offsets the lime effect and the pH returns to near its original level (as coffee in the indicator tube; *Figure 2C*).

The relative amounts of coffee in the two urns *(Figure 2C)* show why a sandy soil and a clay soil with the same pH have different lime requirements. The removal of one cup of coffee from each urn (equivalent to applying a small amount of lime) reduced the total coffee (reserve acidity) by 10 percent in the small urn (sandy soil), but only 2 percent in the large urn (clay soil). In a similar manner, one ton of agricultural limestone will make a greater change in the pH of a sandy soil than of a clay soil.

Management Strategies to Reduce the Rate of Soil Acidification

Acid Forming Fertilizers

Commonly used nitrogen, phosphorus and sulfur fertilizers are acid-forming *(Table I)*. The acidifying effect varies with the forms of these elements in the specific fertilizer used. For example, ammonium-nitrogen, but not nitrate-nitrogen, in fertilizers is acidifying.

Table I. Lime required to neutralize the soil acidity produced by fertilizers if all ammonium-N is converted to nitrate-N.

Nitrogen source	*Composition*	*Lime required (lb $CaCO_3$ / lb N)*
Anhydrous ammonia	82-0-0	1.8
Urea	46-0-0	1.8
Ammonium nitrate	34-0-0	1.8
Ammonium sulfate	21-0-0-24	5.4
Monoammonium phosphate	10-52-0	5.4
Diammonium phosphate	18-46-0	3.6
Triple super phosphate	0-46-0	0.0

Adapted from Havlin et al., 1999.

Nitrogen and Phosphorus Fertilizers

Nitrogen fertilizers used in Nebraska are primarily ammonium based. Following application, ammonium-nitrogen is transformed to nitrate-nitrogen in a process called nitrification. Nitrification is a major cause of soil acidification as two hydrogen ions are released to the soil solution for each nitrate ion produced. This is shown as:

$$NH_4^+ + 2O_2 \rightarrow 2H^+ + NO_3^- + H_2O$$

When anhydrous ammonia is applied, however, it reacts with water to form ammonium and a hydroxide ion (OH^-) with the effect of neutralizing some acidity:

$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$ (OH^- reacts with H^+ to produce water while neutralizing acidity).

This reaction, followed by nitrification, results in a net increase in one hydrogen ion for each nitrate ion produced from anhydrous ammonia.

Acidity produced by applying nitrogen fertilizer is similar for anhydrous ammonia, ammonium nitrate, and urea, but is higher with ammonium sulfate, diammonium phosphate (DAP), and monoammonium phosphate (MAP).

More acidity is produced per unit of nitrogen applied with the phosphate fertilizer *(Table I)*. This may not be of concern as the rates of application are typically much less than for the major nitrogen fertilizers. Nonetheless, producers may want to consider other phosphate sources such as triple superphosphate to minimize soil acidification.

Sulfur Fertilizers

Sulfur is a soil-acidifying element. Approximately 3 lb of calcium carbonate are needed to neutralize the effect of 1 lb of sulfur applied as elemental sulfur or ammonium polysulfide. Applying 20 lb/A of sulfur annually for 10 years, without an increase in plant sulfate uptake, will increase the calcium carbonate needed to maintain soil pH by 600 lb/A. Acidification is negligible with sulfate salt (calcium sulfate) fertilizers, intermediate for ammonium thiosulfate, and high for ammonium polysulfide and elemental sulfur. Plant uptake of sulfate ions has the effect of neutralizing acidity, as explained below *(Figure 3)*. Acidification is expected to be greatest, therefore, when sulfur application does not result in increased plant uptake of sulfate. With the exception of sandy soils, and possibly some low organic matter soils under no-till, major crops in Nebraska are not responsive to applied sulfur. Matching sulfur application with crop needs may be an opportunity to reduce costs while reducing soil acidification.

Organic Fertilizers

Applying animal manure may either increase or decrease soil acidity. Some soil acidity is generated by decomposition of organic matter in manure, resulting in the production of organic and inorganic acids. However, manure often contains enough basic cations and carbonate ions to neutralize this acidification effect as well as some existing soil acidity. Manure samples can be analyzed to determine the liming value.

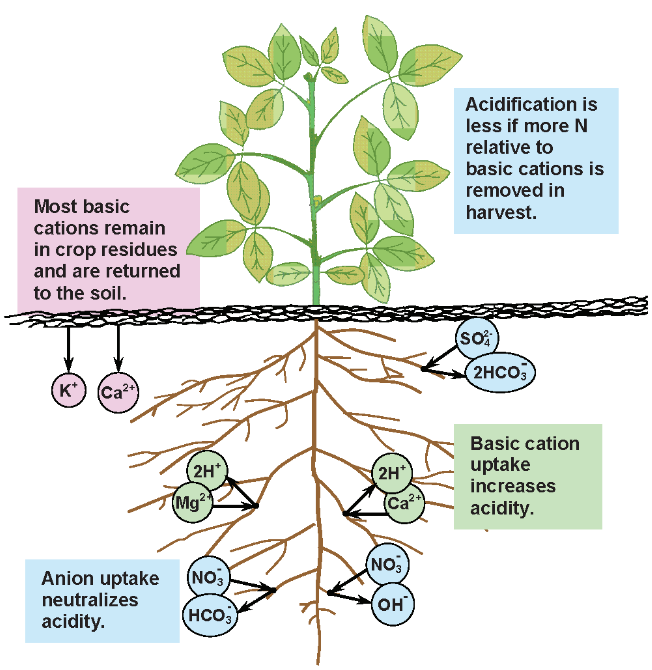

Figure 3. Effects of plant nutrient uptake and release from crop residues on soil acidity.

Crop Growth and Uptake of Nitrogen and Basic Cations

Crop growth results in removal of basic cations, such as calcium, magnesium, and potassium from the soil and exudation of hydrogen ions from the roots. This results in acidification if the basic cations are not returned to the soil *(Figure 3)*. Uptake of anions, mainly nitrate and sulfate, by plants, however, releases OH^- or HCO_3^- to the soil and partially neutralizes the acidity produced by nitrification and plant cation uptake. When plants take up more anions than cations, soil acidification is reduced.

Table II. The ratio of basic cations to nitrogen in the plant product removed from the field (equivalent basis) and lime required to replace the bases removed.

Crop	*Bases:N in the plant*	*Lime required to replace bases removed (lb $CaCO_3$ /100 lb of N taken up by crop)*
Corn grain	0.14	25
Corn stover	0.73	131
Soybean	0.14	25
Oats grain	0.14	25
Oats straw	0.94	169
Alfalfa	1.41	254

The basic cation (base) to nitrogen ratio in the harvested product is useful in predicting the rate of acidification associated with a crop. If the base to nitrogen ratio is less than one, less acidification is expected than with crop harvest having a high ratio. Grain has a low base to nitrogen ratio while stover and straw have relatively high ratios *(Table II)*. If the whole plant is harvested, the trend to soil acidity is greater than if only grain is harvested. Due to a high base to nitrogen ratio, harvest of alfalfa contributes to soil acidification.

Legumes and Nitrogen Fixation

Legumes can derive much of their nitrogen from the atmosphere through biological nitrogen fixation, thereby reducing fertilizer needs. This is, however, a soil-acidifying process as hydrogen ions are products of nitrogen fixation. The acidity resulting from the harvest of one ton of alfalfa hay could require more than 200 lb of ag lime for neutralization. However, the acidification effect

Process of Acidification in Corn

A simplified example of soil acidification under continuous corn production, realizing other factors contribute to soil acidity:

1. 200 lb/A N applied as anhydrous ammonia.
2. Nitrification results in acidification equal to 360 lb $CaCO_3$ (200 lb x 1.8; *Table I*).
3. Corn uptake of 100 lb of N neutralizes acidity equivalent to 180 lb $CaCO_3$.
4. Removal of cations results in additional acidity equal to 25 lb $CaCO_3$ *(Table II)*.
5. $CaCO_3$ required to neutralize the total acidification effect is 205 lb/A.
6. This implies that over 1 ton/A of $CaCO_3$ or 1.7 ton/A ag lime (60% ECCE) will be needed to maintain soil pH for every 10 years of production.

is spread throughout the root zone resulting in less effect on surface soil pH than may be implied.

Leaching of Nitrate

Acidity generated by nitrification of ammonium-based fertilizers is largely due to poor recovery of nitrate ions by plants. Nitrate leached from the root zone does not neutralize acidity as occurs when nitrate is taken up by plants. Matching the fertilizer application rate to the crop's nitrogen uptake minimizes leaching losses and the net effect of nitrification on soil acidity.

Irrigation Water

Most irrigation water in Nebraska contains substantial quantities of calcium and magnesium bicarbonates that neutralize soil acidity. The neutralizing effect of irrigation water can be determined from routine laboratory tests.

Summary

Soil acidification is the net effect of several processes. The rate of soil acidification may be reduced through management. Matching applied nitrogen and sulfur with crop needs may reduce input costs while reducing acidification. Other practices involve choosing less acidifying fertilizers or improving application timing. Such practices may increase input and management costs. When considering changes, these costs need to be weighed against the eventual reduction in cost of lime application. Following are recommended management strategies to reduce the rate of soil acidification:

1. Avoid using the more acidifying fertilizers.
2. Achieve a high rate of crop recovery of applied nitrogen and sulfur fertilizers.
3. Minimize leaching of nitrate-N by applying appropriate amounts of nitrogen fertilizer in a timely manner relative to crop need and with good irrigation management.
4. Consider the acid-neutralizing value of irrigation water.
5. Consider the effect of applied manure on soil pH.
6. Use sulfur only if there is a high probability of crop response.
7. Consider that the ratio of basic nutrients to nitrogen in the harvested product affects the rate of soil acidification.

Glossary

Active acidity — the concentration of hydrogen ions in the soil solution; measured as soil pH.

Anion — a negatively charged ion.

Base or basic cation — a substance which produces OH^- ions when dissolved in water.

Buffer — a solution that resists changes in pH when an acid or a base is added.

Buffer capacity — the ability to resist change in pH.

Cation — a positively charged ion.

Nitrification — the conversion of ammonium in the soil to nitrate with the release of H^+ ions.

pH — the negative common logarithm of H^+ concentration; an index of active acidity.

Reserve acidity — the concentration of hydrogen ions attached to clay and organic matter.

References.

Comfort, S. and K. Frank. "pH and Liming." 2000. p 51-58. In R. Ferguson (ed) *Nutrient Management for Agronomic Crops in Nebraska*, EC155. University of Nebraska–Lincoln Extension, Lincoln, NE.

Havlin, J.L., J.D. Beaton, S.L. Tisdale and W.L. Nelson, 1999. *Soil Fertility and Fertilizers*, 6th ed. Prentice Hall. P 47.

Mamo, M, C. Wortmann and C. Shapiro. 2003. *Lime Use for Soil Acidity Management.* G1504. University of Nebraska–Lincoln Extension, Lincoln, NE.

This publication has been peer reviewed.

Index: Soil Resource Management
Fertility

Issued February 2003, Revised March 2009