Soil Fertility and Nutrient Management

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Soil tests aid vegetable growers with their soil fertility and fertilizer application programs. Soil tests are most useful when growers keep accurate records for each field that include the amount of fertilizers and other soil amendments they applied, crop yields, and rotations. These records allow growers to determine trends in soil fertility and crop response to applied fertilizers over several years.

Efficient vegetable production relies on growers adjusting lime and fertilizer applications to their soils' existing pH and fertility levels. Growers can increase their net returns if they maintain proper soil fertility, which can reduce crop losses from physiological disorders. Applying nutrients based on crop needs and existing soil nutrient levels also reduces the movement of nutrients into groundwater and surface waters.

Take soil samples at the same time each year, preferably in the fall or early spring. Soil pH varies seasonally, so comparing winter and summer samples is difficult. A typical soil test for plants usually determines pH, lime index (also called buffer pH), available Bray P1 phosphorus (P), exchangeable potassium (K), calcium (Ca), magnesium (Mg), and cation exchange capacity. It also includes the% base saturation of Ca, Mg, and K.

In addition to the routine pH test, growers should test soils that are susceptible to large variations in soil pH for salt pH. The salt pH provides a more accurate estimate of the true acidity in these soil types by simulating the effects of fertilizer salts on soil pH.

There are also tests to determine organic matter and other nutrients, including sulfur (S), manganese (Mn), boron (B), and zinc (Zn). Some labs test for microbial activity and water-soluble carbon, which can predict the release of nitrogen and phosphorus from organic sources.

Your land-grant university or extension service can provide you with a list of soil testing labs in your area.

Soilless Growing Media

Test soilless growing media used in transplant or crop production for pH and total soluble salts before using it. Request a test specifically for "soilless media" from the lab. If the crop will be grown in soilless media for more than a month, regularly test the media or plant tissue to catch any nutrient imbalances that may affect crop growth and yield.

Interpretation of Standard Soil Test Results

Organic matter (O.M.) content of the soil is usually reported as a% by weight, determined in a lab by loss-on-ignition. It is composed of the remains of living things after initial decomposition has occurred. This relatively stable O.M. commonly ranges from 1% to 7% in mineral soils. Soil that has received heavy applications of compost may have higher values. Soils with O.M. greater than 20% are categorized as organic or 'muck' soils. Nutrient and lime recommendations differ for muck and mineral soils. O.M. content also influences the effectiveness of some soil applied herbicides. In sandy and sandy loam soils, organic matter improves water-holding capacity.

When management takes these factors into account, vegetables are successfully grown in soils with a wide range of O.M. However, O.M. in cultivated soils declines over time to the detriment of soil fertility. You can add O.M. to the soil by various methods using green manure crops, cover crops, crop residues, animal manures, mulches, and composts. Additions of undecomposed or partially decomposed materials feed soil microorganisms and increase biological activity in the soil. This promotes development of soil aggregates, thus improving drainage, soil tilth, and soil structure. Some laboratories use additional methods to measure less stable forms of soil organic matter that support microbial growth.

Soil pH (sometimes called active soil acidity) is based on the pH scale, which measures the acidic or basic reaction of the soil. A pH less than 7 is acidic; a pH greater than 7 is alkaline. When soil pH is too low for good crop growth, adding lime will raise the pH. Natural processes and agricultural practices tend to lower pH over time, so it is important to measure it every year or two. When soils are alkaline, the testing laboratory may recommend applying sulfur (S) to lower the pH to a level that allows nutrient availability in the soil.

Lime index (sometimes called "buffer pH") measures reserve soil acidity. The lime index is used to make limestone recommendations. It usually takes lime four to six months to correct soil acidity. Your land-grant university or extension service can provide you with liming recommendations specific to your state.

Phosphorus may be reported as P (phosphorus) or P_2O_5 (phosphate). The units for P and other nutrient values may be given as parts per million (ppm) or pounds per acre. The value is an estimate of the amount of phosphorus in the soil that the plant can use for growth. Applying P_2O_5 fertilizer at 100 pounds per acre will increase the soil P test level by about 10 pounds per acre.

Potassium may be reported as K (potassium) or K_2O (potash). The test value estimates the amount of K available per acre. About 50% of the potassium applied in fertilizers is fixed in the soil and is not immediately available to plants — this can vary by soil type and clay content. Soil K declines due crop removal, leaching, and soil erosion.

Calcium (Ca) and magnesium (Mg) soil test values represent the amount of Ca and Mg available in the soil. Ca and Mg values generally are low when soils are acidic. Levels are usually sufficient when pH and the lime test index are at proper levels.

Cation exchange capacity (CEC) is a measure of the soil's ability to hold exchangeable cations such as hydrogen (H), Ca, Mg, K, sodium (Na), iron (Fe), and aluminum (Al). CEC is measured in terms of milliequivalents (meq) per 100 grams of soil. Soil type and soil organic matter determine CEC. Clay-, silt- and loam-type soils generally have a higher CEC than sandy soils because they have many more exchange sites to hold cations. High-CEC soils generally hold nutrients better than low-CEC soils. High-CEC also lose smaller amounts of nutrients due to leaching.

Here are the typical CEC ranges of various soil types:

Soil Texture	CEC Range
Sands	5-15
Silts	8-30
Clays	25-50
Organic soils	50+

Base saturation is the%age of the total CEC occupied by basic cations such as Ca, Mg, and K. Base saturation is related to soil pH and soil fertility. On acid soils, the% base saturation of Ca and Mg is low. The saturation of the different cations is important because plants take up some cations more easily than others. The base saturation for Ca should be 60% or more; Mg should range between 10 and 15%; K should range from 1 to 5%. Excess levels of one cation can reduce the uptake of another. Some soil scientists believe that there should be specific Ca:Mg ratios and Mg:K ratios (2:1). Most horticulturists believe that if base saturation levels are at the minimum levels suggested here, then it is not important to maintain specific proportions or ratios.

Crop Nutrient Requirements

Vegetable crops require 17 essential elements (nutrients) for development and reproduction. In addition to carbon (C), hydrogen (H), and oxygen (O), plants need macronutrients in large concentrations and micronutrients in relatively small concentrations.

Each crop has a crop nutrient requirement (CNR) for particular nutrients. The CNR is defined as the total amount of the nutrient (in pounds per acre) the crop requires to produce optimum economic yield. The concept of optimum economic yield is important in vegetable production, because applying a certain amount of a nutrient might produce a lot of biomass, but may produce negligible marketable product due to small fruit size, small number of fruits, or large number of culls and small number of marketable fruits. Always consider fruit number, size, and quality in the CNR concept for vegetable production.

The best way to achieve the CNR is to begin with a soil test. The results from a soil lab analysis include recommendations for the amount of lime or sulfur needed to balance the soil pH, and indicate the amount of fertilizer needed to deliver the CNR.

Macronutrients

Nitrogen (N), phosphorus (P), and potassium (K) are the primary macronutrients, and they are commonly applied in fertilizers for field vegetable production. Plant nutrient recommendations are often given as pounds of N, pounds of phosphate (P_2O_5) and pounds of potash (K_2O) per acre.

It is up to growers to figure how much fertilizer or product they must apply to meet the suggested recommendations. This can be tricky, because growers may need more than one kind of fertilizer product to meet the recommendations.

Fertilizer products are required to list the% N, P_2O_5, and K_2O equivalent they contain — and the products are listed in the order: N-P-K. For example, a fertilizer labeled 10-10-10 contains the equivalent of 10% N, 10% P_2O_5, and 10% K_2O. So a pound of this fertilizer would contain 0.1 pound each of N, P_2O_5, and K_2O. Urea labeled 46-0-0 contains 46% N, 0% P_2O_5, and 0% K_2O. Potassium chloride (muriate of potash) labeled 0-0-60 contains 0% N, 0% P_2O_5, and 60% K_2O. Organic fertilizers are also labeled this way — a 3-2-2 product contains 3% N, 2% P_2O_5, and 2% K_2O. It is important to note that some of the N and P in organic fertilizers require warm, moist soil and microbial activity before it is available to plants.

Let's say a nutrient recommendation calls for 100 pounds of N and 100 pounds of K_2O per acre.

A grower could meet that recommendation by using 217 pounds of urea (217 pounds of urea X 0.46 N = 100 pounds of N) and 167 pounds of potassium chloride (167 pounds of potassium chloride X 0.60 K_2O = 100 pounds of K_2O).

A grower could also meet that recommendation by using 1,000 pounds of premixed 10-10-10 fertilizer (1,000 pounds of fertilizer X 0.10 N = 100 pounds of N; 1,000 pounds of fertilizer X 0.10 K_2O = 100 pounds of K_2O).

But that same fertilizer would also supply 100 pounds of P_2O_5 that is not needed. So, using such a fertilizer could be a waste of money and could pollute surface or ground water.

If you choose a premixed fertilizer, select the ratio of nutrients that comes closest to the amount of recommended nutrients. It is not necessary to be exact as long as any differences are reasonable. If you can't get to the recommended nutrient application using premixed fertilizers, it is fine to first make a base application using a standard fertilizer ratio, and then apply individual elements to reach the recommended nutrient levels.

For example, you can supply extra N with urea or urea ammonium nitrate (UAN) solution; you can supply extra K with muriate of potash. Custom-blended fertilizers can be made to almost any desired ratio.

Nitrogen (N)

Standard soil tests aren't very useful for predicting how much N fertilizer you need to apply to optimize yield and quality. The recommendations in this guide are based on data from relevant field trials. Adjust these recommendations according to experience, soil type, pH, cropping history, additions of organic matter, and crop culture system.

For example, suppose your vegetable crop is following soybeans, alfalfa, or a grass-legume hay crop. If your soils have more than 3% organic matter, you may not need to add any sidedressed N. If your soils have less than 3% organic matter, then half the total N can be applied preplant and the other half sidedressed early in the crop growth cycle. Now suppose your vegetable crop is following corn, rye, oats, wheat, or a previous vegetable crop. There may be no residual soil N available, so the crop may benefit from additional sidedressed N.

Plants can take up N in the form of ammonium (NH_4^+) or nitrate (NO_3^-). In the soil, ammonium is converted into nitrate, and vice versa, by particular sets of microbes. When soil pH is near neutral (pH 7), and the soil is moist and warm, the microbial conversion of ammonium to nitrate (nitrification) is rapid, and crops generally take up nitrate. In acid soils (pH lower than 6), nitrification is slow, and plants will take up a higher%age of N as ammonium.

Volatilization from N fertilizers that contribute ammonium to the soil (such as urea) is likely to be high at higher soil pH levels. However, depending on soil temperature and moisture, volatilization can be significant at lower soil pH levels, too, especially if the soil is dry and the fertilizer is not incorporated. To minimize volatilization, apply N in just the quantities plants need during the growing season, incorporate it into the soil, and use slow-release sources when possible.

Soil pH is also an important factor in the N nutrition of legumes. Plants in this family are able to fix N from the soil with the help of several genera of soil bacteria known collectively as Rhizobia. As soils become more acidic, Rhizobia decline in activity, fixing less N.

Phosphorus (P)

P recommendations for vegetables are based on the soil test value, the type of crop, and estimates of crop removal. On mineral soils, most vegetables will benefit from P fertilization if the soil test is less than 35-40 ppm P using the Bray-Kurtz P1 extraction method. If a soil tests report P values based on the Mehlich-3 extraction, multiply these values by 1.35. If the soil test on a mineral soil is more than 80 ppm P, then no additional P is recommended for most vegetables.

Plants absorb P from the soil solution in the form of soluble phosphates. P does not move readily in the soil, and applied P easily reacts with soil minerals so that it is unavailable to the plant. The amount of P in solution at any time is usually extremely low — often less than 1 pound per acre. That is why phosphate fertilizer is applied in bands near the crop when possible, and transplant starter solutions that are high in P are recommended.

The type of mineral that gets formed in the soil depends on the soil's pH. In alkaline soils, P in fertilizers such as mono-ammonium phosphate (11-55-0) usually react with Ca to form calcium phosphate minerals. The P in calcium phosphate minerals is not available to plants, but as plants remove P from the soil solution, the minerals gradually dissolve to replenish the supply of P in the soil solution. Greenhouse and field research has shown that more than 90% of the fertilizer P tied up in calcium phosphate minerals will be available to crops in future years.

In acid soils, P usually reacts with Al and Fe, instead of Ca. Aluminum and iron phosphates do not dissolve as readily as calcium phosphates, so in acid soils, applied P tends to be tied up more than in alkaline soils.

Potassium (K)

K recommendations for vegetables are based on the soil test value, the soil CEC, the type of crop, and estimates of crop removal. The soil test values below are based on ammonium acetate extraction. If a soil tests report K values based on Mehlich-3 extraction, multiply these values by 1.14.

Vegetables usually benefit from K fertilization if the soil test is:

- Less than 85 ppm K in soil with low CEC (4 meq/100 g).
- Less than 115 ppm K in soil with med CEC (16 meq/100 g).

The maximum annual K recommendation for most vegetables is 300 pounds of K_2O per acre. K fertilization is not usually recommended if the soil test is more than 135 ppm K on a soil with low CEC, or more than 165 ppm K on a soil with medium CEC.

In soils with certain types of clay, K is fixed at specific sites between clay layers. In acid conditions, Al occupies the binding sites that would otherwise trap K, and so K is unbound to soil and is leachable. Liming increases K stability in these soils.

Calcium (Ca), Magnesium (Mg), Sulfur (S)

Calcium (Ca), Magnesium (Mg) and Sulfur (S) are considered secondary macronutrients because plants require them in smaller amounts than N, P, and K.

Ca and Mg usually are deficient in acid soils, and adding the appropriate form of lime solves most Ca and Mg deficiency problems (see Soil pH and Adjustment). When Ca is deficient and there is no need to increase soil pH, you may use gypsum (calcium sulfate) as a source of Ca. Similarly, you can add Mg without affecting pH by using Epsom salts (magnesium sulfate, 10% Mg), sul-po-mag (11% Mg), or finely ground magnesium oxide (e.g., MAGOX, 58% Mg).

If a soil test shows low Mg (less than 50 ppm in Minnesota or less than 40 ppm in other states), apply Mg at 100 pounds per acre broadcast or 20 pounds per acre in the row.

If a soil test shows medium Mg (51-100 ppm in Minnesota or 40-69 ppm in other states) apply Mg at 50 pounds per acre broadcast or 10 pounds per acre in the row.

You can make foliar sprays of Epsom salts at the rate of 10 to 15 pounds in a least 30 gallons per acre to temporarily solve Mg deficiencies during the growing season.

Plants absorb sulfur as sulfate (SO_3^{2-}), and sulfate availability is little affected by soil pH, though elemental sulfur compounds can be used to lower pH. If a soil test indicates a need for sulfur and there is no need to adjust pH, materials such as gypsum (calcium sulfate), Epsom salts (magnesium sulfate), ammonium sulfate, potassium sulfate, or potassium-magnesium sulfate can be used. Make sure to account for the nutrients in addition to sulfur that these materials supply.

Micronutrients

Micronutrients include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). Of these nutrients, those most likely to be lacking in Midwest soils used for vegetable production are B and Mn. Zn may also be a concern in some areas.

Deficiencies of micronutrients Mn, Fe, Cu, Zn, and B are more likely in high pH soils, and toxicities are more likely in low pH soils. Conversely, Mo deficiency is more likely in low pH soils.

Manganese (Mn)

Mn deficiency is common in some areas. Mn deficiency occurs primarily on lakebed and fine-textured, dark- colored soils with high pH. Cool, wet conditions tend to intensify Mn deficiency. Beans, beets, onions, spinach, and tomatoes have high requirements, but deficiencies also are reported for cucumbers, peppers, and turnips.

Apply manganese sulfate at 2 to 4 pounds per 100 gallons per acre to eliminate deficiency problems observed during the growing season. Fungicides containing Mn can also help correct deficiencies.

Boron (B)

B leaches readily, so responsive crops often need annual applications on sandy loam, loamy sand, sandy, and muck soils. Deficiency symptoms include browning on cauliflower heads, cracked stems on celery, blackheart on beet, and internal browning on turnip.

Broccoli, cauliflower, celery, beet, turnip, and rutabaga are likely to respond to B applications of 3 to 4 pounds per acre when soil levels are low. Cabbage, carrot, lettuce, parsnip, radish, spinach, and tomato show a medium response and usually benefit from 1 to 2 pounds of B per acre.

Bean, peas, and cucumber are sensitive to B, so do not apply it to these crops.

You can add B to the soil with Borax (which contains 10.6% B) or Solubor (which contains 20.5% B). B applications are most effective if applied with the fertilizer at preplant or at the time of transplanting.

Mid- or late season foliar applications are not as effective as early granular or foliar applications. It is important not to exceed recommended B rates to avoid toxicity in subsequent B-sensitive crops. Carryover is most likely after a dry fall and winter.

Other micronutrient deficiencies are rare in field-grown vegetable crops in this region.

Fertilizer and the Environment

Nitrogen from both natural (manure, compost, green manure) and synthetic sources can be lost from fields, which can pollute water and increase greenhouse gasses that contribute to climate change. Similarly, natural and synthetic sources of P can move out of cropped areas and pollute waterways. With proper fertilizer management, vegetable producers can minimize environmental impacts and improve fertilizer use efficiency. Growers should know their crops, account for the nutrient values of all soil amendments, and test soils and plants to support their fertilizer decisions.

Split N applications — applying some N before planting and sidedressing the rest during the season — are generally more efficient than complete preplant applications. However, split applications require growers to pay attention to crop growth and sidedress at the appropriate times: before crops are stressed, and early enough to allow crops to mature.

Banding P at planting (with or without some P being broadcast/incorporated) is generally more efficient than broadcasting all P. Sidedressing P is not recommended because it is not mobile in soils.

Generally, K and the minor elements do not contribute significantly to groundwater pollution, but growers should manage them properly to minimize costs and maximize efficiency.

Minimizing soil erosion, timing irrigation properly, and avoiding excess irrigation will also improve fertilizer use efficiency and reduce losses from the field.

Animal Manures and Composts as Fertilizers

Animal manures and composts can provide significant nutrients to plants. The nutrient content of manures varies among animal species and within each species. Nutrients in composts can vary even more and depend on parent material and processing. Test manures and composts to determine the potential nutrient contributions and plan application rates based on their nutrient content. Avoid using composts of unknown origin or parent material. Improperly made composts, be they of rural or urban origin, can contain heavy metals, inorganic debris, diseases, and insects that are unwelcome on your fields.

It is important to consider the timing of manure and compost applications. Fresh manure has potential to “burn” a crop because it often contains high levels of ammonia, and fresh or casually “aged” manure often contains human pathogens. For these reasons, it is rarely acceptable to apply fresh or “aged” manure to food crops while they are growing. Generally, a fall application is acceptable, ideally to a cover crop, and at least nine months before harvesting the next vegetable crop.

Any use of manure or composts should follow current Good Agricultural Practices (GAPs), and mandates of the Food Safety Modernization Act (FSMA). The demands of a particular market may be more stringent. For guidance about GAPS and FSMA, see Produce Food Safety section.

Fertilizer Application Methods

Fertilizer application timing and methods vary from farm-to-farm depending on cultural practices and equipment. This section outlines common practices of efficient fertilizer placement and utilization. These practices can be modified to suit particular situations.

Usually, growers can apply at preplant and disk into the soil 50-60% of the recommended N and all of the P and K fertilizer. This is especially true when the rates of a complete fertilizer will require more than 400 pounds per acre.

We recommend band application for many direct-seeded vegetable crops. This technique applies a concentrated line of fertilizer 2 inches to the side and 2 inches below the seed furrow. This is an efficient way to apply fertilizer, and much of the P and K fertilizer can be applied this way. However, do not make banded fertilizer applications exceeding 80 pounds per acre of N plus K — this can injure seed.

For crops grown on plastic mulch (with or without a raised bed) growers may apply fertilizer just to the bed area. As with broadcast applications, growers can apply a portion of the recommended N, and all of the P and K before planting. If N will be supplied through fertigation during the season, apply only 20 to 50% of the total N before planting. Apply the remaining N with regular drip irrigation at 5 to 10 pounds of N per week until the total recommended for the season has been applied. K may also be applied through drip irrigation if the crop needs more than has been applied to the soil before planting. For more information on the equipment required for fertigation, and its calibration and use, please refer to the Chemical Application and Safety Chapter.

If you apply only part of the recommended N before planting, apply the remainder as a sidedressing when the plants are still young, or apply N through fertigation before and during the period of rapid crop growth. Early sidedress applications are especially important with crops such as sweet corn, broccoli, and cabbage. The total N applied during the growing season (broadcast, plus banded, plus transplant starter, plus sidedressed, plus fertigated) should equal the recommended N rate. Applying more than the recommended rate of N may be necessary when there are leaching rains.

Transplanted crops often respond to a small amount of water-soluble fertilizer in the transplanting water. Special fertilizer grades (such as 14-28-14, 10-52-10, 23-21-17) are used at a rate of 3 pounds per 50 gallons of water. The high-P liquid 10-34-0 can also be used at the rate of 2 quarts per 50 gallons of water. Apply starter solutions at 8 ounces per plant. If dry weather is prevalent, irrigate after setting the plants.

Soil pH and Adjustment

Soil pH describes whether the soil solution is acidic or alkaline. The native pH of Midwest soils varies from quite acidic (pH 5.0 or lower) to quite alkaline (pH 7.5 or higher). Most vegetable crops prefer a pH range of 6.0-6.8 on mineral soils. On muck soils, a pH of 5.5-5.8 is considered adequate. Vegetables grown under acid soil conditions lack vigor and yield poorly. Acid soils restrict the uptake of nutrients such as P and K. Acid soils also make elements such as aluminum (Al) and manganese (Mn) more available to plants so that the plant may absorb enough to be toxic to the plant. Under severe conditions, visible foliage injury can result from magnesium (Mg) deficiency and/or Mn toxicity. Physiological disorders such as blossom end rot are more common on acid soils. In contrast, when soil pH is high, Mn, B, iron (Fe), and certain other micronutrients become less available for plant uptake. Deficiencies of these micronutrients are most likely to occur on mineral soils with pH greater than 7.4.

Liming Recommendations

Fields usually require lime every few years because Ca and Mg are removed in harvested portions of the crop, leached out of surface soil by rainfall, and lost from the field when soil erodes. Lime is also needed to neutralize acidity produced by acid-forming fertilizers.

Growers sometimes need to add lime to correct subsoil acidity. In that case, apply enough lime to bring the surface soil to pH 6.8. The subsoil pH will increase only if you maintain the surface pH near 6.5 or more. Over time, rain will leach the Ca and Mg into the subsoil, raising its pH. Because this downward movement takes several years, the sooner the lime is applied, the better.

In most cases, make split applications when the recommendation is more than 4 tons per acre. This will achieve a more thorough mixing with the acidic soil.

Apply half the lime before primary tillage and half before soil finishing. For best results, apply the lime at least six months before seeding a legume.

If you have a recommendation for a maintenance application of 2 tons per acre or less, you can apply it at any time in the cropping sequence.

Several types of lime that may be used to manage soil pH and/or Ca and Mg are described below.

Calcitic lime (also called high-calcium lime — 50-56% CaO, 1-4% MgO) is the most soluble form and is the preferred type when soil Ca is low and soil Mg is high. It generally reacts the fastest and is the most common form available in some areas.

Magnesian lime (also called hi-mag lime — 32-42% CaO, 5-15% MgO) is intermediate in solubility and is the preferred type when pH, Ca, and Mg are low. The continued use of high-Mg liming materials increases the base saturation of Mg and decreases Ca saturation, which may result in Ca deficiencies during stress periods.

Dolomitic lime (30% CaO, 20% MgO) is the preferred type when Mg is particularly low. Dolomitic lime is the least soluble of the materials.

Hydrated lime (60% CaO, 12% MgO) reacts most rapidly with the soil, but unlike the ground limestones described above, it does not continue to provide liming activity over a period of years. Hydrated lime is caustic to humans and plants, and applicators must take care not to burn plants. Use hydrated lime only in emergencies when rapid changes in soil pH are needed.

Gypsum is not a liming material and does not affect soil pH. It is a crude calcium sulfate product consisting chiefly of calcium sulfate with combined water ($CaSO_4\ 2H_2O$). Although gypsum is not capable of neutralizing soil acidity, it is a source of calcium and sulfur.

Fluid lime is a suspension of finely ground limestone in water, and may contain other dispersing agents. Finely ground limestone reacts with soil more quickly than normal limestone. In fluid lime, 100% of the liming material must pass through a 100-mesh screen, and nearly 80 to 90% must pass through an even smaller 200-mesh screen. The principles of effectiveness of ground agricultural lime also apply to fine or fluid lime. Lime suspensions do not possess any special capabilities compared with conventional agricultural lime that contains a high degree of 60-mesh or finer particles.

Pelletized lime, or pell-lime, is finely ground lime that has been formed into pellets for easy application. Because it is finely ground, it will react quickly in the soil. Unlike regular ag lime, it will not provide residual liming activity over a few years.

Acidifying Recommendations

Ammonium-releasing nitrogen fertilizers have an acidifying effect on soils over time. Elemental sulfur (90% S) can be used to reduce soil pH more drastically if it is too high for good crop growth. The amount required depends on the pH of the soil, the desired pH, and the soil texture or CEC. To achieve a soil pH of 6.5, use the following amounts of sulfur:

Sandy soil pH 8: 1,200 lb./A or 27.5 lb./1000 sq.ft.
Sandy soil pH 7.5: 500 lb./A or 11.5 lb./1000 sq.ft.
Loamy soil pH 8: 1,500 lb./A or 34.4 lb./1000 sq.ft.
Loamy soil pH 7.5: 800 lb./A or 18.4 lb./1000 sq.ft.

Incorporate sulfur into the soil. pH will gradually decrease when the soil is warm (>55 F) and moist enough for biological activity; don't expect it to occur overwinter or in dry soil. In high tunnels where an increase in soil pH results from alkaline irrigation water, smaller annual applications of sulfur can be used to counteract the alkalinity and prevent gradual increase in soil pH.

Plant Tissue Analysis

Plant tissue analysis for nutrients is a useful tool in managing plant health, and a tissue test is usually required to confirm a diagnosis of nutrient deficiency. Tissue testing can be especially helpful when growing a new crop or a familiar crop in a new production system.

Regular tissue tests, especially early in the growing season, will provide early notice of nutrient imbalances so they can be corrected before yield or quality is affected. With high value greenhouse crops regular tissue testing is often a standard part of production.

Concentrations of nutrients in plant tissue that are normal, deficient, or excessive have been identified for most vegetables. The concentrations depend on the plant part and stage of growth. Before collecting plant tissue, contact a tissue testing lab and request instructions for collecting and submitting samples. The specific plant part to collect for tissue analysis varies depending on the crop; often it is a recently mature leaf. The stage of crop growth is important because normal tissue nutrient concentrations change with growth.

If the tissue test is being used to diagnose a specific symptom, collect separate samples from each of these groups:

- Symptomatic plants
- Healthy plants
- Plants with minor symptoms

Comparing the results of these three samples, along with results of soil tests, can help in determining the problem. For assistance in interpreting plant tissue tests, contact your local extension vegetable specialist.

Cover Crops

Cover crops can improve soil biology, chemistry, and physical characteristics in ways that translate into better crop growth. They can help avoid soil erosion, manage soilborne diseases, and retain nutrients.

Growers typically plant winter cover crops after harvest in late summer or fall and terminate the crop the following spring. Depending on the cover crop, termination is accomplished through natural winter-kill, tillage, herbicide, roller-crimping, or tarping, Additional N may be needed to hasten the decomposition of the cover crop and avoid tie-up of soil nitrogen. This is especially important with winter rye, which should be terminated before it is 18 inches tall if it will be incorporated into the soil.

The overwintering capacity of any cover crop is dependent on prevailing winter temperatures and conditions. Depending on winter weather, a cover crop may overwinter in one region and winter-kill in another. Field peas and crimson clover generally winter-kill, but sometimes they do not and must be terminated in the spring.

Spring and summer cover crops are planted before and/or after an annual cash crop. These crops generally are terminated before they are mature. At this stage, the plants usually contain the greatest amount of N and other nutrients, plus an adequate amount of moisture for rapid decay. However, sometimes they are terminated or tilled under in the mature dry stage. At that stage, they do not decompose as readily, and additional N may be needed to aid decomposition.

Crops planted especially for increasing soil fertility are often called green manures. They include legumes such as clovers, alfalfa, and soybean that increase soil N through their partnership with *Rhizobia* bacteria. Also, non-legumes such as thickly sown field corn, sudangrass, or buckwheat serve as green manures by scavenging nutrients and adding fresh organic matter.

Different cover crops frequently require different soil conditions for optimum growth. For example, alfalfa does best on well-drained soils, while Ladino clover grows on poorly drained soils. Some crops, such as cereal rye, have fibrous root systems, whereas others, such as sweet clover, have large tap roots. Whenever it is possible to use a mixture of these crops, the combination results in more organic matter for the soil.

Cover Crops for Vegetable Farms

This table describes some characteristics of cover crops that may be used for vegetable crops. For more information about cover crops, visit the Midwest Cover Crops Council website, midwestcovercrops.org, or refer to the SARE resource, *Managing Cover Crops Profitably*, at sare.org/resources/managing-cover-crops-profitably-3rd-edition.

Type	Cover Crop	Pounds/ Bushel	Quantity of Seed per Acre (pounds)	Desirable Seeding Dates
Non-legumes	Rye	60	90-120 (alone) 90 (mixture)	Sept. 1-Nov. 10
	Perennial or common ryegrass	24	15-20 (alone) 5-8 (mixture)	Aug. 1-Sept. 15
	Sudangrass	40	20-30	May 15-July 1
	Field corn	56	50-60	May 15-July 1
	Winter barley	48	80-100	2-3 weeks before fly-safe date
	Wheat	60	90-120	Hessian fly-safe date
Legumes	Sweet clover	60	16-20 (alone) 10-12 (mixture)	March 1-April 15 July 15-Aug. 20
	Red clover	60	10-15 (alone)	Feb. 1-April 1
	Soybean	60	90-100	May 15-July 1
	Alfalfa	60	12-18	March-April
	Hairy vetch	60	15-20 (mixture)	Sept. 1-Nov. 1
Mixtures	Rye/ hairy vetch		90/15-20	Sept. 1-Oct. 1
	Ryegrass/ sweet clover		5-8 12-15	July 15-Aug. 20
	Sweet clover/ orchardgrass		6-8	March 1-April 15

Examples of Integrating Cover Crops

Below are examples of five, four-year cropping sequences that you can use with vegetable crops. Each cover crop rotation sequence is designed to take advantage of legumes for N-fixation, grass or buckwheat to suppress weeds, and brassica cover crops for bio-fumigation and reducing soil compaction. These rotations won't work on every farm. Growers should try likely rotations in manageable areas to develop the best strategy for their farms.

Example 1

Year 0
Fall before Year 1: Plant oats and peas as cover crops

Year 1
March: If field peas do not winter kill, terminate by mowing, tillage, or herbicide
April-August: Onion production
August-November: Crimson clover as a cover crop

Year 2
March: If crimson clover does not winter kill, terminate by tillage or herbicide
April-August: Potato production
August-November: Sorghum-sudangrass as a cover crop

Year 3
March-May: Leave winter-killed sorghum-sudangrass
May-October: Sweet potato production
October-June of Year 4: Cereal rye as a cover crop

Year 4
April-May: Terminate cereal rye by tillage, herbicide, or roller-crimping
June-September: Cucumber production
September-November: Oats and field peas as a cover crop

Year 5
Return to Year 1

Example 2

Year 0
Fall before Year 1: Cereal rye and hairy vetch as cover crops

Year 1
March-June: Terminate cereal rye and hairy vetch, leave residue on surface
June-October: Pumpkin production
November-May of Year 2: Cereal rye as a cover crop

Year 2
March-May: Terminate cereal rye as cover crop

May-September: Tomato production
September-November: Buckwheat as a cover crop

Year 3
March: Leave winter-killed buckwheat
April-August: Carrot production
August-November: Crimson clover as a cover crop

Year 4
March-May: If crimson clover does not winter kill, terminate by tillage or herbicide
May-September: Sweet corn production
September-November: Cereal rye and hairy vetch as cover crops

Year 5
Return to Year 1

Example 3

Year 0
Fall before Year 1: Oilseed radish as cover crop

Year 1
March: Leave winter-killed oilseed radish
April-June: Lettuce production
July-August: Buckwheat as cover crop
August-November: Cauliflower production
November-June of Year 2: Cereal rye as a cover crop

Year 2
March-June: Terminate cereal rye cover crop
June-October: Eggplant or pepper production
October-May of Year 3: Triticale as cover crop

Year 3
March-May: Terminate triticale
May-September: Onion production
September-November: Oats and field peas as cover crops

Year 4
March-May: Leave winter-killed oats; terminate field peas if not winter-killed
May-September: Cucumber production
September-November: Oilseed radish as cover crop

Year 5
Return to Year 1

Example 4

Year 0
Fall before Year 1: Cowpea as cover crop

Year 1
March-May: Leave winter-killed cowpea
May-August: Sweet corn production
August-October: Buckwheat as cover crop
October-August of Year 2: Garlic production

Year 2
March-August: Leave garlic
August-November: Sorghum-sudangrass as cover crop

Year 3
March-June: Leave winter-killed sorghum-sudangrass
June-November: Pumpkin or winter squash production
November-April of Year 4: Cereal rye as cover crop

Year 4
March: Terminate cereal rye cover crop
April-August: Potato production
August-October: Cowpea as cover crop

Year 5
Return to Year 1

Example 5

Year 0
Fall before Year 1: Yellow mustard as cover crop

Year 1
March-May: Leave winter-killed mustard
May-September: Cantaloupe production
September-June of Year 2: Cereal rye and hairy vetch as cover crops

Year 2
March-June: Terminate cereal rye and hairy vetch cover crops
June-October: Sweet potato production
October-April of Year 3: Triticale as cover crop

Year 3
March: Terminate triticale cover crop
April-July: Cauliflower production
July-August: Buckwheat as cover crop
August-November: Lettuce or spinach production
November-May of Year 4: Cereal rye as cover crop

Year 4
March-May: Terminate cereal rye cover crop
May-September: Pepper production
September-November: Mustard as cover crop

Year 5
Return to Year 1