Lime Guidelines for Field Crops in New York

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Executive Summary

- The pH of a soil is among the most important soil characteristics for crop production. Lime addition is recommended for field crops grown on agricultural soils that are naturally acidic, given soil pH impacts nutrient supply and microbial activity.

- A measure of the pH of the soil is needed to decide if a lime application should be made. This is done by comparing the measured pH to the minimum desired pH for all crops in a rotation.

- To determine how much lime is needed to bring the pH of a field to the desired level, a measure of the soil's ability to buffer a change in pH is needed. Initially, Cornell University guidelines for pH management used exchangeable acidity to quantify a soil's buffer capacity. An evaluation of five different methods for determining a soil's ability to buffer a pH change was conducted in 2008 using samples from 43 New York agricultural soils. Based on the findings of this study, Cornell University land grant university changed to the use of the Modified Mehlich buffer pH to determine lime needs in 2009.

- This manual presents Land Grant University guidelines for pH and lime management of field crops. It contains background information on pH and acidity, describes analytical tests for pH and buffer pH, outlines how a lime recommendation can be derived, briefly describes what can be done to lower the pH, lists and describes different liming materials, states minimum quality standards and guaranteed analyses for lime materials sold in New York, and outlines considerations for timing of lime application. This manual replaces Ketterings et al. (2006).

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Acronyms

- CCE: Calcium Carbonate Equivalent
- ENV: Effective Neutralizing Value
- TNV: Total Neutralizing Value
- NRCS: Natural Resources Conservation Service
- NYSAGM: New York State Department of Agriculture and Markets
- NYSDEC: New York State Department of Environmental Conservation

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1. Introduction

Achieving optimum pH for crop growth and production is essential because soil pH affects many soil properties and processes including nutrient cycling, soil microbial activity and soil structure. The native pH of a soil is determined by the type(s) of rock, or parent material, the soil was developed from. The characteristics of the parent material influence soil mineralogy and the quantity of exchangeable cations that determine soil pH. Most agricultural soils in New York are acidic and have a pH ranging from 4.5-7.0. Some New York soils are calcareous, meaning they contain free calcium carbonate, or lime deposits in the surface layer. Calcareous soils tend to have a pH in the range of 7.0-8.5 and the pH tends to be quite stable, so pH management is usually not an issue. However, naturally acidic agricultural soils need to be monitored for pH and lime will need to be applied for optimum field crop production.

2. Background Information

2.1 pH Basics

The pH of a soil is a measure of hydrogen ion activity ($[H^+]$) in the soil solution. As the H^+ activity increases, soil pH decreases. As the soil pH decreases, most desirable crop nutrients become less available while others, often undesirable, become more available and can reach levels toxic to plants. See Agronomy Fact Sheet 5: Soil pH for Field Crops for more details.

Hydrogen activity is mathematically expressed as a negative logarithm: $pH = -\log[H^+]$. Because of the logarithmic scale, one unit decrease in pH implies a 10 time increase in acidity. For example, a soil with a pH of 5.0 is 10 times more acidic than a soil with a pH of 6.0 and 100 times more acidic than a soil with a pH 7.0 (Figure 1).

New York agricultural soils: 4.5 ------------- 7 --------- 8.5

Total pH scale: 0 ----------------------------- 7 ------------------------------- 14

Acid Neutral Basic or Alkaline

Figure 1: Total pH scale and common pH range of New York soils.

The pH of a soil can be changed by human activity as well as by natural events. In humid climates such as those found in New York, the leaching of calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+) ions leads to an increase of active hydrogen and aluminum (Al^{3+}) in the soil and results in a decrease in pH. In arid climates, where there is little or no water movement through the soil, the cations Ca^{2+}, Mg^{2+}, and K^+ (and in some regions also sodium, Na^+) dominate, and soils tend to be neutral or alkaline. Typically, the addition of inorganic fertilizers and organic nutrient sources (compost and manure) leads to a decrease in pH due to the formation of two strong inorganic acids, nitric (HNO_3) and sulfuric acid (H_2SO_4).

Pure water has a pH of 7.0. Normal rain is acidic (pH between 5.0 and 6.0) because carbon dioxide (CO_2) in the atmosphere combines with water molecules to form carbonic acid. Rain is called acid rain if the pH is less than 5.0. Acid rain (or snow) is primarily a result of sulfur oxides (SO_x) and nitrogen oxides (NO_x) in the atmosphere reacting with oxygen in the air to form nitric acid and sulfuric acid. The average pH of precipitation in New York tends to range from pH 5.2 to 5.7 (National Atmospheric Deposition Program, 2021).

2.2 Soil Buffer Capacity

The ability of a soil to resist a change in pH is known as the soil's buffer capacity. A higher buffer capacity means that a soil is more resistant to change in pH and will require more lime to achieve the same change in pH as a less buffered soil. Thus, while soil pH can tell us if liming is needed, a measurement of the soil's buffer capacity is needed to determine how much lime to add.

The buffer capacity of a soil greatly depends on its organic matter content and soil texture. A soil with high organic matter will need more lime than a soil with low organic matter. Clayey soils and soils with more organic matter will have greater amounts of salt-replaceable and residual acidity (greater buffer capacity) than sandy and low organic matter soils.

The buffer capacity of the soil reflects its total acidity which is the sum of three different forms of acidity: (1) active; (2) salt-replaceable; and (3) residual acidity:

1) *Active acidity* reflects the H^+ ion activity in the water of the soil (called soil solution) and is measured with a pH in water measurement. To neutralize only the active acidity, very little liming material is needed but such a change is also very short-lived due to the existence of salt-replaceable and residual acidity. Because the active acidity (pH) is only a very small fraction of the total soil acidity, a pH measurement can tell you whether lime needs to be added but it does not tell you how much lime is needed to increase the pH to the desired level.
2) Salt-replaceable acidity and residual acidity can be described as the soil's capacity to resist change in the soil solution pH. *Salt-replaceable acidity* is the H^+ and Al^{3+} activity in solution when shaken with a salt solution. This can be described as relatively weakly bound H^+ and Al^{3+}. The soil's buffer capacity increases with the amount of salt replaceable H^+ and Al^{3+} as these ions can quickly move into the soil solution.
3) *Residual activity* is associated with aluminum hydroxyl ions and H^+ and Al^{3+} ions that are strongly bound in non-exchangeable forms by organic matter and clay minerals.

2.3 Soil pH and Crop Production

As soils become acidic, especially below pH 5.5, nutrient availability to plants decreases and toxic amounts of Al and other metals may reduce crop production or even make the production of some crops impossible. Liming to optimum pH increases the availability of essential nutrients, supplies Ca and Mg, improves soil conditions for microorganisms, increases the effectiveness of triazine herbicides, and improves soil structure.

Table 1: Minimum and desired pH for common field crops in New York.

Crops	Cornell crop codes	Desired pH	Minimum pH
Alfalfa, alfalfa/grass, alfalfa/trefoil	ABE,ABT,AGE,AGT,ALE,ALT	7.0	6.7
Soybeans	SOY	7.0	6.7
Birdsfoot trefoil	BCE,BCT,BGE,BGT,BSE,BST,BTE,BTT	6.5	6.4
Barley	BSP, BSS	6.5	6.4
Wheat	WHT	6.5	6.4
Triticale	TRP	6.5	6.4
Sunflower	SUN	6.5	6.4
Buckwheat	BUK	6.2	6.0
Clover	CGE,CGT,CLE,CLT,CSE,CST	6.2	6.0
Corn	COS,COG	6.2	6.0
Crownvetch	CVE,CVT	6.2	6.0
Grass	GIE,GIT,GRE,GRT	6.2	6.0
Pasture	PGE,PGT,PIE, PIT,PLE,PLT, PNE,PNT	6.2	6.0
Rye	RYC, RYS	6.2	6.0
Millet	MIL	6.2	6.0
Oats	OAS,OAT	6.2	6.0
Sorghum, sorghum sudangrass	SOF,FOG, SSH,SUD	6.2	6.0
Wheat with legume	WHS	6.2	6.0

The optimum pH for most crops falls between 5.5 and 7.0. If the soil's pH is adjusted to optimal for phosphorus (P) availability, the availability of other nutrients, if present in sufficient amounts, will be satisfactory as well. However, there are exceptions to this general rule caused by soil texture or crop selection. For example, liming some sandy soils to pH 6.0 or higher may cause micronutrient deficiencies. Although this is not the case for field crops, certain trees and shrubs require large amounts of certain micronutrients and therefore require a lower optimum pH. Examples include rhododendrons and azaleas which require iron (Fe) and manganese (Mn) that is only available in sufficient amounts when soil pH is low (iron availability decreases with increasing pH from 4.0 to 6.0). In other crops, such as potatoes, lower pH is used to control disease. Soil pH ranges recommended for common field crops grown in New York are given in Table 1 and more specific ranges are located in the Appendix. It is important to test soil to determine if the pH is within the desired range. If desirable pH is not maintained, yield increases expected from improved crop varieties and fertilizer additions will not be realized.

2.4 Effect of Fertilizer Application on Soil pH

The reaction of ammonium forming fertilizers (e.g., ammonium nitrate, urea, urea ammonium nitrate, anhydrous ammonia, ammonium sulfate) with oxygen (a process called oxidation) results in the formation of nitrate (NO_3^-) and H^+ ions (Figure 2). To counter the acid forming reaction of such fertilizers in soils without free calcium carbonate (calcareous soils), lime will be needed. If pure calcium carbonate is used as the liming material, 3.6 lbs of calcium carbonate will be needed to neutralize the acidity produced per lb of N derived from ammonium from anhydrous ammonia, ammonium nitrate, and urea. Ammonium sulfate creates twice as much acidity as other N materials, because of extra H^+ released per pound of N. Thus, ammonium sulfate will need twice as much calcium carbonate to neutralize the acidity it creates (Figure 2). Manure contains urea and organic N. The urea is rapidly mineralized to ammonium and converted to nitrate while the organic N will go through mineralization to ammonium more slowly. Both conversions will acidify the soil. However, the overall acidifying effect of a manure source depends on the type of manure. For example, litter from laying hens typically has a high calcium carbonate content causing it to have a liming effect.

$$2\,NH_3 + 4\,O_2 \rightarrow 2\,NO_3^- + 2\,H^+ + 2\,H_2O$$
(ammonia) (oxygen) (nitrate) ("acid") (water)

$$NH_4NO_3 + 2\,O_2 \rightarrow 2\,NO_3^- + 2\,H^+ + H_2O$$
(ammonium nitrate) (oxygen) (nitrate) ("acid") (water)

$$(NH_2)_2CO + 2\,O_2 \rightarrow 2\,NO_3^- + 2\,H^+ + H_2O$$
(urea) (oxygen) (nitrate) ("acid") (water)

$$(NH_4)_2SO_4 + 4\,O_2 \rightarrow 2\,NO_3^- + SO_4^{2-} + 4\,H^+ + 2\,H_2O$$
(ammonium sulfate) (oxygen) (nitrate) (sulfate) ("acid") (water)

Figure 2: Ammonium fertilizers are acid forming (i.e., they ultimately decrease the soil pH even though urea may initially increase the pH).

3. Sampling a Field for pH

It is recommended to test each field for pH (and fertility) at least once every 3 years or twice per rotation. If past field management is unknown, more frequent sampling is highly recommended as it will help to establish a reliable assessment of lime and fertilizer needs. For each testing event, take a minimum of 10-15 subsamples from across a field (identified as an area differing from its neighboring areas in crop growth, soil type, drainage, fertility levels, and/or past management).

Typically, a sampled unit should not be more than 10-15 acres unless past experience indicates wider uniformity. If considerable within-field variability in pH is expected, grid sampling is recommended as variable rate application of lime can be economically and environmentally advantageous. Grid sampling can be done using regular grids (each grid about the same size) or irregular grids or zones, considering other field features (slope, elevation, soil type, drainage, etc.). For more information on soil sampling, see Agronomy Fact Sheet 1: Soil Sampling for Field Crops. If individual grid cell data are converted to averages across multiple grids for zone-based management, pH values of multiple grids can be converted to an average for a zone, taking into account the size of each grid cell within the zone, and converting to H+ concentration prior to averaging values. This is explained in detail in Agronomy Fact Sheet 106: Determining an Average Soil Test P or pH Value from Grid Samples for Nutrient Management Planning.

Soil samples can be taken at any time during the year when the soil is not frozen or saturated. Soil temperature and moisture change during a growing season and these changes can impact soil properties such as the pH. Research has shown that soil pH values tend to be lower in drier summer months and higher in wet spring and winter months (Figure 3).

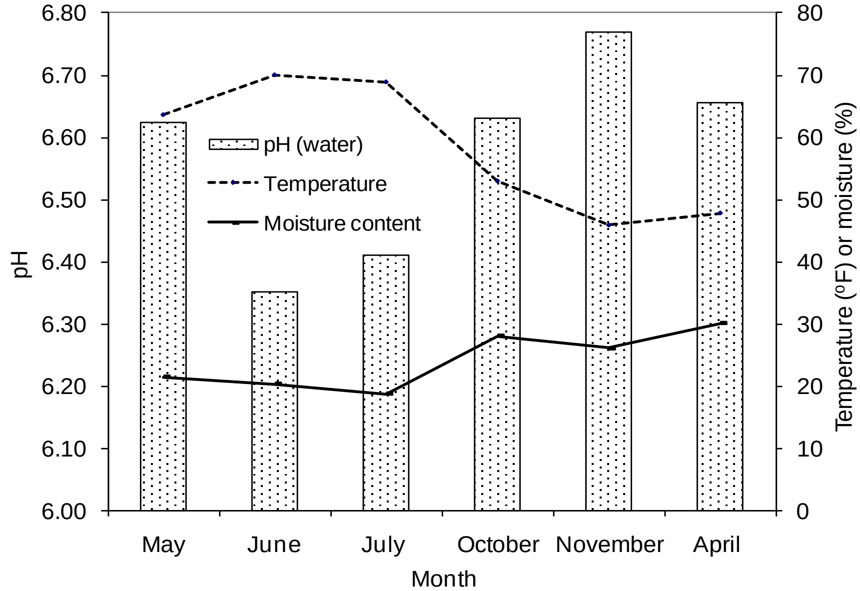

Figure 3: Soil pH tends to be lower in the warmer and drier summer months than in the rest of the year. This figure summarizes the pH trends of twenty New York corn fields and shows an average fluctuation of 0.4 pH unit.

This fluctuation in pH can occur for several reasons. First, as the soil dries in the summer months, the salt concentration increases. Soluble cations such as Ca, Mg and K replace exchangeable H^+ or Al^{3+} ions on the surfaces of the soil particles. The H^+ or Al^{3+} ions enter the soil solution which then becomes more acid. In wet months, salt concentrations tend to be lower. In early spring, New York soils (humid climate) are nearly free of salts due to leaching and the lack of nitrification occurring during the winter season. However, shortly before or after planting, salt levels tend to be higher due to nitrification and fertilizer and/or manure addition. During the growing season, salt levels will decline due to plant uptake. In the months following harvest where there is no crop growing but there is still active mineralization and nitrification occurring, salt levels can be quite high. Thus, in New York, we tend to find the lowest pH values from the end of May to early June and in fall following corn harvest. The highest levels will generally occur after snowmelt. In addition to the fluctuations in salt concentrations in drier conditions, oxidation processes (such as conversion of ammonium to nitrate, decomposition of organic matter) can generate acidity as well. In addition, microbial respiration in the warmer months produces more CO_2 which forms carbonic acid, a weak acid that also contributes to a decrease in soil pH. On the other hand, CO_2 is more soluble at lower temperatures so the net effect of CO_2 on soil pH can be variable. Due to this seasonal variability in soil pH, it is recommended to standardize sampling for soil pH over time for specific fields to a particular season (for example, consistent fall sampling after harvest of the main crop, or consistent sampling in the spring before planting, rather than sampling in the fall one time and in the spring the next time). For information about seasonal variability in soil pH, see Agronomy Fact Sheet 54: Timing of Lime Application for Field Crops.

For conventional tillage systems, a sample core from 0-8 inches is recommended. Under minimum or no-tillage systems, the surface inch of the soil may become acidic more rapidly than the original 0-8 inch plow layer. Thus, in no-tillage systems, the pH values of two soil layers (0-1 and 0-6 inches) should be determined. If soil pH of the surface 0-1 inch depth is low, but the pH of the 0-6 inch layer is adequate, lime addition is recommended to raise the pH of the soil surface. If both layers are strongly acidic, avoid no-tillage methods for the establishment of legumes until lime has been given 6 to 9 months to react with the soil. If the surface (0-1 inch depth) pH is adequate, but the 0-6 inch soil zone has a low pH, legumes could be no-till seeded into the soil without waiting as long for the lime to react as when both zones have a low soil pH. For information about sampling and lime application under conventional versus no-till agriculture, see Agronomy Fact Sheet 54: Timing of Lime Application for Field Crops.

4. Determining pH and Buffer pH

Soil testing laboratories measure soil pH in a suspension of soil in water (1:1 or 1:2 soil to water ratio). Cornell University guidelines specify pH in a 1:1 (volume) suspension of soil and water. Such a pH measurement is accurate to +/- 0.01 pH unit.

Until 2009, Cornell University recommended the use of an exchangeable acidity method to determine the buffer capacity of a soil. In 2009, new guidance was introduced based on the modified Mehlich buffer. This buffer method was selected after a statewide project with 43 New York agricultural soils showed this method (which contains $CaCl_2$ instead of $BaCl_2$) to be the most accurate, non-toxic, alternative to the exchangeable acidity method (Dietzel et al., 2009).

5. Calculating Lime Requirements

Lime recommendations for a crop or a rotation can be calculated once the initial soil pH, target rotation (crop) pH and the soil's buffer pH are known. The process involves five simple steps. Each step is listed below and described as well in Agronomy Fact Sheet 48: Buffer pH to Derive Lime Guidelines. Note that lime recommendations derived here are given in rates of 100% Effective Neutralizing Value (ENV; see section 6), and rates would need to be adjusted based on liming material available to the farmer.

1. *Step 1: Determine the desired and minimum rotation pH:*
   A rotation is defined as a 6-year crop sequence (3 years past, 3 years ahead). The desired pH for common field crops grown in New York is shown in Table 1. The crop with the highest desired pH will determine the desired/target pH for the entire rotation. For example, for a 3-year corn and 3-year alfalfa/grass rotation, the crop with the highest desired pH is alfalfa/grass and, as a result, the desired pH for the rotation is 7.0.
2. *Step 2: Determine if lime is needed:*
   No lime is recommended if the soil pH is above the desired pH. No lime is recommended if the soil pH is below the desired pH but above the minimum pH as applications would not be economical (but test the soil again in 2-3 years). If the soil pH is lower than the minimum rotation pH, go to step 3.

3. *Step 3: Determine the lime rate:*
   If the soil pH is less than the minimum rotation pH, the recommended lime rate can be read from Table 2 using the soil's buffer pH and the desired rotation pH (note: soil pH will tell you if lime is needed; buffer pH tells you how much is needed). For example, if the buffer pH is 5.5 and desired rotation pH is 6.5, 4.5 tons/acre lime is recommended. Lime rates in Table 2 assume liming material with 100% ENV. It should be noted that where the pH of the soil is 6.7 or higher, buffer pH is not reported.

4. *Step 4: Adjust rates for tillage depth.*
   The recommendations listed in Table 2 assume a 6- to 7-inch tillage depth. For an 8-inch tillage depth, multiply the rates listed in Table 2 by 1.33. For a 10+ inch tillage depth, multiply the rate listed in Table 2 by 1.67 (See Table 3 for depth adjustments).

5. *Step 5: Adjust rates for lime source characteristics (% ENV).*
   The recommendations listed in Table 2 are on a 100% ENV basis. To adjust for specific materials, divide the recommended lime rate by the percent ENV of the lime source. For example, if the recommended lime rate is 4.5 tons/acre and the lime source is 75% ENV, 4.5 / 0.75 = 6 tons of this liming material should be applied per acre. This is explained in more detail in Agronomy Factsheet 7: Liming Materials.

Table 2: Lime recommendations for soil with a pH less than the desired minimum pH for the rotation derived from the modified Mehlich buffer pH.

	Desired rotation pH (minimum pH)			
Buffer pH	7.0 (6.7)	6.8 (6.6)	6.5 (6.4)	6.2 (6.0)
	------ tons/acre (100%ENV) -------			
5.0	11.0	10.0	8.5	6.5
5.1	10.0	9.0	7.5	6.0
5.2	9.0	8.0	7.0	5.5
5.3	8.0	7.5	6.0	5.0
5.4	7.5	6.5	5.5	4.0
5.5	6.5	6.0	4.5	3.5
5.6	5.5	5.0	4.0	3.0
5.7	4.5	4.0	3.0	2.5
5.8	4.0	3.5	2.5	1.5
5.9	3.0	2.5	2.0	1.0
6.0	2.0	1.5	1.0	0.5
6.1	1.0	1.0	0.5	0.5
6.2	1.0	0.5	0.5	0.5
6.3	1.0	0.5	0.5	0.5
6.4	1.0	0.5	0.5	0.5
6.5	1.0	0.5	0.5	0.5
6.6	1.0	0.5	0.5	0.5

Table 3: Lime requirement adjustments for depth in tilled systems.

Options	Tillage depth for equation	Lime requirement adjustment
1-7 inches	6	*1.00
7-9 inches	8	*1.33
9+ inches	10	*1.67

As mentioned, in no-tillage or minimum tillage systems, samples of the 0-1 should be taken in addition to a 0-6 inch core. If the pH of the surface 0-1 inches is less than desired, but the pH of the 6-inch core is adequate, a small lime addition (1 to 1 ½ tons of lime per acre) is recommended to raise the pH of the soil surface. If both samples are strongly acidic, do not use no-till methods for the establishment of legumes unless lime has been applied and mixed with the soil for at least 6 to 9 months to permit the lime to react with the soil. If the surface pH is adequate, but the pH of the 6-inch core is lower than desired, legumes might be no-till seeded with a slightly lower overall pH or without waiting so long for the applied lime to react as when both zones have a low soil pH. Downward movement of lime to subsurface layers is very slow and only occurs after the surface layer has reached >80% saturation which means the pH of the surface needs to be around 7.0 for lime to move downward.

Lime requirements for pastures depend on the species in the pasture. Many New York pastures consist of clover-grass mixes which will benefit from lime application if the pH is less than 6.2. For legume establishment and retention, pH management is even more important. Once the legume is established it will contribute a substantial amount of N needed for the pasture through N fixation, thus reducing the need for additional N fertilizer, but only if the pasture is at the desired pH level. For pastures, soil sample to a depth of 0-6 inches. Always apply recommended lime rates when the soils are dry to avoid rutting and reduce the risk of compaction.

For certain soils it may not be economically beneficial to add lime to adjust for a small pH deficit. For New York soils that have a high Lime Index (“high” lime soils; Table 4), lime application can be delayed if the pH deficit (difference from minimum pH listed in Table 1) is less than or equal to 0.4. Once the pH deficit is 0.5 or larger, lime should be applied to bring the pH of the soil to the desired pH for the crop rotation. High Lime Index soils include those that formed in limestone and/or calcareous parent materials, and that have free carbonates and/or limestone or calcareous bedrock within 20 inches (50 cm) of the soil surface, and a pH that ranges to 7.0 or higher within 8 inches (20 cm) of the soil surface.

Table 4: New York agricultural soils with a high Lime Index.

Amenia	Galway	Kingsbury	Phelps
Appleton	Gardenisle	Lima	Runeberg
Aurora	Grenville	Lyons	Ruse
Benson	Groton	Matoon	Vergennes
Bonaparte	Guffin	Neckrock	Waddington
Camillus	Hogansburg	Nellis	Wampsville
Cayuga	Honeoye	Nuhi	Weaver
Cazenovia	Ilion	Ogdensburg	Wilpoint
Chaumont	Kars	Ovid	
Chippeny	Kendaia	Palatine	
Dover	Kings Falls	Palmyra	

6. Decreasing Soil pH

For field crops, decreasing the soil pH is not necessary or economical in most cases. However, there are acid loving plants such as blueberries that do not tolerate moderate to high pH values, and crops that require a lower pH to control soil-borne diseases such as potatoes. If the pH of a soil needs to be decreased, acid-forming organic or inorganic materials such as leaf mold, pine needles, tanbark, sawdust, and acid moss peat can be added. Inorganic chemicals include aluminum sulfate, ferrous sulfate (for plants that require large amounts of iron), and elemental sulfur. Sulfur is usually less expensive and more effective than other inorganic acidifying materials on a per pound basis but may require up to a year for complete reaction. The amount to be added depends on the soil's buffering capacity and its original pH level. For more information on lowering soil pH see Cornell University Pest Management Guidelines for Berry Crops (Section 2.2.1 Basic Soil Test).

7. Liming Materials

New York State law defines agricultural liming material as: "all materials and all calcium and magnesium products in the oxide, hydrate, carbonate or silicate form or combinations thereof and intended for use in the correction of soil acidity, including such forms of material designated as burned lime, hydrated lime, carbonate of lime, agricultural limestone, slag and marl" (§ 142-aa). See *Section 8: New York Lime Law* for a more comprehensive definition. Common materials are listed in Table 5. These materials react with water and CO_2 in the soil to form Ca^{2+} and/or Mg^{2+} and bicarbonate $(HCO_3)^{2-}$. The Ca^{2+} and Mg^{2+} replace H^+ and Al^{3+} on the exchange complex releasing H^+ and Al^{3+} into the soil solution. The bicarbonate reacts with the H^+ and Al^{3+} to form CO_2 and neutral compounds such as water and $Al(OH)_3$. Thus, the liming process contains two steps: (1) replacement of H^+ and Al^{3+} on the exchange complex; and (2) neutralization of the H^+ and Al^{3+} ions in solution by the bicarbonate (Figure 4).

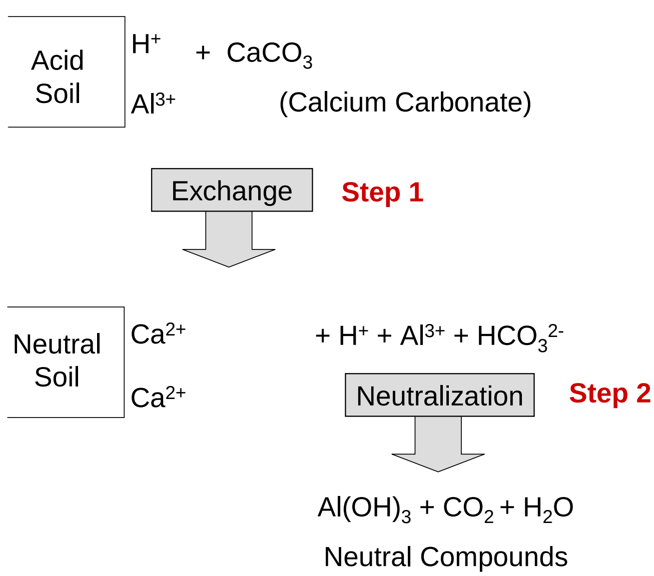

Figure 4: Two-step reaction of agricultural lime (in this case $CaCO_3$) with the soil.

To compare one liming material with another, quality standards must be used. The total neutralizing value (TNV) of a liming material is usually expressed as the Calcium Carbonate Equivalent (CCE) of the material. To calculate the CCE of a lime source, divide 100 by the molecular mass of the liming material and multiply this ratio by 100. For example, the molecular mass of CaO is 40+16=56 so the CCE of pure CaO is (100/56)*100=179% (Table 5). This means that 1 ton of CaO will neutralize as much as 1.79 tons of pure calcium carbonate. In other words, if one ton of pure calcium carbonate is needed, this requirement can be met with 100/179=0.56 tons of CaO.

Table 5: Common liming materials (assume 100% pure materials).

Chemical name	Common name	Chemical formula	Calcium carbonate equivalent
Calcium carbonate	calcitic lime stone,	$CaCO_3$	100
Ca,Mg carbonate	dolomitic lime stone	$CaMg(CO_3)_2$	109
Calcium oxide	lime, burned lime, quick lime	CaO	179
Calcium hydroxide	hydrated lime, slaked lime	$Ca(OH)_2$	136

For a given amount of acidity, a corresponding amount of liming material is needed regardless of the fineness of the material. However, the finer the material, the quicker it will react. Particle size distribution is measured by passing the material through a set of sieves. Sieve sizes are expressed as the number of wires per inch so materials that pass through a 100-mesh sieve are much finer than materials that pass through a 20-mesh sieve. 100% of lime particles passing a 100-mesh screen will react within the 1st year while only 60% of the liming materials passing a 20-mesh sieve (but held on 100 mesh sieve) will react within a year. Material that does not pass the 20-mesh sieve is not expected to react within the first year following application (Figure 5).

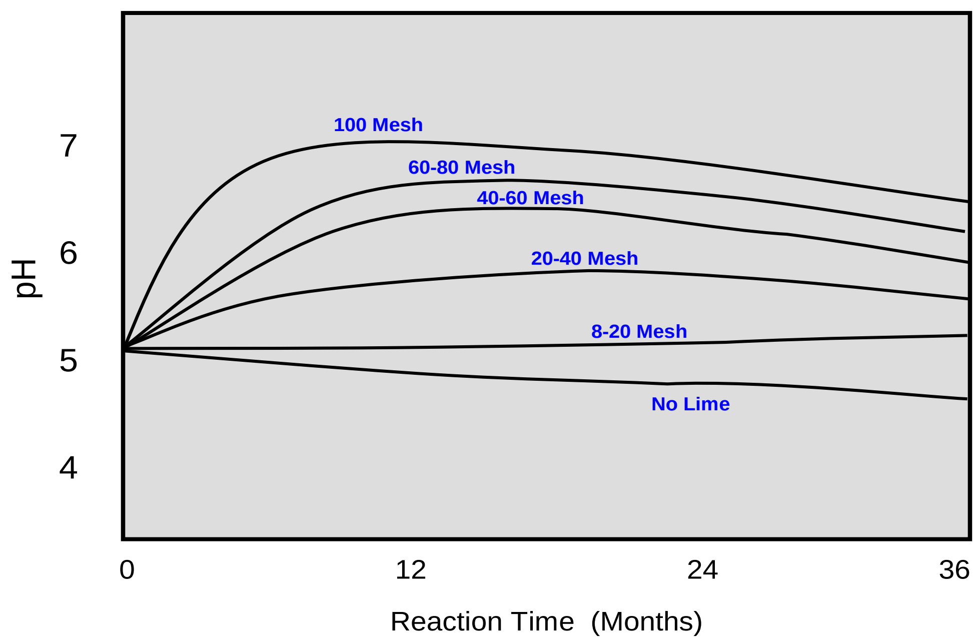

Figure 5: Liming materials react faster or slower depending on fineness of the material.

Oxides and hydroxides are typically powder so 100% of the material is assumed to react within the year of application. These materials react with water so care must be taken to avoid direct contact with skin and eyes. For other lime sources, CCE needs to be adjusted for the fineness of the material. To determine the fineness factor of a limestone:

1) Subtract the percent passing a 100-mesh sieve from the percent passing a 20-mesh sieve and multiply this percentage by 0.60; and
2) add the percent passing the 100-mesh sieve to the value obtained in step 1 and divide the sum by 100.

Thus, the fineness of a material of which 70% passes a 100 mesh sieve and 97% passes a 20 mesh sieve is {(97-70)*0.60 +70}/100=0.86 (see Example A).

Once we know the CCE and the fineness of a liming material, we can calculate its ENV. The Effective Neutralizing Value is calculated by multiplying a liming material's CCE and its fineness factor. As an example: a liming material with CCE of 78.8% and a fineness of 0.86 has an ENV of 78.8*0.86= 67.8 (see Example A).

When a soil sample is submitted to a laboratory to obtain a lime recommendation, the recommended amount of lime on the report is based on 100% ENV equivalent material. To determine the actual application rate, divide the recommended rate by the ENV and then multiply by 100. Thus, if 2 tons/acre 100% ENV is recommended, this can be satisfied with 2 tons/acre calcitic limestone, 1.1 ton/acre burned lime (2/179*100), or 1.5 tons/acre hydrated lime (2/136*100). In Example A, if 3 tons/acre of 100% ENV is recommended, and the ENV of the material at hand is 67.8%, the actual application rate of the material should be 4.4 tons/acre.

Example A:

Lime source: CCE = 78.8%, 70% passes a 100-mesh sieve, 97% passes 20 mesh.
I need 3 tons/acre 100% ENV material. How much of this lime source to use?

Answer:

CCE = 78.8%

Fineness factor = {(97-70)*0.60 +70}/100=0.86

ENV = CCE*fineness factor = 78.8*0.86 = 67.8%

Required: 3 tons/acre 100% ENV = 3*(100/67.8) = 4.4 tons/acre of this material

To compare liming materials for cost effectiveness, compare the price per ENV and not the cost per pound of product. This is shown in Example B. If a soil is deficient in magnesium (Mg), the use of dolomitic limestone is recommended as it is the most economical way to provide magnesium to acidic soils.

It is a common misconception that gypsum is a liming material. Gypsum is calcium sulfate ($CaSO_4$). The Ca in gypsum can displace the H^+ and Al^{3+} on the soil's exchange complex but the sulfate cannot neutralize the acidity. Thus, gypsum is not a liming material. It is, however, an excellent source of calcium and sulfur because it does not alter soil pH.

Example B:

Lime source A has an ENV of 70% and costs $30/ton. Source B costs $35 per ton but has an ENV of 85%. I have a 50-acre field that needs 3 tons of 100% ENV per acre. How much material do I need of source A versus B? Which material is most costs effective?

Answer:

Amount needed:	Lime A: 50*3/0.70=214.3 tons (4.3 tons/acre) Lime B: 50*3/0.85=176.5 tons (3.5 tons/acre)
Total costs:	Lime A: 214.3*$30=$6429 ($129/acre) Lime B: 176.5*$35= $6178 ($124/acre)

Lime source B is more cost-effective ($5/acre less expensive than source A).

8. New York Lime Law

The New York State Department of Agriculture and Markets (NYSDAM) regulates agricultural liming materials as outlined in Article 9-A: Sale of Agricultural Liming Materials (https://www.nysenate.gov/legislation/laws/AGM/A9-A).

Sections 142-cc and 142-gg in Article 9-A state that for New York, a liming material must be properly labeled with guaranteed analyses and have a CCE of 60% or greater, at least 80% must pass a 20-mesh sieve, and 30% must pass a 100-mesh sieve. This implies that the fineness factor should be greater than or equal to 0.60 and that the ENV should be 36% or greater:

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§ 142-cc: *"No agricultural liming material shall be sold, offered, or exposed for sale, bartered, given or otherwise supplied in this state unless there shall be affixed to each package in a conspicuous place on the outside thereof a plainly printed, stamped or otherwise marked label, tag or statement or in the case of bulk sales or transfers there shall be provided a certified weigh slip plainly printed, stamped or otherwise marked, which shall certify as follows:*

1. *The name, principal office address, and plant location of the manufacturer, producer or distributor.*
2. *The identification of the product as to the type of liming material.*
3. *The brand under which it is sold or supplied.*
4. *A statement expressing the minimum total neutralizing value stated as* ***calcium carbonate equivalence*** *and the minimum* ***fineness****, at time of delivery.*
5. *The net weight of the material.*
6. *The kind and amount of adulterant or foreign material therein, if any, expressed by weight of the material.*
7. *In the case of any material which has been damaged, hydrated, adulterated or otherwise changed subsequent to the original packaging, labeling, or loading thereof and before delivery to the consumer, a plainly marked notice to that effect shall be affixed by the vendor to the*

package or accompanying statement, such notice to identify the kind and degree of such damage, hydration, adulteration or other change therein.

8. *A guarantee of the calcium and magnesium content expressed as a percentage by weight of each such element.*
9. *For agricultural liming material sold in bulk, a guarantee of the percentage of its* ***effective neutralizing value****, as determined in accordance with regulations adopted by the commissioner. Such value shall also be expressed separately as the weight of such bulk material necessary to equal one ton of agricultural liming material having and effective neutralizing value of one hundred percent.*

At every site, from which agricultural liming products are delivered in bulk, and at every place where consumer orders for bulk deliveries are placed, there shall be conspicuously posted a copy of the statement required by this section for each brand of material.

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§ 142-bb. Prohibition.

1. No person shall sell, offer or expose for sale, barter, give or otherwise supply in this state as an agricultural liming material, except as provided in subdivision two of this section, any product which does not have ***a minimum*** *total neutralizing value of* ***sixty per centum calcium carbonate equivalence*** *and, except hydrated lime and burned lime,* ***a minimum fineness of eighty per centum passing a twenty mesh sieve and thirty per centum passing a hundred mesh sieve*** *nor for which a certificate of registration has not been filed and a license has not been issued pursuant to this article; nor shall he or she permit any claim or guarantee to be indicated upon any label, tab, or package or accompanying statement to the effect that such material possesses a higher specification than such material does in fact contain; nor shall he or she sell, offer or expose for sale, barter, give or otherwise supply any such material adulterated with any substance injurious to the growth of plants (other than weeds) or animals or humans when applied in accordance with directions for use accompanying the product; nor shall he or she sell, offer or expose for sale any agriculture liming material in this state without a label or accompanying statement and weigh slip as required by section one hundred forty-two-cc.*

2. Insofar as it shall be used as an agricultural liming material in this state, no person shall sell, offer or expose for sale, barter, give or otherwise supply in this state as wood ash, any product which does not have a minimum total neutralizing value of thirty per centum calcium carbonate equivalence and otherwise satisfy the requirements set forth in subdivision one of this section.

(Verified September 14, 2023).

9. Lime Application Timing Considerations

Successful crop production, especially with pH sensitive legumes, requires pH adjustments well in advance of planting. If the soil pH is 6.0 or less and a new legume seeding is planned, the liming materials should be applied at least six months before seeding for the lime to react with the entire plow layer. If there is insufficient time for an adequate reaction, half of the recommended lime should be incorporated into the soil profile with primary tillage and the remainder mixed into the soil surface before seeding. If the pH is 5.5 or lower, apply lime and defer seeding until next year. Many New York farmers have had great success with applying soil test based recommended lime rates for alfalfa fields while the field is still in corn. Another approach is to lime during the last year of hay in the rotation, making the lime application directly after second or third cutting when soils are dry and best able to support heavy lime application equipment, thus minimizing the risk of soil compaction. Also, as the sod regrows, it will help prevent runoff of the lime from heavy rains on fields that are prone to runoff. Lime applied to corn stubble requires some type of incorporation (light disking, field cultivator, or chisel plow). A cover crop of oats, winter rye or triticale will help provide further protection against soil erosion. Lime which is applied to the soil surface (not incorporated or mixed in) in pastures and no-till situations will require more time to react and advanced planning.

If a rapid increase in pH is desired, calcium oxide (burned lime or quick lime) or hydroxide sources (hydrated lime or slaked lime) can be considered. As explained in Section 7 (Liming Materials), these sources increase the pH of the soil much faster than calcitic or dolomitic limestones. This could be desirable if a quick increase in pH is needed, however the effects are of shorter duration. Additional care must be taken when handling calcium oxide and hydroxide sources as they react quickly with water.

Regardless of crop, when the lime requirement is greater than 4 tons/acre, incorporate half of the lime required into the soil profile and work the remainder into the surface. Generally, for economic returns, it is recommended to not apply more than ~6 tons 100% ENV within a 4- to 5-year rotation. If more is required, apply up to 6 tons in the current rotation and retest the soil again in 3 years. If rates are desired on a 1,000 square feet basis, rates in tons/acre need to be divided by 0.02 to equal pounds of lime per 1,000 square feet.

References

Cited reference:

- Dietzel, K., Q.M. Ketterings, R. Rao (2009). Predictors of lime needs for pH and aluminum management of New York agricultural soils. Soil Science Society of America Journal 74(2): 443-448.

Calculator:

- Excel-based lime calculator: Lime Calculator

Relevant Cornell Agronomy Fact Sheets:

- Agronomy Fact Sheet 1: Soil Sampling for Field Crops
  http://nmsp.cals.cornell.edu/publications/factsheets/factsheet1.pdf
- Agronomy Fact Sheet 5: Soil pH for Field Crops
  http://nmsp.cals.cornell.edu/publications/factsheets/factsheet5.pdf
- Agronomy Fact Sheet 7: Liming Materials
  http://nmsp.cals.cornell.edu/publications/factsheets/factsheet7.pdf
- Agronomy Fact Sheet 48: Buffer pH to Derive Lime Guidelines
  http://nmsp.cals.cornell.edu/publications/factsheets/factsheet48.pdf
- Agronomy Fact Sheet 54: Timing of Lime Application for Field Crops
  http://nmsp.cals.cornell.edu/publications/factsheets/factsheet54.pdf
- Agronomy Fact Sheet 106: Determining an Average Soil Test P or pH value from Grid Samples for Nutrient Management Planning
  http://nmsp.cals.cornell.edu/publications/factsheets/factsheet106.pdf

Appendix: Desired and Minimum pH for New York Field Crops

Crop code	Desired pH	Minimum pH	Cornell crop description
ABE	7.0	6.7	Alfalfa trefoil grass, Establishment
ABT	7.0	6.7	Alfalfa trefoil grass, Topdress
AGE	7.0	6.7	Alfalfa grass, Establishment
AGT	7.0	6.7	Alfalfa grass, Topdress
ALE	7.0	6.7	Alfalfa, Establishment
ALT	7.0	6.7	Alfalfa, Topdress
BCE	6.5	6.4	Birdsfoot trefoil clover, Establishment
BCT	6.5	6.4	Birdsfoot trefoil clover, Topdress
BGE	6.5	6.4	Birdsfoot trefoil grass, Establishment
BGT	6.5	6.4	Birdsfoot trefoil grass, Topdress
BSE	6.5	6.4	Birdsfoot trefoil seed, Establishment
BST	6.5	6.4	Birdsfoot trefoil seed, Topdress
BTE	6.5	6.4	Birdsfoot trefoil, Establishment
BTT	6.5	6.4	Birdsfoot trefoil, Topdress
BSP	6.5	6.4	Spring barley
BSS	6.5	6.4	Spring barley with legumes
BUK	6.2	6.0	Buckwheat
BWI	6.5	6.4	Winter barley
BWS	6.5	6.4	Winter barley with legumes
CGE	6.2	6.0	Clover grass, Establishment
CGT	6.2	6.0	Clover grass, Topdress
CLE	6.2	6.0	Clover, Establishment
CLT	6.2	6.0	Clover, Topdress
CSE	6.2	6.0	Clover seed production, Establishment
CST	6.2	6.0	Clover seed production, Topdress
COG	6.2	6.0	Corn grain
COS	6.2	6.0	Corn silage
CVE	6.2	6.0	Crownvetch, Establishment
CVT	6.2	6.0	Crownvetch, Topdress
GIE	6.2	6.0	Grasses intensively managed, Establishment
GIT	6.2	6.0	Grasses intensively managed, Topdress
GRE	6.2	6.0	Grasses, Establishment
GRT	6.2	6.0	Grasses, Topdress
PGE	6.2	6.0	Pasture, Establishment
PGT	6.2	6.0	Pasture improved grasses, Topdress
PIE	6.2	6.0	Pasture intensively grazed, Establishment
PIT	6.2	6.0	Pasture intensively grazed, Topdress
PLE	6.2	6.0	Pasture with legumes, Establishment
PLT	6.2	6.0	Pasture with legumes, Topdress
PNT	6.2	6.0	Pasture native grasses
RYC	6.2	6.0	Rye cover crop
RYS	6.2	6.0	Rye seed production

Crop code	Desired pH	Minimum pH	Cornell crop description
TRP	6.5	6.0	Triticale peas
MIL	6.2	6.0	Millet
OAS	6.2	6.0	Oats with legume
OAT	6.2	6.0	Oats
SOF	6.2	6.0	Sorghum forage
SOG	6.2	6.0	Sorghum grain
SOY	7.0	6.7	Soybeans
SSH	6.2	6.0	Sorghum sudan hybrid
SUD	6.2	6.0	Sudangrass
SUN	6.5	6.4	Sunflower
WHS	6.2	6.0	Wheat with legume
WHT	6.5	6.5	Wheat