SOIL AND NUTRIENT MANAGEMENT

SOILS

The best soils for growing vegetables are well drained, deep mineral topsoil, and relatively high (greater than 2.0%) in organic matter. The pH has been modulated through cycles of cultivation as needed with lime and gypsum and fertility levels (N-P-K) have been augmented as needed. Soil textures, such as sandy loam or loamy sand, are generally best suited for growing early market crops, since they are more accessible to machinery and workers during periods of high moisture. 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 leafy vegetables, 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 supplements 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 and to retain topsoil. Note: The BMP is similar to the GAP described in Section A, and shares many of the same elements. The BMP is aimed at consistently high crop yields and quality, whereas the GAP is focused on avoidance of food safety deterrents.

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 generally obtain soil sample kits or containers and instructions through your local Extension 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 inaccurate. 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. Knowledge of soil nutrient content renders it less likely that ill-advised monetary investments will be made into unnecessary inputs.

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 Extension Agent when you pick up the soil sampling kit or container, so he/she can advise you if any special tests are needed. The Agent will also be aware of costs of the various soil testing services performed by the Soil Testing Laboratory.

LIMING SOILS

Most soils in the Mid-Atlantic Region are naturally acidic or become acidic under crop production systems and rainfall. If soils become too acidic (pH generally less than 6.0), crop performance is hindered by many factors – including reduced availability of plant 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 7.0 range. The grower should also plan rotations such that all crops grown on a given field have similar pH and nutrient requirements. 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
Carrot	6.0	5.5
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	6.2	5.5
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

(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
Squash - winter, summer	6.5	6.0
Sweet corn	6.5	6.0
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 when using water pH. Alternatively, many state and private labs now use buffer solutions to extract active and reserve acidity for pH determination. Buffer solutions reduce interference that commonly occurs when substantial amounts of soluble salts are in soil solution. When using buffer pH, calibrated charts along with the buffer pH can solely be used for lime requirement determination.

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 water 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 (reserve acidity). For the purpose of lime recommendations using water pH, 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 used to determine lime requirement and should not be confused with soil water 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 or colorimetric paper strip kits to be helpful in the planning of their liming program. A reliable portable pH meter will cost over $100, while the paper strip kits are much less expensive than meters, but also less precise.

For the majority of crops that 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 that have a target pH of 5.2, refer to Table B-3 for lime requirement. For snap beans grown on sandy Coastal Plain soils, the target pH should not exceed 6.2 (Table B-4). Excessively high pH increases the possibility of manganese deficiency in sensitive crops.

On soils with high organic content (greater than 6 percent) many crops with a desired pH of 6.5 can tolerate 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 7.0) 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 may further specify "low/high" and "very low/very high". This indicates relative need to remediate the soil by adding or withholding supplements of the indicated nutrient.

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

	Soil Texture and Fertility				
Initial Soil pH	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 (CCE) Recommended per Acre for Potato Varieties with a Target pH of 5.2

	Soil Texture and Fertility			
Initial Soil pH	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

	Soil Texture and Fertility				
Initial Soil pH	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.

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.

By law, the CCE of a liming material must be stated on the product label.

To determine the application rate of liming material in CCE, refer to Table B-5 or use the following calculation:

Actual amount of liming material =

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

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 ÷ 80) x 100 = 2,500 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 x 1.79 = 3,580 pounds CCE per acre

Selection of Liming Material

Liming materials neutralize soil acidity, supply Ca, and supplies or increases available 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 dolomitic liming material that has 3.6 to 9% Mg. If the soil Mg level is *optimum* or *above optimum*, use a calcitic or calcite liming material that has less then 3.6% Mg.

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 appropriate 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 Mg per 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 increase in soil pH 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. 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 such as asparagus is important. Once the crop is established, it is virtually impossible 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 more acidic over time. The frequency of prescribed lime application varies with soil characteristics, cropping system, and fertilizer practice. Heavy use of ammonium and urea nitrogen fertilizers accelerates 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.

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 as deeply as possible up to 24 inches.

Whenever conventional tillage is not practiced (e.g. perennial crops, conservation tillage systems), surface applications are recommended but the rate of pH change is much slower than for conventionally tilled soils. 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.

For crops utilizing plastic organic or mulches, lime should be applied and incorporated prior to bedding rows. It is ineffective to apply lime after plastic mulch has been laid and is not recommended.

Special Considerations

Potato scab is caused by a soil-inhabiting fungus (*Streptomyces scabies*). The disease is suppressed in acid soils (pH <5.2), so increase of soil pH with lime favors development of scab. When lime is needed, therefore, 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 potato varieties may be grown at pH 5.5 to 6.2.

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

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 depends on the crop to be grown, type of soil, soil acidity, and past use of fertilizer materials. Remember also that availability of nutrients is adversely affected by pH less than 5.0 or greater than 8.0.

PLANT NUTRIENTS

Many factors influence the nutrient requirements for optimum yield and quality of a given vegetable crop. The original source of soil particles, 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 of the same crop 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-8, and 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. Soil fertility categories include: "*Deficient*", "*Optimum*", and "*Exceeds crop needs*". *Deficient* is divided into subcategories: *very low*, *low*, and *medium*. These soil fertility categories gauge the probability of 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 factor 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. Crop yields may decrease at very high soil test nutrient levels.

Soil Test Categories

The basic soil test categories for management of soil Calcium (Ca), Magnesium (Mg), Phosphorus (P) and Potassium (k) are: "Deficient", "Optimum", and "Exceeds Crop Needs". 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 *deficient—low* the recommendation will indicate how much K to apply. The amount of K recommended however, depends 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 *deficient*, 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 to maintain *optimum* soil fertility. No nutrient application is generally recommended when the soil test category is *Exceeds crop needs.* This allows "draw-down" of the nutrient level to the *optimum* range. However, certain crops (ex. potatoes and tomatoes) still benefit from low fertilizer applications of root stimulating nutrients (ex. phosphorus) and should be applied as a "starter" fertilizer. These concepts are illustrated in Figure B-1.

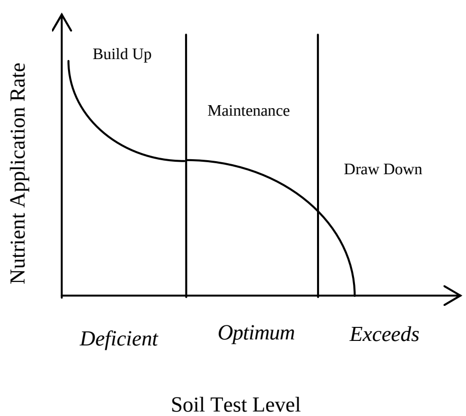

Figure B-1. Nutrient application rates vary in relation to soil test category.

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 nutrients available to crop plants. A soil test only provides 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-1 and Mehlich-3 soil tests are 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-1 and Mehlich-3 categories (Table B-8) 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.

Plant Nutrient Recommendations

To obtain highest yields with least negative environmental impacts, ALWAYS base plant nutrition decisions on a current soil test. Fertilizer is expensive and soil tests are relatively cheap and the only indicator of true nutrient needs. Refer to Table B-8 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 P_20_5 and K_20 together with 25 to 50 percent of the recommended nitrogen before planting. The remaining nitrogen can be sidedressed or applied with drip irrigation using a fertilizer containing nitrogen only. Sidedressing or topdressing potash (K_20) 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 P_20_5 and K_20, 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.

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. Certain crop residues and animal manures release nutrients into the soil over a long period of time as they are degraded.

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-11 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.

In another 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.

NUTRIENT MANAGEMENT

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 (N-P-K). Micronutrients may be supplied along with macronutrients.

Nitrogen Management

Nitrogen is one of the most difficult nutrients to manage in vegetable production systems. Nitrogen is readily leached in sandy textured soils that dominate vegetable production regions or can be immobilized by soil microbes, can volatilize if not quickly incorporated, and is lost via denitrification under water-saturated soil conditions. Due to the numerous nitrogen loss pathways, nitrogen is not routinely tested by state soil testing laboratories for making crop recommendations. Instead, nitrogen recommendations are based on years of fertilizer trials and yield potential. Nitrogen application timings, application methods, and sources are also commonly tested in state fertilizer trials and have resulted in recommendations for splitting nitrogen fertilizer for increased fertilizer use efficiency.

Heavy rainfall, higher than normal yield, and following non-legume cover crops are just a few examples of situations where nitrogen fertilizer may be immobilized, lost from the production system, or another application of nitrogen is warranted. Tissue testing is the best option when deciding if and how much more nitrogen is needed to meet expected yields. Soil testing laboratories can provide nitrogen concentrations of plant materials with quick turnaround times to aid in nitrogen application decisions.

Phosphorus Management

In general, crops are very likely to respond to P fertilization if dictated necessary by soil tests. Crops grown in a soil testing P level of *deficient—very low, low, or medium* indicates a strong response to P fertilizer additions. Crops in soils testing *optimum* may or may not respond to further additions, but P may be applied to maintain the fertility level in the *optimum* range (P fertilizer applied at crop removal rates). Crops in soils that *exceeds crop needs-very high* may also see a response to P fertility if conditions are favorable for high yields or plants have slow growing and/or shallow root systems. Tomato and potato are classic examples of crops benefiting from P fertilizer additions on very high soil test P concentrations.

It is often recommended that a band of P fertilizer be placed near the seed/transplant as a starter fertilizer regardless of the P fertility level. Banded P is especially helpful at low soil test P levels; however, overall field rates should not be decreased. When the soil test level is *deficient*, P should generally be applied as a combination of broadcast and banded methods. Even at P soil test levels that are *"very high-exceeds crop needs"*, a small amount of banded P may benefit crop establishment. Many test results describe the soils as "*exceeds crop needs"* category 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. In high concentrations, soil phosphorus will also interact with ionic micronutrients, such as zinc, to alter availability of P to the plant. Deciding to fertilizer if the soil test report indicates that P "*exceeds crop needs*" should be based on a crop and geographic specific case. However, the general recommendation is that soils "exceeding crop needs" for P should receive very little or no P fertilizer.

Potassium Management

Crops are very likely to respond to K fertilizer when the soil test indicates that K is *deficient—very low* or *low*. A soil testing *deficient—medium* in K may or may not respond to K fertilizer. Soils testing *optimum* or *exceeds crop needs* are unlikely to respond to K fertilizer, but K may be applied to maintain the soil fertility level in the *optimum* range.

In general, most of the K fertilizer should be broadcast. When the fertility level is *deficient*, 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 *exceeds crop needs.* In loamy sand and sand textured soils, split applications of K may be beneficial and may be applied using sidedress applications or applied through trickle irrigation.

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 limestone should be used for 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 regarding scenarios that do not conform to these common soil nutrient ranges..

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 concentrations greater than 5 ppm associated with 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 Tables B-6, B-7, and B-10.

Table B-6 Composition of Principal Macronutrient Fertilizer Materials

Material	N Nitrogen	P_2O_5 Phosphorus	K_2O Potassium	Mg Magnesium	Ca Calcium	S Sulfur	$CaCO_3$ Equiv.
	PERCENT (%)						lbs/ton
Ammonia, Anhydrous	82						-2960
Ammonium Nitrate	33 to 34						-1180
Ammonium Phosphate Sulfate	13 to16	20 to 39				13	-1520 to -2260
Ammonium Polyphosphate (APP)	10 to 11	34 to 37					+1000 to 1800
Ammonium Sulfate (Granular)	21					24	-2200
Ammonium Sulfate (Liquid)	8					9	
Ammonium Sulfate Nitrate	26					15	-1700
Ammonium Thiosulfate	12					26	-2000
Calcium Nitrate	19				19		+400
Calcium Sulfate (Gypsum)					23	17	
Diammonium Phosphate (DAP)	18	46		3			-1400
Limestone, Calcite				11	32		+1700 to 2000
Limestone, Dolomite				11	22	24	+1900 to 2160
Magnesium Oxide (Magnesia)				55			
Magnesium Sulfate (Epsom Salt)				10	2.2	14	
Monammonium Phosphate (MAP)	11	52					-1160
Nitric Phosphates	14 to 22	10 to 22			8 to 10	0 to 4	-300 to -500
Phosphoric Acid		52 to 54					-2200
Potassium Chloride (Muriate)			60 to 63				
Potassium Magnesium Sulfate			22	11		22	
Potassium Nitrate	13		44				-460
Potassium Sulfate			50 to 53			18	
Potassium Thiosulfate			25			17	
Rock Phosphate		30 to 36			33		+200
Sodium Nitrate	16						+580
Sulfur Elemental						32 to 100	
Superphosphate, Concentrated (Triple)		44 to 53			14		-3200
Superphosphate, Normal		16 to 22			20		
Urea	45 to 46						-1680
Urea Formaldehydes	35 to 40						-1360
Urea-Ammonium Nitrate Solutions	21 to 49						-750 to -1760

Table B7. Chemical Sources of Secondary and Micronutrients

Calcium Sources Material	**Chemical Formula**	**% Ca**
Calcitic lime	$CaCO_3$	31.7
Calcium nitrate	$Ca(NO_3)_2$	19.4
Dolomitic lime	$CaCO_3$+$MgCO_3$	21.5
Gypsum	$CaSO_4.2H_20$	22.5
Hydrated lime	$Ca(OH)_2$	46.1
Superphosphate, normal	$Ca(H_2PO_4)_2$	20.4
Superphosphate, triple	$Ca(H_2PO_4)_2$	13.6
Sulfur Sources Material	**Chemical Formula**	**% S**
Ammonium sulfate	$(NH_4)_2SO_4$	24
Gypsum	$CaSO_4.2H_2O$	16.8
K-Mg-sulfate	$K_2SO_4.2MgSO_4$	22.0
Sulfur, elemental	S	32 to 100
Potassium thiosulfate	$(NH_4)_2S_2O_3$	17
Ammonium thiosulfate	$K_2S_2O_3$	26
Boron Sources Material	**Chemical Formula**	**% B**
Borax	$Na_2B_4O_7.10H_2O$	11
Boric acid	H_3BO_3	17
Sodium pentaborate	$Na_2B_{10}O_{16}.10H_2O$	18
Fert. borate-46	$Na_2B_4O_7.5H_2O$	14
Fert. Borate-65	$Na_2B_4O_7$	20
Solubor	$Na_2B_{10}O_{16}.10H_2O$ +$Na_2B_4O_7.5H_2O$	20
Molybdenum Sources Material	**Chemical Formula**	**% Mo**
Ammonium molybdate	$(NH_4)_6Mo_7O_{24}.2H_2O$	54
Molybdenum trioxide	MoO_3	66
Sodium molybdate	$Na_2MoO_4.2H_2O$	39
Copper Sources Material	**Chemical Formula**	**% Cu**
Copper ammonium phosphate	$Cu(NH_4)PO_4.H_2O$	32
Copper chelates	$Na_2CuEDTA$ NaCuHEDTA	13 9
Copper sulfate	$CuSO_4.5H_2O$	25

(table continued next page)

Table B7. Chemical Sources of Plant Nutrients (continued)

Magnesium Sources Material	**Chemical Formula**	**% Mg**
Dolomitic lime	$MgCO_3$+$CaCO_3$	11.4
Epsom salt	$MgSO_4 \cdot 7H_2O$	9.6
Magnesia	MgO	55.0
Potassium-magnesium sulfate	$K_2SO_4 \cdot 2MgSO_4$	11.2
Manganese Sources Material	**Chemical Formula**	**% Mn**
Manganese chelate	MnEDTA	12
Manganese sulfate	$MnSO_4 \cdot 4H_2O$	26 to 28
Manganese oxide	MnO	41 to 68
Zinc sources Material	**Chemical Formula**	**% Zn**
Zinc carbonate	$ZnCO_3$	52
Zinc chelates	$Na_2ZnEDTA$ NaZnHEDTA	14 9
Zinc Oxide	ZnO	78
Zinc sulfate	$ZnSO_4 \cdot H_2O$	35
Iron sources Material	**Chemical Formula**	**% Fe**
Iron sulfate	$FeSO_4 \cdot 7H_2O$	19
Iron ammonium phosphate	$Fe(NH_4)PO_4 \cdot H_2O$	29
Iron ammonium polyphosphate	$Fe(NH_4)HP_2O_7$	22
Iron chelates	NaFeEDTA NaFeDTPA NaFeEDDHA	5 to 14 10 6

Table B-8. Soil Test Categories for Nutrients Extracted by Mehlich 1 and Mehlich 3

	Soil Test Category	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)[1]
Mehlich 3		Mehlich 3 Soil Test Value (lbs/acre)[2,3]			
	Deficient (very low)	0-24	0-40	0-45	0-615
	Deficient (low)	25-45	41-81	46-83	616-1007
	Deficient (medium)	46-71	82-145	84-143	1008-1400
	Optimum (high)	72-137	146-277	144-295	1401-1790
	Exceeds Crop Needs (very high)	138+	278+	296+	1791+
Mehlich 1		Mehlich 1 Soil Test Value (lbs/acre)[2]			
	Deficient (very low)	0-3	0-15	0-24	0-240
	Deficient (low)	4-11	16-75	25-72	241-720
	Deficient (medium)	12-35	76-175	73-144	721-1440
	Optimum (high)	36-110	176-310	145-216	1441-2160
	Exceeds Crop Needs (very high)	111+	311	217+	2161+

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

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Micronutrients

Boron (B) 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-12 for boron recommendations for various crops based on soil or plant tissue test results. Use of excessive amounts of boron can be very toxic to plant growth. **DO NOT** exceed recommendations listed in Table B-12 and in specific commodity recommendations section for Plant Nutrient Recommendations Based on Soil Tests for Vegetable Crop Production.

Manganese (Mn) deficiency often occurs in plants growing on soils that have been over-limed with a pH above 7.0. 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 (Mb) deficiency in cauliflower (whiptail) may develop when this crop is grown on soils more acid than pH 5.5. 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 the Mid-Atlantic U.S. region rare; and when present, are usually caused by overliming or other substandard soil management practices. Contact your county Extension agent for advice 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 Tables B-6 and B-7.

Plant Tissue Testing

Plant tissue testing is an important tool in assessing vegetable nutrient status during the growing season. Three methods are commonly used for tissue testing and include 1. Testing leaf tissue, 2. Testing whole petioles, and 3. Testing petiole sap.

1. For collecting leaf tissue, for analysis:
   - Sample the most recently matured leaf from the growing tip. The sample is a whole leaf sample and it should not contain any root or stem material. For sweet corn or onions, the leaf is removed just above the attachment point to the stalk or bulb. For compound leaves (carrots, peas, tomatoes, etc.), the whole leaf includes the main petiole, all the leaflets and their petioles. For heading vegetables, it is most practical to take the outermost whole wrapper leaf. When sampling particularly young plants, the whole above-ground portion of the plant may be sampled.
   - A proper leaf sample should consist of about 25 to 100 individual leaves. The same leaf (i.e., physiological age and position) should be removed from each sampled plant. Plants damaged by pests, diseases, or chemicals should
   - be avoided when trying to monitor the nutrient status of the crop.
   - Sample across the field, from different rows, and avoid problem areas (low spots, ridges, washed out areas, etc.).
   - Sample when the plants are actively growing (typically between 9 a.m. and 4 p.m.).
   - Do not collect samples from water stressed plants.
   - Send samples to a laboratory in a paper bag. DO NOT SEND SAMPLES IN A PLASTIC BAG. Plastic bags will cause your samples to spoil and will impact results.
2. For collecting whole petiole samples for analysis:
   - Sample the most recently matured leaf. Throw away the leaflets. (Figure B-2)
   - Sample from 30 to 50 plants.
   - Sample across the field, from different rows, and avoid problem areas (low spots, ridges, washed out areas, etc.).
   - Sample between 10 a.m. and 2 p.m.
   - Do not collect samples from water stressed plants.
   - Send samples to a laboratory in a paper bag. DO NOT SEND SAMPLES IN A PLASTIC BAG. Plastic bags will cause your samples to spoil and will impact results.
3. For collecting petiole sap samples:
   - Sample petioles from most recently matured leaf. Throw away the leaflets. (Figure B-4) Sample 30 to 50 plants.
   - Sample across the field, from different rows, and avoid problem areas (low spots, ridges, washed out areas, etc.).
     - Sample between 10 a.m. and 2 p.m.
   - Do not collect samples from water stressed plants.
   - After collection, squeeze collected petioles with a garlic press to extract sap.
   - Use a handheld nitrate meter, available widely from nutrient management supply companies, to read the sap nitrate concentration. Make sure you record the correct units as either NO_3^{-1} or NO_3^{-1}-N.
   - Petiole sap sufficiency ranges are found in Table B10.

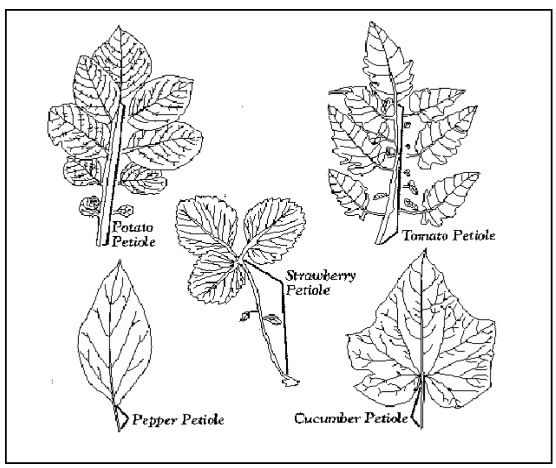

Figure B-2 Petiole delineation for several plant species.

Interpreting Tissue Tests

Tissue tests will be reported as adequate or sufficient in a range; low or deficient below that range; high or excessive above that range; and toxic (if applicable) if in excess. Test interpretation for most vegetable crops can be found at this website at the University of Florida: http://edis.ifas.ufl.edu/ep081. Tissue test interpretations for selected crops are also found in Section F. Petiole sap sufficiency ranges are found in Table B10. The concentrations representing the adequate range (sufficiency range) are those nutrient concentrations to be found in plants that have adequate nutrients available to them. Plants with nutrient concentrations in the high range are indicative of over-fertilization. Excessive values for micronutrients may result in phytotoxicity.

Correcting Deficiencies

Recommendations for correcting specific crop deficiencies are presented in the previous sections and in table B9 below.

Table B9. Recommendations for correction of vegetable nutrient deficiencies.

Nutrient	**Fertilizer**	**Method**	**Application Rate (nutrient) lb. per acre**
Nitrogen (N)	Urea-ammonium nitrate solutions Calcium nitrate	T,S,D[2] T,S,D	30 to 40
Phosphorus (P_2O_5)	Ammonium phosphates Triple superphosphate Phosphoric acid	T,S,D T,S S,D	20
Potassium (K_2O)	Potassium chloride Potassium nitrate	T,S,D T,S,D	30
Calcium (Ca)	Calcium nitrate Calcium chloride	T,S,D D	30
Magnesium (Mg)	Magnesium sulfate Potassium magnesium sulfate	T,S,D T,S	20
Sulfur (S)	Ammonium Sulfate Gypsum	T,S,D T,S,D	20
Boron (B)	Borax, Solubor[1]	D,F	0.1 to 0.2
Copper (Cu)	Copper sulfate	D,F	0.1 to 0.2
Iron (Fe)	Ferrous sulfate, chelated iron	D,F	0.2 to 0.5
Manganese (Mn)	Manganous sulfate, chelated manganese	D,F	0.5 to 1.0
Molybdenum (Mo)	Sodium molybdate	D,F	0.01 to 0.05
Zinc (Zn)	Zinc sulfate, chelated zinc	D,F	0.1 to 0.2

[1] Mention of a trade name does not imply a recommendation compared to similar materials.
[2] T,S,D,F are topdress, sidedress, drip irrigation, and foliar, respectively.

Table B10. Sufficiency levels for petiole sap concentrations in vegetable crops.

Crop	Stage of Growth	Fresh Petiole Sap Concentration (ppm)	
		K	NO_3-N conc.
Cucumber	First blossom Fruits three inches First harvest	N/A	800 to 1000 600 to 800 400 to 600
Broccoli	Six-leaf stage Just prior to harvest At first harvest	N/A	800 to 1000 500 to 800 300 to 500
Eggplant	First fruit (two-inches long) First harvest Mid harvest	4500 to 5000 4000 to 5000 3500 to 4000	1200 to 1600 1000 to 1200 800 to 600
Muskmelon (Cantaloupe)	First blossom Fruits 2 inches First harvest	4000 to 5000 3500 to 4000 3000 to 3500	1000 to 1200 800 to 1000 700 to 800
Pepper	First flower buds First open flowers Fruits half-grown First harvest Second harvest	3200 to 3500 3000 to 3200 3000 to 3200 2400 to 3000 2000 to 2400	1400 to 1600 1400 to 1600 1200 to 1400 800 to 1000 500 to 800
Potato	Plants 8 inches tall First open flowers 50% flowers open 100% flowers open Tops falling over	4500 to 5000 4500 to 5000 4000 to 4500 3500 to 4000 2500 to 3000	1200 to 1400 1000 to 1400 1000 to 1200 900 to 1200 600 to 900
Squash	First blossom First harvest	N/A	900 to 1000 800 to 900
Tomato (Field)	First buds First open flowers Fruits one-inch diameter Fruits two-inch diameter First harvest Second harvest	3500 to 4000 3500 to 4000 3000 to 3500 3000 to 3500 2500 to 3000 2000 to 2500	1000 to 1200 600 to 800 400 to 600 400 to 600 300 to 400 200 to 400
Watermelon	Vines 6-inches in length Fruits 2-inches in length Fruits one-half mature At first harvest	4000 to 5000 4000 to 5000 3500 to 4000 3000 to 3500	1200 to 1500 1000 to 1200 800 to 1000 600 to 800

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 phrase. 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 in the *deficient* category, 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 into the *exceeds crop needs* category, good crop yields may be obtained without adding the nutrient; however, yield and quality are likely to be reduced by reapplying a nutrient already present in very high amounts. Over a period of time, nutrient removal by crops should allow the soil fertility level to fall back into the *optimum* range (see Figs. B-1, B-3).

Very high soil nutrient levels can be as detrimental to crop performance 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

P_2O_5/acre or 160 lbs P/acre) in the soil may lead to deficiencies of other nutrients, especially of iron and zinc. High K levels (above about 205 lbs K_2O/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.

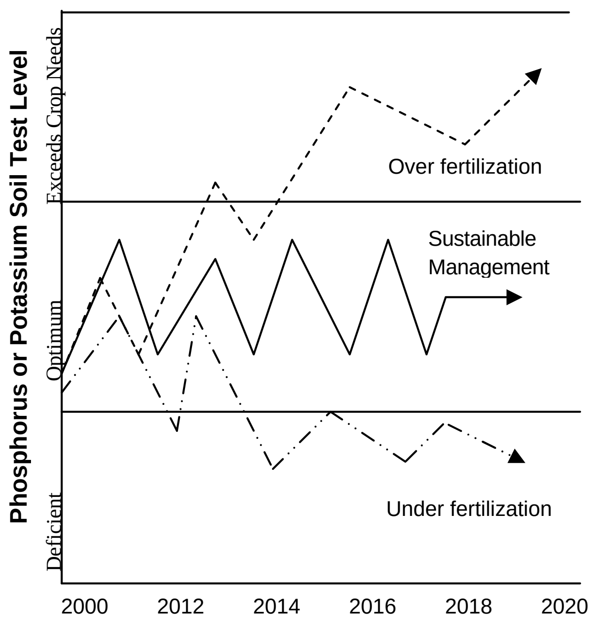

Figure B-3. Changes in soil test levels over time under different nutrient management scenarios.

Sewage Sludge

Sewage sludge, or biosolids, is a by-product of the purification of waste water. This type of material 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 disinfest it. After appropriate treatment, federal and some state regulations allow the use of sewage sludge on vegetables. However, due to our lack of knowledge and biosolids and perishable food commodities. **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.

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. Care should be taken to use approved tank mixes if nutrients are combined with fungicides, insecticides, herbicides, or any other additive. Often, chelated nutrient sources are optimal for most tank mixes; however, care should be taken to read the label and conduct a jar test. Generally, it is difficult to supply ample macro and secondary nutrients as a foliar fertilization, and focus should be directed towards application of this strategy micronutrients only. If deficiency occurs, efforts should be made to correct any deficient nutrient via soil fertilization prior to the next growing season.

Soil Improvement and Organic Nutrient Sources

Cover Crops

Cover cropping is an important practice for sustainable vegetable production. The following are some reasons to consider using cover crops in vegetable rotations.

- Return organic matter to the soil. Vegetable rotations are tillage intensive and organic matter is oxidized at a high rate. Cover crops help to maintain organic matter levels in the soil, a critical component of soil health and productivity.
- Provide winter cover. By having a crop (including roots) growing on a field in the winter you recycle plant nutrients (especially nitrogen), reduce leaching losses of nitrogen, reduce erosion by wind and water, and reduce surface compaction and the effects of heavy rainfall on bare soils. Cover crops also compete with winter annual weeds and can help reduce weed pressure in the spring.
- Reduce certain diseases and other pests. Cover crops help to maintain soil organic matter. Residue from cover crops can help increase the diversity of soil organisms and reduce soil borne disease pressure. Some cover crops may also help to suppress certain soil borne pests, such as nematodes, by releasing compounds that affect these pests upon decomposition.
- Provide nitrogen for the following crop. Leguminous cover crops, such as hairy vetch or crimson clover, can provide significant amounts of nitrogen, especially for late spring planted vegetables.
- Improve soil physical properties. Cover crops help to maintain or improve soil physical properties and reduce compaction. Roots of cover crops and incorporated cover crop residue will help improve drainage, water holding capacity, aeration, and tilth.

Small Grains and Ryegrasses

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, triticale, barley 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. Spring oats also works as a spring planted cover. Annual and perennial ryegrass or a mixture of the two seeded at 15-20 pounds per acre by early September are also good cover crops.

Legumes

Research has demonstrated that certain legumes are also effective cover crops for vegetable rotations. Hairy vetch, crimson clover, field peas, subterranean clover, and other clovers are excellent cover crops and can provide significant nitrogen for vegetable crops that follow. Good examples are hairy vetch drilled at 25-60 lbs/acre, crimson clover at a rate of 15-30 lbs/acre, or field peas such as Austrian Winter planted at 50-70 lbs/acre. Subterreanean clover is an option for the southern part of the region. Hairy vetch works very well in no-till vegetable systems where it is allowed to go up to flowering and then is killed by herbicides or with a roller-crimper. It is a common system for planting pumpkins in the region but also works well for late plantings of other vine crops, tomatoes and peppers. Hairy vetch, crimson clover, field peas and subterranean clover can provide from 80 to well over 100 pounds of nitrogen equivalent. Remember to inoculate the seeds of these crops with the proper Rhizobia inoculants for that particular legume. All of these legume species should be planted as early as possible – from the last week in August through the end of September to get adequate fall growth. Legume cover crops should be planted a minimum of 4 weeks before a killing frost.

Red clover planted late winter or early spring can be used ahead of early summer vegetables. Summer legume cover crops can be used for soil improvement and provide nitrogen prior to planting fall vegetable crops. These include sun hemp, cowpeas, soybeans, annual lespedeza, and a number of medic (alfalfa) species.

Summer Annual Grasses

Summer grass cover crops such as sudangrass, forage sorghum or sorghum x sudangrass crosses , seeded at 20 to 40 pounds per acre, are good green manure crops. Several millet species including forage-type pearl millet, teff, German or foxtail millet, and Japanese millet are also good cover 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.

Brassica Species

There has been an increase in interest in the use of certain *Brassica* species as cover crops for vegetable rotations. These include both fully hardy overwintering species and species that will winter kill but that can be planted in the spring ahead of crop production. They provide significant organic matter, recycle nitrogen, can reduce compaction (larger rooted types), and offer the potential for biofumigation (mustards and rapeseed). Plant by September 15 in the fall or in March-April in the spring.

Brassica types available:

Rapeseed and Canola – overwinter and are good biofumigants

Forage Radish, Oilseed Radish, and Daikon Radish – very good for reducing compaction in soils; forage radish winter kills, oilseed radish is hardier.

Mustards (brown and yellow mustards as well as garden mustard) – offer good biofumigant potential; half hardy

Turnips (forage and garden types) – good biomass production; half hardy

Kale (forage and garden types) – winter hardy; good biomass production

Hybrid Forage Brassicas (such as ‘Typhon’) – these are hybrid crosses of two or more species that will produce excellent fall growth and some will overwinter Rapeseed has been used as a winter cover when planted by early September and has shown some promise in reducing certain nematode levels in the soil acting as a biofumigant. Several mustard species also have biofumigation potential to take advantage of the biofumigation properties of rapeseed and biofumigant mustards you plant the crop in late summer or in spring. Allow the plant to develop until just before it goes to seed. It is the leaves that break down to release the fumigant-like chemical. Mow using a flail mower and plow down the residue immediately. Never mow down more area than can be plowed under within two hours. Mowing injures the plants and initiates a process releasing biofumigant chemicals into the soil. Failure to incorporate mowed plant material into the soil quickly, allows much of these available toxicants to escape by volatilization.

Several mustard species can be used for fall cover but not all varieties and species will winter over into the spring. As stated above, several mustard species have biofumigation potential and a succession rotation of an August planting of biofumigant mustards that are tilled under in October followed by small grain can significantly reduce diseases for spring planted vegetables that follow.

Make sure to mow and disk rapeseed and mustard in advance of seed maturation, since they can become serious noxious weeds.

Other Cover Crops/Special Considerations

A number of other cover crops may be useful. Buckwheat is a quick summer cover crop noted for its ability to smother out weeds, Marigold species have been used as nematode controls.

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, sorghum x sudangrass, timothy, orchardgrass, ryegrass and other grass hay species 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 has 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.

Forage radish and oilseed radish are also very well suited to improving compacted soils.

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.

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:H7, 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.

A good extension web reference on the making and use of compost for vegetable production is https://aggie-horticulture.tamu.edu/vegetable/guides/composts-vegetable-fruits-production/.

For more information on nutrients in organic production see the guide *Using Organic Nutrient Sources* at: http://pubs.cas.psu.edu/FreePubs/pdfs/uj256.pdf.

Herbicide Carryover in Compost

It is important to know the source and composition of any soil amendment or compost that is used on or around vegetable crops. Compost that contains hay, straw, grass clippings, and cow or horse manure may potentially be a carrier of herbicide residue. Several herbicides commonly used in pasture and turf production may be present in straw or hay and can pass through the digestive system of animals and remain in manure. These herbicides are toxic in very low concentrations to many vegetable crops. Symptoms are often similar to growth regulating herbicides and include twisted or cupped leaves, misshapen fruit, reduced yields, or plant death. Additional information can be found at: http://www.ces.ncsu.edu/fletcher/programs/ncorganic/special-pubs/herbicide_carryover.pdf.

Organic Production

Nutrient sources used for certified organic production must be included in the National List of Allowed and Prohibited Substances, which can be found on the web, (www.ams.usda.gov/AMSv1.0/nop). The Organic Materials Review Institute (OMRI) reviews products submitted by companies against the National Organic Standard (NOS) and is a good place to identify which products are allowed in organic production (visit omri.org for more information). Certifying agencies also review products for compliance with the NOS. Before using any product it is best to check with your certifying agency to make sure the product is allowed and thereby avoid compromising your organic certification. See Table B-13 for a list of various products useable on organic farms.

Table B-11. Plant Nutrient Value Credits to Be Allowed for Manure Applications and Crop Residues

	N	P_2O_5	K_2O
	----------- *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[2]	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-12. Boron Recommendations Based on Soil Tests for Vegetable Crops

Interpretation of Boron Soil Tests				
Parts per Million	**Pounds per Acre**	**Relative Level**	**Crops that Often Need Additional Boron[1]**	**Boron (B) 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, tomatoes, and white potatoes	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, tomatoes, and white potatoes	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.

Table B-13. Mineral nutrient value, relative availability and status for organic production of various nutrient sources. Before using any of the listed materials, it's best to check with your certifying agency because some of the materials may be removed from or added to the list in the future.

Materials[a]	Status for Organic Production[b]	Percent Nutrients[c]			
		N	P_2O_5	K_2O	Relative Availability
Animal Tankage (dry)	Allowed	7	10	0.5	Medium
Bone Meal (raw)	Allowed	2 to 6	15 to 27	0	Slow
Bone Meal (steamed)	Allowed	0.7 to 4.0	18 to 34	0	Slow Medium
Cocoa Shell Meal	Allowed	2.5	1.0	2.5	Slow
Compost (not fortified)	Allowed[d]	1.5 to 3.5	0.5 to 1.0	1.0 to 2.0	Slow
Cottonseed Meal (dry)	Allowed[e]	6	2.5	1.7	Slow Medium
Dried Blood (dry)	Allowed	12	1.5	0.57	Medium Rapid
Fish Emulsion	Allowed	5	2	2	Rapid
Fish Meal (dry)	Allowed	14	4	0	Slow
Fish Scrap (dry)	Allowed	3.5 to 12	1 to 12	0.08 to 1.6	Slow
Garbage Tankage (dry)	Allowed	2.7	3	1	Very Slow
Grain Straw	Allowed	0.6	0.2	1.1	Very Slow
Guano (Bat)	Restricted[f]	5.7	8.6	2	Medium
Kelp[g]	Allowed	0.9	0.5	4 to 13	Slow
Manure[h] (fresh)	Restricted[i]	0.25	0.15	0.25	Medium
Cattle		0.25	0.15	0.25	Medium
Horse		0.3	0.15	0.5	Medium
Sheep		0.6	0.33	0.75	Medium
Swine		0.3	0.3	0.3	Medium
Poultry (75%)		1.5	1	0.5	Medium Rapid
Poultry (50%)		2	2	1.0	Medium Rapid
Poultry (30%)		3	2.5	1.5	Medium Rapid
Poultry (15%)		6	4	3	Medium Rapid
Marl	Allowed	0	2	4.5	Very Slow
Mushroom Compost[j]	Allowed[k]	0.4 to 0.7	5.7 to 6.2	0.5 to 1.5	Slow
Peanut Hulls	Allowed	1.5	0.12	0.78	Slow
Peat and Muck	Allowed[l]	1.5 to 3.0	0.25 to 0.5	0.5 to 1.0	Very Slow
Pomaces[m]					
Apple (fresh)	Allowed	0.17 to 0.3	0.4 to 0.7	0.2 to 0.6	Slow
Apple (dry)		0.7 to 0.9	1.2 to 2.1	0.6 to 1.8	Slow
Castor		5.0	1.0	1.0	Slow
Winery		1.5	1.5	0.80	Slow
Sawdust	Allowed[n]	4	2	4	Very Slow
Soybean Meal (dry)	Allowed	6.7	1.6	2.3	Slow Medium
Tobacco Stems (dry)	Allowed	2	0.7	6.0	Slow
Wood Ashes[o]	Allowed[p]	0	1 to 2	3 to 7	Rapid

[a]Some materials may not be obtainable because of restricted sources.
[b]Must be produced in accordance with the National Organic Standard to be allowed. Organic status was determined through listing with the Organic Materials Review Institute (OMRI; www.omri.org). Brand used may affect allowability; check with your certifier before using any product to avoid compromising your certification.
[c]The percentage of plant nutrients is highly variable, mean percentages are listed.
[d]Must be produced in accordance with the National Organic Standards to be used in organic production.
[e]Brand used must not be derived from genetically modified cotton or contain prohibited substances.
[f]Allowed guano is decomposed and dried deposits from wild bats or birds. Must meet requirements for using raw manure.
[g]Contains common salt, sodium carbonates, sodium and potassium sulfates.
[h]Plant nutrients are available during year of application. Nutrient content varies with the amount of straw and method of storage.
[i]Uncomposted or raw animal manure must be used on fields with crops not to be consumed by humans **or** incorporated into the soil a minimum of 90 days before harvesting a product to be consumed by humans provided that the edible portion of the crop does not contact the soil **or** integrated into the soil a minimum of 120 days before harvesting a product to be consumed by humans that does come into contact with the soil. Using sewage sludge is prohibited in certified organic production.
[j]Use only after composting in compliance with the National Organic Standard. Fresh mushroom compost is usually too high in soluble salts.
[k]Must meet compost requirements.
[l]Not allowed if contains synthetic wetting agents.
[m]Plant nutrients are highly variable, depending on the efficiency and the processing techniques at the processing plant.
[n]Allowed only if wood is untreated and unpainted.
[o]Potash content depends upon tree species burned. Wood ashes are alkaline, contain about 32% CaO.
[p]Only from untreated and unpainted wood. Wood stove ash – only if not contaminated with colored paper, plastics, or other synthetic sources.