B. Soil and Nutrient Management

1. Soils

The best soils for growing vegetables have well drained, deep mineral topsoil with a relatively high organic matter (> 2%) content. Soil pH has been fine-tuned through adjustments with lime as needed and fertility levels (N-P-K) have been improved as needed. Sandy loam or loamy sand soil textures are generally best suited for growing early market crops, since they are easier to work with machinery and by farm employees 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 of producing a successful crop. If you plant crops that require well-drained soils on poorly drained soils, you are doomed to failure regardless of your growing skills.

Typical BMPs (Best Management Practices) include 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 or rotations with grain, oilseed, or fiber crops between vegetable plantings are essential to maintain good soil structure, to retain topsoil, and promote system diversity for other management problems (*i.e.*, disease). Note: BMPs are similar to Good Agricultural Practices (GAPs) and share many elements. BMPs are aimed at consistently high crop yields and quality, whereas GAPs are focused on avoidance of food safety problems (see section A 13 Food Safety Concerns).

Soil Tests

The best way to determine the lime and fertilizer needs of your soil is to have it tested. Soil testing should be performed every 1 to 3 years. You can obtain soil sample kits or containers and instructions through your local Extension Office or a private lab.

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. Application rates of lime and fertilizer materials should consider the current soil fertility level, past cropping and soil management practices, and the crop you will grow. Taking a scientific approach minimizes potential for plant damage, reduces water pollution potential, and can save money.

Lime and fertilizer recommendations from soil testing laboratories are based on soil test results, the crop to be grown, past cropping, past liming, and fertilization practices. This is information you supply on the soil sample questionnaire when submitting the sample. For this reason, it is very important to supply accurate information about the history and future use 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/Educator when you pick up the soil sampling kit or container, so they can advise you if any special tests are needed. The Agent/Educator will also be aware of the cost of the various soil testing services performed by the soil testing laboratory.

2. Liming Soils

Most soils in the mid-Atlantic region are naturally acidic or become acidic under crop production systems and with rainfall. If soils become too acidic (generally pH 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 6.0 to 6.8 pH range. 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.

Soil pH alone cannot be used to determine the amount of liming material needed to adjust soil pH. Soil test results provide all the data needed (*i.e.*, soil texture) to determine the lime requirement and type of lime to use. Many state and private labs 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 the soil solution. When using buffer pH, calibrated charts along with the buffer pH for that particular test can solely be used for lime requirement determination.

Table B-1. Target Soil pH Values for Vegetable Crops

Crop	Target pH	Target lime when pH falls below	Crop	Target pH	Target lime when pH falls below
Asparagus	6.8	6.2	Okra	6.5	6.0
Beans - lima, snap	6.2	6.0	Onions - green, bulb, scallions	6.5	6.0
Beets	6.5	6.2	Parsley	6.5	6.0
Broccoli	6.5	6.2	Parsnips	6.5	6.0
Brussels sprouts	6.5	6.2	Peas	6.5	6.0
Cabbage	6.5	6.2	Peppers	6.5	6.0
Carrot	6.0	5.5	Potatoes, sweet	6.2	5.5
Cauliflower	6.5	6.2	Potatoes - white, scab susceptible	5.2	5.0
Collards	6.5	6.2	Potatoes - white, scab resistant	6.2	5.5
Cantaloupes	6.5	6.0	Pumpkins	6.5	6.0
Celery	6.5	6.0	Radish	6.5	6.2
Cucumber	6.5	6.0	Rhubarb	6.5	5.5
Eggplant	6.5	6.0	Rutabaga	6.5	6.2
Endive - escarole	6.5	6.0	Spinach	6.5	6.0
Horseradish	6.5	5.5	Squash - winter, summer	6.5	6.0
Kale	6.5	6.2	Sweet corn	6.5	6.0
Kohlrabi	6.5	6.2	Strawberries	6.2	5.8
Leeks	6.5	6.0	Tomatoes	6.5	6.0
Lettuce - leaf, iceberg	6.5	6.0	Turnips	6.5	6.0
Mixed vegetables	6.5	6.0	Watermelon	6.2	5.5
Muskmelons	6.5	6.0			

Lime Requirement

The lime requirement of a soil depends on total acidity that must be neutralized to raise the 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 exchangeable acid cations bound to clay and organic matter (reserve acidity). For the purpose of lime recommendations using soil-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 classification. Soil texture (*e.g.*, loamy sand) may be considered a fixed soil property because it is not readily changed. Portable pH meters or colorimetric paper strip kits (less expensive but also less precise) may be helpful for planning your liming program. Once soil texture and pH are known, the lime requirement can be determined by referring to the appropriate table for the crop to be grown. Consult Table B-2 for lime requirements for crops with a target soil pH of 6.3 to 6.5 (the majority of crops), for crops with a target soil pH not exceeding 6.2 (*e.g.*, snap beans grown on sandy Coastal Plain soils), and crops with a target soil pH of 5.2 (*e.g.*, scab susceptible potatoes). Note: On soils with high organic content (> 6%) many crops with a desired soil pH of 6.5 can tolerate a lower soil pH (typically pH 5.6) than on mineral soils.

Typical soil test results will include pH and relative availability of magnesium (Mg) and calcium (Ca) to dictate what lime type should best be used. While most vegetables grow best in soils that are slightly acid (pH 6.0-6.8), some (*e.g.*, sweet potato and some white potato varieties) are best grown at soil pH 5.2. Soil test reports will usually report Mg and Ca levels as “above optimum” or “exceeds crop needs”, “optimum”, and “below optimum” or “deficient”, and may further specify “low/high” and “very low/very high”. These qualifications indicate relative need to remediate the soil by adding or withholding supplements of the indicated nutrient and by recommending a specific lime (*i.e.*, dolomitic lime for more Mg and calcitic lime for more Ca). Note: Excessively high pH increases the possibility deficiency in sensitive crops (*i.e.*, Mn, P, etc.).

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% and is the standard against which all liming materials are measured. Since the CCE of liming materials may vary from 40 to 179%, 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 determine the application rate of liming material in CCE, refer to Table B-3 or use the following calculation:
Actual amount of liming material required = Soil test CCE recommendation ÷ % CCE of liming material x 100
Example: A soil test recommends applying 2,000 lb CCE/A and the liming material purchased has 80% CCE.
Actual amount of liming material required per acre = 2,000 ÷ 80 x 100 = 2,500 lb/A

Table B-3 may be used instead of the formula to convert soil test recommendations for lb CCE/A to lb of the actual liming materials to be applied. 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 lb/A practical for spreading equipment. Although liming recommendations should now be given in lb CCE/A, recommendations that are given as total oxides can be converted to CCE by multiplying by 1.79.
Example: If the recommendation calls for 2,000 lb/A of total oxides, the recommendation for lb CCE/A is:
2,000 x 1.79 = 3,580 lb CCE/A.

Selection of Liming Material

Liming materials neutralize soil acidity, supply calcium (Ca) and supply or increase available magnesium (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 using fine-sized liming material. When soil pH is low, soil test levels of Ca and Mg may be *below optimum* or *deficient*. It is important to choose a liming material that contains a significant concentration of Mg; these 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* or *exceeds* crop needs, use a calcitic or calcite liming material that has less than 3.6% Mg.

Occasionally soils test *below optimum* or *deficient* 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 lb/A of Mg from a Mg fertilizer. If Mg is *below optimum-low*, apply 15 lb/A of Mg. If soil pH is satisfactory for the crop, but the Ca level is *below optimum--very low*, apply 350 lb/A of Ca (=1500 lb/A of gypsum). If the pH is satisfactory, but Ca is *below optimum--low*, apply 175 lb/A of Ca (=750 lb/A of gypsum).

Timing of Application

Lime is slow to react in soil. It may take several months after application for soil pH to reach desired levels. 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. 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, or establishing polyethylene mulch is important. Once the plastic mulch is layed or crop is established, it is virtually impossible to correct a soil pH problem using surface applications of lime. Lime should be applied at least six months to a year in advance of planting perennial crops to ensure 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 N fertilizers accelerates soil acidification. Test your soil pH every 1 to 3 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 pH will change 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 lb CCE/A.

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

Special Considerations

Potato scab is caused by the soil-inhabiting fungus *Streptomyces scabies*. The disease is suppressed in acid soils (pH <5.2), so increasing soil pH with lime favors development of scab. When lime is needed, it is best to apply the lime after potato harvest and before other crops are 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 has been a problem in the past, 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. Soil Ca levels should be medium or optimum and in balance with Mg. Plan ahead and adjust pH, Ca, and Mg the season before planting spinach.

Lime and Fertilizer

Lime and fertilizer work together to produce high yields and better crops. Lime is not a substitute for fertilizer, and fertilizer is not a substitute for lime. Proper use of the two together creates optimal nutrient availability for vegetables. 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. The availability of nutrients is adversely affected by pH less than 5.0 or greater than 7.0.

Table B-2. Pounds of Calcium Carbonate Equivalent (CCE) Recommended per Acre

For Crops with a Target Soil 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	0
For Crops with a Target Soil pH of 6.2					
	Soil Texture and Fertility				
Initial Soil pH	**Loamy Sandy**	**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 6.5	0	0	0	0	0
For Potato Varieties with a Target Soil pH of 5.2					
	Soil Texture and Fertility				
Initial Soil pH	**Loamy Sandy**	**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-3. Conversion of Recommended Calcium Carbonate Equivalent to Recommended Limestone

CCE (lb/A) Recommended by Soil Test	Percent Calcium Carbonate Equivalent (% CCE) of Liming Material							
	70	**75**	**80**	**85**	**90**	**95**	**100**	**105**
	Actual Limestone Recommendation (lb/A)[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 amounts 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 lb/A of CCE as a topdressing:** loamy sand 2,000, sandy loam 3,000, loam 4,000, and silt loam 5,000. If fields are to be plowed and the CCE recommendation exceeds 3,000 lb/A, plow under half the needed amount and apply the other half after plowing and then disk in as deeply as possible.

3. Plant Nutrients

Many factors influence the nutrient requirements for optimum yield and quality of a given vegetable crop. The original source of soil particles, texture, 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 affect retention, availability, and uptake of nutrients. Varieties of the same crop often differ significantly in their nutrient requirements. Test soils to determine the kinds and amounts of phosphorus, potassium, calcium, and magnesium 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 Analytical Services Laboratory, College of Agriculture, The Pennsylvania State University; *https://agsci.psu.edu/aasl*. In years when soil tests are not taken, growers in Pennsylvania should use Tables B-4, as described below. Growers in Delaware, Maryland, New Jersey, Virginia, and West Virginia should use Table B-4, as described below.

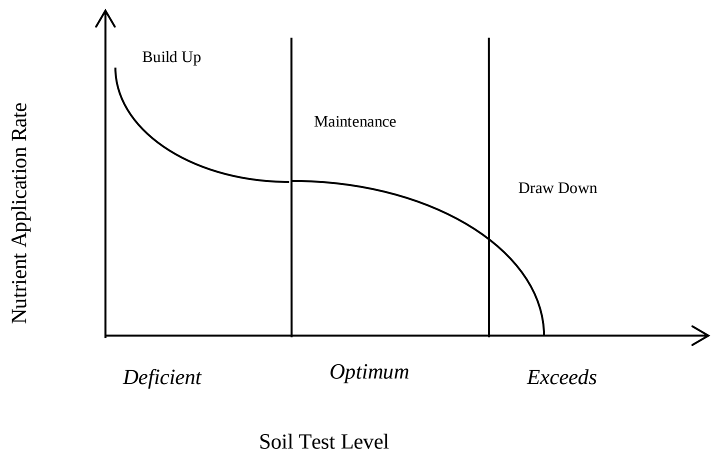
See important notes and discussion in the Plant Nutrient Recommendations section below to adjust nutrient rates and timing based on soil type, cation exchange capacity, cropping and manure history, and soil temperatures.

Soil Test Categories

The basic soil test categories for management of soil Calcium (Ca), Magnesium (Mg), Phosphorus (P) and Potassium (K) are: "**below optimum**" or "**deficient**", "**optimum**", and "**above optimum**" or "**exceeds crop needs**". For limestone recommendations, these categories indicate the concentrations of Ca and 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* or *deficient*, 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. If the soil fertility category is *below optimum* or *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. In general, no nutrient application is recommended if the soil test category is *above optimum* or *exceeds crop needs*. This allows “draw-down” of the nutrient level to the *optimum* range. However, certain crops (*e.g.*, potatoes and tomatoes) still benefit from low fertilizer applications of root stimulating nutrients (*e.g.*, phosphorus) that 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 (lb/A), but they have no meaning in terms of actual quantity of nutrients available to crop plants. 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-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 used. The soil test values for the Mehlich-1 and Mehlich-3 categories (Table B-4) 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.

Table B-4. Soil Test Categories for Nutrients Extracted by Mehlich 3 and 1

Soil Test Category	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)[1]
	Mehlich 3 Soil Test Value (lb/A)[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 Soil Test Value (lb/A)[2]			
Below Optimum (very low)	0-3	0-15	0-24	0-240
Below Optimum (low)	4-11	16-75	25-72	241-720
Below Optimum (medium)	12-35	76-175	73-144	721-1440
Optimum (high)	36-110	176-310	145-216	1441-2160
Above Optimum (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.

Plant Nutrient Recommendations

To obtain the highest yields with the least negative environmental impacts, ALWAYS base plant nutrition decisions on a current soil test and current recommendations. Fertilizer is expensive and soil tests are relatively cheap and the only indicator of true nutrient needs. Refer to Table B-4 to interpret the relative levels of P and K 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 in Recommended Nutrients Based on Soil Tests tables in chapter F.

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

1. For most vegetables grown on mid-Atlantic soils, apply the total recommended P_2O_5 and K_2O together with 25 to 50% of the recommended N before planting. The remaining N can be sidedressed or applied with drip irrigation using a fertilizer containing N only. Sidedressing or topdressing potash (K_2O) is recommended only on extremely light sandy soils with very low cation exchange capacities.
2. It may be desirable to build up the P and K 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 lb/A of P_2O_5 and K_2O, respectively, to the recommendations listed in the table for soils testing low in P and K. Apply additional amounts in broadcast and plow down or broadcast and disk-in application.

Plant nutrient recommendations listed in tables in chapter F (Recommended Nutrients Based on Soil Tests tables) 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 very high.

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 N 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 the Recommended Nutrients Based on Soil Tests tables in chapter F were developed for fields where no manure is being applied and where no legume crop residue is being incorporated prior to planting a new crop. If manure and/or legume crops are being used, the plant nutrient recommendations for the specific crop 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-10.

When warm season crops, such as sweet corn, tomatoes, peppers, eggplants, and vine crops are seeded or transplanted and soil temperatures are below 65°F (18°C), 20 lb/A of P_2O_5 may be applied to replace phosphorus removed by the crop when soil test levels for phosphorus are *above optimum* or *exceeds crop needs*.

Once final fertilizer nutrient needs are determined, it will be necessary to determine the grade and rate of fertilizer needed to fulfill these requirements. For example, if the plant nutrient requirements that need to be added as a commercial fertilizer are 50 lb of N, 100 lb of P_2O_5, and 150 lb of K_2O, you would need a fertilizer with a 1:2:3 ratio, *e.g*., a 5-10-15, 6-12-18, or 7-14-21. Once you have selected the grade of fertilizer, the amount needed to fulfill the plant nutrient requirement can be determined by dividing the amount of the nutrient needed per acre by the respective percentage of N, P_2O_5, or K_2O in the fertilizer, and multiplying the answer by 100. For example, if you choose a 5-10-15 fertilizer grade to supply the 50 lb of N, 100 lb of P_2O_5, and 150 lb of K_2O needed, you can calculate the amount of 5-10-15 fertilizer needed as follows: Divide the amount of N needed per acre (50 lb) by the percentage of N in the 5-10-15 fertilizer (5%), and multiply the answer by 100; the answer is 1,000 lb.

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 fertilizers based on the least costly fertilizer grades available. 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.

4. 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 nutrients (**macronutrients**) are generally required in larger quantities. Nutrients needed in smaller quantities (**micronutrients**) are often as important as macronutrients for achieving desired results. Most commercial fertilizers contain the macronutrients N, P, and K, expressed as a weighted percentage (N-P_2O_5-K_2O). Micronutrients may be supplied along with macronutrients.

Nitrogen Management

Nitrogen (N) is one of the most difficult nutrients to manage in vegetable production. N is readily leached or can be tied-up by soil microbes, can be lost to the atmosphere if not quickly incorporated, and is lost under water-saturated soil conditions. Due to the numerous N loss pathways, N is not routinely tested by state soil testing laboratories for making crop recommendations. Instead, N recommendations are based on years of fertilizer research and yield potential. N application timings, application methods, and sources are also commonly researched and have resulted in recommendations for splitting N fertilizer applications 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 N fertilizer may be tied-up, lost from the production system, or another application of N is needed. Tissue testing is the best option when deciding if and how much more N is needed to meet expected yields. Soil testing laboratories can provide N concentrations of plant materials with quick turnaround times to aid in N application decisions.

Phosphorus Management

In general, crops are very likely to respond to phosphorus (P) fertilization if found to be needed by soil testing. Soil test P levels of *deficient* or *below optimum-very low*, *low*, or *medium* indicate a strong response to adding P fertilizer. 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 with levels in the *exceeds crop needs* or *above optimum-very high* categories may also respond to P fertilizer 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* or *below optimum*, P should generally be applied as a combination of broadcast and banded methods. Even at P soil test levels that are *very high-above optimum* or *exceeds crop needs*, a small amount of banded P may benefit crop establishment. Many test results describe soils as *above optimum* or *exceeds crop needs* due to previous fertilizer and manure applications. When applied in excess of crop removal, P accumulates in the soil. P is strongly adsorbed to soil particles and very little is subject to loss via leaching. In high concentrations, soil P will also interact with ionic micronutrients, such as zinc, to alter availability of P to the plant. If the soil test report indicates that P levels are *above optimum* or *exceeds crop needs*, crop and site-specific factors will determine if P fertilizer should still be applied, but the general recommendation under those circumstances is that soils 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 or below optimum, -very low* or *low*. A soil testing *below optimum-medium* in K may or may not respond to K fertilizer. Soils testing *optimum*, *above optimum* or *exceeds crop needs* are unlikely to respond to K fertilizer, but it may be recommended to apply K to maintain the soil fertility level in the *optimum* range.

In general, most of K fertilizer should be broadcast. When the fertility level is *below optimum* or *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 *above 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 drip- 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 optimum levels.

Secondary and Micronutrient Management

Calcium (Ca), magnesium (Mg), and sulfur (S) are included in the secondary element group. Ca may be deficient in soils that were not properly limed, where excessive amounts of potash fertilizer were used, and/or where crops are subjected to drought stress. Dolomitic or high-Mg limestone should be used for liming soils that are low in Mg.

On low-Mg soils where lime is not needed, Mg should be applied in fertilizer. Magnesium may be applied as a foliar spray to supply Mg to crops in emergency situations. Contact your county Extension Agent/Educator for recommendations regarding scenarios that do not conform to these common soil nutrient ranges.

Sulfur is an important plant nutrient, especially for the onion family and cole crops. S may become deficient on light, sandy soils. S deficiencies may develop as more air pollution controls are installed and with the continued use of high-analysis fertilizers with low S content. S concentrations greater than 5 ppm are associated with increased pungency in sweet Spanish onions, and low soil S will result in reduced pungency. S can be supplied by application of S-containing fertilizers, *e.g.*, Gypsum (Calcium Sulfate) or Epsom Salt (Magnesium Sulfate), see Table B-5.

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-7 for B recommendations for various crops based on soil or plant tissue test results. Use of excessive amounts of B can be very toxic to plant growth. **DO NOT** exceed recommendations listed in Table B-7 and in the Recommended Nutrients Based on Soil Tests tables for specific commodities in chapter F (note: in chapter F, Boron recommendations may be listed in a footnote under the Recommended Nutrients Based on Soil Test table).

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 lb/A or a band application of 4 to 8 lb/A of Mn will usually correct the deficiency. When Mn is applied as manganese sulfate, foliar application of 0.5 to 1 lb/A of Mn in 20 gal of water/A in one to three applications usually will help relieve the deficiency. Use a sulfate or chelate of Mn. Do not apply lime or poultry manure to such soils until the pH has dropped below 6.5 and be careful not to over-lime again.

Molybdenum (Mb) deficiency in cauliflower (whiptail) may develop when this crop is grown on soils that are more acid than pH 5.5. Liming acid soils to a pH of 6.0 to 6.5 will usually prevent the development of Mb deficiencies in vegetable crops.

Deficiencies of other micronutrients in vegetables in the mid-Atlantic region are rare; and when present, are usually caused by over-liming or other substandard soil management practices. Contact your county Extension Agent/Educator 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-5 and B-6.

Table B-5. Composition of Principal Macronutrient Fertilizer Materials

Material	N Nitrogen (%)	P_2O_5 Phosphorus (%)	K_2O Potassium (%)	Mg Magnesium (%)	Ca Calcium (%)	S Sulfur (%)	$CaCO_3$ Equivalent (lb/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	15				19		+400
Calcium Sulfate (Gypsum)					23	17	
Diammonium Phosphate (DAP)	18	46					-1400
Limestone, Calcite					32		+1700 to 2000
Limestone, Dolomite				11	22		+1900 to 2160
Magnesium Oxide (Magnesia)				55			
Magnesium Sulfate (Epsom Salt)				10	2.2	14	
Monoammonium 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	

Table B-5. Composition of Principal Macronutrient Fertilizer Materials - continued on next page

Table B-5. Composition of Principal Macronutrient Fertilizer Materials - continued

Material	N Nitrogen (%)	P_2O_5 Phosphorus (%)	K_2O Potassium (%)	Mg Magnesium (%)	Ca Calcium (%)	S Sulfur (%)	$CaCO_3$ Equivalent (lb/ton)
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	12	
Urea	45 to 46						-1680
Urea Formaldehydes	35 to 40						-1360
Urea-Ammonium Nitrate Solutions	21 to 49						-750 to -1760

Table B-6. Chemical Sources of Secondary and Micronutrients

	Material	Chemical Formula	% B
Boron Sources	Borax	$Na_2B_4O_7$•$10H_2O$	11
	Boric acid	H_3BO_3	17
	Fert. borate-46	$Na_2B_4O_7$•$5H_2O$	14
	Fert. Borate-65	$Na_2B_4O_7$	20
	Sodium pentaborate	$Na_2B_{10}O_{16}$•$10H_2O$	18
	Solubor	$Na_2B_{10}O_{16}$•$10H_2O$ +$Na_2B_4O_7$•$5H_2O$	20
	Material	**Chemical Formula**	**% Ca**
Calcium Sources	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
	Material	**Chemical Formula**	**% Cu**
Copper Sources	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
	Material	**Chemical Formula**	**% Fe**
Iron Sources	Ferrous ammonium phosphate	$Fe(NH_4)PO_4$•H_2O	29
	Ferrous sulfate	$FeSO_4$•$7H_2O$	19
	Iron ammonium polyphosphate	$Fe(NH_4)HP_2O_7$	22
	Iron chelates	NaFeEDTA	5 to 14
		NaFeDTPA	10
		NaFeEDDHA	6
	Material	**Chemical Formula**	**% Mg**
Magnesium Sources	Dolomitic lime	$MgCO_3$+$CaCO_3$	11.4
	Epsom salt	$MgSO_4$•$7H_2O$	9.6
	Magnesia	MgO	55.0
	Potassium-Mg sulfate	K_2SO_4•$2MgSO_4$	11.2
	Material	**Chemical Formula**	**% Mn**
Manganese Sources	Manganese chelate	MnEDTA	12
	Manganese oxide	MnO	41 to 68
	Manganese sulfate	$MnSO_4$•$4H_2O$	26 to 28
	Material	**Chemical Formula**	**% Mo**
Molybdenum Sources	Ammonium molybdate	$(NH_4)6Mo_7O_{24}$•$2H_2O$	54
	Molybdenum trioxide	MoO_3	66
	Sodium molybdate	Na_2MoO_4•$2H_2O$	39

Table B-6. Chemical Sources of Secondary and Micronutrients - continued on next page

Table B-6. Chemical Sources of Secondary and Micronutrients - continued

	Material	Chemical Formula	% S
Sulfur Sources	Ammonium sulfate	$(NH_4)_2SO_4$	24
	Ammonium thiosulfate	$(NH_4)_2S_2O_3$	26
	Gypsum	$CaSO_4 \cdot 2H_2O$	16.8
	Potassium-Mg-sulfate	$K_2SO_4 \cdot 2MgSO_4$	22.0
	Potassium thiosulfate	$K_2S_2O_3$	17
	Sulfur, elemental	S	32 to 100
	Material	**Chemical Formula**	**% Zn**
Zinc Sources	Zinc carbonate	$ZnCO_3$	52
	Zinc chelates	$Na_2ZnEDTA$ NaZnHEDTA	14 9
	Gypsum	$CaSO_4 \cdot 2H_2O$	16.8
	Zinc oxide	ZnO	78
	Zinc sulfate	$ZnSO_4 \cdot H_2O$	35

Table B-7. Boron Recommendations Based on Soil Tests for Vegetable Crops

Interpretation of Boron Soil Tests			Crops that often need additional Boron[1]	Boron (B) Recommendations (lb/A)[2]
Parts per Million	**Pounds per Acre**	**Relative Level**		
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	**1.5**
			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 lb 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.

Plant Tissue Testing

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

1. Collecting leaf tissue for analysis:

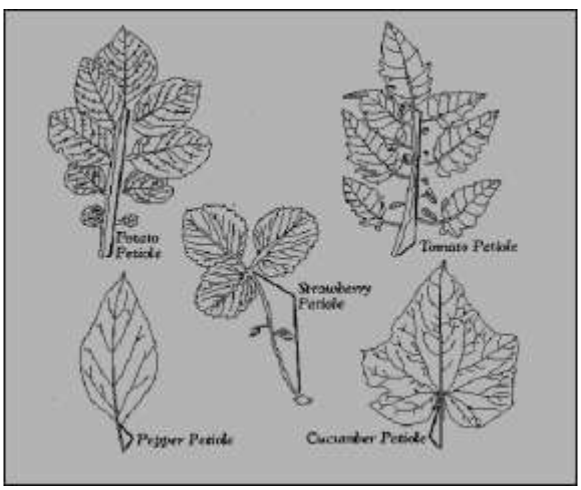
- Sample the most recently matured leaf from the growing tip; the sample should not contain any root or stem tissues. For sweet corn or onions, the leaf is removed just above the attachment point to the stalk or bulb. For compound leaves (*e.g.*, carrots, peas, tomatoes) the whole leaf includes the main 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 collected from each sampled plant.
- Avoid sampling plants damaged by pests, diseases, or chemicals.
- Sample across the field, from different rows, and avoid problem areas (*e.g.*, low spots, ridges, washed out areas).
- 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 use plastic bags** (your samples may rot in plastic).

2. Collecting whole petiole samples for analysis:
- Sample the most recently matured leaf. Throw away the leaflets or leaf blade. (see Fig. B-2). Sample from 30 to 50 plants.
- Sample across the field, from different rows, and avoid problem areas (*e.g*., low spots, ridges, washed out areas).
- 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 use plastic bags** (your samples may spoil in plastic)

3. Collecting petiole sap samples for analysis:
- Sample petioles from most recently matured leaves. Discard the leaflets (see Fig. B-2). Sample 30 to 50 plants.
- Sample across the field, from different rows, and avoid problem areas (*e.g.*, low spots, ridges, washed out areas).
- 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 B-9.

Figure B-2 Petiole Delineation for Several Plant Species.



Interpreting Tissue Tests

Tissue tests will be reported as *adequate* or *sufficient* or *normal* 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 University of Florida website *http://edis.ifas.ufl.edu/ep081*. Test interpretations for selected crops can also be found in chapter F. **Petiole sap** sufficiency ranges can be found in Table B-9. The concentrations in the sufficiency range are measured in plants that have adequate amounts of nutrients available. 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 nutrient deficiencies are presented in the previous sections and in table B-8.
(See next page)

Table B-8. Recommendations for Correction of Vegetable Crop Nutrient Deficiencies

Nutrient	Fertilizer	Method	Application Rate (Nutrient) lb/A
Nitrogen (N)	Urea-ammonium nitrate solutions	T,S,D[1]	30 to 40
	Calcium nitrate	T,S,D	30 to 40
Phosphorus (P_2O_5)	Ammonium phosphates	T,S,D	20
	Triple superphosphate	T,S	20
	Phosphoric acid	S,D	20
Potassium (K_2O)	Potassium chloride	T,S,D	30
	Potassium nitrate	T,S,D	30
Calcium (Ca)	Calcium nitrate	T,S,D	30
	Calcium chloride	D	30
Magnesium (Mg)	Magnesium sulfate	T,S,D	20
	Potassium magnesium sulfate	T,S	20
Sulfur (S)	Ammonium Sulfate	T,S,D	20
	Gypsum	T,S,D	20
Boron (B)	Borax, Solubor[2]	D,F[1]	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]T=topdress, S=sidedress, D=drip irrigation, F=foliar. [2]Mention of a trade name does not imply a recommendation over similar materials.

Table B-9. Sufficiency Ranges for Fresh Petiole Sap Concentrations in Vegetable Crops

Crop	Stage of Growth	Concentration (ppm)			Crop	Stage of Growth	Concentration (ppm)	
		K	NO_3-N				K	NO_3-N
Cucumber	First blossom	N/A	800-1000		**Potato**	Plants 8 in. tall	4500-5000	1200-1400
	Fruit (3 in.)	N/A	600-800			First open flowers	4500-5000	1000-1400
	First harvest	N/A	400-600			50% flowers open	4000-4500	1000-1200
Broccoli	Six-leaf stage	N/A	800-1000			100% flowers open	3500-4000	900-1200
	Just prior to harvest	N/A	500-800			Tops falling over	2500-3000	600-900
	At first harvest	N/A	300-500		**Squash**	First blossom	N/A	900-1000
Eggplant	First fruit (2 in)	4500-5000	1200-1600			First harvest	N/A	800-900
	First harvest	4000-5000	1000-1200		**Tomato (Field)**	First buds	3500-4000	1000-1200
	Mid harvest	3500-4000	600-800			First open flowers	3500-4000	600-800
Muskmelon (Cantaloupe)	First blossom	4000-5000	1000-1200			Fruit (1 in. diameter)	3000-3500	400-600
	Fruit (2 in.)	3500-4000	800-1000			Fruit (2 in. diameter)	3000-3500	400-600
	First harvest	3000-3500	700-800			First harvest	2500-3000	300-400
Pepper	First flower buds	3200-3500	1400-1600			Second harvest	2000-2500	200-400
	First open flowers	3000-3200	1400-1600		**Watermelon**	Vines (6 in. long)	4000-5000	1200-1500
	Fruit half-grown	3000-3200	1200-1400			Fruit (2 in. long)	4000-5000	1000-1200
	First harvest	2400-3000	800-1000			Fruit (half mature)	3500-4000	800-1000
	Second harvest	2000-2400	500-800			At first harvest	3000-3500	600-800

Sustainable Nutrient Management

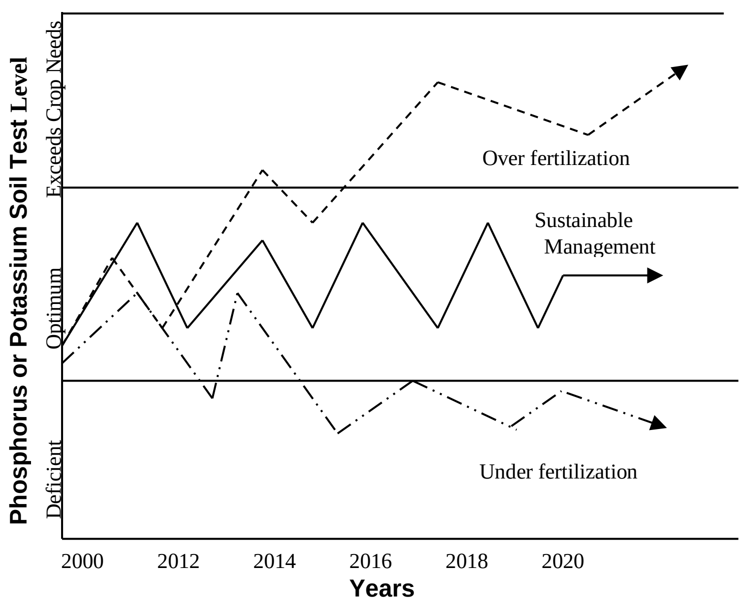
A major objective of nutrient management is to bring the soil fertility level into the *optimum* range and to sustain that fertility level during crop growth. Once soil fertility has reached the *optimum* level, the nutrient application rate should be only large enough to maintain the *optimum* level. 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 you 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 concentrations can vary somewhat from sample to sample and having records helps to spot unusual soil test values that should be rechecked.

Although soil fertility concentrations naturally fluctuate from year to year due to crop rotation and manure application, average concentrations 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 *below optimum* or *deficient* category, under-fertilization is indicated. The nutrient recommendation should be adjusted so that the application rate is sufficient to meet the needs of the current crop, and to gradually rebuild the nutrient supply to the optimum level. If soil fertility concentrations are observed to climb into the *above optimum* or *exceeds crop needs* category, good crop yields may be obtained without adding the nutrient. Yield and quality are likely to be reduced by reapplying a nutrient already present in very high amounts. Over time, nutrient removal by crops should allow soil fertility concentrations to fall back into the optimum range (Figs. B-1 and 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 and/or the environment. Very high soil P levels may lead to deficiencies of other nutrients, especially of iron and zinc. High K levels 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.



Foliar Fertilization

Plants usually obtain nutrients from the soil through roots, but 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 be beneficial. Care should be taken to use approved tank mixes if nutrients are combined with fungicides, insecticides, herbicides, or any other additive. Chelated nutrient sources are often optimal for tank mixes, but make sure to **read the label and conduct a jar test**. Generally, it is difficult to supply ample macro- and secondary nutrients through foliar fertilization, and application of this strategy should be focused on micronutrients only. If a nutrient deficiency occurs, efforts should be made to correct this deficiency via soil fertilization prior to the next growing season.

5. Soil Improvement and Organic Nutrient Sources

Cover cropping is an important practice for sustainable vegetable production; some reasons to consider cover crops:

<u>Return organic matter to the soil</u>: Vegetable rotations are tillage intensive and organic matter is oxidized at a high rate. Cover crops help maintain soil organic matter concentrations; a critical component of soil health and productivity.

Provide winter cover: By having a cover crop - including roots - growing on a field in the winter you recycle plant nutrients (especially N), reduce N leaching losses, 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 maintain soil organic matter concentrations. Cover crop residues can help increase the diversity of soil organisms and reduce soil borne disease pressure. Some cover crops may also release compounds that help suppress certain soil borne pests, *e.g*., nematodes.

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 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 lb/A 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 lb/A 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 lb/A by early September are also good cover crops.

Legumes

Legumes such as hairy vetch, crimson clover, field peas, subterranean clover, and other clovers are excellent cover crops and can provide significant amounts of N for vegetable crops that follow. Good examples are hairy vetch drilled at 25-60 lb/A, crimson clover at a rate of 15-30 lb/A, or field peas such as Austrian Winter planted at 50-70 lb/A. Subterranean 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 reach flowering or early fruiting 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 lb/A of N equivalent. See Table B-10 for estimated N credits from legumes. Remember to inoculate the seeds of these crops with the proper Rhizobia inoculants. All 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 N prior to planting fall vegetable crops. These include sun hemp, cowpeas, soybeans, annual lespedeza, and several 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 lb/A, 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 MD and VA, and July 25 to August 1 in cooler areas of NJ and PA. 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.

Brassicas

There has been increased interest in the use of certain brassicas, including 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 amounts of organic matter, recycle N, can reduce compaction (larger rooted types), and offer the potential for biofumigation (mustards and rapeseed). Plant by September 15 or in March-April. The following Brassicas are available:

Rapeseed and Canola - overwinter and are good biofumigants.

Forage, Oilseed, 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 as a biofumigant, reducing certain nematode levels in the soil. Several mustard species also have biofumigation potential. To take advantage of biofumigation properties (rapeseed and several mustards) plant in late summer or spring. Allow plants to develop until just before going to seed. Decomposing leaves release the fumigant-like chemicals. 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 species/varieties will winter over into the spring. 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

Several 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 using 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 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.

Sewage Sludge

Sewage sludge, or biosolids, is a by-product of the purification of wastewater. 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 of biosolids and perishable food commodities **Extension does not recommend applying sewage sludge/biosolids to soils used for vegetable production.** If you elect 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 with the United States Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS).

Manure and Compost

Manures can be used in vegetable production but must be applied with sufficient time ahead of harvest to minimize the risk from pathogens that cause foodborne illness (*e.g.*, *E. coli* 0157:H7, *Listeria*, *Salmonella*). See Table B-10 for estimated available nutrient content for different manure types by animal. Manure testing is recommended for developing nutrient management plan as the organic source of N in the manure will be available slowly. According to the US Department of Agriculture's National Organic Program, current guidelines for organic producers are to apply un-composted animal manures at least 90 days prior to harvest for crops whose harvestable portions do not come in contact with the soil and at least 120 days prior to harvest for crops whose harvestable portions do come in contact with the soil.

According to the US Food and Drug Administration's Food Safety Modernization Act Produce Safety Rule, current standards for subpart F (112.50-60) are under a deferred action on the application interval until FDA can perform a risk assessment to understand what effectiveness the integration of an appropriate interval or intervals may have on protecting public health.

An alternative to direct application of manure is to compost the manure. Properly composted manure can be applied to produce at any time before harvest.

Application and incorporation of compost to soils will increase soil organic matter and certain soil nutrient concentrations. Compost ingredients can include animal manures, scrap table foods, food wastes, leaves, grass, wood products, or other waste materials. Compost composition, nutrient analysis, and quality should be considered when used in vegetable production. Ingredients which make up specific compost may be alkaline (*e.g.*, lime is often added), resulting in a high pH of 7.5 to 8.5. Composts that have been made from manures may have high salt concentrations. Therefore, application rates of compost must be determined by considering nutrient content, salt levels, crop use, and pH before field applications are made. Composts are generally applied from 1 to 6 ton/A. Higher application rates may be deleterious. A compost analysis is essential to determine safe application rates.

A good extension web reference on the making and use of compost for vegetable production is *http://aggie-horticulture.tamu.edu/vegetable/guides/composts-vegetable-fruit-production/*. For more information on using organic nutrient sources including calculating how much to apply see: *Using Organic Nutrient Sources* at: *https://extension.psu.edu/using-organic-nutrient-sources.*

Table B-10. Plant Nutrient Value Credits to Be Allowed for Manure Applications and Crop Residues

Manure Applications	**Pounds per Ton**			**Crop Residues**	**Pounds per Acre**		
	N	**P_2O_5**	**K_2O**		**N**	**P_2O_5**	**K_2O**
Cattle manure	5-10[1]	3	3	Alfalfa sod	50-100[2]	0	0
Horse manure	6-12[1]	3	6	Birdsfoot trefoil	40	0	0
Liquid poultry manure	7-15[1]	5-10	5-10	Crimson clover sod	50	0	0
(5-15% solids)				Hairy vetch	50-100[2]	0	0
Pig manure	5-10[1]	2	2	Ladino clover sod	60	0	0
Poultry manure	25-50[1]	40-80	30-60	Lespedeza	20	0	0
				Red clover sod	40	0	0
				Soybeans - grain harvest residue	15	0	0
				Soybeans - tops and roots	40	0	0

[1] Lower values for fall- and winter-applied manure and higher values for spring applied manure. Use these data 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

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/or 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 at: *https://www.ams.usda.gov/about-ams/programs-offices/national-organic-program*. The Organic Materials Review Institute (OMRI; see *http://www.omri.org*) reviews products submitted by companies against the National Organic Standard (NOS) and can help identify which products are allowed in organic production. 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-11 for a list of various products useable on organic farms.

Table B-11. Status for Organic Production, Mineral Nutrient Value, and Relative Availability of Various Materials Check with your certifying agency before using any of the listed materials, as the status for organic production may have changed.

Material[a]	Status for Organic Production[b]	Percent Nutrients[c]			Relative Availability
		N	P_2O_5	K_2O	
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
9Kelp[g]	Allowed	0.9	0.5	4 to 13	Slow
Manure[h] (fresh) - Cattle	Restricted[i]	0.25	0.15	0.25	Medium
Manure[h] (fresh) - Horse	Restricted[i]	0.3	0.15	0.5	Medium
Manure[h] (fresh) - Sheep	Restricted[i]	0.6	0.33	0.75	Medium
Manure[h] (fresh) - Swine	Restricted[i]	0.3	0.3	0.3	Medium
Manure[h] (fresh) - Poultry (75%)	Restricted[i]	1.5	1	0.5	Medium Rapid
Manure[h] (fresh) - Poultry (50%)	Restricted[i]	2	2	1.0	Medium Rapid
Manure[h] (fresh) - Poultry (30%)	Restricted[i]	3	2.5	1.5	Medium Rapid
Manure[h] (fresh) - Poultry (15%)	Restricted[i]	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
Pomaces[m] - Apple (dry)	Allowed	0.7 to 0.9	1.2 to 2.1	0.6 to 1.8	Slow
Pomaces[m] - Castor	Allowed	5.0	1.0	1.0	Slow
Pomaces[m] - Winery	Allowed	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; *https://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.