Soil Fertility and Nutrient Management

Reviewed by Liz Maynard and Ajay Nair – Aug 2021

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 percent 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 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

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 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 phosophorus 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 percent 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 percentage 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 percent 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 percent or more; Mg should range between 10 and 15 percent; K should range from 1 to 5 percent. 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 percent 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 percent N, 10 percent P_2O_5, and 10 percent 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 percent N, 0 percent P_2O_5, and 0 percent K_2O. Potassium chloride (muriate of potash) labeled 0-0-60 contains 0 percent N, 0 percent P_2O_5, and 60 percent K_2O. Organic fertilizers are also labeled this way — a 3-2-2 product contains 3 percent N, 2 percent P_2O_5, and 2 percent 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 qualilty. N fertilizer recommendations account for the soil type, amount of organic matter in the soil, field history, and crop. The recommendations in this guide are based on data from relevant field trials. Adjust these recommendations according to experience, soil type, 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 percent organic matter, you may not need to add any sidedressed N. If your soils that have less than 3 percent 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 sidedress N. It may be useful to test the soil for nitrate-N shortly before sidedressing to assess whether the crop will benefit from the application.

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 the soil test on a mineral soil is more than 80 ppm P, then no additional P is recommended for most vegetables. P does not move readily in the soil and applied P easily reacts with soil minerals so that it is unavailable to the plant. That's why P fertilizer is applied in bands near the crop when possible, and starter solutions that are high in P are recommended for transplants.

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.

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 medium 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.

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. 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 percent Mg), sul-po-mag (11 percent Mg), or finely ground magnesium oxide (e.g., MAGOX, 58 percent 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.

If a soil test shows high Mg, no application is necessary.

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.

If a soil test indicates a need for sulfur, 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.

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 percent B) or Solubor (which contains 20.5 percent 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 percent 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 percent 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.

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.

Fertilizer Rates per Linear Bed Foot

You can apply fertilizer in a band while shaping beds or laying plastic. You can also apply it dissolved through irrigation water and delivered by drip tape to the base of the plants. In these systems, it is helpful to calculate the fertilizer rate per linear bed foot (LBF) based on the fertilizer rate per acre. To do so, you will need to know:

- Bed spacing (BS): distance in feet between bed centers
- Fertilizer rate in lb./A (RatePerA)

Use this equation to determine the fertilizer rate in pounds per LBF:

(RatePerA X BS) / 43,560 = RatePerLBF

Example:

Bed spacing (BS) = 5 ft. between centers of beds
Fertilizer rate in lb./A (RatePerA) = 100 lbs./A

(100 X 5) / 43,560 = 0.0115 lb./LBF

For a crop on six 100-foot beds, there would 600 LBF to fertilize. The amount of fertilizer needed to supply 100 lbs./A would be:

600 LBF X 0.0115 lb./LBF= 6.9 lbs.

The Rate per Linear Bed Foot for Various Bed Spacings and Rates table provides conversion of lb./A to lb./LBF for a number of bed spacings and fertilizer rates.

Rate per Linear Bed Foot for Various Bed Spacings and Rates

Bed Spacing (ft)	**Linear Bed Feet (LBF) in 1 Acre**	**Fertilizer Rate (lbs./A)**					
		20	**40**	**60**	**80**	**100**	**120**
		Fertilizer Rate (lb./LBF)					
3	14,520	0.0014	0.0028	0.0041	0.0055	0.0069	0.0083
4	10,890	0.0018	0.0037	0.0055	0.0073	0.0092	0.011
5	8,712	0.0023	0.0046	0.0069	0.0092	0.0115	0.0138
6	7,260	0.0028	0.0055	0.0083	0.011	0.0138	0.0165
7	6,222	0.0032	0.0064	0.0096	0.0129	0.0161	0.0193
8	5,445	0.0037	0.0073	0.011	0.0147	0.0184	0.022
9	4,840	0.0041	0.0083	0.0124	0.0165	0.0207	0.0248
10	4,356	0.0046	0.0092	0.0138	0.0184	0.023	0.0275

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.

Lime neutralizes soil acidity and supplies Ca and Mg, elements necessary for plant growth. A soil test determines how much lime you need. Liming may be necessary every few years because soil pH tends to decline over time. The decline is caused by ammonium-releasing N fertilizers, the crop's removal of Ca, and the leaching of Ca and Mg by rain.

Soil pH and Plant Nutrients

Nitrogen (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 percentage of N as ammonium.

Soil pH also plays an important role in N loss due to volatilization. Volatilization occurs when N compounds turn to gaseous forms (ammonia, nitrous oxides, N gas) and evaporate into the air. Ammonium in the soil solution exists in equilibrium with ammonia gas (NH_3). The amount of each compound depends to a large extent on the soil pH. At lower pH, there is more ammonium and less ammonia gas. At pH 7, the equilibrium condition is 99 percent ammonium and 1 percent ammonia. At pH 8, the equilibrium is about 90 percent ammonium and 10 percent ammonia gas.

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)

Plants absorb P from the soil solution in the form of soluble phosphates. At any time, the amount of P in solution is usually extremely low — often less than 1 pound per acre — because P joins with other elements in the soil to form stable minerals.

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 percent of the fertilizer P tied up this year 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)

In soils with certain types of clay, K is fixed at specific sites between clay layers. This tends to be reduced under acid conditions, presumably because Al occupies the binding sites that would otherwise trap K. Because of this, one might think that raising the pH by liming would reduce the availability of K. However, this is not the case — at least in the short term. Liming increases K availability, probably because Ca displaces K on exchange sites.

Sulfur (S)

Plants absorb sulfur as sulfate (SO_3^{2-}). Sulfate is little affected by soil pH.

Micronutrients

Micronutrients are elements plants need in very small amounts. The availability of the micronutrients Mn, Fe, copper (Cu), Zn, and B, decreases as soil pH increases. The exact mechanisms responsible for reducing availability differ for each nutrient. Deficiencies of these micronutrients are more likely at high pH, and toxicities are more likely at low pH.

The availability of the micronutrient molybdenum (Mo) is reduced under acid conditions. Mo deficiency is more likely to occur in acid soils.

Types of Lime

Several types of lime that may be used to manage soil pH and/or Ca and Mg are described below. After each discussion, the percentage of CaO and MgO in a typical batch of lime is given.

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 percent of the liming material must pass through a 100-mesh screen, and nearly 80 to 90 percent 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.

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 plowing and half before soil fitting. 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.

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 as the crop develops.

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.

Chemigation Management

Chemigation is the process of applying an agricultural chemical (pesticide or fertilizer) to the soil or plant surface through an irrigation system. Depending on the type of agricultural chemical, chemigation may be referred to as fertigation, insectigation, fungigation, etc.

For chemigation applications, you can only use pesticides that display EPA approval for such applications on the label. Each chemigation and irrigation system also must use the safety equipment specified on the EPA label as well as any equipment required in your state. Some states also may require a system or operator permit before you can apply any product with chemigation.

Chemigation can be an effective application option for some labeled pesticides if the irrigation system can apply the chemical/water solution uniformly over the target area with the correct water depth. Some pesticides work best with less than 0.25 inch of water per application.

Most late-model center pivot and linear move systems provide adequate distribution but some may not be able to apply a small enough volume of water. Solid set sprinkler systems may be effective for some pesticides but require close timing of chemical movements to get complete and uniform coverage of the field. Drip irrigation can be used effectively to apply certain pesticides and fertilizers. Traveling gun and hand move systems do not provide water distribution that has high uniformity and are not recommended. Product labels provide more information about appropriate water application amounts and which irrigation systems are recommended.

If you do not have or maintain proper check valves and interlocks, the injected chemicals could backflow into the water source. EPA and many state regulations specify that each system must contain a reduced pressure zone (RPZ) backflow prevention valve, or one or two independent check valves with low-pressure drains and vacuum relief valves, between the irrigation water source and the point of chemical injection. Also, most regulations require a power interlock between the irrigation pump and the chemical injector unit, a low pressure shut down switch and a check valve on the chemical injection hose. For specific requirements, check with the appropriate local or state agency.

It is important to accurately calibrate the irrigation system and pesticide application rate. The chemigation operator must be aware of the irrigation system's application speed (acres per hour) for the chosen water application amount and the concentration of chemical solution to determine the rate of chemical injection.

More information about the special equipment, operations, and calibration in overhead irrigation systems is available from the University of Minnesota Extension Service resources, *Chemigation Safety Measures*, and, *Applying Nitrogen with Irrigation Water*, available at extension.umn.edu.

Organic Matter and Cover Crops

Organic matter affects plant growth and frequently is referred to as the "glue" that holds soil particles together.

It also promotes the development of soil aggregates, thus improving drainage, soil tilth, and soil structure. In sandy and sandy loam soils, organic matter improves water- holding capacity.

You can add organic matter to the soil by various methods using green manure crops, cover crops, crop residues, animal manures, mulches, and composts. Green manure crops include sweet clover, alfalfa, thickly sown field corn, and summer seedings of soybean. These crops generally are plowed under 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, green manure crops also can be plowed under in the mature dry stage. At that stage, they do not decompose as readily and additional N may be needed to aid decomposition.

Typically, growers plant cover crops after harvest to protect the soil against erosion and terminate the cover crops 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 winterkill in another. Field peas and crimson clover generally winter kill, but sometimes they do not and must be terminated in the spring.

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. Whenever it is possible to use a mixture of these crops, the combination results in more organic matter to plow under.

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, mccc.msu.edu, or refer to the SARE resource, *Managing Cover Crops Profitably*, at sare.org/resources/managing-cover-crops-profitably-3rd-edition.

Cover Crop	**Pounds/ Bushel**	**Quantity of Seed per Acre (pounds)**	**Desirable Seeding Dates**
Nonlegumes			
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

Cover crops help add organic matter, manage soilborne diseases, and avoid soil erosion. 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

Transplant Production

Reviewed by Liz Maynard – Aug 2021

Transplant production has replaced direct seeding for many vegetable crops. One of transplanting's primary advantages is earlier fruit production, allowing growers to capture better market conditions. In addition, the high cost of hybrid seed makes it desirable to use each seed as efficiently as possible. Transplanting also gives the crops a competitive advantage against weeds. This section addresses the special skills and knowledge required for successful transplant production.

Most growers use polyethylene-covered greenhouse structures to provide warmth and protection from the environment. Although cole crops do not need the more moderating conditions a greenhouse provides, they can be grown in coldframes, lean-tos, or covered wagon beds.

The heater is one of the most critical features of a transplant ghouse. Vegetable transplants must be kept at the appropriate temperatures. However, if heaters are improperly exhausted, the transplants can be stunted or deformed. To prevent heater fumes from returning into the greenhouse, chimneys should extend two feet above the ridge of the greenhouse.

There should be some provision for bringing fresh air into the greenhouse. Some heaters vent fresh air into the greenhouse every time the furnace operates. For others, a hole or holes should be cut in the greenhouse wall and fitted with tubes to feed outside air to the heater. Avoid space heaters that may "spit" diesel or gasoline onto nearby plants. Heated air should be circulated using a perforated "sock" or tube that runs the length of the greenhouse, or fans placed on opposite sides of the greenhouse and blowing in opposite directions. Place thermometers in several locations to measure the temperature at plant level. At least one high-low thermometer is a good investment.

For detailed information about greenhouse structures, see *Greenhouse Engineering* (NRAES-33), available from Cornell University Library, ecommons.cornell.edu .

Transplant Containers

A wide variety of transplant containers are available, each with advantages and disadvantages. The most common ones are:

- Styrofoam trays (e.g., Speedling)
- Polystyrene or PVC flats or trays.
- Peat strips, pots or pellets (e.g., Jiffy).

Peat pot containers have the advantage that the root system need not be disturbed upon planting. Peat pots also are more forgiving of overwatering than other containers. If peat pots are planted partially above ground, moisture is "wicked" away from the plant, often resulting in plant death — peat pellets do not have this disadvantage.

Polystyrene and Todd planter flats are both designed so that transplants must be "popped" out of the trays, thus disturbing the root system. This is particularly true if the roots are allowed to grow into the ground beneath the tray. Avoid this problem by raising the flats off the ground. Both the polystyrene and Todd planter flats must be watered with care. Todd planter flats have a pyramidal design that forces roots downward to an open bottom where the roots are air pruned. Some polystyrene containers have open bottoms — tube types have open bottoms, groove types have small drainage holes.