



ACIDIFYING SOIL FOR CROP PRODUCTION: Inland Pacific Northwest

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High soil pH limits nutrient supply and plant growth. The goal of soil acidification is to reduce soil pH to improve crop performance and increase economic returns.

Fruit trees, alfalfa, grass seed, corn, onions, and potatoes are a few crops that may benefit from soil pH reduction to maximize crop production. Both commercial producers and homeowners may need to acidify soil for optimum production and/or appearance of maple trees, azaleas, rhododendrons, or blueberries. Some plants, such as blueberries, cannot survive in neutral to high pH soil. Table 1 (page 2) lists soil pH requirements for selected crops.

Soil acidification usually is a long-term and expensive process. The long- and short-term economics of soil acidification can be difficult to assess and should be considered on a site-specific basis. Unfortunately, where soil acidification is necessary, no single soil test is adequate to determine what type of soil amendment is needed or how much to apply.

This publication is a technical and practical guide for soil acidification in commercial fields. It explains the soil chemistry involved, how to determine whether pH adjustment is feasible, and methods for acidifying soil. This guide is divided into five sections:

- Understanding soil pH
- The problem—iron chlorosis
- Causes of iron chlorosis
- Solutions to iron chlorosis
- Methods for acidifying soil in the inland Pacific Northwest

Crop production practices, from seedbed preparation to harvest, must be performed in an appropriate and timely manner for optimum quality and yield. Poor weed or disease control, high levels of salts, poor drainage, or other production problems can be significant limiting factors in obtaining high yields. A soil acidification program will not correct or substitute for these limiting factors.

Understanding soil pH

Soil pH is measured on a scale of 0 to 14. A pH of 7.0 is neutral. A pH below 7.0 is acidic, and above 7.0 is basic (alkaline). Examples of pH for some common materials are: milk (6.4), lime juice (1.9), carbonated beverages (3.0), drinking water (6.5 to 8.5), cheese (5.6), and eggs (7.8).

Table 1. Optimum soil pH range for some common crops.*

Crop	pH range
Alfalfa	6.5–8.4
Asparagus	6.5–9.0
Azaleas and rhododendrons	4.5–5.5
Beans	5.8–8.1
Blueberries and cranberries	4.5–5.5
Corn (field or silage)	5.5–8.4
Fruit trees	6.0–8.0
Garlic	6.5–8.4
Grass for seed or pastures	5.5–8.2
Onions	6.5–8.4
Potatoes	5.0–8.3
Small grains	5.5–8.4
Sugarbeets	6.0–8.5
Turf and pasture grass	5.5–8.0
Vegetables	6.5–8.2

*Determined using deionized water and a 1:2 soil:water ratio.

Origins of soil pH

Soil pH is a product of parent material and the environment. Rainfall and temperature control the processes that determine soil pH.

Soil acidification occurs naturally in high-rainfall areas such as the eastern U.S. and some mountainous and coastal regions of the western U.S. Water from rainfall slowly dissolves minerals containing exchangeable bases. These bases are calcium, magnesium, potassium, and sodium. They are called bases because their presence causes soil pH to be alkaline. As the bases are dissolved, rainfall leaches them from the soil and replaces them with hydrogen from rainwater, making the soil acidic.

The primary base leached, and the one with the largest influence on soil pH, is calcium. The calcium either is leached into the groundwater, causing “hard” well water, or is moved into surface streams and eventually to the ocean. As a result of these processes, soils in high-rainfall areas are acidified.

What is soil pH?

Mathematically, soil pH is the negative logarithm of hydrogen in the soil solution $[-\log(\text{H}^+)]$. A neutral pH (7.0) occurs where hydrogen (H^+) and hydroxide (OH^-) are equal ($\text{H}^+ = \text{OH}^-$).

A soil pH above 7 indicates alkaline soil, with hydroxide greater than hydrogen ($\text{OH}^- > \text{H}^+$). As hydroxide increases and hydrogen decreases, soil pH increases.

A soil pH below 7 indicates acidic soil, with hydrogen greater than hydroxide ($\text{H}^+ > \text{OH}^-$). As hydrogen increases and hydroxide decreases, soil pH decreases.

Because pH is a logarithmic scale, a soil with 6.0 pH has 10 times the amount of acidity as a 7.0 pH soil; a 5.0 pH soil has 100 times the acidity of a 7.0 pH soil.

In precipitation-limited climates, a cemented layer rich in carbonates, known as caliche, is common below the soil surface (Figure 1). A caliche layer or other calcium-rich horizon develops when rainfall is not sufficient to leach calcium and magnesium carbonates from the soil surface into groundwater. Depth to caliche depends on depth of leaching, which is regulated by annual rainfall, season of rainfall, and soil texture. As rainfall and sand content increase, the depth to caliche increases.

Land leveling or erosion commonly exposes caliche or other calcium-rich horizons. These areas have alkaline pH and, compared to



Figure 1.—A caliche layer approximately 24 inches below the soil surface at a road cut southwest of Pendleton, OR.

adjacent soils, are lighter in color, lower in soil organic matter, and more difficult to manage. These carbonate-rich layers commonly cause pH-related problems.

Farming practices contribute to soil acidification. The addition of acidifying fertilizers and pure irrigation water acidifies soil. For example, urea and ammonium nitrogen fertilizers are acidifying (Table 2). Proteins and other nitrogen-containing compounds in organic fertilizers convert to ammonia, then to ammonium, and finally to nitrate. When ammonium nitrogen changes to nitrate, it releases four acidifying hydrogen ions into the soil.

Irrigation water that is low in dissolved minerals can have an effect similar to that of rain; it leaches exchangeable bases, acidifying the soil. Surface waters in the Pacific Northwest contain few dissolved minerals. Conversely, irrigation water from wells is commonly high in calcium and magnesium carbonates, which replace the leached exchangeable bases and keep soil pH alkaline.

Soil N transformations and acidity

organic N \Rightarrow ammonium = ammonification

ammonium \Rightarrow nitrate + 4H = nitrification

organic N \Rightarrow plant-available N = mineralization

Table 2. Lime requirement of selected nitrogen fertilizers.

Nitrogen source	Lime required to neutralize (pound lime/pound N)*
Ammonium sulfate	5.4
Anhydrous ammonia	1.8
Urea	1.8
Calcium nitrate	0
Mono-ammonium phosphate (MAP)	5.0
Manure, compost, and other organic sources	variable

*A higher lime requirement indicates a more acidifying material.

Adapted from Tisdale et al., 1985.

When to sample

Collect annual soil samples at the same time each year to minimize seasonal fluctuations and to accurately monitor soil acidification.

Seasonal soil pH change

Soil pH changes seasonally. Higher soil pH or lower acidity is measured in late winter or early spring before fertilization. Soil pH can decrease more than 1 unit (for example, from 7.2 to 6.2) from spring to fall in sandy, low-organic-matter soils. In areas of low rainfall, soil pH is lowest or most acidic as the growing season begins. Soil pH is lowered by fertilizer application and by the increase in biological activity as soil warms.

Soil buffering capacity determines the extent of seasonal pH changes. Soils with substantial amounts of clay and/or organic matter are buffered against pH change and are likely to have a small seasonal pH change, about 0.3 unit. Soils with relatively little silt, clay, and/or organic matter, and a pH below 7.5, can change 1 to 2 units. Soils containing carbonates are buffered against pH change and will not have as large a seasonal difference.

Seasonal pH fluctuations are an important consideration when monitoring the progress of a soil acidification program.

The problem—iron chlorosis

Plants are excellent indicators of the need for soil acidification. They commonly exhibit symptoms of iron deficiency, but sometimes show the need for zinc or manganese. The most common symptom is a yellowing of leaves (chlorosis). This yellowing sometimes is confused with yellow leaf color caused by nitrogen or sulfur deficiency.

Symptoms of iron deficiency are unique as they generally are most dramatic on new growth. An iron-deficient plant often shows “interveinal chlorosis,” or green veins with

yellowing between the veins (Figure 2). Severe iron deficiency results in smaller than normal leaves that are yellow and might have “burnt” leaf edges. Iron deficiency causes plants to perform poorly or even die.

Plant species, varieties, cultivars, or hybrids can differ dramatically in their tolerance to iron deficiency. Some corn hybrids exhibit iron chlorosis, while other varieties planted in the same location do not.

When nitrogen, potassium, zinc, manganese, or sulfur fertilization do not change yellow leaves to the green color expected in healthy plants, an iron deficiency might be the problem. Tissue analysis sometimes, but not always, helps to confirm iron deficiency. In some cases, tissue analysis shows adequate iron, but the iron is bound in the spaces between cells and is not functional. Consult a plant nutrition specialist before sampling and to help with interpretation.

Causes of iron chlorosis

Iron chlorosis is caused by a variety of factors, but the primary reason is high soil pH. Other factors, such as fertilizers, irrigation water, soil conditions, and weather, can influence pH or interact with pH to create or exacerbate iron chlorosis.

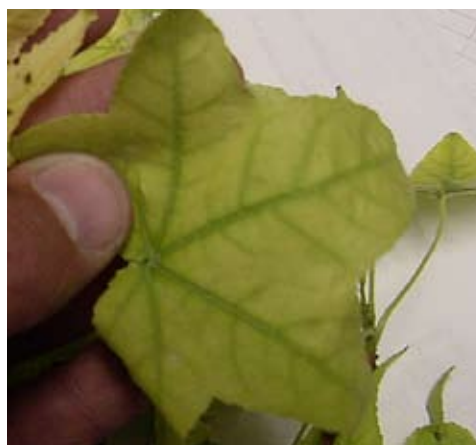


Figure 2.—An iron-deficient sweet gum tree from eastern Oregon showing yellow leaves with green veins.

High soil pH

Iron has limited plant availability when soil pH is near or above 7. Low iron availability is a result of decreased iron solubility when soil pH is above 7.0 (Figure 3). Zinc availability is also affected by soil pH, but less so than iron availability (Figure 4). Lowering the soil pH will make iron more available to plants.

You might ask, “If iron is lacking, why not apply iron to the soil?” Soil already contains tens of thousands of pounds of iron per acre, but most of it is not in a plant-available form when soil pH is high. When iron is added to an alkaline soil, it is rendered insoluble and unavailable to plants in a relatively short time, usually before the plants can use it. Soil acidification programs dissolve enough existing plant-unavailable iron to permit normal plant growth.

Although the primary problem with alkaline soil usually is iron deficiency, plant availability of many other nutrients (phosphorus, zinc, manganese, copper, and boron) also is low in alkaline soils (Figures 4–5). The severity of the nutrient deficiency depends on plant species and the mineral composition of the soil. Iron chlorosis may not be expressed for a variety or species due to the plant’s genetic ability to dissolve and obtain iron across a wide soil pH range. Soil acidification may still benefit these plants by increasing solubility and availability of iron and other nutrients.

Factors related to iron chlorosis

- High soil pH
- Lime applications
- Use of urea fertilizer
- Irrigation water high in carbonate or bicarbonate
- Wet, cool soil conditions leading to poor root growth
- Plastic mulches or other soil conditions that limit gaseous exchange

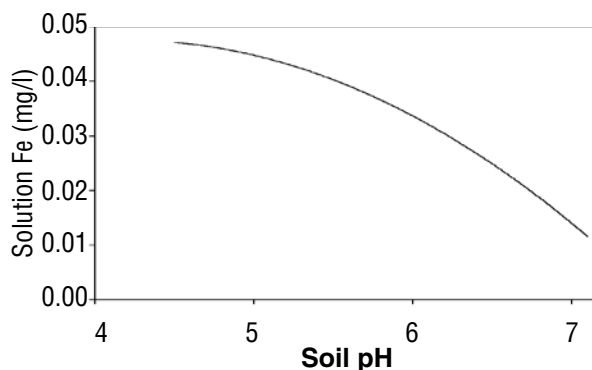


Figure 3.—The relationship of soil pH and iron (Fe) in solution extracted from a Woodburn soil.

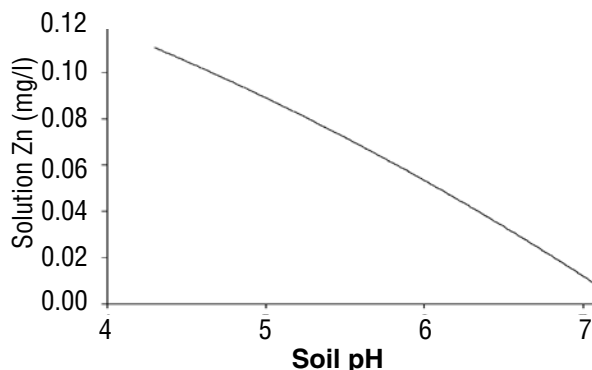


Figure 4.—The relationship of soil pH and zinc (Zn) in solution extracted from Bashaw and Woodburn soils.

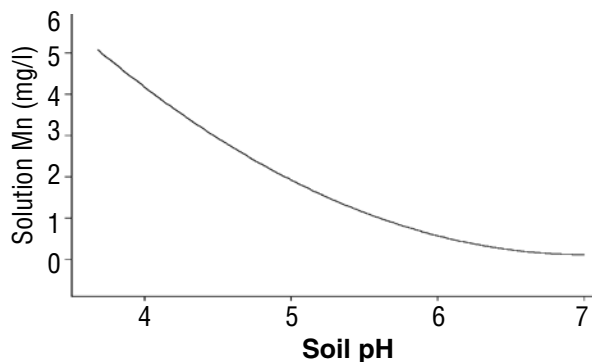


Figure 5.—The relationship of soil pH and manganese (Mn) in solution extracted from a Bashaw soil.

For example, potatoes have a very high nutrient requirement. Phosphorus, zinc, and manganese can be deficient without high fertilizer rates. Research from Idaho shows that the amount of phosphorus and other nutrients needed to adequately fertilize a potato crop increases as soil pH increases.

Lime-induced chlorosis from fertilizer

Chlorosis can be caused by lime and fertilizers that increase bicarbonate (HCO_3^-) concentration in soil solution. Carbonate (lime) or bicarbonate raises pH, inhibiting plants' ability to obtain iron from the soil solution (Figure 3, page 5). Bicarbonate can also reduce a plant's capability to use iron already within the plant (Marschner, 1986). Lime-induced chlorosis has been observed in blueberries.

Lime-induced chlorosis is temporary and may last a few months or a few years. It will be corrected when soil pH is reduced. The short-term effect of lime-induced chlorosis usually is not detrimental for homeowners with perennial plants such as maple trees, but it may be a significant problem in the nursery industry, where appearance is critical. Lime-induced chlorosis in blueberries will not correct itself quickly; therefore, acidification may be necessary.

To avoid lime-induced chlorosis when applying lime to correct low (below 4.5) soil pH, add small annual applications. Lime applications should be based on soil testing. Test soil after 6 to 8 months and add more lime if pH is still low.

Nitrogen fertilizers such as urea (46-0-0) can cause lime-induced chlorosis because they raise the bicarbonate level in the soil solution. The conversion of urea [$(\text{NH}_2)_2\text{CO}$] to ammonia releases carbon dioxide (CO_2) into the soil solution, thus increasing carbonate concentrations (see "Conversion of urea to bicarbonate," below).

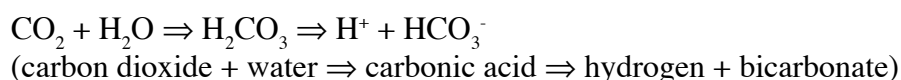
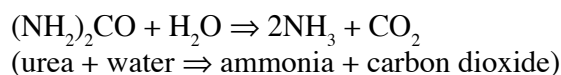
Lime-induced chlorosis is most often observed in the *Vaccinium* species, such as blueberries, and in rhododendrons and azaleas. For these plants, apply nitrogen as ammonium phosphate, ammonium sulfate, or some similar form; avoid urea if possible. When urea is used, make several small applications rather than a single large application.

Lime-induced chlorosis from irrigation water

Irrigating with water high in carbonate (rare) and/or bicarbonate (common) can cause excess bicarbonate in the soil solution and high soil pH. Some crops irrigated with high-bicarbonate water exhibit lime-induced chlorosis. The expression of lime-induced chlorosis depends on factors such as drainage, climate, soil pH, and plant variety.

The best way to predict potential iron chlorosis problems from irrigation water is to monitor water chemistry, soil pH, and crop performance. (See "Calculating calcium carbonate in irrigation water," page 7.) Chlorosis is most likely to occur when soils with pH greater than 8.0 are irrigated with high-pH and high-bicarbonate water.

Conversion of urea to bicarbonate



A common way to reduce carbonates in irrigation water is to inject an acid. (See “Acidifying irrigation water with sulfuric acid,” below). Irrigation water commonly is acidified to pH 6.5 or below. Acidification of high-pH irrigation water usually is the most cost-effective treatment.

Where poor-quality irrigation water is used, soil acidification requires continual applications of acidifying materials and monitoring of plant health and soil pH.

Soil and climatic lime-induced chlorosis

Recent research with Concord grapes indicates that lime-induced chlorosis can be caused

by a combination of soil and climatic factors. Wet, cool soil conditions, either from winter rains or irrigation during the spring, limit root growth and root function. Impaired root function decreases grapes’ ability to extract iron from the soil, increasing the risk of iron chlorosis.

Solutions to iron chlorosis

The best way to avoid iron chlorosis in high-pH soil is to choose species or varieties known to be resistant to iron deficiency. If this is not feasible, iron fertilization and soil acidification are possible solutions to the problem. This section discusses these topics. Ensuring adequate drainage also helps with iron availability.

Calculating calcium carbonate in irrigation water

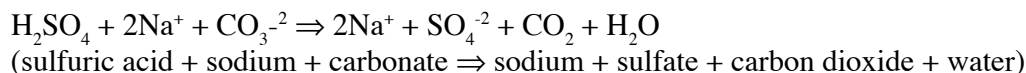
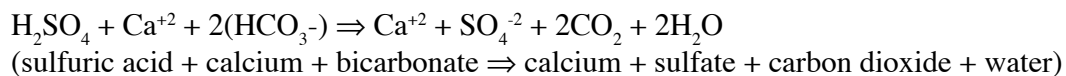
Pounds of calcium carbonate equivalent ($\text{CO}_3 + \text{HCO}_3$) in 1 acre-foot of water = meq/liter bicarbonate x equivalent molecular weight of calcium carbonate (50) x [weight of 1 acre-foot of water (2.7 million) ÷ 1 million]

For example, if irrigation water has 5 meq bicarbonate per liter (305 ppm), and it is all present as calcium bicarbonate, then:

$$5 \text{ meq} \times 50 \times 2.7 = 675 \text{ lb lime (calcium carbonate) per acre-foot of irrigation water applied}$$

You would need to apply 203 pounds of elemental S to the soil for every acre-foot of this water applied. To neutralize with concentrated sulfuric acid (36 N), 170 gallons per acre-foot would be required (see below).

Acidifying irrigation water with sulfuric acid



Acidify irrigation water by adjusting water pH. Add acid until water pH is between 6.0 and 7.0. Water pH below 6.0 will dissolve metal in irrigation systems, while water pH above 7.0 will leave too much bicarbonate in the water. Water pH can be easily checked using paper pH sticks. The accuracy is adequate.

Iron fertilization

Adding iron fertilizer to alkaline soil by broadcast application generally is not effective. Iron fertilizer dissolves in the soil solution, but quickly forms insoluble minerals that plants are unable to absorb. Iron deficiency sometimes can be corrected with the following materials:

- Chelated iron fertilizers
- Acidifying iron fertilizer materials (when placed in a concentrated band)
- Foliar iron sprays
- Iron drenches

Chelated iron. Although most iron fertilizers generally don't work well to supply iron to plants, applying iron in a chelated form greatly enhances its availability. This material is relatively expensive and generally not used for lower value crops. Chelates are short lived, as microbes degrade them. Chelate stability is also a function of soil pH. DTPA, a common chelate, is not stable when soil pH is greater than 8.0, making it unsuitable for high-pH situations. Other chelates are stable over a broader soil pH range.

Banded fertilizer. Ferrous sulfate fertilizer (about 100 lb per acre) adequately supplies iron to field corn when applied in a concentrated band near the seed (2 inches below and to the side). For orchards, injecting iron fertilizer materials 12 to 24 inches deep into the soil every few feet around the drip line corrects iron deficiencies.

What is a chelate?

The word chelate is derived from the Greek word for claw. A chelated iron molecule is wrapped by another larger molecule such as EDTA or DTPA. A good analogy is to visualize a baseball and a mitt. The baseball represents the iron, and the mitt is the chelate. The chelate slows interaction with the soil and prolongs availability of the iron. Soil pH affects how well an individual chelate will work.

Foliar sprays. Foliar iron sprays are used to correct iron deficiency where crop appearance is critical or where soil amendments are not feasible or do not produce desired results. Foliar sprays usually are short lived because iron is not translocated to new growth. They must be applied at least every other week during the growing season. Foliar iron sprays, combined with a soil acidification program, may be the only way to correct a severe iron deficiency.

A foliar iron spray can be made for "spot" use by dissolving 2 oz ferrous sulfate in 3 gal water and adding 2 Tbl mild household detergent. The detergent acts as a wetting agent. Apply foliar iron sprays late in the day when temperatures are lower to avoid leaf burning.

For commercial application, add 50 oz ferrous sulfate and 1 pt surfactant to 100 gal water. Alternative recipes for iron sprays can be found in *Iron Deficiency in Plants* (Agricultural Research Service, 1976). Iron chelates can also be used in foliar sprays.

Soil drenches. Iron can be applied directly to the soil as a drench. This method usually is not suitable for large acreages. The most likely use for this application is in a landscape, nursery, vineyard, or orchard where only a few trees or vines need to be treated. To apply an iron drench for dormant trees, vines, or shrubs, dissolve 1 lb ferrous sulfate in 1 gal water. To determine how much to apply, measure the

Recommendations— Iron fertilization

- Test soil pH annually.
- If using soil-applied iron fertilizers, apply about 100 lb per acre as a band.
- Foliar fertilization will help minimize iron chlorosis symptoms. Mix 100 gal water, 50 oz iron sulfate, and 1 pt surfactant.
- For individual trees, apply 1 lb ferrous sulfate for every foot diameter of the leaf drip line as an iron drench.

diameter of the tree's drip line. Apply 1 gal of prepared solution for every foot of drip line diameter, with a minimum of 1 gal per plant.

To apply the drench, dig a 3- to 6-inch-deep trench around the leaf drip line and pour solution into the trench. If the drip line is too large to conveniently excavate a trench, dig evenly spaced holes around the drip line, making each hole large enough to accommodate a gallon of liquid. After the solution has soaked into the soil, replace the soil in the holes or trench.

Acidification

Lowering soil pH of alkaline soils is more difficult and expensive than raising the pH of acid soils with lime. Soil with pH greater than 8.4 requires the addition of elemental sulfur to lower pH and the addition of gypsum (calcium sulfate) to lower soil sodium content. Soil with pH less than 8.4 generally requires only elemental sulfur to lower pH.

Soil with high pH and carbonates is extremely difficult to acidify and solve iron deficiency problems. Poorly drained soils or areas that are continually wet also are extremely

difficult to acidify. In these soils, high water tables limit root growth, reducing a plant's ability to take up iron. Consider artificial drainage before attempting soil acidification. Without adequate soil drainage, lowering pH is not economical.

The following section discusses materials used for soil acidification. See "Methods for acidifying soil in the inland Pacific Northwest" (page 11) for specific recommendations and methods.

Sulfur as an acidifying material. The primary material used to acidify soil is elemental sulfur (S). Sulfur in the form of sulfate (SO_4^{-2}), including gypsum, is **not** an acidifying material.

Sulfate-containing materials are added to the soil for a variety of reasons, including acidification (see "Fertilizers as acidifying materials," page 11), but the sulfate in these materials does not acidify soil. For example, gypsum (CaSO_4) is added to soils that have both high pH and high levels of sodium. It is an important material used in reducing soil sodium (see "Elemental S Reactions in Soil," below). The soil pH is lowered as a result of decreasing sodium.

Elemental S reactions in soil

Acidification

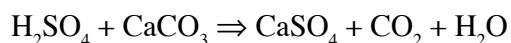
Sulfur is oxidized by bacteria to form sulfuric acid.



(elemental S + oxygen + water + thiobacillus + time \Rightarrow sulfuric acid)

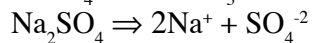
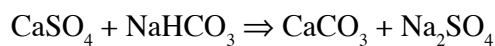
Production of gypsum and leaching of sodium

After elemental S has changed to sulfuric acid and reacted with lime in soil, gypsum is produced. This reaction is fairly rapid. One ton of elemental S is equivalent to 5 tons of gypsum.



(sulfuric acid + lime \Rightarrow gypsum + carbon dioxide + water)

Gypsum reacts with sodic soil, producing sodium sulfate, which is removed by leaching.



(gypsum + sodic soil \Rightarrow calcium soil + sodium sulfate)

(sodium sulfate \Rightarrow sodium + sulfate)

Sulfate is also present in ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$ fertilizer, a common nitrogen fertilizer that acidifies soil. However, the ammonium in fertilizers—not sulfate—is responsible for acidification.

Only elemental S or reduced sulfur materials such as ammonium thiosulfate produce acidity. Acidification from elemental S occurs when elemental S is oxidized by bacteria to form sulfuric acid (see “Elemental S reactions in soil,” page 9). This reaction is temperature-dependent, and the process requires several years to complete. Incorporation of elemental S will increase the rate of conversion to sulfuric acid.

Reducing soil pH may take many years and several elemental S additions. Check soil pH periodically to confirm the need for additional elemental S. For most agronomic crops, continual elemental S additions generally are economical only as sulfur fertilizer. Some high-value horticultural crops can warrant high elemental S additions to acidify soil.

Note that OSU fertilizer guides recommend a maximum of 100 lb of elemental S for S nutrition. Although this rate will supply S to

the plant, it will not be enough to acidify the soil. If you apply enough elemental S or gypsum for soil acidification, additional S for plant nutrition will not be needed.

Elemental S reactions add soluble salt (sulfate) to the soil (Figure 6). This salt will need to be leached. A large single elemental S application, or multiple applications in 1 year, can increase soluble salts to a level detrimental to plant growth. Monitor soluble salts after adding elemental S.

Usually, elemental S and gypsum rates are determined by economics rather than by the amount needed for full pH reduction. These materials can cost as much as \$240 per ton. Generally, a minimum broadcast rate is 500 lb per acre. A single broadcast rate can easily exceed several tons per acre. Elemental S and gypsum rates depend on pH, soil texture, crop, and a grower’s desire to correct pH. For example, 6 inches of soil with 1 percent calcium carbonate contains 10 tons lime per acre and requires 6.5 tons elemental S (100 percent) to neutralize.



Figure 6.—Reaction of elemental S with calcium bicarbonate produced salts that were not leached from the root zone of these blueberry plants. The soluble salt concentration stunted or killed plants (left). Surviving plants continue to exhibit iron deficiency (right).

An alternative to elemental S is the application of acid to the soil (for example, sulfuric acid) to quickly correct alkaline soil temporarily. Unfortunately, acids are very dangerous to use and must be handled with special equipment.

Growers commonly inject or apply small quantities of acid, but these rates rarely have a significant effect on soil pH. Injecting acid may increase water infiltration and improve soil physical properties. Most soils require several hundred or thousand pounds of acidifying material per acre in a single application to effectively lower pH for a single growing season.

Fertilizers as acidifying materials. Ammonium-containing fertilizers can acidify soil. This process is slow compared to acidification by elemental S. In a long-term study in dryland wheat in Pendleton, Oregon, ammonium sulfate was applied at the rate of 135 lb N/acre. Soil pH decreased at the rate of 0.03 to 0.05 unit per year (Rasmussen and Dick, 1995; Rasmussen and Rhode, 1989).

In this example, 10 years of ammonium-containing fertilizer applications were necessary to attain the same degree of acidification as that achieved with a single application of elemental S. The soil in this study was acidic (pH 6.3), with little or no carbonate. When carbonates are present, significant acidification with ammonium-containing fertilizer is not practical. Columbia Basin soils are sandy with little natural carbonate. Farming and nitrogen applications over the past 50 years have acidified many irrigated fields.

Recommendations— Soil with pH between 6.5 and 8.0

- Acidification usually is not required.
- If acidification is needed, follow recommendations in *Acidifying Soil for Crop Production West of the Cascade Mountains*, EM 8857-E.

Methods for acidifying soil in the inland Pacific Northwest

Acidifying soils with pH between 6.5 and 8.0

Soil with a pH between 6.5 and 8.0 rarely needs to be acidified. Most agronomic and horticultural crops grow well in this pH range, although iron chlorosis may occasionally occur. Irrigation water quality, particularly bicarbonate content, will increase chlorosis and the need for acidification. Where acidification is needed for soil with pH between 6.5 and 8.0, follow instructions in the publication *Acidifying Soil for Crop Production West of the Cascade Mountains* (<http://extension.oregonstate.edu/catalog/pdf/em/em8857-e.pdf>).

Acidifying soils with pH greater than 8.0

Soil pH east of the Cascade Mountains is commonly above 8.0. Before attempting acidification, determine whether the soil is calcareous or sodic. Calcareous soils contain free lime (calcium carbonate) and generally have a pH of 8.0 to 8.4. Sodic, or sodium-affected, soils have a soil pH of 8.4 to 10.0 or even higher.

High-pH soils with free lime produce a fizzing reaction when a drop of weak acid, such as household vinegar, is added to the soil. Carbonate content can be estimated by observing the fizz reaction. Hold soil at normal reading distance and apply a few drops of vinegar. A

vigorous fizz usually means the soil has more than 3 percent calcium carbonate. A mild fizz means the soil has approximately 1 to 2 percent carbonate. A fizz that can only be heard means the soil probably has less than 1 percent carbonate.

Consult a local soil expert if you are unsure whether you are dealing with calcareous or sodic soil.

Acidification of calcareous soils

To acidify soils that contain calcium carbonate as determined by the fizz test, apply 1 ton/acre elemental S per year for at least 2 consecutive years (see Table 3). Monitor soil pH and continue applying the same amount of material annually until the desired soil pH is reached. Wait a year for the soil to equilibrate, check the soil pH, and add more S if pH is too high.

Soils containing calcium carbonate are difficult to acidify. For example, let's calculate the

amount of sulfur needed to treat a soil that has a calcium carbonate level of 5 percent. Assuming we treat the top foot of soil, 5 percent calcium carbonate represents 100 tons of lime per acre. One ton of elemental S will neutralize 3 tons of calcium carbonate. Therefore, 33 tons of elemental S would be needed to neutralize the calcium carbonate present in the top foot of soil. This assumes no additional carbonate is added by irrigation water.

This calculation is for **demonstration purposes only**. The addition of 33 ton/acre of elemental S is impractical and is not recommended. Success can be achieved, however, with smaller additions. Instead of acidifying an entire foot of soil, treat a portion of the rooting environment so that plants can grow without pH-induced chlorosis. Localized acidification can be accomplished by banding or creating acidifying holes depending on the crop grown and individual circumstances.

Reclamation of sodic soil

Sodic, or sodium-affected, soils usually have a pH between 8.4 and 10.0. Soil pH greater than 8.4 is caused by the presence of sodium bicarbonate (alkali) in the soil profile.

Sodium bicarbonate (NaHCO_3) accumulates where soil is poorly drained and where the water table allows evaporation to concentrate sodium salts at or near the soil surface. This

Recommendations— Calcareous soils

- Soil test.
- Try banding acid fertilizers.
- Broadcast elemental S based on Table 3.

Table 3. Recommended elemental sulfur treatment needed to overcome iron chlorosis in a calcareous soil, based on vinegar (“fizz test”) assessment of calcium carbonate in the soil.

Fizz test result	Estimated carbonates present* (%)	Annual addition of elemental sulfur (ton/acre)	Duration (years)
None	0	none	none
Heard (barely audible)	0–1	0.5–1	1
Slight (few bubbles)	1–2	1	1–2
Moderate (several bubbles)	2–3	1	2–3
Vigorous (many bubbles)	>3	1	3+

*An analysis for calcium carbonate equivalent is a more precise way of determining calcium carbonates present.

situation often is referred to as subirrigation, or the movement of water from lower in the soil profile toward the surface. As water at the soil surface evaporates, dissolved salts and/or sodium remain. Sodium and/or salts accumulate, soil pH rises, and iron chlorosis and other problems may occur. These soils are called sodic soils if only sodium is a problem or sodic-saline soils if both sodium and salts are a problem.

Shallow groundwater resulting in subirrigation is found in many areas of the inland Pacific Northwest, including floodplains, near waterways, adjacent to leaky irrigation canals, and where the water table has risen due to local irrigation or dam construction.

The amount of subirrigation and the time of year the water table is high influence the severity of a sodic and/or salt problem and the expression of iron chlorosis (Figure 7).

Soils with salt and alkali accumulation need improved drainage before a pH reduction program will be successful. Without correcting drainage, a saline (high electrical conductivity) problem will become more severe with the addition of soil amendments, which are salts.

In addition to improved drainage, reclamation of sodium-affected soil requires both acidification and leaching of sodium (and other salts, if present). For saline-sodic soils, the sodic problem must be corrected before reducing salinity. To reduce sodium, either apply calcium as gypsum or apply an acid to dissolve calcium already in the soil and follow with leaching. Apply elemental S for acidification. Initial rates of 1 ton elemental S/acre and 1 ton gypsum/acre may be needed.

Fruit trees and ornamentals

Acidification of soil around an established tree does not require a broadcast application of acidifying material. The objective is to acidify a small zone from which the plant can obtain nutrients. Dig a minimum of 4 holes (preferably 8 to 12) evenly spaced around the drip line of

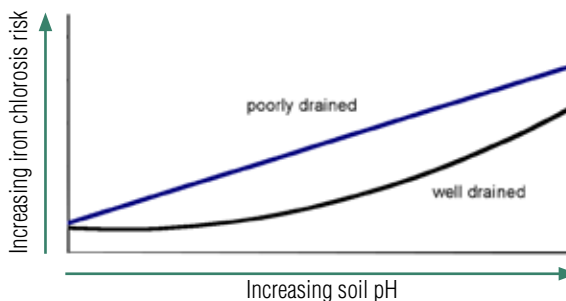


Figure 7.—Hypothetical influence of soil drainage on soil pH and the likelihood that iron chlorosis will be seen in susceptible plants.

Recommendations—Sodic soils

- Soil test for pH, sodium, carbonates, calcium, and electrical conductivity.
- Make sure water can drain through the root zone.
- Apply 1 ton/acre gypsum or other calcium source.
- Broadcast elemental S based on Table 3 (page 12) if adequate calcium is present.



Figure 8.—A large, cemented clod of soil taken from an apple orchard in eastern Washington. Before the center of the clod was treated with elemental sulfur and N-phuric, the soil pH was 8.9. After S application, the soil pH at the clod surface was 2.5, thus demonstrating how small, localized changes can impact pH.

the tree. The holes should be 8 to 12 inches deep. Mix 1 cup elemental S with the soil removed from each hole or add ½ cup N-phuric to each hole. Return the soil to the hole. Alternatively, you could use ½ cup sulfuric or phosphoric acid per hole, but these materials are much more hazardous to handle. A small amount of iron and manganese sulfate can be added to each hole to help increase iron and manganese availability. An iron drench also may be used (see pages 8–9).

When elemental S is added to the soil in concentrated areas such as holes around a tree, the pH of the treated soil can differ dramatically from that of the surrounding soil. Bulk soil pH can be above 8.0, while pH in the soil immediately surrounding the hole may be as low as 2.5. Figure 8 (page 13) shows how small, localized applications can affect soil pH without amending the whole soil. Apple roots were growing in the pictured clod even though the pH was well below what is considered suitable for fruit trees.

Remember, you are changing a small area; don't be shocked if soil pH in that area is well below what would be considered adequate for plant growth. Iron will be supplied to the plant from the treated area, while the rest of the roots continue to take up water and other nutrients from the untreated bulk soil.

Trunk injections of an iron solution may work as a last resort measure. This method should be tried on an experimental basis prior to treating a large acreage.

Other considerations

Sodium can accumulate even in well-drained soils when rainfall is inadequate to leach it deeper into the soil profile. In the case of well-drained soil that has never been farmed, the application of low-bicarbonate irrigation water and commercial fertilizer will facilitate leaching of the naturally accumulated sodium. Most surface waters in the inland Pacific Northwest are relatively pure and low in bicarbonates. Soil

Recommendations—Fruit trees and ornamentals

- Soil test for pH, sodium, carbonates, and electrical conductivity.
- Apply elemental S in four to eight holes around each tree. Apply 8 oz (1 cup) of elemental S in each hole.

amendment may not be needed in this situation or, if needed, only initially.

Irrigation water quality

As discussed on pages 6–7, irrigation water that is high in bicarbonate/carbonate can cause high soil pH and lime-induced chlorosis. See page 7 for possible solutions to this problem.

Irrigation water high in sodium bicarbonate/carbonate and low in calcium also can lead to sodic soils when leaching is not adequate to remove the sodium. Injecting gypsum into the irrigation water can be successful in maintaining adequate soil pH and soil infiltration rate and in keeping sodium from accumulating. Gypsum injection allows sodium to leach because calcium from the gypsum replaces the sodium. An even application with gypsum injectors through pivot systems is difficult, however. See *Irrigation Water Quality for Crop Production in the Pacific Northwest*, PNW 597-E, for more information.

Soil amendments and fertilizers

Some soil amendments, such as compost and manures, can be detrimental if they are high in pH, salt, or sodium. Always analyze soil amendments for pH, EC, and sodium before application.

Soil amendments that are neutral in pH and low in sodium can aid in reclamation of sodic soils by improving aeration and water infiltration, which facilitates leaching of sodium. Amendments can improve crop performance and increase the rate of acidification.

Lime-induced chlorosis can be increased by the addition of a poor choice of amendment, lime, or urea fertilizers. See pages 6–7 for additional explanation and solutions.

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Summary

Acidification of soil sometimes is necessary for optimum plant growth. Plants with yellow leaves—similar to the symptoms for nitrogen and sulfur deficiency—may be suffering from iron deficiency. Iron deficiency occurs when soil pH is higher than a plant can tolerate. Adding iron fertilizer to the soil rarely is successful in correcting an iron deficiency. The most common solution is to acidify the soil with elemental sulfur. If you attempt to acidify your soil, keep in mind the following.

- Proceed cautiously, as soil pH can be lowered beyond the desired level, especially in sandy soils.
- Monitor the change through annual soil testing. Sample soil at the same time each year.
- Keep complete records of the amount of material added, the amount of mixing, and the time of year the acidifying material was added.
- Do not treat sodium-affected soils without correcting drainage problems.

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