Eastern Oregon Liming Guide

EM 9060 • May 2013

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Why is liming needed now when it wasn't in the past?

Soils of the inland Pacific Northwest (PNW) were generally alkaline before cultivation began, with the exception of some higher rainfall areas. Virgin soils contained highly variable amounts of carbonate (naturally occurring lime). Today, however, broad areas, including the Columbia Basin and Palouse, have acidic soil (pH below 6.0) as a result of past farming practices.

The main cause of soil acidification in the inland PNW is nitrogen (N) fertilizer application. Fertilizers that supply the ammonium form of N (such as urea, urea-ammonium nitrate, anhydrous ammonia, and ammonium sulfate) are sources of acidity. Soil microbes transform ammonium (NH_4) to nitrate (NO_3), releasing acidity (H^+). Soil pH declines with increasing amounts of ammonium-N applied. Elemental sulfur (S) application also produces acidity.

Historically, elemental S and ammonium-N fertilizers were recommended as a way to achieve better nutrient utilization from calcareous (pH above 8.0) soils. There was little understanding that the eventual elimination of calcium carbonate in the soil would result in the need to apply lime to maintain the productivity of the soils.

Irrigation with Columbia River water accelerates acidification (lowers pH), while irrigation with well water that is high in bicarbonate can increase pH.

Soil pH effects on crop production

Crop injury from soil acidity is usually an indirect process. Details are provided in Oregon State University (OSU) Extension publications EM 9057 and EM 9061 (in press).

Aluminum (Al) and manganese (Mn) toxicity. As soil acidifies, the solubility of Mn and Al increases. At high concentrations in soil solution, these elements inhibit crop growth. Aluminum toxicity inhibits root development. Manganese toxicity affects plant growth above ground. As soil pH declines, Mn concentration in leaves increases. Crops differ in their susceptibility to Al and Mn.

Legumes, such as alfalfa and peas, are especially sensitive to acidic soil, requiring a higher pH than many other crops. Nitrogen fixation, the conversion of atmospheric N_2 gas to NH_4-N by bacteria of the genus *Rhizobium,* takes place in nodules on legume roots and declines when soil is too acidic. Low soil pH also reduces the solubility of molybdenum (Mo), a nutrient that is essential for N fixation.

Seedling damage. Declining pH starts as a surface soil condition (Figure 1). Young plants with a small

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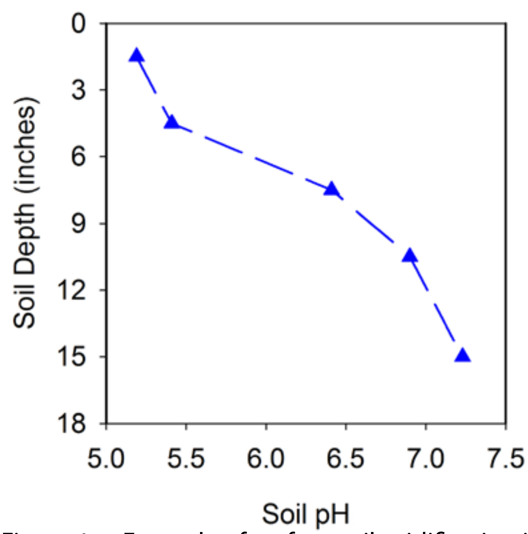

Figure 1.—Example of surface soil acidification in a Walla Walla silt loam soil (Columbia Basin Agricultural Research Center, Pendleton, OR). Soil was fertilized with ammonium sulfate and ammonium nitrate in a wheat–fallow cropping system. Soil pH was measured in 1984 after 44 years of fertilization. Cumulative N fertilizer application rate = 1,970 lb N/a. Tillage was subsurface sweep. Figure by Dan Sullivan. Data from Rasmussen and Rohde, 1989.

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Quick facts

What's in this publication?

Liming is a new practice for the inland PNW, necessitated by soil acidification caused by nitrogen (N) fertilization (Figure 2). This publication provides guidance on: (1) how to evaluate cropping systems for lime need and (2) how to determine lime application rate.

Determining lime rate

The SMP buffer test is used to determine lime requirement, the rate of lime needed to raise soil pH to the desired value. Quarter-strength SMP buffer is used to determine lime requirement for sandy soils.

Irrigated cropping systems

Irrigation water containing bicarbonate may help to neutralize soil acidity (increase pH). Irrigation water should be tested to determine its "liming effect."

Vegetable crops such as onions are especially sensitive to soil acidity. Increasing soil pH from 5.0 to 6.0 increased bulb size and economic return in Columbia Basin trials.

On very sandy irrigated soils, a low-rate lime application may be needed to maintain soil pH in the desired range. To prevent over-liming, no single lime application should exceed 2 t/a of 100-score lime.

When soil texture and pH vary dramatically within a field, variable-rate lime application may be appropriate. Soil in some Columbia Basin fields under irrigation varies from pH 5.0 to 8.0, justifying the variable-rate approach.

Dryland cropping systems

Most soils in dryland cropping systems have never been limed, but liming may be needed in the near future. Cumulative N fertilizer applications have added 1,000 to more than 2,000 lb N/a to most fields. Many dryland soils are now below pH 5.5, the threshold for potential injury to cereals. Yield response to liming has been demonstrated in Idaho trials when soil pH was below 5.0 for cereals and 5.4 for legumes.

In direct-seeded dryland cropping, soil pH is usually lowest at the depth where N fertilizer is banded. Tillage to incorporate lime to the seeding depth may be required to ameliorate subsurface acidity (Figure 3). Ongoing research is evaluating lime injection and surface lime application for efficacy.

For more information

This publication for the inland PNW is complemented by OSU Extension publications that focus on western Oregon cropping systems (EM 9057 and EM 9061, in press). The western Oregon guides provide a more thorough review of liming materials and how lime application alters soil chemistry and biology to benefit crops.

Figure 2.—Lime application.

Figure 3.—Lime incorporation.

root system show the most damage. Soil pH in fertilizer bands is lower than in bulk soil, accentuating the effects of acidity on early plant development.

Interactions. Acidic soils may decrease crop yields because of interactions with other factors, such as increased root disease, reduced herbicide efficacy, and altered soil microbial activity. For example:

- Soil acidity may increase crop injury from some plant diseases, such as Cephalosporium stripe. In Washington State University trials (Murray et al., 1992), liming to increase soil pH above 5.5 reduced disease incidence and increased grain yield and test weight.
- Soil acidity (pH below 6.0) makes herbicides in the triazine and sulfonylurea families less effective. Herbicide response to soil pH varies. Read the herbicide label to determine how soil pH will affect herbicide performance.

Target pH values for crops

Crop pH requirements vary. Onions, garlic, and alfalfa have some of the highest soil pH requirements of crops grown in the inland PNW. Other crops, such as potatoes and wheat, can tolerate greater soil acidity (low soil pH). To maintain crop yield and quality, soil pH should be maintained at or above the minimum pH values listed in Table 1.

The minimum soil pH values listed in Table 1 are general estimates with a small margin of safety built in. The pH value at which you will see yield loss will vary, depending on depth of soil sampling, crop variety grown, and time of year of sampling. These variables are addressed later in this publication.

How lime neutralizes acidity

Liming adds calcium carbonate to soils. Carbonate reacts with acidity in soil to neutralize (remove) it (Figure 4).

Soil pH management: Dryland and irrigated fields

Liming is a management practice that prevents crop damage from acidity. The frequency and amount of lime needed to maintain pH above the injury threshold (Table 1) depends on the following management factors:

- N fertilizer source and rate
- Irrigation water source and quality (discussed under "Irrigated production systems: Special considerations," pages 6–8)
- Tillage

Regular monitoring of soil pH will help you determine the need for lime.

Table 1.—Minimum soil pH values tolerated by crops grown in eastern Oregon.[a]

Crop	Minimum pH
Alfalfa	6.5
Asparagus	6.5
Garlic	6.5
Onions	6.5
Vegetables	6.5
Fruit trees	6.0
Peas	6.0
Sugar beets	6.0
Peppermint/spearmint	6.0
Beans	5.8
Corn (sweet)	5.8
Carrots	5.6
Cereals or small grains	5.5
Corn (field or silage)	5.5
Grass for seed or pastures and turf	5.5
Lentils	5.5
Potatoes	5.5
Blueberries	4.5

[a]When soil pH drops below the minimum value, crop yields may be reduced due to excessive soil acidity.

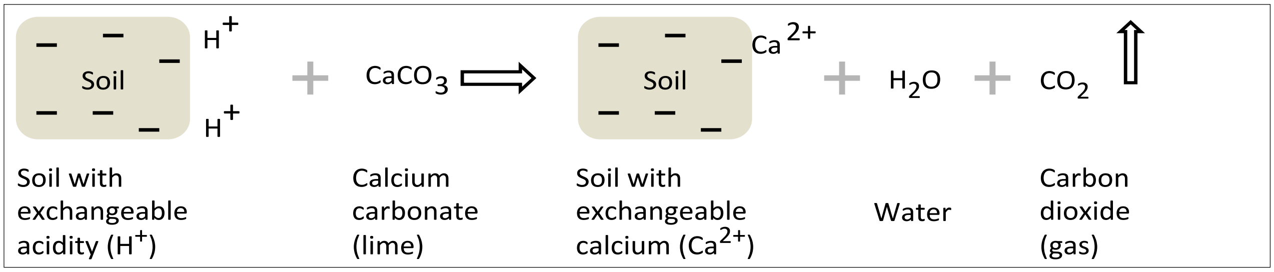


Figure 4.—Soil acidity reacts with lime to form water and carbon dioxide. The carbon dioxide gas is lost to the atmosphere. This chemical reaction continues until all of the lime has reacted. Figure by Dan Sullivan.

N fertilizer source

The most acidifying fertilizers supply all of the N as ammonium-N (NH_4-N, Table 2). Fertilizers that supply some of the N as nitrate, urea, or ammonia (NH_3) are less acidifying per pound of N. Manure, compost, and other organic sources are generally less acidifying than N fertilizers, because most of the N is supplied in organic form, and basic cations—calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) are also supplied.

Tillage

Tillage may provide an alternative to liming in perennial or no-till fields where soil pH stratification has occurred (i.e., soil is most acidic at the surface and less acidic with depth). When soil is acidic in the top 2 to 4 inches but pH is higher at greater depths, plowing to 6 to 8 inches can postpone the need for liming. (See "Liming direct-seeded crops on dryland fields," page 11.)

When the underlying soil pH is below 5.5, tillage won't remedy low pH (below 5.0) at the soil surface. Lime will be needed to bring the surface soil to an acceptable pH. See OSU Extension publication EM 9014 for more information on how to collect soil samples and interpret soil test data for pH-stratified soils.

Monitoring soil pH

Soil pH determines whether liming is needed. However, the soil pH value does not indicate how much lime is needed. Another soil test, the SMP lime requirement test, is used to determine lime rate (see page 5).

Interpretation of soil pH results needs to take into account seasonal variation. In sandy soils, soil pH goes up and down during the year. Soil pH is usually highest in late winter and lowest in the spring. In a loamy sand soil, the winter pH can be 6.5 while spring soil pH is 4.5. In winter, the leaching of soluble salts increases pH. In spring, soil pH is lowered by the addition of fertilizer salts and by the conversion of ammonium-N to nitrate-N by microbes. Collect soil samples at the same time each year to minimize seasonal variation.

For annual crops, monitor soil pH in the 0- to 12-inch depth (also the recommended depth for other routine soil analyses). Soil acidity is usually greatest (pH is lowest) near the soil surface. When soil pH in the 0- to 12-inch depth indicates that soil pH is becoming low enough to evaluate the need for lime, consider a shallower surface soil sample (e.g., 0 to 2 or 0 to 6 inches) to estimate lime need. See OSU Extension publication EM 9014 for soil sampling recommendations for perennial or no-till cropping systems.

Liming management decisions: Dryland and irrigated fields

The next sections review the four management decisions related to lime application: timing/frequency of lime application, lime application rate, liming material (product), and lime placement.

Table 2.—Lime required to neutralize soil acidity from N fertilizers.[a]

N fertilizer	Abbreviation	Analysis ($N-P_2O_5-K_2O-S$)	Lime needed to neutralize acidity (lb $CaCO_3$/lb N)[b]
Calcium nitrate	CN	9-0-0	0
Anhydrous ammonia	AA	82-0-0	3.6
Urea	—	46-0-0	3.6
Ammonium nitrate	AN	34-0-0	3.6
Urea ammonium nitrate	UAN	32-0-0	3.6
Ammonium polyphosphate	APP	10-34-0	7.2
Ammonium sulfate	AS	21-0-0-24S	7.2
Mono-ammonium phosphate	MAP	11-52-0	7.2
Ammonium thiosulfate	ATS	12-0-0-26S	10.8
Manure or compost	—	Variable	Variable

[a]Lime requirement based on chemical reactions that convert fertilizer N to nitrate-N in soil, generating H^+. Actual soil acidity produced in long-term field trials is typically about half of the values listed here.

[b]Lime requirement expressed as pounds of 100-score lime per pound of N applied.

Timing/frequency of lime application

Soil pH monitoring. The need for lime should be kept in mind when planning the frequency and depth of soil testing. See the sidebar "Monitoring pH on sandy, irrigated onion production fields" (page 6) for more information.

Planning ahead. Apply lime well in advance of planting. Lime reacts slowly in the soil over several years. At a minimum, lime should be applied in the fall prior to a spring planting so it can have time to neutralize acidity. For perennial crops such as alfalfa, apply the amount of lime needed for the life of the stand prior to seeding.

Preventing subsoil acidification. There is a danger to letting soils get too acidic. Soils in the Columbia Basin have been measured at pH values at or below 5.5 to depths of 5 feet or more. Acidity deep in the soil profile is difficult to remedy. Lime movement into subsoil takes many years. Periodic lime application will prevent acidification of subsoil.

Lime application rate

Lime requirement test (SMP buffer). The quarter-strength SMP buffer test is recommended for determination of lime requirement in the Columbia Basin. The quarter-strength test has better sensitivity in measuring lime requirement for sandy soils with low pH buffering capacity. Most soil testing laboratories also offer the normal or "full-strength" SMP buffer test. Use the appropriate interpretive table—Table 3 (quarter-strength) or Table 4 (full-strength).

Interpretation of SMP buffer test results. As with most soil tests, the raw value determined using the SMP buffer is only an index value; it means nothing by itself. Use Table 3 or Table 4 to estimate lime rate.

Example: A soil sample is collected (0- to 6-inch depth). The current soil pH (measured in water) is 5.0. You want to increase soil pH from 5.0 (current value) to 6.4 (desired or target value).

Step 1. The lab analyzes the soil sample using the quarter-strength SMP test. It reports a test value of 5.6.

Step 2. Find the lime requirement (SMP) test value in the left column of Table 3 (blue font). For this example, find 5.6.

Table 3.—Interpretation of quarter-strength lime requirement test (SMP test).

	Desired soil pH	
	pH 5.6	pH 6.4
Lime requirement test (SMP) value	Lime to apply to attain desired soil pH (t/a)	
6.4+	0	0
6.2	0.3	0.5
6.0	0.4	0.7
5.8	0.6	0.9
5.6	0.8	1.2
5.4	1.0	1.4
5.2	1.2	1.6
5.0	1.4	1.8
4.8	1.6	2.1

Table 4.—Interpretation of full-strength lime requirement test (SMP test).

	Desired soil pH	
	pH 5.6	pH 6.4
Lime requirement test (SMP) value	Lime to apply to attain desired soil pH (t/a)	
6.6+	0	0
6.4	0	1.1
6.2	1.0	2.0
Below 6.0	2.0	3.0

Step 3. Find the appropriate column for desired soil pH—your desired or target pH. In this example, use the "pH 6.4" column.

Step 4. Read lime to apply (t/a) from the appropriate row and column. In this example, lime to apply equals 1.2 ton of 100-score lime/a.

Table 4 is designed for use with the full-strength SMP test. Ignore this table if your lab used the quarter-strength SMP test.

Liming materials

Liming materials must have a guaranteed analysis, called "lime score" (Table 5, page 6). Lime score, as defined by the Oregon Department of Agriculture, is based on calcium carbonate equivalent (CCE), moisture, and fineness of liming material. 100-score lime is the basis for all recommendations in OSU

Monitoring pH on sandy, irrigated onion production fields

More intense soil pH monitoring is recommended for high-value crops grown on sandy soils with irrigation (e.g., onions). Preplant, whole-field soil samples may not adequately represent soil pH when readings are below 7.

- Soil pH is high in winter or early spring. Fertilizer and soil biological activity reduce pH (increase soil acidity) during the growing season. Thus, lime need may not be recognized until it is too late.
- Soil pH can vary greatly across a field, especially when a field contains areas with exposed caliche (carbonate). A few soil cores containing caliche will mask low pH areas present within the field.

To anticipate and evaluate potential soil acidity problems, we recommend the following:

- Monitor exchangeable Ca via soil testing. Exchangeable Ca exhibits less seasonal variation than does soil pH. Exchangeable Ca below 3 meq/100 g indicates potential soil acidity problems.
- Decrease the soil sampling depth to 6 inches for pH monitoring. Soil pH is usually lowest near the surface. A deeper sample will mask a surface pH problem. Seedlings often are most sensitive to soil acidity.
- Divide the field into management zones for pH management. Applying lime to areas that already have excessively high pH (8.5) may increase management problems.
- Monitor in-row soil pH (0 to 6 inches) during the growing season.
- Monitor leaf manganese (Mn). Crops differ in typical leaf Mn concentrations, but in general, increasing tissue Mn can signify declining soil pH. For onions, measure soil pH when leaf Mn is greater than 100 ppm. Note that leaf tissue Mn concentrations can be misleading if foliar Mn has been applied.

Table 5.—Characteristics of common liming materials.

Liming material	Lime score	Ca (%)	Mg (%)
Limestone ($CaCO_3$)	90–100	32–39	< 1
Dolomite ($CaCO_3 + MgCO_3$)	95–110	18–23	8–12
Sugar beet by-product lime	40–60	25	< 1

Extension publications and for the lime requirement (SMP) tables in this publication.

The lime score of a liming material (product) is used to determine application rate, given a target application rate of 100-score lime.

Example: A sugar beet lime product has lime score of 60. To equal the equivalent of 1 ton of 100-score lime, 1.7 tons of sugar beet lime are needed, as shown below:

Liming product rate needed:

= (desired rate of 100-score lime) × 100 ÷ (product lime score)

= 1 t/a × 100 ÷ 60

= 1.7 t sugar beet lime/a

Evaluate liming materials based on effectiveness (lime score) and cost. For comparison, calculate product cost per ton of 100-score lime (see OSU publication EM 9057). By-product lime can be a cost-effective substitute for traditional aglime. Evaluate by-product lime characteristics carefully. For certified organic crops, use only lime approved by your certification agency.

Lime placement

Liming materials are not water soluble. They are powders, granules, or suspensions that do not move into soil with irrigation or rainfall. All liming materials are more effective when incorporated into soil by tillage.

Irrigated production systems: Special considerations

Lime and fertilizer management for irrigated acidic soils

Soil acidity can be corrected by applying and incorporating lime the fall before planting. Correcting a soil acidity problem in-season is difficult because liming materials have low water solubility and remain at the soil surface.

Preplant application of 500 to 1,000 lb of 100-score lime/a usually is sufficient to correct soil acidity problems for an onion crop on very sandy Columbia Basin soils. Use tillage to incorporate lime into the top 6 inches of soil.

Nitrogen and K fertilization practices have a dramatic effect on soil pH. Where possible, avoid high-rate preplant application of N and K fertilizers on sandy soils subject to soil acidity problems. These materials can decrease pH a full unit (e.g., from 6.0 to 5.0) for weeks after application. Although pH will rebound later in the season, seedlings are damaged. Soil acidity near seedlings is also accentuated by banding N and K fertilizers in starter applications. Chloride from K fertilizers can also increase plant injury by increasing Mn uptake. If necessary, apply N and K in small increments. Minimize the use of acid-forming fertilizers such as mono-ammonium phosphate (MAP, or 11-52-0), urea-sulfuric acid, and ammonium sulfate.

Research example

Onion response to liming was measured in field studies on Warden silt loam soil near Quincy, WA in 2000 and 2001 (Table 6). Aglime (lime score = 97) was applied in October and incorporated to a depth of about 6 inches. Onions were seeded the following spring. Soil pH at midseason (June/July) was increased by about 1 unit with application of 2 t lime/a.

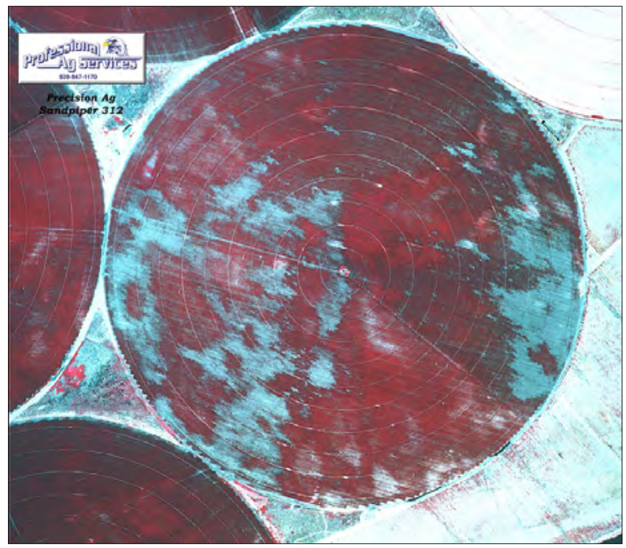
Total bulb yield and bulb size increased with liming (Table 6). Plant population was not affected by liming.

Profit increased by more than $1,500/a with 2 t lime/a (versus no lime application). Profit per acre was calculated as income minus production and packing expenditures. Lime cost was $60/ton, plus an application cost of $10/acre.

Management zones for soil pH in irrigated fields

Because native calcium carbonate content and pH are often quite different within the same field, a variable-rate lime application is often a good management option. Soil pH can range from 5 to 8 in the same field (Figure 5).

Management zones for variable-rate liming can be delineated using a number of methods, including soil survey maps, bare soil photographs, soil conductivity maps, crop yield maps, or grid soil sample data. See publication PNW 570, *Managing Soil Nutrients Using a Management Unit Approach,* for more information.



Tom Muhlbeier, used by permission

Figure 5.—In-field variability in crop loss due to soil acidity. Onions under center pivot irrigation, Hermiston, OR. In bare soil areas (light color), soil pH was acid (near 5.0), killing onion seedlings. Dark areas (healthy plants) had higher pH.

Table 6.—Onion crop response to liming, Warden silt loam soil, Quincy, WA.[a]

Lime rate (t/a)	Plant population (plants/a × 1,000)	Midseason soil pH (0–6 in)	Total bulb yield (t/a)	Jumbo bulbs (3–4 in) (t/a)	Profit per acre ($/a)
0	114	4.8	23	13	$-99
1	117	5.3	32	24	$1,002
2	119	5.8	35	29	$1,463

[a]Data averaged across two field trials (2000 and 2001). Onion prices used were $5 to $7 per 50-lb bag of jumbo size onions (3- to 4-inch diameter), $3.50 to $5.50 for medium size onions (2.25- to 3-inch diameter). Colossal size onions comprised less than 1 percent of total yield. Data from Stevens et al., 2003.

Irrigation water

Water can increase or decrease the need for liming, depending on its quality. Irrigation water analysis can determine water pH and liming potential (carbonate + bicarbonate). Most of the liming potential of irrigation water is in the form of bicarbonate (HCO_3^-). Water from deep wells is most likely to be a significant source of lime. Surface waters are usually low in bicarbonate. Irrigation with these pure waters leaches out native Ca, Mg, and K, accelerating soil acidification.

Table 7 gives an estimate of how much acidity from N fertilizer can be neutralized by bicarbonate supplied via irrigation. Details are provided in "Estimating the liming equivalent of irrigation water." To use Table 7, find your water bicarbonate analysis in the left column and your annual application rate of irrigation water in one of the columns on the right. The pounds of N from fertilizer that can be neutralized by irrigation water bicarbonate are given in the body of the table. For example, when irrigation water contains 1 meq HCO_3/L and 3 acre-feet of water are applied annually, the applied water neutralizes acidity from 113 lb N/a from urea or 57 lb N/a from ammonium sulfate.

Estimating the liming equivalent of irrigation water

The liming potential of water is quantified based on equivalent weights (meq/L). The equivalent weight of HCO_3 as a base is 61. One equivalent of base (HCO_3) can neutralize one equivalent weight of acid. The equivalent weight of urea, in terms of acidity produced, is 14. Therefore, it takes about 4.4 lb bicarbonate to neutralize 1 lb N from urea (61 HCO_3 ÷ 14 N = 4.4).

Example: An acre-foot of water is applied that contains 120 ppm (mg/L) of bicarbonate, or about 2 meq HCO_3/L (120 ÷ 61 = 1.97). A 12-inch application of this water supplies 326 lb of HCO_3, calculated as follows:

$$lb\ HCO_3/a = A \times B \times 0.227$$

where:

A = irrigation water applied (in/a)

B = bicarbonate concentration in water (ppm or mg/L)

0.227 = conversion factor for ppm to lb/acre-inch

so:

$$\text{lb } HCO_3/\text{a} = 12 \times 120 \times 0.227$$

$$\text{lb } HCO_3/\text{a} = 326$$

The amount of bicarbonate applied can be expressed relative to acidity from N fertilizer, using equivalent weights, as:

$$Acidity\ neutralized = HCO_3\ applied\ (lb/a) \div 4.4$$

where:

4.4 = conversion factor (HCO_3 ÷ urea-N) on an acid–base equivalent weight basis

so:

326 lb HCO_3 per acre-foot of irrigation water ÷ 4.4 = 74

Therefore, an acre-foot of this water theoretically can neutralize acidity from 74 lb N supplied as urea (46-0-0) fertilizer.

Table 7.—Capacity of bicarbonate supplied by irrigation water to neutralize acidity from nitrogen fertilizers.[a]

Irrigation water analysis for bicarbonate (HCO_3) (meq/L)	Irrigation water applied (acre-ft/yr) 1 acre-ft	2 acre-ft	3 acre-ft
	Acidity neutralized from urea (lb N/a)		
1	38	75	113
2	75	150	225
	Acidity neutralized from AS (lb N/a)		
1	19	38	57
2	38	75	113

[a]1 meq HCO_3 = 61 mg HCO_3/L. Urea = 46-0-0; AS = ammonium sulfate, 21-0-0.

Dryland production systems: Special considerations

Idaho research

Grain yield response to liming in the dryland PNW was first observed in field trials conducted in northern Idaho with barley, bluegrass for seed, lentils, peas, and wheat. Legumes (peas and lentils) showed yield reduction when soil pH (0 to 12 inches) was below 5.5 (Figure 6). Wheat yield decline began when soil pH was 5.2 to 5.4. Depending on variety, wheat grain yield was 75 to 100 percent of maximum when soil pH was 5.2. Stephens wheat was more sensitive to soil acidity than were other winter wheat varieties evaluated (Daws and Hill81). Grain yield response to liming was most apparent in years with high yield potential (above-average precipitation). For example, lime application increased grain yield from 80 to 116 bu/a in a wet year, but there was no benefit from lime in a drier year (Veseth, 1987).

In Idaho trials shown in Figure 6, soil pH was measured at the 0- to 12-inch depth, and lime or S was incorporated to a depth of 6 inches. Because the soil pH encountered by seedlings at 2 to 4 inches was different than that measured in the 0- to 12-inch soil samples, the threshold pH values shown in Figure 6 should be interpreted carefully. Soils with pH of 5.2 in the 0- to 12-depth probably had lower pH at seeding depth (2 to 4 inches).

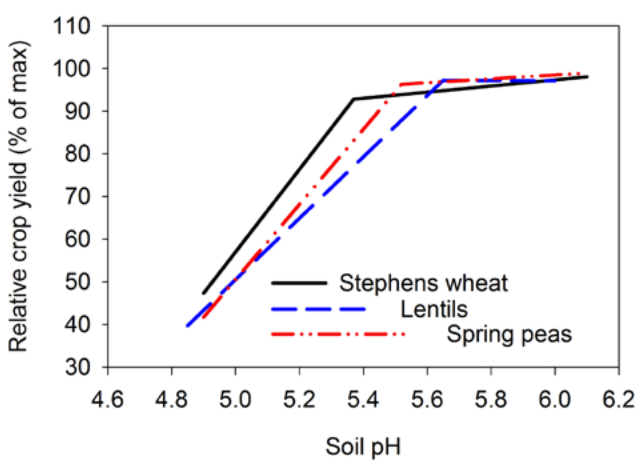


Figure 6.—Grain yield response to soil pH (0 to 12 inches) in northern Idaho. Lines represent data for six trials with spring pea, six with lentils, and more than six with Stephens winter wheat, conducted between 1981 and 1985. Initial soil pH (0 to 12 inches) was 5.0 to 5.3. Soil pH was adjusted to values between 4.9 and 6.1 by preplant lime or elemental S addition, with tillage to incorporate lime 6 inches deep. Figure by Dan Sullivan. Data from Mahler and McDole, 1987.

Oregon research

Long-term field trials were conducted within a wheat–fallow cropping system on a Walla Walla silt loam soil (Pendleton, OR, Figure 7). Soil pH declined with the amount of N fertilizer applied. Soil pH declined most rapidly at tillage depth, about 0.3 pH unit per 1,000 lb N fertilizer applied. Soil pH remained above 6.4 at a depth of 6 to 9 inches.

Recent OSU liming trials with spring peas in the Milton-Freewater area on acidic (pH 5.0) soils showed no crop yield response to liming.

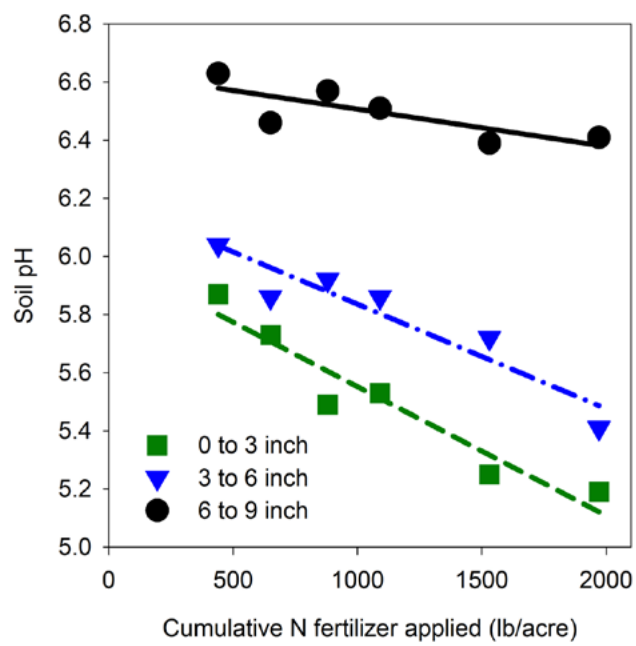


Figure 7.—Soil pH decline with cumulative N fertilizer application rate after 44 years in a wheat–fallow cropping system. Walla Walla silt loam soil with cation exchange capacity (0 to 12 inches) of 16 meq/100 g soil. Tillage with subsurface sweep. Fertilizer was applied from 1940–1983. Soil pH was measured in 1984. Values presented here are soil:water pH (converted from pH determined in $CaCl_2$ by adding 0.7 unit to all values; conversion factor suggested by authors). Figure by Dan Sullivan. Data from Rasmussen and Rohde, 1989.

Washington research (direct seeding)

Direct seed systems have been widely adopted in the inland PNW. Direct seed systems result in very little mixing of soil, so pH becomes stratified with depth (Figure 8). The lowest pH is usually found at the depth where N fertilizer is banded (2 to 4 inches). Surface soil (0- to 2-inch depth) usually has slightly higher pH, the result of Ca, Mg, and K deposited on the soil surface as crop residues decompose.

Trials initiated in 2002 at the Palouse Conservation Field Station (near Pullman, WA) evaluated crop response to liming within direct seed crop rotations. Treatments included surface lime, annual seed-placed lime, or elemental S (to acidify soil). Soil pH and grain yield were monitored. Data collected during the first years of the study showed that soil pH values near 4.5 at seeding depth did not reduce grain yield.

Chemical analyses of soil solution from one of the field sites showed that toxic Al (Al^{3+}) was complexed with organic matter, making it less toxic to root growth (Brown et al., 2008). The researchers suggested that the higher soil organic matter found with direct seed management may provide some protection to plants from soil acidity.

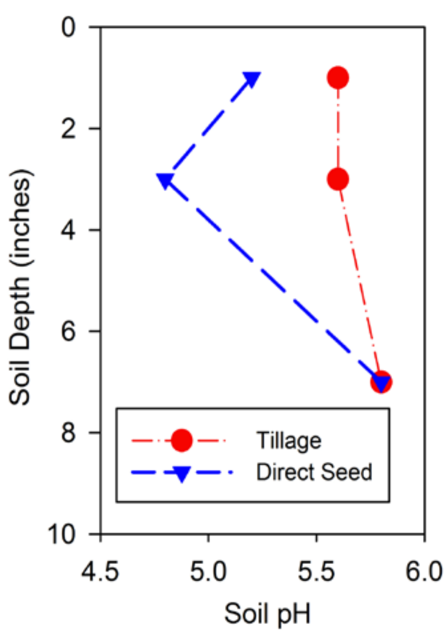


Figure 8.—Soil pH as affected by 10 years of direct seed or conventional tillage management. WSU research trial, Touchet silt loam soil. Figure by Dan Sullivan. Data from Bezdicek et al., 1998.

Conclusions: Dryland soil acidity and liming research

- Soils that have been rapidly acidified by N fertilization (inland PNW) are different than soils that were acidified naturally over millennia (e.g., soils in western Oregon). In our recently acidified soils:

  — Acidity is often present only at the surface (2- to 6-inch depth). Soil below the acidified surface soil has higher pH. Thus, if roots grow into the underlying higher pH soil, they can proliferate without damage from soil acidity.

  — Some of our soils may not contain weathered forms of Al (hydroxides) that are readily solubilized to toxic Al^{3+} at low pH.

- Crop yield response to liming has been inconsistent. Research has not clearly identified why crop performance has not always suffered, even when soil pH is below "normal" crop pH tolerance levels (Table 1, page 3).

  The history of the soil (prior to cultivation) seems to contribute to crop response to acidification by N fertilizer. Soils that developed under forest cover (over millennia) have lower subsoil pH values compared to soils developed under grasslands. Liming of former forest soils (high rainfall areas of the inland PNW) has often improved crop yield, while soils developed under grassland have shown less crop response to liming.

- Nitrogen fertilization continues to acidify soils. Soil pH values are declining with time. The rate of soil acidification increases with annual cropping, because more N fertilizer is applied for annual cropping than for wheat-fallow.

- At some time in the future, soil pH will drop to a toxic level, and crop yield reductions may be severe.

- To better anticipate pH changes, soil can be sampled to determine the degree of stratification. See OSU Extension publication EM 9014 for more information on how to collect soil samples and interpret soil test data for pH-stratified soils.

- Growers are encouraged to evaluate liming as a management practice on a trial basis. It takes a few years for lime to react with soil acidity and change soil pH. Long-term replicated trials are recommended.

- Large differences in wheat variety tolerance to soil acidity have been observed in recent university screening trials. Using varieties with greater soil acidity tolerance may be a good short-term option to maintain yields. Eventually, however, liming will be required, even for varieties that are more tolerant to soil acidity.

Liming options for dryland fields

Lime application rates of 1 to 3 t/a are needed to raise pH 1 unit (e.g., from 4.5 to 5.5) in most soils. Repeated, but infrequent liming (every 5, 10, or more years) may be needed to maintain soil pH in the desired range.

Correcting soil pH requires infrastructure for hauling and spreading lime. This infrastructure has not yet been developed for dryland cropping areas in the inland PNW. In the short term, liming materials and lime application equipment will need to come from outside the region.

Liming direct-seeded crops on dryland fields

A number of approaches have been advocated for neutralizing soil acidity at seeding depth in direct seed systems. Any of these approaches can increase or maintain soil pH. Economics and compatibility with farming systems are important considerations. These alternatives have not been rigorously evaluated for efficacy or for economic outcome in our dryland cropping systems. Evaluate the following alternatives in small-scale field trials before implementation on a large acreage.

- **Periodic tillage to mix the acidic soil layer with higher pH soil**. This approach will produce a temporary increase in soil pH, but it will negate some of the conservation benefits of the direct seed system and create additional management problems. Tillage will delay the onset of very low soil pH, but eventually soil acidity will need to be neutralized with lime.

  Recently, various "vertical tillage" implements have become popular in direct seed systems. These implements could provide a means for partial lime incorporation, with maintenance of surface residue cover. Research trials have not yet evaluated the effectiveness of vertical tillage + liming as a management practice in the inland PNW.

- **Broadcast application of lime to the soil surface.** This approach is used in no-till systems in the Midwest. It takes several years for surface-applied lime to provide benefit at seeding depth. Relatively high rates of lime are usually needed (2+ t/a) to provide benefit at seeding depth.

- **Subsurface application of pelleted lime to the seeding zone (2- to 4-inch depth) with a drill**. Drill application uses pelleted lime (lime dust with a clay binder). The pelleted lime is more expensive than traditional aglime, and economical application rates are only a few hundred pounds of lime per acre. Lime can react with banded ammonium fertilizers to produce ammonia. To reduce potential for seedling damage from ammonia, drill application of lime needs to be done separately from banded ammonium-N fertilizer application.

- **Injection of fluid lime into the seeding zone**. Fluid lime, sometimes called "liquid lime," is a suspension of very fine particles, 100-mesh or finer, mixed with water. Fluid lime products have lime score near 50, but typically cost as much per ton as aglime (lime score = 90+), so they are about twice as expensive on a liming equivalent basis. Aglime takes a year or two to react and increase soil pH. Fluid lime products increase pH more quickly, usually within a few months when soil is moist.

- **Using less acidifying forms of N fertilizer**. The acidity produced from application of calcium ammonium nitrate (CAN) is less than that from other N fertilizers. Other formulations supplying nitrate-N are also less acidifying than N fertilizers supplying urea-N or ammonium-N. The cost/benefit of using CAN or other less acidifying fertilizer formulations has not been evaluated in PNW dryland cropping systems. These products have low N analysis and are specialty products, so they are likely to be an expensive solution to an acidity problem.

For more information

The following OSU Extension publications are available online at: *http://extension.oregon.state.edu/catalog/*

Applying Lime to Raise Soil pH for Crop Production (Western Oregon), EM 9057

Evaluating Soil Nutrients and pH by Depth in Situations of Limited or No Tillage in Western Oregon, EM 9014

Monitoring Soil Nutrients Using a Management Unit Approach, PNW 570

Soil Acidity in Oregon: Understanding and Using Concepts for Crop Production, EM 9061 (in press)

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Acknowledgments

We appreciate thoughtful review comments for this publication from Larry Lutcher, Neil Christensen, and John Hart (all of Oregon State University) and Bob Stevens (emeritus, Washington State University-Prosser). We also appreciate graduate student reviews provided by Alyssa DuVal and Araby Belcher (OSU Department of Crop and Soil Science) regarding the clarity and utility of the layout draft version of the publication.

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Published May 2013.