Determining Lime Requirement for Adjusting Soil pH in Apple Orchards

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As most soils are acidic in New York, achieving and maintaining optimal soil pH via liming is essential for apple productivity and fruit quality (Stiles and Reid 1991; Cheng and Stiles 2004). Liming brings multiple benefits to soil nutrient availability and tree growth and development on acid soils. These include 1) increasing the availability of calcium, magnesium and phosphorus; 2) reducing the availability of aluminum, manganese and iron to avoid toxicity problems; 3) promoting microbial activity in the soil and improving soil structure; and 4) improving root growth and soil retention of nitrogen and potassium and other nutrients for better uptake efficiency.

"Achieving and maintaining optimal soil pH via liming is essential for apple tree growth and production of high quality fruit on acid soils. In this article, I will introduce a few basic concepts related to soil pH, compare the new method for determining lime requirement with the old method, and briefly describe liming materials."

Prior to establishing a new orchard, liming is needed to raise the soil pH. The pH value of topsoil (0 to 8 inches) should be adjusted to 7.0 and that of subsoil (8 to 16 inches) to 6.5 during preplant soil preparations (Stiles and Reid 1991). Adjusting soil pH is one of the most important aspects of pre-plant soil preparations because it has a long-term effect on apple tree growth and development, and it is hard to thoroughly lime an orchard soil after planting the trees. As most apple growers are using high density planting systems now, adjusting soil pH via liming becomes even more important, simply because the financial risk of having poor tree growth is much higher than with the low density system. For varieties such as Honeycrisp that are susceptible to bitterpit and other Ca-deficiency related disorders, getting enough Ca into the soil via liming before orchard establishment lays a foundation for effective management of bitterpit and other Ca-related disorders, which cannot be replaced by any other measure.

Once an orchard is established, the soil pH should be maintained in the range of 6.0 to 6.5 throughout the soil profile to optimize plant growth and nutrient availability (Stiles and Reid 1991). For established orchards that have been properly limed at pre-planting, soil pH needs to be measured every 2 to 3 years to monitor its status. This is because the high annual precipitation with an average pH of 4.4 to 4.6 in New York gradually leaches out calcium, magnesium and potassium in the soil, leading to an increase in active hydrogen and aluminum and a decrease in soil pH (Ketterings et al. 2006). In addition, application of ammonium or ammonium-forming fertilizers (such as ammonium nitrate, ammonium sulfate and urea) acidifies soil by releasing hydrogen ion in the process of its conversion to nitrate. This acidifying effect is more pronounced when the fertilizers are applied in a concentrated area, such as under the drip emitters of the fertigation system (Robinson and Stiles 2004).

Although liming is an old topic, some apple growers still have problems in determining the appropriate amount of lime that is needed for their orchards. Considering that a different method is now used for determining lime requirement in the Cornell Nutrient Analysis Lab and Dairy One, it's necessary to revisit this topic. In this article, I will introduce a few basic concepts related to soil pH, then compare the new method for determining lime requirement with the old method, and at the end I will briefly describe liming materials.

Basic Concepts Related to Soil pH

The pH of a soil is a measure of hydrogen ion (H^+) concentration in the soil solution, mathematically expressed as the negative logarithm. A pH of 7 indicates neutrality. Although the pH scale is from 0 to 14, soil pH generally ranges from 4 to 9. Since pH is on a logarithmic scale, one unit change indicates a 10-fold difference in the concentration of hydrogen ion. Soil pH is typically measured in the suspension solution of 1:1 volumetric ratio of water to soil. The acidity in soil solution indicated by soil pH measurement is called active acidity. To neutralize active acidity, very little lime is needed, but this change in pH is very short-lived due to the presence of exchange acidity in soil that reaches an equilibrium with active acidity and resists a change in soil pH.

Because soil clay particles and humus, collectively called colloids, have negative charges, they adsorb positively charged ions (cations). There are two types of cations adsorbed on the soil colloids (Stiles 2004). One group is acid-forming cations (H^+, Al^{3+}, Fe^{3+}, Mn^{2+}). Exchange acidity or reserve acidity refers to the sum of these exchangeable acid forming cations, which is expressed as milliequivalents of hydrogen ion per 100 grams of soil. The other group is base cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+). The sum total of exchangeable bases and the exchange acidity is cation exchange capacity (CEC). CEC is expressed as milliequivalents of cations per 100 grams of soil. The percentage of CEC that is accounted for by exchangeable bases is base saturation.

The ability of a soil to resist a change in pH is called the soil's buffering capacity. A soil with a higher CEC will require more lime for every unit change of pH than one with a lower CEC. This is why the lime requirement for soils of clay type with high organic matter is higher than sandy soils with low organic matter. The buffering capacity of a soil can be quantified by measuring its exchange acidity, based on which, lime requirement can be derived. Alternatively, a soil's buffering capacity can be indicated by measuring soil pH in a buffer with a known pH value and buffering strength. A lower buffer pH value means a larger buffering capacity, and therefore more lime is need to adjust soil pH to a desired value.

Methods For Determining Lime Requirement

A measure of soil pH indicates whether or not lime is needed, but it alone is not sufficient for determining how much lime is needed. To estimate lime requirement of a soil, an estimate of the soil's buffering capacity is needed. There are two ways to estimate soil buffering capacity and then derive lime requirement.

1. The Exchange Acidity Method. In the past, Cornell's Nutrient Analysis Lab used a direct measurement of exchange acidity (EA) to estimate soil buffering capacity for determining lime requirement. This test chemically measures the total potential acidity (meq/100g) present in a soil between its actual pH and that of pH 8.0 (Greweling and Peech 1960). This test was performed only on soils with a pH of 6.1 or lower because measurements become less reliable for soils with a higher pH. For soils with a pH value higher than 6.2 but lower than the desired pH, the buffer capacity is approximated by using the cation exchange capacity (CEC) of the soil (Ketterings et al. 2006)

Once soil exchange acidity (EA in meq/100g) is known, lime requirement (at 100% effective neutralizing value, ENV) can be calculated based on current and desired pH values, base saturation (BS) at current and desired pHs, and soil depth for the intended lime application (inches):

Lime Requirement (tons/acre) = EA*0.5*($BS_{desired}$ - $BS_{current}$)/(1 - $BS_{current}$)*(soildepth/6)

Where 0.5 is a conversion factor denoting that 1 meq of exchange acidity requires half a ton (1000 lbs) of calcium carbonate per acre-6-inches (2 million lbs) of soil.

Quantitative relationships exist between base saturation, exchange acidity and soil pH, and these relationships (Figure 1) have been well characterized for New York soils (Lathwell and Peech 1964). As base saturation (%) increases, soil pH increases. Base saturation of 62%, 71%, 80% and 100% corresponds to a pH value of 6.0, 6.5, 7.0, and 8.0, respectively. One can easily find the base saturation value corresponding to any given soil pH (Figure 1).

Lime requirement needs to be adjusted to the soil depth for the intended application, as more lime is needed to increase the pH to the same value for a greater depth of soil. For apple orchards, we recommend taking soil samples at two depths: one at 0 to 8 inches and the other at 8 to 16 inches, and calculate the lime requirement separately for these two depths, as the desired pH values differ (7.0 for 0 to 8 inches and 6.5 for 8 to 16 inches) for pre-plant soil preparations.

For example, if both a topsoil sample (0 to 8 inches) and a subsoil sample (8 to 16 inches) taken at a site for pre-plant preparation have a pH value of 5.9 and an exchange acidity of 10 meq/100g, what is the corresponding lime requirement (at 100% ENV) for topsoil (0 to 8 inches) and subsoil (8 to 16 inches)? The base saturation corresponding to a pH of 5.9 is 60%. The desired soil pH for topsoil and subsoil is 7.0 and 6.5, respectively, which corresponds to a base saturation of 80% and 71%. For sandy soils, these corresponding base saturation values are higher (Figure 1).

Lime Requirement for topsoil (tons/acre) = 10*0.5*(0.8-0.6)/(1-0.6)*(8/6) = 3.3
Lime Requirement for subsoil (tons/acre) = 10*0.5*(0.71-0.6)/(1-0.6)*(8/6) = 1.8

The lime tables included in the Cornell Pest Management Guidelines for Commercial Tree Fruit Production (Cheng and Robinson 2015) are generated using this type of calculation. The total lime requirement for a soil depth of 16 inches during pre-plant preparation should be the lime requirement for both topsoil (0 to 8 inches) and subsoil (8 to 16 inches) combined.

2. The Buffer pH Method. As direct measurement of exchange acidity is time consuming and generates hazardous waste, an alternative method that is rapid, accurate enough, and environmentally friendly for routine use in determining lime

Soil pH	Base Saturation (%) 200 soils	Base Saturation (%) Sandy soils
4.5	2.1	6
4.6	3.5	9
4.7	5.0	12
4.8	7.3	16
4.9	10.2	19
5.0	13.5	22
5.1	17.1	27
5.2	22.8	33
5.3	32.0	40
5.4	42.0	45
5.5	48.0	50
5.6	51.5	56
5.7	54.0	62
5.8	57.0	68
5.9	60.0	74
6.0	62.0	80
6.1	63.5	82
6.2	65.5	84
6.3	67.5	86
6.4	69.5	88
6.5	71.0	90
6.6	73.0	92
6.7	74.0	93
6.8	75.5	94
6.9	77.0	95
7.0	79.5	96
7.1	81.2	97
7.2	83.0	98
7.3	84.7	99
7.4	86.3	99
7.5	88.0	100
7.6	90.0	
7.7	92.5	
7.8	95.0	
7.9	97.5	
8.0	100.0	

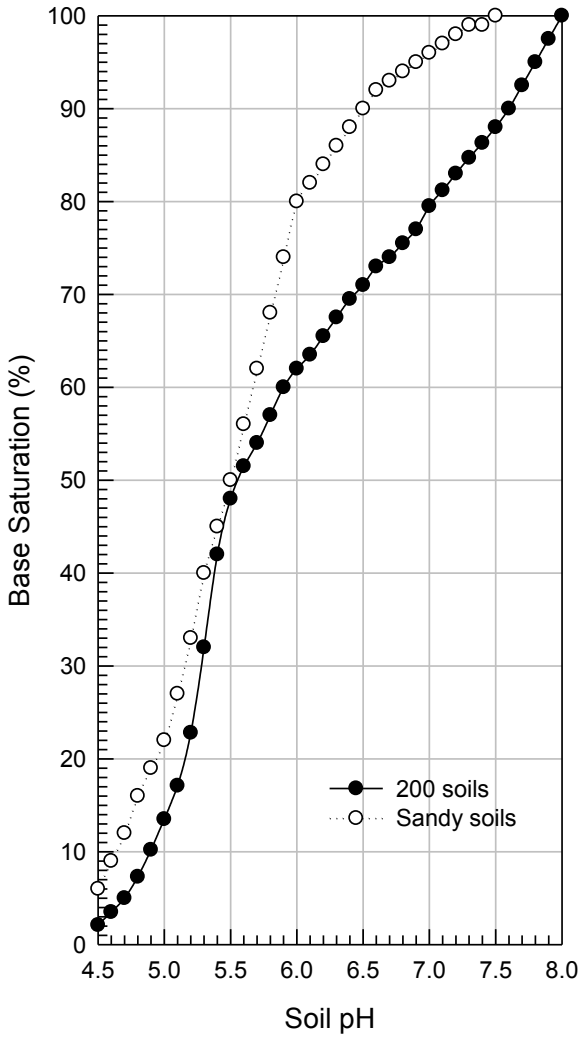

Figure 1. Base saturation in relation to soil pH in 200 New York soils and sandy soils (Adapted from Lathwell and Peech 1964 and Peech 1941)

requirement is sought by the Cornell Nutrient Analysis Lab. Several analytical alternatives to the exchange acidity method are available in the literature for measuring soil buffering capacity, including the most commonly used buffer pH methods: the Shoemaker–McLean–Pratt (SMP) buffer, the Sikora buffer, the Mehlich buffer, and the modified Mehlich buffer, but none of these has been tested in New York. Dr. Ketterings and her colleagues recently compared these 4 different buffer pH methods with the exchange acidity method in a lime incubation study on 43 New York soils with a wide range of pH, exchange acidity and organic matter (Dietzel et al. 2009). The study found that each of the four methods predicted lime needs at three target pHs (6.2, 6.5 and 7.0) with high coefficients of determination and low imprecision. A direct comparison of lime needs for all 43 soils derived from the exchange acidity method and the lime needs predicted using the SMP, Sikora, Mehlich and modified Mehlich buffers indicated that all buffers explained 87% or more of the variability in the predicted lime requirement. The Modified Mehlich and Mehlich buffers showed the highest correlation ($r^2 = 0.91$) to lime requirement and the least imprecision. At the end, the modified Mehlich buffer was chosen to replace the exchange acidity method for determining lime requirement, as it does not generate hazardous waste.

The modified Mehlich buffer, which is derived from the original Mehlich buffer (Mehlich 1976), has a pH of 6.5 and contains ammonium chloride, calcium chloride, glacial acetic acid, sodium glycerophosphate, and triethanolamine. Soil is mixed with water and the buffer at a ratio of 1:1:1 (w/v/v) for 30 minutes before pH is measured. A soil with a high buffering capacity will show a lower buffer pH value than that with a low buffering capacity. The lime requirement expressed as exchange acidity, LREA (meq/100g), has the following relationships with the measured buffer pH value (BpH):

For a target pH of 6.2: LREA (meq/100g) = 76.2 – 12.55*BpH
For a target pH of 6.5: LREA (meq/100g) = 88.75 – 14.44*BpH
For a target pH of 7.0: LREA (meq/100g) = 109.99 – 17.64*BpH

If a soil has a buffer pH value of 5.8, the lime requirement expressed as exchange acidity (meq/100g) for a target pH of 6.2, 6.5, and 7.0 is:

For a target pH of 6.2: LREA (meq/100g) = 76.2 – 12.55*BpH = 76.2 – 12.55*5.8 = 3.4
For a target pH of 6.5: LREA (meq/100g) = 88.75 – 14.44*BpH = 88.75 – 14.44*5.8 = 5.0
For a target pH of 7.0: LREA (meq/100g) = 109.99 – 17.64*BpH = 109.99 – 17.64*5.8 = 7.7

As 1 meq of exchange acidity requires half a ton (1000 lbs) of calcium carbonate per acre-6-inches (2 million lbs) of soil, lime requirement in tons/acre at 100% ENV for a soil depth of 6 inches is:

For a target pH of 6.2: Lime Req (tons/acre) = LR (meq/100g) *0.5 = 3.4 *0.5 = 1.7
For a target pH of 6.5: Lime Req (tons/acre) = LR (meq/100g) *0.5 = 5.0 *0.5 = 2.5
For a target pH of 7.0: Lime Req (tons/acre) = LR (meq/100g) *0.5 = 7.7 *0.5 = 3.85

Using this type of calculation, a lime table is generated for the buffer pH method (Table 1). Once a buffer pH is known, one can easily find the lime requirement for a target pH value from the table. However, please note that this table is for a soil depth of 6 inches. To convert the lime requirement in tons per acre at 100% ENV for a soil depth of 8 inches, you need to multiply the number by 1.33. Additional information can be found in a tutorial workbook developed for determining lime requirement using the buffer pH method (Ristow et al. 2010).

Liming Material

By New York State law, agricultural liming material is defined 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). Common liming materials include calcium carbonate (calcitic lime stone), calcium and magnesium carbonate (dolomitic limestone), calcium oxide (quick lime, or burned lime), and calcium hydroxide (hydrated lime). These materials generate Ca^{2+} and/or Mg^{2+} and bicarbonate after reacting with water and CO_2 in the soil. The Ca^{2+} and/or Mg^{2+} displace H^+ and Al^{3+} on the soil colloids, and consequently H^+ and Al^{3+} are released into the soil solution. The bicarbonate reacts with H^+ and Al^{3+} to form CO_2 and neutral compounds such as aluminum hydroxide and water. So, there are two steps involved in the liming process: 1) replacement of H^+ and Al^{3+} on the exchange site of the soil colloids and (2) neutralization of the H^+ and Al^{3+} ions in the soil solution by the bicarbonate. In this regard, gypsum ($CaSO_4$) is not a liming material and it does not alter soil pH, because the sulfate cannot neutralize H^+ and Al^{3+} once they are replaced with Ca^{2+}. However, it is a good source for both calcium and sulfur.

A liming material's total neutralizing value (TNV) is expressed as the Calcium Carbonate Equivalent (CCE) of the material, with pure calcium carbonate as 100% CCE. To get the TNV of a liming material, you need to divide the molecular mass of calcium carbonate (100) by the molecular mass of the material. Using this calculation method, the TNV of calcium and magnesium carbonate (dolomitic limestone), calcium oxide (quick lime or burned lime), and calcium hydroxide (hydrated lime) is 109%, 179% and 136% CCE, which means that 1 ton of dolomitic lime, calcium oxide and calcium hydroxide will be equivalent to as much as 1.09, 1.79, and 1.36 tons of pure calcium carbonate, respectively.

A liming material's effective neutralizing value (ENV) indicates

Table 1. Tons of lime (100% ENV) per acre required to adjust soil pH to 7.0, 6.5, and 6.2 for a soil depth of 6 inches. To convert the lime requirement for a soil depth of 8 inches, multiply the number by 1.33.

Modified Mehlich Buffer pH	Desired pH Value		
	7.0	6.5	6.2
	Tons per acre (100% ENV)		
5.0	11.0	8.5	6.5
5.1	10.0	7.5	6.0
5.2	9.0	7.0	5.5
5.3	8.0	6.0	5.0
5.4	7.5	5.5	4.0
5.5	6.5	4.5	3.5
5.6	5.5	4.0	3.0
5.7	4.5	3.0	2.5
5.8	4.0	2.5	1.5
5.9	3.0	2.0	1.0
6.0	2.0	1.0	0.5
6.1	1.0	0.5	0.5
6.2	1.0	0.5	0.5
6.3	1.0	0.5	0.5
6.4	1.0	0.5	0.5
6.5	1.0	0.5	0.5

Adapted from Agronomy factsheet 48: Buffer pH to derive lime guidelines

how much of a liming material's total neutralizing value (TNV) will be available for changing the soil pH within one year of application. It is calculated by multiplying TNV with a fineness factor of the liming material. The finer the liming material, the larger % of the material will be available for changing soil pH, because finer particles have larger surface area to react with acids in the soil. 100% of the lime particles passing a 100-mesh screen will react within the first year, whereas only 60% of the liming material passing a 20-mesh sieve but not a 100-mesh sieve will react within a year. Particles that do not pass the 20-mesh sieve have little liming value and are not generally considered when evaluating liming materials. Quick lime and hydrated lime are typically in powder form, so 100% of the material is expected to react within one year following application. However, care must be taken when handling these materials, as they are caustic upon reacting with water.

Please keep in mind that all the lime requirement obtained on a soil analysis report or from any lime table is at 100% ENV. To convert that to an application rate of a specific lime material, the lime requirement at 100% ENV must be divided by the ENV of the lime material. For example, if the lime requirement at 100% ENV is 3.5 tons/acre, the actual application rate for a lime material that has an ENV of 70% should be 3.5/0.7 = 5 tons/acre.

Summary

Achieving and maintaining optimal soil pH via liming is essential for apple tree growth and production of high quality fruit on acid soils. For pre-plant preparation, we recommend the pH value of topsoil (0 to 8 inches) be adjusted to 7.0 and that of subsoil (8 to 16 inches) to 6.5, and for established orchards the soil pH should be maintained in the range of 6.0 to 6.5 throughout the soil profile. Lime requirement for adjusting soil pH can be derived by estimating soil buffering capacity. Two methods, the exchange acidity method and the buffer pH method, are described to illustrate how to determine lime requirement, with the latter being more rapid and environmentally friendly. The lime requirement at 100% effective neutralizing value must be converted to an actual application rate of a specific lime material by factoring in the effective neutralizing value of the material.

Literature Cited

Cheng, L. and W. Stiles. 2004. Adjusting soil pH for optimum nutrient availability. NY Fruit Quarterly 12(1): 11–13.

Cheng, L. and T. L. Robinson. 2015. Nutrient management of apple orchards. In: 2015 Pest Management Guidelines for Commercial Tree Fruit Production, pp. 104–111. Cornell Cooperative Extension.

Dietzel, K. A., Q. M. Ketterings, and R. Rao. 2009. Predictors of lime needs for pH and aluminum management for New York agricultural soils. Soil Sci. Soc. Amer. J. 73: 443–448.

Greweling T. and M. Peech 1960. Chemical soil tests. Cornell Univ. Agric. Exp. Sta. Bull. 960.

Ketterings, Q. A. 2010. Buffer pH to derive lime guidelines. Agronomy Factsheet 48. http://nmsp.cals.cornell.edu/publications/factsheets/factsheet48.pdf

Ketterings, Q. A., W. S. Reid, and K. J. Czymmek. 2006. Lime guidelines for field crops in New York. Department of Crop and Soil Sciences Extension Series CSS E06-2. http://onondaga.cce.cornell.edu/resources/lime-guidelines-for-field-crops-in-ny

Lathwell D. J. and M. Peech. 1964. Interpretation of chemical soil tests. Cornell Univ. Agric. Exp. Sta. Bull. 995.

Mehlich, A. 1976. New buffer pH method for rapid estimation of exchangeable acidity and lime requirement of soils. Commun. Soil Sci. Plant Anal. 7: 637–652.

Peech, M. 1941. Availability of ions in light sandy soils as affected by soil reaction. Soil Sci. 51: 473–486.

Ristow, P., J. Foster, and Q. A. Ketterings. 2010. Lime guidelines for field crops: tutorial workbook. Department of Animal Science. Cornell University, Ithaca NY. 47 pages. Downloadable from: http://nmsp.cals.cornell.edu/projects/curriculum.html

Robinson, T. L. and W. C. Stiles. 2004. Fertigation of apple trees in humid climates. NY Fruit Quarterly 12(1): 32–38.

Stiles, W. C. 2004. Soil analysis and interpretation. NY Fruit Quarterly 12(1): 5–8.

Stiles, W. C. and W. S. Reid. 1991. Orchard nutrition management. Cornell Cooperative Extension Bull. 219.

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