Lime Requirement Estimates for the Inland Northwest: A Guide to the Updated Calculator

Introduction

Buffer testing is a method of soil analysis that can be used to derive an estimation of how much liming material is required to ameliorate acidified soils. Buffer testing accounts for the acidity present and the unique buffering capacity of the soil tested. Properly estimating the lime requirement is foundational for developing a lime program to neutralize soil acidity. This publication aims to provide more information on the methods and underlying principles of each approach used to determine lime requirement estimates (LRE) for acidified soils in the inland Pacific Northwest (iPNW).

This publication includes a detailed outline of the parameters used in the updated Lime Requirement Calculator (https://smallgrains.wsu.edu/lime-requirement-calculator/) developed by the Washington State University Extension Dryland Cropping Systems Team and available on the Wheat and Small Grains website.

A companion to Washington State University Extension's Soil Acidification Series publications Agricultural Lime and Liming part one and part three (Thompson et al. 2016a, 2016b), this publication reflects the latest information regarding lime requirement estimates and updated recommendations based on ongoing research for the region.

Soil pH

Soil pH plays a crucial role in nutrient use efficiency and the functioning of the soil ecosystem, as it significantly impacts soil functions and ultimately crop health and yield. Different crops (and varieties) have varying levels of tolerance to soil acidity, with some overcoming low pH conditions better than others. The pH scale ranges from acidic (below 7.0) to basic (above 7.0), with neutral soil having a pH of 7.0. For optimal crop production, most plants prefer slightly acidic soil, typically with pH values falling between 5.5 and 6.5. This balanced acidity fosters ideal conditions for nutrient uptake and overall plant health. More information can be found in the publication *Soil pH and Implications for Management: An Introduction* in the Soil Acidification Series (McFarland et al. 2015), which explains fundamentals of soil pH and includes effects on crops and varieties under low pH conditions.

Low pH

Productive soils naturally tend to become acidic over time. Factors such as rainfall, soil texture, and the presence of basic minerals influence the pace at which this acidity develops in previously neutral or basic soils. While this process typically occurs slowly in nature, human activities can accelerate it. For instance, long-term application of ammonium-based nitrogen fertilizers over more than five decades has accelerated soil acidification. Ammonium (NH_4^+) undergoes oxidation in the soil environment, is converted to nitrate (NO_3^-), and releases hydrogen ions (H_+) into the soil solution, thus lowering pH levels (McFarland et al. 2015). Extreme acidity in soil may hinder productivity, as elevated levels of toxic elements, like aluminum and manganese released from the soil mineral fraction, can inhibit optimum functioning of plants and microbes. Applying liming materials as soil amendments to raise the pH of acidified soil is a commonly recommended practice. The rate of liming materials needed to reach desired outcomes will depend on acidity present and soil characteristics.

Soil Buffer Capacity: Active and Reserve Acidity

Soil serves as a crucial reservoir for water and nutrients vital to plant growth. The solid fraction plays a pivotal role in maintaining soil pH balance by storing basic or acidic ions. The reservoir-like quality of soil confers resilience to abrupt changes, such as those imposed by the addition of inputs and changes in the environment.

Active acidity is the acidity that is currently present in the soil solution, and it directly influences plant growth. Reserve acidity refers to the amount of acidity held within the soil—retained on soil colloids (residual acidity) and held closely (exchangeable acidity), ready to be released when conditions change, such as when soil pH increases due to lime application. This reserve acidity acts as a buffer against pH changes. The ability of a soil to hold ions is driven primarily by soil texture and organic matter. Figure 1 illustrates how small the active acidity is in comparison to the reserve acidity. Understanding these two aspects of soil acidity is crucial for managing soil health and optimizing plant growth.

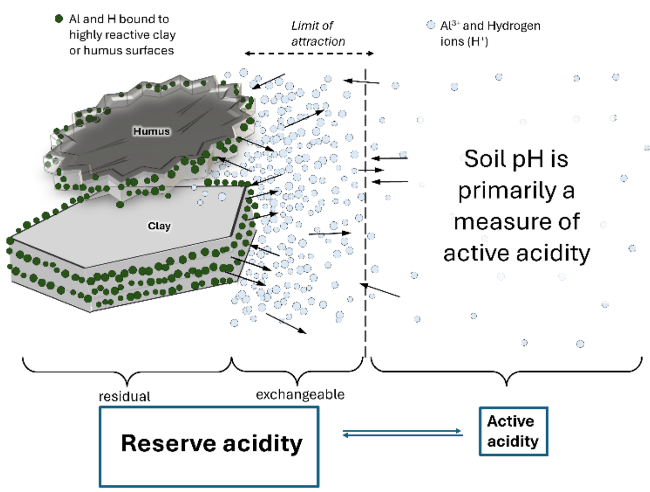

Figure 1. The active acidity is only a small fraction when compared to the reserve (residual + exchangeable) acidity. If the reserve acidity is strong enough (high soil buffer capacity), the soil solution will be easily replenished with more acidic ions as a response to any incremental change in the soil pH. Illustration adapted from Brady and Weil (2002).

Buffer pH Methods

Testing the buffer pH of a soil provides a measure of the soil's reserve acidity, which is used to recommend the amount of calcium carbonate necessary to neutralize the acidity present in the soil, attain a desired target pH, or both, depending on the test. It accounts for both the soil's buffer capacity and the acidity present in the soil solution. In these tests, a soil sample is added to a high pH solution with a predictable, stepwise response to the addition of acidity. The pH of the solution is measured and used to calculate a lime recommendation in 100% pure calcium carbonate. The calibrations of these tests vary by region, along with variability of soil type, so it is important to make sure that the test used is appropriate to the region's soils. The following buffer pH methods have been shown by regional research to provide more accurate lime requirement recommendations for iPNW soils.

Mehlich

The modified Mehlich buffer pH test was shown to consistently provide the most accurate lime recommendation for soils in the Palouse region of eastern Washington and northern Idaho (McFarland et al. 2020). If the Mehlich buffer pH value is equal to or greater than 6.6, lime application is deemed unnecessary (McFarland et al. 2020; Gavlak et al. 2005). The Mehlich buffer is particularly valuable for soils with elevated levels of exchangeable aluminum (see sidebar Exchangeable Aluminum). It assesses the reserve acidity, which is estimated by applying the Mehlich buffer solution and analyzing the resulting pH value. Subsequently, the equation used to derive lime application recommendations is tailored according to the reserve acidity as measured by the Mehlich buffer pH.

A Mehlich or modified Mehlich buffer pH test can often be requested at the soil laboratory (The modified Mehlich buffer exhanges $CaCl_2$ for the original $BaCl_2$ but produces similar results, for soil test labs it is less toxic, easier on lab equipment, and reduces the burden of hazardous waste disposal). You can determine your lime requirement estimate in the companion Lime Requirement Calculator; refer to the section labeled "Mehlich," and enter the Mehlich buffer pH into the "Reported Value" cell. The calculator is based on analysis of a 0–6 in. soil sample. When sampling from a different soil depth layer, use the corresponding conversion calculator (e.g., if sampling from the 0–4 in. or 4–8 in. layers, enter "4"). Lime requirement estimate must be consistent with the soil layer sampled. The calculator will supply an LRE in pounds per acre of calcium carbonate for that depth. Once you have determined your application rate of calcium carbonate, be sure to use the calculator in the "Conversions" section to obtain the rate of lime material required to achieve your pH management goal. Refer to the Converting Lime Recommendations to Lime Applied section of this publication for more information on this conversion.

Exchangeable Aluminum

A high exchangeable aluminum (Al) content in soil is typically considered to be a concentration that can negatively affect plant growth and soil health. The specific threshold can vary depending on the soil type and the crops being grown, but generally, a concentration of exchangeable aluminum above 1 $cmol_c/kg$ (centimoles of charge per kilogram of soil, or meq/100 g—milliequivalent per 100 grams of soil) extracted with KCl (potassium chloride) is often considered high enough to warrant corrective measures.

$1 cmol_c/kg = 91$ ppm

Shoemaker-McLean-Pratt

The Lime Requirement Calculator also includes an option for obtaining an LRE using the Shoemaker-McLean-Pratt (SMP) method, derived from research conducted at Oregon State University for a calibration appropriate in Willamette Valley and Central Oregon (Makepeace et al. 2022; Anderson et al. 2013). Similar to the Mehlich test, the SMP buffer test is particularly effective for soils with high exchangeable aluminum (e.g., greater than 90 ppm of KCl-extracted aluminum) but this method allows for a specific pH target.

For LREs tailored to your soil's SMP buffer pH value and your desired target pH, refer to Table 1 below. The values in Table 1 were used to create an equation for the LRE calculator to accurately determine lime requirements based on any SMP buffer pH and target pH values falling within the specified range: the SMP method is most accurate within pH buffer values ranging from 4.8 (minimum) to 6.7 (maximum), with optimal targeting between 5.6 and 6.4.

This test is the official state recommendation for Washington, based on research conducted in western Washington in 1977. However, it has been demonstrated to not be suitable for statewide implementation, considering that many years have passed since the SMP test's establishment, and the highly variable soils across the state of Washington.

Sikora

Some labs are replacing the SMP buffer with the Sikora buffer test. The Sikora method was developed to mimic the SMP buffer test. It avoids the use of chemicals in the buffer solutions that are classified as hazardous waste and reduces the challenges associated with disposal for soil testing laboratories. Using the calibration from Laboski and Peters (2005) for Wisconsin soils produces a reasonable estimate for soils in the Palouse region (McFarland et al. 2020). Tables for Sikora buffer test pH can be found in the publication *Updated Lime Requirement Recommendations for Oregon* (Moore 2022).

Woodruff

The Woodruff buffer test is usually employed for soils experiencing gradual acidification due to long-term usage of ammonium-based nitrogen fertilizers, especially those with low exchangeable aluminum content. However, research showed that for most low pH soils in eastern Washington the Woodruff buffer underpredicted lime requirement estimates and the Mehlich test was more accurate (McFarland et al. 2020; Gavlak et al. 2005). Table 2 shows LREs tailored to measured Woodruff buffer pH values and various target pH levels. It is important to note that the Woodruff method is optimized for buffer pH values ranging from 5.4 (minimum) to 6.8 (maximum), with pH targets typically falling between 5.5 and 6.5 (Table 2). The values in Table 2 were used to create an equation for accurately determining an LRE based on any Woodruff buffer pH and target pH values falling within the specified range. Please refer to the "Woodruff" section of the Lime Requirement Calculator, and enter the Woodruff buffer pH and your target pH in the "Reported Value" columns.

Table 1. SMP buffer pH and corresponding required effective calcium carbonate equivalent (ECCE) in ton/acre for three target soil pH.

SMP Buffer pH	Target pH 5.6	Target pH 6.0	Target pH 6.4
6.7	0	0	0
6.6	0	0	1
6.5	0	1	1.7
6.4	0	1.1	2.2
6.3	0	1.5	2.7
6.2	1.0	2.0	3.2
6.1	1.4	2.4	3.7
6.0	1.7	2.9	4.2
5.9	2.1	3.3	4.7
5.8	2.5	3.7	5.3
5.7	2.8	4.2	5.8
5.6	3.2	4.6	6.3
5.5	3.6	5.1	6.8
5.4	3.9	5.5	7.3
5.3	4.3	6.0	7.8
5.2	4.7	6.4	8.3
5.1	5.0	6.9	8.9
5.0	5.4	7.3	9.4
4.9	5.8	7.7	9.9
4.8	6.2	8.3	10.4

Source: Adapted from Anderson et al. (2013).
Notes: ECCE = Effective calcium carbonate equivalent. The ECCE (or CCE) recommendation assumes complete neutralization of soil pH by the lime material at 100% power; see Converting Lime Recommendations to Lime Applied section of this publication for more on this conversion.

Table 2. Woodruff buffer pH and corresponding required effective calcium carbonate equivalent (ECCE) in ton/acre for three target soil pH.

Woodruff Buffer pH	Target pH 5.5	Target pH 6.0	Target pH 6.5
6.8	0.3	1.0	1.7
6.7	0.7	2.0	3.3
6.6	1.2	3.1	4.8
6.5	1.8	4.1	6.3
6.4	2.5	5.2	7.8
6.3	3.3	6.4	9.2
6.2	4.2	7.5	10.7
6.1	5.2	8.7	12.1

Woodruff Buffer pH	Target pH 5.5	Target pH 6.0	Target pH 6.5
6.0	6.4	9.9	13.5
5.9	7.6	11.1	14.8
5.8	9.0	12.4	16.2
5.7	10.5	13.6	17.6
5.6	12.0	14.9	18.9
5.5	13.7	16.2	20.2
5.4	15.5	17.6	21.5

Source: Adapted from Van Lierop (1990).

Alternative Methods

Soil Exchangeable Aluminum, Organic Matter, and pH

Two alternative techniques for calculating Lime Requirement Estimates without a buffer test use values of the soil's organic matter (OM) levels along with either KCl-extractable aluminum (KCl-Al) or soil pH. These calculations target a soil pH of 6.0 and are based on OM levels determined using the Walkley-Black method. A request for KCl-extractable aluminum may be required at some soil testing laboratories if it is not included on a standard test result. This method of calculating LREs incurs a slight loss of accuracy compared to the modified Mehlich, which is optimum test for Palouse soils. Using the measured soil properties (OM and KCl-Al or soil pH) with the derived equation provides better estimated rates than the other buffer test recommendations (McFarland et al. 2020). There is a section in the Lime Requirement Calculator that makes these soil-property-based calculations for you.

Base Saturation

When buffer pH methods are not available by request, employing the base saturation (BS%) approach emerges as a reliable alternative. Base saturation is the percentage of base-forming cations (such as calcium, magnesium, potassium, and sodium) that occupy the exchange sites in a soil; the total number of exchanges sites is called the cation exchange capacity (CEC) (Equation 1). Unlike buffer methods, which can lack accuracy across different regions due to calibration limitations, the BS% approach offers a direct focus on reserve acidity (Equation 2), notably represented by "hydrogen + aluminum (H+Al)."

Equation 1:

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

Base Saturation equals the sum of calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}), potassium ions (K^{+}), and sodium ions (Na^{+}), divided by the cation exchange capacity (CEC).

Equation 2:

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

Exchangeable Acidity equals the sum of concentrations of hydrogen ion (H^{+}), aluminum ion (Al^{3+}), manganese ion (Mn^{2+}), and iron ion (Fe^{3+}), divided by the cation exchange capacity (CEC).

The BS% method calculates an LRE by evaluating the ratio of essential cations such as calcium (Ca_2^{+}), magnesium (Mg_2^{+}), potassium (K_+), and sodium (Na_+) against acidic cations (primarily H_+ and Al_3^{+} but also Fe_3^{+} and Mn_3^{+}), and therefore considers nutrient balance rather than solely the pH value. Notably, it does not mandate the removal of all acidic cations, recognizing that crop yields may not significantly improve with further increase in BS% and soil pH. The BS% section in the Lime Requirement Calculator, derived and refined from the studies by Cantarella et al. (1998) and Reganold and Harsh (1985), serves as a practical tool in this regard. Although the BS% threshold for cash crops in the iPNW awaits further study, users can input values between 70% (grasses) and 80% (legumes) for decision-making.

The base saturation numbers 70% for grasses and 80% for legumes serve as general guidelines for users to make decisions regarding cash crops in the iPNW. However, it is important to note that these values may vary depending on factors such as soil type, crop species, and specific environmental conditions. Additionally, the measurement of base saturation percentage itself can vary based on the methodology used for analysis, mainly CEC, the depth of soil sampling, and other factors. Soil lab reports should specify whether CEC was measured directly (displacement method) or estimated (cation summation). Using displacement-based CEC can sometimes yield base saturation values over 100%, underestimating lime needs. Our calculator allows users to enter lab-reported values or use default settings for quick calculations. Therefore, while these numbers provide a helpful starting point for decision-making, users should interpret them cautiously and consider consulting with experts or conducting further research to ensure accurate assessment and appropriate actions.

Reserve Acidity Method

The reserve acidity method involves applying a lime rate that is 1.5 times the initial exchangeable acidity (Kamprath 1970), aiming to achieve a maximum of 15% acidity saturation. This level is widely accepted as the point at which acidity no longer negatively impacts most crops. Like the BS% approach, this methodology does not rely on a calibrated buffer test and finds extensive use in addressing acidic soils. When soil pH is 5.4 or lower and exchangeable aluminum levels exceed calculated exchangeable acidity, it is recommended to use the LRE based on exchangeable aluminum. This method focuses solely on exchangeable aluminum content extracted with KCl. In soils with a pH below 5.4 (except for Mollisols which are rich, dark soils typically found in prairies and grasslands), buffering capacity is primarily controlled by exchangeable aluminum. Thus, applying lime based on this aluminum extraction provides an alternative strategy for acidic soil management.

Converting Lime Recommendations to Lime Applied

Lime requirement estimates are given in rates assuming 100% calcium carbonate (the acidity-neutralizing component of lime). Lime products should come with a "calcium carbonate equivalent" (CCE, or ECCE for "effective calcium carbonate equivalent") that accounts for other materials present in the product. Common CCE values can range from 50% to 98% or higher—as with some dolomitic limes ($MgCO_3$) or quicklime (CaO)—depending on the product. To get the right application rate, it is essential to take the additional step of converting the LRE given for a 100% ECCE to the actual CCE of the product you plan to apply. This will adjust the physical amount of product that equates to the chemically recommended amount of acid-neutralizing calcium carbonate. The ECCE recommendations given in the LRE assume complete neutralization of soil acidity by the lime material at 100% power (100% ECCE). To calculate the amount of product to apply to soil, divide the ECCE recommendation by the actual percentage CCE stated for your product. Remember to also calculate these values based on the dry weight of the product of your choice. More details on comparing lime products, lime analyses, and rate conversions are included in *Agricultural Lime and Liming, Part 3: Aglime Product Selection and Comparison Calculator User Guide* (Thompson et al. 2016b).

Final Considerations

1. For no-till (NT) management systems, surface lime applications with no incorporation may take several years, applications, or both to reach the depth where stratified acidity is often most severe due to banded fertilizer applications. Therefore, it is crucial to sample soil at varying depths—up to 3 or 4 in. where surface applications are made and between 3 in. and 6 in. or 4 in. to 8 in. to monitor acidity levels in the fertilizer band. Consider evaluating at smaller depth increments during subsequent soil testing for pH to avoid incorporating unreacted lime materials into a composite sample, which could create a false representation of pH change within the soil profile. Precision approaches, such as fluid lime applications targeting deeper soil layers with minimal disturbance (Casanova et al. 2024) may be more effective in addressing this issue than surface applications alone.
2. It is advisable to match your buffer testing method to what is most appropriate for your soil type as listed in this publication. The calibrations based on the test results represent the most current recommendations for the inland Pacific Northwest region. You can often request a particular buffer test from whichever soil test lab you are using. Alternatively, you can calculate your lime requirement using either the base saturation, reserve acidity, or the "Soil OM × Al and pH" methods.

References

Anderson, N., J. Hart, D. Sullivan, N. Christensen, D. Horneck, and G. Pirelli. 2013. Applying Lime to Raise Soil pH for Crop Production (Western Oregon). *Oregon State University Extension Publication* EM9057. Oregon State University.

Brady, N.C., and RR. Weil. 2002. The Nature and Properties of Soils. Prentice Hall.

Cantarella, H., B. van Raij, and J.A. Quaggio. 1998. Soil and Plant Analyses for Lime and Fertilizer Recommendations in Brazil. *Communications in Soil Science and Plant Analysis* 29(11–14): 1691–1706.

Casanova, J., G. Heineck, M.K. LeTourneau, J.C. Hansen, J.L. Carlson, and D. Huggins. 2024. Soil and Crop Effects of a Subsurface Fluid Lime Applicator. *Applied Engineering in Agriculture* 40(3): 351–362. DOI: 10.13031/aea.1593.

Gavlak, R., R.O. Miller, and D. Horneck. 2005. *Soil, Plant and Water Reference Methods for the Western Region*, 3rd edition. Western Rural Development Center.

Kamprath, E.J. 1970. Exchangeable Aluminum as a Criterion for Liming Leached Mineral Soils. *Soil Science Society of America Journal* 34(2): 252–254.

Laboski, C.A.M., and J.B. Peters. 2005. Evaluation of Alternate Buffers to SMP for Lime Recommendations in Wisconsin. Presented at ASA-CSSA-SSA Annual Meeting, Salt Lake City, UT.

Makepeace, C., A. Moore, D.M. Sullivan, and D.R. Huggins. 2022. Evaluation of Nonhazardous Lime Requirement Estimation Methods for Oregon Soils. *Soil Science Society of America Journal* 86(5): 1354–1367.

McFarland, C., D.R. Huggins, and R. Koenig. 2015. Soil pH and Implications for Management: An Introduction. *Washington State University Extension Publication* FS170E. Washington State University.

McFarland, C., S. Shiwakoti, L. Carpenter-Boggs, K. Schroeder, T. Brown, and D.R. Huggins. 2020. Evaluating Buffer Methods for Determining Lime Requirement on Acidified Agricultural Soils of the Palouse. *Soil Science Society of America Journal* 84(5): 1769–1781.

Moore, A. 2022. Updated Lime Requirement Recommendations for Oregon. Oregon State University.

Reganold, J.P., and J.B. Harsh. 1985. Expressing Cation Exchange Capacity in Milliequivalents per 100 Grams and in SI Units. *Journal of Agronomic Education* 14(2): 84–90.

Thompson, W.H., C. McFarland, T. Brown, and D.R. Huggins. 2016a. Agriculture Lime and Liming—Part 1: Introduction to Agricultural Lime and Liming (Soil Acidification Series). *Washington State University Extension Publication* FS212E. Washington State University.

Thompson, W.H., C. McFarland, T. Brown, and D.H. Huggins. 2016b. Agriculture Lime and Liming—Part 3: Aglime Product Selection and Comparison Calculator User Guide (Soil Acidification Series). *Washington State University Extension Publication* FS213E. Washington State University.

Van Lierop, W. 1990. Soil pH and Lime Requirement Determination. In *Soil Testing and Plant Analysis*. Soil Science Society of America.

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