

SOIL AND NUTRIENT MANAGEMENT

SOILS

The best soils for growing vegetables are well drained, deep mineral topsoil, and relatively high in organic matter. They have good structure and have been adequately limed and fertilized for the past few growing seasons. Soil textures, such as sandy loam or loamy sand are generally best suited for growing early market crops. Loam and silt loam soils are generally better suited for growing crops for later fresh-market use or for processing. Deep, well-drained muck soils are ideally suited for growing such crops as leafy vegetables and bulb and root crops.

The better suited the crop is to your soil, the greater chance you will have of producing a successful crop. For example, if you plant crops that require well-drained soils on poorly drained soils, you are doomed to failure regardless of your growing skills.

A typical BMP (Plan of best management practices) includes a good soil management program, proper liming and fertilization, good tillage practices, crop rotation, annual additions of organic matter, and adequate irrigation. Using winter cover crops and periodically resting the land with the use of summer cover crops between vegetable plantings are essential to prevent the deterioration of soil structure that is vital for maintaining high levels of production.

Soil Tests

The most economical means of determining the lime and fertilizer needs of your vegetable soils is to have your soil tested. You can obtain soil sample kits or containers and instructions through your county Extension agents' office.

If you do not know the present fertility level of the soil in a field, your application rates of lime and fertilizer materials are likely to be too high or too low. Either situation is undesirable and cost-ineffective. For most efficient production, application rates of lime and fertilizer materials should be matched to the existing soil fertility level, past cropping and soil management practices, and the crop to be grown. A controlled soil fertility program of this nature also minimizes the potential for soil damage and water pollution.

Lime and fertilizer recommendations from a soil testing laboratory are based on the soil test results and past cropping, liming, and fertilization practices you supply with the soil sample questionnaire when submitting the sample. For this reason, it is very important that you supply accurate information about the history and future use to be made of the field along with the soil sample.

If you have a special problem related to soil drainage, tillage, or past history, inform your county Extension Agent when you pick up the soil sampling kit or container, so that he/she can advise you if any special tests are needed. Also, he/she has a current list of charges made for soil testing services performed by the Soil Testing Laboratory.

LIMING SOILS

Most of the soils in the Mid-Atlantic Region are naturally acidic or become acidic under crop production systems. If soils become too acidic (pH less than 6.0), crop performance is hindered by many factors – including reduced availability of soil nutrients. A regular liming program is required to neutralize soil acidity and to supply crops with calcium and magnesium. The first step in a liming program is knowing the optimum or target value of the crop to be grown. Many crops will grow over a wide range of soil pH but most vegetable crops perform best when soils are in the pH 6.0 to 6.5 range. The grower should also plan rotations such that all crops grown on a given field have similar pH and nutrient requirement. The target pH values and the low pH limits suitable for vegetable crop production are listed in Table B-1.

Table B-1. Target Soil pH Values for Vegetable Crop Production

Crop	Target pH	Lime when pH Falls Below
Asparagus	6.8	6.2
Beans, lima, snap	6.2	6.0
Beets	6.5	6.2
Broccoli	6.5	6.2
Brussels sprouts	6.5	6.2
Cabbage	6.5	6.2
Cauliflower	6.5	6.2
Collards	6.5	6.2
Cantaloupes	6.5	6.0
Celery	6.5	6.0
Cucumber	6.5	6.0
Eggplant	6.5	6.0
Endive, escarole	6.5	6.0
Horseradish	6.5	5.5
Kale	6.5	6.2
Kohlrabi	6.5	6.2
Leeks	6.5	6.0
Lettuce, leaf, Iceberg	6.5	6.0
Mixed vegetables	6.5	6.0
Muskmelons	6.5	6.0
Okra	6.5	6.0
Onions, green, bulb, scallions	6.5	6.0
Parsley	6.5	6.0
Parsnips	6.5	6.0
Peas	6.5	6.0
Peppers	6.5	6.0
Potatoes, sweet	5.2	5.0
Potatoes, white, scab susceptible	5.2	5.0
Potatoes, white, scab resistant	6.2	5.5
Pumpkins	6.5	6.0
Radish	6.5	6.2
Rhubarb	6.5	5.5
Rutabaga	6.5	6.2
Spinach	6.5	6.0
Squash, winter, summer	6.5	6.0
Sweet corn	6.5	6.0

(table continued next page)

Table B-1. Target Soil pH Values for Vegetable Crop Production (cont'd.)

Crop	Target pH	Lime when pH Falls Below
Strawberries	6.2	5.8
Tomatoes	6.5	6.0
Turnips	6.5	6.0
Watermelon	6.2	5.5

Soil pH alone cannot be used to determine the amount of liming material to apply to correct soil acidity. Information on soil texture and fertility is also required. Soil test results provide all of the data needed to determine the lime requirement and the type of lime to use.

Lime Requirement

The lime requirement of a soil depends on total acidity that must be neutralized to raise pH to the desired level. It is important to understand that a soil pH measurement only indicates the concentration of active acidity in soil solution. Total acidity represents the active acidity in solution plus the amount of exchangeable acid cations bound to clay and organic matter. For the purpose of lime recommendations, total acidity is estimated from soil texture plus soil pH or it is measured directly by titration (which is referred to as buffer pH or lime requirement index). Buffer pH or lime requirement index measurements that appear on soil test reports are a measurement used to determine lime requirement and should not be confused with soil pH. The interpretation of buffer pH is specific to the buffer method employed by the laboratory and the properties of the soils in the region.

Lime requirement is also commonly determined by soil pH measurement and soil texture. Soil texture classifications (i.e. loamy sand, sandy loam, loam, silt loam, or clay loam) may be considered a fixed property of a soil because it is not readily changed. Thus, once soil texture is known and soil pH is measured, the lime requirement of a soil can be determined by referring to the appropriate table for the crop to be grown without any reevaluation of soil texture. Once growers know the soil texture, they may find portable pH meters to be helpful in the evaluation of their liming program.

For the majority of crops which have a target pH in the range of 6.3 to 6.5, refer to Table B-2 for lime requirement. For scab susceptible potatoes which have a target pH of 5.2, refer to Table B-3 for lime requirement. For beans grown on sandy Coastal Plain soils, the target pH should not exceed 6.2 (Table B-4). An excessively high pH increases the possibility of manganese deficiency in sensitive crops. On soils with a high organic matter content (greater than 6 percent) many crops with a desired pH of 6.5 can be grown at a lower soil pH (typically pH 5.6) than on mineral soils.

The typical soil test will include a summary of pH, and relative availability of Magnesium (Mg) and Calcium (Ca). While most vegetable crops grow best in soils that are slightly acid (soil pH 6.0 to 6.9) some crops such as sweet potato and some white potato varieties are best grown at soil pH 5.2. The soil test report will usually report Mg and Ca levels as "above optimum", "optimum", or "below optimum" and go further to specify low/high and very low/very high. This indicates relative need to remediate the soil by adding or withholding supplements.

Table B-2. Pounds of Calcium Carbonate Equivalent (CCE) Recommended Per Acre for Crops with a Target pH of 6.5

Initial Soil pH	Soil Texture and Fertility				
	Loamy Sand	Sandy Loam	Loam	Silt Loam	Clay Loam
4.1-4.4	4,500	5,400	9,800	11,600	23,300
4.5-4.8	3,600	4,500	8,100	9,800	18,800
4.9-5.2	2,700	3,600	6,300	8,100	15,200
5.3-5.6	1,800	2,700	4,500	6,300	12,500
5.7-6.0	900	1,800	3,600	4,500	8,100
6.1-6.4	500	900	1,800	3,600	5,400
Above 6.5	0	0	0	0	2,700

Table B-3. Pounds of Calcium Carbonate Equivalent Recommended Per Acre for Potato Varieties with a Target pH of 5.2

Initial Soil pH	Soil Texture and Fertility			
	Loamy Sand	Sandy Loam	Loam	Silt Loam
4.5	630	990	1,350	1,790
4.6	540	810	1,160	1,520
4.7	450	630	940	1,250
4.8	360	540	760	990
4.9	270	450	540	760
5.0	180	270	400	490
5.1	90	100	180	270
5.2	0	0	0	0

Table B-4. Pounds of Calcium Carbonate Equivalent (CCE) Recommended Per Acre for Crops with a Target pH of 6.2

Initial Soil pH	Soil Texture and Fertility				
	Loamy Sand	Sandy Loam	Loam	Silt Loam	Clay Loam
4.1-4.4	4,000	4,500	8,000	8,900	20,600
4.5-4.8	3,100	3,600	6,300	7,100	16,100
4.9-5.2	2,200	2,700	4,500	5,400	12,500
5.3-5.6	1,300	1,800	2,700	3,600	9,800
5.7-6.0	500	900	1,200	1,800	5,400
Above	6,500	0	0	0	2,700

Calcium Carbonate Equivalent

Calcium carbonate is a popular form of liming material. Soil test recommendations for liming should be given in pounds of calcium carbonate equivalent per acre (lb CCE/A). Pure calcium carbonate (CaCO_3) has a CCE of 100 percent and is the standard against which all liming materials are measured. Since the CCE of liming materials may vary from 40 to 179 percent, the amount of liming material needed to supply a given quantity of CCE will vary considerably. By law, the CCE of a liming material must be stated on the product label.

To calculate the corresponding application rate of a given liming material: (see Table B-5)

Table B-5 Conversion for Pounds of Calcium Carbonate Equivalent to Pounds of Actual Liming Material Applied

Pounds/Acre CCE Recommended by Soil Test	Percent Calcium Carbonate Equivalent (% CCE) of Liming Material							
	70	75	80	85	90	95	100	105
	-----Actual Limestone Recommendation (lb/acre) ^{1,2} -----							
1,000	1,400	1,300	1,200	1,200	1,100	1,100	1,000	1,000
2,000	2,900	2,700	2,500	2,400	2,200	2,100	2,000	1,900
3,000	4,300	4,000	3,700	3,500	3,300	3,200	3,000	2,900
4,000	5,700	5,300	5,000	4,700	4,400	4,200	4,000	3,800
5,000	7,100	6,700	6,200	5,900	5,600	5,300	5,000	4,800
6,000	8,600	8,000	7,500	7,100	6,700	6,300	6,000	5,700
7,000	10,000	9,300	8,700	8,200	7,800	7,400	7,000	6,700
8,000	11,400	10,700	10,000	9,400	8,900	8,400	8,000	7,600
9,000	12,000	12,000	11,200	10,600	10,000	9,500	9,000	8,600
10,000	14,300	13,300	12,500	11,800	11,100	10,500	10,000	9,500
11,000	15,700	14,700	13,700	12,900	12,200	11,600	11,000	10,500
12,000	17,100	16,000	15,000	14,100	13,300	12,600	12,000	11,400
13,000	18,600	17,300	16,200	15,300	14,400	13,200	13,000	12,400
14,000	20,000	18,700	17,500	16,500	15,600	14,700	14,000	13,300

¹ The amount of CCE recommended in the table are for increasing the pH of an 8-inch soil layer to the desired pH value. Multiply the numbers in the table by 1.25 to adjust a 10-inch plow layer to the desired pH.

² It is not advisable to apply more than the following pounds of CCE per acre as a topdressing: loamy sand 2,000, sandy loam 3,000, loam 4,000, and silt loam 5,000. When fields are to be plowed and the CCE recommendation exceeds 3,000 pounds per acre, plow under half the needed amount and apply the other half after plowing and then disk in as deeply as possible.

$$\frac{\text{Actual amount of liming material} = (\text{Soil test CCE recommendation})}{(\% \text{ CCE of liming material})} \times 100$$

Example: Soil test recommendation is to apply 2,000 lb CCE per acre

Liming material purchased as 80% CCE

Actual amount of liming material required:
 $(2,000 \div 80) \times 100 = 2,500 \text{ lb liming material per acre}$

Table B-5 may be used instead of the formula to convert soil test recommendations for pounds CCE per acre to pounds of the actual liming materials to be applied. To use Table B-5, find your soil test limestone recommendation in the left hand column, then read across the table on the line until you come to the column headed by the percent CCE nearest to that of your liming material. Application rates may be rounded off to the nearest 500 pounds per acre practical for spreading equipment. Although liming recommendations should now be given in pounds CCE per acre, recommendations that are given as total oxides can be converted to CCE by multiplying by 1.79. Suppose the recommendation calls for 2,000 pounds per acre of total oxides; then, to convert the recommendation to CCE:

$$2,000 \times 1.79 = 3,580 \text{ pounds CCE per acre}$$

Selection of Liming Material

Liming materials neutralize soil acidity and supply Ca and Mg. Selection of the appropriate liming material based on its Ca and Mg concentrations is a key to furnishing crops and soils with sufficient amounts of these nutrients. The goal of a liming program is to establish the desired soil pH and to maintain the soil fertility levels for Mg and Ca in the *optimum* range.

Fine-sized liming materials are recommended when rapid neutralization of soil acidity is desired. Medium and coarse-sized liming materials are best suited for maintenance of soil pH once the desired soil pH range has been attained through the use of fine-sized liming material.

When the soil pH is low, the soil test levels of Ca and Mg may be *below optimum*, it is important to choose a liming material that contains a significant concentration of Mg (such liming materials are commonly referred to as dolomitic type or dolomite.) If the soil Mg level is *below optimum—very low* or *low*, use a liming material that has a minimum concentration of 9% Mg. If the soil Mg level is *below optimum—medium*, use a liming material that has 3.6 to 9% Mg. If the soil Mg level is *optimum* or *above optimum*, use a liming material that has less than 3.6% Mg (such liming materials are commonly referred to as calcitic or calcite).

Occasionally soils test *below optimum* in Mg or Ca, but do not need lime for pH adjustment. For soils needing Mg, apply Epsom salt (9.9% Mg) or sulfate of potash magnesia (21.8% Mg). If soil pH is satisfactory for the crop, but the soil test Mg level is *below optimum—very low*, apply 30 pounds Mg per acre from a Mg fertilizer. If Mg is *below optimum—low*, apply 15 pounds per Mg acre.

If soil pH is satisfactory for the crop, but the Ca level is *below optimum—very low*, apply 350 pounds Ca per acre (=1500 pounds per acre of gypsum). If the pH is satisfactory, but Ca is *below optimum—low*, apply 175 pounds Ca per acre (=750 pounds per acre of gypsum)

Timing of Application

Lime is slow to react in soil. The desired soil pH increase may require several months. Thus, it is important to plan ahead and apply lime several months in advance of planting. Lime can be applied at any time of the year provided weather and soil conditions permit. Plan ahead and apply lime well in advance of planting crops that are sensitive to soil acidity. Fall applications have the advantage of allowing the lime to react in the soil prior to the start of the next growing season.

Careful attention to liming prior to planting perennial crops is important. Once the crop is established, it is difficult to correct a soil acidity problem using surface applications of lime. Lime should be applied at least six months to a year in advance of planting to insure that the target pH has been achieved.

Soils naturally become acidic over time. The frequency of lime application varies with soil characteristics, cropping system, and fertilizer practice. Heavy use of ammonium and urea nitrogen fertilizers speed soil acidification. Soil testing for pH measurement should be performed every one to three years. Relime soils before pH drops below the desired range to avoid development of excess acidity in the root zone.

Lime Placement

Lime applications are most effective at neutralizing acidity when they are spread uniformly and thoroughly mixed with the soil by plowing, disking, and harrowing. When applying large amounts of lime, it is best to use split applications. Apply half the lime and plow it under. Next apply the other half to the plowed surface and disk it into the soil.

Whenever tillage is not possible (e.g. perennial crops, no-tillage systems), surface applications are recommended but the rate of pH adjustment is much slower. Monitor soil pH change and the need for lime to avoid higher lime requirements. Surface lime application rates should not exceed 3,000 pounds CCE per acre.

Special Considerations

Potato scab is caused by a soil-inhabiting fungus (*Streptomyces scabies*). The disease is suppressed in acid soils (pH <5.2) but the addition of lime favors development of scab. When lime is needed, it is best to apply the lime after potato harvest and before the other crops grown in rotation. The optimum soil pH for growing scab susceptible potato varieties is about 5.0 to 5.2. Scab resistant varieties may be grown at pH 5.5 to 6.2.

Cabbage, broccoli, and leafy greens are subject to infection by the clubroot fungus. If clubroot is known to be present, cole crops should be grown at pH 6.5 to 7.0. The disease is suppressed at pH 7.2 to 7.4 but crop production and/or quality may be decreased.

Sweet potato production is optimum at pH 5.2. Use Table B-3 to adjust soil pH.

Spinach requires an initial pH of 6.5 to 6.7 for good growth and leaf quality. Calcium levels in the soil should be medium or optimum and in balance with magnesium. Plan ahead and adjust pH, calcium, and magnesium the season before planting spinach.

Lime and Fertilizer

Lime and fertilizer work together as a team to produce high yields and better crops. Lime is not a substitute for fertilizer, and fertilizer is not a substitute for lime. The proper use of the two together makes for profitable vegetable crop production. The rate and frequency of their use depend on the crop to be grown, type of soil, soil acidity, and past use of fertilizer materials.

PLANT NUTRIENTS

Many factors influence the nutrient requirements for optimum yield and quality of a given vegetable crop. The parent material of soils, textural classification, cation exchange capacity, organic matter content, and drainage are important soil properties that influence the rates of nutrients applied to vegetables. In addition, rainfall amounts and distribution, irrigation types and management, and soil and air temperatures during the growing season can alter the retention, availability, and uptake of nutrients. Varieties within a vegetable species often differ significantly in their nutrient requirements. Growers are encouraged to test soils to determine the kinds and amounts of preplant fertilizer nutrients required for optimum production. During the growing season, sap and tissue testing should be used when they have been shown to be effective to adjust nutrient applications to current growing conditions and the nutrient status of the crop.

Pennsylvania growers will receive soil test results directly from the Agricultural and Analytical Services Laboratory, College of Agriculture, The Pennsylvania State University. Growers in Delaware, Maryland, New Jersey, Virginia and West Virginia should use Tables B-7, and B-10 as described below.

See important notes and discussion in the following Plant Nutrient Recommendations section to adjust nutrient rates and timing based on soil type, cation exchange capacity, cropping and manure history, and soil temperatures.

Soil Fertility Test Interpretation

A soil fertility test evaluates the nutrient-supplying power of a soil. The results of the test are used to predict if, or how much fertilizer is required for optimum plant growth. The relationship between soil nutrient level and plant response is shown in Figure B-1. Relative fertility levels, are classified into three main categories: *Below optimum*, *optimum* and *above optimum*. *Below optimum* is divided into subcategories: *very low*, *low*, and *medium*. These soil fertility categories gauge the probability of a plant showing a beneficial response to the addition of a given nutrient (assuming that other factors such as temperature, moisture and disease are not limiting growth). The critical level is the soil test level; below which a crop response to a nutrient application may be expected, and above which no crop response is expected. At very high soil test levels crop yield may decrease.

Soil Test Categories

The soil test categories as described in Table B-6 are the basis for how much phosphorus (P) and potassium (K) to apply to reach optimum growth levels. For limestone recommendations, these categories indicate the concentrations of calcium (Ca) and magnesium (Mg) most suitable for use as a liming material. Soil test categories, along with crop nutrient requirements, are the basis for nutrient recommendations.

For example, when the soil test category for K is *below optimum—low* the recommendation will indicate how much K to apply. The amount of K recommended however, depending on the crop. Various crops accumulate different amounts of nutrients. Generally, crops that produce large

yields of harvestable material will remove large amounts of nutrients from the soil and will have a higher nutrient recommendation. When the soil fertility category is *below optimum*, the nutrient recommendation for a particular crop is designed to achieve its full crop yield potential and to build the soil fertility level into the *optimum* range over time. If the soil fertility level is already in the *optimum* range, the nutrient recommendation is designed to replace the amount of nutrient removed by the crop so as to maintain *optimum* soil fertility. No nutrient application is generally recommended when the soil test category is *above optimum*. This allows “draw-down” of the nutrient level to the *optimum* range. These concepts are illustrated in Figure B-2 and summarized in Table B-6.

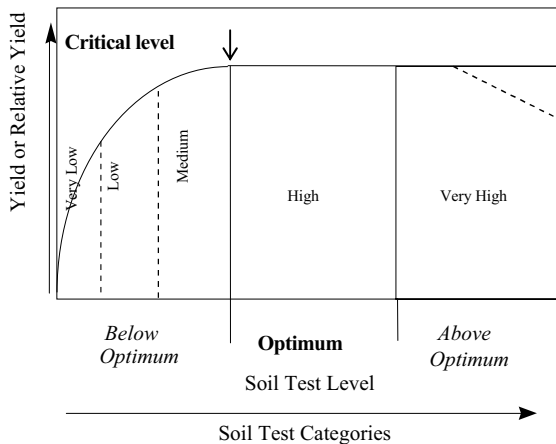


Figure B-1. The relationship between soil test levels and yields.

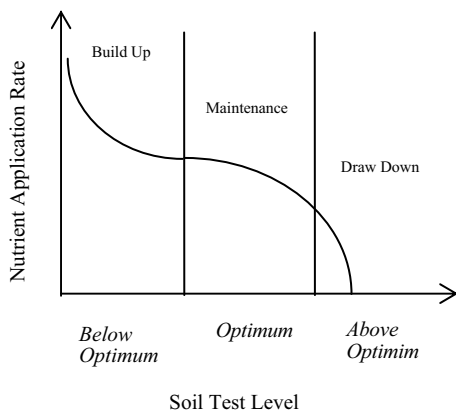


Figure B-2. Nutrient application rates vary in relation to soil test category.

Soil Test Method and Interpretation

A common misconception is that a soil fertility test is a direct measurement of the total nutrient content of a soil that is available to the plant. Soil test values have historically been expressed in units of pounds per acre, but they have no meaning in terms of actual quantity of plant-available nutrients. A soil test only provides an index of soil nutrient availability that is correlated with plant response. This correlation is determined by soil test calibration research and is the foundation for soil test interpretation.

Many different types of soil test extraction methods are in use, but only a few are appropriate for our local soils. The Mehlich-3 soil test is most appropriate for soil types found in the Mid-Atlantic Region. Soil test results and interpretations are specific for the soils of a region and for the particular soil test method employed. The soil test values for the Mehlich-3 categories (Table B-7) were established based on research conducted on soils in the Mid-Atlantic Region. The categories were developed from crop yields that were observed during nutrient response studies conducted over a range of soil test levels.

Reading and understanding the soil report from any particular laboratory depends on knowing what soil test method is being used and what units are used to express the soil nutrient levels. If the soil test report does not state the method used, call the laboratory to find out. This information is needed before interpreting the soil test results based on the categories given in Table B-7.

Plant Nutrient Recommendations

To obtain the best results, always base plant nutrition decisions on a current soil test. When soil test results are not available, use recommended amounts of P₂O₅ and K₂O listed under medium phosphorus and medium potassium soil test levels for the crop to be grown. Although this is not necessarily accurate, the chances are good that beneficial results will be obtained.

Refer to Table B-7 to interpret the relative levels of phosphorus and potassium in the soil based on the soil test report from the laboratory.

When a current soil test is available, use recommendations for the specific commodity listed under Recommended Nutrients Based on Soil Tests located in Section F

The following adjustments to the nutrient recommendations in section F are recommended based on soil type and cation exchange capacity.

1. For most vegetables grown on light-textured soils, apply the total recommended P₂O₅ and K₂O together with 25 to 50 percent of the recommended nitrogen before planting. The remaining nitrogen can be sidedressed with a fertilizer containing nitrogen only. Sidedressing or topdressing potash (K₂O) is recommended only on extremely light sandy soils with very low cation exchange capacities.
2. It may be desirable to build up the phosphorus and potassium levels in very low-fertility loam and silt loam soils more rapidly than provided by these recommendations. In such instances, add an additional 40 to 50 pounds of P₂O₅ and K₂O, respectively, to the recommendations listed in the table for soils testing low in phosphorus and potassium. Apply the additional amounts in broadcast and plow down or broadcast and disk-in application.
3. **For Pennsylvania growers producing vegetables on clay loam soils:** If you use the recommendations in the tables in section F, reduce the recommended nitrogen and potassium rates by 20 percent and increase the phosphorus rate by 25 percent of the rates indicated in the table.

NUTRIENT MANAGEMENT

Plant nutrient recommendations listed in tables in Section F under Recommended Nutrients Based on Soil Tests are expressed in terms of nitrogen (N), phosphate (P_2O_5), and potash (K_2O), rather than in specific grades and amounts of fertilizer.

When soil test results are available, the phosphate (P_2O_5) and potash (K_2O) needs for each cropping situation can be determined by selecting the appropriate values under the relative soil test levels for phosphorus and potassium—low, medium, optimum, or excessive.

The cropping and manuring history of the field must be known before a fertilization program can be planned. This history is very important in planning a nitrogen fertilization program.

Plant nutrient recommendations listed in tables in Section F under Recommended Nutrients Based on Soil Tests were developed for fields where no manure is being applied and where no legume crop residue is being incorporated prior to the planting of a new crop. If manure and/or legume crops are being used, the plant nutrient recommendations in the specific commodity should be reduced by the amounts of nitrogen (N), phosphate (P_2O_5), and potash (K_2O) being contributed from these sources. See Table B-9 for value credits to be allowed for manure applications and legume crop residues.

When warm season crops, such as sweet corn, tomatoes, peppers, eggplants, and the vine crops are seeded or transplanted and soil temperatures are below 65°F (18.3°C), 20 pounds per acre of P_2O_5 may be applied to replace the phosphorus removed by the crop when soil test levels for phosphorus are above optimum.

Once the final fertilizer-plant nutrient needs are determined, it will then be necessary to determine the grade and rate of fertilizer needed to fulfill these requirements. For example, if the final plant nutrient requirements that need to be added as a commercial fertilizer are 50 pounds of nitrogen (N), 100 pounds of phosphate (P_2O_5), and 150 pounds of potash (K_2O), you would need a fertilizer with a 1:2:3 ratio, such as a 5-10-15, 6-12-18, 7-14-21, etc. Once you have selected the grade of fertilizer you need to use, the quantity needed to fulfill the plant nutrient requirements can be determined by dividing the percentage of N, P_2O_5 , or K_2O contained in the fertilizer into the quantity of the respective plant nutrient needed per acre and multiplying the answer by 100.

For example, if you choose a 5-10-15 fertilizer grade to supply the 50 pounds of N, 100 pounds of P_2O_5 , and 150 pounds of K_2O needed, you can calculate the amount of 5-10-15 fertilizer needed as follows: Divide the amount of nitrogen (N) needed per acre (50 pounds) by the percentage of N in the 5-10-15 fertilizer (5 percent), and multiply the answer (10) by 100, which equals 1,000 pounds.

This same system can be used for converting any plant nutrient recommendations into grades and amounts of fertilizer needed. When you use this system, it is possible for you to select your fertilizer needs based on the most economical fertilizer grades available to you. In cases where the preferred grade is not available, it is also possible to change from one fertilizer grade to another, providing the plant nutrient ratio is the same. This flexibility may be necessary because of a shortage of some fertilizer materials.

Plants remove substances from the soil and air to enable them to grow and reproduce. The specific substances they remove are termed nutrients. Certain of these are generally required in larger quantities, and termed macronutrients. Those needed in smaller quantities, micronutrients, are often as important as macronutrients for achieving desired results. Most commercial fertilizers feature macronutrients nitrogen (N), phosphorus (P), and potassium (K), expressed as a weighted percentage (NiPiK). Micronutrients may be supplied along with macronutrients.

Phosphorus Management

Crops are very likely to respond to P fertilization when the soil test indicates that P is *below optimum—very low* or *low*. A soil testing *below optimum—medium* will sometimes respond to P fertilization and will sometimes not. Soils testing *optimum* or *above optimum* are unlikely to respond to P fertilizer, but P may be applied to maintain the fertility level in the *optimum* range. Crops are more likely to respond to P fertilizer when growing conditions are favorable for high yields.

It is often recommended that a band of P fertilizer be placed near the seed as a starter fertilizer regardless of the P fertility level. Banded P is especially helpful at low soil test levels. Even at P soil test levels that are *above optimum*, a small amount of banded P may benefit crop establishment. When the soil test level is *below optimum*, P should generally be applied as a combination of broadcast and banded methods. When the level is *above optimum*, only a small amount of P may be applied as a band. Many soils test *above optimum* for P due to previous fertilizer and manure applications. When applied in excess of crop removal, P accumulates in the soil. Phosphorus is strongly adsorbed to soil particles and very little is subject to loss via leaching. When the soil test level is *above optimum*, growers can benefit economically by withholding P fertilizers.

Potassium Management

Crops are very likely to respond to K fertilizer when the soil test indicates that K is *below optimum—very low* or *low*. A soil testing *below optimum-medium* in K may or may not respond to K fertilizer. Crops are more responsive to K when growing under drought stress or when growing under favorable conditions. Soils testing *optimum* or *above optimum* are unlikely to respond to K fertilizer, but K may be applied to maintain the fertility level in the *optimum* range.

In general, most of the K fertilizer should be broadcast. When the fertility level is *below optimum*, it may be advantageous to apply a portion of the total K application as a band. There is generally no benefit to applying banded K when soil fertility levels are *optimum* or *above optimum*.

Crops remove larger amounts of K than P from the soil during a growing season. In addition, sandy soils have low reserves of K, and K is susceptible to leaching. Therefore, frequent applications of K are needed to maintain K at an optimum fertility level.

Secondary and Micronutrient Management

Calcium (Ca), magnesium (Mg), and sulfur (S) are included in the secondary element group. Calcium may be deficient in some soils that have not been properly limed, where excessive potash fertilizer has been used, and/or where crops are subjected to drought stress. Magnesium is the most likely of these elements to be deficient in vegetable soils. Dolomitic or high-magnesium limestones should be used when liming soils that are low in magnesium. Magnesium should be applied as a fertilizer source on low-magnesium soils where lime is not needed. Magnesium may be applied as a foliar spray to supply magnesium to the crop in emergency situations. Contact your county Extension agent for recommendations.

Sulfur is an important nutrient for plants, especially those in the onion family and cole crops. Sulfur may become deficient on light, sandy soils. Sulfur deficiencies may develop as more air pollution controls are installed and with the continued use of high-analysis fertilizers that are low in sulfur content. Sulfur levels where greater than 5 ppm will cause increased pungency in sweet Spanish onions. Likewise, low soil sulfur will result in reduced pungency. Sulfur can be supplied by application of sulfur-containing nitrogen fertilizers, gypsum, or Epsom salts. See Table B-8.

Table B-6 Definition of Soil Fertility Test Categories

Category Names (Commonly used terms)	Category Definition	Recommendations
Below Optimum (Very Low, Low, Medium)	The nutrient is considered deficient and will probably limit crop yield. There is a high-to-moderate probability of an economic crop yield response to additions of the nutrient.	Recommendations are based on crop response. These recommendations will generally build the soil into the optimum range over time. Starter fertilizer is recommended as appropriate.
Optimum (High)	The nutrient is considered adequate and will probably not limit crop growth. There is a low probability of economic crop yield response to additions of nutrient.	If soils are tested annually, no nutrient additions are needed for the current crop. For other than annual testing, recommendations are generally for maintenance applications to maintain the soil in the optimum range. Starter fertilizer is recommended as appropriate
Above Optimum (Very High)	The nutrient is considered more than adequate and will not limit crop yield. There is a very low probability of an economic crop yield response to additions of the nutrient. At very high levels there is a possibility of a negative impact on the crop if nutrients are added.	No nutrient additions are recommended. Starter fertilizer may be recommended as appropriate. At very high levels, remedial action may be required.

Adapted from *Recommended Soil Testing Procedures for The Northeastern United States*, Northeastern Regional Publication No. 493.

Table B-7 Soil Test Categories for Nutrients Extracted by Mehlich 3 and Mehlich 1

	Soil Test Category	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca) ¹
			Mehlich – 3 Soil Test Value (lbs/acre) ^{2,3}		
Mehlich 3	Below Optimum (very low)	0-24	0-40	0-45	0-615
	Below Optimum (low)	25-45	41-81	46-83	616-1007
	Below Optimum (medium)	46-71	82-145	84-143	1008-1400
	Optimum (high)	72-137	146-277	144-295	1401-1790
	Above Optimum (very high)	138+	278+	296+	1791+
Mehlich 1			Mehlich – 1 Soil Test Value (lbs/acre) ²		
	Below Optimum (very low)	0-13	0-29	0-35	0-400
	Below Optimum (low)	14-27	30-70	36-70	401-800
	Below Optimum (medium)	28-45	71-134	71-125	801-1200
	Optimum (high)	46-89	135-267	126-265	1201-1600
	Above Optimum (very high)	90+	268+	266+	1601+

¹ Calcium values are for sandy loam soils. Multiply the calcium values in the table above by 0.625 to use for loamy sand soils; by 1.25 for loam soils; by 1.5 for silt loam soils, and by 1.75 for clay loam soils.

² Values are reported in elemental forms.

³ Soil tests that based on Bray-1 extractable P and neutral, 1N ammonium acetate extractable, K, Ca, and Mg are very similar to the Mehlich-3 extractable amounts of these nutrients.

⁴ Soil fertility levels for Ca, Mg, and K in the optimum range should typically have about 65 to 70% Ca to 10 to 20% Mg, and 3 to 5% K saturation of the soil cation exchange capacity.

Boron is the most widely deficient micronutrient in vegetable crop soils. Deficiencies of this element are most likely to occur in the following crops: asparagus, most bulb and root crops, cole crops, and tomatoes. See Table B-10 for boron recommendations for various crops based on soil test results. Use of excessive amounts of boron can be very toxic to plant growth. DO NOT exceed recommendations listed in Table B-10 and in specific commodity recommendations section for Plant Nutrient Recommendations Based on Soil Tests for Vegetable Crop Production.

Manganese deficiency often occurs in plants growing on soils that have been over-limed. A broadcast application of 20 to 30 pounds or a band application of 4 to 8 pounds of manganese per acre will usually correct the deficiency. When manganese is applied as manganese sulfate, foliar application of 0.5 to 1 pound of manganese in 20 gallons of water per acre in one to three applications usually will help relieve the deficiency. Use a sulfate or chelate of manganese. Do not apply lime or poultry manure to such soils until the pH has dropped below 6.5, and be careful not to overlime again.

Molybdenum deficiency in cauliflower (whiptail) may develop when this crop is grown on soils more acid than pH 5.5. An application of 0.5 to 1 pound of sodium/ammonium molybdate per acre will usually correct this deficiency. Liming acid soils to a pH of 6.0 to 6.5 will usually prevent the development of molybdenum deficiencies in vegetable crops.

Deficiencies of other micronutrients in vegetable crops in this area are rare; and when present, are usually caused by overliming or other substandard soil management practices. Contact your county Extension agent if you suspect a deficiency of zinc, iron, copper, or chlorine in your crops. Sources of fertilizers for the essential plant nutrients may be found in Table B-8.

Sustainable Nutrient Management

A major objective of nutrient management is to bring the soil fertility level into the optimum range and to sustain that fertility level during the crop growth phase. Once soil fertility has reached the *optimum* level, the nutrient application rate should be only large enough to maintain the *optimum* level. This can be accomplished by applying nutrients at a rate that closely matches the rate of nutrient removal in the harvested crop. The rate may need to be slightly higher to account for other losses such as leaching.

Keeping records of soil test results enables growers to track changes over time and to adjust recommendations as needed to maintain soil fertility in the *optimum* range. Meaningful records require a consistent approach to soil testing in terms of sample collection, sampling depth, and laboratory submission. Soil test levels can vary somewhat from sample to sample and having records helps to spot unusual soil test values that should be rechecked.

Although soil fertility levels naturally fluctuate from year to year due to crop rotation and manure application, the average levels of nutrients over time should remain in the *optimum* range, as shown in Figure B-3. If soil fertility levels are observed to fall *below optimum*, under fertilization is indicated. The nutrient recommendation should be adjusted so that the nutrient application rate is sufficient to meet the needs of the current crop and also gradually rebuild the

nutrient supply to the *optimum* level. If soil fertility levels are observed to climb *well above optimum*, good crop yields can be obtained without adding the nutrient. Over a period of time, nutrient removal by crops should allow the soil fertility level to fall back into the *optimum* range (see Fig. B-2, B-3).

Very high soil nutrient levels can be as detrimental as low or deficient levels. High soil nutrient levels may not only result in an economic loss but they may also cause problems to animals or the environment. Very high P levels (above about 370 lbs P₂O₅/acre or 160 lbs P/acre) in the soil may lead to nutrient deficiencies, especially of iron and zinc. High K levels (above about 205 lbs K₂O/acre or 170 lbs K/acre) can induce magnesium or calcium deficiency through competition for plant uptake and vice versa. Use best management practices to avoid increasing soil nutrient levels that are already high.

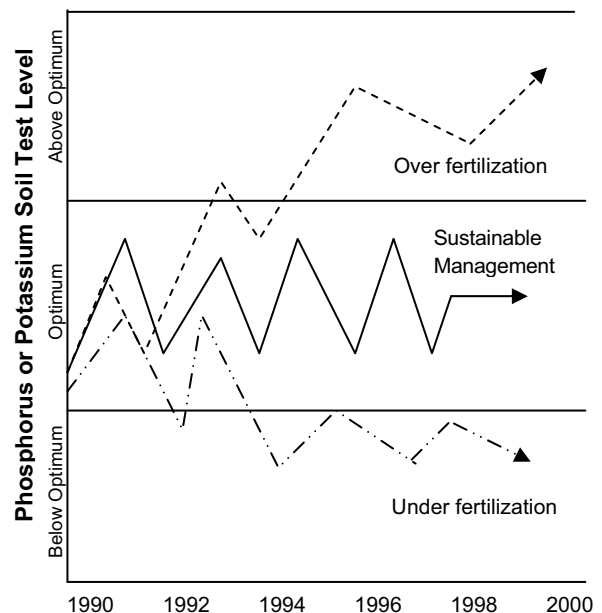


Figure B-3. Changes in soil test levels over time under different nutrient management scenarios.

Sewage Sludge

Sewage sludge, or biosolids, is a by-product of the purification of waste water. It has significant organic matter content and contains micro- and macronutrients essential for plant growth. Sewage sludge can also contain contaminants such as heavy metals, organic contaminants, and human pathogens. Before it can be used for land application, sewage sludge must undergo additional treatment to stabilize and disinfect it. After appropriate treatment, federal and some state regulations allow the use of sewage sludge on vegetables. However, Cooperative Extension guidelines are more conservative than current regulations due to disagreements related to science, public perception, and liability issues. **Cooperative Extension does not recommend the application of sewage sludge/biosolids to soils used for vegetable production.**

If the grower elects to use biosolids despite this warning, the material should not be applied to steeply sloping land, soils with bedrock near the surface, highly leachable soils, soils having a pH less than 6.0, soils with high water tables, or fields near surface water. When considering the land application of biosolids, carefully review the regulations and consult USDA/NRCS and your county Extension Agent.

Foliar Fertilization

Plants usually obtain nutrients from the soil through roots. It is known that plants can also absorb a limited amount of some nutrients through aerial organs such as leaves. Properly managed soils are usually able to supply the essential mineral nutrients the crop will need during its development. If one or more soil-supplied nutrients become deficient or unavailable during the development of the crop, foliar nutrient applications may then be beneficial.

Organic Nutrient Sources

Cover Crops

Seeding spring oats at 60 to 100 pounds per acre during August or early September provides a good cover crop that will winter-kill in the colder areas but may overwinter in warmer areas. Rye or winter wheat can be seeded at 80 to 110 pounds per acre after early September. These crops can also provide strips for wind protection during the early part of the next growing season. A mixture of annual and perennial ryegrass (domestic) seeded at 15 pounds per acre before September is also a good cover crop.

Proper management of living cover crops can reduce nutrient loss during the winter and early spring. Living cover crops should be disked or plowed to return nutrients to the soil and before they seriously deplete soil moisture.

Summer cover crops such as sudangrass or sudex, seeded at 20 to 40 pounds per acre, are good green manure crops. They can be planted as early as field corn is planted and as late as August 15 in Maryland and Virginia, and July 25 to August 1 in cooler areas of New Jersey and Pennsylvania. These crops should be clipped, mowed, or disked to prevent seed development that could lead to weed problems. Summer cover crops can be disked and planted in wheat or rye in September or allowed to winter-kill and tilled in the spring.

Many soils that are not very productive due to poor physical properties can be restored and made to produce good crops through the use of a good rotation program. This practice also helps to counteract the buildup of many diseases and insects that attack vegetable crops. Small grains, sudangrass, sudex, timothy, orchardgrass, and ryegrass are good soil-resting crops. Consult your state field crop or agronomy recommendations for details on seeding rates and management practices.

Intensive cropping, working the soil when it was too wet, and excessive traffic from using heavy-tillage equipment have severely damaged many soils. These practices cause the soils to become very hard and compact, resulting in poor seed germination, loss of transplants, and shallow root formation. Also, such soils crust easily and compact severely, making them very difficult to irrigate properly. This results in poor plant stands, poor crop growth, low yields, and loss of income. Subsoil tilling in the row may help improve aeration and drainage of soils damaged by several years of excessive traffic from heavy equipment.

Alfalfa can aid in breaking up deep soil compaction. It is useful as a soil-resting crop and in crop rotations. However, it should not be used in rotation with other legumes such as soybeans; peas; and snap, dry, and lima beans; and especially where soil-borne diseases have been a problem.

Compost and Manure

Application and incorporation of compost to soils will increase soil organic matter and certain soil nutrient levels. Since compost ingredients can include animal manures, scrap table foods, food wastes, leaves, grass, and sawdust, both microbial and nutrient content (phosphorus) of the compost become extremely important considerations in field applications. Microbial populations (*E. coli* 0157:47, *Listeria*, *Salmonella*, etc.), heavy metals such as nickel, lead, or cadmium and excessive nutrient levels such as nitrogen may be present in the composts containing human or animal waste so it should not be used for edible food production. Also, the ingredients which make up specific compost may be highly alkaline, resulting in a high compost pH of 7.5 to 8.5. Therefore, application rates of compost must be determined by considerations of nutrient content, microbial content, crop use, and pH before field applications are made. Applications should be made at low rates (1 to 3 tons per acre) since high rates of compost (10+ tons per acre) can result in soil pH problems, nutrient imbalance in the soil, or microbial contamination.

Organic Production

Nutrient sources used for certified organic production must be approved by the Organic Materials Review Institute. See Publication Resources in Section R of this publication, or visit the website at www.omri.org for detailed information.

Table B-8. Percentage Equivalents and Conversion Factors for Major, Secondary, and Micronutrient Fertilizer Sources

Fertilizer Source Material	Nutrient Contents, %	Lb of Material Required to Supply 10 Lb of the Initially Listed Plant Nutrient
----- Nitrogen Materials -----		
Monoammonium Phosphate	11 (N) and 48 (P ₂ O ₅)	91
Nitrate of potash	13 (N) and 44 (K ₂ O)	77
Nitrate of soda-potash	15 (N) and 14 (K ₂ O)	67
Calcium nitrate	15 (N) and 19 (Ca)	67
Nitrate of soda	16 (N)	63
Diammonium phosphate	18 (N) and 46 (P ₂ O ₅)	56
Nitrogen solution	20 (N)	50
Ammonium sulfate	20.5 (N) and 23 (S)	49
Ammonium sulfate nitrate	26 (N) and 14 (S)	38
Nitrogen solution	30 (N)	33
Nitrogen solution	32 (N)	31
Ammonium nitrate	33.5-34.0 (N)	30
Nitrogen solution	40 (N)	25
Urea	45-46 (N)	22
Anhydrous ammonia	82 (N)	12

(table continued next page)

Table B-8. Percentage Equivalents and Conversion Factors for Major, Secondary, and Micronutrient Fertilizer Sources (cont'd)

Fertilizer Source Material	Nutrient Contents, %	Lb of Material Required to Supply 10 Lb of the Initially Listed Plant Nutrient
Phosphorus Materials		
Normal superphosphate	20 (P ₂ O ₅) and 11 (S)	50
Triple superphosphate	44-46 (P ₂ O ₅)	22
Monoammonium phosphate	11 (N) and 48 (P ₂ O ₅)	21
Diammonium phosphate	18 (N) and 46 (P ₂ O ₅)	22
Potassium Materials		
Nitrate of soda-potash	13 (N) and 14 (K ₂ O)	71
Sulfate of potash-magnesia	21.8 (K ₂ O) and 11.1 (Mg)	46
Nitrate of potash	13 (N) and 44 (K ₂ O)	23
Sulfate of potash	50 (K ₂ O) and 17 (S)	20
Muriate of potash	60 (K ₂ O)	17
Magnesium Materials		
Epsom salts	10 (Mg) and 13 (S)	96
Sulfate of potash-magnesia	21.8 (K ₂ O) and 11.1 (Mg)	90
Kieserite	18.1 (Mg)	55
Brucite	39 (Mg)	26
Sulfur Materials		
Granulated sulfur	90-92 (S)	11
Ammonium sulfate	23 (S) and 20.5 (N)	43
Gypsum	15-18 (S) and 19-23 (Ca)	61
Ammonium sulfate nitrate	14 (S) and 26 (N)	71
Epsom salts	13 (S) and 10 (Mg)	77
Boron Materials		
Fertilizer Borate		
Granular*	14.30 (B)	7.0
Fertilizer Borate-48	14.91 (B)	6.7
Solubor	20.50 (B)	4.9
Fertilizer Borate-68	21.13 (B)	4.7
*Best for fertilizer blends		
Manganese Materials		
Manganese sulfate	24.0 (Mn)	4.2
Manganese sulfate	25.5 (Mn)	3.9
Manganese sulfate	29.1 (Mn)	3.4
Manganese oxide	48.0 (Mn)	2.1
Manganese oxide	55.0 (Mn)	1.8
Zinc Materials		
Zinc sulfate	36 (Zn)	2.8
Zinc oxide	73 (Zn)	1.4
Molybdenum Materials		
Sodium molybdate	39.5 (Mo)	2.5
Sodium molybdate	46.6 (Mo)	2.1
Ammonium molybdate	56.5 (Mo)	1.8

Table B-9. Plant Nutrient Value Credits to Be Allowed for Manure Applications and Crop Residues

	N	P ₂ O ₅	K ₂ O
----- Pounds per Ton -----			
Cattle manure	5-10 ¹	3	3
Poultry manure	25-50 ¹	40-80	30-60
Pig manure	5-10 ¹	2	2
Horse manure	6-12 ¹	3	6
Liquid poultry manure (5-15% solids)	7-15 ¹	5-10	5-10
----- Pounds per Acre -----			
Alfalfa sod	50-100 ²	0	0
Hairy vetch	50-100	0	0
Ladino clover sod	60	0	0
Crimson clover sod	50	0	0
Red clover sod	40	0	0
Birdsfoot trefoil	40	0	0
Lespedeza	20	0	0
Soybeans			
Tops and roots	40	0	0
Grain harvest residue	15	0	0

¹ Lower values for fall- and winter-applied manure, and higher values for spring applied manure. Use these figures only if manure being used has not been analyzed.

² 75% stand = 100-0-0, 50% stand = 75-0-0, and 25% stand = 50-0-0.

Table B-10. Boron Recommendations Based on Soil Tests for Vegetable Crops

Interpretation of Boron Soil Tests			Crops that Often Need Additional Boron ¹	Boron (B)
Parts per Million	Pounds per Acre	Relative Level		Recommendations Pounds per Acre ²
0.0-0.35	0.0-0.70	Low	Beets, broccoli, brussels sprouts, cabbage, cauliflower, celery, rutabaga, and turnips	3
			Asparagus, carrots, eggplant, horseradish, leeks, muskmelons, okra, onions, parsnips, radishes, squash strawberries, sweet corn, and tomatoes	2
			Peppers and sweet potatoes	1
0.36-0.70	0.71-1.40	Medium	Beets, broccoli, brussels sprouts, cabbage, cauliflower, celery, rutabaga, and turnips	1½
			Asparagus, carrots, eggplant, horseradish, leeks, muskmelons, okra, onions, parsnips, radishes, squash, strawberries, sweet corn, and tomatoes	1
>0.70	>1.40	High	All crops	0

¹ If boron deficiency is suspected in vegetable crops not listed above, a soil and/or plant tissue test should be made and used as a basis for treatment recommendations.

² Approximate conversion factors to convert elemental boron (B) to different boron sources: Boron (B) x 9 = borax (11.36% B); boron (B) x 7 = fertilizer borate granular (14.3% B); boron (B) x 6.7 = fertilizer borate-48 (14.91% B); boron (B) x 5 = fertilizer borate-65 (20.2% B) or Solubor (20.5% B); boron (B) x 4.7 = fertilizer borate-68 (21.1% B).

Note. The most practical way to apply boron as a soil application is as an additive in mixed fertilizer bought specifically for the crop or field where it is needed. Do not use fertilizer containing more than 0.5 pound of boron (B) per ton of fertilizer for crops not listed above, unless specifically recommended. To avoid possible boron toxicity damage to crops, apply boron in broadcast fertilizer rather than in bands or as a sidedressing. Boron may be broadcast preplant as a soluble spray alone or with other compatible soluble chemicals.