



# AGRICULTURAL LIME AND LIMING, PART 1: INTRODUCTION TO AGRICULTURAL LIME AND LIMING

Soil Acidification Series

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# AGRICULTURAL LIME AND LIMING, PART 1: INTRODUCTION TO AGRICULTURAL LIME AND LIMING

By

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## Abstract

Decreasing soil pH, also called soil acidification, is a growing concern in eastern Washington and northern Idaho. Researchers and farmers have measured soil pH values below 5.0 throughout the Palouse region, in particular. Decreasing soil pH has serious implications for the cropping systems of the Palouse.

This publication is part of a series on soil acidification and discusses the basic principles of how and why calcareous amendments are land-applied to elevate the pH of acid soils. The series begins with An Introduction, covering the fundamentals of soil pH and acidification, and continues with other fact sheets on more specific topics such as the influence of pH on pathogens and microbes, recommended varieties of specific crops, herbicide activity, crop nutrition, and liming.

Agricultural Lime and Liming is a three-part publication that introduces the basic principles of how and why calcareous amendments are land applied to elevate the pH of acid soils. Part 1 contributes to the discussion on the increasing incidence and severity of acid soils in the IPNW and emphasizes soil sampling and monitoring, the role of soil testing, and the characterization of liming materials.

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# Agricultural Lime and Liming, Part 1: Introduction to Agricultural Lime and Liming

*Agricultural Lime and Liming* is a three-part publication that introduces the basic principles of how and why calcareous amendments are land-applied to elevate the pH of acid soils. It is also part of the companion series [Soil Acidification in the Inland Pacific Northwest](#).

Part 1 – Introduction to Agricultural Lime and Liming. This section contributes to the discussion on the increasing incidence and severity of acid soils in the Inland Pacific Northwest (IPNW) and emphasizes: i) soil sampling and monitoring concepts to consider when managing acid soil conditions; ii) the role of soil testing; and iii) characterization of liming materials used to elevate pH of acidified soil.

Part 2 – [Laboratory Testing to Determine Lime Requirements](#). This section delves more deeply into variations among soil types and why laboratory testing is used to characterize soil pH. We define the term “lime requirement” and how it relates to soil buffering capacity. We also provide information on lime requirement test methods commonly performed by soil testing laboratories. A companion [Lime Requirement Worksheet](#) based on common buffer tests and base saturation is provided for reference.

Part 3 – [Aglime Product Selection and Comparison Calculator User Guide](#). This is a user’s guide for the interactive online [Agricultural Liming Material Selection and Comparison Calculator](#). The publication describes the attributes used to perform calculations to characterize liming material, while the interactive utility provides a platform to compare up to three liming materials for their relative effectiveness, costs, and economic efficiency.

## Introduction

During the past fifty years, crop production in eastern Washington has undergone significant intensification. Fertilizer use, specifically ammoniacal-nitrogen, has increased more than sixfold to meet the nutritional needs of improved, high-yielding crop varieties (McFarland et al. 2015). This change in practice is contributing to the acceleration of a natural chemical process often referred to as soil acidification (Koenig et al. 2011).

The increasing incidence and severity of soil acidification in eastern Washington is evidence that landowners and producers may need to remediate acidified soils with liming materials to maintain soil quality (Anderson et al. 2013; Collins 2012; Mahler and Tindall 1998; Rasmussen and Rohde 1989). While the practice of liming soil with agricultural lime is the most common and effective solution for managing soil acidity, representative soil sampling, accurate soil testing, and liming material characterization are the keys to successful soil pH management.

## Effect of Fertilizers

Mahler et al. (1982) reported that soil acidification in eastern Washington is increasing in severity because of increased use of ammoniacal nitrogen-based fertilizers. Table 1 lists common fertilizers and the calculated amount of calcium carbonate needed to neutralize the acidifying effects of nitrogen (N) or sulfur (S) in an unbuffered soil (Havlin et al. 2013). To counter the acidifying effects of fertilizers, a laboratory-determined equivalent application of neutralizing soil amendments (liming materials) should be included every three to six years as part of a nutrient management plan (Anderson et al. 2013; Brown et al. 2008; McFarland et al. 2015).

## Soil Sampling to Identify and Monitor Soil Acidification

Georeference representative sampling points to monitor for changes in nutrients and pH from year to year or over time within the same season (Anderson et al. 2010).

Table 1. Common fertilizers and equivalent amounts of calcium carbonate needed to neutralize their acidifying effects.\*

Fertilizer Products	Guaranteed Nutrient Analysis (N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O-S)	lb CaCO <sub>3</sub> per lb of N or S Applied	lb CaCO <sub>3</sub> per 10 lb of Fertilizer Product Applied
Anhydrous Ammonia	82-0-0	3.6	29.5
Urea	46-0-0	3.6	16.6
Ammonium Nitrate	34-0-0	3.6	12.2
Ammonium Sulfate	21-0-0-24	7.2	15.1
Ammonium Thiosulfate	12-0-0-26	7.2	8.6
Elemental Sulfur	0-0-0-90	7.2	64.8
Triple Super Phosphate, TSP	0-46-0	0.0	0.0
Monoammonium Phosphate, MAP	11-52-0	7.2	7.9
Diammonium Phosphate, DAP	18-46-0	5.4	9.7

\*Adapted from California Plant Health Association (2010) and Havlin et al. (2013).

Typically, soil samples should be collected in the same season for each year of sampling. This is because soil water content has a significant effect on soil pH and the availability of nutrients. For example, soil pH measured on a dry soil after harvest can be more than one pH unit lower than on the same soil in late winter or early spring after the soil has equilibrated to higher water content (Horneck et al. 2007).

Soil acidification is most apparent in the zone of fertilizer placement where the effects of ammoniacal nitrogen- and sulfur-based fertilizers (Table 1) are most concentrated (Koenig et al. 2011). Vertical changes in pH with depth or acid stratification of soil can be identified and georeferenced when field scouting. Portable pH meters offer a rapid and reliable option to measure soil pH in small increments by depth (Anderson et al. 2010).

Figure 1 illustrates stratification of soil pH, acid-forming cation aluminum (KCl-extractable), and two base-forming cations (calcium and magnesium). These charts show that soil acidity and extractable aluminum concentration increase at the depth of nitrogen fertilizer placement, while the concentration of base-forming cations decreases. Nutrient and pH stratification is common in long-term minimum tillage systems, when fertilizer placement is at a depth of two to six inches and crop residues are retained on and very near the soil surface. A zero- to one-foot soil sample for the illustrated soil has a pH value of approximately 5.2 or higher and completely masks the nutrient and acid stratification. Sampling at three-inch increments (0–3, 3–6, 6–9, and 9–12) would more accurately reveal stratified acidification with a pH of about 4.6 in the zone of fertilizer placement. Sampling in two-inch or three-inch depth increments should be used to identify and manage stratified soil conditions. One-foot soil samples average out the stratification and underestimate the severity of the problem.

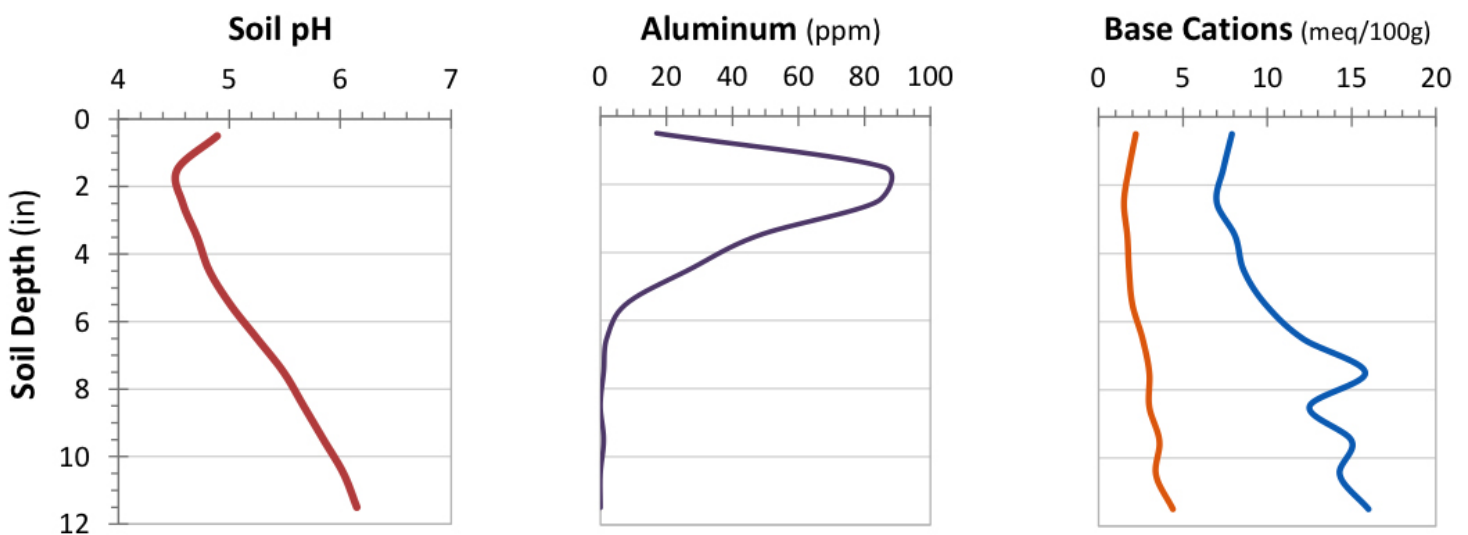


Figure 1. Nutrient stratification and soil acidification in the upper 12 inches of soil. From left to right: Soil pH, Exchangeable Aluminum (KCl-extractable), and Base-forming Cations where [Mg] is orange and [Ca] is blue. Adapted from unpublished WSU Extension field demonstration data by Wayne Thompson.

Sampling depth for nutrient management in tilled systems should match the depth of tillage. For example, sampling depth for a system using an off-set disc is three to four inches, but six to eight inches for a moldboard plow. Sampling at three-inch to six-inch increments below the tillage layer or zone of fertilizer placement in direct-seed systems can be used to monitor nutrient cycling and changes in concentrations of base-forming cations and extractable nutrients that leach below the strata of acidification, depth of fertilizer placement, or tillage layer (Anderson et al. 2010; Corp et al. 2006; Mahler et al. 1982).

## Mapping Soil Acidification

Accurate mapping of soil spatial variability is one of the most complex challenges faced by the farming community (Dinkins and Jones 2008). Soil organic matter content, soil texture, bulk density, cation exchange capacity, base saturation, and exchangeable acidity affect the outcome of lime requirement testing and can vary markedly across farm fields. One tested approach for mapping variability involves the selection of individual georeferenced soil sampling points at a full range of representative slope positions and orientations within a field and using geostatistics (Huang et al. 2010) to establish correlation models with other spatial data (e.g., combinations of grain yield and protein monitor data, remote infrared imagery of bare soil and maturing crop, digital elevation models, and conductivity data captured using electromagnetic induction ground conductivity sensors).

The management zone approach is another tested method that shows promise (Collins 2012; Corp et al. 2006). Zones of relative uniformity are delineated as polygons at a spatial resolution compatible with the dimensions of fertilizer, planting, and harvest equipment. Fifteen or more soil samples are composited within each management zone to generate an average value for each soil test parameter.

## Laboratory Testing to Determine Lime Requirements

A soil test report provides a lime requirement that is specified as an application rate of pure calcium carbonate with an assumed depth of soil incorporation, usually six inches. The actual application rate based on a laboratory recommendation is adjusted up or down to account for product reactivity, particle size distribution, water content, depth of soil incorporation or placement, and soil bulk density.

A soil pH measurement can indicate an acidification problem, but it is not a definitive measure of lime needed to change pH. To determine lime requirements a quantitative measure of the exchangeable acidity that occupies cation exchange sites is necessary. The amount of liming material needed to elevate soil pH is proportional to measured exchangeable acidity.

More in-depth discussion on parameters evaluated by laboratory testing for lime requirements is provided in the companion document of this series, [\*Agricultural Lime and Liming – Part 2. Laboratory Testing to Determine Lime Requirements.\*](#)

Soil testing laboratories use two or more parameters to determine lime requirements in addition to pH: cation exchange capacity, base saturation, soil organic matter content, and exchangeable acidity. Lime requirement methods are designed to measure exchangeable acidity, the amount of acid-forming cations that occupy exchange sites on soil clays, soil aggregates, and organic matter. The measured amount of exchangeable acidity is used to calculate the amount of base-forming cations needed to displace acid-forming cations. The resulting determination is a laboratory recommendation that provides a lime requirement in pounds or tons per acre of dry 100% calcium carbonate equivalent (CCE) liming material.

## Liming Materials

Liming materials are applied to raise the pH of an acidified soil to a desired level. To be effective, the chemical reaction of a liming material when exposed to acid soil conditions must release hydroxyl ions ( $\text{OH}^-$ ) to neutralize hydrogen ions ( $\text{H}^+$ ).

In-depth overview of agricultural liming materials is provided in [\*Agricultural Lime and Liming, Part 3: Aglime Product Selection and Comparison Calculator User Guide.\*](#)

Terminology used to describe agricultural liming materials and labeling guideline interpretations are not the same across all states. For this reason, we provide agricultural lime and liming guidelines that are specific to the state of Washington. We use terminology and definitions to describe liming material characteristics such as purity, reactivity, effectiveness, fineness, and efficiency that are well defined in the textbook *Soil Fertility and Fertilizers: An Introduction to Nutrient Management* by Havlin et al. (2013).

## Product Purity

The standard reference for liming material purity is 100% pure calcium carbonate and reported as CCE. Lime product forms include calcium carbonate derived from pulverized calcitic limestone, calcium and magnesium carbonates or pulverized dolomitic limestone, and highly refined calcitic and dolomitic products available as micronized powders, liquids, and prilled or pelleted liming products. Byproducts or unclassified liming materials that serve as suitable lime sources include paper mill sludge, lime-stabilized wastewater biosolids, fly ash, wood ash, various sources of poultry litter, and sugar beet processing byproducts (Havlin et al. 2013). Unclassified liming materials are typically recycled waste that contain oxides, hydroxides, or carbonates. They also contain contaminants that have no neutralizing value as liming material.

## Product Effectiveness

The effectiveness of a liming material can be defined as the time required for the product to achieve a desired change in pH and is estimated by evaluating the particle size distribution of the material (Figure 2). Particle size distribution of lime is determined by measuring the dry weight percentage of material passing through a series of sieves. Liming material is washed or shaken through a stack of sieves, where material first passes through a sieve with large mesh openings (e.g., 10-mesh) followed by a series of sieves with increasingly smaller mesh openings (e.g., 60-mesh and 100-mesh). The amount of material that passes each sieve size is weighed and recorded, and the percentage of material passing each sieve size is calculated and reported to the nearest whole number on a percentage dry weight basis.

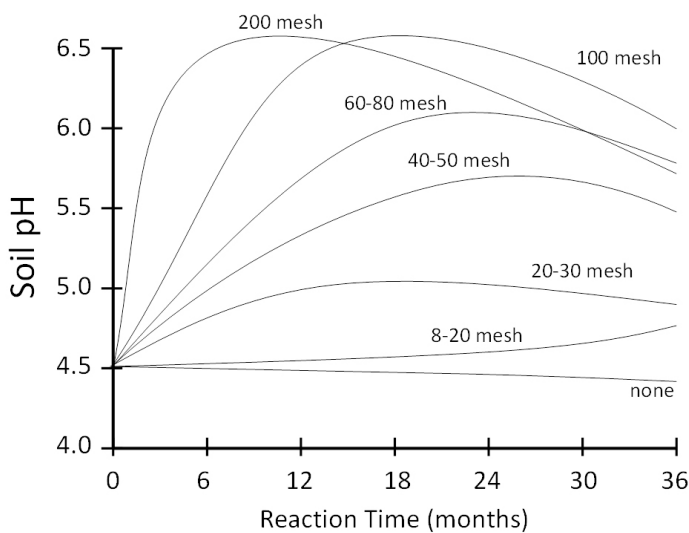


Figure 2. Relative reaction times for different mesh sizes of calcitic limestone. Adapted from Havlin et al. (2013).

Liming material that does not pass an 8-mesh to 10-mesh sieve is generally considered non-reactive. Material that passes a 10-mesh screen and is held on a 60-mesh screen typically reaches its maximum reaction after 24 months, and may provide residual soil reaction for decades. Material that passes a 60-mesh sieve and is held on a 100-mesh sieve can reach its maximum reaction in 12 to 18 months, and may provide residual reaction for up to five years pending the intensity of farming practices (e.g., biomass removal and high nitrogen fertilizer application rates). Very fine materials that pass a 100-mesh sieve provide rapid reactions, achieving the target pH in less than six months. The residual reactivity of fine materials may diminish within two to three years.

Mahler (1994) demonstrated how liming material mesh size can be used to calculate an efficiency factor (E-Factor) for each particle-size fraction of a liming material (Figure 3). The weighted sum of E-factors is used to calculate a fineness factor (F-Factor) of a liming material, which in turn is used to adjust the product CCE. The adjusted CCE for a liming material is referred to as the effective calcium carbonate equivalent (ECCE).

## Application Timing and Equipment

Liming materials require ample time to react prior to seeding. Fall and early winter applications in the IPNW are more favorable than spring and summer applications, where winter rains and colder temperatures help to accelerate the chemical reactions needed to elevate the pH of acidified soil (NLA 2007).

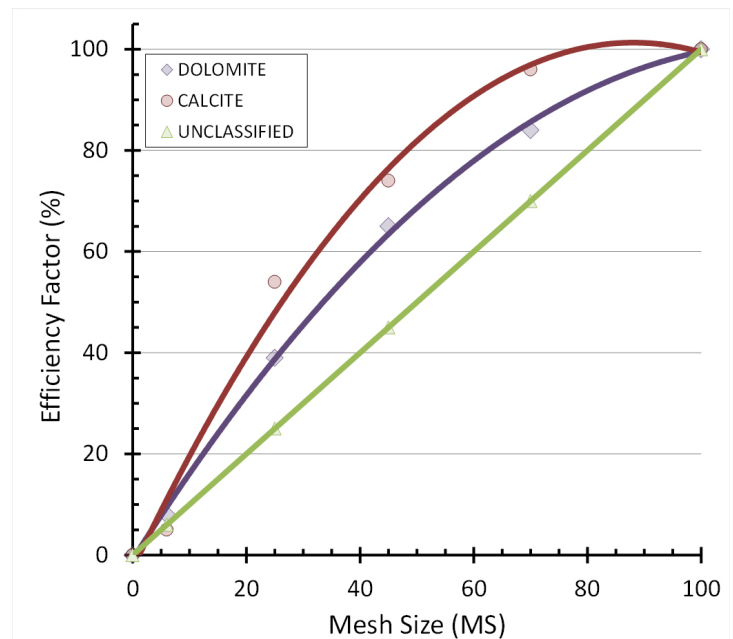


Figure 3. Theoretical liming material E-Factors for dolomitic, calcitic (Mahler and Tindall 1998), and unclassified liming materials. Formulas used to calculate E-Factors: Dolomite =  $-0.0077 \times MS^2 + 1.78 \times MS - 0.87$ ; Calcite =  $-0.0134 \times MS^2 + 2.36 \times MS - 2.50$ ; and Unclassified =  $1 \times MS$ , where MS = mesh size.

Liming materials are typically broadcast applied. Both liquid suspension and dry products can be banded with seed at planting. Liquid suspensions can also be injected by knife. Uniform broadcast applications of lime combined with thorough incorporation by tillage effectively commingle lime with soil to produce a more responsive, uniform soil reaction. Under minimum tillage systems, the double-disc direct-seed drill provides some soil churning and product incorporation but relies on time and aggressive earthworm activity to move surface-applied liming products into the strata of acidification.

Broadcast liquid suspensions offer the most uniform coverage. Under low-wind conditions, well-calibrated broadcast applications of dry products provide acceptable coverage. A low-rate band application of either a liquid suspension or dry pelletized lime can be attractive because it provides precise product placement by directly targeting the narrow zone or strata of soil acidification (Anderson et al. 2013).

## Considerations for Managing Acidified Soil Conditions

### Soil Sampling and Planning

- Budget lime applications to counter the acidifying effects of fertilizers.
- Sample soils to identify pH stratification. WSU Extension recommends soil sampling at a minimum of three-inch increments to one foot (i.e., 0–3, 3–6, 6–9, and 9–12 inches).
- Capture and map spatial variability of soil pH across fields. Georeference composite soil samples at multiple landscape positions to monitor soil-specific changes in pH.

### Determining a Liming Material Application Rate

- Lime requirement tests calibrated for the IPNW provide better lime application rate recommendations.
- Management factors, such as depth of soil incorporation and the chemical and physical characteristics of each liming material source, should be considered when determining an appropriate economic and agronomic application rate.

## Choosing the Liming Material Source

- Transportation and application cost and the high price of liming material are highly relevant factors to consider when choosing an agricultural lime source.

## Methods of Agricultural Lime Application

- Lime spreaders should be well calibrated to ensure accurate and precise application.
- Variable rate applications of agricultural lime offer agronomic and cost benefits.

## Evaluating Soil pH Changes

- Re-sample soils at georeferenced sampling points for several years to evaluate the effects of agricultural lime applications, management practices, and other corrective measures.
- Monitor grain yield response to lime applications over time. Yield response is often gradual, and may become apparent as late as two to three years following an initial application of agricultural lime.

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